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Invited Address - The Role of Water Quality

Gordon E. McCallum

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It is a real pleasure to be back on this campus and particularly at this time of year. It is certainly an honor and a privilege to speak before this distinguished gathering.

A portion of your program has dealt with the staggering complexities which scientists face in getting man safely into outer space and back to earth. My discussion will point up another complex challenge in maintaining an earthly resource affecting the health and well-being of all mankind. Only this week a spokesman at the National Watershed Congress in Washington stated that wise use of our water resource can mean the difference between success and failure of such new ventures as the probing of outer space.

We are beginning to realize that we must consider water quality in its broadest aspects. Problems of the future about which we have talked for years are now problems of the present for they are already with us. Our most pressing need is to recognize them.

Water—its use, misuse, and reuse—is today a major national issue. Our population growth of more than 40 percent in the last 25 years is an ominous indicator. The periodic upward revision of predictions toward the 260 million range by 1980 is a clear warning. Within the next 20 years, three-fourths of our population will live in metropolitan centers. Already developing are metropolitan-industrial complexes which will extend unbroken for hundreds of miles along major waterways. What effect will these developments have on the quality of our waters?

Water is withdrawn for use over and over again for many purposes as it flows to the sea. In the United States we are now using some 300 billion gallons daily. By 1980, dependable supplies can be developed by impoundments and other measures to a maximum of about 515 billion gallons per day. Predictions of a 600 billion gallon daily use by that time give rise to real concern for our daily requirements will then exceed capturable supplies by some 85 billion gallons. This, then, is the indicated gross water reuse just one generation hence.

[1]Address presented as a part of the symposium, "*Present and Future Availability of Water.*"

[2]Chief, Division of Water Supply and Pollution Control, Bureau of State Services, Public Health Service, U. S. Department of Health, Education, and Welfare, Washington, D. C.

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Many river basins are already reusing their available water several times. Waters of the Ohio, for example, during periods of low flow are used 3.7 times before they join the Mississippi.

The important point is that virtually every use of water, whether for cooling an industrial process or carrying away land drainage, impairs its quality to some extent. This in turn reduces its value to the next user. The expanding need for water, therefore, emphasizes the necessity for preserving its quality, as demand rapidly approaches a final limit of supply.

More and more we are finding that water pollution is affected by new factors. In the early days we were dealing largely with local nuisance and public health problems. The older problems of pollution resulting from man's body wastes and from sewage-like industrial wastes have for the most part been well defined. Effective solutions were developed for many of these wastes and put in practice.

Along with the older problems attendant upon population increase, postwar technology has introduced into man's environment many new types of pollutants. Among those with which we are most concerned are synthetic organic chemicals and radioactive materials. Equally involved in today's water pollution problems are the unknowns of the many viruses, such as hepatitis and other disease-producing organisms.

These newer wastes present problems which are much more subtle and difficult than the old ones. A water sparkling and crystal clear may contain toxic substances. It may contain the nutrients which sustain the objectionable green algal scums that are increasingly destroying our recreational waters. It may be detrimental to fish and aquatic life. It may produce taste and odor in drinking water. The challenge to research not only to control but even to identify these newer substances is formidable. Many scientific disciplines will be required in the solution of these problems.

Water pollution may be defined as the adding to water of any substance, or the changing of the water's physical characteristics in such manner as to interfere with its further use. The Public Health Service, in reporting to the Senate Select Committee on National Water Resources, recently classified pollution in the following general categories:

1. *Sewage and Other Oxygen Demanding Wastes,* the traditional putrescible organic substances which come mainly from domestic sewage and from such industries as food processing plants.

2. *Infectious Agents,* the disease-causing organisms which are carried into streams, lakes, and ground water reservoirs by wastes from

municipalities, sanatoria, and certain industries, such as tanning and slaughtering plants.

