WATER

SOURCES - TREATMENT - DISTRIBUTION

by

WILLIAM BOAZ
Chief Sanitary Engineer

Unofficial

PAN AMERICAN SANITARY BUREAU
Washington, D. C.
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RAIN WATER

RAIN

Exposed water surfaces of lakes, swamps, rivers, and seas are vaporized by the sun and are absorbed by the atmosphere. When these water vapours do not rise, they produce humidity and mist.

As the atmosphere cools in rising to a higher level, contacting mountains or cooler air currents, its point of moisture saturation is lowered so that the excess moisture drops out.

Atmoshperic moisture is supposed to condense around particles of foreign matter to form rain drops which gain in size as they fall by uniting. The falling rain drops entangle suspehded matter with which it comes in contact. Harmless micro-organisms have been found in the atmosphere up to 11,000 feet above the land surface, the most common being harmless wild yeast spores. Rain falling in crowded industrial sections collects bacteria from the dust and smoke laden air, often hundreds per cc. Rain falling in remote districts usually tests between 0 and 10 live organisms per cc. The first rain after a dry period shows higher counts.

Rivers will not usually discharge into the seas as much as half of the water falling on their drainage area. The amount of precipitation ranges from 0 in desert regions to a maximum of around 50 feet a year in some tropical parts. The rainfall in exceptionally dry or rainy years may be some 50% less or 50% more than the rainfall in an average year.

Rain dissolves gases from the atmosphere, the principal of these being oxygen and carbon dioxide.

ARTIFICIAL PRECIPITATION

Some tests and many suggestions have been made for causing rain to fall in drouth striken areas. These have usually been based on simulating electrical storms and projecting shells from cannons which burst in a cloud nearly saturated with atmospheric moisture releasing finely divided dust or lime around which the moisture could condense. The latter method has induced rainfall, but over such limited area and at such cost as to make it prohibitive.

No practical economical means has yet been developed for condensing and precipitating atmospheric moisture. In spite of this "rain makers" with secret processes which are kept secret because they will not bear investigation, are still collecting fees for their valuless services.

DEW

Water vapour condensing on galvanized steel sheet roofs and other surfaces is sometimes collected and used for drinking water. This is practised at Gibralter, Aden, Canary Islands and Jamaca.

RAIN WATER

Run-Off - Rain water reaching the earth, runs off to feed streams, seeps into the soil, is absorbed by plants, and evaporates.

After warm dry periods more water will be absorbed by the ground. Steep slopes increase run-off. There is more infiltration in plowed fields than in uncultivated pasture and woodland. Porosity of the soil is another factor effecting run-off-open sandy soils will permit the infiltration of more water than will dense formations like clay.

Forest and underbrush leaves hold rain water--some of it evaporates, some is absorbed by the plant and some drops off slowly. Though there is no way of accurately determining the amount of rain water which plant leaves prevent from reaching the ground, it will probably be 3% to 4% in grass pastures, 6% to 7% in timber lands of the temperate zones, and 10% to 13% in dense tropical jungles.

Run-off will often be between 2% and 18% of the rain fall.

One inch of rain on one square mile, gives 17,380,000 gallons.

Transpiration - The loss of water to the atmosphere through transpiration in the temperate zone will usually exceed that taken by the atmosphere in evaporation. In dense tropical jungles transpiration will probably exceed twice the amount evaporated during the same period.

Evaporation - The writer knows of little data which has been collected on the evaporation from exposed water surfaces of lakes and reservoirs in the Latin American countries. In Panama, the total annual evaporation is between 52 and 65". Evaporation in the British Isles varies from 11 to 17" per year, averaging 14". The amount of evaporation will depend on the clearness of the skies, humidity, and winds--especially the last.

Characteristics - Rain water is nearly always wholesome when it reaches the earth's surface, though it may become polluted soon thereafter. Such water has a fresh agreeable taste due to its being nearly saturated with dissolved oxygen. It is free of hardness and has no alkalinity. It has some carbon dioxide and is slightly acid.

There are almost no suspended solids in remote regions but in inhabited industrial sections these are often 30 to 40 p.p.m. The same applies to live micro-organisms--in remote regions only 0 to 10 per cc are usually found while hundreds per cc may be present in rain waters washing the atmosphere of thickly settled regions.

RAIN WATER

Rain water always contains some salt, the quantity decreasing with the distance from the sea. Rain water contains no calcium which is required by the bones and teeth. This deficiency can be corrected by the addition of lime to the water. Calcium in the lime will combine with carbon dioxide in the water and when the gas becomes so consumed, the excess lime will settle to the bottom of the cistern so there will be no ill effects from over dosing.

Collection of Rain Water - Where no safe water is available or where the water is hard, rain water is often drained from the roofs of residences. This water is caught as it drops from the eaves into semicircular copper or galvanized steel traughs--effective slope is 1% and diameter 6" unless the drainage area is exceptionally large. At the corners of the house the eave gutters empty into 4" diameter copper or galvanized steel downspouts. If the water is to be wasted, the downspout can discharge directly onto the ground.

Filters are sometimes installed at the upper or lower end of the down-spout. This may consist of a simple box of sand, at least 6" deep. Sometimes activated carbon is mixed with the top layer of sand. Perforated wood or sheet metal should be placed above the sand to distribute the falling water. The objection to such filters is that when neglected and not kept clean bacteria and other micro-organisms will find very favorable conditions in the sand for their propagation.

Cisterns - Rain water storage reservoirs were formerly built under the floors of dwellings from where the water was raised by bucket or hand pump. This practice is not now common as such underground cisterns are exposed to contamination from surface waters seeping through imperfections in the reservoir lining. The bottom of such cisterns should never be below the surface of the underground water table.

The present practice is to place a tank on supports at a corner of the dwelling with its top a few inches below the eave. These tanks are made of galvanized steel sheets and occasionally of reinforced concrete. Such tanks are preferable to the submerged type as they are less exposed to pollution and they provide gravity circulation of the water in the residence.

Cisterns should be roofed with all openings screened with No. 16 screening. It is advisable to chlorinate the water in the cistern about every three months, by adding enough hypochlorite of lime to give a chlorine dose of 1 p.p.m. This should be applied just before retiring, stirred quickly and thoroughly into the water and stirring up the settled material on the bottom so the chlorine can destroy the bacteria and oxidize the organic matter which the sediment contains. By morning there will probably remain little or no objectionable odor or taste of chlorine. Once a year the cistern should be emptied, the inside surfaces scrubbed with stiff brushes and washed dowm. Inspection should be made to determine if paint is needed.

The size of the cistern to meet the individual needs should be calculated. The uses to which the water is to be put will determine the average consumption per person daily--that is whether the water will be used for all domestic purposes or for drinking or washing only. If meteriological records for the region have been kept then the maximum period between rains will represent the dry period which will have to be tided over. The rainfall data will permit rough calculations of the water which may be collected from the roof at various seasons of the year.

STREAMS

There are purifying influences at work in a flowing stream and the principal of these are: dilution from unpolluted tributaries, soil bacteria and predatory protozoa destroying intestinal organisms, the bactericidal and bleaching effect of sun rays which only penetrate a few centimeters below the surface in turbid water, and oxidation and sedimentation. Though these purifying processes are not entirely dependable, they are helpful. If the volume of pollution is not sufficient to lower the free oxygen content to less than 3 p.p.m. and little or no new organic matter reaches the stream then the natural purifying process will usually re-establish the water to its condition before the pollution reached it within a period of 100 hours. Raw sewage should not be discharged into a stream in excess of 1% of the stream's flow volume.

The flow volume of streams at various seasons is often required for estimating available supplies, especially in the dry seasons. This can be determined by stream gauges which give the level of the water and the velocity of flow which, with the area of the section at the place where the gauge was set, the volume can be calculated. In small streams a measuring weir can be built across the stream. A measured quantity of salt may be added to the stream in solution. The chlorine content of the water taken some distance down the stream before and after the addition of the salt will give the increase in chlorine from which the volume of the stream can be calculated.

After rains there is an increase in organic matter, bacteria (especially soil bacteria), and turbidity. Due to dilution there is a decrease in acidity and mineral content. Streams in flood are commonly very polluted the first day or two after which they may be less so than at normal flow.

<u>Highland Streams</u> - In hill and mountain regions, especially those with exposed rock surfaces, the surface drainage water picks up very little clay or other material and so remains clear. Slopes are sufficient for such streams to flow over rough stream beds producing effective aeration usually resulting in a free oxygen content exceeding 5 p.p.m. These waters contain less soil bacteria and are generally less exposed to pollution due to being in less populated regions and they are cooler than the water in streams. Shallow, less turbid streams receive more bactericidal action from sun rays. Such desirable waters are often brought down from distant mountains in aqueducts to cities where they are used as potable water supplies without treatment other than disinfection with chlorine or other agents if their bacterial count, organic content, and turbidity are low. With the development of more efficient treatment methods, it is sometimes found more economical to use the more turbid water of nearby lowland streams after treatment.

SURFACE WATER

Tropical Streams - The Amazon River and most other large tropical rivers carry much finely divided material in suspension, which gives the water a milky, light appearance, after the heavy material has settled out in 12 hours--the raw water is light brown. Other large tropical rivers as the Rio Negro and Tapajos, both tributaries of the Amazon, are very highly colored and with almost no turbidity.

A number of coli-aerogenes tests were made by the writer on raw water from the Amazon River from Iquitos, Peru, down to Belem, Brazil at its mouth. These tests were usually negative which is probably accounted for by the fact that these regions are very thinly settled or to the presence of predatory protozoa.

Lowland Streams - These streams receive the clear waters of the mountain streams as well as the surface washings of humus earth containing myriads of soil bacteria, clay, and other matter which increases turbidity as the water flows along its course. In such flowing streams, much bacteria is carried down with settling silt.

When the bottom of a river bed is below the water table, water will flow to or from the stream depending on whether the water surface is above or below the water table. During the dry seasons the ground water may be the only water the stream receives.

DAMS

Where the minimum flow of a stream in the dry season is apt to be less than the volume needed for a public water supply, a dam may be required to impound some of the rainy season flow in an artificial lake or storage reservoir.

For dam design the following data would be needed: present and future volume of water required, flow data at all seasons and for various years, needs and riparian rights of the down stream population.

Where there is no stream flow data, then estimates will have to be made of the amount of water which will run off of the drainage area.

Favorable conditions for a dam site are a narrow gorge above which there is an expanding valley. The value of the land to be inundated may be a determining factor in locating a dam site.

SURFACE WATER

DAMS

Earth Dams - For the smaller dams, earth is commonly used. The embankment may be constructed by placing 8" to 12" layers of earth horizontally. After wetting, these are compacted by rolling or tamping. Both faces of earth dams may have a slope of 2 horizontal to 1 vertical, except the lower 75% of the up-stream face which should be 3 to 1. The upper part of the up-stream face should have its surface protected against the eroding action of waves by rip rap or gravel. The down-stream face should be protected against erosion by rain water with Bermuda grass. They are so designed that when the reservoir is filled the excess water will discharge over a spillway at one side of the dam, which, under ordinary conditions, is from 4 to 5 feet below the level of the top of the dam. It is protected against erosion by masonry and abutments at both ends.

A trench is cut across the stream at about the center of the dam. As the dam is built a core wall will be made extending from the trench to the top of the dam. These were formerly made of masonry but now the more common practice is to use impermeable clay.

The highest largest rock and earth filled dam ever built is the San Gabrial Dam near Los Angles, completed in 1938. Its capacity is 10,809,000 cubic acres, 375 feet above bed rock, base width 1,950 feet, and crest length 1,540 feet.

Masonry Dams - Many designs of stone and concrete are used. The present tendency is to build the larger dams of ribbed or arched reinforced concrete instead of solid. They are usually built on a hard rock base. The over-flow is ordinarily over the crest of the dam.

The largest masonry dam in the world is Boulder Dam, completed in 1936, cost $76,500,000, height 726 feet, capacity 10,000,000,000,000 gallons.

The Don Martin Dam at Tamavlipas, Mexico, was completed in 1930 at a cost of $8,000,000, its height is 131 feet and its capacity 360,000,000,000 gallons.

RESERVOIRS

When water is impounded by a dam the land to be inundated should be free of very porous, deep soils and especially of outcroppings of porous stratums such as sand. If such places where water may seep out are not discovered before the dam is built, the only way to correct it is to cover the places where water is seeping with dense, impermeable clay which is expensive and not altogether satisfactory.

SURFACE WATER

RESERVOIRS

Trees and brush must be removed from the ground to be inundated, as well as their trunks and roots to a distance of a foot or so under the surface. Grass and weeds should be burned. If this clearing is not carefully done, objectionable tastes and odors may be in the water for two or three years.

Vegetable growths are likely to increase around the edges of reservoirs at low water. When the water rises, many of them will die, producing objectionable odors and adding to the organic content of the water. Where shallow boggy areas occur adjoining lakes from which they water recedes in dry periods when vegetation may grow, they should be filled in if small or cut off from connection to the lake by dykes if large.

It is a very common occurance that certain micro-organisms develop in large quantities in new impounded reservoirs, later natural enemies will develop to reduce their number. This biological balance may require about a year to assert itself.

Due mainly to fermentation of settled organic matter collected on the bottoms of larger lakes, the waters may vary in chemical content with depth, referred to as chemical stratification. Fermentation reduces the free oxygen and augments the carbon dioxide, making the water more acid with depth. In the temperate zone there is often no free oxygen at a depth of about 2 meters while in the tropics this often occurs at 1.2 meters.

When the water reaches a temperature of 4°C or 39.2°F it is at its maximum density or weight. Surface waters approaching this temperature will descend to the bottom in convextion currents. The displaced bottom water will bring up with it much deposited material. This phenomina is referred to as seasonal over-turn and there is no remedy for it.

Silt will deposit in reservoirs to reduce their capacity by around 0.5 acre foot per square mile of water shed or 1 1/2% reduction in volume of water per year, if the surface soil is uncultivated, loose sand loam. Besides the loss of water by evaporation there will be some loss from seepage into the ground.

SWAMPS

Often flat areas are poorly drained so the water remains stagnant, permitting lush vegetable growths, water plants and plankton. Leaves and other vegetable matter decays in such waters, which frees carbon dioxide to the water and takes up organic acids, which acidity increases with the time of contact. These organic acids are solvent to lead.

SURFACE WATER

SWAMPS

The water also takes up vegetable dyes in colloidal form which imparts color to the water ranging from yellow to brown. Swamp waters are likely to be almost free of turbidity. Though it is possible to prepare waters for domestic uses which are acid, high in organic matter and color content, it may be more economical to drain off swamps and use more favorable waters if available.

POLLUTION OF SURFACE WATER

Practically all surface waters are more or less polluted or are subject to accidental pollution. Impounded waters in lakes and reservoirs are usually less polluted than water flowing in streams. The water of lakes and large slow flowing streams contains much less pollution at some distance from the bank where depths are greater. Almost any degree of pollution can be eliminated by the modern methods of treatment and the water made potable.

Sand covering the water shed furnishes some natural filtration whose effectiveness depends upon its fineness, lay and depth.

Persons having typhoid fever or other water borne diseases, or carriers of these diseases, should be detected and special care taken to prevent their waste from finding its way in to the water system.

Untreated and incompletely treated sewage effluent is the main cause of surface pollution, probably accounting for over half of it.

Strams may be polluted by effluents from sewers, manufacturing plants, quaries, mines, and cultivated fields fertilized with manure. Where river waters are used for the potable water supply of a city, even though they are completely treated, they with their tributaries and feeding drains should be inspected regularly for some miles above the intake to locate sources of pollution. Chemical and bacteriological tests of the water taken at different places will be helpful in locating concealed polluted matter reaching a stream. The health authorities may require partial or complete treatment of such effluents before delivery to streams.

Another source of surface water pollution is from bathing and washing clothes in such water.

SURFACE WATER

WATER SHED AND INTAKE SANITATION

Where the intake is located in a natural lake or impounded reservoir, the water entering it should be protected as much as possible against contamination. Two zones may be established for this purpose. One including the water and land at a distance of around 1,000 feet or 300 meters which may be indicated by anchored floats strung on a cord, and another at a distance of about 5,000 feet or 1.5 kilometers from the intake.

No sewer treatment plant or Imhoff or septic tank should be permitted within the first zone. If it is necessary to have such instalations in the second zone, the instalation, location design and operation should be approved and supervised by health officials. Their effluents should be chlorinated.

Pit and chemical privies may also be installed in the outer zone with the approval of health officials.

No animals should be kept withing the first zone. Inspectors should locate promptly any dead animals on the water-shed and have them removed without delay.

Fishing, boating, and hunting should be limited to the water edge, piers, and dams outside of the first zone. Picnicing should be confined to certain designated sites outside the first the first zone where sanitary services can be provided. Covered garbage cans should be placed near these sites. No swimming should be allowed within either of these zones.

A highway may be built at a distance of about 50 feet from the edge of the lake. The space between the highway and lake should be cleaned of underbrush. There should be no camping nor picnicing in this area. Signs are useful in informing the public that they are to observe the sanitary rulings as they are on the drainage shed of the public water supply. Park police should be informed as to the sanitary regulations and enforce them. The water department should own the property of the first zone and should have sanitary supervision over the second. Where the intake is in a flowing stream, similar precautionary measures should be taken above the intake.

Cases and carriers of typhoid fever and other water borne diseases living on the water shed should be located and moved off. Human wastes should be completely sterilized or diverted so it cannot find its way into the potable water system.

A map of the water shed is convenient. It should be kept up to date and have located on it, dwellings, roads, and possible sources of pollution.

GROUND WATER

GEOLOGY

Under the earth's surface at varying depths lay the dense formations of igneous, fused, or metamorphic rock, such as quartz, mica, schist, gneiss, granite, and crystilline limestone. Such rocks are practically impervious so carry no water except what might have lodged in their crevices.

Above the igneous rock are stratified layers of materials which washed from the fused rock and was deposited by the water in horizontal layers. In these deposits are found the fossil remains of once living forms. The identification of the species found in a stratum determines the geologic age in which it was deposited--this is the science of Paleontology. Since the depositing of these stratums, the contraction and expansion of the earth's crust, due to temperature changes, has bent, folded, upturned, and faulted, nearly all of these layers except those most recently deposited.

An outcropping of a stratum is where that stratum comes to the surface. In the case of water bearing strati, surface water percolates through the outcropping. Some water bearing strati do not reach the surface--have no outcropping--while in other cases outcroppings are overlain with top soil which is so slightly permeable that only small amounts of surface water can reach the water stratum. Wells tapping such strati will become dry when the water is pumped to the surface as there is no way for water to enter to replenish the water taken out.

As surface water is usually polluted or subject to pollution, its bacterial content and turbidity will be reduced or eliminated by the natural filtering effects of the formation through which it passes. The effectiveness of this depends on the fineness of the filtering material and the distance traversed through it. Fine grained sand will filter out all organisms and other suspended matter in 25 feet, coarser sand in 50 feet.

Water may be found in pervious strati such as gravel, conglomerate, sand, sandstone (varying from very dense to porous), or broken or creviced rock. In fine grained formations, the water is retained by capillary action so the stratum from which water is taken has to be of open porous character to yield water in large quantities.

The temperature of well and spring water is that of the stratum from which the water comes. The earth's temperature increases with depth from the surface but the rate of increase varies considerable in various parts of the world. Temperature increases will run 1°C each 27 to 33 meters or 1°F each 50 to 60 feet for the first 650 meters, after which increase is less being about 1°C in 43 meters.

GROUND WATER

GEOLOGY

Sometimes shallow dug wells will take water from the gravel of old river beds.

Well yields depend on the amount of water which enters the water bearing stratum through its outcropping, the hydro-static pressure which forces the water through the porous material--overcoming friction and capillarity--the fineness of the voids or interstices which impedes the free passage of the water.

Thick water bearing strati retain more water in reserve and the well screen can tap a larger infiltration area and so produce a larger volume of water with the same rate of flow than through a thinner stratum.

If the water level in a stratum tapped by a well is above the level of the surface where the well is drilled, then the water will be a flowing or aeration well.

An outcropping may be located, cleared of top soil, and earth dykes placed on the lower side to prevent surface drainage from running off and to give it time to percolate into the permeable stratum.

CHARACTERISTICS

The mineral content of deep well waters is likely to be more highly mineralized than that of surface waters and shallow wells. Mineral content and other inorganic impurities will vary only slightly over long periods of time. Wells located near each other are likely to show about the same analysis, but occasionally there has been considerable variation which is likely due to the water of each well flowing through different formations from which it dissolves impurities.

Minerals most commonly found in ground waters are: sodium chloride (salt), clacium sulphate (gypsum), sodium sulphate (glauber salts), iron, manganese, calcium bicarbonate and sodium bicarbonate.

Some well waters contain such quantities of saline or mineral matter as not to be economically usable. Such waters are sometimes used as mineral waters.

Well waters often have considerable carbon dioxide, hydrogen sulphide, and oxygen.

The carbon dioxide is absorbed from decomposing organic matter through which the water has passed, making the water more acid and solvent to minerals with which it may later come in contact.

CHARACTERISTICS

Sulphur bacteria grow in the presence of hydrogen sulphide. This can be prevented by adding 0.1 p.p.m. of activated carbon. Iron bacteria and other fungi sometimes persist in wells from where they reach the mains. Treat with sodium hypochlorite solution, pumping out after.

Ground water is generally free of turbidity and crystaling clear if nearly free of iron. If the water comes from a stratum of fine grained sand, considerable sand may be pumped up to the surface with the water. Nearly all of this sand will settle out if the water is passed through a "sand trap" which is a simple basin where the velocity of flow will not exceed 1 foot per second.

The only treatment well water is likely to require is aeration for freeing gases such as carbon dioxide and hydrogen sulphide, iron and manganese removal and disinfection if polluted.

The temperature of ground water is that of the stratum from which it comes.

Bacterial tests of deep well water usually give 0 to 10 E-Coli per cubic centimeter with other intestinal organisms absent and little organic matter.

WATER TABLE

Infiltering rain water will seep downward until it reaches impermeable formations. Above these formations the water will fill the interstices and the earth will become saturated. The top of this zone of saturation or water table may not be horizontal as the water is impeded from moving through the more or less porous material. As these waters are from direct surface infiltration of rain water, the height of the water table is dependent of the rainfall and varies with the seasons.

In low flat regions and near large streams the water table varies little and slowly. The underground water flows in the same general direction as the surface water of the vicinity except near large rivers when it flows toward the river. This flow is slow, rarely exceeding 1 foot per hour in open sandy formations and in clay, sandstone, and other more or less dense formations it may move at a rate of a foot a week or month. The velocity of flow to a well decreases faster than the inverse of the distance from the well.

Shallow wells are those taking water from the underground water table while deep wells are those tapping a water bearing stratum which is overlain with one or more impervious strati. This classification is preferred to calling wells of 100 feet and less, shallow and deeper ones deep wells.

GROUND WATER

WATER TABLE

Voids in sand will run around 40% or about 3 gallons per cubic foot of sand.

Surface pollution which is not filtered out in percolating the ground before it reaches the water table will not ordinarily penetrate far into the zone of saturation. For this reason shallow wells should be sealed to at least 30 centimeters or 12" below the water table.

Sometimes water is stored underground. This can be effected where the strati overlying the water table are sufficiently porous to permit the water to percolate from the surface. If the land to be used is fairly level, low earth dykes can be built for retaining the water until it has time to seep downward. In less level lands, channels are dug from which the water seeps. These methods are resorted to extensively in California and have the advantage of cheap storage and purification by natural filtration, but some additional cost is incurred by the necessity of pumping the water to the surface when needed.

SPRINGS

Spring waters are often high in carbon dioxide and consequently acid. They may be soft or hard and sometimes contain sulphur, iron, and other metals. The temperature depends on the depth from which the water comes.

Seasonal fluctuations in volume and the appearance of turbidity after rains indicate danger from surface pollution.

Spring water is potable if it flows through sand or other filtering formations if fine grained and thick. The crystaline appearance of nearly all spring waters inspires confidence in their purity though they may be polluted. Impurities may reach spring water by surface drainage carrying it through open places such as cracks in clay, crevices in rocks, or solution channels in limestone. Spring water is often made unpotable after it reaches the surface by people and domestic animals.

Where spring waters are used for drinking, the spring should be protected by a concrete or other impervious wall on the 4 sides with the bottom left open for the spring water to enter. There should be a concrete cover which will prevent the growth of algae, by preventing the entrance of light. If small this cover may be removable but if too heavy it should be provided with a manhole to permit access for cleaning. The removable cover or manhole should be locked to prevent access and possible pollution by unauthorized persons. An outlet may be made by imbeding a piece of galvanized steel pipe in the protecting wall a few inches below its top. The inside of this outlet tube should be screened against insects.

SPRINGS

The ground should be sloped away from the spring so that no water will collect on the surface in the vicinity of the spring. There should be a fence around the spring to keep out large and small domestic and wild animals. Some spring waters are bottled and used as table waters and are often used for domestic purposes by rural communities. Water from springs is seldom of sufficient volume for city supplies though there are exceptions: Portsmouth, England, derives eight to ten million gallons of water per day from chalk formations and San Antonio, Texas, U.S.A., derives a large volume from solution springs.

Springs may be classified as follows:

1. Contact springs--rain water infilters through pervious to impervious formations which they follow along to some lower point outlet such as a river, valley, or base of a hill or mountain.

2. Solution springs--water containing carbon dioxide will take up calcium from limestone formations to form open solution channels. Bacteriological control of such waters should be maintained as pollution reaching them can be carried great distances.

3. Surface seeps--water may seep from saturated soil at hill sides or foot of hills but their volume usually diminishes or they may become dry during drouths.

4. Fracture and crevice springs--water from such springs does not get natural filtration and may be polluted.

5. Fault springs--such waters like those of contact springs may follow along impervious formations until an outlet is encountered along some geologic fault.

6. Marsh springs--in low lying, water soaked, marsh or swamp lands, drain tile may be laid underground with open joints and slight grade. Water so collected may flow by gravity to a low point to empty into a covered concrete crib provided with a pipe outlet.

DUG WELLS

Wells dug by hand are 1 meter diameter of more which allows space for a workman to excavate with pick and shovel. Depths will often be between 15 and 30 feet with an occasional well carried down to 75 feet or more but for depths exceeding this a tubular well is likely to be more economical. The well should be dug and lined to at least 1 foot below the surface of the water table and preferably 5 feet below it. The well lining must be tightly sealed against the infiltration of surface water to at least 10 feet below the ground surface.

GROUND WATER

DUG WELLS

Impermeable well linings can be made of concrete by pouring in one piece, without joints, 6" thick of 1:2:4 mix. Another satisfactory construction is a double brick wall with horizontal and vertical joints staggered. Hard common brick free of cracks should be used. Apply 1:1 cement mortar 1" thick to outside of brick wall or between the two rows of brick.

As it is not generally possible to get properly sealed joints when using such well linings as brick and stone masonry, vitrified clay sewer pipe, concrete pipe, riveted culvert pipe, and corrugated galvanized iron pipe, these should have an outside backing of 6" of concrete, especially if located withing 200 feet of any source of contamination.

Dug wells are covered with a reinforced concrete slab at least 4" thick with a manhole and cast iron manhole cover which should be locked down to prevent access of unauthorized persons. The slab should slope away from the pump and the ground should slope away from the well so storm waters will drain off and leave no standing water in the vicinity of the well.

The well water should not be raised by bucket and rope-over-pulley nor by endless chain buckets as these devices expose the water to pollution.

Force type hand pumps so designed and installed as to be sealed against contamination are satisfactory. The pump cylinder should be below the water surface so priming will not be required. The pump delivery spout should be of the tubular type and not the open channel type. The casing should extend at least 6" above the pump floor.

In the case of a shallow water table well using power pump, two wells should never be located at a distance from each other of less than 50 feet--more would be better. Where a series of wells are constructed, they should be located perpendicular to the underground flow of water. This flow may be determined approximately by using the static levels of wells in the vicinity--the ground water will flow toward the lower static levels.

New wells should be disinfected with chlorine before using the water.

Such shallow dug wells are not used for municipal water supplies but for residences, schools, hospitals, and other institutions.

DRIVEN WELLS

Where ground is soft enough, pipe may be driven to a depth of 75 feet, though they are not often over 30 feet deep. Such wells are made of from 1 to 4" wrought iron pipe usually 2 and 2 1/2". The end of the pipe is pointed, with a shoulder shrunk on. Often a conical perforated brass strainer is used. The screen is protected by a slotted sleeve below the shoulder and resting against it. The upper end should project at least 6" above the ground and be tightly connected to the pump, to avoid surface pollution from entering. Pipe may be driven by two men by raising a heavy block by pulley supported on a tripod and dropping it.

Sinking of the casing in larger diameter driven wells, is often facilitated by pumping water through the pipe for raising the loosened material to the surface--this is called the "wash method." The pump cylinder can operate submerged inside the larger diameter tubing while with the smaller casing the pump cylinder is connected into the drive pipe like a short joint and operates as a suction pump.

Sometimes driven wells are operated in groups. The best location in such cases, is on a straight line at right angles to the underground flow.

