WATER QUALITY RELATIONSHIPS FOR URBAN AND INDUSTRIAL USES

Haskell R. Street[1]/

Quality water has not been defined in simple terms in spite of all that has been said and written about it. There are many classes of water users, each with specific requirements and quite often the characteristics that make a particular water objectionable to one group are unimportant or even desirable to other groups. Perhaps there is no simple definition for the term because it means a different thing to different people. To the sanitary engineer it has one connotation, to the industrial engineer it means something else and to the agriculturist it has still another meaning.

Water quality specifications for cooling the condensers in an electric generating plant or in the manufacture of steel differ greatly from those required for bottling soft drinks, brewing beer or air conditioning. Water that is satisfactory for agriculture is far from adequate for domestic use or for the production of steam. Fortunately, most water users have some flexibility in the specifications which determine the suitability of a water for their particular requirement. For such users, the average domestic quality water will suffice with a minimum amount of treatment. For those uses that have restrictive specifications, it is necessary that extensive treatment be given to the water and close control be maintained over the quality. Boiler feed water for the production of steam to be used in high pressure boilers is an example of a water requiring special treatment. Water required in the manufacture of pharmaceuticals is another example.

The home owner considers water to be of good quality when it is clear, free of odors, tastes or colors, non-staining, cool, safe to drink and reasonably soft. In recent years, with the advent of so many water operated home appliances the domestic user is beginning to demand a few additional qualities. There are inquiries from many sources about the fluoride content, the hardness, the total mineral content, and the sodium content.

One thing is quite certain--water users of all classes are becoming more conscious of water quality if one can judge by the number of inquiries that are received in our offices. These inquiries are from engineers, consultants, business people, motel owners, and most of all, from school children. The ringing telephone quite often heralds some slight change in the quality of water being delivered to the customers. Raymond J. Faust, Executive Secretary of the American Water Works Association, says

1/ Manager, Production and Treatment
El Paso Water Utilities
El Paso, Texas

"the people want water that meets the needs of the home much more closely than do our present supplies."

Processing water in a public water utility to meet the needs of the many classes of users is quite impractical. As a result each public utility adopts a set of quality specifications, influenced in some degree by the quality of raw water available for treatment, and attempts to maintain the same quality at all times through constant control methods. The water produced under these conditions should meet the needs of all domestic users, should be safe, sparkling clear and free of taste and odor. It should conform to the U.S. P.H.S. Drinking Water Standards in every respect and far exceed them in most respects. Users that require a water of different characteristics must then supply any additional treatment needed.

Perhaps most of you are not aware that the earliest water system in this country was for the purpose of providing water for fire fighting. No quality controls were necessary for this type of water. As the community grew and the system expanded beyond the one street it originally served, the demand for a water suitable for human use caused the upgrading of the quality of water in the system. This has been the pattern followed through the years. The demands of the customers have resulted in the improvements in quality and in close quality controls. This must continue to be the pattern and when the customers require a higher quality of water and demand that it be furnished, the demand will be met.

Water has a number of characteristics that are quite interesting, some of which are quite beneficial to man and some of which are not so advantageous. As we all know, water travels in a cycle. Nature is constantly freeing water of all its impurities and transporting it from low places to higher elevations and releasing it to flow again toward the low places. It is fortunate for mankind that water is released, free of all impurities, at higher levels. This makes water available to man all over the earth. Unfortunately, water is an excellent solvent and picks up various minerals as it moves through and over the earth's crust. Because water is moving toward the low places, man takes advantage of this fact and puts his unwanted wastes in the stream to be carried along. These minerals and wastes constitute the problems we have in using water.

Fortunately, the water is not permanently affected by any of these minerals it has dissolved or the man made wastes that have been discharged into it. They can all be separated from the water by appropriate methods. Some of the materials can be separated easily and at very little cost. Others can be separated only by use of more expensive methods. From this over-simplified version of the water cycle, it is obvious that the cost of water treatment must be balanced against the desire for higher quality in the water we use.