3. *Plant Nutrients,* mineral substances (primarily compounds of nitrogen and phosphorus) which in solution serve as food for aquatic plant life such as algae and water weeds, which not only in themselves interfere with water use but, as they die and decay, cause secondary oxygen-demanding pollution, tastes, and odors.

4. *Organic Chemicals,* including such substances as household detergents and the new insecticides, pesticides, and weed killers which are now being increasingly used.

5. *Dissolved Mineral and Chemical Substances* from various mining and industrial processes and land drainage. These materials range from common salt, metals, and metal compounds in solution, to acids and a wide array of manufactured chemicals.

6. *Sediments* which are primarily soils and mineral particles washed from the land by rain or floodwaters. They erode power turbines, pumping equipment, and other structures; reduce fish and shellfish populations by blanketing spawning grounds, fish nests, and food supplies; and clog water filters.

7. *Radioactive Substances* from various sources. The three major factors determining the importance of these wastes are: (a) the quantity of material, (b) the duration of the waste discharge, and (c) the degree of hazard associated with the specific radioisotopes involved.

8. *Heat* added to water used for industrial cooling processes. This has a direct detrimental effect on aquatic life by reducing the amount of oxygen that can be held in solution.

Reasonably effective treatment has been developed for only the first two of these eight classes of contaminants. The remaining six categories pose imminent threats to water quality. They increase the waste load and thus overtax the stream's assimilating capacity; with the exception of heat they are not effectively removed by treatment or, for that matter, by the processes of nature in the stream. In fact present waste treatment processes in some cases may make certain of these compounds *more* destructive to the aquatic environment.

It is interesting that the early great developments in water treatment were made by non-technical, non-scientific individuals. The primary qualification of these men was simply a strong humanitarian impulse to reduce the intolerable filth of the early 1800's—the initial period of the Industrial Revolution. Only later when the germ

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theory of disease had been developed was it determined that our great predecessors in public health had done the right things for the wrong reasons. Of this Rene du Bois in his "Mirage of Health" said:

> "In Germany the most successful health reformer of the nineteenth century was the chemist Max von Pettenkofer, also an opponent of the germ theory. Like his English contemporaries, Pettenkofer regarded hygiene as an all-embracing philosophy of life, implying that not only an abundant supply of clear water and air but also trees and flowers would contribute to the well-being of men by satisfying their aesthetic longings. He persuaded the Munich city fathers to have clean water brought in abundance from the surrounding mountains and to dilute the city sewage downstream in the Isar. With these steps the great cleaning up of Munich began and the typhoid mortality fell from 72 per million in 1880 to 14 in 1898. Munich thus became one of the healthiest of European cities, thanks to the efforts of this energetic hygienist who was entirely uninfluenced by the germ theory of disease."

Treatment of Water

Much filth in water is evident and it was early demonstrated that it could be removed by straining. Therefore, attention was naturally directed to filtration of water through beds of sand—used for the first time in 1829 for the clarification of Thames River water for London. Pasteur was not to publish his classic paper on the germ theory of disease until 28 years later. Interestingly, treatment units of this 1829 type are still employed in a number of American cities, including Washington, D. C.

With the establishment of the germ theory of disease and its application to the great waterborne epidemics of typhoid, paratyphoid, cholera, and dysentery—disinfection of public water supplies became routine in the United States. Today every major water supply in the nation employs the disinfection process. Chlorine in gaseous form or as a hypochlorite is almost universally used.

Sanitary engineers and associated scientists have gained considerable sophistication in water purification techniques. We understand the chemistry and mechanics of flocculation, sedimentation, and filtration; hardness removal; and of disinfection. But as knowledge grows, new uncertainties are beginning to trouble us. The age of chemical-nuclear expansion confronts us with new challenges—as it does so many other segments of society.

