Critical Review

of

THE OKLAHOMA STATE WATER RESOURCES QUALITY CRITERIA

Prepared by

The Bureau of Water Resources Research
The University of Oklahoma
Norman, Oklahoma

Supported by

Bureau of Water Resources Research, University of Oklahoma
Norman, Oklahoma

Office of Water Resources Research, Oklahoma State University
Stillwater, Oklahoma

and

Department of Interior, Grant #14-01-0001-883

ACKNOWLEDGMENTS

This report is the result of a research project conducted by the University of Oklahoma Bureau of Water Resources Research, through the assistance of a matching grant from the Office of Water Resources Research of the Department of the Interior.

I wish to extend my gratitude to all of the Bureau staff members who worked so diligently to prepare this report, particularly Dr. Maxwell J. Wilcomb, Associate Professor of Sanitary Biology; Dr, Edwin H. Klehr, Associate Professor of Sanitary Chemistry; Dr. Robert Y. Nelson, Assistant Professor of Radiological Health; Dr. Joseph R. Assenzo, Associate Professor of Sanitary Engineering; Dr. Andre Corbeau, Assistant Professor of Economics and Sanitary Science; Colman Robison, Graduate Assistant; Carl Bartone, Graduate Assistant; Mohammed Esfahani, Graduate Assistant; and Linda M. Hawkins, Secretary.

George W. Reid
Director
April, 1967

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The interests of Oklahoma can best be served by developing the optimum beneficial use of her waters. Barring a change in our climate or the development of inter-basin transfers, the total volume of Oklahoma's water resources will not significantly increase in the future. As more and larger reservoirs are built in an attempt to regulate the flow of our rivers, far greater withdrawals will become possible, higher losses through evaporation and consumption will be experienced, and our total water resources will, in all probability, decline. Faced with a relatively fixed or declining water supply, we will concurrently experience increased demands from an ever growing population and expanding industry.

Because of this limitation in our total supply, repeated re-use of water will increasingly be required in the future if all needs are to be met. Such huge future demands are not necessarily a cause for alarm since water can be used over and over again as it flows through the State. Thus, the real problem is not the total amount of water required, but the fact that water, in the process of being used and reused, becomes polluted, and may be rendered unfit for further use for some purposes unless means can be found to cleanse it. Pollution can be just as effective in reducing or eliminating a water resource as a drought or consumptive withdrawal. Thus, water quality control is the key to the amount of re-use that can be achieved, and therefore to the amount of water we shall have available in the future for all needs. There is, therefore, an urgent need for the establishment of comprehensive water quality criteria and a scheme for their implementation through effective water quality management.

The purpose of this report is to critically review the 1959 Oklahoma Water Quality Criteria, to bring it up to date, and to provide guidelines for determining present and future water quality standards. Not only have the loads impressed on Oklahoma's water resources accelerated since 1959, but considerable progress has been made in treatment techniques, pollution evaluation, and in defining conceptual approaches to the implementation of quality standards with regard to various beneficial uses. There is much greater need today for a sound approach to the determination of water quality requirements and a corresponding greater understanding by the public of this crucial problem.

The water quality criteria proposed in this report are not intended to be inflexible rigid standards, but must be susceptible to adjustment under proper circumstances by the various regulatory and enforcement agencies. Simply, they are our best current judgments of optimum water quality based on an exhaustive study of engineering and scientific literature and a survey of the several states as to the status of their water quality criteria. The discrete values were determined on the basis of nationwide practices and professional and scientific evaluations of permissible intake concentrations for each of the various potential pollutants for four broad use categories: Domestic and Municipal, Direct Industrial, Agricultural, and Recreational.

Stated in another fashion, these values describe in terms of our best knowledge today what can reasonably be expected of a river or lake at the point of water intake for one of the four general uses. This necessarily implies that the water user will exercise some treatment. For domestic use, if these values are met at the point of water intake, with reasonable treatment the water can be made to conform with the U.S.P.H.S. Drinking Water Quality Standard.

The water quality criteria established in 1959 specified by category 39 items of potential pollution. The burden was placed upon the water user to provide sufficient waste treatment at the point of discharge to secure a level acceptable to the next point of beneficial use. Any improvement through dilution and natural agencies occuring between the discharge point and the next point of beneficial use was taken into consideration. This was defined as an in-stream standard by categorical use.

In 1959, withdrawals in Oklahoma represented only a fraction of the then available water. This factor is rapidly increasing, requiring in many instances administrative decisions to support the best beneficial use of our waters at the expense of other potential users. The multiple use and re-use of water results in a high degree of interaction between users (pollutors) within a common basin making it difficult to assess individual responsibility for the ultimate or total damage to the stream. Implicit in the 1959 Criteria was a one-to-one analysis without consideration to this interaction. This is no longer feasible as the interaction of pollutants must be evaluated in relation to the total load impressed upon the river basin.

The most beneficial management of water quality requires the effective treatment or control of pollutants at their source in relation to the dilution or assimulative capacity of the stream. Due regard must be given to present and future anticipated uses of the stream and their respective quality requirements. This dictates that water quality plans and programs must be prepared on a basin-wide basis providing for treatment and flow regulation facilities throughout the basin.

This is the only way adequate water of a satisfactory quality for all future needs may be assured.

New techniques and models made practicable by high speed computers makes it possible to analyze pollution in terms of optimum damage functions, thus permitting the viewing of a basin as an entire research entity to be used to the greatest benefit of all. It is to these new facets as well as to the discrete levels of pollution that the criteria proposed must address itself.

Administrative and Legal Control of Water Pollution

Water pollution has often been described as "a national problem, but a local job." Thus, each of the fifty states have enacted laws and established water pollution control agencies to insure the protection of its waters. Twenty-five states have established and rely on water quality criteria by which to set standards imposed by law.[1] In each of thirty-three states a single agency has the primary responsibility for preventing and abating water pollution, while seventeen states, including Oklahoma, rely on multiple agencies for this task.[2]

Most water pollution laws, including those of Oklahoma, are of two distinct types. One type provides that a permit must issue from the local control agency before a user may discharge deleterious wastes into a state watercourse. Certain conditions, including a specified level of treatment, may be required before a permit will be granted. The other type of law grants authority to the state's control agency to make rules and regulations governing existing discharges of wastes where such discharge constitutes harmful pollution. Generally, such laws include the power to order the discharge to cease, conduct hearings, prosecute offenders, and issue "clean-up" orders.

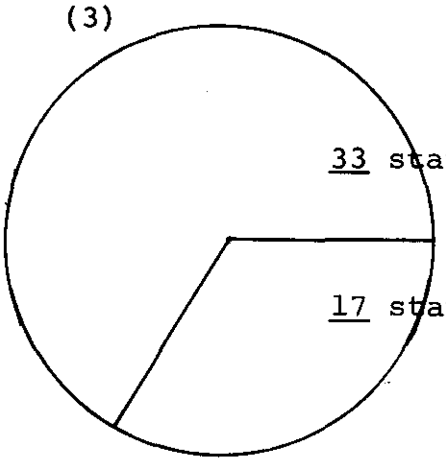
FIGURE I

Water Pollution Policy in the United States

(1) ALL the states have some law relating to the control of Water Pollution.

(2) 25 states have established some type of Water Quality Criteria.

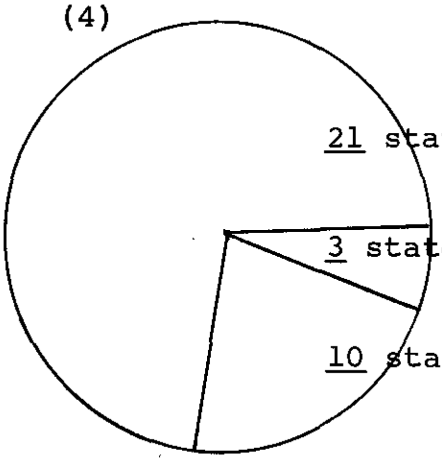
(3)



33 states rely on a SINGLE AGENCY to determine water pollution control POLICY

17 states rely on MULTIPLE AGENCIES to determine water pollution control POLICY

(4)

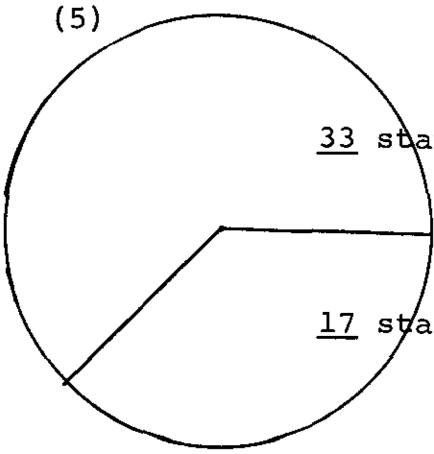


21 states utilize INSTREAM STANDARDS

3 states utilize EFFLUENT STANDARDS

10 states utilize BOTH INSTREAM and EFFLUENT STANDARDS

(5)



33 states rely on a SINGLE AGENCY for the ENFORCEMENT of water pollution policy.

17 states rely on MULTIPLE AGENCIES for the ENFORCEMENT of water pollution policy

Water pollution control and the assurance of an adequate supply of potable water to support present and anticipated population and industrial growth are among the most pressing administrative and legal problems Oklahoma faces today. The contamination and pollution of Oklahoma lakes and streams is a menace to public health, is harmful to wildlife, fish and aquatic life, and impairs domestic, industrial, agricultural, recreational and other legitimate uses of water for beneficial purposes.[3] To protect the future development of our State, various laws have been enacted to prevent the contamination and pollution of Oklahoma waters.

Essentially, the responsibility for the prevention of water pollution and maintenance of water quality standards is divided among four state agencies. Our policy regarding water quality criteria, therefore, requires the upmost cooperation for the mutual benefit of the State of Oklahoma and the individual water user. These agencies and their respective areas of responsibility include:

(A) Oklahoma Water Resources Board, created in 1957, was given general authority to advise, consult, and cooperate with affected groups, political subdivisions, and industries in furthering the purposes of the Oklahoma Water Pollution Control Act of 1955.[4] All the powers, duties and authority previously imposed on the Oklahoma Planning and Resources Board was expressly conferred on the Water Resources Board,[5] along with other broad general powers to promulgate regulations and administer the water laws of the State of Oklahoma.[6] More specifically, the Oklahoma Water Resources Board is empowered to develop statewide and local plans to assure the most effective use of water, to negotiate agreements with the Federal government to arrange for the development of water resources, and to institute proceedings before the courts to prevent the unlawful pollution of any of the waters of the State.[7]

Under the <u>Water Pollution Control Act of 1955</u>, the Oklahoma Water Resources Board is authorized to develop programs for the control or abatement of water pollution, to encourage and conduct research and disseminate information in this field, and to adopt and promulgate water quality standards, classifying such waters in the best interest of the public for the prevention and control of pollution.[8] The Board is given the general power to adopt and enforce rules and regulations to effectuate their responsibilities under the Act.

Generally, the Oklahoma Water Resources Board has sought to prevent the pollution of the waters of this State by industry. In the last several years the growth of Oklahoma industry has been gratifying, but such growth has resulted in the ever present threat of contamination of our waters. Water, not consumed by industry, but returned to the stream polluted by harmful matter could be disastrous. With the assistance of the Water Quality Branch of the United States Geological Survey and various other governmental agencies, the Oklahoma Water Resources Board has sought to determine, through chemical and other scientific analysis, what constitutes the maximum deleterious waste which can be put into a stream before it constitutes harmful and thus, unlawful pollution.

The Board works very closely with new industry and the expansion of existing industries by assisting them in working out their waste disposal problems. By taking samples of water above and below such industrial use the amount and extent of deleterious substances discharged into the stream and the effect upon the entire stream system can be measured. From this data the Board will impose controls and suggest treatment measures for the prevention of unnecessary and harmful contamination of Oklahoma's streams and watercourses.

Whenever there exists or has been violation of the Water Pollution Control Act or an order of the Board resulting in the unlawful pollution of Oklahoma waters, the Board may, upon proper notice, require that the matters complained of be corrected or that the alleged violator appear before the Board to answer the charges levied against him.[9] The Board has the power to enter upon and inspect any private or public property for the purposes of investigating conditions relating to existing or possible water pollution.[10]

Any person who fails to perform any duty imposed by the Act or has violated any order of the Oklahoma Water Resources Board will be guilty of a misdemeanor and subject to proper punishment.[11] In addition, the Attorney General of the State of Oklahoma must, upon request of the Board, bring an action to enjoin the alleged violator from disregarding any order or determination of the Board.[12]

(B) Oklahoma State Corporation Commission, has the general duty and authority to protect Oklahoma waters from pollution by the oil and gas industry. More specifically, it is vested with the power to make and enforce rules and regulations governing the disposition of salt water, mineral brines, waste oil and other deleterious substances connected with the drilling, producing, refining and processing of oil and gas within the State.[13] The Water Resources Board and the Oklahoma Department of Wildlife Conservation are expressly given the duty to assist the Corporation Commission in the performance of its duties under the above statute by making investigations, gathering evidence and filing reports and recommendations with the Commission in the furtherance of water pollution control.[14] A 1965 statute gives the Corporation Commission the authority to order abandoned oil or gas wells to be plugged or repaired to prevent the leaking of salt water, oil, gas or other harmful substances upon the land or into fresh water formations.[15] The Commission is also aided by an early Oklahoma statute which prohibits the dumping of any inflammable product from oil or gas production in any water used for the watering of stock.[16]

(C) Oklahoma Wildlife Conservation Commission has the duty to police and patrol Oklahoma lakes and streams to see that water quality is maintained at a level suitable for sustaining and propagating fish and wildlife.[17] More specifically, in the fishing regulations as enacted by the Oklahoma Legislature, it is made unlawful to deposit or allow any explosive, poison, salt water, crude oil or other deleterious substance to be washed into any of the streams, lakes or ponds of the State.[18] Any party violating this statute as a result of the production of oil or gas must be reported to the Corporation Commission for corrective action; if no action is then taken, criminal proceedings may be instituted.