DRILLED WELLS

Formerly, wells were simple drilled holes with pipe of small diameter, set with slots or perforations opposite the water bearing formation. Such wells caused trouble where the water bearing stratum was of fine loose sand due to its clogging the perforations in time.

Refinements have been added in recent years. Pipe diameters are larger, usually 6" to 12". The larger casing helps to increase the yield of the well, lends itself to more economical pumping equipment, and facilitates repair work. Sometimes two or more sizes of casings are used, the larger at the top extending to the required pump setting with extra depth provided for lowering the pump as the water table recedes. No standard type of well is suitable to all conditions. Where the water is to be taken from creviced formations of sandstone, limestone, or rock, large diameter infiltration wells are used.

Where sand is pumped out with the water in volume, a space may be created into which clay might cave to entirely stop the flow of water, surrounding same with a gravel wall will avoid this. This greatly increases the area of the surface of the water bearing sand at the extracting point and reduces the velocity of the water so that the amount of sand reaching the pipe perforations is small.

DRILLED WELLS

Where waters are corrosive, it is advisable to use special materials. Wrought iron pipe is less subject to corrosion than steel pipe. Screens of various metals and designs are made. The one should be selected which is best fitted to withstand the corrosive action of the water for which it is to be used.

Casing should be cemented in properly above the top of the water sand. This will prevent water from above running down the side of the casing. This also prevents drill mud from reaching the water bearing formation which could shut off the water from the well.

Water in a well may remain at the level where it was tapped or it may rise above that level--this is called the static level.

When using a power pump, water may discharge from the well faster than it can enter. The level of the water in the well recedes from its static level which is called the draw-down. At this draw-down level, the added pressure will force the water into the well at the same rate it is being pumped out. In some cases the draw-down may be as much as 100 feet or even more, so the screen must be set low enought to always remain submerged.

Deep wells which are to be heavily pumped should be at least 1,000 feet apart. In the case of deep wells the flow will follow the dip of the geologic formations. Increasing the diameter of wells will not increase the yield as much as might be expected.

A record of the formations penetrated or well log should be kept.

WELL DRILLING

Where the formations are not very hard and a well is not to be dug to a great depth, a standard rig or cable tools are used for drilling. A heavy solid steel bity, larger than the well casing to be used is raised by power operated cable and dropped into the ground. The broken material is bailed out using the same cable.

Wells of greater depth which may go through hard formations, are most easily drilled by a rotary outfit. These work by a revolving grind augur action. Mud is pumped from the top down through the gollow drill stem and oozes out at the cutting edge. the mud plasters the sides of the hole and prevents the material from caving in and also carries the loosened material to the top of the well.

Portable drilling outfits, both cable and rotary, are mounted on trucks or trailers. Where several drilling units are required in a certain region it is more economical for them to be mounted on trailers with one truck to move them from drilled well to new site.

GRAVEL WALL WELLS

After the location is determined the rotary rig is set up and a test hole of about 5 to 7" is bored to the water bearing stratum. If the showing justifies completing the well, a hole is then bored 4" larger in diameter than the surface casing to the water bearing stratum, and the surface casing is then lowered. The present practice is to electric weld the joints of the casing lengths, thus eliminating ordinary screw joints. (Joints are made through taper fit.)

This surface casing is cemented by putting the wet cement below a plug which is forced down to the bottom of the casing by forcing water on the top of it by pump. This forces the cement up the two-inch amular space to the surface of the ground. This seals off surface seepage from the water bearing stratum and is a protection for the outside of the casing against corrosion.

After allowing this cement to set seventy-two hours, the cement in the bottom of the hole is drilled through and the hole is carried on through the water bearing stratum. At the end of the hole a smaller hole is drilled for a short distance, about half the diameter of the surface casing, to center the line pipe and screen on. Before the line pipe is places an under-reamer is lowered. This clears out the space for the gravel. The size of gravel usually employed is from 1/8 to 3/8 of an inch, and may take a quantity ranging from 25 to 75 cubic meters.

Occasionally, after a long period of service, a void is created due to the amount of sand produced with the water. In this case gravel is added as when the well was originally made.

The life of such wells is usually determined by the resistance of the casing to corrosion.

As the gravel wall greatly increases the surface of the water bearing stratum from which the water is taken, the rate of flow is much reduced so less sand is carried to the screen than would be the case if the screen was directly in contact with the water stratum.

Wells of large capacity taking water from sand strati of some septh are now generally of this gravel wall type as they are successful if properly constructed are a great improvement in every way over other types. Some other types are still built because the volume of water needed does not justify the capital investment required for this type.

GROUND WATER

WELL CLEANING

Gravel and sand packed with clay and other obstructing materials may be cleaned out with dry ice broken up in small chunks. The first carbon dioxide will be absorbed by the water.

Hydrochloric and sulphuric acid dilutions are also used for cleaning obstructing materials from the water bearing formations of the bottoms of tubular wells.

WELL PUMPS

Plunger type pump - A deep well pump of the plunger type consists of a working barrel in which the stationary and traveling valves work. The stationary valve serves as a foot valve or check valve. The traveling valve is raised and lowered by a sucker rod which is operated by a pump jack on the surface. Pump jacks are driven by either direct connected motors or by a belt from an electric motor, gas engine, or other prime mover. Pump jacks should be operated at from 25 to 30 strokes per minute.

The advantages of this type of pumping are low cost, simplicity, ease of repair, and the ability of handling sand or gritty water. It must be remembered however, that when gritty water is to be pumped, a special type of leather must be used on the traveling valve. One of the chief disadvantages of this system is the uneven power demand which causes an uneven load on the prime mover. This is overcome to a very marked degree by the proper use of counter-weights to counter-balance the weight of the sucker rod and the column of water above the traveling valve.

Deep Well Turbines - The turbine type of pump is rapidly replacing plunger pumps and air lift systems for pumping deep wells. This type of pump is installed beneath the surface of the water and is driven by a vertical shaft, which is often direct connected to an electric motor set on the surface. In some cases, a pulley is installed at the top of the shaft and the pump is driven by a gas or electric engine.

The chief advantages of centrifugal pumps are their high efficiency which ranges from 65 to 85%, depending upon the speed which they are driven; their freedom from breakdown; and the small amount of power required to drive them. Against these advantages may be charged high initial cost; their inability to handle sandy or gritty water; the inaccessibility of the working parts; the danger of polluting the water with lubricating oil and the weight due to the multiplicity of units suspended from the surface--standard pumps are not made for lifts much exceeding 600 feet though special pumps can be made with extra heavy thrust bearing for considerably higher lifts.

Most vertical centrifugal deep well pumps operate at 1750 R.P.M. but in recent years many have been made to operate at double this speed, Such high speed pumps are much more efficient in power consumption but some experienced well operators are afraid to use them because if the shaft gets slightly out of alignment there would be more vibration and quick wear on the bearings.

The lubrication of centrifugal pump bearings was long a problem to engineers. This condition has been overcome by the use of water lubricated bearings and enclosed iol lubricated bearings.

When installing this type of pump, precautions should be taken to insure the top of the well's being tightly sealed to prevent water leaking back into the well. When the pump is removed for repairs, it should be properly sterilized before replacement to avoid pollution of the water.

Air Lift Pumping - The air lift system of pumping consists in forcing compressed air to the bottom of a well through a small pipe inside the well tubing. The air mingles with the water. The mixture of air and water weighing about half as much as the water alone, the latter will balance a column of water twice or more its own height. The water and air bubbles so raised will run out at the top of the well. Compressed air is supplied by a compressor located on the surface.

The advantages of this system of pumping are the absence of working parts in the well; accessability of the compressor; the ability to handle muddy or gritty water; the expansion of the air will decrease the temperature by about 5°F; and aerate the water which is pumped. Disadvantages are: high initial cost of the instalation, and the inability of the system to deliver water under pressure, and high power consumption--power efficiency of air lift is generally less than 30%.

The cities of Santa Ana and Natal, Brazil, are supplied from air lift wells.

POLLUTION OF WELL WATER

The most common ways in which well water may become fouled are:

1. Overflowing of pump pit.
2. Improperly sealed well top.
3. Surface seepage following along outside of well casing or masonry lining in the case of dug well.
4. Penetration of polluted water through rust holes or other openings in casing or lining of well.
5. Boring animals and insects.

POLLUTION OF WELL WATER

6. From contaminated pump packing.
7. Priming pumps with contaminated water.
8. Proximity to pollution sources such as privies, cess pools, septic tanks, stables, barnyards, abandoned wells, sewers, poor drainage, minimum distance 50 feet in fine sand, 100 feet in medium sand, and 150 tc 200 feet in coarser materials.
9. Contamination during construction of well.
10. Salt water entrance into underground formations where pressure has been reduced by pumping out petroleum and/or water.

Deep wells are protected from surface infiltration by one or more overlying strati of impermeous material. Artesian water is further protected by being under pressure.

Most pollution of the water table is likely to remain on the top 12" of the plane of saturation so water should be taken from below this level.

Shallow wells are more subject to pollution, especially after heavy rains when bacteriological tests should be made.

Sewage and other pollution may be indicated by an increase in the chloride content of the water.

Filtration through most sand and other earth not containing fissures of a thickness of 50 feet, is sufficient to eliminate all harmful micro-organisms and all of the suspended material.

INFILTRATION GALLERIES

Underground galleries or large diameter wells may be built to receive the natural filtered waters from large rivers or lakes nearby. The distance from the bank at high water, to the galleries should not be less than 50 feet. They should be constructed with the longitude parallel to the bank. The infiltration rate will depend on the resistance and pressure. The resistance as well as effectiveness of filtration will depend on the fineness of the intersticies on the formations through which the water passes.

The pressure will be increased as the water in the galleries is drawn down by pumping. The infiltration rate will increase rapidly when the inclination from the water level or the lake or river and that of the well being pumped exceeds 4%--that is if the well were 100 meters from the edge of the lake the draw down would be 4 feet. This of course, would depend on the porosity of the filtering formation. The 4% given was observed by the writer in the case of sand of medium fineness.

GROUND WATER

INFILTRATION GALLERIES

Such sources are more likely to be satisfactory where the volume of water to be taken is not very great. There will probably be a loss of producing capacity of from 1/2% to 1% per year, due to the intersticies becoming clogged.

An economical arrangement successfully employed by the writer for using water from the Amazon River was effected by digging a well of 1 meter diameter down to the low level of the water of the river from where an arched gallery was built paralleling the river at 25 meters from it. The open bottom of the channel was 2 meters wide and the vertical joints of the bricks on the side of the arch towards the river were left open.

GROUND VS SURFACE WATER

The advantages of ground waters are that they are generally crystalline clear and free of pathogenic organisms so may be used without treatment. Unless coming from very deep strati ground water is cooler than surface water in warm climates.

The disadvantages of ground water are that it may be hard, mineralized, contain staining minerals (iron and manganese) or gases (carbon dioxide and hydrogen sulphide), and sulphur and iron bacteria. If the chemical and bacteriological analysis of the water show it to be satisfactory then there is the uncertainty as to the quantity available. The yield of a well can be accurately determined but how long that yield can be sustained undiminished is unknown. Wells of greater depths are apt to be more stable in production that wells of less depth. The cost of pumping well waters is usually more than that required for surface waters.

Ground waters are more commonly developed for supplying isolated institutions, towns, and the smaller cities because of simplicity. Surface waters---except some mountain streams--- require treatment. The cost of a water treating plant and its proper operation and maintenance will , for small towns and instalations, be more than producing from wells.

Where it is possible to supply cities of less than 50,000 population with water from ground sources this should be done not only for economy but because treatment of surface water is not likely to be very effective in small cities as they will not be able to pay for competent experienced plant operators and laboratory technicians.

The unit cost of treated surface waters decreases with the quantity consumed while with well water the unit cost is apt to be higher with increased volume or about the same.

The largest cities deriving all their potable water supplies from wells are, Houston, Texas, producing 80 m.g.d. from a land area of 91 square miles, Manheim, Germany and Kingston-upon-Hull, England. London secures some water from wells---Buenos Aires is considering drilling wells to add to the present treated river supply. In Europe 83% of water for domestic and industrial uses is from underground, while in the United States, only 36% is from this source.

WATER TREATMENT

QUALITY OF WATER - The following is a general outline listing the principal impurities and conditions affecting the quality of water and the means of correcting them.

1. Sanitary Quality:
   - A. Pollution
     - 1. Causes
       - a. fecal matter
       - b. industrial waste
     - 2. Treatment
       - a. chlorine and other disinfecting agents
       - b. coagulation
       - c. sedimentation
       - d. aeration
       - e. filtration
       - f. activated carbon.
2. Physical Quality:
   - A. Taste and Odor
     - 1. Causes
       - a. gases -
         - 1. carbon dioxide
         - 2. hydrogen sulphide
         - 3. chlorine
         - 4. gases of organic decomposition
       - b. micro-organisms
       - c. organic matter
       - d. industrial wastes
       - e. chlorine, chloro-phenols
     - 2. Treatment
       - a. coagulation
       - b. sedimentation
       - c. filtration
       - d. aeration
       - e. activated carbon
       - f. chlorine or other oxidizing agents
   - B. Color
     - 1. Cause
       - a. vegetable dyes from decayed organic matter
     - 2. Treatment
       - a. bleaching by ultra-violet rays.
       - b. activated carbon
       - c. coagulation
       - d. sedimentation
       - e. filtration
       - f. chlorine and other oxidizing agents
   - C. Turbidity
     - 1. Causes
       - a. coagulation
       - b. sedimentation
       - c. filtration
   - D. Temperature
     - 1. Causes
       - a. heat transfer from atmosphere and underground formations.
     - 2. Treatment
       - a. aeration
   - E. Hardness
     - 1. Causes
       - a. calcium compounds
       - b. magnesium compounds
       - c. iron
       - d. dissolved carbon dioxide
       - e. factory effluents
     - 2. Treatment
       - a. softening with
         - 1. lime
         - 2. lime and soda-ash
         - 3. zeolite
   - F. Corrosiveness
     - 1. Causes
       - a. relation of carbon dioxide and alkalinity
       - b. free oxygen
     - 2. Treatment
       - a. aeration
       - b. addition of lime
   - G. Dissolved Metals
     - 1. Causes
       - a. iron
       - b. manganese
     - 2. Treatment
       - a. aeration (oxidation)
       - b. coagulation
       - c. sedimentation
       - d. filtration.

FILTRATION

PRE-FILTRATION

Roughing filters are occasionally used for removing some of the suspended matter in very turbid waters or part of the color in highly colored water to reduce the load on the treatment plant.

These are usually located near the water source from where the water flows by gravity in a pipe or flume to a concrete canal at one end of the battery or roughing filters. The raw water may flow from a rectangular contrete canal into the filter units through louvers places at 45° to force the water down into the gravel. The outlets at the opposite end are also provided with louvers placed in the reverse position leading to a canal like the one delivering the water to the filters.

The concrete canals are so arranged that the raw water can flow through the filter in the opposite direction for washing and wasting the wash water. The gravel size may be between 3/4 and 1 1/2" with the larger sizes for the more turbid waters. The gravel should be removed at least yearly for thorough cleaning. The rate of operation may be 70 to 80 million gallons per acre per day.

Roughing filters can be installed and operated at small cost and in the opinion of the writer, could more often be economically employed.

A roughing filter is in successful operation at Salvador, Bahia, Brazil. The raw water handled has little turbidity but colsiderable color much of which is removed in the roughing filter.

In Europe filters are sometimes arranged in series called the Puech-Chabal System, from coarse to fine gravel. There are sometimes as many as 6 filters with screened gravel 3/4", 1/2", 1/3" 1/5", with respective bed depths of 1', 1.5', 2.5', and 5 feet.

PRE-TREATMENT

PRE-SEDIMENTATION

The expense of pre-sedimentation or tile storage of surface waters may be justified in some cases by reducing the load on the water treating plant and by effecting economy in coagulating chemicals,

The advantages of time storage of raw water are: reduction of material in suspension by settling, partial elimination of pathogenic and other micro-organisms from settling, sun rays, predatory protozoa, and unfavorable conditions. Plain sedimentation will often reduce turbidity and bacteria by 60 to 70% and sometimes more. The disadvantages of time storage are; reduction of free oxygen content consumed in oxidizine the settled matter, increase in carbon dioxide content evolved in fermentation of settled matter and propagation of alage.

The settling period is ordinarily between 6 hours and 5 days. It is considered preferable not to store raw water fro over 5 days for biological reasons--increase in plankton, fermentation fo settled matter, oxygen consumption, increase in carbon dioxide and acidity, chemical stratification, etc. Some 90% of the pathogenic organisms will perish in 5 days. The usual storage period is perhaps between 12 and 24 hours. Nearly all of the inorganic matter in suspension will settle out within 12 hours as well as some of the coarser organic matter. Some of the remaining matter will settle very slowly and some is so finely divided that it will not settle at all.

Settling takes place much more rapidly in warm than in cold water.

Stored water should be protected against pollution by surface drainage from the water-shed.

Circulation through the storage reservoir should be arranged so as to avoid short circuiting of the water direct from inlet to outlet and the consequent formation of non-circulating areas of stagnant water.

Natural sedimentation is now less commonly practiced than formerly, due to the development of other treatment methods. In the tropics where streams are usually very turbid during the rainy season pre-sediment of river waters during this season will often prove economical.

The writer obtained effective pre-sedimentation in the case of two very turbid tropical streams by digging a canal with mules and scraper at right angles to the rivers. The intake crib was placed at the ends of the unlined canals. The accumulating sediment had to be scraped out of the canals yearly. This is appliable on large streams where the variation of water level is not apt to be so great as in smaller ones where pumping might be required.

WATER TREATMENT

WATER TREATING PLANTS

Plant Location - Usually water treatment plants are located either near the source or near the city where the treated water is to be consumed.

To determine which of these is preferable, and there is often little choice, there is the matter of economy of pumping, as well as other hydraulic considerations. In bringing the raw water to the city there would be some increase in organic content in the conduit which would cause some additional load on the filters and other treating processes. On the other hand, if the treated water were transported in a conduit more chlorine would be consumed in oxidizing the organic matter but disinfection would be more effective due to longer contact.

As water plants are usually surrounded by public lands which are made attractive by gardening, they should be, if convenient, located where the citizens can visit them.

Plants located on sloped ground offer the economy of providing means for the water to flow to the various treating processes by gravity with a minumum of excavation. This also provides for the easy disposal of waste water and sludge used in washing out the mixing channels and sedimentation basins.

Plant Design - Complete treatment refers to the application of coagulating chemicals, their rapid mixing, slow mixing, sedimentation and filtration. Disinfection of the finished or treated water is not commonly spoken of as a treating process.

In addition to the ordinary treating processes there are special treatments not required for all water such as aeration, softening, recarbonation, correction for corrosion and iron and manganese removal.

Sometimes complete treatment is proceeded by rough treating processes to prepare the water for the regular treating process, the purpose of which is economy of treating chemicals and to reduce the load on the filters and other treating processes which is equivalent to increasing the plant capacity. This may comsist of natural sedimentation and/or pre-filtration with roughing filters.

Each water will have to have its plant specially designed as there are so many conditions to meet that no plant would satisfy all of them unless it were especially worked out for the water concerned. Besides the physical, chemical and bacteriological conditions of the water which should be carefully determined by laboratory tests before the plant is designed, there is the water temperature and climate. In warm water sedimentation is more rapid as well as chemical reactions such as flocculation.

WATER TREATMENT PLANTS

Plant Design (con) - Biological activity is more intense, which is noticed in the prolithic growths of algae and other micro-organisms as well as germentation and putrifaction of settled sludge.

Plants should be built to take care of the consumers needs for only a couple of years after its completion but the plant should be laid out and its final capacity calculated for 30 years thereafter. This is especially true in warm climates. The writer has seen a number of plants which were built too large, resulting in the water flowing through them too slowly, giving time for the propagation of much algae, floc settling in the mixing channel, the fermentation and souring of settled sludge, as well as other conditions making operation difficulties.

Usually tropical rains are intense over short periods resulting in turbidity of streams as high as 5,000 p.p.m. which may drop back to around 200 p.p.m. within a couple of hours. There should be sufficient reservoir capacity so that highly turbid water could be by-passed the treating plant for a few hours.

No roofs are required on treating plants in warm climates, excepting over the operating floor.

CHEMICAL DOSING

DRY FEED

The feeding of coagulating chemicals and alkalis in the dry powdered form is becoming more general, especially at the larger plants.

The powdered material is dumped into a hopper provided with a revolving arm which prevents the powder from sticking to the sides and keeps it moving to the bottom of the hopper. The powder works out through a hole onto a revolving disc or belt. The writer has observed that the quantity fed by many dry feed machines is not the quantity registered as much more powder will fall through and spread out when it is very dry than in humid weather. This will not occur if the powder goes through a gauged opening with one side adjustable. Dosing accuracy can also be attained by the use of scales.

The powder drops into a small tank or traugh which receives enough water to carry the chemical by gravity through a pipe of a material resistant to the corrosive action of the chemical handled, to the point where it is applied to the water which should be nearly under the dry feed maching.

SOLUTION FEED

Formerly coagulating and other chemicals were fed in solution but this is not now common except in small treating plants.

A solution of known strength--1% to 2%--is made in a wood or concrete tank. Various means are used for feeding the solution at the desired rate: orifice with constant level maintained by float valve, varying capacity of pump and displacement of the solution by water.

Such chemicals are very agressive to steel and concrete, especially in solutions stronger that 2%. Hard burned floor tile makes a good protective lining.

CHEMICAL STORAGE

It is convenient to keep the reserve water treating chemicals in a room above the chemical feed machines. The storage space should be kept as dry and free of humidity as possible.

In countries where chemicals have to be imported, storage space will have to be much larger than where nearby sources of supply permit prompt replenishment of stocks.

MIXING COAGULANTS

FLASH MIX

The pipes delivering the raw water to a treatment plant usually flow into a small tank of reinforced concrete. The coagulant chemicals are applied here where the movement of the water may be sufficiently violent to provide good mixing. In some cases power driven mixers are used.

This flash mix should be completed before the floc becomes visible to the naked eye which is about 4 minutes in warm climates and 5 or 6 minutes in cooler climates.

These represent the maximum times but usually the flash mix tank is designed for a detention period of only about 1 minute.

SLOW FLOW MIX

Following the flash mix the water is moved slowly--between 0.5 and 1.5 feet per second, usually 0.75 to 1.0 foot per second--for a period of from 10 minutes to 1 hour, usually 13 to 30 minutes. This gives the forming floc opportunity to increase in size by sticking together and heavier by enmeshing the suspended matter and so to settle quicker in the sedimentation basins.

Initial mixing velocity may be greater, decreasing gradually as the flocs become larger and more fragile.

Mechanical mixers or flocculators are becoming more generally used--they require a detention period of from 20 to 30 minutes. some plants mix by introducing compressed air through perforated plates or pipe into the water.

Over and under the flow channels have been used for small plants while around the end type is generally used for plants of 25 m.g.d (95,000 cubic meters.)

Recent instalations for these flocculation basins are provided with baffle walls placed at 45°. The writer has observed that the water has no circulation in the inside corners of these and suggests that a small space of about 2", be left open between the baffle and the side walls of the basin.

In mixing channels which were not operating well, the writer has found that hydraulic calculations indicated the right detention period and flow velocity but that by removing alternate baffles in the last 1/4 length of the mixing channel the floc was usually improved. To permit such changes being readily made the baffles should be of wood and removable.

For convenience and economy in construction, the flocculation channel should be of the same depth as the sedimentation basins.

COAGULATION

SULPHATE OF ALUMINUM

Flocculation - Alum or sulphate of aluminum is the most commonly used coagulant. It is acid, corrosive, readily soluble in water, and weighs 39 pounds per cubic foot.

When a coagulant is added to water it will dissolve to form the positive hydrogen ion and the negative hydroxyl ion. The insoluble curd or floc is formed. It is positive so attracts the negatively charged clay colliods, bacteria, and other material in suspension. As the forming floc moves slowly through the mixing or coagulating channel, it entangles other suspended material with which it comes in contact. Later as it descends in the sedimentation chamber other matter is entangled.

The positive hydrogen ions impart acidity to water and lower the pH.

Optimum coagulation with alum for soft waters with little mineral is--pH 5.8 to 6.4, hard waters is --pH 6.8 to 7.8 and highly colored waters is--pH 5.0 to 6.5 and very turbid waters without color flocculate best with a high pH. Some waters may vary considerably from these figures. Waters with high pH may not flocculate well, in which case surfuric acid is sometimes added.

Waters with very little turbidity may flocculate well, but the floc whose specific gravity is about the same of that of water, may not settle readily. In such cases, clay may be added to the water which besides increasing the weight of the floc widens the pH coagulation range, reduces tastes and odors, especially those due to oils, reduces vegetable colors and reduces hardness some. Silica and silicate of soda may also be used as aids to coagulation.

Alum doses are usually 0.5 to 2.5 G.p.g. or 8.6 to 42.9 p.p.m. and occasionally 5.0 g.p.g. Large doses are required when much colloidal clay is present. For economy the quantity should be determined in the laboratory, especially when there is a variation in the turbidity of the water due to rains.

Alum favors algae due to its liberating carbon dioxide. Where high alum doses are applied to lime softened waters, recarbonation will be unnecessary if the quantity of carbon dioxide liberated is sufficient. Alum lowers the pH slightly and increases the permanent hardness by 10 p.p.m. for each p.p.m. of alum added. Each p.p.m. of alum decreases the alkalinity by 0.54 p.p.m. and increases the carbon dioxide by 0.40 p.p.m.

There should be no residual alum in the treated water. The logwood test is used for its detection.

COAGULATION

SULPHATE OF ALUMINUM

Coagulation is often credited with more taste and odor removal than is actually effected. In some cases the addition of lime sets the odor so that subsequent removal is difficult: here activated carbon should be added ahead of coagulation. In colored waters, alum coagulation has been found to markedly reduce odor.

$$3Na_2Al_2O_4 + Al_2(SO_4) + 12\ H_2O = 8Al(OH)_3 + 3Na_2SO_4$$

Cold waters which do not flocculate well with alum alone, may do so by adding 3.4 p.p.m. of sodium aluminate.

BLACK ALUM

Alum with 2% to 5% by weight of powdered activated carbon is referred to as black alum. This product is convenient as it can ba applied to the water by one feeder. If the quantity of carbon is not sufficient to remove all tastes and odors, more may be added separately.

AMMONIUM ALUM

This product is used in alum pots with which pressure filters at swimming pools are commonly provided. It contains 3.7% of ammonia by weight.

IRON SALTS

Copperas or ferrous sulphate, a granular acid is cheaper than alum. It must be employed with lime which is applied to the water first. Copperas is used with hard turbid waters, not hoghly colored. The pH range of 9.0 or above is required. About 1 part of lime to 4 parts of copperas will react to form a fragile but heavy floc.

Chlroinated copperas or chlorinated ferrous sulphate contains about 1 part of chlorine to 8 parts of ferrous sulphate and flocculates over a wide pH range---3.5 up. The chlorine disinfects the water.

Other iron salts used as coagulants are, ferric chloride and ferric sulphate.

ALKALIS

Soda-ash or lime are often used as auxillary chemicals with alum or other coagulants where a higher pH is required for optimum flocculation. Soda-ash has the advantages that it is easily applied to the water, being soluble, and it does not add hardness, but it is not so generally used as lime due to its greater cost.

Soda-ash should contain 98% sodium carbonate. It combines with the non-carbonate hardness---sulphates, chlorates, and nitrates which precipitate. It is a buffer, quickens coagulation by reaction with alum, and prevents the formation of free carbonic acid. Lime is not so readily applied to water as soda-ash as it is almost insoluble. Lime adds hardness but is generally used as it is much cheaper than soda-ash.

SEDIMENTATION

CHEMICAL PRECIPITATION

Formerly the raw water containing coagulants moved directly into the sedimentation basins where the reaction took place and the floc was formed. Now it is a common practice to form the floc in a slow flow mixing channel. As the floc passes from the slow mising channel into the sedimentation basins, the delivery velocity should not exceed 1 1/2 feet per second and preferably 1 foot as these are very fragile and would be broken if these velocities were exceeded. The velocity through the sedimentation basin should not exceed 2 1/2 feet per minute, the flow should be uniform from inlet to outlet.

The average time for sedimentation of detention in the United states is six hours--it varies from 2 to 10 hours. More time is required for cold than for warm waters. From observations and from laboratory tests made by the writer, it is believed that the following detention periods will give good results in the tropics:

Sea level to 200	meters	above sea level	- 3 hours
200 to 400	"	"	- 31/2"
400 to 1000	"	"	- 4 "
1000 to 1800	"	"	- 41/2"
1800 to 3000	"	"	- 5 "
3000 to 4500	"	"	- 51/2"
Above 4500	"	"	- 6 "

Settling basins are commonly made with a depth of 3 to 6 meters--12 feet is most common. For economy in construction they may be made the same depth as the mixing channels. Length is often about twice the width but a length of 3 times the width would probably be more efficient. When exposed to wind, use board floats to prevent waves on the surface.

The water should be fed to the sedimentation basins near the bottom and should be taken off at the top.

The water from the sedimentation basins should reach the filters with about 10 p.p.m. of turbidity, but it should not exceed 20 p.p.m. as an excess of this amount would result in uneconomical operation of the filters--short runs and excessive wash water. Bacterial reduction effected by chemical precipitation is commonly 90 to 95%.