In the early days there was no knowledge of the germ theory of disease and the quality of the water was judged solely by the physical qualities. With the explanation of the germ theory and the introduction of such devices as the slow sand filter, and later, the rapid sand filter, the sanitary quality of water was improved. Use of coagulating chemicals, and later, the introduction of chlorine as a disinfectant made possible the production of drinking water that was practically free of turbidity and free of harmful bacteria. The health authorities and the water supply agencies have been diligent in their efforts to protect the health of the public. The extent to which they have succeeded is demonstrated by the drastic reduction in water borne diseases over the past 50 years.

In a large measure, the establishment of the U.S. P.H.S. Drinking Water Standards has had a great deal to do with the steady improvement in the quality and safety of the public water supplies. In the U.S. one can drink from a public water fountain anywhere in the country with no fear for the safety of the water. There are very few other countries in the world where this is true.

The drinking water standards were first promulgated in 1914 to protect the health of the traveling public. These standards were not obligatory for use by municipally or privately owned water systems unless they served as watering points for railroads, ships or passenger carriers of some type. The standards have been revised from time to time as changes in the environment have brought about the need for change. Major revisions were made in 1927, in 1942 and again in 1961-62.

The revision of the drinking water standards in 1961-62 was accomplished through the combined efforts of representatives of fifteen major organizations interested in the health and welfare of the public, the quality of water in the streams and the quality of water served to the public. Included in the group were such organizations as the U. S. Public Health Service, the American Water Works Association, and Water Pollution Control Association and the National Committee on Radiation.

The drinking water standards are generally accepted as the minimum standards throughout the U.S. A water supply will, in most cases, far exceed the quality required by these limiting criteria. Water supplies that exceed the limits in more than two or three of the categories are considered unsatisfactory. It has been stated that as many as 1,000 to 1,500 water supplies in the U.S. could be classed as unsatisfactory on this basis.

The criteria are listed in two groupings. Those substances considered toxic and known to have harmful effects upon humans are listed in one group. If a water supply contains one of these minerals in excess of the limiting value, the supply should be rejected as unsatisfactory.

Another group includes substances that are undesirable above the limits shown. Supplies containing one or more of these substances in amounts greater than listed are rated as undesirable.

The substances that are objectionable in drinking water and their limiting value are listed below in the two groups mentioned.

HARMFUL SUBSTANCES

Substance	Concentration-ppm
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	0.01
Chromium (Cr^{+6})	0.05
Cyanide (Cn)	0.2
Fluoride (F)	Varies with temp
Lead (Pb)	0.05
Selenium (Se)	0.01
Silver (Ag)	0.05

UNDESIRABLE SUBSTANCES

Substance	Concentration-ppm
Alkyl benzine sulfonate (ABS)	0.5
Arsenic (AS)	0.01
Chloride (Cl)	250.
Carbon Chloroform Extract (CCE)	0.2
Cyanide (Cn)	0.01
Fluoride (F)	0.4-1.2 Varies w/ temp
Iron (Fe)	0.3
Manganese (Mn)	0.05
Nitrate (NO_3)	45.
Phenols	0.001
Sulfate (SO_4)	250.
Total Dissolved Solids	500.
Zinc (Zn)	5.0

Both industrial and community wastes have gone into our streams in the past with little or, at best only partial treatment. No one seemed to feel that this was wrong and full advantage was taken of the diluting effect and assimilative capacity of the stream to hold down capital investments as well as operating costs. In most instances this caused no particular problem until the volume of wastes grew to such proportions that the streams could not assimilate the load. Now, the load of wastes being discharged into our waterways has become so great that many of the streams are virtually open sewers and have no value for any other use.

An alarmed Congress passed the Water Quality Act in 1965 establishing a Water Pollution Control Agency and charged the Agency with the responsiblity for control and abatement of stream pollution. The federal agency has requested each state to prepare suitable stream standards that will prevent further deterioration of the quality in the streams. It will be very interesting to observe the manner in which the Water Pollution Control Agency, the State Pollution Control agencies and local authorities cooperate to bring about the abatement of pollution.

Not only are the streams being overloaded but many new types of wastes are being introduced into the streams. Most of them are of industrial origin but some originate in the domestic wastes. Some are known to be dangerous to human beings, while others are still on the doubtful list. Not enough research work has been done to determine the effect of long time consumption of water containing the substance in question.

