

Water Pollution Surveys

Training Course
held in May-June 1980



**INSTITUTE OF
PUBLIC HEALTH ENGINEERING
AND RESEARCH**

UNIVERSITY OF ENGINEERING AND TECHNOLOGY LAHORE-31 PAKISTAN

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FOREWORD

Water is an important natural resource. Pakistan is fortunate in having a great heritage of inland waters in the form of extensive river systems. As the demand for water for public supply, for industry, for irrigation and for recreational purposes increases it is our responsibility to keep our clean streams and rivers in their present state and to rid others of pollution. The need for a national policy on water pollution control should therefore not only be recognised but also measures taken now to provide institutional framework for its implementation. In addition to voicing this need at appropriate forums in the past this Institute undertook a programme of monitoring of Ravi river near Lahore with a view to assess the state of its pollution and to highlight the imperatives of treating the wastewater being discharged into it. This programme has generated data which is now available in the form of technical publications of this Institute. Due to the success in its implementation this programme can act as a model for monitoring of natural water bodies which are subject to pollution elsewhere in the country. A notable aspect of this work is that an opportunity was made available to the Institute staff in gaining valuable experience in planning and conducting river pollution surveys. This prompted the Institute to organise and offer the present Training Course on Stream Pollution Surveys so as to share the experience and knowledge with those interested in the environmental protection in the country.

The Course was held at this Institute from 31st May to 5th June 1980. The organisations which nominated their engineers and scientists to participate in it included important industrial establishments, reputable engineering consulting firms, development authorities of major cities and the provincial public health engineering departments in the country. The Course programme consisted of lectures followed by discussions, laboratory work and a field visit to some of the monitoring stations on the Ravi river for demonstrating the use of equipment and procedures which are essential part of stream pollution surveys. The general feedback from the participants was very favourable.

Professor Dr. A.H. Qureshi, Vice-Chancellor University of Engineering and Technology Lahore gave away certificates of accomplishment to the participants. Addressing the concluding session of the Training Course he stressed the need to provide safeguards for environmental protection in the national development efforts. He appreciated the work of the Institute and noted with satisfaction that by offering of this Training Course the Institute has contributed towards building up necessary expertise in the important field of environmental protection.

I take this opportunity to bring on record the role of the WHO/UNDP assistance which has contributed in a large measure to the success of this Training Course. In fact this assistance has gone a long way in expanding and strengthening of research facilities including Staff development at this Institute enabling the Institute to offer a number of training programmes and undertake research studies in the relevant fields. I

also take this opportunity to gratefully acknowledge the work of the Staff of the Institute including WHO staff namely Dr. Ping-Wah Lin WHO Project Manager and Dr. W. J. Schaefer WHO Sanitary Chemist who contributed to the success of this Training Course. Thanks are extended to Mr. Waris Ali Assistant Professor and Professor Dr. Javed Anwar Aziz who helped in the programme co-ordination and preparation of the final manuscript.

Lahore
12th August 1980

DR. MOHAMMAD NAWAZ TARIQ
Director and Professor of
Public Health Engineering.

COURSE PROGRAMME

Saturday 31st May 1980	0800	Registration
	0900	Planning and Management Principles in Stream Sanitation
	1030	Break
	1100	Nature of Stream Pollution (Organic)
	1230	Nature of Stream Pollution (Inorganic, Bacterial and Viral)
Sunday 1st June 1980	0730	Identification and Measurement of Sources of Pollution
	0900	Role of Biological Life in Streams
	1030	Break
	1100	Sampling Station Selection
	1230	Sampling Procedures
Monday 2nd June 1980	0730	Laboratory Techniques
	0900	Laboratory Techniques
	1030	Break
	1100	Laboratory Techniques
	1230	Stream Flow Measurements and Analysis of Flow Data
Tuesday 3rd June 1980	0730	Dissolved Oxygen Sag in a River
	0900	Field Visit
Wednesday 4th June 1980	0730	Analysis of Stream Pollution Data
	0900	Waste Assimilation Capacity of Streams
	1030	Break
	1100	Mathematical Modelling in Stream Pollution Control
	1230	Stream Standards
Thursday 5th June 1980	0730	Pollution Control Planning for Streams
	0900	Course Review
		Presentation of Certificates Photograph

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PLANNING AND MANAGEMENT PRINCIPLES IN STREAM SANITATION

DR. M. NAWAZ TARIQ

Director and Professor of Public Health Engineering

Introduction

Natural systems are credited with order and stability. The economic activities of man disturb these systems. One such system encompasses water in rivers and streams, an aspect of which is the topic of discussion for our short course. Stream sanitation (Potomology—science of rivers) should be looked upon as an integral part of the broader problem of the development, use, and management of the total water resource. Water is the life blood of a community as the socio-economic structure of any community is shaped to a large degree by the water resource available and how it is used, developed, and managed. Two unique characteristics of water resources should be appreciated if a rational balance among uses is to be attained; first, that water is a dynamic resource; second, that it is inherently a multiple use resource.

In addition to a very unequal geographical distribution, water in the natural setting is a highly dynamic resource. Unlike a fixed mineral deposit, water varies in the amount that is available at any location from day to day and season to season. Seen from aloft a river appears as a fixed entity whose size is measured by the number of square miles of tributary drainage area, but seen from a location on its bank a river becomes dynamic, its size varying with the amount of water flowing by in a unit of time. What appears to be a large river during floods may become a small stream during dry season. It is this highly dynamic character of streams that adds to the difficulties of dependable use and control of quality.

Nevertheless, 'dynamic' does not mean 'chaotic'; observed over a period of years, stream run-off, although variable, is orderly, following the laws of chance occurrence—unless the natural setting has been tampered with. Statistical analyses of the run-off record determine the range of stream-flow available and the drought severities that can be expected. Man must either design his activities within this range of variation and decide on a level of risk of water shortage during drought or develop the water resource by such practice as drought control to regulate variations between the extremes of flood and drought. In turn the capacity of the stream to handle pollution and associated water quality are not fixed quantities but rather ranges in potential paralleling the natural variations in stream flow.

THE PLANNING CONTEXT

Definition

If water is withdrawn from the stream, it may be used in homes, industries, or farms. If the water is left in the stream, it serves as a transportation artery, a place to

fish, boat, or swim, and contributes to the environment which makes a community a pleasant place to live in. Finally, streamflow may be used to carry waste material away from homes, factories, or mines. Streamflow has a value in use, a value in transit, and a value as a waste carrier. The first two functions compete with the third because a waste load infringes on the value of water in other uses.

Water quality planning requires selection and preservation of water quality standards, the rules specifying the kinds and quantities of waste material which will be permitted to enter the stream. It is not in the public interest to allow everyone to discharge waste material freely into streams, but it is equally unwise to outlaw all use of the stream as waste carrier. Optimum water quality control lies at the point between these two extremes where the sum of the value of the water in the three uses is a maximum. At the optimum water quality standard, the marginal decline in the sum of the values of the water in use and transit which would be caused by the discharge of additional waste material equals the marginal cost incurred in waste treatment or nonstream disposal to maintain the standard.

Types of Pollution

The impurities in water can be divided between degradable (non-conservative) wastes, which decompose into harmless substances or are otherwise removed from the stream by natural biological, chemical, or physical processes, and non-degradable (conservative) wastes, which are not altered by such processes. The first class includes domestic sewage, heat, plant nutrients, most bacteria and viruses, and non-colloidal sediments. The second includes salts and other inorganic chemicals, radiological waste products, persistent organic chemicals including many detergents and agricultural chemicals, and colloidal suspensions. Contamination refers to impurities posing a hazard to human health.

The only natural process mitigating the adverse effects of non-degradable wastes in the stream is dilution. Their concentration at any point can be predicted by dividing the weight of waste material entering the stream by the quantity of diluting water.

The concentration of a degradable waste is much more difficult to predict because it is reduced by natural processes as the waste travels downstream. Organic-pollution load is measured by biochemical oxygen demand (BOD), the oxygen in parts per million which would have to be withdrawn from the stream to oxidize all the organic material into relatively harmless compounds. Stream oxygen balance depends on the rate that oxygen is withdrawn from the stream to oxidize the organic material (deoxygenation) and the rate oxygen dissolves in the stream from the air (reoxygenation). If the BOD completely depletes the stream of dissolved oxygen, the resulting anaerobic conditions retard decomposition, produce objectionable odors, and kill fish and other water life. Because the solubility of oxygen in water varies inversely with temperature, the danger of anaerobic conditions is greater in summer than winter and greatest during summer low-flow periods. Heat pollution, primarily caused by use of water for industrial cooling, aggravates deoxygenation.

By oxidizing organic matter, waste-water treatment liberates the mineral constituents. These dissolve in the effluent and fertilize aquatic vegetation, particularly unicellular algae. Phosphates are the biggest offender. The luxuriant vegetation in the receiving water produces obnoxious odors, clogs intake structures, and may become toxic to desirable plants and animals. The resulting aesthetic and economic degradation is called eutrophication and is rapidly becoming the major fresh-water quality problem.

Coordination with other Project Purposes

Each water use has distinct water quality requirements and distinct effects on the quality of the water it uses. Water used for domestic supply must be free from disease-causing bacteria and viruses as well as toxic chemicals and must contain a minimum of unattractive tastes, odors, or colors. Corrosive or hard waters may harm household appliances or plumbing and increase soap use. Domestic water quality requirements are primarily to preserve human health, make water psychologically more pleasing to the user, and reduce the cost of household appliances and plumbing. Waste water from residential areas contains large quantities of degradable waste, bacteria, and nondegradable household chemicals.

About 80 percent of industrial water use is for cooling, and about 20 percent is for use in other industrial processes. Cooling water should have a low temperature and be free from corrosive and scale-forming materials. Process uses tend to be more sensitive to water quality than cooling uses are, but the exact water quality requirements depend on the nature of the process. For example, iron, manganese, and carbon dioxide interfere with paper-making processes; and steel rolling mills are damaged by high chloride concentrations. The primary effect of the cooling use on water quality is the addition of heat, which limits cooling use by others and reduces stream-oxygen content. Industrial-process wastes are widely varied, and some are extremely toxic or otherwise objectionable. A single food or paper-processing plant may produce as much waste as a medium size city.

Irrigation requires water free from chemicals or bacteria toxic to plants, to persons or animals who eat the plants and from chemicals which react with the soil to produce unsatisfactory moisture characteristics. Boron concentrations over 4 ppm harm most crops. Selenium is absorbed in the plant and is toxic to livestock. When sodium cations exceed about 10 percent of the total, the aggregation of soil grains begins to break down to make the soil less permeable and crust when dry and to cause its pH to rise above tolerable limits. Crusting restricts soil drainage and aeration. Total dissolved solids in excess of 700 ppm restrict plant osmotic activity and absorption of soil nutrients. Water quality requirements vary greatly among plant species and become more restrictive for soils of lower permeability or in areas of high water table. A given crop is more salt tolerant in cool than in warm climates. The salt tolerance of a specific crop depends on the sensitivity of the plant to increased osmotic pressure. Bacterial contamination is a threat to public health when severely contaminated water is used to irrigate vegetables customarily eaten raw.