Sometimes the settled sludge decomposes from which gases arise and objectional tastes and odors are produced. This may be corrected by the use of continuous mechanical sludge removing equipment or by the application of activated carbon with the coagulant.

CHEMICAL PRECIPITATION

Where algae has begun to grow attached to the walls, it should be removed and the walls scrubbed down with stiff brushes, when it can be painted with a 5% solution of copper sulphate, to which about 10% of lime has been added. This should be allowed to dry before water is let into the basins.

Where the waters being treated are warm, it is often necessary to clean out the sedimentation basins every month because fermentation and putrifaction are much more rapid, so that entrapped gases are apt to float slugs of settled sludge which will cause objectionable tastes and odors. These will pass on to the filter bed. Where there is a large accumulation of settled floc, some of it is apt to be swept up by the water flowing through the basins. When this begins to occur the basins should be emptied and cleaned.

The amount of micro-organisms which will settle out will be in porportion to the suspended matter so removed from the raw water. The sedimentation basins should be cleaned out at least twice yearly.

At some plants the settled sludge is returned to pre-sedimentation tanks, which is effective in accelerating sedimentation in the raw water by about 30 to 50%.

A perforated masonry baffle to still and distribute the water entering the sedimentation basins is sometimes used. Other plants are provided with a baffle across the basin but with the lower 1/3 open to permit the water to pass under it. Baffling should prevent water from short circuiting direct from inlet to outlet leaving slower moving or stagnant areas at the sides or corners. a line of floats on the surface when there is no wind will indicate whether the water is circulating uniformly through the basins.

FILTRATION

RAPID SAND FILTER - DESIGN

Filter Units - Treatment plants are provided with at least two filter units as one will be out of service some of the time for backwashing and repairs. A convenient width for the filter box is 15 feet and length from 15 feet to 22'-6" capacity 648,000 and 972,000 gallons per day. Filters have been built with sand areas up to 1?500 square feet, capacity 4,320, 000, gallons per day.

Delivery - The settled water should flow from the top of the settling basins into the filter channel where its flow will be dissipated against the walls from where it will rise to flow slowly into the traughs and walls to avoid currents over the sand surfaces which prevents the formation of evenly distributed slime material.

Filtration Rate - A rate of 125 gallons per acre of sand area per day is common--this is equivalent to 2 gallons per square foot per minute or a vertical drop of 3.2" per minute. Some filters are now being built for a rate up to 3 2/3 gallons per square foot.

Filter Box - The box is commonly of reinforced concrete, rectangular, with side walls rough finished. Depth is usually 8 to 9 feet.

Sand - Sizes recommended--0.35 to 0.50 mm. For average waters effective size of 0.45mm with uniformity coeficient of 1.8 may be used. For highly polluted water use effective size of 0.37 with uniformity coeficient of 1.6. Larger sizes should be used for water which has been lime softened, of high turbidity, and of high organic content.

Sand beds should be 24" deep--occasionally they are 30" when 0.55 mm sand is used.

Sand should be hard, insoluble in water, clean, and free of dirt. Rounded grains are preferred by some to angular ones as water passes through them with less loss of head, but angular gives longer runs.

Anthracite coal is sometimes used in place of sand as in the plant at Niagra Falls, N. Y. built in 1937. It effects longer runs with better effluent and requires less backwash.

Gravel - A bed of graded gravel is placed under the sand to support it and to prevent other than vertical movement of the filtering and backwash waters, and for diffusion of backwash water. Filter gravel should be as round as obtainable though broken stone may be used if round gravel is not obtainable. Flat stones are to be avoided as wash water will scuttle them to the corners of the filters.

FILTRATION

Gravel - The filter gravel bed may be 10" to 20" but it is usually 18" deep. Sizes range from 2 1/2 to 1/8" in layers about 3" thick.

Underdrain - On the bottom of the filter box an underdrain system is provided for collecting the filtered water and for distributing the reverse flow of backwash water. A number of designs have been used but the most common is a closed concrete header channel of square section to which 4" lateral pipes are connected at right angles. These lateral pipes have a row of 1/4" holes on the under side and their ends are sealed. Where the lateral pipes are of cast iron or steel the perforations may become clogged, especially if the water is acid. To avoid this, asbestos-cement pipe is often used.

Traughs - Most filters have two wash water traughs or gutters for carrying of the dirty wash water to waste. They are made of cast iron, sheet steel or reinforced concrete, the last being most common. Recommended slope 4%, clear width 12" to 14", depth at high end 6" to 7", clear distance between traughs, 6 feet, clear distance between traugh and side wall 3 feet, section half round or half octagon. The edges over which the water flows should be accurately leveled at 2'-0 above the sand surface.

Often the water traughs are built so near the surface of the sand bed that as the sand rises with the backwash water, the fine grains will be deflected from the bottom of the traugh and settle on the sand surface between the traughs. In this way the top sand under the traughs will be coarser grains which will offer less resistance to the filtering water, permitting more water to penetrate that part of the filter than where the fine grains have been thrown.

Backwash - The most common instalation for backwashing consists of an elevated covered tank to which filtered water is pumped from the clear well. A valve is opened slowly and the filtered water flows by gravity through the filter underdrain system and rises up through the gravel and sand to over flow into the traughs which drain it off to waste.

The wash water reservoir should hold at least enough water to wash two filters, the water level when full should be 35 feet above the filter sand surface with a head range or depth of tank not exceeding 12 feet. The pump delivering the water from the clear well to the reservoir should be provided with a float controlled switch. Use recording depth gauge on washwater storage as metering the supply is more expensive. Wash water rate controllers are expensive and are not necessary unless wash water storage is at too high elevation.

RAPID SAND FILTER - DESIGN

<u>Backwash</u> - Water from the distribution system with pressure reducing valve is sometimes used for backwashing. Water direct from pumps has also been used. The same limits of head discharge should be provided as for the elevated reservoir.

Recently constructed filters have been provided with a system of perforated pipe with 3/32" holes to jet water on the sand surface at 30° from the horizontal.

Washing with air and water has certain advantages and disadvantages. Engineers differ in opinion as to the effectiveness of this method. It is now little used in the United States--many instalation having been transferred since 1923 to washing only with water. English engineers continue to use this system. The rapid sand filter of the large water plant at Montivideo, which is owned by an English Company, washes their filters with air and water and have just completed the instalation of some new filters of the same type. The largest water treatment plant in the world, at Buenos Aires, was washing with water until recently when they transformed their filters for washing with water alone. Three of these filters were left for washing with air and water to compare the results obtained with filters being washed with water alone. They have found the effluent is better when washing is done with water alone and consider it the better method.

There is some economy in wash water when air is used, as it usually amounts to 1% or less of the water filtered. Washing with air and water appears to be more effective in preventing the forming of mud balls and cracks in the sand bed than washing with water alone.

The disadvantages are the first cost of the air compressors and their operation. In examining the filter at Buenos Aires and those at Salvador Bahia, Brazil, which wash with water and air, it was observed that the sand did not settle back on to the filter bed in hydraucily graded layers as would occur after washing with water alone.

The writer has examined filters in operation in several cities in Brazil in which the backwashing water was forced up through th the center of the filters by air pressure, though the air itself did not go through the filter with the wash water. None of these were working effectively due to the fact that the wash water did not enter with enough pressure to expand the sand except a little in the center. These are called Reisert Filters and were designed in Germany. These are more complicated and have no advantages over the siipler rapid sand filter.

FILTRATION

RAPID SAND FILTER -DESIGN

Filter Appertenances - Essential control instruments are loss of head gauge and rate of flow gauge. Variable rate controllers are preferred to the fixed type.

Valves in the pipe gallery of small plants may be operated directly by rods to the floor above. Larger plants use hydraulically operated valves.

There should be transparent divices for observing and sampling the water from each filter. These are most conveniently located on the filter operating tables.

RAPID SAND FILTER - OPERATION

The mechanical or rapid sand filter is nearly always preceded by the application and mixing of coagulants and sedimentation. The operating water level should be maintained at 4 to 5 feet above the filter sand surface.

Slime Mat - The filter sand surface should be covered with a straining layer 1/16 to 1/8" thick, consisting mainly of small floc which does not settle out in the sedimentation basins but passes over onto the filter where most of the floc should be retained on the sand surface, though some will penetrate an inch or so into the sand bed. If the floc reaching the sand surface is very small it will penetrate the sand and not form the desired mat, readily. If too much larger floc reaches the sand, the mat will thicken quickly and the gauge will register increasing loss of head and will result in shortening the filter runs. The floc will have gathered some suspended matter such as finely divided silt, organic matter and micro-organisms. The latter may contain predatory protozoa which prey on bacteria.

This slime mat is carried off with the wash water. After backwashing the filtered water should be wasted until the slime mat is formed as the straining effect of sand alone is not sufficient to prevent the passage of bacteria which are much smaller than most of the other suspended matter.

A common practice is to waste the water for 3 to 5 minutes after backwashing which should allow time for some mat to form. Some prefer to operate the filters at a very slow rate for from 1/2 to 1 hour after backwashing. Another method which permits the formation of some mat is to allow the suspended matter to settle out of the water above the sand surface for 1/2 to 1 hour after backwashing and before starting to filter.

FILTRATION

RAPID SAND FILTER - OPERATION

It is necessary that the slime mat form equally over the entire surface of the sand bed. If there are uncovered areas the water will rush to such areas where resistance is less. These areas are caused by horizontal currents. Filters are frequently built with the settled water delivered so that these currents are produced. Wood baffles placed at 45° before the incoming delivery pipe to force the water down in the channel facing the filter will be effective in eliminating these currents.

Filtration Rate - The rate for which the rapid sand filter is usually designed is 2 gallons per square foot per minute. To accomodate excessive demands on very hot days, this rate may be exceeded by 50%. The slower a filter is operated the greater will be the amount of suspended matter removed.

Filter Runs - The time that a filter will effectively operate before needing to be backwashed is commonly between 12 and 72 hours with an average probably around 24 hours. Long runs are economical as less water is required for backwahsing. Runs are shortened by too much floc passing over to the filter, by the clogging of the filter bed with algae, clay, floc, organic matter, and mud balls.

Backwashing - When the loss of head gauge registers between 7 and 9 feet, the filter run will be stopped and backwashing will be started. Other factors may determine the time when backwashing should begin, such as, when the water ceases to flow through the filter at the rate for which the filter was designed or when laboratory tests indicate that aluminum sulphate is passing through the filter or that the turbidity of the filtered water exceeds 0.5 p.p.m.

When the top sand is clogged and there is excessive mat, hosing may be resorted to before backwashing. Surface washing of filter sand beds is becoming more popular.

Before starting to backwash, lower the water to the level of the over-flow edges of the waste traughs--some operators lower it to 6" above the sand surface.

The wash water should be applied slowly and increased gradually. If applied suddenly the water will break through the sand bed in places rather than rise evenly. This will upset the hydraulic grading of the sand so that the resistance to the filtering water will be uneven resulting in parts of the filter bed taking more water than others.

FILTRATION

RAPID SAND FILTER - OPERATION

Washing should continue until the turbidity of the waste water is reduced to about 75 p.p.m.--the operator can keep a jar of water with this turbidity on hand for comparing. When the waste water becomes clear enough for the observer to begin to see the sand surface, then washing may be discontinued. There is no need to continue washing until the waste water becomes clear--to do so entails a waste of water. Washing may take from 3 to 10 minutes but usually 4 or 5 minutes.

From 1% to 5% of the filtered water produced is used for backwashing--the average is 3%. Wash rate is between 20" and 42" while the economic wash rate is probably around 2.7 feet vertical rise per minute or 20 gallons per square foot per minute. Coarser sand will require a higher wash rate than for finer sand.

The sand should rise or expand from 30 to 50% of its depth--usually 50%. The operator should control this sand expansion when washing the filters. The level to which the sand rises can be determined by rubbing the fingers together in the water until the gritty feeling of sand is sensed. Sand expansion may be measured by using a piece of wood to which metal cups have been nailed at intervals of 3". This pole can be held vertically in the water during washing. The last cup into which sand has settled will indicate the height to which the sand has risen.

Do not drain to the surface of the sand but if this has to be done to inspect the sand do not apply the unfiltered water to the sand surface, but raise the water to the over-flow level of the waste truaghs by applying backwash water before starting the filter.

Filtered Water - The turbidity of the filtered water should be 0.2 p.p.m. or less. Maximum allowable not to exceed 0.5 p.p.m.

PRESSURE FILTERS

Pressure filters are not usually employed in large municipal supply systems. They are often used for industrial plants, institutions, and for swim pools. At least 45 of the smaller cities of Canada employ pressure filters. Such filters have the advantage of conserving the pressure, and of occupying less space, but the disadvantages of higher first cost, operation not being exposed to constant inspection and less effective in bacteria removal.

Pressure filters are cylindrical air tight steel tanks. Vertical filters are 18" to 9 feet in diameter and 7 to 8 feet high and the horizontal ones usually 8 feet in diameter with lengths up to 25 feet.

FILTRATION

PRESSURE FILTERS

The working pressures are 65 to 75 pounds per square inch, but they are commonly designed for water pressures up to 150 pounds per square inch, rate of filtration 2 to 3 gallons per square foot per minute, loss of head in passing through filter, not over 10 feet, backwashing 15 gallons per square foot per minute, filter runs 4 to 24 hours, wash water used between 2% and 5% of water filtered.

The water is delivered at the top, strikes against a baffle distributor, is gathered by an underdrain system. Inlet and outlet gauges show loss of head. Backwashing is effected by reversing the flow.

RAPID SAND FILTER - MAINTENANCE

Sand - Sometimes floc will cement together sand, clay, and organic matter to form small lumps which grow in size. These are sometimes observed on the sand surface when about the size of a bean. Often these are soft enough to be broken up by hosing down the sand surface or by running a garden rake through the sand. Small forming mud balls may be removed during washing by a piece of 1/4" wire net fastened to the end of a pole. When mud balls become large they may be located by the irregularities they form on the sand surface or by sounding with a pole during backwashing. These should not be broken up in the sand bed but should be taken out by hand and thrown aside.

When the filter top sands become clogged with hydrate, clay, algae, and other organic matter it may be scraped off mechanically with some waste of sand. Clogging of filter sand and mud balls will be more troublesome in warm water, as backwashing with warm water is less effective than with cold. If the material causing such a clogged condition in the upper part of the sand bed is mostly organic then it may be loosened by applying a 2% solution of caustic soda, sometimes soda-ash is used. As the sand interstices are partly filled up they will represent less than 1/3 of the volume. If the clogging organic matter has penetrated the sand bed to a depth of 6" then the sand surface should be covered with a little over 2" of the caustic soda solution. The filtering valve will then be opened slightly to permit the surface to lower enough to barely cover the sand surface.

The effectiveness of this treatment, the concentration of soda-ash, and the contact period--usually at least 6 hours should be determined in the laboratory first.

Chlorine and chlorine compounds are also used for cleaning filter sand.

FILTRATION

RAPID SAND FILTER - MAINTENANCE

Before the filter is put back into service it should be backwashed until the pH of the waste water is the same as that of the incoming wash water.

Such dirty conditions of the filter bed may cause irrugularities on the sand surface, especially around the corners and cracking open of the sand bed and opening away from the walls, particularly if the water is acid.

The main cause of such conditions is the penetration of floc and algae into the sand bed, insufficient flow velocity of backwash water to remove it, and too long between backwashings. Organic slime can be removed better with brine than with lye. Manganese, iron, and alumina coatings can be removed from filter sand grains with a 17% solution of caustic soda.

Underdrain System - If the backwash water does not rise up through the sand evenly, and well distributed, then parts of the underdrain system are probably stopped up and need clenaing out. The sand and gravel should be taken out and the clogging materials removed. If parts of the underdrain system are stopped up, the wash water will open channels in the sand and result in ineffective washing and will disturb the hydraulically graded layers. A broken underdrain will raise gravel into the sand and produce mounds and craters.

Valves - Keep valves operating easily by oiling. Open, clean, and change packing when needed--at least yearly.

Operating Control Devices - Maintain in good working order. Replace the rubber diaphragms on the rate controllers when necessary and open pet-cocks occasionally to release collected air. Check accuracy of loss of head gauges by actually measuring the difference of water level in the two vertical pipes containing the floats.

SLOW FILTERS

These were developed in England and are often referred to as English filters. Not many of them are built now, not because they are obsolete but because other methods are now available to perform its functions more economically in the majority of cases, though not in all.

The operation of slow sand filters is simpler and more economical than rapid sand filters, particularly when not preceded by coagulation.

FILTRATION

SLOW SAND FILTERS

As each filter unit occupies considerable space, usually 1 acre but they have been built from 1/4 to 1 and 1/2 acres, they cannot be built on very expensive land nor on property where much expense would be incurred in leveling off the ground.

The slow sand filters will not efficiently handle waters with turbidity exceeding 30 p.p.m. as they are not provided with a reverse flow system for backwashing, the surface must be scraped off by hand. The water for these filters is not usually prepared for them by coagulation and sedimentation but may be preceeded by plain sedimentation and/or roughing filters.

Slow sand filters should remove 98% of the bacteria, all suspended solids and 30% or 40% of the color.

Sand - The effective sand size is 0.2 to 0.3 mm--London filters use 1/70"--, depth of sand bed 2 to 4 feet usually 3 feet, with uniformity coeficient of 1.5 to 2.5.

The water to be filtered is maintained at a level 3 to 5 feet above the sand surface. Filters should never operate with less than 1 foot of water over the sand. If loss of head exceeds the depth of the water laying over the sand bed, it may rupture the sand surface and release sufficient dissolved air from the water to bined the sand beds, due to the suction or negative head. The water should be filtered to waste, after scraping the sand surface, until a biological film forms, consisting of dead and live algae, bacteria, and other plankton. This slimy layer takes 2 or 3 days to form on the surface of the sand bed.

Filtering may continue until the loss of head reaches 3 to 4 feet when the filter surface requires cleaning. This is effected by removing 1/2" to 1" from the surface. Sometimes the biological layer is of such consistancy that it can be rolled up like a carpet after allowing it to dry a little. It is more common, however, to scrape the top sand up in piles which is carried away in wheelbarrows running on planks which have been placed on the sand surface.

In washing the sand, care should be taken not to wash off the fine grains with the organic matter, silt, clay, etc.

FILTRATION

SLOW SAND FILTERS

Sand - Piling of sand scraped from the surface and left in mounds on the sand bed while operating the filter which may result in so decreasing the effective area of the sand bed as to result in an excessive filtering rate is not recommended. In some cases, the dirty surface sand is washed in a revolving steel cylinder or by hand. This will consume between 0.3% and 3.0" of the filtered water produced. Where there is an abundance of suitable sand nearby, it may be more economical to replace the dirty sand with new sand instead of washing it. In no case should the sand bed be operated with a depth of sand less than 18".

The average operating rate is 2 1/2 million gallons per acre per day while it may vary between 2 and 5 million gallons (0.031 to 0.08 gals. per sq. ft. per min.). There are various underdrain systems, sometimes there is a main drain with terra catta tile feeding laterals, in others the gravel supporting the sand rests on open jointed bricks.

All of the public water supply of San Jose, Costa Rica and Gauyaquil, Equador, goes through slow sand filters. Such filters were used for many years by the English company operating the public supply at Montevideo, Uruguay, but new rapid sand filter capacity is now adequate so the English filters are maintained in operating condition as stand-by units.

DOMESTIC FILTERS

Many types are manufactured for home use, employing various filtering materials such as unglazed porcelain, diatomaceous earth, asbestos discs, pumice, paper, porous rock, and activated carbon. These will all practically eliminate the turbidity, leaving a water of fine crystaline appearance which gives the family full confidence in the filtered water. Such water, however, may contain pathogenic or disease causing organisms. These may porpagate in the filter media itself, especially if it is dirty or they may pass through a crack or other defect in the filtering medium.

The filtering medium should be cleaned at least once a week and preferably twice. Brush the surfaces and sterilize by boiling.

In many tropical places where the water is considered to be dangerous, it is both filtered and boiled. The almost universal practice is to boil first then filter. The water should be filtered first then boiled after which it should not be handled any more than necessary--that is it should be left in the container in which it was boiled. Boiling affords more dependable disinfection than filtration and boiled water might become reinfected in an unclean filter.

FILTRATION

INDUSTRIAL FILTERS

Various designs and filtering materials are used, such as, paper, jute and cocoanut fibers. Synthetic fibers have been developed like Vinyon, made by the American Viscose Corp., which is resistant to both acids and alkalis.

Rough filters are sometimes employed to remove objectional matter from factory effluents so they may be discharged into streams without unduly polluting the water. Oil may be taken from refinery effluent by running it through common straw--when it begins to clog, it can be removed and burned.

AERATION

Water is brought in contact with the atmosphere or aerated for the following purposes.

1. Removal of objectionable gases, principally carbon dioxide and hydrogen sulphide.
2. By reducing the carbon dioxide content, less lime will be required for coagulation and softening. Reduction of hydrogen sulphide lowers the chlorine demand as chlorine oxidizes hydrogen sulphide.
3. To add dissolved oxygen to the water for the oxidation of iron and manganese, organic matter, and to supply residual oxygen to remove the flat taste and freshen it. Aerated water will have 7 p.p.m. of free oxygen or more.
4. Removal or reduction of odors and tastes due to gases of organic decomposition and residual chlroine.
5. To expose the water to the actinic or violet rays of the sun which reduce the color by bleaching and kills some bacteria.
6. Miscellaneous: Kills some delicate micro-organisms due to the violent movement of the water, thoroughly mixes chemicals previously added to the water for treatment, and may assist coagulation by reducing the carbon dioxide content which raises the pH, and beautifies the water works, creating favorable public opinion.

Many kinds of aerating instalations are in use--some standard equipment catalogued and sold by concerns supplying water works--others are designed and installed by the local water men.

The most commonly used method of aeration is by jet or spray nozzle, which throws the water into the air. For this system, a minimum head of 11 feet is essential and more is better.

Water containing chlorine or other gaseous residual will lose some of it by aeration, especially if the water is acid.

Water may be sprayed over coarse gravel. A slimy dark deposit of dead and living micro-organisms will be formed on the surface of the rocks which will entangle bacteria. Layers of trays with lump coke of 1 to 2" laying 6" deep are sometimes used for running the water through.

Water may be run over steps or cascades carefully pitched so that the water will flow over the smooth surfaces in thin sheets of uniform thickness. Such aeration requires little head and exposes the water to the bleaching and sterilizing action of the sun rays.

AERATION

An effective traugh with rounded wooden cross pieces is used at various places--the traugh slopes about 30% which may be determined by first making a minature working model. The water reaches the bottom of the incline, a seething mass of water and air.

Well water is sometimes delivered to its reservoir by discharging it vertically against a steel sheet umbrella with sufficient force to break it into drops and spray.

At one place visited, well water is delivered to an elevated steel tank by flowing over an old tractor wheel through whose axle-hole the water flows, running over the rim in a thin even sheet from where it drops into an elevated tank,

A small instalation observed was made of a metal traugh, slightly inclined so the water flowed slowly, trickling through perforations in the side, falling on a nearly vertical coarse copper screen to be caught below by another traugh and carried away. Screens of such an aerator have to be cleaned of algae frequently.

Rarely water is aerated by blowing compressed air through it.

Aeration is helpful in removing petroleum wastes, but is of little value in removing phenol tastes and odors. Aeration is usually on untreated water but sometimes after filtration.

When water contains 10 p.p.m. or less of carbon dioxide around 1/2 will be freed to the atmosphere by aeration--if this concentration is exceeded, removal will be about 60 to 80%. Ordinarily waters will contain 3 to 5 p.p.m. of free carbon dioxide after aeration.

If the main purpose for aerating a water is the reduction of carbon dioxide, this can be generally effected more economically by the addition of lime if the carbon dioxide concentration is not over about 12 p.p.m.

If water is aerated primarily to furnish the oxygen for oxidizing iron, this may be done by chlorine which would not add so much to the corrosiveness of the water as the added oxygen. If the carbon dioxide content of the raw water is high, then the reduction in corrosiveness due to freeing the carbon dioxide may compensate for the corrosiveness added by the oxygen dissolved from the atmosphere.

WATER SOFTENING

HARDNESS

The carbonate hardness formerly referred to as temporary hardness is caused by calcium bicarbonate and magnesium bicarbonate. The carbon dioxide is loosely held and is driven off by heat, leaving the insoluble calcium and magnesium (partially) carbonates to settle out and form deposits in boiler tubes and other devices where water is heated.

The non-carbonate or permanent hardness is caused by sulphates and non-carbonate salts, chlorides, nitrates of calcium and magnesium.

Water in which soap readily lathers are soft. The calcium and magnesium compounds react with soaps, forming a greasy curd which adheres to fabrics, clouds the water and produces a gritty feeling, causing spotting and added wear in washing. Soap consumption is 2 ounces per 100 gallons of water for each p.p.m. of hardness. Hard waters are objectionable for domestic, laundry, wool, textile, dying, leather, tanning, rayon manufacture, chemical industries, distilleries, glue factories, fermentation, starch works, sugar refineries, ice plants, breweries, paper making, boiler feed, and natural gasoline plants (effects their cooling coils, heat exchangers and absorbers). Hard waters are not unwholesome for drinking. Vegetables in being prepared for canning such as beans and peas, are toughened by hard waters.

Both types of hardness are of equal importance in augmenting soap consumption. The consumption of soap increases 1.7 pounds per 1,000 gallons of water for each grain per gallon of hardness.

The following hardness classification is commonly used in England:

under 50 p.p.m.	very soft
50 - 100	moderately soft
100 - 150	slightly hard
200 - 300	hard
over 300	very hard

One degree of hardness (French) is 10 p.p.m. or p.p.m. of $CaCO_3$ = 100/7 X degrees of hardness. Hardness is always calculated as equivalent of $CaCO_3$.

Hard scale forming waters are particularly objectionable to certain industries. The location of such industries is sometimes determined by the softness of the available water supply.

WATER SOFTENING

LIME-SODA-ASH SOFTENING

The addition of lime almost completely removes the temporary hardness caused by calcium and magnesium bicarbonate. By adding five grains per gallon (65.5 p.p.m.) of quick lime, 100 p.p.m. of bicarbonates will be removed. Lime added for softening will often establish the sulphate-alkalinity ratio sufficiently to prevent caustic embrittleness in boiler steel.

Sometimes so much lime is added for softening that the degree of alkalinity is raised above pH 9.5 producing caustic alkalinity which imparts a disagreeable flat taste and forms deposits in the pipes of the distribution system--pathogenic organisms cannot survive in such water. This is corrected by the addition of carbon dioxide to the water, called recarbonation, which converts the mineral to the soluble form, or "stabilizes" it. Carbon dioxide is produced from power plant stack gas or burning of gas, oil, or other fuel. The products of combustion are washed in a coke tower and applied to the water before filtering. Excessive lime will deposit on the sand grains, causing them to "grow" and become ineffective.

The calcium and magnesium chlorides and sulphates causing permanent hardness, are treated by the addition of soda-ash (sodium carbonate), which converts the calcium and magnesium salts in solution to their corresponding carbonates and are replaced by sodium compounds. Adding 6.5 grains per gallon (107.15 p.p.m.) of soda-ash will remove 100 p.p.m. of permanent or non-carbonate hardness. For each 100 p.p.m. of hardness removed by soda-ash, the sodium sulphate content is increased 150 p.p.m.

Variation in mineral content of surface water complicates the softening treatment as the amounts of lime and soda-ash added will have to be changed. Iron and manganese are removed by this softening process.

Softening by the lime-soda-ash process costs around ten cents p.m.g. for each p.p.m. removed, in the United States.

For excess lime and soda-ash treatment for bacteria at pH 9.5 or over, allow 24 hours. Lime also eliminates the entamoeba histolytica, and the tropical cyclops which harbours the Guinea worm enbroyo, an intestinal parasite.

Lime sludge may be reclaimed, de-watered and sundried--a large volume of sludge residue is left by this process.

This lime and soda-ash method softens water effectively to 43 p.p.m. but it is not generally economical to reduce the hardness to less than 60 p.p.m. by this process.

WATER SOFTENING

ZEOLITE SOFTENING

Sodium and aluminum silicates or zeolites are used in a filter similar to a vertical pressure filter. The water to be softened enters the top of the filter and descends through the zeolite sand 4 to 5.5 feet deep--where the calcium and magnesium compounds are replaced by sodium salts by the base exchange principle of chemistry. In two or three hours the zeolite is depleted and has to be regenerated by reverse flow of brine whose sodium is exchanged for the calcium and magnesium taken from the waters.

There are natural zeolites which are mined from the earth in New Jersey--deposits exist in South Texas and other places.

A cubic foot of greensand should soften 3,000 grains of hardness (as calcium carbonate,) while good synthetic zeolite will take out 9,000 to 12,000 grains. Due to so much less synthetic zeolite being required, the softening filters may be made much smaller than if greensand were used, reducing its cost.

The cost of zeolite softening depends upon the price of sant. In some places where sea water is available, it may be used for regenerating zeolite filters as it has a salt content of around 23,000 p.p.m. This has resulted in considerable economy in some large instalation though sea water is not generally clean enough to use without treating.