(D) Oklahoma State Department of Health has the general authority to protect domestic and municipal water supplies and to see that sewage from towns and cities is disposed of in a manner not harmful to health.[19] The source of every public domestic water supply must be investigated by the Board of Health to determine its sanitary quality, and no use may be made or construction begun on a public water supply without a written permit from the State Commissioner of Health.[20] Whenever the Commissioner has reason to believe that the sanitary quality of water supplied to the public for domestic purposes is such as to be prejudicial to health he has the power to investigate the character of the water supply and order changes in the source, manner of storage, distribution, purification or treatment.[21]

All sewage disposal and treatment plants must be designed to the approval of the State Commissioner of Health so that effluent therefrom will not pollute the waters of the State in a manner harmful to health.[22] In addition, no sewage disposal systems may be constructed without compliance with the minimum requirements as set by the Board.[23] Upon a determination that Oklahoma waters are being polluted by any person, corporation, institution or municipality to constitute a hazard to health, the Commissioner of Health has the authority to order that such pollution cease within a reasonable time or to require such treatment as well as prevent further contamination.[24]

In 1963, the Oklahoma Department of Health was designated as the official agency of the State of Oklahoma to cooperate with federal agencies in the treatment of sewage, the control of water pollution and other matters affecting public water supplies.[25]

References

1. Questionnaire response to a survey by the Bureau of Water Resources Research, University of Oklahoma, Norman, Oklahoma.

2. Statuatory Provisions on Water Pollution Control Agencies in the Several States, Oklahoma State Legislative Counsel.

3. Declaration of policy of the Oklahoma Water Pollution Control Act of 1955, 82 O.S. 1961, Sec. 904.

4. 82 O.S. 1961, Sec. 903-916.

5. 82 O.S. 1961, Sec. 1073.

6. 82 O.S. 1961, Sec. 1072.

7. 82 O.S. 1961, Sec. 1072.

8. 82 O.S. 1961, Sec. 903-916.

9. 82 O.S. 1961, Sec. 909.

10. 82 O.S. 1961, Sec. 911.

11. 82 O.S. 1961, Sec. 912.

12. 82 O.S. 1961, Sec. 912.

13. 52 O.S. 1965, Sec. 139, Supplement.

14. 52 O.S. 1965, Sec. 142, Supplement;
29 O.S. 1965, Sec. 409, Supplement.

15. 52 O.S. 1965, Sec. 309, Supplement.

16. 52 O.S. 1965, Sec. 296, Supplement.

17. 29 O.S. 1961, Sec. 106;
29 O.S. 1965, Sec. 409, Supplement.

18. 29 O.S. 1965, Sec. 409, Supplement.

References (Continued)

19. 63 O.S. 1965, Sec. 1-904, Supplement.

20. 63 O.S. 1965, Sec. 1-906, Supplement;
    63 O.S. 1965, Sec. 1-907, Supplement.

21. 63 O.S. 1965, Sec. 1-906, Supplement;
    63 O.S. 1965, Sec. 1-907, Supplement.

22. 63 O.S. 1965, Sec. 1-908, Supplement;
    63 O.S. 1965, Sec. 1-909, Supplement.

23. 63 O.S. 1965, Sec. 1-910, Supplement.

24. 63 O.S. 1965, Sec. 1-908, Supplement.

25. 63 O.S. 1965, Sec. 1-911, Supplement.

Water Sources and Uses

Oklahomans withdraw and use substantial quantities of water from municipal systems, public and private sources, either from the ground or from the surface. Surface water, because it is usually more accessible and plentiful than ground water, is generally most often used to fulfill the enormous demands of large cities and huge industrial complexes. Where surface waters are available in large quantities they are becoming an increasingly valuable source for irrigation and other agricultural purposes, as well as for water-based recreational activities. To this end, recreation has become a most important consideration in planning and developing both State and Federal water resources programs.

Ground water, too, is one of Oklahoma's most valuable resources. Estimated at more than 300 million acre-feet, ground water in Oklahoma supplies more than 70% of all water used for irrigation. Some 300 Oklahoma towns and cities derive their municipal water supplies from the ground and more than half the people of the State rely on underground sources for drinking water and household supplies.*

Water, from the ground or from the surface, is demanded,

---

* Oklahoma's Water Resources - Oklahoma Water Resources Board.

used, and consumed for many diverse purposes. Water is necessary and vital to life itself; the dominant constituent of every living thing. Generally taken for granted, municipalities, representing the smallest of Oklahoma towns to our great cities, supply an urban population of over 1,500,000 with safe, economical water for drinking, bathing, cooking, sanitation and a variety of other domestic uses.

Municipal water systems also supply water to industry and other commercial enterprises. In fact, most industrial firms located in Oklahoma utilize municipal water supplies by virtue of their proximity. In recent years, however, many large industrial users have had to establish private water supplies due to increased costs of "city" water or the inability of the municipal system to satisfy their needs. Nearly every manufacturing process requires some water for power, cooling, processing, transportation or for the cleanliness and sanitation of its employees. Presently, 1300 to 1500 gallons of water per capita per day is used in the United States for all purposes and about half of this amount,or 600 gallons per capita per day,is used by industry for a myriad of purposes.

Water, a substance of an infinite number of uses, is best analyzed with reference to those general uses most easily understood today. For purposes of this study as to the

TABLE I

U. S. Public Health Service Drinking Water Standards - 1962

Characteristic	Limit Not To Be Exceeded[1]	Cause for Rejection[1]	Proposed Water Quality Goals [2]
Physical			
Color	15 Units		3
Taste	Unobjectionable		-
Threshold Odor No.	3		-
Turbidity	5 Units		0.1 Unit
Chemical	mg/l	mg/l	
Alkyl benzene sulfonate (ABS)	0.5	-	-
Arsenic (As)	0.01	0.05	-
Barium (Ba)	-	1.0	-
Cadmium (Cd)	-	0.01	-
Chloride (Cl)	250	-	-
Chromium (hexavalent) (CrO_4)	-	0.05	-
Copper (Cu)	1	-	0.2
Carbon Chlorodorm extract * (CCE)	0.2	-	0.04
Cyanide (CN)	0.01	0.2	-
Fluroide ** (F)	0.7-1.2	1.4-2.4	-
Iron (Fe)	0.3	-	0.05
Lead (Pb)	-	0.05	-
Manganese (Mn)	0.05	-	0.01
Nitrate (NO_3)	45	-	-
Phenols	0.001	-	-
Selenium (Se)	-	0.01	-
Silver (Ag)	-	0.05	-
Sulfate (SO_4)	250	-	-
Total Dissolved Solids (TDS)	500	-	200
Zinc (Zn)	5	-	1
Methylene-blue-active substances ***	-	-	0.20

* Organic contaminants

** The concentration of fluoride should be between 0.6 and 1.7 mg/l, depending on the listed annual maximum daily air temperatures.

*** To replace ABS Standards in new detergents.

[1] Federal Register, 3/6/62. pp. 2152-2155 (Source).

[2] Suggested by the AWWA Task Force 2640-P, Willing Water, 3/31/67, p. 11.

suggested water quality criteria for the State of Oklahoma, the uses of water will be limited to four general categories: Domestic or Municipal, Direct Industrial, Agricultural (irrigation) and Recreational.

Domestic or Municipal Waters

Domestic or municipal waters are used for many purposes, with an increasing fraction going directly to industry, though the controlling use in determining quality requirements is that used for human consumption. Water, used for this purpose, must be afforded the highest degree of sanitary protection and the source must be suitable for safe and economic treatment to produce finished water meeting the standards specified by the United States Public Health Service Drinking Water Standards shown in Table I.

Domestic and municipal water systems are also sources of supply for industries, although in many cases these users require more stringent water quality standards than required for domestic use. Zeolite-softened water from municipal systems is often harmful to irrigation, and forms of aquatic life may be destroyed by concentrations of copper and zinc often permissible for domestic use.

Of great importance to those engaged in water pollution control are the standards or criteria that have been promulgated for raw waters to be used as sources for domestic supply. Such criteria have been issued by several state and interstate agencies, including those suggested by this agency in 1959 and re-evaluated by this document. The ranges in the Table II can be used as a guide in evaluating raw water quality for domestic use.

Direct Industrial Water Supply

Oklahoma industry demands water in great quantities and in varying degrees of quality for many purposes. Water, as industry's most widely used material, is utilized as a coolant, solvent, flotation medium, energy transfer agent, dilutent, for fire protection, sanitation, or as an ingredient combined with other raw materials to form the finished product. Water is by far the major industrial solvent and is an essential and necessary waste carrier. Few products are manufactured today without the expenditure of an amount of water weighing many times more than the finished product.

Within any given industry, it can be expected that no two manufacturing plants will require exactly the same amount of water per unit of production, Differences in plant design and manufacturing processes as well as varying water qualities greatly affect the amount of water required per unit of output. In recent years, limited water quantity has encouraged

TABLE II

Raw Water Source Quality for Domestic Use

Constituents	Good	Fair	Poor
BOD (5-day) ppm Max. Sample	1.0-3.0	3.0-4.0	above 4.0
Monthly Average:	0.75-1.5	1.5-2.5	above 2.5
Boron ppm	1	2	3
Chlorides ppm*	0-50	50-250	above 250
Chrome ppm	0	0-.05	above .05
Coliform organisms MPN/100 ml Monthly Average:	0-50	50-5,000	above 5,000
Color (units)	0-15	15-25	above 25
DO ppm	75% sat.	60% sat.	less than 4 ppm
Fluoride ppm	0.5-2.4	2.4-3.0	above 3.0
Nitrate ppm	0-10	11-45	45
pH	6.5-8.5	5.0-6.5	3.8-5.0
		8.5-9.0	9.0-10.5
Phenolic type compounds ppm	0.0005	0.001	above 0.001
Temperature (normal stream temperature)	50°	60°	above 60°
Turbidity ppm	1-40	40-250	above 250

* Special attention to chlorides is required by persons suffering from hypertension or on a salt-free diet. Sodium chloride is the usual source of sodium, the offending ion.

a far greater degree of reuse of our available water resources, often at the expense of polluting our lakes and streams. Being essentially nonconsumptive, about 90% of all water used by industry is ultimately discharged and can be used again downstream if a desired quality level can be maintained.

Table III indicates the range of per unit water intake requirements for selected segments of Oklahoma industry. The discrete values, given in terms of wide ranges, are based on a survey of individual plants within each industrial segment and located throughout the State. Table IV directs attention to the fact that different industrial activities have widely diverse water requirements.

To many industries, quality is of vital importance, and, in many instances, a water supply must be selected with regard to the particular requirements of a specific manufacturing process. Although an industry can treat its water to reach the desired quality, such expenses are avoided wherever possible. Each industry must adjust its own economic balance between the cost of desired water quality and the value of the manufactured product. Although supplies are frequently of adequate quality for most industrial uses, additional treatment is sometimes necessary. Many industries treat only

TABLE III

Water Intake Required Per Unit of Output

Selected Oklahoma Industries

Product or Use	Unit	Water required (gallons)
Ammonia - Urea	ton	1,300 - 2,250
Blown Glassware	1000 pcs.	2,230 - 7,500
Bread	ton	450 - 900
Calcium Carbide	ton	900 - 1,200
Canning (food)	case #2 cans	50 - 102
Compost	pound	50 - 145
Cottonseed Meal	ton	425 - 820
Gasoline (natural)	gallon	20 - 60
Glass Jars	gross	4 - 7
Hydrated Lime	ton	75 - 125
Paper	ton	7,500 -13,000
Ready Mix Concrete	yard	30 - 60
Portland Cement	barrel	20 - 140
Poultry Processing	ton (live weight)	3,500 - 4,500
Raw Milk Processing	1000 pounds	550 - 2,000
Soft Drinks (bottles)	case	8 - 12
Sulfuric Acid	ton	650 - 1,000
Window Glass	square foot	2 - 5
Zinc Processing	ton	800 - 2,000

TABLE IV

Average Daily Water Requirements

Selected Oklahoma Industries

(Gallons of water per production worker per day)

Industry	Average Daily Water Intake per Worker (gallons)
Paper Manufacturing	20,600
Petro-Chemical Production	5,000
Petroleum Refining	5,000
Metal Smelting and Fabrication	2,500
Chemical Production	2,500
Glass Production	1,900
Cement Production	1,500
Food Processing	630
Transportation Equipment	400
Machinery (Except Electrical)	400
Printing and Publishing	260
Clothing Production	60

Source: Bureau of Water Resources Research, University of Oklahoma; Water - Oklahoma's No. 1 Problem.

portions of their water supply to be used for specific purposes such as boiler feed water or process water. Since water quality requirements are critical to many manufacturing processes, maximum recommended tolerances are indicated in Table V. The Water Resources Board has available detailed water quality requirements for specific industrial and manufacturing processes most suited for location in Oklahoma.