Irrigation return flows are normally more saline than the applied water, because of evapotranspiration losses and the use of the water for leaching soil salts. Agricultural chemicals occasionally contaminate return flows and add phosphates to intensify eutrophication. Quality improvements include lower temperatures, turbidity, and coliform bacteria counts. Drainage flows from humid areas are normally less saline than irrigation return flows but may contain toxic agricultural chemicals.

Surface mining, logging, heavy construction, and forest fires destroy soil cover and substantially increase the sediment content of runoff until the cover is restored. Coal and mineral ore mines may discharge acid or other harmful chemicals into the water. Petroleum production brings brackish water to the surface that may enter the stream if it is not returned to underground aquifers.

Fish require a minimum of dissolved oxygen of about 4 ppm, and no water-related wildlife, can tolerate anaerobic conditions. Many agricultural and industrial chemicals

are toxic. Any activity which disturbs the natural, ecological environment of the stream is detrimental to natural habitats. Since specific fish species require specific salinity and temperature ranges, slow changes may cause a habitat to shift from one species to another, and fluctuations too rapid for biological adjustment will eliminate most species. Waterfowl may be harmed by pollution of their breeding and feeding grounds.

Recreation requires water free from disease-causing bacteria or viruses or poison causing bodily harm upon internal or external contact and is enhanced by the absence of aesthetically uninviting colours, odours, or turbidity in the water.

Municipalities may restrict the recreational use of their water supply reservoirs and even of the tributary watersheds through fear of pollution. The trend has been toward opening municipal reservoirs for multiple use as long as the facilities are properly maintained and adequate waste-disposal methods are provided and used.

The water quality requirements for navigation and hydroelectric power projects are minimal. Turbines or propellers may be harmed by unusually large sediment or debris and various corrosive chemicals. Chemical cleaning residue may be left in the water, and reservoir storage may significantly reduce stream waste-carrying capacity. Flood control works are unlikely to reduce water quality.

Reservoirs affect downstream water quality in a number of ways. A net evaporation loss increases average downstream salinity. Sediment deposition in the reservoir reduces downstream turbidity. Reservoirs tend to delay river temperature rise. Reservoir stratification will reduce the dissolved oxygen content of the released flows. Degradable wastes change much more slowly in ponded than in flowing water. Inadequate clearing of organic material from a reservoir site may have a number of undesirable effects on water quality.

Developing the Supply

A great many methods must be coordinated in formulating the optimum water quality control system. The technical design of system elements is described in sanitary engineering literature, but it is necessary to review the basic approaches briefly in order to understand how they may be coordinated effectively.

Wastewater Treatment

Waste-water-treatment plants improve the quality of waste-water before it is discharged into the stream. Communities can remove degradable organic wastes by primary treatment (screening and sedimentation) supplemented by secondary treatment (use of biological processes) to accelerate the self purification which occurs in natural waters. New tertiary treatment processes are being developed to further purify the effluent from secondary treatment. Where the use of water as a waste carrier conflicts with its value in use rather than with its value in transit, the water may be treated as it is withdrawn.

Unit treatment costs vary with the volume of waste flow to be treated, the variability of the rate of incoming waste flow, the concentration of the waste, the character of the waste, and the required degree of waste removal. Cost increases with the purity of the required effluent.

Water may be taken from a river, used, and returned with a waste load several times on the way to the sea. The cost of required treatment before use is reduced by

natural purification within an intervening river reach. Popular aesthetic objections to direct recirculation of treated waste-water into urban supplies also diminish if the natural purification processes of streams or aquifers are used.

Within a recirculation system, economic trade-off possibilities exist between waste and water supply treatment. The more completely wastes are treated before being discharged into a stream, the less completely water supplies must be treated after they are withdrawn. The optimum combination of waste and water supply treatment is that which maintains the desired water quality standards for water in use and water in transit at least cost.

Smaller communities and industries may realise economies of scale in combining to build one large, rather than many small, treatment plants. Treatment-plant construction cost per volume of water treated declines with plant size. Large plants can afford more highly skilled operators who are able to run the treatment process more efficiently. Both savings may be offset by the increased cost of a collection system which must bring the wastes from greater distances and difficulties with objectionable chemical reactions or odours in transit. The economically optimum plant size has the minimum sum of plant costs and collection costs.

Wastewater Dilution

Since the harmful effects of pollution increase with waste concentration, damages may be reduced by bringing the time patterns of waste discharge and streamflow more in line with one another. One method is low-flow augmentation by which reservoirs provide water for supplementing flows during dry periods. An alternative approach is to build storage facilities to contain the wastes during dry periods for release into the stream during times of higher flow. The two approaches may be combined in a search for the least-cost combination. Streamflow regulation is most profitable for increasing extreme low flows, and waste-storage facilities are most profitable for dampening peak rates of waste accumulation.

Wastewater Separation

Cities may provide separate systems for collecting their storm runoff and their sanitary wastes. More recently, large-scale specialized channels to carry non-degradable wastes, which cannot be removed at reasonable cost by treatment, and to provide waste collection to take advantage of the economies of scale of large treatment plants have been proposed. Such channels or pipes can also be used to distribute outlet points into the receiving water geographically in the manner best promoting water quality management objectives. Some treatment is required before discharging industrial or municipal wastes into a specialized channel to prevent degradable wastes from producing particularly undesirable odours or appearances. Lining may be required to prevent the waste material from contaminating the ground water. The cost of waste transport includes the value of the water required to transport the wastes. A major advantage of carrying more concentrated wastes in a separate channel is the resulting savings in water used.

Industrial Process Modification

Pollution damages may also be reduced by process adjustments by industries who discharge their waste into the stream or who use the stream for water supply. An industry discharging waste might shift to an industrial process producing smaller quantities of a less obnoxious type of waste material, or it might re-schedule its operations so

that more of the waste would be produced during high-flow seasons. A water using industry might shift to an industrial process less sensitive to poor water quality or re-schedule its more sensitive processes during high-flow periods. It might store high-quality flows for use during periods of low-quality flow or develop an alternative ground-water supply for temporary use. A cost analysis is needed to evaluate each potential adjustment. Water pollution damages may also be reduced by incorporating water quality consideration in industrial location decisions. Industries requiring a high-quality water supply should locate in upstream areas, and industries discharging an extremely low-quality effluent should locate downstream.

Stream Monitoring and Survey

In the management of stream water quality a system of monitoring may involve setting up of sampling stations for collection of continuous or routine periodic samples and their analysis in the laboratory as well as arrangements for stream flow measurements.

Engineering measurements for water quality control are economically justified if they reduce the damage caused by poor water quality by an amount in excess of their cost. Benefit evaluation thus require evaluation of damages involving economic analyses.

SYSTEM MANAGEMENT

Economic Optimization

Water pollutants do not endanger health or produce other undesirable effects if their concentration is low enough. As concentrations increase, a point is eventually reached where consequences to public health, community development, or others become too severe to be permitted. This threshold concentration defines a minimum acceptable water quality standard selected on the basis of known qualitative factors. Economic damages are evaluated to determine whether a higher standard can be justified. Many non-degradable wastes are not detrimental in certain concentration ranges to health, wildlife, or aesthetics; but they may inflict an economic damage to industry or agriculture great enough to warrant water quality improvement measures.

Water quality standards determined by economic optimization display several characteristics. The optimum concentration of waste material increases with decreasing flow rate because of the increasing marginal cost of removal. As waste discharge which can be prevented at little cost is stopped, further prevention becomes increasingly costly. The optimum concentration rises downstream from each urban area because of the resulting demand for waste disposal. Optimum concentration also increases as the river proceeds downstream because fewer parties remain further downstream to be harmed.

Coordinated System Management

The goal of river-system water quality management is to minimize the sum of the damages caused by poor water quality and the cost of water quality control measures. Difficulty in damage measurement has often caused substitution of the approximate goal of maintaining set of water quality standards at least cost. Unless an economic analysis is performed to determine optimum standards, arbitrarily set standards may result in non-optimum development. Some management alternatives (low-flow augmentation and a specialized waste channel) may be accomplished by public agencies, but others (location adjustment, waste-water treatment, and modification of waste discharge patterns) require action by industries and municipalities. Successful water quality management must get

all these diverse groups to work together efficiently through a combination of legal regulation and economic incentives.

A sound program of water quality management should (1) make those who discharge wastes responsible for the effects of their action; (2) consider the implications of extra-market values; (3) encourage a balance between the cost of the measures employed and the gain in value achieved through higher water quality; (4) encourage economies of scale in pollution treatment through cooperation among industries, municipalities, and other parties; (5) be flexible enough to adapt to local needs. Even where extra-market considerations determine the standards, economic efficiency requires the marginal cost of each water quality control effort to be equal. The greatest weakness of uniform water quality standards is the elimination of diversity, which should exist in order to reflect local conditions. Having some streams of very high and others of very low water quality may be better management than having every stream contain a standardized marginal-quality water.

Establishment of a Management System

As urban and industrial growth impose a greater burden on the waste-carrying capacity of rivers and streams, increasing effort must be directed toward water quality management. The task of regional water quality management is to supplement projects constructed for water pollution control by measures which prevent the uninhibited discharge of wastes into streams from eliminating projects benefits and to coordinate the planning of structural with the planning of other management measures. The task begins with the establishment of an agency jurisdiction over the drainage basin and authority to enforce, finance, and operate an effective program. The agency must be institutionally free to explore and implement as necessary all management alternatives and technically capable of doing so. The agency must assemble regional concentration-damage, concentration-flow, and flow-duration data and analyse it to set regional water quality standards after giving due consideration to extra-market values. The agency must formulate an enforcement program combining legal regulation with the use of less costly and more efficient economic incentives. Finally, the program must be implemented and periodically modified to reflect changing conditions or advance in knowledge

The water quality management agency should be free to select its standards according to conditions within its jurisdiction and vary its standards from stream to stream and point to point on the same stream. Within a large river basin, sub-basin agencies must agree to mutually acceptable quality standards at the points where rivers flow from one jurisdiction to another. The water quality agencies must also coordinate their efforts with those of the water supply and other water resource agencies serving the same region. Coordination with agencies serving other areas or purposes is one of the most complicated but essential elements of water resources management.

NATURE OF STREAM POLLUTION (ORGANIC)

DR. W. J. SCHAEFER
WHO Sanitary Chemist

Introduction and Definitions

In a lecture on the nature of stream pollution, it is first necessary to clarify the term "pollution" as far as it refers to streams or to water in general. Apart from "pollution", the terms "contamination" and "impurities" are sometimes used in the same sense. This, however, is not precise.