Synthetic or gel zeolites are manufactured chemically. They are made by mixing sodium silicate with an aluminum compound. The gelatinous material formed in this way, is partially dried and then dropped into water which causes it to break up into granules. Chemically zeolites are hydrated double silicates. Formulas are:

$$3H_2O; Na_2O:2Al_2O_3 5SiO_2 \text{ and } CaO \cdot 2Al_2O_3 \cdot 5SiO_2$$

Synthetic zeolites also effect a saving in salt consumption, as they require 0.30 to 0.35 pounds per 1,000 grains of hardness (as calcium carbonate,) while greensand will require 0.45 to 0.50 lbs. The calculated theoretical salt required is only 0.17 pound, so more effective zeolite softening methods may be worked out to considerably reduce this salt consumption.

The advantages of synthetic zeolite over greensand are; lower cost of and smaller softener equipment, 25 to35% saving in salt consumption, 50 to 75% reduction in volume of wash water, the amount being in porportion to the volume of zeolite, less frequent regeneration, less pumping, and less loss of head, as the synthetic grains are larger. All of these advantages are greatly decreased if only a small amount of hardness is to be removed. Waters having total hardness of 7 grains per gallon or less may be softened economically with greensand.

WATER SOFTENING

ZEOLITE SOFTENING

The efficiency and life of both the natural and synthetic zeolites vary greatly, depending on their innate character and processing and frequency of regeneration. Zeolites will not last forever, but if of good quality, they should last many years.

The chief advantages of zeolite softening are removal of nearly all of the hardness, simplicity of plant operation, it leaves no sludge to be disposed of, and the equipment takes up little space.

The disadvantages of zeolite softening are that it adds sodium bicarbonate to the water, which becomes sodium carbonate when carbon dioxide is driven off by heat. It may also add some to the silica content of the water, due to the solvent action of the water on the zeolite.

Turbid or muddy waters cannot be economically softened by the zeolite process unless preceeded by coagulation, sedimentation and filtration. For this reason, the zeolite process is not commonly used for softening surface waters. Even when this process is used on well water it is usually preceeded by a pressure sand filter.

Hard waters high in sodium content cannot be economically softened with zeolite on account of the large amount of salt and water required for reganeration.

Temporary or bicarbonate hardness can be removed by lime at half the cost of salt required in the zeolite process. The removal of permanent or non-carbonate hardness by soda-ash costs arount 25% more than by salt. For this reason some plants whose water has a total hardness exceeding 170 p.p.m., first remove the bicarbonates by adding lime. After the lime has settled out, the water may be put through a zeolite softener to remove the remaining hardness.

It is a usual practice to zeolite soften water to zero hardness and by-pass enough unsoftened water to raise the hardness to four to six grains per gallon or 68.5 to 102.7 p.p.m. This will furnish calcium carbonate alkalinity and raise the pH sufficiently to protect the pipes against corrosion and cause a protective coat of calcium carbonate to form on the inside of the pipes. If the remaining hardness is insufficient to bring about these protections against red water formation, sodium carbonate or lime may be used.

Some believe that zeolite removes iron in solution by basic exchange, while others think that it only filters out mechanically, the iron which reaches it in the oxidized state. It is not considered good practice to use the zeolite softener for iron removal if the amount of iron is large, as the deposited iron will form a covering on the zeolite grains which will result in a loss of efficiency up to 10% and also damage the underdrain system. Waters high in iron should be aerated and filtered before reaching the zeolite.

WATER SOFTENING

ZEOLITE SOFTENING

The zeolite filter bed should be maintained in a loose free condition for optimum exchange capacity.

The maximum backwash rate is 5.5 gallons per square foot per minute.

Too high a salt dosage is wasteful--around 0.7 pounds per cubic foot of zeolite is often found economical.

SODIUM HEXAMETHAPHOSPHATE

This chemical produced and marketed under the name of Calgon, by Calgon Inc., 111 West Jackson Street, Chicago, Ill., has been successfully used since 1937 for softening water. Between 1 and 2 p.p.m. is the usual dose, added after filtration. It does not add to the corrosiveness of the water, nor does it lower the pH. It will not dissolve already deposited calcium incrusted in pipe but will soften it to 1/8" from the surface.

In doses of 4 p.p.m., Calgon is reported to hold iron, manganese, and other metals in suspension.

Health officials have tested this chemical and did not find any toxic effect.

BOILER FEED WATER

Water for boilers should not cause incrustation, embrittlement, corrosion, or foaming. Water should not have a hardness exceeding 35 p.p.m. for use in boilers operating under ordinary pressures. For boilers using very high pressure, water should have no hardness, but 4 p.p.m. may be tolerated. Where railroads or large industrial plants use considerable water whose hardness exceeds these limits, they usually prepare their water to suit their own needs as the public suppliers could not be expected to do this.

There are on the market a number of boiler compounds which are special reagents to condition boiler feed water to avoid the more complicated softening processes. The manufacturers of these do not divuldge their contents to the users so the dosing cannot be adjusted to the operation of the boiler, nor to the water treatment.

Such internal treatment to prevent the formation of scale on the inside of the boiler tubes may be affected by the use of sodium carbonate when the pressure is low and sodium phosphate for higher pressures. Other reagents for internal treatment are caustic soda, sodium aluminate, sodium sulphate, and tannin. Proportions for these reagents should be worked out by an expert chemist.

WATER SOFTENING

BOILER FEED WATER

Condensed steam contains minute particles of oily matter which forms films on the metal surfaces of boilers which may cause rupture of tubes from over heating. These may be removed by coagulation or filtration.

Boiler water should be free from CO_2, dissolved oxygen, free acids, organic compounds, oils, and greases, and non-carbonate hardness. Ratio of alkalinity to sodium sulphate should be 1 to 3 for 250 pounds and over.

Causes of foaming and priming are:

1. Boiler design: inadequate water area or steam space.
2. Boiler operation: variation of load on water level and firing irrugularly.
3. Water: presence of organic matter and suspended matter and high alkalinity.

Scale forming in the water tubes of boilers causes loss of efficiency as the deposits act as insulation, interfering with the transfer of heat. Scale 1/9" thick will cause a heat loss of 16%. The softer deposits of calcium carbonate and calcium sulphate being more porous, furnish better insulation, consequently they reduce the boiler efficiency more than the harder and denser deposits of magnesium carbonate and magnesium sulphate.

Analysis of boiler feed water should give: Alkalinity, hydroxides, carbonates, hardness, chlorides, total dissolved solids, and suspended matter.

Mechanical means are employed for removing scale from boiler tubes. Mechanical processes consist of tube cleaning drills, scrapers, and air and water oscillating hammers.

ACTIVATED CARBON

Activated carbon is charcoal which has had its porosity increased and consequently its capacity of absorption. This is accomplished by an industrial process, using steam and air under pressure. The charcoal is made from various substances, especially lignite, wood pulp and birch wood. There is considerable variation in the efficiencies of these carbons. The carbon is crushed and carefully screened to size: then distilled and washed with hydrochloric acid to reduce the ash content. Activated carbon is 70% carbon and 30% siliceous material.

Activated carbon is used for removing odor, tastes, residual, chlorine, color, phenols, condensor oil, iron, and manganese. The use of carbon reduces the chlorine demand so a smaller post-chlorine dosage will result in the required residual.

Activated carbon is used in about five hundred American cities where both the powdered and granulated forms are employed.

Powdered Activated Carbon - Powdered or pulvarized carbon is usually added to the raw water with the coagulant with which most of it settles, that reaching the filters remaining on the surface mat. The carbon must be completely saturated or it will become air locked, resulting in inefficient absorption. If used alone, it penetrates the filter sand. Powdered carbon is not reclaimed it is carried off with the backwash water.

The weight of activated carbon is 200 to 240 kg. per m^3. Power of absorption diminishes with use a little quicker than the granular. It is commonly applied in water at the rate of 2 to 15 p.p.m. The usual carbon dosage is about 16 pounds per million gallons or 2 p.p.m. but the maximum is 150 pounds per million gallons at the filters and the same amount at the mixing chambers, to eliminate tastes and odors. The odor control is more effective with the carbon when filters are operated at a slow rate.

The usual purpose for applying powdered activated carbon to water is to eliminate gases and other volatile matter which produces tastes and odors. This is effected by the absorbing power of the porous carbon particles. The carbon surfaces are very adhesive and so will reduce suspended and colloidal matter.

Powdered carbon may be fed alone or with alum or lime from dry feed machines. It may also be fed in suspension but in doing so the water in which carbon is put will have to be stirred to prevent its settling. Some 63% of the plants in the United States apply powdered carbon before filtration, 28% after filtration, and 9% apply at both places. Opinion differs regarding which is the more effective point of application--very likely it will vary with different waters.

ACTIVATED CARBON

Where the carbon is applied with the coagulant, most of the carbon will settle with the floc, where it will retard fermentation and absorb gases in the settled sludge and so prevent entrapped gases from causing slugs of sludge from rising to the surface.

Where the activated carbon is applied to the water being fed to the filters in the beginning of the filter runs, it will be retained in the slime film on the sand surface, from where it will be washed off to waste when the filter is back-washed.

On several occasions the writer has found it more effective to mix the wet carbon into the upper 3 or 4" of the filter sand, especially for color removal.

Granulated Mounded Activated Carbon - Granulated moulded activated carbon is used in filters sililar to vertical pressure filters, the tank being nearly filled with carbon. Depth of bed in U.S. is 24 to 48" and the rate is 2 gallons per square foot for 24" and 4 gallons for 48". In Europe the depth is 8'-6". The maximum upward flow is 4 gallons to avoid undue expansion. Upward flow is preferable as it results in less clogging and less loss of head. Granular carbon is sometimes reactivated with steam but this is not very effective. The best reactivation is obtained by returning the carbon to the manufacturer. No chemical solution has been found to be very effective for this purpose.

Small grains of granulated activated carbon give better results. Moulded grains are harder, more resistant--sizes 0.75 to 2.5 m/m For domestic use filters and for removing oil from condenser water use 0.75 to 1.5 m/m. For removing color at large water treating plants and industrial plants, use 1.5 to 2.5 m/m with filter bed 1.5 to 2.5 meters thick. Weight of granulated carbon is 385 kg. per cubic meter. This type of activated carbon is of long life and may be backwashed, which cleans the carbon bed some,

It is necessary to run the water through a sand filter before it goes to the carbon filter. Such a filter operates at the same rate as rapid sand filters--2 g.p.m. per square foot of carbon surface. Carbon filters require cleaning about twice a year. Granulated carbon is more effective than powdered carbon but is more costly. Carbon filters are not now extensively used.

Granulated carbon filters accomodate varying intensities of taste and odor and require no regulation of dose as does powdered carbon.

Granulated Amorfous (not moulded) Activated Carbon - This is less expensive than the moulded. It does not resist much change in pressure, is not as hard and does not last as long as the moulded. Sizes are 1 to 4 m/m. It can be partially regenerated with steam.

CORROSION

Water is aggressive or corrosive when acid, that is when it contains considerable carbon dioxide and low alkalinity, acids, iron and aluminum sulphates, calcium chloride and nitrate, magnesium sulphate (in appreciable amount), chloride, nitrate, and dissolved oxygen when pH is below 10. Dissolved salts also effect corrosion, chloride sulphate, bicarbonate, and nitrate ions are corrosion-stimulating ions, and hydroxyl, carbonate, phosphate, and chlromate as corrosion-retarding ions.

Corrosion may take place without producing "red water" and without showing increase in the iron content of the water. The metal surfaces exposed to running water will rust more rapidly than where the water is still as the flowing water removes the protective coating.

When the pipe mains become corroded, they may be scraped out but such scraped surfaces will oxidize more rapidly than the original ones.

Pipes of non-corrosive materials may be used where the water is aggressive, such as, concrete or cement asbestos pipe. Cast iron, steel, or other metal pipe may be coated with non-corrosive material such as cement, Bitumastic, etc.

The corrosiveness of water may be corrected by the addition of sufficient lime to combine with the free carbon dioxide, to form calcium bicarbonate. If the water is super-saturated with more calcium than is needed to combine with the carbon dioxide, it will deposit in the tubes and form a protective coating. Care must be taken that excess lime is not sufficient to produce heavy incrustations in the pipes which would reduce carrying capacity, nor to cause scaling in hot water pipes, nor to clog the meters. Before this protective coating is permitted to form, the surfaces should be thoroughly cleaned of rust and tubercules--if this is not done, the oxidation will continue under the coating. Care must also be taken to control this correction operation--it should be continuous and not intermittent.

In some cases the calcium is imparted to the water by passing it through contact beds of crushed marble or limestone instead of dosing with lime. This will increase the pH to a maximum of about 8.2.

Such addition of calcium to reduce the corrosion of water will add to its hardness and consequently augment the soap consumption. This would not occur if soda-ash were added instead of lime, but it is much more expensive and would not be justified in most cases.

CORROSION

Sodium silicate is good for treating soft acid waters as it decreases alkalinity anf forms silicate coating. It combines with calcium to form a hard calcium silicate incrustation in pipe. If there is not sufficient calcium in the water, lime may be added with the sodium silicate. Doses of 0.6 to 2.4 p.p.m. of sodium silicate are usual. Hardness will not be increased.

This means of protecting pipeing against corrosion is often used in hot water systems of buildings and is beginning to be used in public water supplies.

Galvanic Corrosion - This occurs where pipes of dissimilar metals are joined. The usual treatment of water with lime does not prevent galvanic corrosion.

Electrolysis - Where stray currents leave pipe or other metal surfaces, rapid electrolitic corrosion takes place, which may soon pit and later produce holes in the pipes.

Rails should be well bonded with connections from water pipe to rails.

Grounding of secondaries of lighting transformers on water pipes should be avoided. Radios should not be connected to water pipes.

CLEAR WELLS

The treated or finished water flows by gravity from the filters to the filtered water reservoir which is located under the filters or along-side of them. Such reservoirs are ordinarily built with the top at, or near the ground level. To prevent algal growths, they are covered with a flat concrete roof. The roof is often covered with about 1 foot of soil which may be made attractive by gardening. This earth covering serves as insulation, preventing the sun from heating the water.

The capacity of the clear well is commonly 3 hours consumption. Where the treatment plant is at a high elevation, it may be desirable to store as much as 24 hours consumption in order to conserve the pressure, when the clear well would also serve as a distribution reservoir.

For economy these tanks are made square with a center wall so one side may be cleaned while the other is in operation.

DISINFECTION.

DISTILLATION

Evaporation and condensation effects absolute sterilization.

Where distilled water only is used for drinking, the teeth and bones are quickly injured--such water is harmless if lime or other alkali is added or the deficiency may be made up by injesting milk.

Distilled water will absorb carbon dioxide from the atmosphere establishing equilibrium at pH 5.7--the pH may be driven off by boiling until the pH goes to 6.6 to 6.8.

A few ships are using distilled sea water for drinking. Incrustation in heating coils os sea water evaporation is slight if heated only to 128°F. The distillate is filtered through activated carbon and aerated.

A brewery at Galveston, Tesas, uses distilled water for beer making where distillation, using cheap petroleus as fuel, costs $0.o7 U.S. Currency per keg of 32 gallons.

HEAT

Authorities differ on what constirutes complete heat sterilization, barying between 230°F, and time 5 to 25 minutes. All non-spore forming organisms are killed within on half hour in 60° to 65°C or 140° to 150°F, water.

Certain micro-organisms - Thermophiles - are highly resistant to heat, some resisting boiling for hours. These are found in soil, hot springs, and animal intestines--they are harmless. Tetanum and gangrene organisms which may contaminate woulds are resistant to boiling for short periods--under 12 minutes. Pathogenic organisms have narrow growth temperature range.

Boiling at high altitudes is less effective germicide, due to low temperature at which water boils.

Heat sterilization leaves no toxic residue, it frees the oxygen and carbon dioxide to the atmosphere.

The hands cannot resist water hot enough to destroy pathogenic organisms.

DISINFECTION

PRE-CHLORINATION

Sometimes the raw water is chlorinated before treating to reduce the organic matter, iron, color, hydrogen sulphide, algae, pipe growths, and as an aid to coagulation. Dose is between 0.5 and 1.2 p.p.m. This practice is becoming more common especially where pressure filters are used, but some sanitary engineers do not favor it because it interferes with the biological action in the slime mat on the filter sand.

The pre-chlorine dose may be enough to maintain a residual until the water reaches the filters which would give it a long contact period, making possible ample dosing without excessive residual being present in the water when it reaches the consumers.

When water is heavily polluted, a preliminary light chlorine dose may be given the raw water as an additional safety factor. This can be done at small cost--the chlorinator and chlorine. The latter will be partly compensated as the final chlorine dose will not have to be as much.

Where the object of pre-chlorination is as an oxidizing agent for the removal of iron, manganese, color, and hydrogen sulphide the chlorine serves better alone. It is more common to apply both chlorine and ammonia to ray water as it is more stable, is not as likely to produce odors, and is more effective against crenothrix and slime growths.

Pre-chlorination should follow not precede aeration, otherwise some of the resicual chlorine will be taken off by the atmosphere, especially if the water is acid.

Activated carbon applied with coagulants will remove about 18% of the chlorine residual but all of it will be absorbed if the carbon is applied to the filter bed.

SUPER-CHLORINATION

Large concentrations of chlorine, cammonly from 1.2 to 2.4 p.p.m. and occasionally up to 5 p.p.m. are sometimes employed for destroying algae, bacteria, to reduce color, taste, and odor, and to oxidize phenols and iron. It is usually necessary to de-chlorinate later. If chloro-phenols are formed it will take 1 to 2 hours for the excess chlorine to oxidize them which must occur before de-chlorination. Ample time will be provided by applying the chlorine to the raw water and de-chlorinating the finished water.

DISINFECTION

DE-CHLORINATION

In order that water does not reach the consumer with a chlorine residual above 0.3 p.p.m., it is sometimes necessary to dechlorinate. This may be effected by aeration, sulphur dioxide, sodium sulphate, sodium bisulphide, sodium thiosulphate, hyposulphates, ammonia, or activated carbon. Sulphur dioxide is applied like chlorine from steel cylinders containing the liquid.

CHLORINATION

Chlorine is a chemical element applied to water mainly to destroy bacterial life. Chlorine also reduces taste and odor, oxidizes organic matter and reduces algae. It was formerly applied as chloride of lime or bleaching powder, but is now usually applied as a liquid supplied in steel sylinders. It is the cheapest most effective and the most generally used method of sterilization for public water supplies through out the world.

Chlorine has the following characteristics: yellowish-green color, unpleasant odor, over twice as heavy as air, easily condensed to liquid, inactive to most metals when dry, very corrosive to metals when wet, irritating to nost and throat membranes, requiring care in handling.

Pre-cautions to be taken in making repairs should include a gas mask. When chlorine odor is noticed, do not stoop, because the gas will be more potent below, due to its being heavier than air. To detect chlorine leaks, test frequently by holding an open bottle containing ammonia water where the leak is expected. Dense white clouds of ammonium chloride will form.

Where practicable, chlorine cylinders should be housed in a well ventilated building separated from the water plant building. The house or room containing the chlorinator should be well ventilated and its temperature should not exceed 50°F or 10°C. If temperature reaches 150°F or 66°C pressure will blow out fuse plugs and release the chlorine gas.

Chlorine is manufactured by decomposing common salt into sodium and chlorine. The gas is cooled and compressed to liquid form and shipped to the users in steel cylinders containing 50, 100 and 150 pounds of chlorine. It is manufactured at Niagra Falls, N. Y. and other places where electricity is cheap. There is one plant for its manufacture in South America which is owned and operated by the Brazillian Government at Nicheroy, near Rio de Janeiro.

DISINFECTION

CHLORINATION

Chlorine will destroy all micro-organisms found in water with a concentration of 0.2 p.p.m. and over, with exception of certain spore formers which can resist as much as 15 p.p.m., such as B-Subtilis (aerobic) B-mycoides (aerobic) and B-Welchii (anerabic). The cystic forms of the amoeba are also highly resistant to chlorine and various investigators have reported that it takes from 2 to 100 p.p.m. of chlorine to destroy them. Chlorine will not kill parasitic worms. Crustacea such as cyclops and daphnia are resistant to chlorine, requiring 3 p.p.m. to kill them. Nitrifying bacteria which are resistant to chlorine, will reduce free ammonia to nitrite which later will consume much chlorine.

Algal growths are restrained only with heavy doses of chlorine of 1 to 2 p.p.m.--a residual above 0.5 p.p.m. must be maintained.

The usual chlorine dose ranges from 0.2 to 0.5 p.p.m. colored waters and waters with high organic content may require more. If less than 0.2 p.p.m. is administered it will only inactivate the organisms for a time, after which some of them will come to life again. There is no way to calculate the chlorine dose, but it should be so gauged that there will be a residual when the water reaches the consumers not exceeding 0.3 p.p.m., as there are a few sensitive people who can smell and taste concentrations exceeding this.

Destruction of bacteria is more rapid the higher the concentration. Chlorine probably destroys all organisms within 15 minutes after being applied and completes its action of oxidizine the organic matter in 30 minutes. Action of chlorine is more rapid in warm than in cold water and less chlorine is required in warm water. Chlorine does not effect the pH, fixed chlorides, hardness, corrosiveness, nor any of the usual treatment reactions. Chlorine is more effective in acid and neutral waters than in alkaline waters.

Trout are killed in 3 hours by 0.17 p.p.m. of chlorine and several other varities are killed by 2.0 to 2.5 p.p.m. Fish eggs are sensitive to chlorine and are destroyed by 0.1 p.p.m.

Chlorinated water has no effect on plants and flowers. After a period of 48 hours in cool climates and a little less in warm climates, an aftergrowth of bacteria often occurs in stored chlorinated water, especially if it is high in organic matter. These are usually aerobic spore formers such as B-mycoides, they later decrease. This is one of the reasons why it has become a practice to design the distribution reservoirs with a capacity for 24 hours consumption of water and a maximum of 48 hours.

DISINFECTION

CHLORINATION

The cost of chlorination is very little, usually amounting in the U.S. to about 1c per capita per year. 75% of the inhabitants of the U.S. drink chlorinated water.

All surface waters are exposed to contamination and nearly all of them are contaminated. The usual treating methods would eliminate nearly all of the pathogenic organisms but some of them may get by, especially when there is a defect in some of the treating processes. In the case of ground water from wells and springs these most likely will contain no pathogenic organisms when they come from the ground but are exposed to contamination as soon as they reach the surface during the passage through the pipes of the distribution system, and in the reservoirs as are also surface waters after treatment. For these reasons all public water supplies should be chlorinated or otherwise continuously disinfected.

LIME-CHLORINE COMPOUNDS

Fresh chlorinated lime may contain as much as 38% chlorine but it usually contains only 25 to 30%. It loses chlorine at about the rate of 1% per month when kept in a cool dry place, but much more is lost in damp warm surroundings. This material is not much used at present, due to its bulkiness for the small chlorine content.

High test chlorinated lime is now made, containing 50 to 70% of free chlorine, it is called hypochlorate of lime. This product loses its chlorine much slower than the ordinary chlorinated lime. Hypochlorate of lime is handy to use as a disinfectant of small quantities of water, such as for villages and isolated institutions which could not afford the chlorinator needed for the application of chlorine gas from cylinders. The hypochlorate of lime may be thrown into the water tank or cistern and quickly stirred into the water, calculating the quantity of free chlorine to give a chlorine dose of 0.2 to 0.5 p.p.m.

For larger quantities of water, the hypochlorate of lime may first be dissolved in a barrel or 5 gallon bottle of water and the solution fed in proper proportions to the water.

It is convenient to purchase the hypochlorate of lime in small sealed cans, so that it will be used before it loses much of its strength.

DISINFECTION

CHLORINE AND AMMONIA

These two disinfectants used together are called chloramine. This disinfectant is more stable than chlorine alone and its action is slower. Some consider that the action is completed in 1.5 hours and other investigators believe it to be 4 to 6 hours. The ammonia is applied first with the chlorine as soon after as convenient. The proportions are commonly 1 part ammonia to 4 parts of chlorine. If phenolic tastes develop, then the ammonia may be increased. A residual of about 0.4 p.p.m. should be maintained. This will not impart taste or odor to the water.

To test ammonia-chlorine treated water for chlorine residual by orthotolidine, the colormetric readings will show double the actual residue, so to get the true residual, divide the reading by two.

Chlormaine prevents the formation of chloro-phenols and is more effective than chlorine alone for preventing the formation of organic growths in filters and pipe. In small plants where the chlorine demand is variable, this treatment has the advantage that the chlorine residaul taste is not present if over-dosed. Chloramine is being more used nor than formerly.

Ammonia-chlorine is used for the sterilization of dug wells and for swimming pools as it is more stable and consequently lasts longer than chlorine alone, and also works much slower.

Ammonia-chlorine is not effective for the treatment of taste and odor. The world's largest chlorine-ammonia plant is at the San Francisco Water Department, using 2,000 lbs chlorine and 400 lbs ammonia daily. Here it has proven very effective in removing biological slime growths in their aqueduct, where lime, copper sulphate, and chlorine had failed.

Ammonia is applied to water from a cylinder of liquid ammonia under pressure by an ammoniator, which is similar to the chlorinator but the latter cannot be used for applying ammonia.

OZONE

The atoms of oxygen, being a gas, are together in pairs in the air. Lightening or electric sparks between terminals split some of these apart. The strong odor of ozone is generally noticable around operating electrical equipment of high voltage. The third atom is loosely held and readily becomes detached to join another loose one, thus forming oxygen again and so ozone is very unstable. Some of these detached oxygen atoms combine with organic matter and bacteria and are oxidizing agents and disinfectant. Ozone is usually applied in concentrations of 3/4 to 1 and 1/2 p.p.m. Residual may remain 1 to 2 hours. There is no simple method for controlling ozone residual like the ortholidine test for residual chlorine.

DISINFECTION

OZONE

Ozone is a very active form of oxygen and reduces or oxidizes organic matter and bacteria rapidly. It has not found general use as a disinfectant for water as it generally costs more, is less stable and is not quite as reliable as chlorine.

Ozone is used at some swimming pools and bottling works. Some of the newest hotels have circulating ice water with taps in each room. Such water is usually from a treated city supply but if objectionable tastes and odors are present ozone may be applied to reduce and add an additional factor of safety.

The following cities are using ozone in their public water supplies: Wiesbaden, Germany; Florence, Italy; Paris (St Maur-24,000 cubic meters dialy) Balicu-sumer, Brest, and Nice, France; Leningrad, and London. So far as the writer know, the only public water supply in the U.S. which usues ozone is Hobart, Indiana. In 1930 there were 54 ozone instalations in operation in France. Paris now treats 60 million gallons daily with ozone and London has an ozone treating instalation since 1937 for 30 million gallons daily.

Ozone successfully removes odors, tastes and color, but like chlorine it does not kill resistant forms of micro-organisms, and is an active disinfecting and oxidizing agent and destroys chloro-phenols. Ozone is not readily soluble in water, so considerable agitation of the water is required to get it dissolved therein. With the usual price of electricity disinfection with ozone would cost several times what it would cost if done with chlorine. As chlorine combines with the acid phenolic effluents of certain factories and with the drainage from asphaltic paving to form disagreeable medicinal tastes, such waters are often disinfected with ozone which produces no such ill effects.

In concentrated form ozone is a deadly poison. It is a violent irritant of muccous membranes as it reacts chemically with muccous to form a thick froth which stops the air supply to the lungs in a minute or two.

SILVER

Silver ions in very small concentrations are lethal to pathogenic organisms in water. This action is interfered with by organic matter, iron rust, color, sulphurated hydorgen, and other suspended and colloidal matter. Several processes have been developed for introducing silver ions into water.

DISINFECTION

SILVER

The Katadyn silver process is effected by covering quartz sand with silver, this sand being used as a filter. The bactericidal power is retained in the water for a long time. Inflated silver has also been used.

A concentration of 0.10 to 0.15 p.p.m. destroys E-Coli in 2 and 1/2 hours at 20°C.

This process is very new and not a great deal of experience has been had with it. It is referred to as the "Oligo Dynamic Silver" and the Katadyn" process. An authority, Dr. Frank Hale, Director of Laboratories, N.Y.C. Water Supply, states in a recent report:

> "While laboratory results indicate that the E-Coli group may be controlled in the absence of ammonia, both the laboratory experiments and swimming pool results indicate that the 37°C count of bacteria is not effected, and among these bacteria may be disease germs affecting the eye, ear, nose, and throat. The required time for sterilization is too long, at least two hours. The economy of the process is also questioned when compared with chlorine. The recommended silver dose for a pool is from 0.15 to 0.20 p.p.m. As silver costs several dollars per pound and chlorine a few cents the comparison is evident. The most serious drawback is the possibility of an outbreak of argyrosis. This malady causes the skin to become permanantly dark as the result of a silver deposit. Once it develops, there is no known cure at present."

> "Silver acts as an algicide in the same manner as copper."

ULTRA VIOLET RAYS

Sunlight has a bleaching effect which reduces color in water and kills bacteria due to the ultra violet rays. This action effects only the surface and a few inches below in turbid water, while in very clear water these rays have some effect to about 4'-6" so thin sheets of water are more exposed to ultra violet rays as when flowing over weirs, rapid shallow streams with uneven rocky beds, and where aeration is used--especially the step type.