Treatment of Waste

Our predecessors learned that to have a healthful environment they must not only treat water for drinking but also treat domestic and trade wastes before discharging them to public waterways. Historically, the first objective in waste disposal was exactly that—getting the filth away. It was finally learned, however, that merely piping it to the river was not the sole answer and that downstream neighbors' health must also be protected from dangerous pollution. So the treatment of sewage became necessary.

For the most part, the art of treating wastes has not changed significantly for more than a generation. Its objectives—the removal of solids in suspension and the satisfaction of oxygen demand—remain unchanged. Even the nomenclature is unchanged and waste treatment processes are identified now, as a generation ago, as primary and secondary. The latter is often erroneously referred to as "complete" treatment.

The first step—primary treatment—is simply the mechanical removal of solids. Secondary treatment employs biological processes which further reduce the solids and remove 70-90 percent of oxygen demand of the waste.

Secondary treatment of waste is an aerobic process in which microbial communities utilize organic substances as nutrients. The rate of solids stabilization by these organisms is roughly equivalent to their rate of oxygen utilization. The stabilization phenomena in the secondary processes are actually an intensified form of those occurring in natural stream purification.

Two types of environment are used in biological treatment: (1) rock surfaces on which microflora attach themselves, and (2) aerated chambers in which microbiological flocs are held in suspension.

The complex nature of microbial activity in the former process is interestingly described by one of my colleagues who writes:

> "The slime was for all the world a reproduction of the earth surface—particularly in respect to the vicious competition for survival among organisms. The fungi in the slime held tightly to the underlying rock and gave the slime its structural strength. Filamentous algae likewise gave support to the slime layer. The fungi were our jungle trees, and the filamentous algae our green foliage. Broad savannahs were represented by extensive growths of surface algae. A variety of protozoa and higher animals browsed among the diverse plant life, and still others preyed indiscriminately on all the microscopic forms. Feeding on everything they came across were insect larvae, worms, and snails. Here, in the slime, like in our familiar life, it is a brutal survival of the fittest. Fortunately for us, the fittest represent a well balanced energy and material flow, assuring good waste treatment."

The fundamental mechanisms of stabilization of wastes by activated sludge—the second method mentioned—were elucidated about 30 years ago in a classic series of experiments by two great predecessors of mine in the Public Health Service, Theriault and Ruchhoft. They found that the quantity of carbonaceous material oxidized biologically in a given time could be accurately predicted by assumption of a first order reaction. The rate "constant" varied, with different wastes, but the range in variation was relatively narrow. Their work led to the development of the five-day Biochemical Oxygen Demand (BOD), a widely used parameter of water pollution throughout the world.

While Theriault and Ruchhoft were working wtih activated sludge, their equally great contemporaries, Streeter and Phelps, also of the Public Health Service, were studying the self-purification phenomena of streams. From their efforts came the formulation on the deoxygenation-reaeration effect by which oxygen depletion in a stream receiving wastes may be predicted. This has been perhaps the most important concept in stream sanitation practice over the past two generations.

This logarithmic formulation equates the oxygen deficit at any particular time to the degradation of the initial load on the stream and the beneficial effects of turbulence, air entrainment, and aquatic plant respiration on satisfying this initial load:

$$D_t = \frac{k_1 L_o}{k_1 - k_2} (e^{-k_1 t} - e^{-k_2 t}) + D_o e^{-k_2 t}$$

D_t = Oxygen deficit at time t
D_o = Oxygen deficit at time t=0
L_o = Stream BOD at time t=0
K_1 = Deoxygenation rate constant
K_2 = Reaeration rate constant

Thus, the work of Streeter and Phelps provided the answer to the famous question posed by Samuel Taylor Coleridge, when at the end of the 18th century he visited Cologne and observed how filthy the Rhine River was below the city. Coleridge put his question in this poetic form:

"The River Rhine it is well known
Doth wash your city of Cologne,
But tell me, nymphs, what power devine
Shall henceforth wash the River Rhine?"