The problem of make-up or feed water for boilers is common to almost all industries. Water may be entirely satisfactory for domestic and most industrial uses but completely unsatisfactory for boiler use if it leaves a harmful residue of mineral matter when evaporated. Operating boilers without feed water of an adequate quality will result in scale formation and corrosion, both of which are responsible for lowered efficiency, fuel wastage, tube failures, and increased shutdown for repairs and cleaning.

Boiler feed water must be clear, free from noncarbonate hardness, and should have a total hardness not exceeding 35 ppm. It must be practically free from oxygen, organic matter, grease, oil, soap, suspended solids and certain organic salts. It must not be corrosive or scale forming, nor contain excessive dissolved solids, and it must have a low silica content. Modern water treatment methods permit the operation of boilers at high

TABLE V

Water Quality Tolerances for Industrial Applications

Water Use	Hard.	Alka.	Turb.	Color	Odor	O_2 Consumed	pH	T.S.
Air conditioning								
Baking			10	10				
Boiler feed-lbs/sq inch								
0-150	75		20	80		100	8.0+	3000-1000
150-250	40		10	40		50	8.5+	2500-500
250-400	8		5	5		10	9.0+	1500-100
400 and over	2		1	2		3	9.6+	50
Brewing								
Light		75	10		Low		6.5-	500
Dark		150	10		Low		7.0+	1000
Canning								
Legumes	25-75		10		Low			
General	50-85		10		Low			
Vegetables and fruits	100-200							
Peas	200-400							
Carbonated beverages	250	50	2	10	0	10		850
Confectionary					Low		7.0	100
Cooling	50		50					
Dairy								850
Electroplating								
Food								
General			10		Low			
Equipment washing	10						7.5	850
Processing	10-250							
Ice (raw water)	70	30-50	1-5	5				300
Laundering	50						6.0-6.8	
Oil well flooding							7.0	
Plastics, clear			2	2				200
Paper and pulp								
Groundwood	180-200		50	20				500
Kraft pulp, bleached	100		25	15				300
Steel manufacture	50						6.8-7.0	
Synthetic rubber	50							
Tanning	50-135	135	20	10-100			6.8	

efficiency for long intervals without cleaning. Where treatment costs are not excessive many large users completely demineralize their waters used for boiler feed. This permits the use of generally low quality water for this purpose.

Cooling represents the largest single industrial use of water. This may be for cooling condensers in power plants, oil refineries, or chemical plants; for cooling furnace fronts in steel mills or smelters; for cooling tubes in radio broadcasting stations or large computer complexes; for cooling refrigeration compressors; for air conditioning and a considerable variety of other cooling processes. The amounts of water required for cooling vary greatly, depending on the temperature of the water source and the particular use. Typical to the oil industry, the water may be circulated in a closed system, gaining heat as the product is cooled and losing heat in a tower or spray system prior to recirculation or discharge into the stream.

Cooling waters should have an appropriate initial temperature and should be free of substances causing corrosion, scale deposition, and algae or slime formation. Characteristics of water which are detrimental to its use for cooling purposes are hardness, suspended soils, dissolved gases, acids, oil and other organic compounds and slime-forming organisms. Because of its constant and usually low temperature, ground water is generally considered to be most desirable for cooling water but usually requires the removal of harmful impurities. Many surface supplies are well suited for recirculating cooling systems without the need for costly treatment, but such are usually subject to large seasonal variations in temperature.

Cooling water, frequently discharged into surface streams, should not increase the resulting temperature of the stream so as to alter the aquatic balance. Also, the chemical treatment for corrosion control, commonly chromium, presents a potential source of serious pollution for domestic and agricultural uses.

Many industries use water as a necessary ingredient in the finished product or in such close connection with the manufacturing process that impurities in the water will directly affect the quality of the manufactured goods. Food producing industries such as those which produce carbonated beverages, ice, bread and pasteries, and canned or frozen fruits and vegetables often require water of more stringent quality than that for drinking water or general domestic supply. Confectionaries often require water of distilled quality and all food processing or food handling industries should meet aseptic conditions.

It should be noted that iron, manganese, and suspended matter generally interfere with the dyeing and finishing of silk, wool and cotton by causing stains. The most important constituent to be avoided in water used for laundering is hardness which causes the wastage of soap and formation of curds. Rayon manufacturing requires completely demineralized process water to produce an ash free product. Proper tanning requires water free from iron and manganese and with low concentrations of free carbon dioxide, bicarbonate, hardness, color and turbidity.

The quality requirements for process water used in manufacturing pulp and paper varies with the desired quality of the product. Suspended matter affects colors and interferes with texture and uniformity. Turbidity and color must be in constant low concentrations for manufacturing fine grade paper but may be present in greater concentrations for cardboard or rough paper products.

Polluting substances in water have an adverse effect on the strength and durability of concrete. Concrete will deteriorate at an accelerating rate by the presence of slimes, certain bacteria, high concentrations of organic matter or B.O.D., or high temperature of the process water. The Portland Cement Association recommends that water used for mixing concrete be free of acids, alkalies and oil, that mixing

TABLE VI

Typical Process Water Quality Requirements for Representative Industries

Manufacturing Process	Undesirable Constituents	Remarks
Textiles	Color, turbidity, suspended solids, hardness, manganese and iron.	Precipitate forms in fabric; interferes with finishing
Dye Works	Varying pH, hardness, iron 0.2 ppm.	Poor dyeing; hardness reacts with dyes, causing shades, spots, streaks.
Laundries	Hardness, iron, manganese.	Costs for soap; ppts. stick to fabrics, causing grayish color.
Paper	Color, iron, manganese, for fine paper (not newsprint), oils, and fats.	Oils and fats cause spots.
Ice	Color, suspended solids, iron 0.2 ppm., bacteria, and bicarbonates 70 ppm, calcium sulfate, magnesium, sodium carbonate 300 ppm.	Cause cloudiness in the ice; retard the freezing; cause shattering.
Food Canning	Bacteria, hardness, and low mineral content.	Hardness causes toughening of beans and peas.
Tanning and Hides	Iron, lime salts, carbonates.	Form insoluble compounds with tannins; calcium hydroxide washing leaves ppt. in the skin.

Table VI (Continued)

Manufacturing Process	Undesirable Constituents	Remarks
Carbonated Beverages	Iron, manganese, turbidity, color, odor, organic matter. Treated water should be balanced, alkalinity 100 ppm, hardness 200 ppm, algae.	Tends to neutralize flavoring acids; cause essential oils to separate.
Beer	pH = 7.0, sodium chloride 250 ppm.	Calcium sulfate desirable.
Vinegar	Iron, hardness	
Concrete	Sulfates, chloride	Detrimental to setting up.
Glass	Color, suspended solids, a trace of iron or manganese.	
Photo Films	Color, suspended solids,iron, zinc, manganese, traces of radioactive isotopes.	Develop deposits..

TABLE VII

Examples of Industrial Pollution

Industrial plants producing oxygen-consuming wastes (high BOD):

- Beet Sugar Refineries
- Breweries
- Canneries
- Dairies
- Distilleries
- Laundries
- Packinghouses
- Pulp Mills
- Tanneries
- Textile Mills

Industrial plants producing wastes with high suspended solids:

- Breweries
- Canneries
- Coal Washeries
- Coke and Gas Plants
- Distilleries
- Packinghouses
- Paper Mills
- Tanneries

Industrial plants producing wastes with high dissolved solids:

- Chemical Plants
- Sauerkraut Canneries
- Tanneries
- Water-softening Plants

Industrial plants producing oily and greasy wastes:

- Laundries
- Metal-Finishing Shops
- Oil Fields
- Packinghouses
- Petroleum Refineries
- Tanneries
- Wool-Scouring Mills

Industrial plants producing colored wastes:

- Electroplating Shops
- Paper Mills
- Tanneries
- Textile Dyehouses

Industrial plants producing taste and odor-bearing wastes:

- Chemical Plants
- Coke and Gas Plants
- Petroleum Refineries

Table VII (Continued)

Industrial plants producing toxic wastes:

- Nuclear Energy Plants
- Nuclear Weapon Plants
- Chemical Plants
- Electroplating Shops
- Pulp Mills
- Tanneries

Industrial plants producing alkali wastes (high pH):

- Chemical Plants
- Tanneries
- Laundries
- Textile-Finishing Mills

Industrial plants producing high-temperature wastes:

- Bottle-Washing Plants
- Electroplating Shops
- Power Generating Plants
- Laundries
- Textile-Finishing Mills
- Oil Refineries

Industrial plants producing acid wastes (low pH):

- Chemcial Plants
- Electroplating Shops
- Iron and Steel Mills
- Sulfite Pulp Mills
- Coal Mines

water be suitable for drinking purposes with the exception that it must not contain large amounts of sulfates.

Table VI indicates some of the undesirable constituents of process waters for selected manufacturing processes. Table VII shows many of the sources of industrial pollution of waters by the types of wastes discharged. By comparing the information depicted in Table VI and Table VII one can easily recognize those industries which, without effective waste treatment, are incompatible on the same stream system.

Agricultural Waters

Consideration of agricultural waters in this document is limited to irrigation. The establishment of quality criteria for irrigation water is contingent upon such variable factors as soil conditions, drainage considerations, climate and the specific crop planted. Plants vary widely in their tolerance to salinity. Thus, strict criteria for "irrigation waters", as such, are not possible.

Certain salts or ions, harmless in small concentrations, may cause toxic reactions in plants if accumulated in the soil in sufficient concentrations. Such ions include sodium, chloride, bicarbonate, and sulfate. Less frequently, crops grown in soils having an excessive amount of calcium and magnesium may also show similar reactions. Interactions between and among the several ions may be significant, the effect of one ion may be modified by the presence of another. For example, antagonistic influences are experienced between calcium and sodium; boron and nitrates; and selenium and sulfates.

If irrigation water is of good quality, the soils to which it is applied may be improved due to calcium in the water and by leaching and washing away salts from the lands. If, however, the quality of the water is poor, the soil may deteriorate until the land will not produce satisfactory crops.

Boron, found in almost all water used for irrigation, is essential for plant growth. Plants vary in their sensitivity to boron and a concentration only slightly in excess of that needed for optimum growth may be toxic. While some crops such as alfalfa are not injured by a concentration of as much as 20 ppm of boron, waters containing more than 3.0 ppm are generally unsuited for irrigation.

Recreational Waters

This category includes waters for bathing and waters for fish and wildlife. The quality criteria of natural bathing waters are established for the protection of the bathers, based on coliform density, aesthetic values and absence of toxic contaminants. Generally drinking water quality is not required, but a sanitary survey should demonstrate freedom from pollution.

For fish life, the whole aquatic food chain must be considered. This includes plankton, attached algae, and other plants, bottom organisms, and fish.

Algae, bottom organisms, and bacteria are the most important in bringing about the self-purification of a stream. These organisms are also important links in the food chain and, therefore, any substance that adversely affects them will affect the fish life.

The more common effects of wastes on stream life include:

(a) Oxygen deficiencies as a result of the bacteria utilizing dissolved oxygen in their metabolic processes while attacking the wastes.

(b) Toxicity to aquatic life, due to one or a number of characteristics of the wastes: to toxic chemicals, such as cyanides and many others; to pH effects caused by alkaline or acid discharges; or to excessive alteration of osmotic pressures by such wastes as brines.

(c) Temperature changes beyond optimum essential to fish life.

(d) Damage to stream life because of physical characteristics. Abrasive suspended solids can mechanically injure gill membranes of fish. Oil may coat the gill structures and interefere with absorption of oxygen. Suspended solids may cut out sunlight necessary for desirable algae production.

(e) Unfavorable aquatic environment. Suspended solids may settle out and clog up the natural habitats or eggs may become buried. Resistance of the organisms to normal environmental factors is lowered and the population eventually dies out.

Bibliography

1. Water Pollution Control - 1966, Hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works, United State Senate, Eighty-Ninth Congress.

2. Water Quality Management, P.H. McGauhey, University of California at Berkeley, 1966.

3. Economic Evaluation of Water Quality, Richard J. Frankel, University of California at Berkeley, 1965.

4. Proceedings, Conference on Physiological Aspects of Water Quality, Washington, D. C., September 8-9, 1960.

5. Implementation of the California Water Plan, Department of Water Resources, State of California, 1966.

6. The Optimum Allocation of Stream Dissolved Oxygen Resources, Jon C. Liebman, Cornell University Water Resources Center, 1965.

7. Multidisciplinary Research As An Aid to Public Policy Formation, Virginia Polytechnic Institute, 1965.

8. The Population Challenge . . . What it Means to America, United State Department of the Interior.

9. Water Pollution - Economic Aspects and Research Needs, Allen V. Kneese, Resources for the Future, 1962.

10. Arkansas-Red River Basins Water Quality Conservation, U.S. Department of Healthm Education and Welfare, 1964.

11. Oklahoma's Water Resources, Oklahoma Water Resources Board, 1965.

12. The Impact of New Techniques on Integrated Multiple-Purpose Water Development, Edward A. Ackerman, 1960.

13. Water Resources Activities in the United States, Select Committee on National Water Resources, U.S. Senate, Committee Prints 7, 9, 24, and 32.