Defining pollution appears to be very simple. Polluted water is a water that is not pure. That would imply that all impurities in natural water are pollutants. But this is not so. Pollution is an unwanted phenomenon, it is to be avoided. Impurities, however, cannot be avoided. In the whole of nature, there is not such a thing as pure water, meaning water which does not contain anything, being nothing but the pure compound H_2O . Even in rain water, even in mountain lakes or in melting snow you find some impurities, dissolved gasses, for instance, and dissolved solids. Pure water can only be prepared in a laboratory, and even the distilled water, commonly referred to as pure, contains traces of various impurities.

It is not every impurity that renders water polluted. According to Sartwell's handbook on Preventive Medicine and Public Health, polluted water means water containing those impurities which impair the physical and chemical qualities such as colour, turbidity, taste; and water containing organic matter and contaminants. Some of those water impurities which are the cause of pollution find their way into the water without any action of man. This type of pollution is often called "Natural Pollution". Its level is generally quite low as compared with man-made pollution. However, particular aspects of natural pollution, e.g., the amount of suspended matter in a river after rains, can attain a great magnitude.

The term "contamination" is sometimes used as a synonym for pollution. According to Sartwell, however, "contamination" has a specific meaning. It is that type of pollution that presents a direct hazard to health. Contaminated water contains pathogenic (disease producing) micro-organisms or chemical substances in concentrations that directly affect human health.

The nature of stream pollution, be it natural or man-made, may be classified into organic pollution, inorganic pollution, and bacterial-cum-viral pollution. Classifications other than this are also conceivable, e.g., into physical, chemical and microbial.

There is a great number of substances and organisms that potentially pollute the streams. For a stream pollution survey, we want to identify these substances and

organisms are to be identified and measured. In other words, they should be determined qualitatively and quantitatively.

However, as the substances and organisms in question are so numerous, it is not always possible to analyse them individually. It is also often not necessary to do so, rather it is sometimes sufficient to determine certain groups of substances (e.g., total dissolved solids or organic nitrogen) or select indicators for other pollutants (e.g. ammonia or coliform organisms) or measure something that is no "substance" in itself but rather a characteristic of certain substances in water (e.g., electrical conductivity or BOD).

Whatever is measured because of its significance for pollution survey is called a parameter. So, a parameter may be an individual substance (e.g., chromium or chloride), an indicator, or a certain characteristic of the particular water.

Organic Pollution

Organic pollution means pollution with organic substances or organic matter. It does not mean the presence of living organisms, which will be dealt with later.

The name "organic substances" was coined long ago for a certain group of compounds. These were believed to be produced by plants and animals only. Later, however, chemists were able to synthesize many of these substances. Moreover, a very great number of new compounds, which nature is not able to produce has been synthesized and this number is still increasing. Since the chemical composition of these new compounds follows the same basic principles as is found in those produced by organisms, the name "organic" has been retained for all of them. Organic substances now no longer refers to the origin of compounds. But to all compounds (with very few exceptions) that contain the element carbon.

It is one of the properties of many organic compounds that they are not stable in natural water. They are decomposed or degraded. This decomposition is effectuated by the microbial life in water, therefore, the substances able to undergo decomposition are called "Biodegradable."

There is a continuous scale of the ease of biodegradation, ranging from very easy to very difficult. Almost all organic substances that pollute streams will eventually be decomposed by micro-organisms, but for some of them it will take a considerable length of time. There are compounds which may persist in water for months or even years. This type of organic substances may be called "Persistent."

Biodegradable Organic Pollutants

The organic compounds which are easily decomposed are generally those produced by plants and animals. A great number of them is related to food. They are either wastes of food itself or, to a considerable extent, human and animals excreta. The majority find their way into the stream in untreated domestic sewage. However, the effluents of dairies, food processing or canning factories, beverage industries, etc., may also be the origin of this type of organic pollutants. Biodegradable compounds other than food are discharged in the wastes of textile industries, paper mills, tanneries, and so on.

Food for humans and higher animals is mainly composed of 3 classes of organic substances: carbohydrates, proteins, and fats. Although other substances are essential

for a balanced diet, notably vitamins and certain minerals, they can be neglected because their quantity is so small. In average domestic sewage, 60-70% of the total solids is organic matter, and of this organic matter, about 50% is made up of carbohydrates, 40% of proteins and derivative products, and 10% of fats. These classes will be described below in some more detail.

Carbohydrates

All the compounds that fall into this large group are composed of carbon, hydrogen and oxygen. The hydrogen to oxygen ratio is always 2 to 1. Since this is the same ratio as that of hydrogen to oxygen in water (H_2O) it was believed in the olden days that these compounds contain water molecules somehow attached to carbon. Hence their name: carbohydrates, meaning hydrated carbon. This should not be mixed up with hydrocarbons, which are completely different type of organic substances. Later on, the chemists found out that this is not the case and that this ratio is a mere coincidence. The definition of carbohydrates is now quite different (polyhydroxy-aldehydes or ketones) and it is not necessary here to explain this chemical term further. The old name carbohydrates, however, dies hard, like many other obsolete things, although it has been replaced by the more accurate term "saccharides."

There are monosaccharides, disaccharides and polysaccharides. Mono and disaccharides are sugars. They are easily soluble to form true solutions. The best known of the monosaccharides (there are about half a dozen of them) is glucose, occurring naturally in many types of fruits. It is also the most important building block for di- and polysaccharides. Amongst the disaccharides, it is sucrose which plays the greatest role, as it is common sugar, grown in sugar cane and sugar beets.

The polysaccharides form two groups. The first one is starch. Starch, is found in wheat, maize, rice, potatoes and other food items. Thus, it makes up a great portion of human diet. Chemically, a starch molecule is composed of about 100—1000 condensed glucose units. Because of their size, these molecules form a colloidal dispersion in water, and may render it turbid. The most important fact in this context is that the starch molecules can undergo enzymatic hydrolysis in a natural environment. They are broken up into their building blocks, the monosaccharides. This happens only in water, as a water molecule is needed to be added to the place where the link was. This is the meaning of hydrolysis. But water is not enough. The presence of enzymes is required. Enzymes are biological catalysts produced by microorganisms. Also disaccharides (e.g. the common sugar) are decomposed in this way. These monosaccharides (glucose and others) can now be utilised as food by bacteria. The aerobic bacteria ingest them and metabolize them in the presence of oxygen. This metabolism is a long sequence reactions, but it is only the end products that interest us; carbon dioxide and water. At the final stage, the carbohydrates are no longer; nature has eliminated them.

However, there is the second group of polysaccharides, the cellulose. It is found in many plants as structural fibres, and is also an inevitable part of vegetable foodstuff. Man cannot digest it but ruminants like cows and buffaloes have the necessary enzymes in their stomach to break the cellulose molecules up. A particular source of cellulose as river pollutant are the effluents of paper and textile mills.

Cellulose molecules are even bigger than the starch molecules, they are formed of about 2000—3000 condensed glucose units. Enzymatic hydrolysis is generally possible, but since the linkage of the glucose units is stronger than in starch, decomposition is more difficult than in starch, which means the process is very slow. For this reason, cellulose could also be reckoned amongst the persistent organic substances. Cellulose as

fibrous substances belong to the suspended solids. When in suspension, they cause turbidity. Under quiescent conditions they will settle.

Proteins

The word "protein" comes from a Greek word meaning "first" or of primary importance. Proteins are the compounds of which the tissues of all animals and man, in particular the muscle tissues, kidneys, brain etc., are made. Lean meat and fish are essentially protein. But also animal products like eggs and cheese, are mainly protein, and it is found, apart from sugar and fat, in milk. There are also many plants that contain some protein, although it is never the main component of a plant.

Proteins like polysaccharides are macromolecules. Some of them form colloids in water, others are not soluble at all, they remain suspended. Similar to polysaccharides, proteins can undergo enzymatic hydrolysis.

The hydrolysis breaks the large protein molecule up, first into intermediary substances, the polypeptides, and then into its building blocks, the amino acids. Each protein molecule consists of a certain number of various amino acids, and this accounts for the great variety of proteins found in nature. It accounts also for the fact that some proteins, e.g., those of fish and of offal, are easily hydrolysed, while others, namely those that form skins and horny substances, are much more resistant to degradation.

Amino acids are particular type of organic acids. Their main characteristic is not so much their acidity, which is very low (or for certain reasons even practically not existent), but the fact that they contain an amino group, $-\text{NH}_2$. This is to say in all amino acids and hence in all proteins, there is, apart from the usual carbon, hydrogen and oxygen atoms, also nitrogen present. In addition, some amino acids contain sulphur or phosphorus.

The amino acids are already small enough to be ingested by bacteria. However, they are usually further decomposed by enzymatic actions. The amino group is split off to yield free ammonia, NH_3 , while the amino acid becomes a hydroxyacid and is utilised as food by bacteria. The metabolism products of these acids are the same as for carbohydrates, namely CO_2 and H_2O .

It is possible to determine the nitrogen in proteins and their derivatives. The procedure, called the Kjeldahl method, is often employed, and the result is referred to as "organic nitrogen", which is widely used as a parameter in stream pollution surveys.

As the ammonia released from amino acids by natural degradation can be detected and measured easier than organic nitrogen, it therefore serves as a convenient indicator of pollution from protein. The metabolic breakdown of proteins in the body of humans or animals results in urea, which is excreted in urine. Urea also contains amino groups, and enzymatic action in water also releases ammonia from it. Ammonia is therefore an important parameter for stream pollution surveys. The ammonia, however, does not accumulate in natural water. Its concentration remains low (not much more than approx. 1 mg/l), because oxidation of NH_3 to nitrite, NO_2^- , takes place. This again occurs under the influence of certain enzymes. The nitrite concentration in streams is, however, even lower than that of ammonia since it is even less stable. Soon, it is oxidized to nitrate, NO_3^- . Nevertheless, nitrite is also used as an indicator of pollution, for very small amounts can be detected without difficulties.

The nitrate, which is eventually formed, is quite stable (as long as aerobic conditions prevail), because nitrogen is now fully oxidized. Nitrate may therefore reach

higher levels than ammonia and nitrite. Nitrate is also considered an indicator of pollution. But being the very end product of protein degradation, it indicates that the water has been polluted a long time ago, and that the decomposition of proteins and of other nitrogen containing organic compounds may be completed. Nitrate, however, can also be of inorganic origin. This fact limits its value as an indicator of pollution.

In spite of the stability of nitrate, it also does not reach high concentrations, rarely more than about 10 mg/l. It serves as fertilizer for aquatic plants, in which case it is thus partly removed from water. Should anaerobic conditions occur, nitrate may be reduced to gaseous nitrogen. This is seldom the case in streams. Under anaerobic conditions, hydrogen sulphide may also be formed.

Thus there are 4 parameters more or less specifically related to pollution by proteins and their decomposition products: Organic nitrogen, NH_3 , NO_2^- and NO_3^- . There are also small amounts of phosphate released when certain proteins are decomposed. This phosphate, however, is not very indicative of protein pollution, because it may stem from other sources.