One may be surprised that the complex interplay of biological, chemical, and physical phenomena occurring in the stream may be depicted by such a relatively simple logarithmic expression as the

Streeter-Phelps formulation. The fact is that many simplifying assumptions are concealed in the apparently innocuous deoxygenation and reaeration constants ("k_1" and "k_2"). Actually, these factors are not constant but vary with each stream and location. Fortunately, a large body of experience has accumulated, permitting the sanitary engineer by use of this formula to predict impeccably a given stream's approximate capacity to assimilate oxygen consuming wastes.

Persistent Substances in Sewage Effluents

The reduced dilution factor resulting from the discharge of increased quantities of municipal and industrial waste of changing nature and growing complexity into a fixed water resource has made it necessary to reexamine our concepts of waste treatment and reevaluate the assimilation capacity of streams. The burden imposed on the nation's waters by the residual pollution in treatment plant effluents, together with untreatable new chemicals and dissolved minerals, constitutes a challenge as great as any confronted by our predecessors. We find that municipal wastes are assuming new and important characteristics. For example, synthetic organic chemicals are often undetected and unsuspected components of sewage. It is possible, for example, that the presence of alkyl benzene sulfonate, the basic ingredient of household detergents, would be unsuspected if it were not associated with foam. One could speculate on the presence and biological effect of other substances, equally resistant to treatment and equally persistent in the stream, which give no physical or chemical clues to their identity.

Recently studies on the secondary effluents in a number of cities were conducted to determine the composition of the soluble persistent organics present. Employing the most sensitive methods conveniently available, the following categories of substances were identified: ether extractable compounds, proteins, carbohydrates, and polysaccharides; tannins and lignins; and alkyl benzene sulfonates. Clearly there is a large area of uncertainty concerning the specific nature and health significance of substances contained in the most thoroughly treated waters from our best waste treatment processes.

Industrial Wastes

Although the traditional industrial or trade wastes, such as those from the pulp and paper, textile, and meat packing industries, are still major problems, the newer wastes in many instances may be even more troublesome.

Increasing interest is being directed to radioactive wastes from uranium ore refining plants and nuclear power reactors, thermal effects of power plants and industrial cooling operations, and the complex of substances discharged by the chemical industry. Synthetic organic substances are becoming a more widespread problem because of the very rapid growth of the petro-chemical industry. The increased incidence of these materials in our streams indicates that our present methods of treating wastes are no longer adequate. We have identified many substances which resist biological destruction and pass through conventional waste treatment process essentially unaltered in character. In like manner, they persist in the stream and reach locations of water use many miles below the point of waste discharge. Even more sobering is the fact that they do not respond to conventional water treatment. Nitrochlorobenzene is a good example of a synthetic organic compound that resists microbial attack indefinitely. We were able to follow this benzene derivative in the Mississippi River from St. Louis to New Orleans, a distance of nearly 1,000 miles. We were able to recover this compound in a treated water supply utilizing the Mississippi River as its source. We do not believe that this situation is unique.

Farmland Drainage

Increased use of agricultural poisons, particularly insecticides, is reflected in the appearance of these chemicals in bodies of water receiving farmland drainage. DDT has frequently been recovered from streams, and even from treated drinking water supplies. One of the new chlorinated hydrocarbon insecticides, which is more toxic to fish than any known substance, has been found to be persistent in water and capable of passing through conventional water treatment processes. As materials of increased potency come on the market, public concern with their impact on water safety must inevitably grow.

Characterization of a Waste

Questions which are of increasing concern are: How can we predict the potential pollutional effects of a new waste? Can we confidently predict the effect of the waste on the dissolved oxygen of the stream, (a) its toxic effect on fish and other aquatic life, (b) its tainting effect on fish flesh, (c) its possible damage to water treatment processes, (d) its effect on water palatability, and (e) its harmful effect on persons who drink that water over a long period of time?