Recent studies show that the sun rays of mid-summer are 8 times brighter in the morning, five times brighter at noon, and ten times brighere in the afternoon that in mid-winter.

DISINFECTION

ULTRA VIOLET RAYS

Water is sometimes treated with ultra violet rays, artifically produced. As glass will not permit the free passage of the rays, a quartz tube is made, ganerally flat, and a yard or two long, containing mercury vapor, through which an electric current is passed. Water is flowed in a thin sheet over this mercury lamp. The quartz of the ultra violet ray lamp tends to cloud with time when its efficiency is reduced. Such treatment is used for swimming pools and other places where no very large amount of water is to be treated.

About 1/10% of the total rays from the sun are ultra violet while 17% of the rays from the mercury quartz lamp are ultra violet.

This system of disinfection is not commonly used, the only instalation the writer has heard of in the U.S. are at Berea, Ohio, installed in 1923, treating about 2,000 cubic meters dialy and at Horton, Kansas, installed in 1924, where the same amount is treated. One public water supply in Canada disinfects its water with ultra violet rays. To be effective the water should be very clear. It is not very costly.

Some claim that this system leaves a toxic residual protecting the water against subsequent pollution, but this is controversal as no proof has been given to substantiate the claim.

LIME

Natural waters flowing through limestome formations may have sufficient calcium to produce caustic alkalinity and a pH of around 9.5. This condition may also be attained through softening water by the lime-soda-ash method. Such water destroys (in 24 hours) practically all micro-organisms, including entamoeba histolytica, and the tropical cyclops which harbours the Guinea worm embroyo, and intestinal parasite. Such highly alkaline waters have a flat astringent taste.

PEROXIDE

Hydrogen peroxide is unstable, costly and is a weak germicide, and for these reasons is not now used for disinfecting public water supplies.

IODINE

This disinfectant is more stable but more costly than chlorine. It is not used for disinfecting public water supplies, though it is effective for disinfecting small quantities of water such as may be needed by campers, for which one drop in one liter of water with a contact period of 15 minutes may be used.

IMPURITIES IN WATER

SALTS

The following salts are found in natural waters--they are named in the order of the frequency of their occurance:

1.	Sodium Chloride	$NaCl$ (common salt)
2.	Calcium bicarbonate	$Ca(HCO_3)_2$
3.	Iron - Usually as ferrous carbonate, sometimes as ferric sulphate.	
4.	Magnesium bicarbonate	$Mg(HCO_3)_2$
5.	Calcium sulphate	$CaSO_4$
6.	Magnesium sulphate	$MgSO_4$
7.	Manganese	Mg
8.	Sodium sulphate	Na_2SO_4 (Glaubers salts)
9.	Sodium bicarbonate	$Na(HCO_3)_2$
10.	Calcium chloride	$NaCl_2$
11.	Sodium nitrate	$NaNO_3$
12.	Calcium nitrate	$Ca(NO_3)_2$
13.	Magnesium nitrate	$Mg(NO_3)_2$
14.	Magnesium chloride	$MgCl_2$

TOTAL SOLIDS

Most of the total solids in water consist of dissolved minerals. If the concentration is high, the water will acquire a taste which is disagreeable to the unaccustomed drinker.

Allowable tolerance is 1,000 p.p.m.

SODIUM

The sodium compounds are non-incrusting solids. Sodium sulphate, sodium chloride, and sodium nitrate, are usually present in water but not in objectionable quantities. Very small amounts of potassium usually accompany the sodium salts.

Sodium sulphate or Glaubers salts are laxative in concentrations exceeding 500 p.p.m. and is one of the causes of priming and foaming in steam boilers.

Sodium chloride or common salt, can be tasted in concentrations of 300 p.p.m. The salt content of sea water varies--it is often around 23,000 p.p.m. No way is known for removing salt from water except by distillation.

Epsom and Glaubers salts, in high concentrations, cause rundown condition in live stock and decalcification of bone which may be due to phosphorous deficiency.

IMPURITIES IN WATER

SODIUM

Sodium carbonate or washing soda--in England a water of 710 p.p.m. carbonate of soda has been used many years for drinking and domestic use and beer making without complaint. Sodium carbonate and sodium bicarbonate (baking soda) imparts alkalinity to water.

Soda soaps will not dissolve in saline waters due to their high sodium content which causes their hardness.

CALCIUM

Calcium imparts hardness and alkalinity and is almost insoluble in water. The carbon dioxide in water flowing through limestone, chalk, or other calcium bearing formations will combine chemically with the carbon dioxide to form calcium bicarbonate which will be carried off in solution. This reaction is as follows:

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2$$

The carbon dioxide is loosely held and is driven off by heat. This occurs in boilers when the insoluble calcium forms incrustations in the boiler tubes. When the carbon dioxide is consumed the water may carry off in suspension some finely divided particles of calcium bearing minerals which will later deposit in the water pipes.

Excess calcium is harmless and is left in water which has been softened by lime. When there is sufficient calcium and other alkalis in a water to produce a flat astringent taste with pH of 9.5 or more than caustic alkalinity develops which is lethal to pathogenic and other micro-organisms.

Large amounts of calcium are taken into the system by milk and other foods. Infants and children up to 13 years of age should injest 1 gram of calcium daily--older people require some less. The absence of calcium salts has been thought to cause rickets but recent investigations have been unable to verify this.

To reduce the amount of excess calcium in suspension in the water, carbon dioxide may be introduced. This is called recarbonation. As carbon dioxide is produced by imperfect combustion available flue gases may be used or any cheap fuel may be burned for the purpose. Special equipment is on the market for producing and applying carbon dioxide to water.

IMPURITIES IN WATER

CALCIUM

A new chemical has come on the market under the name of Calgon which is sodium hexamethaphosphate. This is commonly applied in doses of 1 to 2 p.p.m. to dissolve excess calcium in the water. Another chemical, tetra sodium pyrophosphate, has also been used for the same purpose.

Calcium chloride imparts hardness to water. When heat is applied, acid is produced which causes rust pits in boiler tubes.

Calcium sulphate or gypsum is less soluble in hot water, so when heat is applied in boilers, hard scale is formed in the boiler tubes.

MAGNESIUM

Magnesium sulphate or Epsom salts produce scale in boiler tubes and is laxative in water containing 500 p.p.m. or over.

Magnesium chloride imparts hardness and produces acid when heated causing rust pits in boiler tubes.

IRON

Iron detracts from the appearance of water, due to the reddish color it imparts. The color produces stains in washing textiles and discolors plumbing fixtures. Tolerance is usually given as 0.3 p.p.m. for iron and manganese together but little ill effects will be observed until 0.5 p.p.m. is exceeded. Iron also produces an objectionable taste, deposits in pipe and clogs meters.

Surface waters rarely contain iron in more than small concentrations.

Excessive iron in public water supplies may be from the iron bearing formations with which the water has come in contact, from the agressive action of water in the pipes, or taken out of solution by iron bacteria.

Iron encourages the growth of iron bacteria--crenothrix, clanothrix, caladothrix, gallionella, spirophyllum and lepthothrix which form long filaments in pipe. There are also iron depositing bacteria--siderocapsa and bacillus M.F. Crenothrix is the most connom form--it survives in water with less than 2 p.p.m. of iron. These organisms impart taste and odor and increase "red water". These may be removed by the application of chloramine or by super-chlorination--at least 0.5 p.p.m.--followed by dechlorination with sulphur dioxide. Iron bacteria are resistant to copper sulphate. They will recur after any treatment is discontinued.

IMPURITIES IN WATER

IRON

Iron is often present in the form of ferrous bicarbonate, due to the iron combining with the free carbon dioxide in the water. Aeration of such water exposes it to atmospheric oxygen when it becomes almost insoluble ferric hydroxide or iron rust, which settles out with the floc, or is filtered out. Aeration is not very effective with waters of low pH. Iron rarely occurs in solution except in acid waters. Insoluble or colloidal iron is commonly ferric.

Iron cannot be easily removed from all waters. Those containing vegetable matter, mineral acids, manganese, excessive carbon dioxide, and very soft waters offer difficulties. Nearly all iron is generally removed in the ordinary water treating processes.

Aeration furnishes the oxygen for oxidizing iron and manganese, these oxides being insoluble, settle out.

Special methods have been employed for removing iron from water. Potassium permanganate has been used, but is not very effective. Aeration onto coke beds is also used. Powdered activated carbon is effective in removing small quantities of iron. Small concentrations of iron in solution may be removed in passing through a zeolite filter.

If an adult requires 5 mg. of iron per day he would have to injest 16.7 liters of water, it it contained the allowable 0.3 p.p.m. Spinach and other food will better furnish the iron needs of the body than water.

COPPER

It was formerly thought that copper in relatively small concentrations was injurious to health, but no ill effects from ordinary concentrations have been found and some investigators consider that .5 p.p.m. may be tolerated. Copper in concentrations exceeding 1.5 p.p.m. can be tasted, while concentrations of 30 p.p.m. or more will stain plumbing fixtures.

Copper sulphate ionizes in water and forms insoluble copper carbonate which precipitates.

Water containing copper compounds from corroding service lines may be fatal to goldfish.

IMPURITIES IN WATER

SILICA

All natural waters contain some silica, as sand, quarts, opal, agate, and infusorial earth, which is very slightly soluble in water. It is only objectionable for boiler use.

Usual water treatment will remove some silica. Salts of ferric iron and barium have been used successfully for silica removal.

CHLORIDE

Sewage, industrial wastes, and other polluting materials add to the chloride content of water so it is considered an importatn indicator of the sanitary condition of water.

The chloride in water may also be from salt deposited in the earth, sea water vapour from the atmosphere, oil field brines, high tide or storm sea or brackish waters mingling with fresh waters, and refrigeration brines discharged into streams with industrial effluents.

MANGANESE

This metal is rarer in water than iron, with which it is usually associated, it oxidizes much slower, and is more difficult to remove. Manganese is more common in acid waters. It imparts color to water and stains textiles black in washing. Tolerance is 0.2 p.p.m,

There are various methods employed for reducing the manganese content of water.

Under certain conditions manganese content may be reduced by coagulation. In water with pH 6.8 to 7.0 potassium permanganate is added for oxidation, then alum and sodium aluminate are used as coagulant. Some manganese can be removed from water with pH 9.4 and above by using lime with iron as coabulant. Lime combines with beicarbonates of magnesium to form magnesium hydroxide, which will precipitate.

Upward flow manganese---zeolite filters may also be used at 50 gallons per square foot per minute. Recharge with 1.1 to 1.8 lbs of potassium permanganate for each pound of magnesium removed.

Filter sand grains in time can become coated with manganese and are effective as a catalyst, but later the filter becomes clogged as the backwashing does not remove the manganese. It may also stop up under drains. This can be corrected by applying 2% sulphur dioxide gas by circulating water containing this gas for 12 hours. If there is considerable manganese, use 4% sulphur dioxide with longer contact period. This will increase filter runs and decrease consumption of backwash water. A 1% caustic soda solution is also effective in removing manganese from sand. Potassium permanganate is sometimes used for this purpose also.

MANGANESE

If the water from which the manganese is to be removed is hard and contains carbonates or sulphates, or both, it probably will not be difficult to remove the major part by aeration. Manganese salts are not oxidized by the oxygen provided by aeration unless the pH is very high as would be the case with lime softened water.

Manganese can usually be removed by spraying the water over trays filled with pyrolusite, a manganese dioxide rock or ore, size, one half to one inch, followed by sand filtration. This rock may be made artificially by covering the surface of anthracite coal with manganese.

Manganese is removed at **Dresden**, Germany, by the use of cultivated manganese bacteria.

Dissolved oxygen in water is rapidly abosrbed by manganous hydroxide to form higher oxides of manganese.

LEAD

Lead does not occur in natural waters, except in those regions where the water traverses formations containing lead deposits. Its presence in a potable water supply is nearly always due to the waters solvent action on lead pipe through which it passes.

Water containing over 0.3 to 0.5 p.p.m. of lead causes definite poisoning of consumers--safe tolerance is 0.1 p.p.m. Lead is a cumulative poison, is not thrown off by the system as are most other poisons, but accumulates, causing a painful disease whose effects are similar to infantile paralysis. A blue line on gums is one symptom of lead poisoning.

Water containing considerable carbon dioxide will take lead from pipe to form soluble lead **carbonate** and bicarbonate. Where little carbon dioxide is present and there is free oxygen compounds, then lead oxide, lead hydroxide, or lead oxycarbonate will form--these are insoluble, and will settle out to form a protective coating against further oxidation. The presence of nitrates or chlorides also augments aggresiveness to lead. Though warm is more solvent to lead than cold, the latter is generally more active as it is apt to have more free oxygen. Increase in pressure also augments the solvent action. Aeration will leave only 3 to 5 p.p.m. of carbon dioxide and will nearly saturate the water with free oxygen. Such water low in carbon dioxide and high in oxygen should form the protective coating.

IMPURITIES IN WATER

LEAD

Organic acids, which are always found in colored swamp waters are very solvent to lead. Very hard waters with very low carbonate hardness and high nitrate, dissolve lead.

Lead may be removed by filters containing a mixture of chalk and magnesia.

When occupants of a house are absent for sometime, the water would lay in the pipes and siphone or goose necks, where it may dissolve a dangerous concentration of lead. In such cases where the service has been disconnected, the employee of the water service who reconnects it should open the facuets and drain out all the water which has stood in the pipes before any is used. This precaution is necessary as consumers are not usually informed of the danger of using such water.

PHENOLS

These are constituents of coal-tar and contain 98% or over of carbolic acid. Phenols are present in the effluents from coke ovens and other industrial plants.

Cresol and creosol also find their way into surface waters from factory effluents and from surface washings over highways treated with asphalt and other petroleum products. They are soluble in water.

All these materials combine with chlorine to impart an objectionable medicinal taste and odor to water in concentrations as low as 0.02 p.p.m., which are more promounced in warm water. For this reason such waters are not disinfected with chlorine--chloramine or ozone should be used. In waters of pH 5.5 or less ferrous sulphate and chlorine may be used.

Super-chlorination will oxidize phenols but sometimes as much 25 p.p.m. is required.

OXYGEN

The oxygen present in fresh waters, uncombined with hydrogen, organic matter, or other, is referred to as free or dissolved oxygen and is in the gaseous form. Dissolved oxygen imparts the following qualities to water:

1. The agreeable flavor of fresh water.
2. Oxidizes the organic matter, as well as iron, mangnaese, and other minerals.
3. Is unfavorable to anerobic bacteria.
4. Increases the corrosiveness of the water.

Dissolved oxygen is consumed in oxidizing organic matter which may be in the water.

IMPURITIES IN WATER

OXYGEN

When the free oxygen content is less that 3 p.p.m. the water takes on stagnant characteristics and loses its fresh taste and some fish begin to die. Fish accustomed to mountain streams, like trout, require 5 p.p.m. of oxygen while most fish require about 3 p.p.m. and a few fish have been found in streams with as little oxygen as 1.5 p.p.m. Shallow rapid flowing streams replenish their consumed oxygen quicker than the slow flowing deep ones, due to their waters having more contact with the atmosphere from which the oxygen is taken.

When the oxygen free in water becomes depleted, green plants and other aerobic life die while worms, lower animals, and other anerobic life prevail. Algae release free oxygen to the water in their life processes. Oxygen deficiency will also cause bacteria to break down sulphates releasing hydrogen sulphides and precipitate sulphide of iron.

The free oxygen saturation point of water at atmospheric pressure are:

50 C. - 12.7 p.p.m.
10 C. - 11.2 p.p.m.
15 C. - 10.1 p.p.m.
20 C. - 9.6 p.p.m.
25 C. - 8.2 p.p.m.

About twice these concentrations can be attained by blowing pure oxygen through water.

HYDROGEN SULPHIDE

This gas has a rotten egg odor and is often present in underground waters. It is evolved in the putrifaction of sulphur bearing organic matter. It combines quickly with chlorine and so interferes with disinfection. Chlorine displaces the sulphur which precipitates. Hydrogen sulphide is itself slightly germicidal. Some specialized, harmless bacteria live in hydrogen sulphide waters which will be eliminated by applying 1 p.p.m. of activated carbon.

CARBON DIOXIDE

This carbonic acid gas may be from settled organic matter or from water seeping through such matter, it being a product of decomposition. Coagulation with alum also adds carbon dioxide and some is dissolved from the atmosphere. When water has a carbon dioxide content of 0.5 p.p.m. it is in equilibrium with the atmosphere but with concentrations of 3 to 5 p.p.m. the carbon dioxide is absorbed very slowly by the atmosphere.

IMPURITIES IN WATER

CARBON DIOXIDE

Carbon dioxide adds to the corrosiveness and acidity of water. At atmospheric pressure water saturated with carbon dioxide has pH 3.8--carbonated beverages have pH 3 approximately. Carbon dioxide is most active as a bactericide at low temperature.

ORGANIC MATTER

There is some organic matter present in all natural waters. In clear water is is mainly in solution while in turbid waters it is colloidal with some in suspension.

Organic matter is composed almost entirely of carbon, oxygen, hydrogen, and nitrogen-COHN- and sometimes also sulphur and phosphorous. Nitrogen is in all organic compounds, being necessary to all animal and plant life.

The organic matter in water is not unwholesome but is it objectionable as it provides nutrition for micro-organisms and promotes their propagation.

Bactericides are less effective in the presence of organic matter.

Nitrites retard and interfere with the bactericidal action of chlorine.

Sanitary chemical analysis are made to determine the degree of oxidation of the dissolved organic matter which gives some indication as to whether pollution has recently reached the water or if it is of remote origin. The latter is indicated by low concentrations os albuminoid ammonia, free ammonia, and organic nitrogen - nitrites and especially nitrates will have been formed. High content of chloride, albuminoid ammonia, free ammonia, and organic nitrogen, carbon dioxide, and absence of free oxygen is indicative of recent sewage or other pollution.

Presence of organic matter is indicated by the oxygen consumed in its oxidation measured by the oxygen absorbed in 3 hours at $37^{\circ}C$, or by the bio-chemical oxygen demand.

COLOR

In water color is from decayed vegetable matter, iron and manganese. It does not refer to the general brown appearance of turbid and muddied waters, caused by clay and other particles carried in suspension. Ultra filters will remove all color from waters showing color to be in the colloidal state and not soluble. Much of the iron in colored swamp waters is apt to be in organic combination.

IMPURITIES IN WATER

COLOR

Color is not unwholesome but is objectionable becasue of its appearance. Color content of 20 p.p.m. is noticable in a tub or drinking glass. 10 p.p.m. is tolerated.

Color is not removed to any **extent** by ordinary filtering. Filtering through activated carbon, chlorine treatment, alum, and the bleaching effects of the sun all help in reducing color. The sun has effect up to a maximum depth of 4.5 feed in very clear water, but only a few inches in turbid waters. Surface waters from swampy regions are generally colored.

Not all of the acidity of colored waters is due to carbon dioxide, some is due to organic acids--tanic acid and humic acid. The pH of colored waters is sometimes variable, due to seasonal changes resulting from rainy and dry periods.

Color is determined by comparing standards made of platimum and cobalt salts.

METHANE GAS

This gas occurs in some ground waters being a product of decomposition. It is released to the atmosphere by aeration.

In covered reservoirs, methane will rise to the surface of the water and be taken by the atmosphere. If such atmosphere has a concentration in excess of 5% of methan, it is explosive. Where such conditions exsist, storage reservoirs should be well ventilated so that the methan bearing atmosphere will be carried off.

TASTE & ODOR

These are usually treated together as they are often caused by the same impurities in the water which are principally: algae, protozoa, decomposing organic matter, gases (especially hydrogen sulphide), trade wastes, chlorine, and chlorine organic compounds.

Tastes and odors often due to algae--the blue green cyanophceae infusoria, and diatoms, also protozoa-synura and usoglena--imparts taste and odors, clog filters, the latter prefer sunlight and cold.

Decomposing of stale sludge produces taste, odor, and gas. Continuous mechanical sludge removing equipment or activated carbon will correct this.

IMPURITIES IN WATER

TASTE & ODOR

Objectionable odors and tastes may be reduced or eliminated by the following: aeration will remove hydrogen sulphide, some gases of decomposition and other volatile odors, activated carbon absorbs gases fo decomposition and other taste and odor producing impurities.

All odors are not completely removed by carbon, but reduction is usual. A threshold odor of two is always satisfactory and in some cases up to 6 may be tolerated. Application of carbon just ahead of the filters is more economical than before coagulation, though some carbon may be added with the coagulant to absorb gases of fermentation in the settled sludge. Some carbon should be added to the first water flowing onto the filters after washing.

Coagulation is not often very effective in removing taste and odor. Sometimes lime sets odor, making removal difficult--in this case add activated carbon before coagulation. Inccolored waters alum coagulation greatly reduces odor and taste.

Adding potassium permanganate sometimes helps to reduce taste and odor.

Super-chlorination followed by de-chlorination reduces tastes due to organic decomposition, as soes also ozonation. Some odors are intensified by applying 0.5 p.p.m. of chlorine or less while they may be reduced by a heavier dose.

FLUORINE

Fluroine is the most active non-metal element and it and its compounds attack glass, porcelain and the teeth. Fluorine does not occur alone in nature, but as fluorides or fluorisilicates. Fluorine combines with hydrogen but not with oxygen, nitrogen, or chlorine.

Fluorspar or chalcium fluoride frequently occurs accompanying lead ores and sometimes alone. It is used as a flux in metalergy and in the manufacture of glass, enamels and glazes.

Cryalite or sodium aluminum fluoride is mined in Greenland and is also employed as a flux.

IMPURITIES IN WATER

FLUORINE

Fluorides cause mottled enamel or dental fluorosis--at first the enamel loses its luster which is replaced by an opaque chalky white surface and is followed by discoloration--yellow to brown. Then spots and pits appear with the discoloration turning darker and the pits deepening. These ill effects only occur during the forming of enamel on the permanent teeth of children between the ages of 5 and 8 years. There are no ill effects produced after the permanent teeth are fully developed.

To be injurious to the teeth water has to have a concentration of fluorides exceeding 1 p.p.m. Such water should not be drunk by children, nor used in preparing food for them, rain or distilled water should be used.

Removal of fluorine from potable water by tricalcium phosphate. Experiments have been made on the effectiveness of granular tricalcium phosphate in removing fluorides from water. The influence of the particle size of the regenerating the tricalcium phosphate have been investigated. Coarse tricalcium phosphate will absorb fluorides if the flow is sufficiently reduced. The fluoride content of the water was found to have no significant effect on the quantity of fluoride removed by the phosphate before the fluorine content of the effluent exceeded 1 p.p.m. With high fluoride concentrations in some natural waters it may be necessary to use a reduced rate of flow. The experiments indicate that a satisfactory removal of fluoride can be obtained at rates of between 4 and 8 gallons per minute per square foot of filter area. Since most of the natural waters containing fluoride investigated were of low hardness, the decrease in the capacity of the tricalcium phosphate which occurs with sodium hydroxide followed by water and hydrochloric acid was found to be the most practicable method of regenerating the tricalcium phosphate. Comparative tests showed that tricalcium phosphate has over twice the capacity of the same weight of activated alumina.

It was found that fluoride can also be removed from water by precipitating tricalcium phosphate in it, i.e., by adding lime followed by phosphoric acid to give a pH value of 7 to 7.5; the equivalent of 1 kilogram to tricalcium phosphate will remove 6.05 grams of fluorine when the lime and phosphoric acid are added so that the weight of the tricalcium phosphate precipitate is about 200 times that of the fluoride present. Although the removal of fluorides was assumed to occur by absorption, it may be due to the formation of a complex compound such as fluorapatite.

IMPURITIES IN WATER

FLUROINE

There is an article marketed as fluorex, composed of tricalcium phosphate and hydroxy apatite. The water is filtered through this material which is regenerated with caustic soda and hydrochloric acid. Fluorex and the filter in which it is used are manufactured by the International Filter Company.

Alum floc and activated alumina will reduce fluorides some. Activated carbon will remove fluorides at very low pH. In lime softened water, fluorine reduction depends on the amount of magnesium sulphate removed. By adding magnesium sulphate to the water, a larger proportion of the fluoride will be removed. This method is only practical for removal of small concentrations of fluorides.

Zeolite softening does not materially reduce fluoride content of water.

SUSPENDED MATTER

Clay, sand, and other inorganic particles carried in suspension be streams have an average specific gravity of 2.5. The larger of such particles settle out when the rate of flow is less than 2 feet per second. The specific gravity of organic matter in water is usually 1.2. Water containing a high proportion of sand, clay, and minerals will require less time to settle than when the suspended matter is lighter. Large particles settle before small ones. This is because the weight increases as the cube of the diameter whele the surface area, which furnishes the resistance to settlement, increases as the square of the diameter.

As the amount of matter which water will carry in suspension depends on its velocity, when the speed of flow is quickened in a stream by added water due to rain, more turbidity results. When dry weather provides less water in streams, the ensuing reduction in velocity causes the suspended matter to settle out. Though these natural purifying processes are very helpful, they are not dependable. Much of the settled organic matter becomes sterile by oxidation, which action is more active if the water gets plenty of dissolved oxygen by flowing over rough places or dams which provide aeration. The rate of settling is about twice as fast in summer, when the water is warmer than in winter.

The finest particles contribute most to the turbid appearance of water. At least 50% by weight of the suspended matter in a stream would settle out in 24 hours when impounded in lake or reservoir. More bacteria, being very small, settle the second day with the small particles.

IMPURITIES IN WATER

SUSPENDED MATTER

Surface drainage from heavy rains often carry much clay, soil bacteria, and other suspended matter. Where the source of water supply is a natural lake or impounded reservoir, such water should not be permitted to go directly to the intake. This can be accomplished by digging a trench near the lake shore to catch these waters and by-pass them below the lake. If the body of water is very large, it would only be necessary to provide such protection to a distance of 600 meters from the intake.

TOXIC SALTS

Toxic salts are of rare occurance in natural waters.

Arsenic is insoluble in water. Arsenic bearing minerals are common in small quantities where sulphides occur. Paris green is about 50% arsenic. Tolerance is 0.5 p.p.m. Arsenic may be eliminated by precipitating with fresh ferric-hydroxide as ferric arsenate and filter.

One case has been reported in which there was a fine suspension of ferrous arsenate in well water from a limestone formation.

Barium compounds occur widely in nature, especially $BaSO_4$ and $BaCO_3$ and less commonly in manganese ores. It occurs in sea water, mineral water, marine plants, and in the ashes of some trees, especially birch.

Boron is a non-metalic element, crystal or powder, is present in bauxite clay. Boric acid is found in lagoons of the volcanic regions of Tuscany.

Selenium is found with sulphur, which it resembles, and sulphate ores. Its toxic action is like that of arsenic. This element is present in some waters of North Carolina.

Cyanide compounds are present in the effluents of certain gold extracting operations.

BACTERIOLOGY

Classification - Microbes are minute living things, some are plants and others are animals. Both forms consist of a single cell which is structurally similar to the cells that make up the the flesh of animals and man. It is difficult to determine to which classification some of these belong as they are between the animal and plant form, (bacteria & protozoa). The animal are low one-cell forms, some are active and others inactive, some are delicate, others robust.

Some produce lactic acid, useful in industries, some cause fermentation used in bread making (yeast). Some forms thrive in the presence of air or oxygne and are called aerobic, others cannot, and are called anerobic. Some forms adapt themselves either to the presence or absence of oxygen, these are called facutative bacteria. Over 1?400 kinds of bacteria have been observed. These take the following forms: rod or bacillus about 900, sphere or coccus about 350, and spiral or spirillum about 100.

Size - The unit of measurement used is the micromillimeter, called micron, being 1/1,000 mm. or about 1/25,000 of an inch. Laboratory microscopes usually have a sicron scale above the lens for for comparison with the organisms being studied.

The largest pathogenic or disease causing micro-organism is the sprillum of relapsing fever--length 40 microns: about the smallest is the influenza bacteria---.5x.2 microns. The germs producing pluero-pneumonia in cattle appear like points when magnified 3,000 times or diameters. The foot and mouth disease germs are invisible but can be cultivated or inoculated in animals. Yellow fever germs will pass through a compact porcelain filter. The typhoid bacillus has a length of 1 to 3 microns.

Multiplication - The rod and spiral forms multiply by dividing in the center at right angles to the long axis. The sphere forms divide in one, two, or three planes and may remain together to form chains or clusters. The higher protozoa or animal forms usually divide once or twice in 24 hours. Some multiply sexually and a few by both division and sexually--the germ producing malarial fever multiplies in both ways.

Micro-organisms multiply very rapidly if environmental conditions are favorable, but checks and hindrances generally slow up this increase. Such are, lack of food, and moisture, unfavorable temperature, and their own toxic secretions.

BACTERIOLOGY

Movement - Some bacteria are observed to move and are called motile--some move very actively while others barely move or have been observed to not move at all. The typhoid bacillus can go 4 mm in one hour which is 2,000 times its length and the cholera spirella some 18 mm in one hour.