Water Quality Management:

Stream Responses and System Analysis

Central to our thoughts on Water Quality Criteria is the basic idea of assuring the optimum beneficial use of Oklahoma's water resources. Much is involved in defining this objective. There are perhaps two general approaches that are not necessarily compatible - namely, economic efficiency and welfare efficiency. Using an economic efficiency criteria in a free market system one assumes (1) that the allocation of resources and costs to an activity will be of such a nature that no reallocation will yield a greater net benefit and (2) that all profits and costs stemming from such activity will accrue to that activity. Implicit in this notion is the assumption that each user of water must bear the cost of all damages resulting from that use. This forces all dischargers of wastes to consider the downstream effect of their discharges as costs. The major problem associated with this concept is one of defining these damages, particularly when the interaction of several effluents is involved.

Hopefully, a balance between benefits on one hand and harmful effects on the other is being sought. This approach does consider the economy of using the assimulative or natural purification capacity of a stream, but a considerable conflict of attitudes revolves around this notion. Also it is difficult to quantify all the gains and losses associated with a system; consequently, optimal allocation of costs and benefits to maximize benefits and minimize costs cannot be achieved. Many benefits and costs are virtually impossible to measure in terms or dollars. Prime examples include health and aesthetics; thus these are generally handled as constraints by using a referral to social costs embodied in a welfare economics criteria. To these limitations must be added those resulting from our heritage of institutional constraints and the independence of facilities producing discharges.

One widely publicized approach which addresses itself primarily to the institutional problem is that of the Basin Wide Firm suggested by Allen Kneese of Resources for the Future. In this concept, one governmental unit represents a basin operating all treatment facilities and bearing all the costs. This unit must, from its power to set costs, determine appropriate performance levels and require each user to treat to an optimal point but to pay the corresponding damage costs is still a problem.

In the Ruhr Valley of Germany, optimal conditions are obtained when the marginal cost of treatment equals the marginal damage cost, but unfortunately this does not reflect the interaction of discrete sources of wastes; thus, damage charges tend to become arbitrary. The development of some institutional arrangements to serve as a basin wide firm will be difficult to achieve in the United States. The present Delaware Basin program is perhaps the closest approach today. As the problem of economic utilization of water increases, as it will, tradition must give way to this approach.

The assessment of damages, as has been noted, is a difficult problem. Many attempts have been made to formulate damage functions. For example, the cost can be related to the depletion area under the dissolved oxygen sag curve:

$$\text{Cost} = K \int_{o}^{t} D dt \quad \text{or} \quad K \int_{o}^{t} D^{p} dt \qquad (1)$$

where D is the dissolved oxygen deficit at t time. Related to the discharged load it becomes:

$$\text{Cost} = K \left[K_i \; L_i^{p} + K' \Pi \, L_i \right] \qquad (2)$$

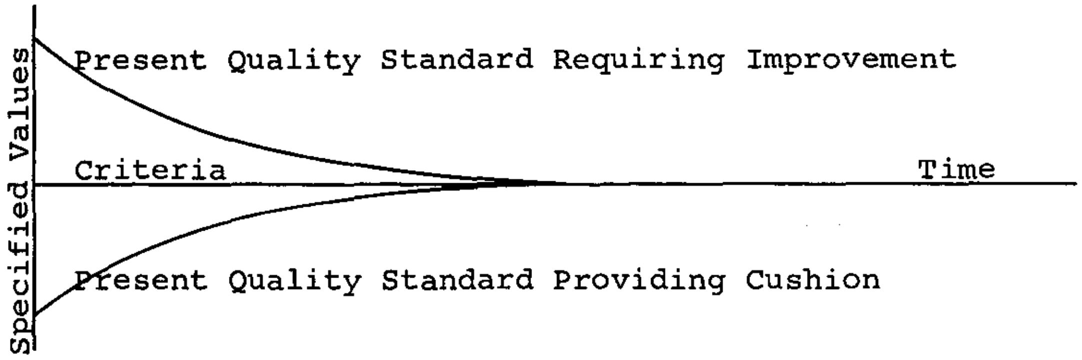
where K_i represents stream response and L_i, the load. This formula for two discrete discharges, A and B, with interaction would be:

$$\text{Cost} = K \left[K_1 \; L_1^{p} + K_2 \; L_2^{p} + K' L_1 L_2 \right] \qquad (3)$$

To cope with the problem of evaluating damages the stream standard is substituted and the damage charge becomes the cost of treatment to obtain a required quality for a specified use at some point downstream. This is to say that the damage is minimal below the required quality standard and intolerable above.

$$\begin{array}{c}\text{damage}\\ \text{minimal}\end{array} < \text{RQS} < \begin{array}{c}\text{damage}\\ \text{intolerable}\end{array} \qquad (4)$$

Water Quality <u>Criteria</u>, in this text, are values describing what is considered acceptable at the point of intake for a specified use. Water Quality <u>Standards</u> are legally interpreted levels of the criteria. They may be above or below the criteria. If the present waters cannot meet the criteria associated with a specified use, the criteria becomes an asymptote to which the standard will approach with time and improvement. On the other hand, if the standards are set below (more stringent) the criteria, the criteria can be considered as minimal standards providing a "cushion" between the standards and the criteria.



In the past, standards have specified levels of treatment or treatment efficiencies and have been applied to effluents. This is the simplest method and construed to be the fairest in that it can be uniformly applied to all. The first claim is correct, but whether it is equitable to all users presents a difficult problem. For example, a 25 ppm BOD effluent standard would require 90% treatment of most municipal sewage, but 99% treatment of many biological wastes. The last 9% treatment would cost as much as the first 90%. On the other hand, the 90% treatment of many biological wastes would be tantamount to the discharge of raw domestic sewage.

At the present time three states use "effluent" standards and twenty-one states use an "instream" standard. Ten states and the suggested Federal Water Pollution Control Agency Guidelines involve both. The consensus, at present, appears to call for at least primary treatment applied to the effluent directly. The modern trend favors an "instream" standard by categorical use, the uses being those that are most readily understood today; namely, Municipal, Direct Industrial, Agricultural, and Recreational.

Previously, the concept of uses was covered by stream grading, though the grades were defined by coliform densities, dilution ratios, or dissolved oxygen levels. The 1959 Oklahoma

Water Quality Criteria states the four use levels for thirty-nine criteria defining the chemical, physical and biological pollutants. The levels were, at the time, the best professional and scientific judgments defining acceptable values by use. Upon re-evaluation in this document, the uses have remained the same, but the criteria have been expanded to over fifty. The matrix of values, current today, follows:

TABLE VIII

Suggested Raw Water Quality Criteria - 1966

Ion, Organism or Substance	Water Uses			
	Municipal	Recreation	Industrial	Agricultural
Persistent Chemical				
Alkalinity (ppm $CaCO_3$)	120	-	50-150	-
Alkyl benzene sulfonate(ABS)**	0.5	1.0-2.0	-	-
Arsenic (ppm As)	0.01-.05	1.0	0.01-.05	1.0-5.0
Barium (ppm Ba)	0.5-1.0	0.5-1.0	-	-
Bicarbonates (as ppm $CaCO_3$)	120	-	3-100	-
Boron (ppm B)	1.0	-	-	0.2-0.5
Cadmium (ppm Cd)	0.01	0.1	0.01	-
Calcium (ppm Ca)	-	-	-	40
Carbonates (as ppm $CaCO_3$)	120	-	200-400	10
Carbon dioxide (ppm CO_2)	-	30	-	20-40
Chlorides (ppm Cl)	250	50	50-250	100
Chromium (ppm Cr)	0.01-0.05	1.0	0.05	0
Color units	15	30	50	-
Copper (ppm Cu)	1.0	0.2	-	0.2
Fluoride (ppm F)	1.4-2.4	5.0	1.5	-
Hardness (as ppm $CaCO_3$)	80	-	50-400	-
Halogonated hydrocarbons(ppm)	0.006	0.01	-	-
Hydrogen ion concentration (pH)	6.5-8.5	6.5-9.0	6.0-9.5	6.0-9.5
Iron (ppm Fe)	0.3	-	0.5	-
Lead (ppm Pb)	0.05	0.1	-	-
Magnesium (ppm Mg)	125	-	-	20
Manganese (ppm Mn)	0.01-0.05	-	0.5	-
Phenolic compounds (ppm)	0.0005-0.001	0.2-1.0	0.001-0.01	0.005-0.02

** In view of the soap and detergent industry's scheduled replacement of ABS with linear alklate sulfonate (LAS) see biodegradable classification.

Suggested Raw Water Quality Criteria - 1966

Ion, Organism or Substance	Water Uses			
	Municipal	Recreation	Industrial	Agricultural
Persistent Chemical (continued)				
Radioactivity	Background	Background	Background	Background
Gross Beta (uuc/L)	1000	-	-	-
Radium (uuc/L)	3	-	-	-
Strontium 90 (uuc/L)	10	-	-	-
Selenium (ppm Se)	0.01	-	-	-
Silica (ppm SiO_2)	10	-	40	-
Silver (ppm Ag)	0.02-0.05	0.01	-	-
Sodium (ppm Na)	0-10	-	50	30-60
Sulfates (ppm SO_4)	250	-	100-250	190
Taste	0	-	-	-
Total dissolved salts (ppm)	500	1000	-	1000
Zinc (ppm Zn)	1-5	0.1-3.0	-	-
Sediments				
Floating Solids	0	0	0	0
Oil (ppm)	0	0.3	0	0
Specific Conductivity (micromhos/cm.)	-	-	-	$25 < K\text{x}10^5 < 300$
Suspended Solids	0.1	absence of sludge deposit	-	absence of sludge deposit
Total dissolved solids (ppm)	500	3000	100-1000	-
Turbidity (Jackson units)	1-25	10-25	250	-

Suggested Raw Water Quality Criteria - 1966

Ion, Organism or Substance	Water Uses Municipal	 Recreation	 Industrial	 Agricultural
	Biodegradable			
Biochemical Oxygen Demand(ppm BOD)	1-3	-	10	10
Cyanides (ppm CN)	0.01-0.2	0.02	0.2	0
Dissolved Oxygen (ppm DO)	4-7	4-7	1-2	0.2
Linear Alkylate Sulfonate(ppm LAS)	0.45	-	-	-
	Bacterial			
Coliform organisms(MPN/100 ml)	1-50	1000-5000	5000	5000
	Thermal			
Temperature (^{o}F)	50	32-93	55-90	60
	Nutritional			
Algae (std. units/ml)	100	absence of toxic algae	1000	absence of toxic algae
Ammonia (ppm Ammonia N)	0.1	1.0-2.0	-	-
Nitrate (ppm Nitrate N)	1-45*	44	-	-
Total Nitrogen (ppm N)	5-10	10	-	-
Phosphates (ppm PO_4)	10	10	-	-

(-) indicates that no values have been established for this broad category.

* Warnings should be administered for infant feeding if Nitrate concentration exceeds 45 ppm.

Many of the individual criteria represent similar things, for example, BOD and DO are cause and effect. If possible, it would appear desirable to reduce this list to a smaller number representative of the principal constituents affecting stream quality. One approach, and perhaps an over simplification, would be to characterize by <u>conserved</u> and <u>non-conserved</u> wastes. In reality, this is an appraisal in terms of the stream's response to an impressed load.

There are six categories of stream responses: Biodegradable, Nutritional, Bacterial, Solids, Persistent or Slowly Degradable Chemicals, and Thermal. The response of a given stream to these categories can be formulated; or the reverse, given an instream criteria (RQS), allowable effluent quality can be calculated. The criteria in the above tables are grouped under the suggested six general headings. If primary treatment is established as a lower constraint on the effluent; the solids criteria can be deleted, and further, if a public health constraint on toxic and bacterial levels can be exercised, four rather than six responses can now be used leaving a four by four matrix to be examined.

	Municipal	Industrial	Agricultural	Recreational
Biodegradable	Controlled by D.O. levels			
Nutritional	Controlled by N or P levels			
Thermal	Controlled by Temperature Increases			
Persistent Chemical	Controlled by Salt, CCE's or ABS, etc.			