Organic compounds constitute the greater portion of these new contaminants. They come from chemicals used as insecticides, fertilizers, detergents, paints, lubricants, automotive fuels, and many others. The identification and detection of these compounds is extremely difficult and in many instances no method is known at this time for positive identification. It is possible for the well equipped and well staffed research laboratories to identify most of them but the average water utility laboratory makes no attempt to detect or measure these compounds. Fortunately, it is possible to get assistance in this work from federal and state agency laboratories for analyses of quarterly or semi-annual samples.

The concentrations involved are very small, being in the order of a few parts per million down to a part per billion. While this may seem like an insignificant quantity to those of us accustomed to thinking in terms of tons per acre foot or grains per gallon, some of these contaminants have caused sizeable fish kills in concentrations of less than one ppb.

The literature does not report any direct or physiological damage to human beings as a result of the consumption of water containing present day low concentrations of these organic pollutants. It is known that they cause objectionable odors and tastes, foaming, high clorine demands, and fouling of ion-exchange media. We have no knowledge yet of the long term effect of consuming water with one or more of these contaminants. Research projects are in progress on this subject as well as many other aspects of the effect of the organic compounds upon human beings.

The method used to extract the organic compounds from the water is based upon the tremendous adsorptive power of activated carbon. Large quantities of water are filtered through carbon and the carbon is then subjected to chloroform to extract those substances soluble in chloroform. Evaporation of the chloroform leaves the extracted materials for possible identification. The method was developed by U.S. P.H.S. research technicians in connection with their water quality network project. More than 150 sampling points covering all the major rivers in the U.S. are taking part in the project and send monthly samples to the Taft Memorial Center at Cincinnati. Quarterly reports of the results of the program are distributed to all participants. Interested persons or agencies can get the reports by requesting to be placed on the mailing lists.

Some of the compounds that have been detected and identified include DDT, Aldrin, orthonitrochlorobenzene, tetralin, napthalene, chloroethyl ether, acetophenone, dephenyl ether, pyridine, nitriles, aldehydes, ketones and alcohols. To date no safe limit for any of these substances has been established.

After chloroform extraction the carbon is then treated with ethyl alcohol and additional organic compounds may be extracted. Frequently there remains a portion of the extracted material from one or both extractions that cannot be identified by known methods. Obviously there must be some concern about the presence of unidentified substances. Much work needs to be done in the development of methods to identify and test these unknown portions of material.

The increased use of insecticides, herbicides and pesticides is another cause for concern. There are over 9,000 compounds of this type manufactured and more than one and one-half billion pounds are produced annually. Some 50,000,000 acres are sprayed each year by airplanes. Wind and air drift causes some of the compounds to enter streams and lakes. Runoff carries more into the waterways. Some of these compounds, such as DDT, are known to accumulate in the body. DDT has been isolated from the bodies of animals in very remote parts of the earth.

The water plant operator and the health authorities need to know more about the effect on the quality of the water when it receives these and other agricultural chemicals. Investigations have shown little to cause concern to date. What we need to know is the effect of increasing concentrations.

Infectious hepatitis is the only virus that is definitely known to be transmitted by means of drinking water. In a few epidemic outbreaks of poliomyelitis, water has been suspected, but not proven, of being the carrier. In outbreaks of other enteric virus diseases where the exact cause was not determined it was stated that water could have been the carrier, along with several other common vectors. Epidemiologists have failed to implicate water as the carrier in these virus disease outbreaks but there are those who continue to point to the possibility.

Investigation has shown that in every case where water was suspected of being the carrier, the public water supply did not conform to the U.S. P.H.S. Drinking Water Bacteriologic Standards. These studies also show that where filter effluent turbidities are kept below 0.2 units consistently and a chlorine residual of one ppm is maintained in the clear water, the incidence of virus disease is very low. On the basis of experience and the evidence obtained in these studies, it seems reasonably safe to say that outbreaks of water borne infectious hepatitis are unlikely where the water conforms with the drinking water standards. The principal concern of the health authorities is that the level of virus pollution may increase to the point that present-day methods are not adequate to prevent the viruses from passing through the plant. Primary sewage treatment does not significantly reduce the virus concentration and the activated sludge process removes only about 90% of the viruses placed in the raw sewage in field experiments.