Some move by simple wiggling while others possess filamentious appendages which look like hairs and are called flagella. These organs of locomotion may be attached to one or both ends of the bacteria which are called polar flagella or they may be attached to the sides--sometimes in large numbers.

Many bacteria have an outer cell which has the appearance of a transparent enveloping capsule. When stained these capsules surround the cell like a halo. Capsules are prominent in milk cultures. The flagella appear to rise from the capsule and move with its contraction and expansion.

There is an oscillating or quivering motion exhibited by all minute particles suspended in water which is considered as due to the surface tension. This is called the Browian movement.

Spores - Spores spring from vegetable cells, are dense and of compact structure, resistant to high temperature, dryness, and poisons: they stain with difficulty. A single cell forms only one spore (rare exceptions). Spore forming is not a reproductive device but is a resistant dormant stage to meet unfavorable conditions, and may be compared with the hibernation of mammals. Spore forming has not been observed in most bacteria though it may occur under certain conditions in bacteria not now known to be spore forming. It occurs most frequently in bacillus, less often in spirilla, and very rarely in cocci. Spore forming anerobic bacteria are tetanus and malignant edema. The anthrax bacillus form spores only in the presence of oxygen, and most abundantly at 30 to 32°C, and none below 12°C. Spores sometimes remain alive for years in a dormant state, even though dry.

Isolation of Species - This is done by inoculating a semi-hard or stiffened medium in which the micro-organisms will not be free to move about. A colony is then allowed to develop from which some are fished off with a sterilized wire to re-inoculate a fresh plate.

Spore forming bacteria may be isolated by heating to 80°C at which temperature other bacteria are killed. Animal inoculation is also resorted to in certain cases. The stab test is used to determine if bacteria are aerobic or anerobic--those developing on the surface being aerobic, below-anerobic.

BACTERIOLOGY

Culture Media - These are synthetic materials used in laboratories, which contain matter favorable to the life processes of bacteria, and are used by inoculating with the bacteria to be studied after which they are kept at a favorable temperature in an incubator.

Many different substances have been developed, each answering its special purpose and used for the cultivations of certain types of bacteria.

Gram Stain - Micro-organisms are sometimes stained for testing their permeability to boluble substances and as an aid to identification of species. Analyne dyes most used for this purpose are: violet gentain, methlene blue, and fuschin. Removal test is iodine solution and alcohol wash.

Soil Bacteria - Bacterial life in the top soil is very abundant to a depth of about 18", and usually drops off until there is very little bacterial life at a depth of 4', and at a depth of 9'-6", the soil is usually completely sterile. Any organic matter which comes in sontact with the top soil is worked on by these bacteria, which material they convert into nitrogenous plant food without which most plants would not grow. As most of these organisms require oxygen to carry on their activities, they do best in open soils and are much less active in dense clays. As pathogenic bacteria porpagate only in humans or warm blooded animals, they thrive at the body temperature, and due to unfavorable environment, they are not generally found in the soil, though by experiment typhoid fever germs have lived nine days in the soil.

Bacterial Infection - Most readily infected are: children, those exposed to hunger, thirst, lack of meat in diet, fatigue, excessive heat or cold, severe local injury resulting in generally weakened condition, and mother at child birth, (uterine cavity especially).

Pathogenic bacteria often enter the body through weakened tissues such as the tonsils when they are not healthy.

Pathogenic Bacteria - Fortunately most of the prolific life which is so abundant in waters, especially surface waters and in soil, are beneficial: however, a few are detrimental and produce disease. These are called pathogenic bacteria.

BACTERIOLOGY

Young small malaria bacteria fasten themselves to the surfaces fo blood corpuscles, bore slowly in, increase in size, swell the corpuscle throw off their young, which attack other corpuscles. This complete cycle takes 24, 36, or 48 hours and corresponds to to the fever and chill period of the host.

Sleeping sickness, trypanosome, is produced by a free swimming parasite of the blood which occurs primarily in animals, especially in horses and cattle to which it is highly fatal, and to man. Transmission is by biting insects--in Africa the Tsetse fly is the usual carrier.

Disease germs or pathogenic organisms are all parasites adapted to the conditions of food, temperature, and moisture, found in the human and animal body.

B-Subtilis, or hay bacillus, are very common in water, air, and soil. They cause serious infection of the human eye. This bacteria is one of the most resistant to temperature changes.

Escherichia Coli - This organism is always present in large numbers in the intestines of man and other mammals and birds where it is a harmless parasite. Outside of the intestines it sometimes exerts pathogenic powers. Coli infection of the urinary tract is frequent and cure is often difficult.

The presence of these organisms in water is sought in the laboratory as their presence is proof that fecal matter is polluting the water and this fecal matter may also contain pathogenic organisms such as those which produce typhoid and dysentary. There is no simple way of isolating the latter so the E. Coli are sought as indicator that the pathogenic organisms may be present.

E-Coli has a much longer longivity in salt water than in fresh water.

E-Coli generation time in broth is 0.32 hour at 42°C and 1.3 hour at 20°C.

There is no way of distinguishing between the E-Coli of human and of animal excreta.

E-Coli are not found to propagate in other than fecal pollution.

B-Aerogenes - Present in soil, grain, feces, sewage, milk, and water. Ferments carbohydrates more vigorously that E-Coli and are more resistant to acids and other deleterious substances than coli.

These organisms have been isolated from infections and may contribute to food poisoning but are not believed to be harmful when injested with water or milk.

BACTERIOLOGY

B-Welchii - Normal human feces will contain 1/4 to 1/2 of their weight in bacteria, most of which are dead when injested, though 1,000 million per gram may be alive. About 90% of these organisms will be E-Coli, 8% B-Welchii, and 1.5% streptococci.

B-Welchii are present in 72% to 80% of gas gangrene poisoning and are often present in wounds where there is no gangrene, though B-Welchii are apparently pathogenic in wounds they appear to be harmless when injested in water.

B-Welchii, called B-aerogenes capoulatus in Britain, Frankel bacillus in Germany, and B-perfringens in France. It is a short, thick, anaerobic, most strains not spore forming, gram positive, non-motile, and ferments sugars producing much gas.

ALGAE

These are simple plants, ranging from one cell micro-organsms to giant sea-weeds. Algae with bacteria were likely the first forms of life to appear on the earth. They are widely distributed in nature--in snow, in hot springs, in sponges, on some animals, and insects, on Artic ice, and on water plants. Water men are only concerned with algae which grow in water, which are often microscopic, but when clustered together can be seen with the naked eye.

They propagate best in sunlight, excepting a few species which grow in darkness, and usually in temperatures exceeding 18°C or 65°F. They grow both on the submerged sides and bottoms of tanks containing water, in lakes, and running streams. They also grow unattached in the water. Requiring sunlight, they are more abundant in clear than in turbid water and are often found in the shallow water at the edges of lakes.

Algae thrive in waters containing carbon dioxide from which they free the oxygen to the water. This evolving oxygen stimulates aerobic bacterial growth in the vicinity of the algae.

Algae occurs in great varities of colors and shades.

Blue-green algae are slimier than the green and many are poisonous. They are associated with polluted water. Blue-green algae resemble bacteria, has no starch, reproduces asexually and gives off oxygen. Water bloom or "Fanny" is often poisonous and sometimes fatal to livestock.

Green algae is closer to ordinary plants and not so like bacteria. They are of cellulose as are higher plants and most have sex and may have originated it.

Among brown algae are kelp as large as trees in the seas.

Red algae often grows at great depth in the Red Sea and other bodies of salt water.

A form of algae, Crenothrix, thriving in darkness, often grow in water mains which obstruct the flow of water. Lumps or slugs of this growth break off--they are brown and look like pieces of disintegrating meat. Treatment for this nuisance is chlorine and ammonia, 4 to 1.

ALGAE

Algal slimes and gelatinous films build up rapidly on the walls of condenser tubes in power stations and paper works, interfering with heat interchange, causing increase in steam consumption and friction head, and making the maintenance of the high vacuum impossible. This is corrected by intermittent dosing with chlorine.

Some forms (tabellaria, synura, uroglena) produce objectional taste, others (asterionella, synedra, cyclotella, fragilaria) clog filter sand.

Tastes and odors are often due to algae--blue green cyanophyceae-infusoria, and diatoms. Also protozoa-synura and uroglena-impart taste and odors, clog filters, prefer sunlight and cold.

Algal growths cause increase in organic content favorable to bacteria, produce color, odor, and interfere with filters, settle to bottom, consume oxygen in fermenting, anerobic decomposition sets in, biological action puts organic matter in solution and produces sulphites and other odors, increases color and turbidity, seasonal overturn accentuates all this.

During periods of low water, algae tends to accumulate rapidly which may interfere with settling after coagulation and result in accumulating algae slime on filters which is difficult to remove by backwashing.

ALGAE CONTROL

Commercial copper sulphate is most commonly used to prevent the growth of algae in reservoirs and in basins of water treatment plants. A copper content of 1.0 p.p.m. in drinking water is considered safe. In concentration of 0.25 p.p.m. it will not kill fish except trout which succumb at 0.14 p.p.m. Copper sulphate adds to the corrosiveness of water.

Where algae are free unattached forms, they may be destroyed by adding copper sulphate to the water. In case the algae is giving trouble at a water treating plant, copper sulphate may be fed in solution from a barrel. If the copper sulphate is applied to the water of a lake, a bag of copper sulphate crystals may be pulled back and forth behind a row boat. In the case of very large bodies of water, it would be impractical to try to keep the algae down except in the vicinity of the intake.

ALGAE

If they attach themselves to the submerged sides of reservoirs or basins, these should be emptied, the walls scrubbed with a stiff brush and hosed down. These walls should be painted with a 5% solution of copper sulphate to which about 10% by weight of lime has been added.

Copper sulphate does not destroy bacteria. Sometimes copper sulphate used with chlorine or chloramine is effective in algae control where neither is effective alone.

Little if any copper sulphate added before filteration will go through the filters.

Copper is more effective as a preventative for destroying the young plants, as the full grown luxuriant algae require more copper sulphate.

In the case of a very large reservoir, economy of copper sulphate used may be effected by identifying the various types of algae by the use of a microscope. Some types are more resistant to copper sulphate than others. The amount required to kill the various types has been determined by specialists so that the proper dose may be calculated.

Where algae form a floating scum, this may be treated by spraying with a 5% copper sulphate solution.

Odors developed when treating by copper sulphate last 2 or 3 days--such freshly treated water may cause diarrhea.

Chlorine is not effective in destroying algae in doses under 1 to 2 p.p.m. A residual of at least 0.5 p.p.m. should be maintained. Chloramines are effective in eliminating slime growths in conduit pipes and pipes of the distribution system.

Reservoirs may be pre-chlorinated for algae by applying the dose at a point some 50 feet above where inflowing streams empty into the reservoir.

If much algae is present, taste may persist after disinfection, due to the oils released from the destroyed algae. These may later be reduced by coagulation and filtration or with activated carbon.

There is a new chemical, sodium pentachloraphenate, which is highly toxic to algae and slime forming organisms, but cannot be used in potable water or swimming pools, as it is poisonous to man, but may be used for preparing waters for industrial use.

FUNGI

These do not require sunlight, often growing profusely in water mains.

Fungi are less suseptible to the toxic effects of copper sulphate than most of the lower forms of algae. They are usually more susceptible to chloramine.

PIPE GROWTHS

Microscopic forms which propagate in darkness, such as iron, manganeses, bacteria, crenothrix, tryozoa, and hyrozoa, clog filter sand and underdrains, collect in reservoirs, and water pipes. These usually add to the turbidity, color, taste, and odor, as well as reduce the carrying capacity of the pipes. These forms are found especially in dead ends.

Pipe growths are stimulated by the presence of iron, mangnese hydrogen sulphide, and possibly also by ammonia and methane.

Mains should be flushed out frequently, the organic content and carbon dioxide reduced and free oxygen increased.

Such organisms may be eliminated by dosing with sodium hypochlorite solution calculated to give 1 p.p.m. of chlorine with a contact period of 6 to 12 hours, then flushed out. Chloramines are also effective in destroying pipe growths.

AQUATIC VEGETATION

Higher plant forms like water weeds and lillies are not destroyed by ordinary doses of copper sulphate but may be killed by a chlorinated hydrocarbon.

Rooted water plants may be pulled up with a rake or similar device, though they will grow back in time.

Such growths are not very objectionable in reservoirs unless receeding water leaves the plants stranded on the shore to die and produce odor. Rising water would permit this objectionable putrifying vegetable matter to gain access to the water.

Water plants furnish protection to mosquito larvae, making it difficult for top feeding minnows to reach them.

WATER BORNE DISEASES

TYPHOID

In water 90% of the typhoid germs die within five days and 99% within seven days. Typhoid bacillus have been found alive in 32°F water after five weeks, in 65°F water after 2 weeks, in sewage sludge after thirty five days, in top soils 9 days, in ice 103 days and in human feces after 52 days. Their death rate is higher in the tropics.

Characteristics - Due to Bacillus Typhosus, fever usually lasts some 4 weeks, rose-colored eruptions, diarrhea, intensity varies from mildness to fatal infection--average 10%, ulcerations may cause intestinal hemmorage, immunity results from one attack, period of incubation usually seven to 23 days, probably under 25% of epedemics are from water, most prevalent in small towns, very little now in the larger cities. Typhoid fever weakens its victim, whose full strength is not usually regained before three years.

Transmission - Typhoid fever is contracted by direct contact with a person having the disease or a carrier, or indirectly through water, milk or milk products, fresh vegetables, oysters, and other sea food, other foods, fingers, flies, occasionally ice, and inanimate objects or fomites, especially textiles which have come in contact with the bodily discharge of a person with the disease or a carrier.

The typhoid germ enters through the mouth, multiplies in the intestinal tract, but the disease only shows up after the organisms enter the blood stream and other parts of the body. Some 17% of typhoid cases carry the organism for a month or 6 weeks after apparent cure.

Preventative Measures - Water purification especially more general chlorination, more sanitary milk supplies, pasturization, typhoid preventative inoculation, dessimination of information to the public, improvement in general hygiene and sanitation. In case of epedemic from water, increase dose up to 1 p.p.m.

The typhoid organism is found nowhere in nature unless recently contaminated by excreta. These organisms are more delicate adn less numerous than E-Coli in sewage, though there is a very high number in the urine of a sufferer or carrier. These survive longest in cool temperature, and are quickly destroyed by sunshine, and by other bacteria and protozoa. They live longer, then, in purer waters, so great care must be taken that they do not reach the treated water.

WATER BORNE DISEASES

PARATYPHOID

Paratyphoid is a disease like a mild case of typhoid fever, seldom fatal, which may be transmitted by water, though it is usually carried by milk, ice cream or other foods. Many healthy persons are carriers of paratyphoid.

Paratyphoid symptoms resemble thoses of typhoid. The causitive organism, Salmonella paratyphi, is between the typhoid and colon bacillus. There are three types designated as A,B, and C.

AMOEBIC DYSENTARY

This is a disease of the intestine, particularly the colon, c causing severe inflamation of the muccous membrane, and large ulcers in the intestines and liver, producing fever, pain, diarrhea, and blood and muccous in the bowel movement.

The amoeba is a one cell microscopic animal which constantly changes its form by extending leg-like projections (pseupodia). They are often present in stagnant fresh water ponds and damp earth. These organisms are pathogenic to both man and animals. Humidity fovors the organisms--when dried they only survive a few minutes--and incidence of the disease increases toward the end of the rainy season.

The infecting organisms are mature cystic or resistant forms of the endamoeba histolytica. This form is not generally found in the excrements from acute cases but from convalescent, chronic cases, and carriers.

The cyst is an enveloping protective sac or capsule evolved about itself by the organism. Cysts live three to seven days in moist feces at 10° to 20°C, in water at same temperature 14 to 21 days--some surviving to 37 days in water at 7°C., 46 days, at 37°C, 3 days, at 0°C, 48 hours.

Cysts or resistant forms of these protozoa (endamoeba histolytica) are very resistant to chlorine--investigators report that from 2 p.p.m. to 100 p.p.m. of chlorine is required to destroy them.

Cysts of the amoeba are several hundred times as big as pathogenic bacteria, so more of them will settle out and they are much less likely to pass through filters.

The incubation period of amoebic dysentray is from 15 days to 2 or 3 months.

WATER BORNE DISEASES

AMOEBIC DYSENTARY

Neither isolation of patients nor quarantine of contacts is necessary for dysentary. The disease should be promptly reported, all food protected against contamination, and unsanitary conditions and practices corrected. Prompt medical treatment of this diesase is important.

Anoebiasis is prevalent in almost all tropical regions in both the lowlands and high regions, and less so in sub-tropical countries.

This disease is transmitted through the infected feces by water, milk, and other food, by direct contact or by insect.

Though amoebic dysentary has occured by mass infection from one source, it is exceptional, as most cases occur sporadically and not in epidemic form.

Low incidence of amoebic dysentary with high amoebiasis is indicative that the native population has developed resistance to the parasite.

BACILLARY DYSENTARY

This disease is more common in the tropics than in the temperate zone. It may be borne by water through excremental pollution or by food polluted by flies or other insects.

Bacilli are eliminated in the excreta--not in the urine.

Bacillary dysentary germs are difficult to identify. Virulence varies, causing both fatal and mild illnesses.

The disease is more prevalent in the rainy season and is usually common among soldiers during campaigns.

New arrivals to tropics are especially susceptible to bacillary dysentary.

There are three kinds of organisms of bacterium dysentary. Shiga, Flexner-Y, and Sonne. The first is most common in the tropics and accounts for the most virulent epidemics.

WATER BORNE DISEASES

CHOLERA

This often fatal disease is more common in the Orient than elsewhere, especially in India, China, and Siam, where it has been endemic for centuries. There has been a decrease in the incidence of cholera in recent years except in Siam.

Cholera infects the small intestine of man-animals and birds do not have cholera. The causitive organism-Vibrio cholerae-was discovered by Koch in 1883. The organism is eliminated in the excreta and not usually in the urine.

Cholera is spread chiefly through water,flies, and food. It is not resistant outside the human host. The cholera vibrio dies quickly in sea water. A weakened condition resulting from chills, fasting, opium, and alcohol, are considered factors predisposing to the agravating severity of attack.

TABC vaccine protects against cholera as well as typhoid and paratyphoid A and B, though only for 6 months. This vaccine was used in the recent Ethiopian war when no case of cholera was reported.

Incubation period is usually five days.

SCHISTOSOMA

Flukes or trematodes are leaf shaped parasites which infect the liver, lungs, intestines, and blood vessels. They occur in India, Africa, China, and South America. The ova occurs in feces. There are 3 species of flukes which affect man: shistosoma haematobium - Egypt, S. mansoni - South America, and S. japonicum, Japan, China, and the Phillippines. The last effects domestic animals also.

S. mansoni inhabits the portal and mesenteric veins, the eggs are usually passed in the feces and rarely in the urine, they have a lateral spine. The eggs of these worms hatch in water and die in 24 hours unless they reach a host usually a snail where the larvae becomes a sporocyst which produces large numbers of cercariae which leave the snail (Planorbis guadalupensis), swim 40 hours, look like white hairs, then die unless they infect man by piercing the skin or membrane to enter the blood stream, to the liver and portal veins. These are not killed by chlorine--use 1 to 10,000 cresol. For drinking, the water should be boiled.

This disease is reported as endemic in Martinique, Gaudeloupe, Porto Rico, French and Dutch Guiana, North Brazil, and Venezuela.

WATER BORNE DISEASES

SCHISTOSOMA

The A.P.H.A. recommends the following control measures for schistosoma.

1. Regulation of disposal of sewage.
2. Conservation of night soil long enough to sterilize ova through fermentation of medium.
3. Cleansing of banks of infested water supplies to remove snail shelters.
4. Application of lime or copper sulphate to kill infested shelters.
5. Filtration of drinking water from infested sources.
6. Treatment of the infested person by tartar emetic or its derivatives.
7. Education of the people regarding spread and prevention of infestation.

In infected regions persons should not wade or bathe in water from small pools or ditches or from large bodies of water. The disease can also be contacted by drinking the water.

The snail host may be destroyed by the use of lime, chlorinated lime or copper sulphate.

INTESTINAL PARASITES

Intestinal parasites as worms and flukes are sometimes present in water through ova and larvae in the feces. Parasitic worms are: oxyuris which inhabits the colon and rectum, the feces contain many worms and ova, the male is 4 milimeters long and female 10 milimeters, usually found in children irritating the anus. Trichuris trichiura or whipworm inhabits the large intestine, is 4 to 5 milimeters long, the fore part is thicker than the rear end, symptoms are slight or absent. Taenic saginata is a flat worm.

ASCARIASIS

This disease is caused by the Ascaris lumbricoides, occuring in the intestines of man, and an indistringuishable form found in pigs. This is the common round worm (tapering at both ends) of world wide distribution. The size of the female is 20 to 35 centimeters by 3 to 6 milimeters in breadth, the male is 15 to 31 centimeters by 2 to 4 milimeters: pale yellow or brown with whitish longitudinal lines.

The eggs are discharged in the feces--they are protected by a thick cover. The infection reaches man through food and water or soil containing the ova.

WATER BORNE DISEASES

ASCARIASIS

Worms inhabit the small intestine but may penetrate other parts of the body and cause serious trouble.

Water infected with these organisms should be boiled. Such waters should not be used for watering green vegetables. Chlorine as applied to potable waters will not destroy these organisms.

GASTRO-ENTERITIS

Water is the most probable infective agent of this sickness, though it may be caused by milk and such low growing vegetables as lettuce, radishes, celery, and strawberries.

Symptoms are abrupt onset, nausea, and vomiting, abdominal pain, diarrhea, occasionally slight fever and jaundice. Symptoms usually subside in 72 hours though they may last from a few hours to a week. The incubation period is commonly 1 to 2 days but may be from 6 hours to 6 days.

As this disease is transmitted by polluted water, the coli-aerogenes test will indicate such pollution, but the disease is sometimes carried in water which this test indicates to be free of pollution.

DIARRHEA

Diarrhea, vomiting and stomach cramps may be caused by impure water, probably due to the activity of great numbers of non-pathogenic organisms. Children of tender age are especially susectible and to whom it is often fatal.

When moving into a new region, people often find that the water has a disagreeable taste and acts as a laxative, but this ordinarily passes in a week or so.

Sodium sulphate (Gluabers salts) and magnesium sulphate (Epsom salts) impart a laxative effect to water in concentrations exceeding 900 p.p.m.

WEIL'S DISEASE

Infective jaundice or Weil's disease is characterized by headache, backache, vomiting, diarrhea, muscular pain, hemmorages of the skin, and muccous, enlargement of the liver, albuminuria, and sometimes enlargement of the spleen. These are later followed by fever and jaundice. The incubation period is 4 to 7 days with symptoms lasting for from 10 to 14 days.

WATER BORNE DISEASES

WEIL'S DISEASE

The causitive spirochaete is common in the urine of rats, so the disease is prevalent among sewer workers, river and dock men, fish mongers, miners, and those farmers who are exposed to wet soil which has been contaminated by wild or field rats and mice. The organisms are also present in the urine of infected persons. With good medical attention, fatalities are rare. The organisms live in wet cool soil, brackish or fresh water. They enter man through the alimentary tract or through abrasions in the skin. This disease also occurs in dogs and foxes.

WORMS

Hookworm - (Nematodes-anclostoma, doudenale, and necator americannus) is generally contracted through the skin of the feet, but may enter the system by drinking water or uncooked vegetables which have been contaminated by the feces of persons having the disease. It is of wide distribution, being found in all tropical and sub-tropical countries, especially where the inhabitants defecate on the ground and where shoes are not worn. The eggs are discharged in the feces, the larvae is a free swimming, climbing one which makes for water.

Dracontiasis or Guinea Worm - Occurs in Africa, India, and other tropical countries. The male is 1", female 1 to 3 feet. The empregnated female bores out through the skin, often at the foot or ankle, to deliver the embroyo to water, where they seek an intermediate host, generally a cyclops. The embroyo survive 6 days in clear water and 2 to 3 weeks in muddy water. Man drinking water containing these cyclops is infected. The cyclops are very resistant to chlorine but are killed by lime.

Red Worms - Often there are numbers of active, red worms about 1 centimeter long on the bottoms or sides of reservoirs. These are the harmless larvae of the Pschoda, Midge fly, or other knat flies. They are not destroyed by chlorine or most other disinfectants and all openings should be screened so the flies will have access to the water.

INFUSORIO

The flagellates-trichamanas hominis, lambilia intestinales and balantidium cole, from the feces of an infected person are pathogenic. These are occasionally present in water.

CYSTIC DISEASE

Taenia echinococcus, a tapeworm, common in Argentina, South Brazil, Uraguay, and Australia, 4 to 5 milimeters long, with head and 2 or 3 segments. Adult worm inhabits the intestines of dogs which discharge the eggs with feces which may contaminate water and infect man, resulting in hytadid or cystic disease.

WATER BORNE DISEASES

POLIOMYCLITIS

As the virus of infantile paralysis is recoverable from feces, water is suspected of being the means of spreading this disease especially at sewage polluted bathing places.

TULAREMIA

Commonly a disease of rodents, which may be transmitted to man by biting insects and the meat of infected animals. It produces undulant fever. Incubation period 3 to 9 days. Mortality is about 5%.

B-tulerense in water has been reported from Russia.

PSYCHROPHILES

These are bacteria propagating below 14°C in cold water. Sometimes they are found in cold storage food such as poultry, but they multiply slowly. Phosphorescent sea water bacteria are psychrophiles, as are also many moulds and yeasts. These organisms are believed to be harmless in water.

SUPPLY SYSTEM

INTAKE

In impounded reservoirs the intake is generally located near the center of the dam with the outlet pipe traversing the dam. In the case of large natural lakes and rivers, the intake should be located at some distance from the shore where the water is less exposed to pollution than the shallow water near the bank.

Provision is made for taking the water from lakes at the most favorable level--that is where the water has least turbidity, algae, taste and odor, and where the pH favors economical floc. These favorable conditions are often found at a distance of 1 meter or a little less below the surface.

This is accomplished by providing the intake crib with 3 or more openings at varying levels. These openings are provided with gate valves or sluice gates. A simple arrangement for small instalations is to install an elbow, to which a length of pipe is attached which may be raised or lowered as desired.

All intake openings should be provided with removable coarse screens to prevent the entry of fish, sticks, and other large objects. Fine screens may be used inside the coarse ones to impede the passage of algae. Screens in intakes located in rivers should be protected against floating logs and other debris by a heavy grating.

Where turbid surface water must be used for the supply of small towns which cannot afford a complete treating plant, the writer uses removable sand filters over the openings into the intake crib. A 50 centimeter square frame is made of steel channels or wood to both sides of which are attached fine copper screens to hold the sand. These filters are made so that they can be opened readily for cleaning the sand. They rest on two inclined steel rods projecting from the crib wall which keeps the filter tight against the wall--a piece of old fire hose is fastened to the filter frame to prevent the passage of water.

Two of these removable 4" sand filters are placed at each opening--the one on the outside will have to be cleaned more often than the inner one unless coarser sand grains are used. On being removed, about each 24 hours, for hand cleaning, filters with clean sand should be ready immediately to drop in place. This is an inexpensive make-shift arrangement and does not remove as large a proportion of the bacteria as would a properly operated complete treatment plant, but will reduce the turbidity to around 20 p.p.m. if the removable filters are kept clean, to which water chlorine can be applied without further treatment.

SUPPLY SYSTEM

INTAKE

Sometimes intakes are placed on floats in order to maintain a constant distance from the water surface. In this case a flexible joint would be required to permit movement with the varying water level.

The suction line from an inlet to the pumps should be laid above ground so that air would be drawn in at defective joints instead of contaminated material which might enter if the pipe were buried underground.

CONDUIT

For conveying water from a river or lake to water treating plant, pipe or canal conduit is used. Pipe conduits follow the general contour of the ground and go in a straight line, but may detour to avoid deep depressions and elevations which would produce too high pressures.

The velocity of flow should be about 1 and 1/2 to 1 and 3/4 feet per second for six to twelve inch pipe: 2 to 2 and 1/4 feet for one foot to 3 foot pipe: and 2 and 1/4 to 2 and 1/2 feet for 3 to 4 foot conduit. If the velocity of flow is two feet or over very little suspended matter will be deposited, if the flow is less more deposit will necessitate frequent flushing out of the pipe.

In determing the kind of pipe conduit to be used, choice will have to be made between using large diameter pipe with resulting low friction head and smaller pipe through which the water will have to be forced by pump.

For conduits, cast iron (flange joints for large sizes), steel, wrought iron, and spiral riveted and welded steel pipe are used. Steel pipe is made in lengths of 20 to 40 feet. Cast iron will not resist the higher water pressures. Also pre-cast concrete or reinforced concrete cast in place for large sections are employed.

Conduits should not be laid above the hydraulic gradient, nor on the beds of streams, lakes or swamps, as it is practically impossible to maintain joints tight, due to uneven settling. If such places cannot be avoided, the conduit may be carried above the water on trestle or bridge.

For inspection and repairs, stop valves should be installed at one or two miles apart. Provide an air valve at all summits, and blow-off valves at depressions. These valves should be about 1/3 of the size of the main pipe. Check valves should be provided at foot of long upward inclines to prevent back-flowing.