It should be pointed out that ammonia, nitrite and nitrate are actually inorganic compounds. Strictly speaking, they belong to the section "inorganic pollutants". However, it is well justified to mention them here, since their significance lies in their character as indicators of organic pollution. Ammonia, nitrite and nitrate as such are not hazardous to man in concentrations in which they occur in polluted waters. Ammonia, however, in concentrations above 1.5 mg/l, may be dangerous to fish. Moreover, it interferes with the chlorination process in water treatment. Nitrite and nitrate are harmful only in higher amounts which are rarely encountered in streams, and if so, they come from other sources.

Fats and Oils

Fats and oils is the third group of biodegradable organic substances. They are also called lipids. They occur in plants as well as in animals. While most of the fats are produced by animals, the oils usually come from vegetables. It should be pointed out that mineral oil and grease for engines, being petroleum products, do not fall into this category; they are not lipids.

Fats and oils are not water soluble, but they easily form emulsions in water. Their molecules are large, although they are not macromolecules like starch, cellulose or proteins. Chemically speaking they are esters. An ester is a substance composed of an alcohol and an acid. In the case of the lipids, the alcohol is glycerol. This is a viscose liquid with a sweetish taste, quite different from the ethyl alcohol in spirits. Glycerol in lipids is linked with 3 molecules of organic acids having a long chain of 15—18 carbon atoms. This sort of acids are called after their occurrence "fatty acids". The difference between the fats and the oils is that the chains of fatty acids in oils are a bit shorter, and have one or more C=C double bonds, which property makes them "unsaturated", whereas the chains of fatty acids in fats are longer and do not have double bonds; they are "saturated."

Fats and oils undergo enzymatic hydrolysis in natural waters although some of them somewhat slowly. Each molecule yields 4 small ones, glycerol and 3 fatty acids. These smaller molecules can be metabolised by bacteria. Lipids are composed only of carbon, hydrogen and oxygen, they have no other atoms in their structures.

Parameters for Biodegradable Organic Compounds

Carbohydrates, proteins and fats are never determined as such in an ordinary

water analysis, be it for stream pollution surveys or an other purpose. Such determinations are possible in principle, but the procedures would be exceedingly complex and time consuming. Instead, we measure an important characteristic common to all biodegradable substances. While they are metabolized under aerobic conditions in the bacterial cells they consume oxygen dissolved in water. It is this oxygen demand which can be easily determined in the laboratory under standard conditions. The test is known as the Standard Biochemical Oxygen Demand, BOD₅.

The BOD is a very valuable parameter in stream pollution surveys and is widely employed. However, it has its limitations. The standard BOD is a measure for biodegradable organic matter, more precisely, for those substances which undergo easy degradation. Cellulose, for instance, of which not much is hydrolysed during 5 days, will yield a much lower BOD than the same amount of a sugar.

As a measure for organic matter with a low BOD, another test has been devised, the Chemical Oxygen Demand, known as COD. In this test a very strong chemical oxidant under standard conditions (which imply heat and an extremely acid medium) is applied. The oxygen released by the chemical oxidant and used for the total oxidation of the organic matter, whether biodegradable or not, is measured.

It goes without saying that the COD is always higher than BOD and it is quite informative to see how much higher. A small difference indicates that all the organic matter in this stream is easily biodegradable, while a big difference shows that there are substances which do not easily undergo decomposition. The two parameters BOD and COD are complementary in a stream pollution survey, and they should always be interpreted together.

Detergents

Detergents are cleansing materials. They are used for washing and cleaning purposes and consequently form part of the domestic sewage. The oldest detergent is soap. Soaps are sodium salts of fatty acids. As pointed out above, the bacteria in the streams can cope with fatty acids and eliminate them.

Hard water interferes with the lather formation of soap. For this and other reasons, synthetic detergents have been developed. The detergents first manufactured are of a chemical structure that bears little resemblance to soap. They are derivatives of benzene with a branched carbon chain, known as ABS, alkyl benzene sulphonate. These ABS detergents show excellent washing properties. Even when they eventually get into the receiving water body they go on causing excessive foaming, especially where the water becomes turbulent. The reason for this is that there are no enzymes in natural water that could decompose them and no bacteria want them as food. In other words, they are not biodegradable, neither in the stream nor in the sewage treatment plant, and consequently they are called "hard" detergents.

These substances actually belong to the "persistent" category. In the meantime, another type of synthetic detergents was developed. Their molecular structure is more similar to soap, having long straight chains and an acid radical at one end. The only difference is that the acid radical is a sulphonate group instead of the carboxylic group of soap. They are named LAS, meaning Linear Alkyl Sulphonate. As they are biodegradable in water, they are called "soft". After their introduction in the 1960s by law in a number of countries, the problems caused by hard detergents were greatly reduced.

Tests are available to detect synthetic detergents in water, and if it is felt necessary, this parameter may be included in a stream pollution survey.

Significance of Biodegradable Organic Pollution

By far the majority of the organic matter in streams stems from domestic and municipal sewage, or from direct discharge of farming and animal waste into water courses. This invariably contains a variety of micro-organisms, some of which may be capable of producing disease. Organic pollution of the kind so far described is inseparably associated with bacterial pollution originated from human and animal excreta. Consequently the whole range of biodegradable organic matter has to be considered an indicator of potential bacterial contamination.

The decomposition of the organic matter itself, even if it were free from pathogens, is of great relevance to the stream. If a stream with all its aquatic life should remain healthy, it needs a certain amount of dissolved oxygen. Biodegradable organic substances, however, use up this precious oxygen. Too high an amount of organic load may deplete the stream of oxygen and this has a number of unwanted effects. It is only a small consolation that biodegradable organic matter is eventually eliminated. Until it comes to this happy end, anaerobic conditions may arise resulting in killing fish, destroying or damaging other aquatic life, giving rise to offensive smells and causing other nuisances. The concentration of dissolved oxygen in a stream is therefore an inverse indicator of organic pollution and one of the most important parameters in any stream pollution survey. Also, a stream loaded with organic pollutants becomes turbid, unsightly, loses much of its aesthetic and recreational value. This aspect should also not be overlooked.

One might want to know how much does nature itself pollute streams with biodegradable matter? After all, aquatic animals and waterbirds produce waste, plants shed their leaves into water, and organic life in and around the water courses dies. Streams that receive effluents from moors, bogs or marshy grounds may contain humic acids, which can be the cause of yellowish or brownish colour. Nevertheless, naturally polluted rivers have on average, a low concentration of organic substances. Attempts have been made to approximate the natural pollution level of streams, and it was found that the average BOD is around 1.5 mg/l. For comparison, in a river polluted by human activity, average values of 20 mg/l and more are often found. This figure can be considerably lowered if wastes are treated prior to their discharge.

Persistent Organic Pollutants

The organic compounds which are not easily decomposed are generally products of modern industrial activities. The majority of them find their way into the streams in effluents from industries. Municipal sewage, or runoff from agricultural land may also be their source.

Before going into detail, it will be useful to summarize some of their characteristics.

(1) Being persistent organic compounds, one cannot expect them to show a significant BOD. Since there is no biodegradation (or only an extremely slow one) there is no demand for oxygen, neither in the BOD test in the laboratory nor in the natural streams. This has at least the advantage that these compounds contribute practically nothing to the oxygen depletion of rivers.

(2) Their response to the COD test varies. Depending on their chemical structure, some of those substances are completely chemically oxidized, others resist even to

the strong oxidant or are only partially oxidized in the COD test. COD is, however, not always a suitable parameter for these compounds, even if they are chemically oxidizable. Many of them occur only in small amounts in streams, and the COD test is not very sensitive for low concentrations of organic matter. Yet some of the persistent pollutants are already a cause for concern even in very low amounts. Specified tests have to be employed in such cases.

(3) Unlike biodegradable matter, the persistent organic substances are not indicators of bacterial contamination; but some of them are contaminants in themselves. Actually, the substances in question may cause a variety of unwanted effects. Some give rise to nuisances such as taste, odour or foam, others are toxic to micro-organisms or fish while others accumulate in the tissues of aquatic animals used in human food. In small amounts, these substances do not constitute an acute direct toxic hazard to man, but some are suspected of causing long-term effects, such as cancer and other diseases.

Hydrocarbons

Hydrocarbons are compounds of carbon and hydrogen only. They should not be mixed up with carbohydrates. Their main source is mineral oil, petroleum. They have become a potential pollutant with the increasing use of mineral oil products for satisfying our energy needs, for the petrochemical industry, and for the growth of the motorised traffic. Petrol, diesel oil, kerosene, fuel oil, lubricating oil, asphalt, these are all hydrocarbons. There are many more used for industrial purposes.

How do these substances get into the streams? It is not only through wastewater of refineries and petro-chemical industries, but also through municipal wastewater. Spillages at every petrol station and garage are washed by rain into the drains that discharge into a river. There are also tank-truck accidents, and on navigable rivers it is the motor ships and boats that contribute a good deal to the pollution with mineral oil products. Since these products are not miscible with water, they tend to form a thin oil film on smooth water surfaces. This film may reduce the oxygen uptake from the air and thus impair the reoxygenation of a water body. Under turbulent conditions, small amounts of mineral oil may be dissolved or emulsified. This is particularly true for crude oil. Very low concentrations of around 0.1 mg/l may already produce unpleasant taste and odour.

A particular type of hydrocarbons, the so called polynuclear ones, have given rise to concern. These substances are very potent carcinogenic agents meaning they are liable to induce cancer in man. Structurally, they have several condensed aromatic rings (benzene rings), and they are not part of petroleum products. However, they may be part of all kinds of soot and smoke, including the exhaust gases from combustion engines. They have also been found in water, though in traces only.

Hydrocarbons are very persistent in natural water. They are also quite resistant to chemical oxidation, which means they yield a very low COD. Tests that were carried out at an institute of water chemistry in Germany showed that a particular crude oil sample from Kuwait in water yielded a COD value of only 13% of the calculated theoretical figure; another sample from Libya gave just 8% of the expected figure. This shows how misleading the COD test can be in the assessment of pollutions with mineral oil. Other more specific methods are available based on the adsorption of hydrocarbon on activated carbon or alumina. If the total amount of carbon in every organic compound in water is to be measured, then only the TOC test (Total Organic Carbon) can give the answer. For this test, however, an expensive apparatus, the TOC analyser, is necessary.

Organochlorine Compounds

Organochlorine compounds are chlorinated hydrocarbons. This group includes several important organic pesticides. Pesticides are used for the control of objectionable insects, rodents, fungi, weeds etc. Those applied for insect control are called insecticides. They include DDT, benzene hexachloride (BHC), known as lindane, and others, such as endrin and dieldrin.

There are two main sources of organochlorine compounds in stream water, namely agricultural runoff and discharge of wastes from industries that manufacture pesticides. The outstanding property of these substances is their stability. Chlorination of a hydrocarbon generally increases the resistance of the compound to both biochemical degradation and chemical oxidation. Their presence in the environment may persist for years.