A few years back there was much written about the effect of fallout of radioactive particles. Research since that time indicates that radioactive material in drinking water can be harmful. Strontium 90 and Radium 226 are both deposited in the bone structure, interfere with the production of blood cells and cause leukemia. The three radio nucleides known to exist in water include the two mentioned and gross beta particles which include the other radioactive substances.

Samples have been collected from the Rio Grande at El Paso for about eight years for the water quality network program. You may be interested to know that the reports on radioactive substances, the organic chemicals and other harmful substances in the water are shown to be quite low in concentration and much below the recommended levels.

Having discussed briefly the nature of the many new contaminants, let us turn to the water treatment plant and see how well it functions in the removal of these impurities. Water plants are being built today on much the same principles as 30 years ago. Coagulation and flocculation, sedimentation, filtration and chlorination provide the basic stages of treatment and even the chemicals and the basin sizes are about the same. The organic compounds are not removed by these processes. Chlorination has little effect upon them. They cannot be flocculated and settled out. The only method that has been found to be effective is that of adsorbing the compounds on activated charcoal particles. Research indicates that an effective method of producing a water relatively free of the insecticides, the chlorinated hydrocarbon and the organo-phosphate materials as well as the viruses is to pass the filtered water through a deep bed of activated charcoal. Such a procedure would require a change in the design of plants. An alternate proposal is to replace the top portion of the filter media with granulated activated charcoal.

There is a great need for improvement in the design and in the operation of water treatment plants to meet the challenge imposed by the presence of new pollutants in the raw water.

Why has the philosophy regarding the treatment of water remained essentially unchanged so long? There are at least three groups involved in the building of a water plant. The municipality engages a design engineer to build a plant. The engineer prepares plans which the health department officials must approve prior to construction. All three of these groups must share the blame for the delay in accepting new ideas. The municipality does not want to risk large capital outlays on untried procedures and methods. The health department official, feeling all the responsibility for a mistake in judgment will fall back on his shoulders, takes a very conservative attitude and approves only what he knows will work. The design engineer, the only one of the three with enough background and experience to properly evaluate new methods of treatment, is reluctant to take the time and incur the expense to research the new proposals. Of the three, the design engineer is most fitted by training, experience and knowledge, to be in a position to advance the art of water treatment.

Ironically, the responsibility of the health department officials for the health of the public may eventually be the very thing that will force these officials out of their conservative position. To maintain their present attitude is certainly not entirely in the interests of public health.

The A.W.W.A. endorses the U. S. P.H.S. Drinking Water Standards and has participated in the revisions of these standards. Nevertheless, there is a considerable number of A.W.W.A. members who feel that minimum standards are not sufficient to provide a stimulus that will cause the water utility operators to strive for a higher quality product. They feel there should be a set of criteria for drinking water of sufficient excellence that few, if any, waters could qualify as this "ideal" water. There should be a goal to attain.

There are over 20,000 water systems in the U.S., 90% of which serve communities of less than 10,000 population, and 80% of them serve less than 5,000 people each. It is not likely that all these systems have the facilities and the personnel to properly safeguard the water being served. It is the plan of the A.W.W.A. Task Group 2225M to devise a plan of rating each water system. The basis for rating would be the quality of the water, the facilities available and the qualifications and abilities of the personnel. The rating plan is designed to encourage the updating of facilities, the training of personnel and the improvement of quality of water.

The criteria are set up as guides or goals and are not intended as standards. Some of the criteria are limited at present by the sensitivity of the methods used in testing. Some will change as more information becomes available relating to the physiological effects of trace elements after long-time consumption.

The criteria for the "ideal" water are listed below and the limit for each is given in ppm except where otherwise indicated.