SUPPLY SYSTEM

CONDUITS

Concrete conduits may become coated with slime and organic matter. They should be cleaned one or two times yearly, otherwise the water will have an objectionable taste and odor. Such pipe growths can be eliminated by chloramine or other disinfectant.

Open aqueducts or uncovered canals are not often employed now for transporting raw waters from sources to treatment plants. As such aqueducts must follow the contour of the land, they would be longer than a pipe conduit besides the water would be exposed to pollution and to algae grwoths.

PUMPS

Two sources of power and duplication of pumps should be available for fire protection and to take care of emergencies. Pump sizes and power should be ample. For small pumping stations with only one source of power, a standard gascline engine is often used for peak, domestic, and high pressure fire requirements.

Electrical power is often supplemented by deisel engine or gasoline motor. Dual power is not essential if steam is used on account on its dependence.

In the U.S., pumps provide a minimum of 50 gallons for domestic uses and 60 gallons per capita for fire fighting purposes.

Pumps should be housed in fire proof structures and above the high water level, or protected against flooding.

The replacement of old and obsolete pumps often results in economy, due to their inefficiency.

The efficiency and operation costs of pumps is determined by official tests under full load. Under operating conditions these will be less favorable.

Theoretical suction lift at sea level is 33.9 feet. This includes velocity head, and friction in suction line. Maximum permissible suction lift is 22 feet, but pump guarantees are based on 15 feet so with friction and other losses, pumps if possible should not be over 12' above low water elevation, when instalation is at sea level.

Centrifugal pumps are more commonly used now than reciprocal pumps for ordinary heads.

SUPPLY SYSTEM

PUMPS

Among the advantages of centrifugal pumps are their simplicity of design and operation, they do not require skilled attendants, there are no valves in the pump, no internal lubrication, no vacuum nor air chambers on suction or discharge, low first cost, they are compact and occupy small space, operate noislessly, pumping against closed valves will not injure the pump, they are easily connected to an electric motor or deisel engine and to steam turbines in larger instalations.

Disadvantages are the need for careful priming, the effect of head on efficiency and out-put, and inability to accomodate very high heads, though multi-stage centrifugal pumps may be used for fairly high heads.

Reciprocal pumps are made in many designs but they are always heavier, take up more space, and are more costly than centrifugal pumps of the same capacity. This type of pump may be used for high heads where the added efficiency might compensate for the added first cost and skilled attendants.

DISTRIBUTION SYSTEM

WATER CONSUMPTION

Male adults will drink 1.8 to 2.1 liters of water daily--less in cool humid weather than when it is hot and dry. In addition to this, some 0.6 liters is injested with food. Insufficient water causes shrinking of tissues, drying of skin, and diminution of blood.

The lowest scale of living families with no bath and one water closet will use 30 liters of water daily per person. If there is a bathroom which is used sparingly then at least 100 liters per person per day will be required. A bath tub with 6" of water holds 28 gallons but 15" is more common and requires 70 gallons.

Minimum dpmestic requirements per person per day are about as follows:

Drinking	1.8	liters
Cooking, dish washing, kitchen sanitation	4.0	"
Personal hygiene	15.0	"
Cleaning rooms, porches	10.0	"
Washing clothes	11.2	"
Bathing - 1 bath per week	27.0	"
Flushing water closet	23.0	"
Waste	8.0	"
	1 00.0	Liters

The domestic consumption in Latin American towns and cities as well as those of Southern Europe will average about as follows:

Up to 5,000	population	100	liters per person per day
5,000 to 15,000	"	125	"
15,000 to 50,000	"	150	"
50,000 to 100,000	"	200	"
100,000 to 300,000	"	250	"
300,000 to 600,000	"	300	"

The largest total consumption--domestic and industrial--in South America is Buenos Aires with 515 liters per day. This supply is unmetered.

Total water consumption in the U.S. is from a minimum of 40 gallons or 151.4 liters, an average of 105 gallons or 397.4 liters and a maximum of 160 gallons or 605.6 liters per capita per day.

In England's six most important cities consumption is from 37 to 49 U.S. Gallons per capita per day, in cities of Scotland 46 to over 90 gallons.

With improvement in quality and attractiveness of public water the per capita consumption increases.

DISTRIBUTION SYSTEM

WATER CONSUMPTION

Improvement in economic status and general living conditions also increases water consumption. In estimating future water needs this should be allowed for as progressive communities are apt to consume 1% to 1.5% more water per capita each year. Water reaching consumers under good pressure will be used in larger quantities than under low pressure.

There is always a difference between the quantity of water shown on the large meters in the sources or at the treating plants and the amount shown on the consumers meters. All consumers should be metered even though they do not pay for the water consumed. When this difference exceeds 20% of the water shown on the big meters, it is excessive and inspection should be made to find out if there are clandestine connections or broken mains. Some water systems have gotten this difference down to as little as 10% but rarely under this. This water which does not show up on the meters is consumed in flushing mains, street cleaning, fire fighting, water in public parks and squares, broken mains, joint leaks, and evaporation at treating plants and reservoirs. Water for fire fighting will average 1% where frame construction prevails, and 1/2% in masonry constructed areas.

PIPE MAINS

Design of System - The distribution systems are generally laid out with parallel mains going down each built up street or every other one. Smaller mains connect these at right angles. Long narrow districts may be served by a single long pipe of gradually decreasing size, with smaller branch pipe serving the side streets. Branch lines should return to the large main to permit circulation of the water, provide pressure from both sides of any connection, to reduce loss of head, and to prevent the stagnation of water in dead ends.

To serve a few consumers, 4" laterals may be expanded a short distance from large mains--street mains should never be smaller than 4" diameter. For cities up to 50,000 population, the large parallel mains may be eight inch C.I pipe, with laterals or secondary mains of six inches. New York and some other large U.S. cities have established 8" mains as the minimum size permitted to be laid in the streets. Water mains should be located, if possible, in streets and alleys and not across private properties.

A desirable main pipe velocity is 3'-to 6' per second.

A uniform arrangement of locating water lines should be adopted for convenience in locating in case records become misplaced. For instance, mains could be located ten feet from the center of the street, on the north side of E and W streets, and the west side of N. and S streets.

DISTRIBUTION SYSTEM

PIPE MAINS

In the business sections of some cities where the street is over 80 feet wide, the large water main is laid to one side and a 4" line on the other side of the street with a 4" connection to the main at each street intersection. This is done to avoid opening paving across the street for service lines.

Water and sewer pipes should be laid in separate trenches at least 10 feet apart. Where water and sewer pipes are within ten feet of each other, the water pipe should be at the higher level.

When service pipes or street mains cross sewer pipe, use cast iron sewer pipe with leaded joints for ten feet on both sides of the water main. The water pipe should cross the sewer pipe at the higher level.

For protection against freezing and vibration, pipe should be laid 24" or more underground.

Hydraulic Calculations - Water flow in pipes may be computed by the Hazen Williams formula:

$V = CR^{0.63}S^{0.54}0.001^{-0.04}$
V = Velocity of flow in feet per second
C = Coeficient of friction = 130 for new pipe
R = Hydraulic radius of pipe in feet
S = Slope in hydraulic gradient.

A special slide rule for working the above formula is manufactured by Abbot-McKay Corporation, Boston, Mass.

Cast Iron Pipe - Cast iron pipe with ball and spigot joints, is the most commonly used for water mains. It is usually cast in 12' lengths with diameters up to 6' or more. Cast iron pipe has been used for centuries, and early instalation being that of the fountains at the Palace of Versailles, France, still in operation after over 250 years service. Cast iron pipe has long life, is resistant to corrosion, and any special forms may be readily cast. There is often loss from breakage in shiping, and carrying capacity will be reduced when tuberculation or calcium incrustations are formed in the pipe.

Pipe should be completely covered both inside and out with an approved non-taste producing protective coating. Sometimes the inside of cast iron pipe is coated with about 1/8" of cement. Suppliers may furnish pipe with this coating or it may be done by the water department. At Montevideo, Uraguar, a cement coating is successfully applied by placing the required amount of cement morter in a length of pipe and rolling it down an especially constructed ramp. The centrifugal force evenly spreads the cement morter over the inside surface of the pipe.

DISTRIBUTION SYSTEM

PIPE MAINS

Pipe of Other Materials - Other materials for pipe making have come into use in recent years. Cement--asbestos pipes have been successfully used for some years in Italy and the U.S. especially. These are lighter in weight than cast iron pipe and their inside surface is smoother, having a coeficient of 145. They are easy to lay.

Reinforced concrete pressure pipe has been successfully used at Montreal, Canada, since 1929, as well as at other places. Centrifugally cast and vibrated pipe are more dense and stronger. An advantage to these non-metal pipes is that their carrying capacity is not reduced by age due to rust or tuberculation, nor are they effected by electrolysis.

As wrought iron or steel pipe, galvanized or balck, ordinarily has a life of from 7 to 16 years, it is not advisable to lay such pipe under paving, or in streets likely to be paved.

Bitumastic enamel is a hard rust protective coating used on the inside and outside of pipe, leaving a smooth surface.

Laying Mains - Sanitary conditions should be maintained for workmen, including sanitary privy and safe drinking water.

The top of the pipe should be at least 24" below the street surface for protection against heavy traffic and freezing.

The bottom of the trench should be excavated to six inches below the flow line of the pipe for the purpose of providing space for earth or sand to properly bed the pipe. Such bedding of the pipe is especially required in rock, as such brittle material must not touch the pipe as it will scrape off the protective coating, and uneven settling will often break the pipe.

Pipe should be subjected to 150 pound per square inch hydrostatic pressure for six hours before connecting it up for service.

After the pipe has been laid and tested and the defects repaired, all as above specified, earthly materials shall be deposited in the trench on both sides of the pipe simultaneously, and tamped with hand rammers, up to the horizontal diameter of the pipe. Above this level, the trench shall be filled by hand, scraper, push boards, road grader, or otherwise. In the business area and across railroads, the back-fill shall be thoroughly tamped with hand rammers approved by the engineer, in layers not exceeding six inches in depth: or if water is available, such sections of the trench shall be flooded and water tamped. Surplus dirt shall be heaped up over the middle of the trench and neatly smoothed and rounded.

DISTRIBUTION SYSTEM

PIPE MAINS

Pressure Testing - The section of pipe to be tested should be filled with water. All air should be expelled. The joints should not be covered, though the pipe may have up to 6" of earth fill above it.

Water pressure may be applied by a hand pump, or by power pump for long sections of large pipe. The test pressure should be 50 pounds per square inch greater than the pressure under which the system is to operate.

The amount of water pumped into the pipe can be metered and the amount deducted from the pipe capacity to determine the amount of loss by leakage. Allowable leakage is 100 gallons per 24 hours per mile of pipe per inch of normal diameter for 12 foot lengths and 75 pounds for 16 foot lengths.

Where pipe is laid with sulphur base joints, they should lay filled with water for at least 10 days before pressure testing.

Dead Ends - Where a main is laid to terminate at some point in a street without returning to the distribution system, a dead end is created. As there is no circulation of the water, it becomes stagnant. Organic matter, rust, and other material is deposited there. The free oxygen becomes consumed, usually in 2 to 4 weeks and the water becomes more actively corrosive, due to the increase in carbon dioxide evolved in fermentation. Conditions are favorable in dead ends for the propagation of iron bacteria and other organisms which do not require sunlight. Tastes and odors are often produced in dead ends.

A valve may be installed at the end of the line to flush out such dead ends once or twice a month. It is preferable to connect the dead end back to the distribution system so the water will have continuous circulation as the flushing out of dead ends is apt to be neglected.

Pipe Joints - After cast iron pipe is laid in the trench, a fiber is placed on the inside of the ball and spigot joint. This fiber is commonly jute or hemp, but cotton has been used. These fibers should be wet or dry heat sterilized or with cupric ammonium sulphate. In spite of this precaution, phenolic tastes will be produced. Rubber and other special products have been experimented with to replace these fiber joint materials on account of their harboring bacteria--jute is worse than hemp in this case. Tarred jute should not be used as chloro-phenolic tastes will be produced. Some rubber and other special products are now on the market as substitutes for fibers.

DISTRIBUTION SYSTEM

PIPE MAINS

After placing the fiber joint material, the joint is sealed with molten lead or with cold lead caulked into the joint. There are a number of special joint materials used in place of lead which are usually made of sulphur and fine sand. Care must be exercised in heating such compounds or some of the sulphur may be burned out causing brittleness and cracking. Skill is required to pour these joint materials. Such composition joints should set from 10 to 30 days with the main full of water before pressure testing. Such materials cost from 10% to 35% less than the material for lead joints. Faulty joints made with these compounds cannot be repaired successfully---they have to be removed and replaced. Sulphur compound joints are apt to be more rigid than leaded joints.

> "Certain bacteria, which are relatively resistant to Ammonia-chlorine treatment, may attack the sulphur present in commercial preparations used for sealing pipe joints. Sulphates are formed by the oxidation of sulphur to sulphuric acid by thiobacteria. Anerobic bacteria reduce the sulphates to hydrogen sulphide, which combines with the iron of the pipe." Beckwith and Bovard.

In some places 1 to 1 cement mortar has been successfully used for joints. Dry mortal is rammed tightly against the fiber.

Curves - Curves can be constructed by deflecting the straight cast iron pipe lengths at joints. Minimum radii for these curves are: 4" to 8" pipe, 150 feet; 16 to 24", 250 feet; 24 to 36", 500 feet.

Cleaning - Water should be flushed out through the fire hydrants once or twice a month, especially if such flushed water is red from rust or discolored from sediment, when it should be allowed to run until the water becomes clear.

Mains of 8" and larger may be cleaned by water propelled scraping devices attached to the end of the fire hose. Optimum results are obtained when this device travels at 50 feet per minute. A torpedo device is also used which is propelled unattached through the pipe by the water flow.

For 4" and 6" pipe a similar metal scraper may be drawn through the pipe by hand operation windlass.

DISTRIBUTION SYSTEM

PIPE MAINS

Such scraping devices should remove most of the tuberculation and calcium incrustations and restore the pipe to 85% of its original carrying capacity. Sometimes calcium deposits are so hard that they cannot be removed by scraping devices. Where deposits of iron rust and lime are soft, cleaning has been done successfully be forcing large air bubbles into the main from an air compressor alternating a rapid flow of the water with big air bubbles.

Pollution Hazards - Sterilization of new mains with dry calcium hypochlorite or chlorinated lime is not very effective. If, however, this method of disinfection is used, the following may be observed: when pipe is laid sufficient hypochlorite of lime should be left in the pipe to give 50 p.p.m. of available chlorine when the line is filled with water. This is obtained by the following amounts for each 20 feet of main: 4" pipe, 1/8 ounce; 6" pipe, 1/3 ounce; 8" pipe, 5/8 ounce; and 10" pipe, 7/8 ounce.

When completed, fill line with water, allow to stand at least three or four hours then flush out until residual chlorine, by O. T.O. test, shows under 0.5 p.p.m.

Chlorination, contact for several hours, and flushing is effective.

Laying pipe under water or steam beds is to be avoided. Bridge trestle, and dam crossings are recommended. Drains from hydrants should not be connected to sewers, but wasted to gravel pockets or the ground.

Chambers or pits for gate valves, air relief valves, or blowoffs, should not be connected directly to storm or sanitary sewers.

AUXILARY WATER SUPPLIES

For certain uses where potable water is not required, such as for watering roads, gardens, street cleaning, flushing sewers, for boiler feeding, and fire fighting, cities have considered putting in separate systems in order to economize on treated water. This however, has not usually been found to be economical.

Paris has a separate system principally for street cleaning. At Guayaquil, Equador, there is a separate system for fire fighting. In this case the raw water is pumped from the Guagas River at the edge of the city to reservoirs placed on high hills nearby which gives a pressure of around 60 pounds per square inch. Most of the buildings of Guayaquil are of frame construction and the potable supply is hardly adequate to the present needs of the population which are the principal reasons for this separate system.

DISTRIBUTION SYSTEM

SERVICE CONNECTIONS

Pipes from the street mains to residences or other buildings are called service connections. Pipes to residences should be 3/4" diameter--it is false economy to use smaller pipe, as they get stopped up too readily. The water meter is usually on the line between the street curb and the sidewalk--5/8" or 1/8" diameter less than the pipe which it is on. The pipe from the meter to the building, as well as the pipe lines and other water accessories within the building, should be maintained by the property owner, while the street mains and the service connections to the meter as well as the meter itself are maintained by the public water supply service. Service pipe are often perforated by corrosion, causing waste of water. Red and white lead and other pipe compounds should not be used on service pipe.

Copper and Copper Alloy Pipes - Red copper pipe is soft, ductile and easy to work. Nails driven by carpenters during construction, often go through the boards and pierce copper tubing. contraction and expansion open the hole, causing a leak. Nails striking brass pipe are deflected as that alloy is harder.

Pipe is made with various percentages of copper and zinc. Yellow brass pipe or Muntz metal contains 60% copper and 40% zinc. High brass pipe contains 67% copper, 0.5% lead, and 32.5% zinc. Such pipe is subject to dezincification or corrosion of the zinc. Red brass pipe with 85% copper or ober will not dezincify.

Water is corrosive to copper and copper alloy pipe if high in dissolved salt content, free oxygen and carbon dioxide. High Carbon dioxide content is very high and the carbonate hardness low, tin coated copper tubing is recommended.

Copper and copper alloy pipes are well adapted for service connections as they are easy to work, of long life, and their carrying capacity is not reduced by rust or tuberculation, nor are there ill effects from dissolved metal as in the case of lead. Copper pipe is joined by sweating.

The grounding of radio wires to copper or brass pipe causes rapid desintegration and turns the water blue. Brass pipe is made in the same sizes and with the same threads as steel but direct connection them will result in electorlytic decomposition.

DISTRIBUTION SYSTEM

SERVICE CONNECTIONS

Wrought Iron and Steel Pipe - Wrought iron pipe is less corrosive than steel pipe and is more costly. The difference of the life of galvanized pipe over the ungalvanised or black pipe is not as much as might be expected, due to the fact that the threads at the end of the pipe are not galvanized and it is here that the pipe rusts through first.

Wrought iron and steel pipe--should not be used for service connections over which pavement may be laid as such pipe does not usually last longer than from 7 to 16 years in service. Digging through pavement for replacing such pipe is costly.

Lead Pipe - No lead pipe should come in contact with potable water. Where such instalations have been used they may be continued in service if the water is not very solvent to lead and if precautions are taken to assure that the consumer will suffer no ill effects. Leaks in lead service pipe is usually due to poor wiping of lead joints.

Lead pipe is satisfactory for, and generally used to carry off waste water.

DISTRIBUTION STORAGE RESERVOIRS - are provided for the following purposes:

1. Equalize pumping and power demands
2. Maintain pressure without stand-by pumps
3. Relieve excessive pressures at plant.
4. Reserve supply for fire, broken mains, power failure, and water plant shut-down.

Storage reservoirs are usually elevated steel tanks, concrete surface reservoirs, or steel standpipes.

All openings above the high water level should be screened with No. 16 screens to exclude insects. Openings below the water level must be tightly sealed.

Elevated steel tanks should be protected from rust by being kept well painted, both inside and out.

Concrete surface reservoirs are generally built with their bottoms at the ground surface level or with half of the height underground. Reservoirs should be built above the surface water table.

DISTRIBUTION SYSTEM

DISTRIBUTION STORAGE RESERVOIRS

The ground should slope away from the reservoir and all water drained away from the bottom and sides. These surface reservoirs should be located on high ground to provide head and at some distance from the pumps to equalize the pressure. Well supplies are usually pumped directly from the well into the surface reservoir or through a sand trap is sand is being pumped. Bottom drains are provided in concrete reservoirs as slime must be brushed and then hosed from the walls.

Standpipes are seldom used now. An objection to them is the great variation in head due to changing water level.

Storage reservoir capacity is very often 24 hours average water consumption, which is good practice, as it is sufficient to take care of the ordinary requirements, as well as emergencies unless they are exceptional. Storage capacity does not usually exceed 48 hours consumption because it is not usually needed, and the addition to the cost and secondary bacteria growths will often become active in finished waters after this period. No reservoir unit should be under 50,000 gallons capacity.

Elevated tanks for backwashing filters are constructed with large diameters and shallow depths to reduce head variation.

STEEL RESERVOIRS - MAINTENANCE

Their surfaces should be maintained well covered, both inside and out, with protective paint.

Before applying paint the metal surface should be thoroughly cleaned by sand blasting or with wire brushes. Wipe dust off by hand. For the first, or primer coat, red lead and pure linseed oil is recommended, lead chromate or blue lead, or a combination of these stable pigments may serve. To produce a cheaper paint, red iron oxide is sometimes added. Use as little vehicle (linseed oil) as possible, otherwise the paint coating will be weakemed due to there not being enough pigment to fix the oil permanently.

Red lead should be brushed out fairly thin. It dries very slowly but if fast drying is necessary, add litharge but not turpentine. Letharge (two pounds per gallon of paint) improves the paint for submerged surfaces, but weakens it if exposed to the weather.

As the primer coat may not be very weather resisting, it must be protected with a top coating. Satisfactory pigments for this purpose are, flake graphite, flake aluminum, and hematite (micaceous iron ore). A weather resisting vehicle should be used,

STEEL RESERVOIRS - MAINTENANCE

such as linseed oil. Another satisfactory top coating is coal tar or asphalt. Where such paints are exposed to the weather, they should be reinforced with powdered aluminum, otherwise checking and cracking will develop. The aluminum makes the coating opaque and reduces the ill effects of sunlight. Aluminum paint also furnishes a satisfactory top coating, being used much for the outside of elevated steel tanks and for the structural supports. After cleaning metal surface, cover with linseed oil as primer, dry for two weeks or more, then apply aluminum paint.

For the interior of water tanks, the following are generally used due to their being taste-free: natural asphalts, such as gilsonite, rock asphalt, lake asphalt, or a mixture of these. Particularly subject to corrosion is that part of the interior of the tank where the rising and lowering of the water level expose the surface to alternate wetting and drying--such surfaces will rust around four times as rapidly as submerged ones.

Under-caotings should be perfectly dry before painting on them.

Paints should contain around 45% of pigment and 55% of vehicle by weight. One gallon of paint will cover around 500 feet of surface. Paint will take some 72 hours to dry thoroughly.

Bitumastic coatings are durable and satisfactory as rust protection. They are of a coal-tar base.

PRESSURE

The water pressure in the pipes of the distribution system will vary at different points and at different hours due normally to increase or decrease in demand. Fire fighting or broken mains will reduce pressures in their vicinity. This will also occur when large consumers pump water from the mains.

A pressure of at least 20 pounds per square inch or 1.4 kg per square centimeter is required to serve the second floors of buildings. During heaviest demand pressures at all points of the city should not drop below 20 pounds.

Higher pressures are advantageous in that more water will be consumed, upper floors of buildings will be served, hose can be direct connected to fire hydrants instead of using fire department pumps, sprinkler systems for fire protection will be better served and occasional excessive demands will be accomodated without reduding pressures below that required for domestic and other normal needs.

DISTRIBUTION SYSTEM

PRESSURE

Pressure recording gauges, located at various points on the larger mains are useful in keeping track of variations in pressures, which data may be needed in planing extensions of pipe lines and may indicate leaks.

Main pressures, as tested at the nearest fire hydrant may be adequate but greatly reduced in buildings due to leakage in service lines, accumulative carrying capacity and increasing loss of head.

LEAKS

If there is no sealed paving over a pipe-line, leaks can ordinarily be detected by water at the surface, especially if the soil is dense. In permeable soil water may percolate downward and not app-ear on the surface for a time, if the quality is not large.

Leaks will cause the main to vibrate. By touching a thin metal rod to the main or fire hydrant, the vibration may be sensed if held between the teeth. Small portable electrical leak detectors are on the market--the pitometer is also used.

An effective test for locating large leaks or unauthorized connections is made by cutting off a certain small section of the distribution system, introduce a metered quantity to the cut off section by a hose from a hydrant outside the section to one inside it. If the quantity registered by the meter is considerably in excess of the amount which would normally be used by the consumers connected to the closed off section, then the leaks or clandestine connections should be looked for.

Recording pressure gauges are useful for locating leaks.

Loss of water by leakage should not exceed 250 gallons per inch diameter of pipe per mile in 24 hours.

METERS

Often when water services are not metered and it is proposed to install them, public sentiment is against it. Such opponents feel that water is supplied abundantly by nature and should be free. This would be true if the water were taken and consumed from its original sources without the cost of transporting, treating, and disinfecting it, which entails a definite expense for eachliter produced. Another argument sometimes advanced is that the poor people would not use sufficient water for sanitation and health if they had to pay in proportion to the quantity used. The price charged is usually so low that this has little validity. Usually the amount of water which they are allowed on the minimum charge is sufficient for sanitary purposes.

DISTRIBUTION SYSTEM

METERS

In the U.S. where meters have been installed, there has been a reduction of consumption exceeding 50%--the Latin American countries have had a larger reduction. By reducing the amount of water wasted, large savings are effected in the cost of pumping, chemical dosijg, and other treatments, chlorine consumption, besides these economies there are other advantages such as the facility in checking and locating losses from leaks and unauthorized connections. Pressure will be increated, adding to fire protection. The mains will be large enough to carry the smaller amount of water and will not have to be replaced by larger ones as soon as would otherwise be the case. Sometimes with unmetered services the water waste is so great that it is impossible to maintain a continuous 24 hour service which might be done if the services were all metered. The metering of services is equitable for all, as each will pay for what he consumes and no consumer will have to pay for the extravagant waste of of others and the water department can consentrate on the quality of the water rather than the quantity.

Great care should be taken in selecting the meter to be bought It is very important that one make of meter be decided upon so that the serviding department will become familiar with one make and spare parts can be carried for it, rather than spare parts for a number of different types of meters. The disc meter is the most generally used. It operates by displacing a fixed quantity of water for each revolution of the disc spindle. The pressure loss in passing through the meter is quite small.

Meters are made with the reading register consisting of round clock-like dials or with the hand moving across a straight rectangular marker. The latter is easier for inexperienced men to r read but the former is preferred as it registers small flows more accurately.

The meter size will be such as to meet the service demands. The 5/8" meter has spuds and couplings threaded for connecting to 1/2 or 3/4" pipe; 3/4 meter to 3/4" pipe and 1" meter to 1" of 1 and 1/2" pipe. The 5/8" meter should be used on 3/4" service pipe.

In ordering meters, specify--quantity, size, type, kind of reading register (whether round reading circular, or straight) whether dials register in liters or gallons, whether with or without connections, and if connections are straight or bent.

DISTRIBUTION SYSTEM

METERS

Meters should be protected aginst freezing and heat exceeding 100°F. The cheapest meters usually represent poor economy due to the great amount of servicing they require. They are usually quite accurate when new but later develop inaccuracies, especially in low flows when they nearly always register less than the quantity passing through them.

Annual meter inspection is desirable but all shoud be tested at least once in five years.

Meters should be disinfected on being installed by placing a teaspoon of calcium hypochlorite on the lime side of the meter, make connection, open faucet in the building until chlorine appears in the water. Close faucet and let water stand in pipe for 1 hour, then flush out.

When water carries excessive sand, or pipe scale, install a strainer or fish trap on inlet side of meter.

The current velocity or turbine type of meter is used for measuring large flows through pipes from 2" to 12" diameter.

FIRE PROTECTION

Fire hydrants should be located at all street intersections in the business section and at alternate ones in the residential sections.

Each hydrant should have 5" valve or larger, two 2 and 1/2" outlet connections, and one connection for fire pump. Fire hydrants should not be connected to mains smaller than 6" diameter.

Hydrants should be inspected at least every six months and painted once a year.

In towns where buildings are mainly of wood, around 1% of the total water consumed will be required for fire fighting--if of masonry 1/2% or less.

VALVES

All valves should be located uniformly, so that they may be easily found if records are misplaced.

Gate valves should be placed so that no more than 500 feet of main in the business section nor 800 feet in the residential section need be cut out of service in case of break or for other servicing.

DISTRIBUTION SYSTEM

VALVES

Stop valves should be placed on small mains where they intersect with the larger ones. At intersection of mains there should be a valve in each line.

Each dead end should be provided with a valve for flushing out.

Vavlves should be inspected yearly--the large ones every 6 months. Put a little light oil or kerosene to lubricate and soften the packing. Open and close the valve several times.

CROSS CONNECTIONS

A direct cross connection occurs when a polluted water supply or one subject to pollution or of doubtful sanitary quality, or one whose chemical and bacteriological qualtites are not tested at frequent intervals by competent laboratory technicians, is connected to a potable public water supply.

Often in small towns, such connections exist between the private supply of an industrial plant and the public water system. Small municipalities and industrial plants find it convenient to connect their mains as a protection against interruption of supply due to a breakdown in their system, or to assure an adequate supply of water for fire fighting.

When the water in the supply mains of a system loses pressure or head, then polluted water may be sucked or siphoned from cross connections to contaminate the public supply. This may be caused be reduction of head, loss of head, or by a negative head or suction. These conditions are usually brought about by broken mains, or by heavy demand for fire, or by booster pumps which supply nearby large buildings.