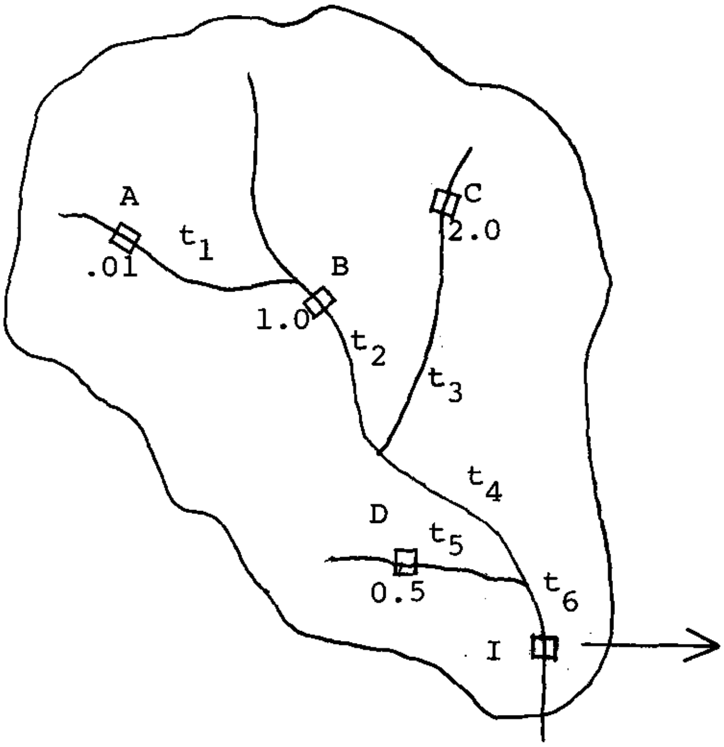
The establishment of water quality criteria should be done without reference to specific rivers, and the establishment of water quality standards, as legally workable values, should be reasonable, realistic approximations appropriate to the current and predictable future stream requirements and capabilities. A socio-economic planning study of the state or basin should indicate the type and level of activity most appropriate for a particular basin or sub-basin and the categorical use for its water. The categorical use will in time, suggest the quality criteria. If the existing water quality is lower than the criteria, the discrete criteria values become asymptotes for both the pollutor and regulatory agencies to work. If the existing quality is higher, the resource may be carefully allocated for additional use.

In time our water resources will be in such a state of critically short supply that we will no longer have the luxury of independent action nor better than minimum standards of quality. It will then be necessary to erase present institutional constraints, develop basin units, and provide minimum standards of performance by locating treatment facilities in an optimal fashion.

Based on a matrix such as the above (4 X 4) and socio-economic projections, a basin model can be built and operated to provide the optimal use of water resources. This can best be explained by a hypothetical case using a greatly simplified basin.

Assume a basin with four discrete waste discharges (A, B, C, D) and one point of intake (I), the river distance between discharges being depicted as length divided by velocity or time (t).

FIGURE II



Model Basin

Further assume that specific waste loading and volumes will be as follows:

Source	Location	Flow	BOD	L	N	T	P
Industrial	A	.01	5000	50	2.5	Nil	Cd=2.0
Municipal	B	1.0	200	200	10	Nil	Nil
Ind./Municipal	C	2.0	250	500	23	=20°	Cr=0.9
Municipal	D	0.6	200	100	5	Nil	Nil
Total	ABCD			850	42.5	-	-

L, N, T, P represent Biodegradable, Nutritional, Thermal, and Persistent Chemical Loads, L and N as pounds per day of BOD and nitrogen, T as rise in degrees, and P as ppm of a specified element.

To develop the model, it is necessary to formulate input-output relationships between RQS on one hand and stream responses on the other. For example, the biodegradable model would be as follows for a continuously applied load:

$$R = (S - RQS) \cdot Q \cdot C_L$$

where R is the permissible load that will maintain the RQS dissolved oxygen level, with a saturation level S, a stream flow Q, and stream characteristics C_L, which is a function of reaeration, reach, velocity, number of successive reuses, and degree of disaggregation required $(n \cdot (D/L) \cdot C_L\ k_2)$.

Using this macro-level model the following values of L_i

were estimated:

Reach (identified by t)	Flow Q	Reaeration or Permissible Load (R)
t_1	0.5	6.0
t_2	5.0	120
t_3	8.0	192
t_4	13.0	104
t_5	5.0	60
t_6	18.0	36
	TOTAL	518

Given the impressed biological load (850) and the regenerative capacity (518) the problem is to write an objective and constraint relationship in terms of possible decisions and subject it to an economic optimization. The decisions will be the level of treatment (e) required at A, B, C, and D. Using three discrete levels, primary, secondary, and tertiary with associated costs:

Treatment	Efficiency (e)		Residual Discharge (1-e)		Removal Cost (C)	
	L	N	L	N	C	Ce
Primary	0.3	(0.3)	0.7	(0.7)	15	5.0
Secondary	0.7	(0.5)	0.3	(0.5)	25	17.5
Tertiary	0.9	(0.7)	0.1	(0.3)	35	31.5

<u>Min Cost</u> <u>Subject to</u>

$$C = \sum_{i=1}^{n} C_i e_i \qquad \sum_{i=1}^{n} L_i (1-e) \leq \sum_{j=1}^{m} R_j \qquad (5)$$

or the minimum cost will be:

$$\text{Min } C = 50 \text{ X } Ce_a + 200 \text{ X } Ce_b + 500\ Ce_c + 100\ Ce_d \qquad (6)$$

subject to:

$$50(1-e_a) + 200(1-e_b) + 500(1-e_c) + 100(1-e_d) \leqq 518 \qquad (7)$$

This problem can be put on a digital computer with instructions to try all possible combinations of e for A, B, C and D at three levels as shown in the print out which follows. It is of interest to note that it required only 50 minutes to program and 5 minutes to run at a total cost of $4.00.

TABLE IX

PRINT OUT

Biodegradable

ABCD IJKL	BOD LOADING	COST	
1111	595.0	4250.0	
1121	395.0	10500.0	
1131	295.0	17500.0	
1211	515.0	6750.0	Optimal Solution
1221	315.0	13000.0	
1231	215.0	20000.0	
1311	475.0	9550.0	
1321	275.0	15800.0	
1331	175.0	22800.0	
2111	575.0	4875.0	
2121	375.0	11125.0	
2131	275.0	18125.0	
2211	495.0	7375.0	
2221	295.0	13625.0	
2231	195.0	20625.0	
2311	455.0	10175.0	
2321	255.0	16425.0	
2331	155.0	23525.0	
3111	565.0	5575.0	
3121	365.0	11825.0	
3131	265.0	18825.0	
3211	485.0	8075.0	
3221	285.0	14325.0	
3231	185.0	21325.0	
3311	445.0	10875.0	
3321	245.0	17125.0	
3331	145.0	24125.0	
1112	555.0	5500.0	
1122	355.0	11750.0	
1132	255.0	18750.0	
1212	475.0	8000.0	
1222	275.0	14250.0	
1232	175.0	21250.0	
1312	435.0	10800.0	

PRINT OUT

Biodegradable

ABCD IJKL	BOD LOADING	COST	ABCD IJKL	BOD LOADING	COST
1322	235.0	17050.0	1223	255.0	15650.0
1332	135.0	24050.0	1233	155.0	22650.0
2112	535.0	6125.0	1313	415.0	12200.0
2122	335.0	12375.0	1323	215.0	18450.0
2132	235.0	19375.0	1333	115.0	25450.0
2212	455.0	8625.0	2113	515.0	7525.0
2222	255.0	14875.0All	2123	315.0	13775.0
2232	155.0	21875.0Secondary	2122	215.0	20775.0
2312	415.0	11425.0	2213	435.0	10025.0
2322	215.0	17675.0	2223	235.0	16275.0
2332	115.0	24675.0	2223	135.0	23275.0
3112	525.0	6825.0	2312	395.0	12825.0
3122	325.0	13075.0	2323	195.0	19075.0
3132	255.0	20075.0	2333	95.0	26075.0
3212	445.0	9325.0	3113	505.0	8225.0
3122	245.0	15575.0	3123	305.0	14475.0
3132	145.0	22575.0	3133	205.0	21475.0
3312	405.0	12125.0	3213	425.0	10725.0
3322	205.0	18375.0	3223	225.0	16975.0
3332	105.0	25375.0	3233	125.0	23975.0
1113	535.0	6900.0	3313	385.0	13525.0
1123	335.0	13150.0	3323	185.0	19775.0
1133	235.0	20150.0	3333	85.0	26775.0
1213	455.0	9400.0			

1 - Primary 2 - Secondary 3 - Tertiary

Nutrient

ABCD IJKL	NUTRIENT LOADING	COST	ABCD IJKL	NUTRIENT LOADING	COST
1121	24.750	10500.0	1213	25.750	9400.0
1122	23.750	11750.0	1221	22.750	13000.0
1123	22.750	13150.0	1222	21.750	14250.0
1131	19.750	17500.0	1223	20.750	15650.0
1132	18.750	18750.0	1231	17.750	20000.0
1133	17.750	20150.0	1232	16.750	21250.0

PRINT OUT

Nutrient

```
ABCD  NUTRIENT                            ABCD  NUTRIENT
IJKL  LOADING     COST                    IJKL  LOADING     COST

1233    15.750  22650.0                   2323    18.250  19075.0
1311    25.750   9550.0                   2331    15.250  23425.0
1312    24.750  10800.0                   2332    14.250  24675.0
1313    23.750  12200.0                   2333    13.250  26075.0
1321    20.750  15800.0                   3121    23.750  11825.0
1322    19.750  17050.0                   3122    22.750  13075.0
1323    18.750  18450.0                   3123    21.750  14475.0
1331    15.750  22800.0                   3131    18.750  18825.0
1332    14.750  24050.0                   3132    17.750  20075.0
1333    13.750  25450.0                   3133    16.750  21475.0
2121    24.250  11125.0                   3212    25.750   9325.0 Optimal
2122    23.250  12375.0                   3213    24.750  10725.0 Solution
2123    22.250  13775.0                   3221    21.750  14325.0
2131    19.250  18125.0                   3222    20.750  15575.0
2132    18.250  19375.0                   3223    19.750  16975.0
2133    17.250  20775.0                   3231    16.750  21325.0
2213    25.250  10025.0                   3232    15.750  22575.0
2221    22.250  13625.0                   3233    14.750  23975.0
2222    21.250  14875.0                   3311    24.750  10875.0
2223    20.250  16275.0                   3312    23.750  12125.0
2231    17.250  20625.0                   3313    22.750  13525.0
2232    16.250  21875.0                   3321    19.750  17125.0
2233    15.250  23275.0                   3322    18.750  18375.0
2311    25.250  10175.0                   3323    17.750  19775.0
2312    24.250  11425.0                   3331    14.750  24125.0
2313    23.250  12825.0                   3332    13.750  25375.0
2321    20.250  16425.0                   3333    12.750  26775.0
2322    19.250  17675.0

      1 - Primary          2 - Secondary          3 - Tertiary
```

The optimal solution is for primary treatment at A, C and D and secondary treatment at B. If secondary treatment had been required at each discharge, the basin would be charged in excess of 2.2 times (14,875 ÷ 6750). Now, the nutritional load should also be examined; only the constraint is changed:

$$2.5(1-e_a) + 10(1-e_b) + 25(1-e_c) + 5(1-e_d) \leq 25.9 \tag{8}$$

Using the 1-2-1-1 decision

$$2.8(.7) + 10(.5) + 25(.7) + 5(.7) = 27.75 > 25.9$$

Since this combination results in a value greater than 25.9, a new combination below 25.9 should be sought. Thus, treatment would be based on N rather than L. To meet this requirement ($\sum N_i \ (1-P_1) \leq 25.9$) we found the treatment combination 3-2-1-2 to give the minimum cost.

$$2.5(0.3) + 10(0.5) + 25(0.7) + 5(0.5) = 25.75 < 25.9$$

Cost = $9325.

Treatment (e) has no effect on P or T and must be handled as requiring dilution.

Source	Dilution (Q/q)	P	T	
A	180	.01 = RQS	-	
B	18	-	-	
C	9	.01 = RQS	$T = 2^{\circ}$	10° allowable
D	30	-	-	

Thus, all 81 possible combinations of treatment have been examined for four stream responses. Any new entrants, or changes in uses or criteria can quickly be evaluated in a similar fashion.

Now that the optimal treatment levels have been assigned it remains to apportion the cost among the discharges. For example, A must pay B the following:

$$\text{Cost to A} = L_a \left[\frac{\text{Total Cost}}{\sum L_i} - Ce \right] \qquad (9)$$

or

$$50 \left[\frac{9325}{850} - 5.0 \right] = 300$$

Specific Quality Constituents

The significance of the most common parameters and potential pollutants encountered in our streams and water courses is discussed below.

Alkalinity

Alkalinity is a measure of buffering power and is a property imposed by the presence of carbonate, bicarbonate, and hydroxide ions, and to a lesser degree by borates, silicates, phosphates and various organic salts. Alkalinity and acidity are related to "pH", the term used to designate the logarithm of the reciprocal of the hydrogen ion concentration. pH values below 7.0 indicate an acidic condition, above 7.0 an alkaline condition. For most water uses, the pH value should be between 6.5 and 8.5. Acidity, generally, is a measure of carbon dioxide concentration but is also indicative of the presence of mineral acids commonly found in industrial waters. In agricultural waters high alkalinity values add to total salinity and are accompanied by high pH values. Fish and other aquatic life are not affected by high alkalinity values when the pH is 9.0 or less.

Arsenic (As)

Elemental arsenic is generally insoluble in water but many of its compounds are highly soluble. Potential sources of arsenic pollution include insecticides and weed-killers as well as the effluent from the paint, glass, and dye manufacturing industries. Arsenic is found in small amounts in body tissues, but is highly toxic to man if it becomes excessive through its carcinogenic properties. Low concentrations of arsenic stimulate plant growth, but the presence of excessive soluble arsenic in irrigation waters will sharply reduce the crop yield.

Barium (Ba)

Barium is a yellowish-white alkaline earth metal which is rapidly decomposed in water to form barium ions. Many of its salts are soluble, but the carbonate and sulfate are highly insoluble. Soluble barium salts are very toxic to man, affecting muscular tissues including heart muscles, blood vessels and nerves. Potential sources of barium pollution include barium chloride and barium nitrate used in the dyeing, paint and explosive manufacturing industries.