Chlorinated hydrocarbons are very slightly soluble in water. They have a tendency to be adsorbed on suspended particles in water. On the other hand, they are very soluble in the fatty tissues of animals and man. Some aquatic organisms may store them up to levels exceeding 10,000 times that in the water in which they live. Prolonged exposure to water containing a certain level of DDT and dieldrin constitutes a significant hazard to aquatic life, especially to fresh-water fish. Moreover, when this is eaten by predatory birds or man, the compounds are then stored in their organs. Many studies have shown this, not only in industrialized countries but also in a country like Iran, where high levels of pesticides were found in mothers' milk.

There is experimental evidence that DDT and other chlorinated hydrocarbons are potential carcinogenic agents. However, up to recently, there has been so far no clear relation found between cancer patterns in different countries. Nevertheless, some countries have restricted the use of DDT or banned it altogether. This has been done not so much because of the potential carcinogenicity but more for various ecological reasons.

Not all pesticides are chlorinated hydrocarbons. Another group, the organic phosphorus compounds (parathion, malathion) are also quite toxic, but somewhat less persistent. A third group, the carbamate pesticides, have a low toxicity and are subject to biodegradation.

The presence in the environment of a different type of organochlorine compounds, the polychlorinated biphenyls (PCB), have recently given rise to concern. They are used commercially as plasticizers, lubricants, hydraulic fluids, dielectrics in transformers etc. Like DDT, the PCBs can be stored in fatty tissues. They can cause liver and other diseases and their long-term effect is not yet known, but is suspected to be hazardous. The analysis of organochlorine compounds is performed by means of gas chromatography, for which expensive equipment is needed.

Other Persistent Organic Compounds

Another organic compound sometimes discharged into streams is phenol. It is a derivative of benzene. Strictly speaking there are several phenols. Phenols are recovered from coal tar and considerable amounts are manufactured synthetically. They occur as a component in industrial wastes from coal-cooking, and from other industries involving the use of phenols as raw material in the synthesis of organic products.

Phenols are toxic to micro-organisms as well as to some fish. They can also be a nuisance to humans. When surface water containing phenol is chlorinated for water

supplies, chlorine reacts with phenols to produce mono-, di- or trichloro-phenols, which may impart unpleasant tastes and odours to water. This happens with very small amounts of phenolic compounds (as low as 0.002 mg/l), which would otherwise not be noticeable or harmful to man. Fortunately, phenols are not too persistent in natural water: after some time they are oxidized to more harmless substances. Analytical methods are available to analyse them if considered necessary.

The persistent organic compounds mentioned so far are not the only ones that can be found as pollutants in streams. Chemical and other industries may discharge a lot more, such as various solvents, organic acids, dyes, tanning agents, plasticizers, and so on. The complete enumeration of these substances potentially present in industrial waste-waters as a whole would run into a very high figure. The streams of a developing country like Pakistan are probably not yet so much affected by persistent organic substances, but what is not yet the case today may happen tomorrow. An awareness of these potential hazards should therefore be created amongst responsible public health officials.

NATURE OF STREAM POLLUTION (INORGANIC, BACTERIAL AND VIRAL)

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Inorganic Pollutants

Inorganic substances are, as their name implies, all the substances that are not organic, no matter whether they are compounds or elements, whether molecules or ions.

In the definition of pollution we stated that all organic substances, whatever their origin or their concentration, are considered as pollutants. This cannot be said for the inorganic substances as a whole. Some of them having low concentrations are just harmless impurities.

There are other differences between organic and inorganic pollution. Whereas natural pollution with organic pollutants is mostly low, this is sometimes not so in the case of inorganic pollution. Nature may dump into streams quite high levels of unwanted inorganic substances.

A great part of organic pollution, namely the biodegradable one, is largely destroyed in due course. But there are only a few inorganic substances that undergo changes which lead to their elimination. Most of them are completely persistent.

Suspended and Colloidal Solids

Inorganic solids which are suspended or colloidal can be major pollutants. Both suspended and colloidal solids render the water turbid, thus preventing light to penetrate into it, they may be the cause of colour, and the suspended solids may give rise to problems of silt deposits wherever the flow velocity is slowed down. Suspended solids, also referred to as total suspended matter, is no doubt an important parameter in stream pollution surveys. Turbidity is also frequently measured, in particular when colloidal rather than suspended solids prevail. It should, however, be kept in mind that the parameters "suspended solids" and "turbidity" comprise organic matter as well. Other tests have to be employed in order to differentiate between the organic and inorganic nature of these pollutants.

Although untreated wastewaters contribute to suspended and colloidal solids they are often of natural origin, in particular if present in considerable quantities. In this case they consist largely of soil particles washed into the stream by runoff from rainfall. Drainage from agricultural land may also add to them. A great portion of these solids consists of clay and very fine sand, but a variety of other insoluble minerals may also be

found. If the stream shows a brownish or reddish colour it is due to iron oxides in the clay particles or other iron minerals.

As rainfall is the major cause of heavy pollution of this sort, it varies considerably with the season. A river at high water level may contain as much as 1000 mg/l of suspended solids or even more. The amount of suspended solids constitutes then a multiple of the dissolved solids. It is clear that suspended solids are an indispensable parameter in every stream pollution survey. Although nature can be blamed for this type of pollution, man cannot always be completely excused. Soil erosion may be due to poor land management, overgrazing, deforestation and so on. By improving land use, it is possible to reduce suspended solids carried away in streams.

Dissolved Solids

Almost all of the dissolved inorganic solids in a stream are salts. Hence, they constitute the salinity of a water body. A salt is a compound usually formed by a metal ion called Cation, which is positively charged and an acid radical, which is a negatively charged so-called anion. Some of the properties of salts are : they form true solutions in water, although their solubilities may vary greatly, and in aqueous solution, almost all of them are ionized. Once a salt is dissolved, the ions become independent. No more bond exists between them. They do not "remember" where they once belonged to.

Water has a special ability for the dissolution of salts, and because of that we find dissolved solids in each and every stream. While water passes through the ground before it emerges as springs, it dissolves various minerals. Others undergo chemical reactions with water prior to their dissolution. In most of the natural streams, this leads to a low or moderate salt content or salinity. Such a natural salinity does not harm anybody, nor does it impair the water quality for domestic, agricultural, and most of industrial purposes. According to the definition given in the introduction, these dissolved solids are natural impurities, not pollutants.

The major cations that constitute the salinity of a stream are sodium, potassium, calcium and magnesium, while chloride, bicarbonate, nitrate, sulphate and sometimes phosphate are the major anions. Their concentrations, are low in the natural state of stream, average figures, e.g., for chloride being 17 mg/l, for hardness 25 mg/l CaCO_3 .

However, man's activities may significantly increase the salinity of a stream, or it may only raise the concentration of particular ions, until limits are reached where the water use is impaired. When this happens we can call it pollution. Industrial activities may also add to the stream substances which were not naturally present and which often have harmful effects.

The discharge of domestic wastewater usually leads only to a smaller increase of the salt content of a stream. It is primarily the chloride concentration in sewage which is higher than that of the supplied water. Well pronounced effects can be experienced when large quantities of municipal wastewater are discharged and the dilution factor is low. Drainage water from irrigated fields can carry away salts that have accumulated there due to evaporation. Great contributions to rising salinity can be made by mining industries. Potassium salt mines in the upper Rhine valley, to give an example, dump their waste salt into the river, which significantly increases salinity as a whole and almost doubles the chloride content in particular. The chloride concentration in this river has now-a-days reached 250 mg/l already, which is considered quite a high figure. Several other industries have salt waters, which may be the result of neutralization in the plant of very acid or highly alkaline wastes.

These industries often happily discharge the brines into the nearest stream. The criteria related to the water use control the allowable salinity level in a stream. If the water of the stream is to be utilized for drinking-water supply, the "highest desirable level" of the International Standards for Drinking-Water by WHO, which is 500 mg/l, should be applied. The same should also be done for every other water constituent listed in these standards. If irrigation is the main purpose for the water use, there are other limits to be observed, and moreover, different crops can tolerate different levels of salinity. The concentration of various individual ions such as Cl^- , Na^+ , and the ratio of Na^+ to the total cations also play a role in irrigation water.

Salinity is indirectly measured by the parameter TDS, Total Dissolved Solids. Strictly speaking, this parameter includes also truly dissolved organic substances the concentration of which is, however, usually small in streams. It is also useful to measure the specific electric conductivity (or conductance) of a water sample. This is a very rapid test, and as conductivity is roughly proportional to TDS, this measurement can be used for a quick approximation of the water salinity. Unfortunately, this test is not as widely practised as it deserves.

As chloride can be considered a sort of representative for the whole salt content, and as it is easy to measure, determination of Cl^- has become a widely used parameter in stream pollution survey.

Nutrients

Certain ions *i. e.*, potassium, ammonium (or ammonia), nitrate and phosphate are known as nutrients.

These substances act as plant fertilizers, and when in water in certain quantities they increase weed growth and promote excessive growth of algae, the algal "blooms". This phenomenon is called Eutrophication and is primarily encountered in lakes. Streams sometimes discharge into lakes or artificial lakes formed by dams. Eutrophication is a nuisance, because the excessive amount of algae creates difficulties in water treatment plants, may impart unpleasant taste and odour to water, and increases organic matter in the lake.

The nutrients can be natural impurities in water, in which case they will be present in small concentrations only. In an unpolluted stream, one may find an average 0.5 mg/l NO_3^- and 0.02 mg/l PO_4^{3-} . In a heavily polluted river, these figures may go up 10—20 times for nitrate, and about 100 times for phosphate. Sources for these pollutants are: agricultural runoff from land where fertilizers have been applied, effluents from fertilizer factories, and domestic wastewater also. The phosphate content of urine is very high, as much as 4,500 mg may be excreted by a person in 24 hours. On the other hand, many household detergents contain phosphate (as polyphosphate) which hydrolyses in streams to form ortho-phosphate. Phosphate should always be included as a parameter in stream pollution surveys. It can often be the nutrient that limits the growth mentioned above. In such a case, the other nutrients are present in abundance, but they cannot stimulate the growth, unless the amount of phosphate is increased. The nitrogen compounds have already been mentioned as parameter for organic pollutants.

Minor Constituents

In many streams we find inorganic substances in such low concentrations that these do not contribute significantly to the salinity, but impair, as such, even in small amounts, the water quality. These are the H^+ -ions and OH^- -ions being responsible for low

or high pH, the heavy metals and radioactive substances. The probability of the presence of radioactive substances in streams in Pakistan is very remote, in particular since there are no more nuclear tests carried out in the atmosphere. There is, however, reason to elaborate on the other minor constituents.

pH

Acid and alkaline wastes are sometimes discharged by industries into streams. If the stream water does not contain much buffering compounds, such as bicarbonate ions, and if the dilution factor is not very great, the pH of the river water may easily drop below about 6.5 or rise above 8.5. This may be hazardous, if not directly lethal, to fish, and pH changes may throw out of balance the tolerance of fish to low dissolved oxygen concentrations. The life and functioning of micro-organisms may also become endangered, in particular bacteria which are generally quite sensitive to pH values beyond normal range. A low pH is generally more dangerous to them than a high one. The pH value of a stream is therefore an essential parameter, and it should not be left out in any pollution survey.