A number of ways have been devised for reducing the hazard of pollution of the potable water supply but all of these are subject to failure from neglect or for other reasons, so that many cities in the U.S. will not permit any direct physical cross connection between their potable water supplies and other doubtful ones.

Some protection may be provided by the instalation of two check valves on each line with pressure gauges for determining whether they are well seated or leaking--this test should be made monthly and reported to the health authorities.

Sometimes the last joint of pipe carrying the doubtful water has a universal joint so that it may be disconnected when no water is needed from the municipal supply.

CROSS CONNECTIONS

Vacuum breakers have been used on smaller pipe.

Cross connections can often be avoided by the use of an elevated tank or one placed on top of a building into which the potable supply is delivered by pipe above the over-flow line of the tank.

INTERCONNECTIONS

Besides these direct cross connections above referred to, pollution may enter the potable water supply through improperly designed or installed plumbing fixtures.

All toilet fixtures except the toilet bowl, bidet, and a few special fixtures for washing glassware and dishes, such as used in restaurants, bars, and soda fountains, should be designed with their inlet at least 2" above the over-flow level of the fixture. In the case of the other fixtures where the inlet is submerged or may become submerged when the drain becomes stopped up, some protection against pollution will be provided by installing a vacuum breaker between the valve and the fixture, or by the use of a combination check valve and stop--the former arrangement is best.

For toilet bowls the delivery pipe or inlet to bowl should rise above the over-flow level of the closet bowl, and should not be submerged. The check valve should be above the over-flow level of the closet bowl.

Besides the reduction in main pres-sure, due to the reasons mentioned above, inadequate pipe pressures reaching plumbing fixtures may result from insufficient pipe capacity, incrustations in pipes, turns and bends, bad joints, inefficient valves, excessive water demands on lower floors and supply risers being drained for repair.

LABORATORY

ANALYSIS

Before funds are expended on the development of water sources, the water should be thoroughly tested in the laboratory to determine its physical, chemical, and bacteriological qualities. Such complete analysis will not be required often, perhaps once a year. Ordinarily there is some physical manifestation which will indicate the presence of impurities in excess of the established tolerance, above which concentrations, they are considered objectionable. For instance when spotting occurs in washing textiles or plumbing fixtures become discolored, then tests should be made for the staining minerals--iron and manganese.

Physical and chemical tests are made primarily for the purpose of determining the effectiveness of treating processes, improving them, and to accomplish economies in treating chemicals. As the characteristics of all waters are not the same, different treating processes, as well as laboratory tests are requied for each water.

In most cases the following determinations are made frequently turbidity, pH, residual chlorine, total solids, alkalinity, and if contents are high, iron, manganese, calcium, sulphates, silicates, nitrates, organic matter, color, taste and odor, free carbon dioxide, and total hardness.

For the determination of the effectiveness of flocculation and sedimentation, observations will be made in the coagulation channel sedimentation basin, and of the water over the filter sand.

Filter operation will require a number of observations and tests for free oxygen, carbon dioxide, hydrogen sulphide, pH, iron and manganese, before and after filtration.

If correction treatment for reducing corrosion of water is applied, the pH, alkalinity, and carbon dioxide, will have to be determined.

LABORATORY EQUIPMENT

Apparatus required for making physical tests can be made by hand except the turbidimeter for measuring turbidities under 25 p.p.m.

Equipment required for making chemical analysis will include gas burners, evaporating dishes, scales, oven, chlorimetric outfit for determining pH, chemicals for preparing reagents and stock standard solutions, and such glassware as tubes, cylinders, pipettes, flasks, funnels, etc. The minimum requirements for a chemical laboratory for water work will cost around $500.00 in the United States.

LABORATORY

LABORATORY EQUIPMENT

Equipment required for making bacteriological tests include an incubator for 37°C, autoclave, platinum needle, glassware such as Petri dishes, 4 or 8 ounce glass stoppered sampling bottles, fermentation tubes, small gas collecting tubes, pipettes, and media preferably in the dehydrated (powdered) form. The minimum requirements for a bacteriological laboratory will cost around $1,000 in the United States.

The most costly item is the incubator. Where funds are not available for the purchase of one it can be made from an old ice box by boring a hole in the top to insert a thermometer and installing a thermostat on the floor. The thermostat will cost about $30.00.

A microscope may be needed occasionally for the identification of algae or other micro-organisms. Often microscopes are available at hospitals or other institutions which may be used by the water department until they can acquire one for themselves.

PHYSICAL TESTS

Turbidity - The appearance of mirkiness or muddiness in water due to such suspended matter as clay, silt, organic matter, micro organisms etc, is referred to as turbidity. Its determination at various points from the raw water to the finished water is useful as a measure of the effectiveness of the treating precesses.

Measuring turbidities from 100 to 1,000 p.p.m. may be done with a candle turbidimeter which consists of a standard tallow candle placed below a graduated glass cylinder into which the water is poured until the light of the candle disappears from view in looking down longitudinally through the cylinder. The glass cylinder is placed inside a metal tube to keep out the light. The mark on the cylinder at the water level will give the turbidity in p.p.m.

For turbidities exceeding 1,000 p.p.m. the water may be diluted by a known proportion. The turbidity of the diluted sample will then be multiplied by the proportion of dilution.

For turbidities between 25 and 100 p.p.m. the candle turbidimeter may be used for approximation.

For turbidities between 5 and 100 p.p.m. comparison can be made with standard suspensions in bottles or tubes based on the unit of turbidity being represented by 1 p.p.m. of silica, (diatomaceous earth or fullers earth) in distilled water.

LABORATORY

PHYSICAL TESTS

For turbidities under 5 p.p.m. the Baylis or other special turbidimeters will be required.

When turbidity of filtered water reaches 1.5 p.p.m. filters should be backwashed.

Color - The color of water does not refer to substances in suspension, so they should be taken out of the laboratory sample by centrifuging and not by filtration as the latter would remove some color.

The test for determining the color is made by comparing with platinum cobalt standards or with colored glass discs.

Odor - There is not usually any need to accurately determine the amount of odor in water. A test sample of water may be put in a bottle and shaken vigorously. The odor may be sensed by placing the nose at the open neck of the bottle. To prevent the surrounding air from entering the nostrils to dilute the odor, a glass laboratory tube may be placed in the nostril and extended down to about one half inch of the water surface. The odor will be intensified by heating to about 65°C. as it will drive off gases and other volatile substances.

These tests for odors should be carried on in a room whose atmosphere is free of other odors.

Taste - There is no test for taste except to simply taste the water. No test is needed as taste is ordinarily imparted to water by the same impurities which cause odor. Tastes imparted by iron, calcium, and other inorganic matter are detected in the mineral analysis of the water.

Temperature - Water treating plant operators often record on their laboratory reports, a record of the temperatures of the raw and finished water as well as the atmospheric temperature. Ordinary thermometers are adequate for this purpose.

Coagulation, chlorine, and nearly all other chemical reactions are more rapid in warm water. Sedimentation, algae propagation, fermentation, and putrifaction of settled sludge in sedimentation basins, and all other biological processes are faster in warm than in cooler water.

Perhaps the highest temperature of any water supply in the U.S. is that of Austin, Texas, which is 96°F or 32°C in the summer.

Cool water results in considerable economy in refrigeration and air-conditioning.

JAR TEST

There is no way of determining the amount of coagulant and auxilary chemicals (alkalis or acid) which will produce optimum flocculation and sedimentation except by trial and error in the laboratory. The characteristics of most surface waters varies often requiring adjustment of the chemical doses. By frequent jar tests determination of the amount of chemicals to be fed for flocculation, big economies may be effected.

Apparatus for the jar test consists of 5 glass jars of about 2 liters capacity, each. They should be of uncolored glass to permit observation of the forming floc and have large opening like fruit preserve jars. Small brass tubes may be used for shafts for the revolving brass blades fastened at their end and immersed in the jars of water. Each of these shafts has b pulley at its upper end with a groove for a round leather belt or cord. The belt would be connected to a 1/20 horsepower motor with two pulleys, one for quick agitation of the water and the other gauged to move the water at an average of 1 foot per second, which would simulate the flash mix and the slow flwo mix of the treating plant. This apparatus would be supported on a wood frame and operated on a laboratory table.

To make the test put 2 liters of the water being tested in each jar. Solutions of the coagulants and auxilary chemicals shoud be kept on hand for these tests as the amount is more easily and accurately applied than be weighing the dry chemicals. The amount of chemicals which the technician thinks may give best results should be measured into the middle jar. Larger and smaller amounts should be added to the other jars. Rapid mix should continue for 1 minute, then slow mix for 15 minutes or longer, after which the water is left quiescent 1 to 3 hours to observe the settling. The time required for settling and the clearness of the water above the settled floc are the most important factors.

FLOCCULATION

The effectiveness of coagulting chemicals being applied in quantities previously determined by the jar test should be observed and tested as follows: a sample of the water should be taken just before it leaves the coagulation channels and another one just after. By comparing these, the observer will notice whether the floc is being broken up in passing from one channel to the other, due to the accelerated velocity. The same test may also be made just before and after the water leaves the sedimentation basins.

LABORATORY

FLOCCULATION

The turbidity of the water lying over the filter sand should be taken. The water should not reach the filters with the turbidity exceeding 20 p.p.m. and preferably not over 10 p.p.m.

To facilitate observation of the floc as it leaves the mixing channel, as it leaves the sedimentation basins, in the water over the filter bed, and in the clear well, submerged water proof electric light bulbs with reflectors above, facing downward, may be installed at these places.

Flocculation may be tested with a simple device made by connecting a two liter flask so that the water will flow through a small tube inserted in the top and extending to 1" of the bottom. Another short tube of the same size would be inserted for the water to flow out. The jar would be kept in a box, the inside walls of which are painted black. A 100 watt electric light bulb would be placed at the side of the jar. The condition of the floc in the water passing through the jar can be readily observed by looking through it when the light is on. This device is called a floc detector.

FILTER SAND EXPANSION

Sand expansion during backwashing may be determined by a simple hand made device. A 1" X 1" square wood pole about 2 meters long may be used. Attach small tin cups at 3" intervals so they will stand horizontal to the pole. Drive a large nail partly into the pole at a distance from its end equal to the distance from the sand surface to the overflow edge of the waste water traugh. The pole is held vertically in the water while the filter is bein backwashed, with the nail resting on the edge of the traugh. The pole should be raised slowly from the water to prevent the sand from being washed from the cups. The distance from the bottom of the pole to the highest cup in which sand is found gives the sand expansion.

MARBLE TEST

This test is to determine the pH-alkalinity relation of water when it is at $CaCO_3$ Equilibrium--that is when all of the free carbon dioxide has combined with calcium.

Into a jar of 1 liter of the water being tested, put a gram of pure calcium carbonate. Stir continuously or frequently for at least 24 hours. When the uncombined calcium has had time to settle, determine the pH and alkalinity of the water.

If pure calcium is not available then a chip of marble, or lime will serve but the contact time should be 48 hours or over.

MARBLE TEST

A water treated by the addition of lime or soda-ash or run through contact beds of limestone, until the pH and alkalinity determined by the test are attained will have its corrosiveness reduced by the part of it which was due to the presence of carbon dioxide.

If a small excess of alkali is added it will deposit on the inside of the pipe to form a portective coating. Care should be taken not to add such an amount of alkali that the incrustation will materially reduce the carrying capacity of the pipe. Clogging of small pipes and meters will indicate whether too much alkali is being added to the water.

Though such correction of the corrosiveness of water by the addition of calcium may add up to some 20 p.p.m. of hardness to the water it is justified.

TRACING WATER

Where it is desired to determine whether pollution is reaching a certain body of water, a chemical may be put into the polluted material and the water later analized, for its presence in the water. Ammonium chloride or sodium chloride may be used for this purpose.

Where facilities for making these analysis are not available a dye may be used. Fluorescein, also called uranin, is preferred but if not abailable fuschin, potassium permanganate or preafin oil may be used.

Use one part of fluorescein and one part of caustic soda, in 83 parts of water. It will not filter out in traversing permeable formations. Fluorescein if worthless in swamp or peaty soils. In concentrations as low as one to 50,000,000 this organic dye will impart a fluorscent green tint to the water.

Cultures of Seratia marcesens may be used as a bacterial indicator--these organisms color the water.

CHEMICAL

Total Solids.-By evaporating a known quantity of water and weighing the residue the total solids in suspension is determined.

The loss on ignition of these solids may be determined by igniting the residue at red heat over a burner and weighing the residue.

CHEMICAL

The amount of solids which settle out at the end of any period of time may be determined by carefully pouring off the water, drying the settled material, and weighing.it.

Alkalinity - Add 3 drops of phenolphthalein indicator to 100 milimeters of the water sample. If the indicator imparts a pink color to the water, add 0.02N sulphuric acid to the water until the color disappears. The number of p.p.m. of phenolphthalein alkalinity of the water will be the number of ml. of acid added times 10.

Follow the same proceedure with methyl orange indicator to determine the methol orange alkalinity.

Carbon Dioxide - Add 10 drops of phenolphthalein indicator to 100 ml. of the water sample. Add n 44 sodium hydroxide, stirring gently until a permanent pink color appears. The number of mL. of sodium hydroxide added times 10 will give the number of p.p.m. of carbon dioxide in the water.

pH - An apparatus is required for determining the pH of water. It consists of an enclosed metal holder for 2 square glass tubes and a revolving wheel containing glass color discs.

Place 10 ml. of the water sample in each of the 2 tubes. Add the indicator to the tube not opposite the color discs. Compare the color of the water containing the indicator with the glass disc and read off the pH for the color disc most nearly approximating that of the water.

Total Hardness - Place 50 ml of the water sample in an 8 ounce glass stoppered bottle. Add standard soap solution, shaking after each 0.5 ml. Repeat until the lather holds on the surface for 5 minutes, when the bottle is laid on its side.

$$\text{The p.p.m. of hardness as } CaCO_3 = \frac{\text{Ml. of soap} \times 0.93 \times 1{,}000}{\text{Ml. of sample}}$$

Large concentrations of carbon dioxide interfere with this test--it may be reduced by aeration or eliminated by adding sodium hydroxide.

This test is only approximate--for greater accuracy use the soda-reagent method.

LABORATORY

CHEMICAL

Residual Chlorine - Add 1 ml. ortho-tolidine reagent to 100 ml of the water sample. While the color is developing--5 to 15 minutes--the sample should not be exposed to direct sunlight or preferably it should be kept in darkness. When the deepest color is reached comparison should be made with the color standard.

The presence of the following substances in concentrations exceeding those given will interfere with this test; nitrites 0.3 p.p.m., and manganese 0.01.

This test will measure both the free chlorine as well as the chlorine in chloramines.

BACTERIOLOGICAL

Sterilization of Equipment - After cleansing and rinsing in clean water, sterilization of glassware may be effected by boiling or in an autoclave with steam under 15 pounds pressure for 15 minutes. It is also satisfactory to dry heat in an oven for at least 1 hour at 160°F or 71°C--heating over 190°F or 88°C will destroy cotton plugs and paper wrappings.

Chemical sterilization may be effected by washing glassware with 2% to 5% cresol solution.

Media - Dehydrated or powdered media is prefered on account of the ease in preparing it--the simple addition of distilled water and its uniformity. Its added cost will be compensated for be the time saved.

Dry Media are made by:

Difco Laboratories, Detroit, Michigan, U.S.A.
Baltimore Biological Laboratory, 432 N. Calvert, Balto, Md.

The media used for the coli-aerogenes tests are: lactose, peptone broth, and eosin-methylene blue agar (or Endo's media.)

SAMPLING

Water sampling for bacteriological tests should be taken in glass, stoppered sterilized bottles--size 4 or 8 ounces.

If the laboratory test cannot be made within one hour, the bottle containing the sample should be packed in crushed ice. The iced sample should be tested within 12 hours if raw water, and within 24 hours if the water was treated.

COLI-AEROGENES TEST

Confirmed Test - The confirmed test may also be made by seeding from a lactose fermentation tube in which gas has formed to a confirmatory liquid medium--brilliant green bile broth, crystal violet lactose broth, fuschin-lactose broth, or formate-ricinoleate broth.

If these tubes develop ags after 48 hours of incubation at 37°C the test is complete and positive. If no gas appears, the test is complete and negative.

Completed Test - Routine tests are not usually carried beyond the confirmed test so the more complicated completed tests are not given here--they are explained in the laboratory manuals.

BOOKS ON WATER

WATER - GENERAL

Manual for Waterworks Operators, by various authors,
published 1938 by Bureau of Sanitary Engineering, Texas State Department of Health, Austin, Texas, price $2.50

Water Supply & Treatment, by Charles P. Hoover,
published 1936 by National Lime Association, Washington, D.C. price $1.00

Water Treatment & Purification, by William J. Ryan,
published 1937 by McGraw-Hill Book Co., New York State, price $2.50

Water Supply Control, By Charles R. Cox
published 1935 by Division of Sanitation, New York State, Department of Health, Albany, New York, price $.50.

Water Supply Engineering, by Babbitt and Doland.
published 1939, 3rd edition, by McGraw-Hill Book Co. N.Y. price $6.00

Water Supply & Sewage, by E.W. Steel,
published 1936 by McGraw-Hill Book Co., N. Y. price $5.00

Water Supply, by W. A. Hardenbergh
published 1938 by Internation Texbook Co., Scranton, Pa. price $2.30

Rural Water Supply & Sanitation, by F. B. Wright
published 1939 by John Wiley & Sons, 440 - 4th Ave, N. Y. price $2.50.

Limnology, by P.S. Welch,
published 1935, by McGraw-Hill Book Co., N. Y. price $5.00

WATER - HYDRAULICS

The Flow of Water, by Williams
published 1935 by the Sherwood Press, Box 552, Edgewater Branch, Cleveland, Ohio. price $4.00

Handbook of Water Control
published 1937 by Armco Internation Corp., Middletown, Ohio.

Handbook of Culvert & Drainage Practice
published 1938 by Armoco International Corp. Middletown, Ohio, price $3.00.

BOOKS ON WATER

WATER - HYDRAULICS

Hydraulic Tables, by G. S. Williams & Allen Hazen
published 1937 by John Wiley & Sons, New York, price $2.00

Introduction to the Microbiology of Water & Sewage, by
P.L. Gainey, published 1939 by Burgess Publishing Co.
426 S. 6th street, Minn. Minn., price $3.00

Handbook of Hydraulics, by H. W. King
published 1939, 3rd edition, by McGraw-Hill Book Co., N. Y.
price $4.00

WATER - BIOLOGY

Bacteriology of Water, by S. Prescott & C. E. A. Wislow,
5th edition published 1931 by John Wiley & Sons, N. Y.
price $2.50

A Guide to the Study of Fresh Water Biology, by Needham &
Needham, published 1938 by Comstock Publishing Co. New York.
price $1.00

The Life of Inland Waters, by Needham & Lloyd,
published 1937 by Comstock Publishing Co. N. Y.
price $3.00

Fresh Water Algae of the U.S. by Gilbert M. Smith,
published by McGraw-Hill Book Co., N. Y. 1933, price $6.00

Fresh Water Biology, by H. B. Ward & G. C. Whipple
published by John Wiley & Sons, N. Y. 1918, $7.00

The Algae and Their Life Relations, by Tilden,
published 1935 by University of Minnesota, Minneapolis
price $5.00

Microscopy of Drinking Water, by Whipple.
reprinted 1938 by John Wiley & Sons, N. Y. price $7.00

WATER - LABORATORY MANUALS

Standard Methods for the Examination of Water & Sewage, by
various authors, published 1936 by American Public Health
Association, 50 West 50th Street, N. Y. price $2.50. This
is the U. S. Official manual of physical, chemical, and
bacteriological technique.

BOOKS ON WATER

WATER - LABORATORY MANUALS

Laboratory Manual for Chemical & Bacteriological Analysis of Water & Sewage, by Theroux, Eldridge, & Mallman, published 1936 by McGraw-Hill Book Co., N. Y. price $2.50 A compact, simplified, laboratory manual.

Water Purification, by C. R. Cox. published 1939 by Case - Sheppard - Mann Publishing Corp. 24 West 40th Street, N. Y. price $1.00.

WATER - CHEMISTRY

pH and Its Practical Application, by La Motte, Kenny, & Reed, published 1932 by the Williams & Wilkins, Co., Baltimore Md. price $3.50

Determination of Hydrogen Ions, by Clark and Luks, 2nd edition published by Williams & Wilkinson, Baltimore, Md. Contains pH color charts which may be ordered separately for $1.00 per set. Title, Color chart of indicators, 1921

Hypo-Chlorination of Water, by Walter L. Savell, published by Mathieson Alkali Works, Inc., 250 Park Ave. N. Y.

Disinfection & Sterilization, by E. C. McCulloch, Philadelphia, Lea, and Febige, published 1936, price $5.50

WATER - SPECIAL

Water Purification Control, by Edward S. Hopkins published 1936 by the Williams & Wilkins Co. Baltimore, Md. price $1.75. A practical manual for water treatment plant operators.

Ground Water, by C. F. Tolman, published by McGraw-Hill Book Co , 576 pages, price $6.00

Elimination of Taste & Odor in Water, by John R. Baylis, published 1935 by McGraw-Hill Book Co., N. Y., price $5.00

Corrosion, Causes and Prevention, by Dr. Frank N. Speller published by McGraw-Hill Book Co., N. Y. 2nd ed. 1935, $7.00

Cross Connections in Water and Plumbing Supply Systems, published 1934 by University of Wisconsin, Madison, Wis. price $.25

MAGAZINES ON WATER

Journal of the American Water Works Association, monthly.

Water Works and Sewerage, 330 South Wells St. Chicago, Ill. monthly, subscription \$2.00 per year in U. S. and Canada, \$3.00 for other countries.

Water Works Engineering, fortnightly, \$2.00 per year.

Journal of the New England Water Works Association. \$6.00 to non-members.

Southwest Water Works Journal, monthly \$1.00 controlled free distribution.

PORTUGUESE MAGAZINES

Boletim Da Repartica De Aguas E Esgotas, published quarterly by Reparticao de Aguas e Esgotas, rua Riachuelo No .25-1º andar, Sao Paulo, Brazil.

PORTUGUESE BOOKS

Saneamento E Urbanismo, by Lincoln Contintino, published by Cama & Campania, Caixa Postal 1813, Bello Horisonte, Minas Gerais, Brazil.

Regulamento Da Directoria De Saude Publica Do Parana (State Sanitary Code) published 1938 by Empresa Grafica Parananse, Curitiba, Parana, Brazil

SPANISH MAGAZINES

Buletin de Obras Publicas De La Republica Argentina, published monthly by Obras Publicas de la Republica Argentina, Florida 32, Buenos Aires, Argentina.

La Revista Sanitaria - Organo Oficial del Centro Constructores de Obras Sanitarias. - Tio Bamba 879, Buenos Aires.

Boletin de Obras Sanitarias de la Nacion, Published monthly by Obras Sanitarias de la Nacion, Charcas 1840, Buenos Aires, Argentina, yearly subscription 5.00 pesos nacional en Argentina, 5.00 pesos oro in other countries.

SPANISH BOOKS

Sobre Saneamento de Poblaciones, por Ing. Juan C. Alteberro, published 1934 by Ministerio de Obras Publicas, Montevideo, Uruguay.

Tratado de Hidraulica, por el Prof. Phillip Forcheimer, published 1935 by Editorial Labor, S. A. Bacelona, Madrid, Buenos Aires, Rio de Janeiro.

WEIGHTS & MEASURES - METRIC & ENGLISH

Length

1 inch = 2.54 centimeters
1 foot = 0.3048 meters
1 yard = 0.9144 meters
1 mile = 1.60935 kilometers = 5,280 feet.

1 centimeter = 0.3937 inches
1 meter = 3.2808 feet = 1.0936 yards - 39.37 inches
1 kilometer = 0.62137 miles = 3,280.8

Area

1 square inch = 6.4514 square centimeters
1 square foot = 0.0929 square meters
1 acre = 0.4047 hectares = 4046.9 square meters = 43,560 square feet.
1 square mile = 2.59 square kilometers = 640 acres

1 square centimeter = 0.155 square inches
1 square meter = 10.764 square feet = 1.196 square yards
1 hectare = 2.471 acres
1 square kilometer = 0.3861 square miles

Volume

1 cubic inch = 0.01639 liters - 16.3872 cubic centimeters
1 cubic foot = 0.02832 cubic meters =28.316 liters = 7.48 U. S. Gallons
1 acre Foot = 1233.49 cubic meters = 325.815 gallons = 43,560 cubic feet.

1 cubic centimeter = 0.06102 cubic inches.
1 cubic meter = 35.315 cubic feet = 264.2 U. S. Gallons.
1 liter = 61.025 cubic inches = 0.035 cubic feet = 0.2642 U. S. Gallons

Capacity - Liquid

1 dram = 3.6966 mililiters = 0.2256 cubic inches.
1 ounce = 2.9573 mililiters = 1.8047 cubic inches
1 pint - 0.4732 liters
1 quart = 0.9463 liters = 57.75 cubic inches
1 U. S. Gallon = 3.78533 liters = ~~213~~ cubic inches = 0.1337 cubic feet 231

WEIGHTS & MEASURES - ENGLISH & METRIC

Capacity - Liquid

1 imperical gallon = 0.83267 U. S. Gallons
1 mililiter = 0.2705 drams
1 liter = 1.0567 quarts = 0.2642 gallons = 61.02 cubic inches
1 cubic meter = 264.17 U. S. Gallons = 35.315 cubic feet.
1

Weight

1 grain = 0.0648 grams = 64.8 milligrams
1 ounce, Troy = 31.103 grams
1 ounce, avoidupois = 28.350 grams
1 pound, avoidupois = 0.54536 kilograms = 435.6 grams = 7,000 grains.
1 short ton = 0.9072 metric tons = 2,000 pounds

1 gram = 15.4324 grains = 0.0353 ounce avoidupois.
1 kilogram = 2.20462 pounds, avoidpois.
1 metric ton = 1.1023 short tons = 1.016 long tons

Weight of Water

1 cubic inch = .03617 pounds
1 cubic foot = 62.4 pounds
1 U. S. Gallon = 8.355 pounds
1 short ton = 268.8 U. S. Gallons

1 pound = 0.1198 U. S. Gallons = 27.68 cubic inches
1 liter = 1 kilogram = 2.20462 pounds
1 cubic meter = 1 metric ton = 2204.62 pounds

WEIGHTS & MEASURES - METRIC & ENGLISH

Concentration

1 p.p.m. = 1 miligram per liter = 0.0584 grains per U.S. Gallon
= 0.07016 grains per Imperical Gallon
= 8.354 pounds per million gallons
1 pound per miligram = 0.1199 p.p.m.
1 grain per U. S. Gallon = 17.118 p.p.m. = 142.86 pounds per million U. S. Gallons
1 grain per Imperical gallon = 14.254 p.p.m.

Time

1 day = 24 hours = 1440 minutes = 86,400 seconds.

Volume X Time

1 gallon per second = 3.7854 hours per second = 327.05856 cubic meters per day, 11,549,952 cubic feet per day.

1 gallon per minute = 0.06308 liters per second = 8.0208 cubic feet per hour = 5451.976 liters per day.

1 cubic foot per second = 7.4805 U.S. Gallons per second = 694 gallons per minute = 28.317 pounds per second = 646,315.2 U.S. Gallons per day = 2466.689 cubic meters per day.

1 cubic meter per sedond = 264.17 U.S. Gallons per second = 35.315 cubic meters per second = 22,824,288 U.S. Gallons per day = 86,400 cubic meters per day.

1 cubic meter per minute = 380,404.8 U. S. Gallons per day - 1440 cubic meters per day.

1 million gallons daily = 1.547 cubic feet per second = 694 gallons per minute.

Pressure

1 kilogram per square cemtimeter = 14.2233 pounds per square inch = 1.0241 short ton = 0.9678 atmospheres
1 kilogram per square meter = 0.2048 pounds per square foot.
1 atmosphere = 14.697 pounds per square inch = 1.0333 kilograms per square centimeter.

1 foot column of water = 0.43315 pounds per square inch = 0.030453 kilograms per square cemtimeter.
1 meter column of water = 1.4211 pounds per square inch = 0.99913 kilograms per square eentimeter.
1 pound per square inch = 2.3087 feet or 0.70368 meter column of water.

WEIGHTS & MEASURES - METRIC & ENGLISH

Pressure

1 kilogram per square centimeter = 32.839 feet or 10.009 meters per column of water.

1 atmosphere -- 33.929 feet or 10.342 meters per column of water.

Temperature – Temperature C = $\frac{\text{Temp. F} - 32}{1.8}$ and Temperature F = 1.8 Temperature C X 32

Degrees C	F	Degrees C	F	Degrees C	F	Degrees C.	F.
0	32	10	50.0	19	67.2	28	82.4
1	33.8	11	51.8	20	68.0	29	84.2
2	35.6	12	53.6	21	69.8	30	86.0
3	37.4	13	55.4	22	71.6	31	87.8
4	39.2	14	57.2	23	73.4	32	89.6
5	41.0	15	59.0	24	75.2	33	91.4
6	42.8	16	61.8	25	77.0	34	93.2
7	44.6	17	63.6	26	78.8	35	95.0
8	46.4	18	65.4	27	80.6		
9	48.2						