Biochemical Oxygen Demand (BOD)

BOD is a measure of the oxygen required for the chemical and biological stabilization of a stream over a specific time interval, most often taken as five days. Aerobic decomposition of organic matter by micro-organisms in the stream requires oxygen in varying quantities. The greater the organic load, the greater the need for oxygen to bring about this decomposition. The effect of a load evidencing a high BOD value is to lower the supply of available oxygen and create conditions which may be detrimental to fish life and other beneficial uses. A high BOD may also indicate an increase in the number of microflora present and interfere with the well-being of larger aquatic life.

High BOD frequently causes complete depletion of dissolved oxygen in streams, and results in an area devoid of fish and higher forms of aquatic life. Such a condition will produce unsightly and malodorous nuisance conditions. An excessive amount of algae, as indicated by a high BOD value, may cause taste and odor complaints and filter clogging. Industrial plants producing high oxygen-consuming wastes (high BOD) include breweries, canneries, dairies, packing houses, and pulp mills.

Synthetic Detergents (ABS)

Alkyl benzene sulfonate (ABS), one of the most frequently used surface active agent in household detergents, is a persistent organic molecule. ABS is persistent to biological attack and remains present in treated sewage. ABS is limited in drinking water to 0.5 mg/l by the PHS Drinking Water Standards. Since drinking water purification processes cannot be depended upon for removing this element, source waters should contain no more than the specified limit. Synthetic detergents interfere with coagulation in water treatment, and may produce unpleasant tastes following chlorination, but most industrial processes can tolerate moderate amounts of ABS. Groundwater pollution by ABS has caused some serious problems, foaming wells being one of the most prevalent harms. ABS also has direct toxic properties upon aquatic life.

Carbonates (as $CaCO_3$)

The concentration of carbonates in natural and polluted waters is a function of the temperature, pH, cations, and other dissolved salts. Certain carbonate salts are removed from polluted waters by precipitation and adsorption due to the fact that they are generally insoluble in water. In chemically treated waters, the USPHS Drinking Water Standards limits the normal carbonate alkalinity to 120 ppm, but places no restriction on carbonates in natural waters. Excessive carbonates and bicarbonates add to the salinity and total solids content of water, thus interfering with the making of acid and carbonated beverages; brewing and ice making and with the desirability for boiler feed purposes. Carbonates are not detrimental to fish life but their buffering action and effect upon pH may contribute to the toxicity of a high pH value.

Boron (B)

Boron occurs naturally in most waters as borax or borates, boric acid and various boro-silicates. For domestic use, waters containing a high concentration of boron is undesirable as it is harmful to man by interfering with digestion due to its preservative action on food. Boron, in small quantities, is essential to the normal growth of all plants, but has a deleterious effect upon certain plants if greater than 2 ppm in irrigation water. Some plants are adversely affected by concentrations as low as 1.0 ppm. Crops may be grouped according to their tolerance to boron, the most sensitive being citrus fruits, nuts, and deciduous fruits.

Cadmium (Cd)

Cadmium is an element of high toxic potential. It is generally insoluble in water and not likely to be found in nature, yet the chloride, sulfate, and nitrate of cadmium are water soluble, and are likely to be found in wastes from pigment works, textile printing, lead mines, and various chemical industries. As little as 14.5 mg of cadmium taken orally will cause nausea and vomiting and small concentrations can be lethal to animals, fish, and plant life.

Calcium (Ca)

The presence of calcium in water in the form of salts or ions results from passage through or over deposits of limestone, dolomite, gypsum and gypsiferous shale but may be found in certain industrial wastes. The calcium content may range from zero to several hundred mg/l, depending on source and treatment of the water. Calcium salts break down upon heating to form harmful scale in boilers, pipes and cooking utensils. Calcium is essential for normal plant growth and for the maintenance of good tilth in soil, and is thus desirable in irrigation water. Calcium in stream water reduces the toxicity of many chemical compounds to aquatic life through its antagonistic effect.

Carbon Dioxide (CO_2)

Carbon dioxide is a product of aerobic or anaerobic decomposition of organic matter, and is soluble in water. Free carbon dioxide in domestic waters has no physiological effect but a high concentration accelerates the corrosion of iron and steel. Restriction of pH, acidity, and alkalinity indirectly controls the carbon dioxide in water for industrial use. Free CO_2 in water increases the solvent action on calcium carbonate in cement and concrete. The sensitivity of fish to carbon dioxide decreases directly with an increase in temperature, concentrations above 12 ppm having a detrimental effect.

Chloride (Cl)

Chlorides are present in nearly all natural waters as a result of soil leaching, salts spread on fields for agricultural purposes, from sewage or from industrial effluents including those from paper mills, galvanizing plants, water softening plants, oil wells, and petroleum refineries. Moderate concentration of chlorides are not harmful to man but a concentration above 250 ppm will impart an objectionable taste to drinking water. High concentration of chlorides in domestic and industrial water will accelerate corrosion in pipes, boilers, and other fixtures. Some fresh water fish are sensitive to chloride concentrations as low as 200 ppm. High concentrations of chlorides will also interfere with food processing such as sugar refining, canning, and frozen food manufacturing. Chlorides are among the most harmful anions in irrigation water being more toxic than sulfates to most plants, including lemons, alfalfa, fruit trees, and potatoes.

Chromium (Cr)

Chromium is found in water primarily due to discharges from various industrial processes such as electroplating, ceramics, paints, and dyestuffs, and as a corrosion controlling agent in cooling and process waters. Chromium is seldom present in natural waters except in trace concentrations. The element in its hexavalent state is toxic to man with as little as 0.1 ppm exhibiting chronic effects. Trivalent and hexavalent chromium are known to be highly toxic to fish and very small amounts adversely affect the agricultural use of waters.

Color and Turbidity

True color is due only to substances which are actually in solution. The unit of color considered as a standard is the color produced by the platinium - cobalt method of measuring, with the unit being one ppm of platinium in water. For an industrial waste, color is defined as the color of the light transmitted by the waste solution after removal of the suspended material, including the pseudocolloidal particles. Turbidity, on the other hand, is caused by suspended matter, such as algae, sand, clay or other insoluble matter. Excessive turbidity or color in streams interferes with domestic and industrial uses, destroys fish spawning grounds, reduces the transmission of light necessary for plankton growth, obstructs navigation channels and causes silting of reservoirs. High turbidity also increases the cost of water treatment due to added chemical consumption and shorter filter runs.

Copper (Cu)

Copper salts occur in natural waters only in trace amounts, but may be attributable to certain industrial effluents. It is found in traces in all plants and animal life, and is essential for nutrition. Copper in high concentrations causes disagreeable taste in drinking water and is also toxic. Traces of copper in the water used for canning foods may affect the oxidation of fats and is generally undesirable for most industrial uses. Minute quantities of copper are beneficial or essential for plant growth, however, 0.17 to 0.20 ppm concentrations have been toxic to certain plants. The toxicity of copper to aquatic organisms varies with the species and the physical, and chemical characteristics of water. Generally copper concentrations from .25 to 1.0 ppm are not toxic to most higher aquatic forms of life.

Coliform Organisms

Coliform organisms may gain access to water from many sources, including excretion from human beings, animals, amphibians, birds, surface run-off, and the multiplication of non-fecal forms of fibrous and vegetable substances in the water. The presence of either type of coliform bacteria renders the water potentially unsatisfactory and of unsafe sanitary quality. The bacterial requirements for industrial water vary widely depending on the purpose of which the water is put. Recreational water must be reasonably free from

Pathogenic organisms. Health authorities recommend a high degree of treatment for sewage effluents to be used in irrigation. Treatment should insure a consistent reduction in coliform bacteria of not less than 90% when sewage is used for irrigation of forage crops.

Cyanides (CN)

Cyanide is not present in natural waters but is found in wastes from electroplating, metal refining, metal working, and certain chemical manufacturing processes. Generally, cyanide does not persist in natural waters, but becomes dissipated by hydrolysis or by bacterial action. Toxicities of cyanide are relative to the dissolved oxygen and pH concentration of the water in which it is found. The tolerance of fish to cyanides increases with the dissolved oxygen content and pH value, but the toxicity of cyanides increases with an increase in temperature. Because of the severe toxic effect, cyanide should not be permitted in waters.

Dissolved Oxygen (DO)

Dissolved oxygen in water is essential to the existance of fish and other aquatic organisms in a well-balanced natural environment. Although oxygen is abundant in the air we breathe, the amount which can be dissolved in water is limited by the temperature of the water. Certain effects on the stream, such as a rise in temperature from cooling water discharges or the addition of chemicals or organic matter requiring stabilization, will cause a reduction in the dissolved oxygen. If the dissolved oxygen is depleted beyond certain limits, this results in an environment unfavorable to the propagation of fish and aquatic life, a large increase in the numbers of undesirable and unsightly microflora, and an increase in taste and odor problems due to the decaying organic matter. Agricultural waters are not adversely affected by DO but high concentration of DO in industrial water creates corrosion problems.

Fluoride (F)

Fluoride is never found free in nature, but it is a constituent of fluorite or fluorspar, calcium fluoride in sedimentary rocks, cryolite, sodium and aluminum, fluoride in igneous rocks. The USPHS Drinking Water Standard allows a limit of 1.4 to 2.4 ppm of fluoride in water. Excessive fluoride in water results in dental decay. Most industrial process waters are not affected by fluoride concentrations of 1.5 ppm or less and fluoride has an insignificant effect on plants in agricultural waters. Effects in stock water are analogous to those on humans and aquatic life is little affected by fluoride levels below 5 ppm.

Hardness

Hardness in water may be caused by the natural accumulation of salts from contact with soil or it may enter from the discharge of industrial wastes such as beamhouse liquors from tanneries. The harmful effects of hardness include excessive soap consumption in homes and laundries, the toughening of vegetables cooked in hard water, and the formation of scale in boilers, hot water heaters, pipes, and utensils. Hard waters have no demonstrable harmful effects upon the health of consumers, however, the role of hard water in the formation of urinary concretion is controversial. Reports from different parts of the world show that the incidence of tooth decay is lower in hard water areas than in soft water areas. Water with a hardness below 50 ppm is often corrosive to metals but excessive hardness is undesirable in waters used for laundries, metal finishing, dyeing and textile industries. Soft water solutions increase the sensitivity of fish to toxic metals; in hard waters, toxic metals may be less dangerous.

Hydrogen Ion (pH)

The symbol pH is used to designate the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. A pH of 7 is considered neutral. Addition of acids lowers the pH value. Wastes from industries as acid dyes, coalmine drainage, sulfite waste liquors, pickling liquor and some brewery discharges will lower the pH of the receiving stream. Wastes of an alkaline nature such as laundry wastes, bottle wash waters, and wool scouring discharges will raise the pH. Raw water pH has an effect on taste, corrosivity, and efficiency of chlorination. For most uses of water, pH should be controlled between the limits of 6.5 and 9.0. Fish and aquatic organisms are adversely affected if the pH is beyond these limits. Corrosive effects of water are markedly enhanced by pH values below 6.0.

Iron (Fe)

Metallic iron is corroded by water in the presence of oxygen and the resulting products of corrosion may constitute water pollution. Natural waters may be polluted by iron bearing industrial wastes such as those from pickling operations, and by the leaching of soluble iron salts from soil and rocks such as in acid-mine drainage. The USPHS Drinking Water Standards of 1962 suggests a limit of 0.3 ppm for the sum of iron and manganese. The limit is not based upon any physiological concern, but rather upon esthetic and taste considerations. Excessive iron is detrimental if the water is used for laundry and carbonated beverage production but is of little importance in irrigation usage.

Lead (Pb)

Lead is found in some natural waters but may be introduced into water as a constituent of various industrial and mining effluents. Lead is a cumulative poison and water should not contain more than .03-.05 ppm. In organic lead salts in irrigation water may be toxic to plants. In water containing lead salts, a film of coagulated mucus forms, first over the gills, and then over the whole body of the fish, causing suffocation of the fish.

Magnesium (Mg)

Magnesium is a common constituent of natural water supplies. Magnesium salts are highly soluble and they contribute to the hardness of water. They also form deleterious scale in boilers. Magnesium is considered non-toxic to man because, before toxic concentrations are reached in water, the taste becomes quite unpleasant. The USPHS Drinking Water Standards recommend a limit of 125 ppm. Magnesium is essential to normal plant growth and limits up to 20 ppm will not seriously affect the condition of underground basins, growth of trees, or condition of the soil.

Manganese (Mn)

The presence of manganese in water causes discoloration, turbidity deposit, and taste. Manganese appears more frequently in ground water than in surface waters and is found in mining effluents along with sulfates, chlorides, or nitrates. In domestic water supplies the presence of manganese causes unpleasant taste, deposits on food during cooking, staining, and fosters the growth of some micro-organisms in reservoirs, filters, and distribution systems. For domestic water supplies a maximum concentration of .05 - .01 has been recommended. An excessive concentration of manganese is undesirable to the textile, dyeing, food processing, and brewing industries. Small amounts of the element are essential for optimum plant growth but a seemingly low concentration may be toxic.