Heavy Metals

Heavy metals may be present in streams as ions or as compounds, such as oxides for example.

It is useful to differentiate between two categories. Those metals which may affect the acceptability of the water for various purposes when a certain limit is exceeded, and those which are not wanted at all, because they present a direct hazard to health. The first category comprises iron, manganese, zinc and copper; in the second one, there are the toxic substances. The first category metals occur as natural impurities in unpolluted streams. Their average concentrations range from 0.01 mg/l (Cu, Mn) over 0.02 mg/l (Zn) to 0.1 mg/l (Fe). Their presence in higher amounts is due to man-made pollution. Metal industries will have to be blamed for it, as well as mining. Iron and manganese occur mostly as insoluble oxides, and they are often found in sediments on the bottom of a stream. All is well as long as aerobic conditions prevail there. Should the bottom layer of water, however, become anaerobic, which can easily happen when the stream is impounded, iron and manganese may be dissolved. The undesirable effects produced by iron and manganese are discolouration, deposits and, in higher concentrations, taste. Moreover, they interfere with many industrial processes. The iron content of a heavily polluted river may be as high as 3-4 mg/l.

Copper and Zinc are less widespread as stream pollutants. Sources are also metal industries as well as chemical industries. Copper and zinc can be toxic to certain micro-organisms and dangerous to fish, and copper may cause corrosion of pipes, fittings and utensils. In addition, copper and zinc ions give rise to an astringent taste to the water, if the limits of the International standards are exceeded.

Toxic Substances

The second category of heavy metals comprises arsenic, cadmium, chromium, lead, mercury and selenium. Cyanide is usually found on this list, although it is not a metal. These substances may have toxic effects on man and aquatic life. Hence they are not only pollutants but also contaminants. In a stream in its natural state they are practically non-existent, only traces are found.

The first possible source for the toxic heavy metals is mining. It is not only mining of these metals themselves that may lead to contamination of streams. The toxic

metals sometimes occur together with other minerals which are mined, e.g., cadmium with zinc, and selenium with sulphur.

The second source are industrial effluents. The chemical industry may discharge virtually all of them. In the wastes of electroplating industries, one may find hexavalent chromium, cadmium and cyanide. The manufacturers of the plastic pipes may discharge cadmium and lead, and a main source of lead are also the producers of storage batteries. Hexavalent chromium may also be discharged with cooling water in which it is sometimes used as corrosion inhibitor. Chlorine alkali plants which employ electrolysis of sodium chloride are potential source of mercury and tanneries may discharge trivalent chromium.

Apart from industrial effluents, arsenic may get access into streams with agricultural runoff as it is used as inorganic insecticide. Lead which is added to fuel as antiknock agent is found in the exhaust fumes of automobiles. This lead, originally an airborne pollutant (as tiny particles in aerosol form) can easily settle on nearby water surface or be washed into streams.

Although these substances are being referred to as toxic, this does not mean one gets killed as soon as one ingests the smallest amount of them. If certain limits, as published by WHO in the International Standards for Drinking-Water, are exceeded, the substances may constitute a danger to health. The limits are very low indeed, e.g. as low as a thousandth of a milligram for mercury. Acute manifestation of illness, or even death, occur only when the quantity ingested is considerably higher than established by the limits. Low-level exposure to these pollutants, however, may lead to long-term effects with chronic diseases. Some of them, notably lead, cadmium and arsenic accumulate in the human body, and young children are particularly at risk in the case of lead. It accumulates in their blood and their bones, and can also cause brain damage. Arsenic and chromium (and possibly others) are carcinogenic, and selenium may cause disease in animals. As regards chromium, its toxic effect depends very much on its chemical valency. Trivalent chromium as in chromic salts, is believed to be no cause for concern in drinking water. Hexavalent chromium, however, as in chromate compounds, is the one that is suspected of being carcinogenic.

It is, however, not only man and the higher animals, but also the aquatic life that can be endangered. Chromium (in its tri- and hexavalent state), cadmium and especially cyanide are potent toxicants to fish, they can tolerate only a fraction of a milligram per litre. Fortunately, cyanide has only a limited lifetime in a river. Since it is not a metal but a carbon-nitrogen compound (CN), it is slowly oxidised to CO_2 and gaseous nitrogen. Near a wastewater discharge of an electroplating plant, however, it may contaminate a certain stretch of the receiving stream before it is decomposed.

The microbial life of a stream may as well be affected by all the toxic substances. Micro-organisms may die away, or be damaged and stop their function. Arsenic, cadmium and above all mercury, have a great tendency to accumulate in the aquatic food chain. When mercury is discharged into natural water bodies, it forms in the bottom sediments of receiving streams an organic compound, methyl-mercury. In this form, mercury is easily absorbed by all organisms and is concentrated biologically. It has been shown that the amount of mercury in fish and shellfish may reach a concentration as high as 10 mg/kg. Man who eats such seafood will be poisoned. The disease caused affects the central nervous system, and even damages to the human fetus have occurred. Thus heavy metals should become parameters in a pollution survey. It is not necessary to try to determine each and everyone of them. But if there is reason to assume that the one or the other of these heavy metals may be present in an excessive concentration, attempts should be made to detect it and to estimate its quantity. Analytical methods are available for each of them. Very low amounts can be measured if modern analytical equipment is used, as for instance

an atomic absorption spectrophotometer. Such an instrument is expensive, but the IPHER is so fortunate to have one.

Bacterial Pollution

Bacterial pollution is part of the pollution by micro-organisms. Bacteria are by no means the only micro-organisms associated with pollution, but they are the most important ones.

Micro-organisms are defined as organisms not visible to the naked eye. Bacteria, are all unicellular, meaning they consist of a single cell which carries out all the basic functions of life. They are very small, their size ranges from one hundredth to one thousandth of a millimeter.

Bacteria are found everywhere in nature, in water, soil and air. But water, surface water in particular, is their favourite environment. Even in the clearest stream high up in the mountains there are bacteria. So the mere presence of bacteria cannot be called pollution. On the contrary bacteria in surface water are very necessary for the process of self-purification of water. This beneficial task is performed by a large group of the lower bacteria called saprophytic. They are the ones which require organic compounds as their food, deriving their energy by decomposing these compounds.

Although a certain bacterial population is wanted in rivers, too high a population is undesirable, and therefore they are sometimes regarded as a pollution parameter. A total count of an order of magnitude of 1,000 bacteria per milli-litre (ml) may be considered as mere natural pollution. However, when this figure exceeds 100,000 per ml, this particular stream is certainly polluted by man's activities.

Pathogenic Bacteria

The parameter "total count of bacteria" is not a very significant one. What is of a greater concern is the small group amongst the lower bacteria in streams which is capable of causing certain diseases in men. These are the pathogenic bacteria, or pathogens.

Stream water is not their original medium. They live in humans and sometimes animals, generally in the intestinal tract. Such a person may be suffering from the disease, or may be just a carrier without recognizable symptoms. In any case he excretes the pathogenic bacteria in his stool, and carried away with sewage, they finally reach the natural water bodies. In water, they can survive for a couple of days or even weeks, as the organic wastes in rivers provides them with food. If such a water is drunk by a healthy person, he may, with a certain probability, contract a disease. The diseases in question are those of the intestinal tract, also called enteric infections :

- cholera, caused by *vibrio cholerae* ;
- typhoid fever, caused by *salmonella typhosa* ;
- paratyphoid, caused by *salmonella paratyphi* ;
- bacillary dysenteries (3 types) caused by *shigella* ;

These are only the main bacterial waterborne diseases. There are others, caused by other micro-organisms.

These diseases are all dangerous. If not treated the fatality rate is high. Bacillary dysenteries affect especially children below the age of five. Quite a high number of deaths of young children in developing countries can be attributed to waterborne diseases. The diseases may also cause epidemics in densely populated areas.

Indicator Organisms

It is not practical to examine the water of a stream for all the types of pathogenic bacteria that might be present there. Bacteriological methods are available, but an attempt to isolate all possible pathogens is quite time consuming, and well equipped laboratories with specialists in bacteriology are needed.

It is much easier to detect normal excremental organisms, the most important of them being the coliform organisms. This group are regular inhabitants of the intestinal tract of human beings and animals, where also the pathogens live. They are not pathogenic themselves (apart from one particular strain). Everybody excretes them in very large numbers in the faeces (an average adult about 2,000,000,000 each day), healthy persons, as well as those who are carriers of pathogens. But the coliform organisms always greatly outnumber the pathogenic organisms. If coliforms are not found in water it can be concluded that no faecal pollution has occurred, and that the pathogens must be absent as well. If, on the other hand, there is a certain number of coliforms in water, this indicates that faecal matter has gained access to this water. And wherever there is faecal matter, there is a probability that pathogenic organisms may be present. The greater the number of indicator organisms, the greater is the risk of the presence of pathogens.

Thus, the coliforms are indicator organisms of faecal pollution. The number of coliforms, expressed as organisms per 100 ml, (or coliform density) is an important parameter for every stream pollution survey.

A river in its natural state is not free from coliforms. Due to wild animal excreta the density may be in the range of about 1—10 organisms per 100 ml. In a polluted stream, however, the figures may go up to some 100,000 and in a heavily polluted river, even up to hundreds of million per 100 ml.

The coliform group is not the only parameter used as indicator for bacterial contamination. This group is large and consists of many species. They may be of faecal origin, but this is not always so. Some members of that group live in the soil. One particular species, however, the *E. coli* (*Escherichia coli*), practically identical with *faecal coliforms*, is undoubtedly of faecal origin, and that is why *E. coli* is a more precise indicator of faecal pollution.

In the past, the detection of *E. coli* used to be more troublesome and more time consuming than that of the whole coliform group. Therefore, the latter was given preference for pollution surveys. Now a days, there are techniques and media available that make the detection of faecal coliforms as simple as that of the total coliform group, and consequently, faecal coliforms should always be included, in stream pollution surveys.

Faecal coliforms indicate beyond doubt that faecal pollution has occurred. They have also another advantage. In hot climates, the high temperature permits growth of the total coliforms but not of faecal coliforms. The latter die away after some time at the same rate as pathogens do. Consequently, the numbers of total coliforms are not reduced to the same degree as those of the faecal coliforms, which are therefore better indicators of the possible presence of pathogens.

Apart from coliforms and faecal coliforms, other indicator organisms for faecal pollution are sometimes used. One such indicator organism is Faecal Streptococcus (*Streptococcus faecalis*) which regularly occurs in faeces in numbers usually considerably smaller than those of faecal coliforms, but still sufficiently numerous to be easily detected. Its die-away rate in water is about the same as that of faecal coliforms which makes it suitable for pollution surveys.

Viral Pollution

Viruses have become of concern in recent years, and increasing attention is being paid to them now all over the world. Whereas extensive practical knowledge of the monitoring of bacterial contaminations of waters is available, there is only limited experience with regard to viral contamination. However, in view of the growing public health importance of this type of pollution, it might be useful to pass on some of the existing information.