IDEAL WATER QUALITY - CHARACTERISTICS AND CONCENTRATIONS

Physical Characteristics	Maximum in Ideal Water
Turbidity	Less than 0.1 unit
Non-filterable residue	0.1
Microscopic & Nuisance Organisms	None
Color (true)	3 units
Taste	None
Odor	None
Chemical Characteristics (Toxic)	
Lead (Pb)	0.03
Barium (Ba)	0.5
Arsenic (As)	0.01
Cyanide (Cn)	0.01
Silver (Ag)	0.02
Selenium (Se)	0.01
Cadmium (Cd)	0.01
Chromium (Cr^{+6})	0.01
Insecticides, Total	None
Chemical Characteristics (Non-toxic)	
Aluminum (Al)	0.05
Iron (Fe)	0.05
Manganese (Mn)	0.01
Copper (Cu)	0.2
Zinc (Zn)	1.0
Nitrate - Inorganic (N)	5.0
Filterable Residue	200.0
Phenolic Compounds (as phenol)	0.0005
Chloroform soluble - Carbon Absorption	0.04
Alcohol soluble - Carbon Absorption	0.10
ABS	0.20
Hardness (as $CaCO^3$)	80.0
Coliform Organisms	Not more than one/1
Radioactive materials	
Grosbeta activity	100 pc/1
Radium	3 pc/1
Strontium	5 pc/1

In order to supplement existing supplies some communities may find it advantageous to remove excess salt from brackish waters rather than transport a better quality water long distances. There are several processes available to remove this excess mineral.

The Office of Saline Water is a government agency that is directing research and operating pilot plants to test several methods of converting saline waters to usable drinking water. The methods being tested include various versions of evaporating the water to separate it from the salts; freezing water and evaporation under partial vacuum. To date they have been quite successful in producing a good quality water but the cost of operations have been quite high. The costs have been dropping as experience has helped solve some of the problems but they still are quite high when compared with present-day prices for treated water from other methods. The lowest cost figures obtainable have ranged from $0.80 to $1.00 per 1,000 gallons as compared to the cost of about $0.10 per 1,000 gallons for a treated surface water and about one-third that for pumping well water

The use of electrically charged membranes to separate mineral salts from water is a patented process. Several smaller installations are in successful use, one being the plant at Buckeye, Arizona. Water is passed between layers of thin membrane material which bear a DC charge. The metallic ions in the water are attracted to the membrane that possesses an electrical charge opposite its own. Many of these ions pass through the membrane causing the water in alternate channels to be supercharged with salt particles and the remaining channels to have water with reduced mineral salts. The water costs about $0.40 to $0.60 per 1,000 gallons, depending upon electrical costs and membrane maintenance figures, and upon the amount of salt reduction required.

In the Industrial Engineering Journal an ion exchange process was reported which uses lime and sulphuric acid as regenerants to reduce 2,300 ppm solids to 500 ppm. Operating costs were stated to be in the order of $0.11 to $0.22 per 1,000 gallons with the cost of a one million gallon per day plant estimated at $300,000.

One of the more promising processes uses the ion exchange method. Instead of a fixed bed of resin, a closed loop with quick operating valves has been devised that permits continuous operation. Part of the loop contains a portion of the resin that is treating water to remove salts. Another portion of the loop contains resin that is being regenerated with an appropriate regenerant. A third portion of the loop is used to wash the regenerated resin. On a pre-arranged time schedule, the valves open, the resin is hydraulically shifted from one portion of the loop to the next and in less than a minute the flow of water is being treated with freshly regenerated resin. A one million gallon per day plant can be erected in a day or two after delivery and occupies a space of about 10' by 10'. Everything is automatically timed and chemical costs are greatly reduced over other ion exchange units. The cost of treating a 2,000 ppm brackish water to produce a 500 ppm quality water is estimated to be in the order of $0.10 per 1,000 gallons.

One of the newest processes proposed for reducing salt solids in water is called reverse osmosis. In the process of osmosis, if two solutions are separated by a semipermeable membrane, the liquid from the more dilute solution moves through the membrane into the more concentrated solution. The differential in pressure developed between the two solutions is called osmotic pressure. The reverse osmosis process consists in the application of sufficient pressure on a saline liquid to force it through a membrane. The liquid which passes through the membrane contains considerably less dissolved salt. Inasmuch as no change in form is required as in the standard saline conversion technique, it has promise of being much less expensive. Its success depends primarily upon the development of a suitable membrane.

In summary, it would appear that two opposing trends are involved in the problem of maintaining and improving the level of quality in our drinking water. The demand for a water which must steadily improve in quality is being made more difficult by the increase in population, the increase in pollution and rapid change in the kinds of contaminants. The problem of supplying a potable, safe and desirable water for domestic and industrial users has become a problem for both the waste treatment agencies and the water treatment operators. The responsibilities of the waste treatment plant operators must be extended and correlated with those of the water utility operator in order that the whole job of water treatment can be effectively accomplished.

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