Nitrogen Compounds

The most important inorganic nitrogen compounds likely to be encountered in water, are ammonia, nitrates, and nitrites. These result from the decomposition and utilization of organic nitrogen by the stream biota and are contributed to the streams through sewage and industrial waste discharges. Their presence exerts a secondary effect by promoting the growth of algae. Excessive concentration of nitrates may cause methemoglobienemia (nitrate cynarosis), a condition sometimes fatal to infants.

Ammonia and other nitrogenous materials may also reach the stream from runoff in areas where fertilizers have been utilized. Ammonia is given off as a waste product by chemical plants, ice plants, and some cleaning operations. Ammonia exerts a significant chlorine demand at water plants, thus increasing the cost of water treatment.

Oil-Petroleum

The principal detriment of oil to domestic or municipal water supplies is taste and odor. Industrial waters must be free from oil; and oil pollution is harmful to marine life. Formation of surface films, emulsification, sedimentation and coating of benthal organisms are the four principal effects of oil pollution on fish and other aquatic life.

Phenolic Compounds

These materials occur through discharges from various industries, such as by-product coke plants and oil refineries. Although such substances are highly toxic in large concentrations, their principal effect on streams is the production of unpleasant tastes and odors when the water is processed for drinking. Phenols will increase the BOD by a factor of two times the concentration, and consequently can be expected to be depleted by nature. The USPHSDWS of 1962 set a limit of 0.001 ppm of phenol in drinking water. Phenol in irrigation waters may impart its undesirable taste to crops.

Phosphates

Phosphates may occur in surface or ground waters as a result of leaching from minerals or areas in natural processes of degradation; from agricultural drainage, as one of the stabilized products of decomposition of organic matter, as a result of industrial wastes; or as a constituent of cooling waters that have undergone phosphate treatment. In raw water sources, polyphosphates are detrimental in that they inferfere with coagulation, flocculation, and the lime-soda treatment of water. Phosphates are of little importance in agricultural and industrial waters and do not exhibit toxic effects upon fish and other aquatic life, but an excessive amount may result in an over abundant growth of algae in the stream.

Radioactivity

Radioactive substances are potential pollutants that may be harmful to health and damaging to industrial processes. Mineral deposits, scientific research centers, and radioisotopes in medical therapy are the principal sources of radioactive materials. These substances are not destructable by any known chemical or physical method and must be disposed by dilution with water or stable isotopes. Radiation is divided into four classes of alpha, Beta, Gamma, and Neutron particles or rays. Externally as well as internally, in either air or water, beta particles, neutrons, x-rays, and gamma rays are a hazard. Internally, alpha, and to a less extent, beta particles are particularly hazardous.

As a result of nuclear reactions, water is contaminated by a great variety of fission products simultaneously, while as a result of therapy, research, and industry only one or a few radioisotopes are involved at any one time. Certain radioactive isotopes of strontium, iodine, radium, cesium, and cobalt are very critical because of their long half lives which can produce continued damage over long periods when assimilated. Every effort should be made to confine radioactive discharges to minimum amounts compatible with beneficial uses by man.

Selinium (Se)

Selinium is found in some natural waters or it may be introduced into streams as a constituent of selinigerous industrial wastes. Selinium may increase dental cavaties in man and it may be carcinogenic. It is toxic to man and the USPHS has set a limit of 0.01 ppm for interstate waters. Selinium poisoning produces alkali diseases among cattle, sheep, horses, pigs, and even poultry and the presence of selinium in soil from agricultural waters causes injury to some plants.

Silver (Ag)

Silver is found in both ground and surface waters. Silver salts are used in water purification. Silver metal is used in the processing of food and beverages, and silver nitrate is used in photography, ink manufacture, electroplating, and as an antiseptic. From such sources traces of silver often reach natural waters. 0.01 ppm of silver is sufficient to sterilize water. Fatal doses of silver nitrate for humans has been reported as 10 grams. The USPHS allows no more than 0.02-0.05 ppm in drinking water.

Silica ($SiO2$)

Silica is insoluble in water or acids, except hydrofluoric, but it may occur in natural waters as finely divided or colloidal suspended matter.. Silica is used in industry for making glass, ceramics, abrasives, and petroleum products. Silicates are used in water treatment as coagulants and sodium silicofluoride has been used as a fluoridating agent. Silica in a concentration greater than 20 ppm may cause difficulties arising from turbidity. It is undesirable in boiler feed waters because it deposits on steam - turbine blades.

Sodium (Na)

All natural waters contain compounds of sodium and potassium dissolved from rocks. Most sodium salts are soluble in water, and any sodium ion leached from the soil or discharged into the stream with industrial wastes will remain in solution. Sodium in drinking water may be harmful to those suffering from cardiac, renal, and circulatory diseases. High concentrations of this element in soil may become toxic and deleterious to certain plants. Other harmful effects include foaming in boiler waters, soil clogging, and toxicity to fish.

Sulfates (SO_4)

Sulfates reach streams through soil leaching. Many industries such as paper mills, tanneries, and textiles contribute considerable quantities. Sulfates in association with calcium cause "permanent hardness" in water producing a hard scale in boilers. The USPHS has set a limit of 250 ppm of sulfate for domestic water supplies. Concentrations above this has a laxative effect on humans. Abundant fish life can exist in waters with a sulfate content up to 90 ppm.

Temperature

Temperature changes in streams or bodies of water may result from natural climate conditions or from the discharge of industrial wastes. Temperature affects the palatability, utility for cooling purposes, and the water's suitability as a habitat for aquatic life. In general, cool waters are in greatest demand for most water uses. Survivial of fish is highly dependent upon temperature, and thermal pollution is responsible for a great number of fish killed. The extreme range of temperature in which fish may survive is from 32° to 93°F. Higher temperature increases the consumption rate of oxygen by biochemically oxidizable materials and further reduces the dissolved oxygen content. For domestic purposes a temperature around 50°F is desirable. High temperatures increase the growth of taste and odor producing organisms, increase corrosion, and makes water useless for cooling purposes.

Total Dissolved Salts (Specific Conductivity)

Conductance is one of the most important criteria for the classification of irrigation waters. Natural waters usually contain some quantities of mineral salts in solution, but in waters polluted by brines and various chemical wastes the salt concentration may rise to levels harmful to living organisms. Salinity is expressed as specific electrical conductance. Specific conductivity (K) is expressed as the reciprocal of the resistance in ohms of a column of solution one centimeter long and with a cross section of one square centimeter, at a specified temperature, usually 25°C.

Plants vary widely on their tolerance of salinity, as well as of specific salt concentrations. Soil types, climate conditions, and irrigation practices may all influence the reaction of the crop to the salt constituents. Good drainage of the soil may be a more important factor for crop growth than the salts in the irrigation supply. Municipal waters often contain high quantities of dissolved salts but the USPHS recommends that the salt concentration of good palatable water not exceed 500 ppm.

Total Dissolved Solids

In natural waters the dissolved solids consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, and possibly nitrates of calcium, magnesium, sodium and potassium. Mineral content of natural waters may be lowered by dilution. All salts in solution change the physical and chemical nature of the water and exert osmotic pressure and some have physiological or toxic effects as well. Many authorities, including the USPHS, recommend the dissolved solid concentration of potable water should not exceed 500 mg/l. The USPHS Drinking Water Standards do not set a limiting concentration for suspended solids (in either raw or treated water), but such concentrations are indirectly controlled by the turbidity requirements.

Conventional water treatment methods remove suspended solids, but exert little effect upon dissolved solid concentrations. Dissolved solids removal is done by the method of de-ionization using ion exchange resins, and distillation.

Zinc

Zinc, in the form of zinc chloride and zinc sulfate is soluble in water and commonly found in many industrial and mining wastes. Zinc carbonate and zinc oxide are highly insoluble and will thus precipitate to become more easily removalable from natural waters. Zinc salts are used in paint pigments, cosmetics, pharmaceutics, insecticides and in myriad of industrial processes. Zinc seems to have no adverse physiological effect upon man but high concentrations cause an unpleasant astringent taste in drinking water. Small amounts of zinc are necessary for nutrition in most crops but even a low concentration may become toxic. Zinc is highly toxic to all aquatic organisms. In soft water, .1 to 1.0 ppm of zinc is lethal, but calcium is antagonistic toward such toxicity.

BIBLIOGRAPHY

Arnold, Gerald E., "Thermal Pollution of Surface Supplies", AWWA Journal, Vol. 54, November 1962.

Berger, B. B., "The Goal of Research: Better and Safer Water", Water Works Engineering Journal, Vol. 116, May 1963.

Chamber, Cecil W., Proctor, M., and Kahler, Paul W., "Bacterial Effect of Low Concentration of Silver", AWWA Journal, Vol. 54, February 1962.

Chanin, Gerson, "Solving Odor Problem", Water Works and Waste Engineering, Vol. 1, January 1964.

Craft, T. F., Erb, T. L., and Hill, D. F., "Chemical Analysis of Radioactive Materials in Water", AWWA Journal, Vol. 56, October 1964.

Erdei, J. F., "Control of Taste and Odor in Missouri River Water", AWWA Journal, Vol. 55, December 1963.

Faust, Samuel D., Aly, Osman M., "Determination of 2, 4 - Dischlorophenol in Water", AWWA Journal, Vol. 54, February 1962.

Frost, Colin R., "Effect of Detergents on the Decontamination of Radioactive Waste Water by Precipitation and Coagulation", AWWA Journal, Vol. 54, September 1962.

Gorham, Paul R., "Toxic Algae as a Public Health Hazard", AWWA Journal, Vol. 56, November 1964.

Grune, W. N., "Radioactivity Effects in Water Supplies", Water Works Engineering, Vol. 116, May 1963.

Hager, W. R., DeGeer, M., "Investigation of Natural Brine and Its Control in the Arkansas and Red River Basins", AWWA Journal, March 1965.

Hanes, N. B., Sarles, W. B., and Rohlich, G. A., "Dissolved Oxygen and Survival of Coliform Organisms and Enterococci", AWWA Journal, Vol. 56, April 1964.

Hill, W. H., Shapiro, M. A., and Kobayashi, Y., "Determination of Alkyle Benzene Sulfonate in Water", AWWA Journal, Vol. 54, April 1962.

Hyndshaw, Albert Y., "Treatment Application Points for Activated Carbon", AWWA Journal, Vol. 54, January 1962.

Lehman, J. A., "Control of Corrosion in Water Systems", AWWA Journal, Vol. 56, August 1964.

Liskka R. J., etc., "Evaluation of Methods for Determination of Minerals in Water", AWWA Journal, Vol. 55, May 1963.

Longley, J. M., Engelbrecht, R.S., and Margrave, G. E., "Laboratory and Field Studies on the Treatment of Iron-Bearing Water", Vol. 54, June 1962.

Safferman, R. S., and Morris, Mary-Ellen, "Control of Algae with Viruses", AWWA Journal, Vol. 56, September 1964.

Setter, Lloyd R., "Reliability of Measurement of Gross Beta Radioactivity in Water", AWWA Journal, Vol. 56, February 1964.

Tsivoglou, E. C., Burke, George W., "Radioactivity Standards for Water", AWWA Journal, Vol. 55, June 1963.

Webb, Hubert J., "Water Pollution Resulting from Agricultural Activities", AWWA Journal, Vol. 54, January 1962.

Wilcox, Lloyd V., "Salinity Caused by Irrigation", AWWA Journal, Vol. 54, February 1962.

"Water Quality Criteria", California State Board of Water Pollution, Central Board, Sacramento, California, 1963.

"Status of Fluoridation in the United States and Canada 1963, AWWA Journal, Vol. 57, January 1965.

Stream Sampling (Interpretation of Required Quality Standards)

The required quality standards (RQS) must be viewed in light of their collection point in time and space as well as the laboratory procedure used. When testing or analyzing waters, sewage or other waste effluents to determine their degree of conformity with required quality standards (RQS), samples should be collected in such a manner to reflect actual conditions and composition of the subject matter. Factors such as frequency of sample collection, and time of year for sampling must be taken into account. There is a considerable body of knowledge on experimental design and sampling which, although not elucidated herein, should be implicitly recognized in the standards. Laboratory analytical methods used to determine compliance or non-compliance with quality standards should be made in accordance with the methods and procedures approved by the latest edition of "Standard Methods for the Examination of Water and Waste Water" published by the American Public Health Association and Water Control Federation. Other tests or analytical methods found to be more appropriate under the circumstances could also be utilized.

Samples should be collected as frequently as is necessary to accurately determine the pollution loads on a stream and their compliance with RQS values. Ideally, there should be continuous sampling by means of mechanical testing and recording devices, but this is not generally feasible except, perhaps, for municipal and industrial water supplies. Frequency will depend upon two considerations - uniformity of waste discharge and the statistical formulation of the RQS. Continuous and uniform discharges lead to easily predictable concentrations, most municipal wastes and many industrial discharges are of this type. However, consideration must be given to wastes which are discharged in intermittent or infrequent slugs and the subsequent fluctuation in pollutant concentrations. In such cases sampling would have to be frequent enough to determine the critical peak concentrations. The RQS is specified as an instream value, and as such, the

$$\text{RQS (PPM)} = \frac{\text{(Pollutional Loading)}}{\text{(Stream Discharge)}}$$

Consequently, these values will vary widely regardless of the consistency of the discharged waste concentrations and volumes.