Nature of Viruses

Viruses are on average, 40 times smaller than bacteria. Whereas bacteria can be retained on filter membranes viruses usually pass through these. It is not possible to see them by an optical microscope like the other micro-organisms. They must be observed through an electron microscope.

Unlike bacteria, viruses are not cells. They cannot carry out all the functions of life, as cells can do. A virus resembles in certain aspects a large and complicated molecule rather than a living organism. In order to reproduce itself, it has to invade a living cell. While lodging in this cell, it causes damage by robbing it of vital materials needed for its cellular development. This causes disease. All viruses are parasitic pathogens. But they are highly specific. A virus may pass through a series of hosts with no reaction. But once a particular type of cell is found, it becomes virulent, destructs the cells and multiplies rapidly.

Types of Viruses

Like bacteria, viruses find their way into river water along with human feces. The viruses disseminated only by the fecal route are known as *enteroviruses*. There are many species in this group, but only a few are important. There is the *poliovirus* (actually 3 different species exist) which can cause serious nervous system disease resulting in paralysis, in particular in children. Fortunately, clinically manifest disease occurs only in between 1 in 100 and 1 in 1000 cases of infection. In other words, most individuals who ingest the virus do not develop the symptoms of this disease. Another important enterovirus found in water is the *hepatitis virus*, responsible for waterborne outbreaks of viral hepatitis, a liver disease.

Rotaviruses, a recently discovered group, have been found to be the major cause of nonbacterial infantile diarrhoea throughout the world. This virus has been detected in approximately 40% of infants with diarrhoea.

There are many more types of viruses known to be excreted in human feces, all together more than 100 different species, but most of them cause such a broad spectrum of disease symptoms that the disease is difficult to diagnose and to recognize as being waterborne. So the role of many viruses, although known to be infectious, is not yet clearly established.

Excretion and Persistence

Viruses may be excreted in high numbers. Concentrations up to 100,000 infectious virus units per litre have been detected in raw sewage. From this figure one can derive that in a polluted river the virus density may easily reach the figure to 1000 to 10,000 units per litre.

Studies have shown that viruses can persist for several months in natural water. Even in sea water they can survive over 130 days, and in soil even longer. This shows that viruses are significantly more resistant to environmental factors than bacteria whose survival time is usually much shorter.

To become infected, it may be enough, under certain circumstances, for a susceptible individual, to ingest a single virus unit. This is in contrast to bacteria, where the ingestion of a certain number is always required to contract a disease. The reason is that all bacteria are sensitive to acid. Very few can survive the passage of the low pH (around 2) of the gastric juices in the stomach, and therefore the initial number has to be high. Viruses, however, can easily tolerate an acid medium.

Viruses are also more resistant to water and wastewater treatment processes than are bacteria. Even disinfection process designed to destroy all pathogenic bacteria may not be sufficient for the inactivation of viruses. In case of chlorination, a higher dose of chlorine and a longer contact time are necessary for virus destruction. Ozone has also been shown to be an effective viral disinfectant.

Detection of Viruses

Detection of viruses and their identification is not easy. It needs a specially equipped laboratory and the necessary expertise. The principle is concentration of the number of viruses from large water samples, their culture and identification. For culturing, the virus is inoculated on living cells, which are necessary for multiplying, as pointed out before.

Bacterial indicator organisms, as used in bacteriological water examination, are meaningless for virus monitoring. Because of the difference between the persistence of bacteria and of viruses, the absence of coliforms or faecal coliforms offers no assurance that viruses are also absent. It is the virus itself that has to be determined.

This makes virus monitoring not very popular for stream pollution surveys. Due to lack of facilities at present, it cannot become a regular parameter for those surveys in developing countries. But an awareness should be created that this type of pollution exists. WHO encourages each country to set up at least one laboratory for virological water examination. Such a laboratory could participate in stream pollution surveys and also pursue further research on this subject.

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IDENTIFICATION AND MEASUREMENT OF SOURCES OF POLLUTION

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“Pollution” is a very general term and may be defined in many ways. However water is considered polluted when its composition or conditions are changed and it becomes less suitable for any or all of the functions and purposes for which it would be suitable in its natural state. This definition includes changes in the physical (including temperature) chemical and biological properties of water, or such discharges of liquid, gaseous or solid substances into water as will be likely to create nuisance or render such waters harmful to public health safety or welfare, or to domestic, commercial, industrial, agricultural, recreational or other legitimate uses of water, or to live stock, wild animals, fish or other aquatic life.

Pollution may be accidental sometimes but often it is caused by the uncontrolled disposal of sewage and other liquid wastes resulting from various sources like domestic uses of water, industrial wastes containing a variety of pollutants, agricultural effluents from animal husbandry and drainage of irrigation water, and urban run-off. The other causes of pollution may be the use of chemicals to increase lands productivity or the addition of chemicals to water to control undesirable organisms. The application of chemical fertilizers and of pesticides for the control of aquatic weeds, insects and molluscs can be cited as examples.

The primary sources of pollution can be divided into four groups : Municipal Domestic, Industrial, Agricultural and Natural.

Municipal/Domestic Source

The Municipal sewage normally contains decomposable organic matter, that exerts a demand on the oxygen resources of the receiving waters, which consists primarily of carbohydrates, proteins from animal matter, and miscellaneous fats and oils. The specific classes of organic compounds found in sewage include amino-acids, fatty acids, soaps, esters, anionic detergents, amino-sugars, amines, amides etc. Main inorganic dissolved salts found in this source of pollution are of sodium, potassium, calcium, manganese, ammonium, chloride, nitrate, bicarbonate, sulphate and phosphate in the form of ions. Much of the impurity in municipal wastes is settleable material that may be deposited at the bottom of the receiving waters forming deep layers of organic sludge. The BOD values range from around 1 mg/l (for natural water) to 300—500 mg/l (for untreated domestic sewage). Domestic and municipal sewage invariably contains a variety of micro-organisms, some of which may be pathogenic. Although most human intestinal pathogens do not survive for extended periods outside the body of the host, there is evidence that they may remain sufficiently viable in different types of aquatic environment to infect men. The

presence of indicator organisms, especially the faecal *E. coli*, affords presumptive, though not conclusive, evidence of pollution by sewage and thus of the possibility of a public health hazard.

Industrial Source

The wastes from industrial sources are more difficult to characterise as compared to municipal pollutants. These usually contain traces or larger quantities of the raw materials, intermediates products, final products, co-products and by-products and of any ancillary or processing chemicals used. The composition and amounts of pollutants discharged by a specific industry can usually be determined only by detailed analysis of its effluents.

The complete enumeration of the substances present in industrial waste waters, as a whole would run into thousands including detergent, solvent, cyanides, heavy metals, mineral and organic acids, nitrogenous substances, fats, salts, bleaching agent, dyes and pigments, phenolic compounds, tanning agents, sulphides and ammonia and many of these compounds are biocidal and toxic. Some organic or toxic compounds give rise to serious difficulties in the treatment of surface waters for domestic and industrial purposes. For example, phenols cause tastes and odours in potable water after chlorination. Oils, fats and bituminous substances make the water unfit for bathing. Since surface films collect particles of dust, rust and industrial grime, these films can cut down the transfer of oxygen from the air into the water for self purification.

Sometimes organic wastes may contain compounds like liquosulphonic acids which act as protective colloids and make the softening of the contaminated water most difficult. Layers of foam act in a similar way to oil films ; these are caused by foaming agents and occur generally in sulphite wastes produced in the manufacture of wood pulp, in tannery, wastes and from the plants using synthetic surface-active agents. Highly saline wastes or wastes containing heavy toxic metals are unfit for irrigation of agricultural lands. They unfavourably affect the growth of plants by leaching fertilizers out of soil. Again toxic substances (like lead, zinc, etc) sometimes collect on the surface of grasses, causing diseases or fatal poisoning of livestock. The interaction of wastes discharged from a variety of industrial processes may also cause serious damage. For example when wastes containing sulphides come into contact with acidic wastes they give off hydrogen sulphide, which gives rise to toxicity and causes serious depletion of oxygen in the receiving water.

In spite of the variety, many industrial wastes can be measured by the same parameters as those applicable to municipal wastes, such as BOD, COD, turbidity, suspended solids etc. But sometimes the lack of information on the composition of industrial discharges may cause the great difficulties in water quality management.

Agricultural Source

It might be strange to think of agricultural practices as sources of pollution. But in fact agricultural activities contribute pollution towards receiving waters streams and is generally due to animal wastes, chemical fertilizers, material eroded from land, plant nutrients inorganic salts and minerals resulting from irrigation; pesticides and herbicides, to these may be added various infectious agents contained in wastes. If the manures used on pasture and crop lands are allowed to stand, much of the nutrients are leached by rainfall and are carried by landwash and drainage to water-course. It is recognized that normally the wastes of one dairy cow are equivalent to that of 17 humans, so the magnitude of organic and nutrient loss is quite significant.

The agriculture wastes reach the stream primarily by two routes, through the land drain systems and by landwash and erosion. Drainage systems that serve cultivated lands collect seepage water containing residual applied chemicals leached from the top

soil. Of the primary plant nutrients applied as fertilizer, the nitrogen moves readily with the drainage water and in a study 70% of the nitrogen applied was found in the drainage effluent. Phosphorus comparatively tends to be fixed in the soil, and reaches streams principally through erosion, and only 3% of the applied phosphorus could be detected in the previously mentioned study. Pesticides and herbicides applied to soil or plant surfaces are generally fixed by soils, so usually not found in measureable concentrations in the effluent of land drainage systems. However, a significant quantity is found in the streams as soil is eroded, in the process of spray application, from spillage etc. Studies confirm that landwash runoff of agricultural areas, in which pesticides are used, can result in widespread low level pollution of streams by these toxic chemicals. In addition, tons of topsoil are eroded and washed into streams and rivers.

Natural Source

In the strict sense, more or less every water course contains some degree of pollution. This pollution arises from stormwash, seepage from groundwater, swamp drainage, and aquatic life of the stream. Stormwash may carry large quantities of organic matter from flora and fauna and inorganic silt from soil erosion and bank scour. Seepage from groundwater can contribute a variety of chemical compounds dissolved from the soil and geological formations through which the seepage water passes in reaching the watercourse. Swamp drainage contains high concentration of colour, substantial organic and inorganic material and is usually low in pH and dissolved oxygen. When flushed by a sudden rainstorm, the swamp waters drastically alter the normal quality of the streams and may result in a heavy fish kill. The aquatic life of the streams in its life cycle also constitutes a natural source of pollution. The normal flora and fauna depend on nutrients reaching the watercourse. When the latter is naturally well fertilized, a large and diverse population is maintained; in streams with poor nutrient content aquatic life is sparse. Excessive aquatic growths, that die and decomposes, add significantly to the organic pollution load and deplete dissolved oxygen particularly if residues deposit and accumulate in quiescent reaches, pools and lakes. Some forms are toxic or produce toxic products.