Several years ago the Public Health Service undertook to evaluate its ability to make such predictions. Our experience indicates that a well-equipped, well-staffed laboratory can obtain the information needed to predict with confidence a new waste's probable impact on certain important water uses. I should add that this work is expensive and time-consuming. The specialized services and cost place such investigations out of reach of many public agencies. Furthermore, toxicological studies require considerable time to develop answers. This approach of studying one compound at a time becomes almost unrealistic when we appraise the larger numbers of new substances which we must consider each year.

Cleansing of Wastes

To a very large extent in the last 25 years, waste treatment research has been directed to improvement of methods for satisfying one requirement—oxygen demand. It has been noted that many persistent organic materials discharged in sewage and in chemical wastes exert no oxygen demand—our traditional scale of measuring water pollution. They are either non-oxidizable or they exert their oxygen demand so slowly as to be considered non-oxidizable. Unfortunately, the absence of oxygen demanding properties gives no assurance that such compounds may not have other and perhaps even more serious effects.

Increasing attention is being given to the possibility that secondary waste treatment—the best we have today—is not sufficient. A new interest has been stimulated in the future's need for what we term tertiary treatment processes and, beyond that, for ultra-cleansing of wastes—i.e., complete recovery or virtually 100 percent removal of all contaminants. In this connection. you may be interested in a few of the processes under consideration at our Research Center in Cincinnati:

Fundamental studies on microbial enzyme systems.

Destruction of organic substances by strong chemical oxidants.

Application of adsorption to waste treatment.

Many other physical-chemical phenomena are being explored for their potential development as waste treatment processes. Among these are advanced methods of electrodialysis, ion exchange, solvent extractions, and evaporation which offer interesting research possibilities in water cleansing.

Water Quality Measurement

Only recently has surveillance been adequate to portray a realistic picture of changing conditions in our streams. We are gaining competence in the rapid detection of many types of pollution. Recent improvements in sampling and analytical techniques for coliform organisms and enterococci permit us to discern fecal contamination more readily than ever before. The successful development of equipment for continuous recording of dissolved oxygen represents a significant advance in the monitoring of streams for oxygen demanding wastes. The current emphasis on radioactivity monitoring is providing steadily improved instrumentation for this purpose.

We must not only develop new methods of measuring pollution but make better use of those already available. A most urgent need is the improvement of procedures in detecting pollution by highly stable organic compounds. We must also take greater advantage of stream biota as indicators of pollution. Although biologists repeatedly stress the sensitivity of aquatic life to pollution, we are only beginning to use biological indicators in determining water quality.

Water Treatment

Again I return to water use—actually reuse—the municipal and industrial water treatment plant. The main accomplishment of modern water treatment is the removal of particles in suspension, the destruction of micro-organisms that survive flocculation and filtration processes, and control of tastes and odors. Until recently, we were reasonably sure of the quality of our treated waters. The problem of viruses, however, especially the virus of infectious hepatitis, is forcing us to reexamine our water treatment methods. It is clear that these ultra-microscopic particles are much more difficult to remove or destroy than bacteria.

With the exception of hardness, little attempt is made to remove soluble chemicals from potable water. Tastes and odors are removed by carbon—a selective agent whose absorption properties are little understood. There are no effective methods for removing many of the new contaminants we are finding in water. This seems to leave us two alternatives:

(1) Keep these substances from reaching our water courses, or

(2) Step up our research to find means by which they can be removed.

Conclusion

I have tried to present to you some mid-20th century problems which we must solve to maintain the quality of the nation's waters. Research is one of the most pressing needs in a long and imposing list. Time has permitted me to mention but a few. It is increasingly clear that we must develop new treatment processes—methods yet unknown and unconceived—which will remove much more of the contaminants from water and wastes than we are able to do by present methods, because these waste waters are going to become the entire flow of many of our streams as they move along from city to city. Science must unravel the pollution mysteries which science itself has created so that our urban dwellers—now more than 100 million—who must rely on surface water, may drink with safety the same water which serves all their other needs.