Statistical considerations are of importance in sampling to evaluate the water quality of a stream. Is the sample to be used in finding a daily, monthly or yearly average, or a mean, median, mode or other value? The answer will indicate how frequent sampling should be. For example, for D.O., a daily average is generally required. However, it is necessary to know the daily maxima/minima ratio and its duration; since a low D.O. for a short time may extensively damage fish life (see below). Because of noctural-durial variations, this necessitates a minimum of three samples properly spaced throughout the day.

The total number of samples to be taken depends upon the objectives (in this sense, desired precision) of the over-all program. A well-designed survey with a specific objective will of course require a minimum number of samples. If, for example, the river characteristics are to be determined - especially the D.O. profile - during low flow periods, a few samples, collected at the proper time, generally will suffice. These samples, however, must be collected during critical drought periods if factors influencing the character of the stream are to be accurately investigated. River factors such as flooding at the banks during certain seasons, or a peculiar flow pattern during droughts, etc., may require the collection of more than the minimum number.

Points of sample collection should be selected with great care. Sources of pollution, dilution by branch stream and slope of the river should all be given due consideration. A minimum of four sampling stations (points) is recommended to define confluence. These stations should include: (1) upstream site, where water is clean; (2) stream just below sources of pollution or dilution; (3) stream at worst condition due to a specific source of pollution - bottom of oxygen sag; (4) stream at point midway between bottom of oxygen sag and recovery of oxygen level. Sampling stations should also be located as nearly as possible, at point of uniform cross section, non-shifting bottom, minimum stream width, and average velocity. Studies should be made to ascertain the degree of mixing or discharge effluents from point of discharge.

All samples should be analyzed as soon as possible after collection even with preservatives in the field and on the bank analysis is preferable if feasible. However, some of the detailed tests such as coliform counts, determination of phenol concentration and suspended-solids quantity are more easily performed in the laboratory. Generally bacterial samples must be iced and analyzed within six hours of collection, and chemical samples within twenty-four hours.

Data to be obtained depends upon the objectives of the survey, but it must be remembered that several elements may be necessary to properly understand the pollution load because of interaction. For example, if the oxygen resources of a stream are the main concern of the regulatory agency, D.O., water temperature, and stream flow should be measured over as long a critical period as possible. If the survey is of a general nature, the analyst should undertake as many chemical, physical and biological tests as possible to assist in the later evaluation of the data. Usually surveys containing measurements of rate of flow, temperature, nitrogen, phosphorus, solids, BOD, DO, pH. color, and turbidity can supply information sufficient for design of waste treatment units. Biological analysis are required when the stream water is used for drinking, bathing, or fishing.

Time of year and time of day will also affect stream sampling. In stream studies the concern is primarily with critical conditions of pollution which usually occur when the temperature is greatest and stream flow is lowest. Normally these conditions occur during the summer months. Daily temperature changes are also important, keeping in mind that many parameters vary with temperature (e.g., DO content varies inversely with temperature).

To use a specific example, sampling for DO should be conducted in such a manner that fluctuations in oxygen concentration are noted. In a twenty-four hour period DO levels are usually highest between 2:00 and 4:00 pm due to photosynthetic action, and lowest just before or just after sunrise. Samples for DO, therefore, should include some taken during periods just before or just after sunrise and at any other time likely to be critical, such as periods of exceptionally warm weather, cloudy days, etc. The objective of every stream analyst should be to collect data during critical stream conditions, since the probability of error will be minimzed.

Statistical handling of river data is an important factor in the interpretation of the RQS. Should the RQS parameters be measured as a mean, mode, discrete minima or other value? For example, when studying the "most probable number" (MPN) of coliform bacteria present in a stream, use of the arithmetic mean would not clearly describe and emphasize this number, but the geometric mean or mode may well illustrate this standard more accurately. Consequently, the E. Coli. RQS is a geometric mean value, so the specified RQS can be violated.

The rate of flow level during critical evaluation is also of great importance. Incorporating the so-called absolute minimum flow recorded for a stream would be an unrealistic evaluation, but use of the mean summer or low flow value can also be dangerous since lower flows than this occur quite often. A statistical expression is better, but what level should be used? Some state regulatory agencies use the minimum seven day flow likely to recur once in ten years as the criterion for for designing waste treatment facilities. It should be realized that figures of peak waste flows are significant under certain conditions but the arithmetic mean, for example, BOD values should be required when design is for waste treatment.

The RQS usually refers to a concentration (ppm mg/l) of a pollutant. Damages, and this essentially is what is being evaluated, can usually be assessed in terms of concentration, and most often a Time x Concentration product. When viewed in this way it can be seen that the RQS may represent a chronic or tolerance level rather than an absolute acute level. A chronic standard is one which will result in damage if violated over a long period of time. An acute standard, if violated, will result in instantaneous permanent damage. For example, an exposure to 6 ppm DO for 1½ hours would be essentially the same as 3 ppm DO for 3 hours. This approach is valid insofar as an absolute, toxic lower limit is not violated. Consequently, an RQS of 5 ppm DO is understood to be an average value for 24 hours, with an acceptable spread. That is to say, for 8 hours the value could be 5 ppm or 3 ppm even as low as 2 ppm for 8 hours if there was a 16 hour period of 7.5 ppm. The basic question then is how low can the value be permitted to go, if the daily average is still acceptable, without creating damage. In this instance studies indicate that fish can tolerate 3 ppm DO for as long as 8 hours, if the 24 hour average RQS value is maintained. If the DO drops below 3 ppm, even for short periods of time, permanent damage will result. So 3 ppm DO can be viewed as the acute level for fish. The RQS value of 5 ppm averaged over 24 hours is a chronic level.

The Aquatic Life Advisory Committee recommends that the minimum permissible oxygen concentration for a well-rounded warm water fish population shall be as follows:

> "The dissolved oxygen content of warm water fish habitats shall be not less than 5.0 ppm during at least 16 hours of any 24 hour period. It may be less than 5 ppm for a period not to exceed 8 hours within any 24 hour period, but at no time shall the oxygen content be less than 3 ppm. To sustain a coarse fish population the dissolved oxygen concentration may be less than 5.0 ppm for a period of not more than 8.0 hours out of any 24 hour period, but at no time shall the concentration be below 2.0 ppm."

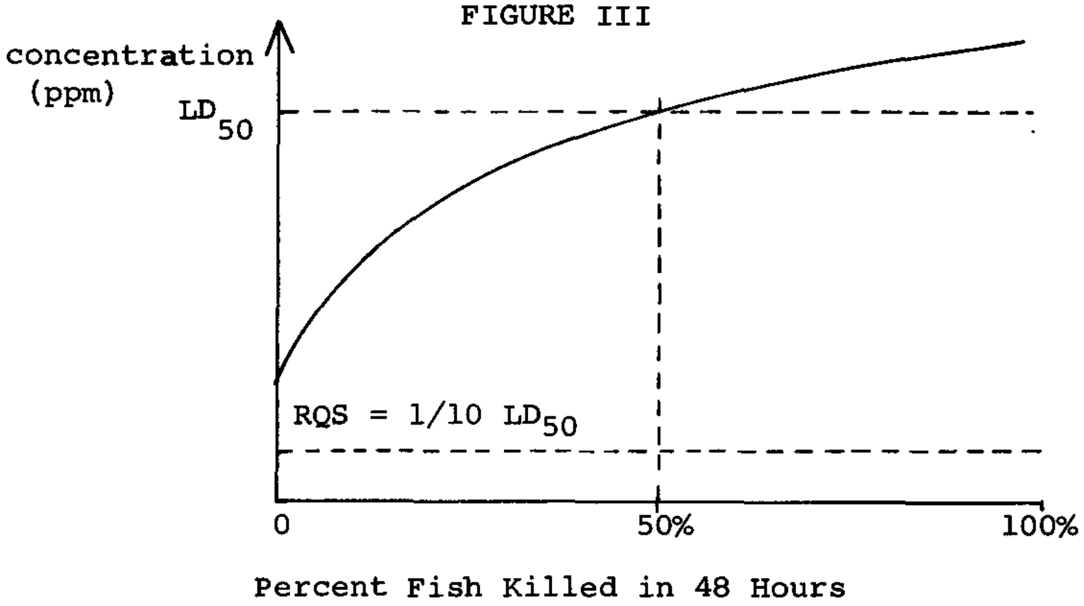
The following table indicates how the DO RQS might be treated (based on the Oklahoma RQS of 4 ppm DO for a 24 hour period):

TABLE X

DO Concentration	Allowable Violation	Allowable Duration	Necessary To Exceed
5 ppm	24 hr.	24 hr.	--
4 ppm	8 hr.	24 hr.	Long enough to maintain average
3 ppm	4 hr.	4 hr.	20 hr.
2 ppm	0 hr.	0 hr.	24 hr.
1 ppm	0 hr.	0 hr.	24 hr.

For recreational waters, the RQS for many persistent chemicals, such as phenol, zinc, and arsenic, are often given as one tenth of the median tolerance level LD_{50}. This median tolerance level is defined as the concentration of the toxic substance that would kill the median number of fish (50%) in a 48 hour period. We can view it graphically as follows:

FIGURE III



It is necesssary to realize, however, that this should be a 3-dimensional plot with a third time axis. Consequently, the RQS represents a chronic toxicity. We may be able to violate it for very short periods of time without causing damage as long as we do not exceed the acute toxicity concentration of a particular chemical. On the other hand, violations extending over long periods of time would result in progressively increasing damage to fish life.

Temperature standards for recreational waters are not well-defined. The Oklahoma RQS reads simply as a temperature range of 32-93^{o}F, but this is insufficient. Fish may be adversely affected by an abrupt temperature differential of more than 9^{o} even if a short duration. Furthermore, although fish might withstand abnormally high temperatures for short periods of time, they cannot complete their life history at such high temperatures. For good propagation temperatures within a favorable range are required. Limits on seasonal temperatures should be established - otherwise stream biota and food chains may be destroyed, or spawning may be induced at unnatural times.

The RQS for coliform density might be viewed in a different way. It makes use of the monthly geometric mean of many samples, as well as a maximum concentration or chronic level. The chronic level is set at a coliform most probable number (MPN) of 2400/100 ml. If this is exceeded, the probability of swimmers contracting bacterial infection due to repeated exposure may become too great. Since the coliform population can explode in a relatively short time due to a geometric reproduction rate, the further control is put on the RQS. A monthly geometric mean of 1000/100 ml (MPN) must be maintained with no more than 20% of the samples exceeding the mean, and no sample exceeding 2400/100 ml. This protects against the coliform density suddenly getting out of hand.

To summarize, in order to adequately determine compliance of stream waters with the RQS values, data must be obtained by means of correct sample collection and analysis, and the data must be properly interpreted by use of statistical methods. Factors to be taken into account include: frequency of sampling, number of samples taken, time and place of sample collection, and methods used to analyze samples. Proper statistical interpretation of the data insures a proper understanding of the meanings of the RQS values. To be able to provide more meaningful RQS values will require a much greater depth of information as to chronic and acute tolerances than is available from present sources. Presently, only minimal data is available for DO, Temperature, and *E. Coli.* with virtually no reliable data for the other parameters.

BIBLIOGRAPHY

Bean, Elwood L., "Progress Report on Water Quality Criteria", AWWA Journal, Vol. 54, November 1962.

Gloyna, E. F., "Water Quality Evaluation", Presented at Texas Section (ASCE) Spring Meeting, 1959.

Hurtung, H. O., "Practical Considerations in Defining Quality Water", AWWA Journal, Vol. 57, March 1965.

McCartney, David M., Beamer, Norman, H., "Continuous Recording of Water Quality in the Delaware Estuary", AWWA Journal, Vol. 54, October 1962.

Patrick, Ruth, "Effects of River Chemical and Physical Characteristics on Aquatic Life", AWWA Journal, Vol. 54, May, 1962.

Rosebery, Dean A., "Relationship of Recreational Use to Bacterial Densities of Forrest Lake", AWWA Journal, Vol. 56, January 1964.

Silvey, J.K.G., Roach, A.W., "Studies on Microbiotic Cycles in Surface Waters", AWWA Journal, Vol. 56, January 1964.

"Standard Methods for the Examination of Water and Waste Water", American Public Health Association and Water Control Federation, New York, 1955.

"Subfactant Effects on Humans and Other Mammals", The Soap and Detergent Association, Scientific and Technical Report, No. 4, November 1966.

Sylvester, R. O., Seahloom, R.W., "Influence of Site Characteristics on Quality of Impounded Water", AWWA Journal, Vol. 57, December 1965.

Tarzwell, Clarence M., "Development of Water Quality Criteria for Aquatic Life", WPCF Journal, Vol. 34, November 1962.

Tarzwell, Clarence M.,"Water Quality Criteria for Aquatic Life", United States Department of Health, Education and Welfare, 1957.

Tarzwell, Clarence M., Gaufin, A. R., "Some Important Biological Effects of Pollution often Disregarded in Stream Surveys", Proceedings of the 8th Industrial Waste Conference, Purdue University, May 1953.

Taylor, Floyd B., "Effectiveness of Water Utility Quality Control Practices", AWWA Journal, Vol. 54, October 1962.

"Water Quality Criteria", California State Board of Water Pollution, Central Board, Sacramento, California, 1963.