The pollutants present in the wastewaters from the above mentioned sources may be classified as:

Persistent toxic chemicals, non-persistent toxic chemicals, petroleum, organic matter, nutrients for plants, disease germs, floating surface debris, sediments and heat. Table I gives the idea of the types of pollutants, their major sources, and the undesirable effects due to these pollutants.

TABLE I
Pollutant Sources and Effects

Type of Pollutant	Major Sources	Undesirable Effects
Persistent Toxic Chemicals		Enter cells of aquatic organisms low in the food chain, and tend to accumulate in tissues or organs of subsequent grazer or predator organisms. Generally, organisms at the top of the food chain contain highest concentrations. Above certain levels, cause illness or death for individuals, and may cause decreases or extinction of population. When used as pesticides, may lead to sterility or death in many species besides those for which they were intended.
Heavy Metals (arsenic, cadmium, chromium, lead, mercury, zinc, copper, etc.)	Industrial discharges Industrial runoff	
Pesticides (Nonbiodegradable)	Agricultural runoff Urban & suburban runoff	

Type of Pollutant	Major Sources	Undesirable Effects
Non-Persistent Toxic Chemicals acids, alkalis, phenols, cyanides, etc ; also biodegradable pesticides	Industrial discharges or Spills Agricultural runoff Urban & suburban runoff	Cause toxic conditions until neutralized or diluted, or until broken down to harmless forms by certain aquatic organisms.
Petroleum	Industrial and Maritime Spills	Toxic compounds in petroleum dis- solve in water, affecting aquatic life. Oil slicks smear water fowl and stain shore- lines. Some components settle to the bottom and attach to sediments, resul- ting in an oily sludge which is toxic to bottom life forms. Oil slicks impede oxygen uptake which occurs at water's surface.
Organic matter	Human waste, House- hold waste, Animal waste, Industrial waste.	Various organic substances discharged into water are food for certain aquatic micro-organisms, spurring very rapid population increases. These forms of life do not produce oxygen, but require it for the same reasons we do. Their rapid growth creates a high "oxygen demand" which exceeds the normal rates of oxygen supply. If reserves of dissolved oxygen drop low enough, aquatic animals may die in large numbers "fish kills" as an example. If the organic pollution is large and continuous, a body of water may be- come largely oxygen-free (anaerobic), the biota will change to undesirable forms, and desirable forms die or abandon the area.
Nutrients for plants (both algae and rooted aquatics)		These—and, probably, molecules con- taining other key elements—act as fertilizers for aquatic plants. Above very low levels, overfertilizing (known as "eutrophication") occurs, leading to serious overgrowths of plant life. One example would be the "algal bloom" phenomenon. As a result, the plants unnaturally, dominate the aquatic en- vironment especially so by their own daily oxygen cycles. Furthermore, some natural plants may be replaced
Nitrogen compounds	Human waste Animal waste Fertilizer runoff.	

Type of Pollutant	Major Sources	Undesirable Effects
Phosphorus compounds	Human waste animal waste Detergents Fertilizer runoff.	by others that thrive under the unnatural conditions for example, green algae replaced by blue-green algae. Such "species shifts" can disrupt entire food chains, thereby destroying natural communities. Plant overgrowth may impede human activities simply by clogging the surface, and they block light penetration to lower levels in the water. Lastly, temperature changes or times of low dissolved oxygen may result in the death of large masses of the plant, which sink to the bottom, adding to the existing organic load waiting to decay. The necessary bacterial decay process usually exhausts deep-water dissolved oxygen for long periods of time. Throughout geologic history, rivers and lakes have been turning into swamps and bogs by this process, but man's contributions to eutrophication have accelerated it, and he is hastening the "death" of many bodies of water.
Disease germs (pathogens)	Untreated human and animal wastes	Transfer of numerous types of human and animal diseases, especially through contamination of drinking water.
Floating surface debris	Land runoff Storm Sewers (trash in streets) Deliberate dumping or littering	Reduces aesthetic and recreational values of water bodies. May present serious navigational hazards.
Sediments	Erosion from land (especially when lacking proper vegetation)	When suspended in the water, sediments block light rays necessary for photosynthesis by aquatic plants, possibly upsetting food chain. Reduces aesthetic and recreational values of water. As sediments settle, they blanket and smother bottom life forms. Man's contribution to land erosion has accelerated the natural processes which "age" lakes and rivers.

Type of Pollutant	Major Sources	Undesirable Effects
Heat	Industries and Public Utilities who use water as a coolant	Increased temperature reduces ability of water to hold oxygen in solution, while raising biological oxygen demand through increased biological activity. Furthermore, heating may disrupt ecology of natural communities. For example: Heat-sensitive species will disappear in summer; abnormal temperatures may block seasonal migration of fish; fish congregating near the heated water in winter are susceptible to over-fishing.

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Measurement of Waste Flow

To take any wastewater problem, information on the volume and characteristics of the wastes must be obtained. The data can be simply the volume, BOD and suspended solids contents. In the case of plant processes involving many reagents, the parameters required could include heavy metals, cyanide, chlorine etc. But among all these parameters, the measured volume of flow for each type of waste is the most important information to be determined in any study, as it affects the concentration and total mass of the pollutants. Thus if we know the flow rate and concentration of the parameters are known, total organic load of the stream in terms of BOD can easily be calculated.

For example if the BOD of any stream is 450 mg/l and the stream flow is, say 7.0 cusecs. The determination of total load on BOD basis could be $16982 (8.34 \times 450 \times 7.0)$ lb of BOD per day.

The transfer of pollutants, from their sources to the receiving waters, takes place either in closed pipes, generally from industries, municipalities, or in open channels, normally from agricultural and natural sources. The methods applied for the measurement of the flowing waters are by weirs, Parshall measuring flume, orifices venturimeters current meters, pitot tubes float measurement, chemical tracers, radioactive tracers, magnetic flow meters, electric methods etc., etc.

The oldest form of measuring flow in an open channel is by the weir. This method has been used for decades in irrigation, mining and other operations in which water flows by gravity in a channel, pipe, or open drain. The main component of a typical V-notch weir are head (H) width of weir bottomnappe, submerged or drowned, (L), free discharge and crest of the weir. The head is usually measured about 2.5 ft upstream of the weir. To avoid turbulence of fast flowing water, a stilling basin may be installed adjacent to this

point. Measurement of H is then made in the stilling basin. Some of the very common weir formulas are as under :

for rectangular weirs

$$Q = 3.33 H^{3/2} (L - 0.2H)$$

for Cipolletti weirs

$$Q = 3.367 \times L \times H^{3/2}$$

for 90° triangular

$$Q = 2.54 \times H^{5/2}$$

Parshall Measuring Flume

This type of weir has a narrow specially designed throat with a tapered inlet and outlet. Two gauges are provided, one at the inlet and the other at the throat. For free flow the measurement of the head is made at the upper gauge only while for a submerged flow the head is read at both upper and lower gauges. With a proper recorder, the weir will record the deviation in flow at different hours of the day. It will also show the total flow for a given period. These units are easy to operate, no constant attention requirements.

Venturimeter

This can be a constricted short length of pipe with a throat diameter between one-half and one quarter of the main pipe diameter. The formula for determining flow is based on Bernoulli's theorem, neglecting friction.

$$Q = C K_1 d_2^2 \sqrt{h_1 - h_2}$$

Where

C = co-efficient between 0.97 and 0.99

K = a factor depending upon ratio

d_1/d_2 (about 6.31 to 6.51).

The flow is determined by the difference in static pressure at the throat and at a point upstream of the transition and is determined by the following equation :

$$Q = C \frac{d_1 d_2}{4 (d_1^4 - d_2^4)^{1/2}} (2gh)^{1/2}$$

C is a coefficient which reflects the construction features of the meter and the loss due to friction between the entrance and the throat.

Manual Measurement

Wastes discharged into a pit which does not receive any other waste may be used to determine flow rate. The outlet from the pit may be closed, and the time required to raise the level of the liquid in the pit a foot or a fraction of a foot in a given time is observed. When this information is combined with the dimensions of the pit, the flow

rate can be determined. If this type of system is employed, the data should be taken periodically through the normal operating period of one hour, shift or day to determine any fluctuations in the flow.

When no operating flume or pit is available, but the open end of the pipe may be reached, an operator can get a fairly accurate measure of the flow with a 5 gal bucket, or even a quart bottle, held over the end of the pipe, observing the time in which the container is filled, this again requires attention over one entire operating day.

Water Meter Determinations

If the plant has a water meter which registers the total amount of water used in the factory during the day, the engineer has an alternative method of determining the waste flow. If the water is not consumed in the process, purchased water reading can give a fairly accurate reading of the total waste discharge volume as well as periodic readings every 30 mins. Purchased water may not be the plants only source of water. Well water may also be used. Neglecting its volume could upset design calculations.

ROLE OF BIOLOGICAL LIFE IN STREAMS

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Introduction

Rivers and lakes are the natural results of the surface runoff. As the water flows over the ground surface, they pick up organic and inorganic materials which stimulate biological growth. A high mountain stream will show little biological life because of the lack of nutrients in the water. But river flowing through a rich agricultural area will teem with biological life. To maintain a normal balance of biological forms in a river or a lake there must be a certain amount of organic matter as well as the necessary nutrient elements.

Streams have long been used for the disposal of domestic sewage and industrial wastes. As long as the load of wastes remain below the streams assimilative capacity, the normal biological flora and fauna will be predominantly aerobic and beneficial to man. Once the load of wastes exceeds the streams assimilative capacity, the higher forms of biological life are displaced by an excessive growth of bacterial and anaerobic conditions set in which are detrimental to man. It is the overload that establishes the normal pattern for stream pollution.

Ecological Cycle

The bacteria are the keys to the normal biological cycle. It is the role of the bacteria to convert the soluble organic matter into bacteria cells and inorganic elements. The inorganic elements are taken by the algae and converted into algal cells. The newly formed bacteria and algae become food for the protozoa, rotifers and crustaceans. The animal forms and some of the larger algae and bacteria become food for the minnows and tiny fish. The small fish become food for the larger fish which become food for man. Man discharges his wastes back into the streams where the bacteria metabolize the organic matter and complete the cycle. Thus it is that waste discharge into streams is a normal part of the biological life as is shown in Fig. 1. Without the organic waste there would be little fish for man to remove from streams.

While a certain amount of organic wastes are necessary for the normal biological cycle, too many wastes can destroy it. The key in the normal biological cycle is oxygen, which is essential for the development of the beneficial animal forms. As the organic waste concentration increases, the bacterial growth is stimulated with a greater and greater demand for oxygen. As the bacteria decrease the oxygen level, the higher forms begin to die off. Sensative game fish are the first to feel the effects of oxygen depletion followed by the normal game fish and finally by the crustaceans, rotifers and higher protozoa. The bacteria remain as the sole form of biological life. In the absence of dissolved oxygen the

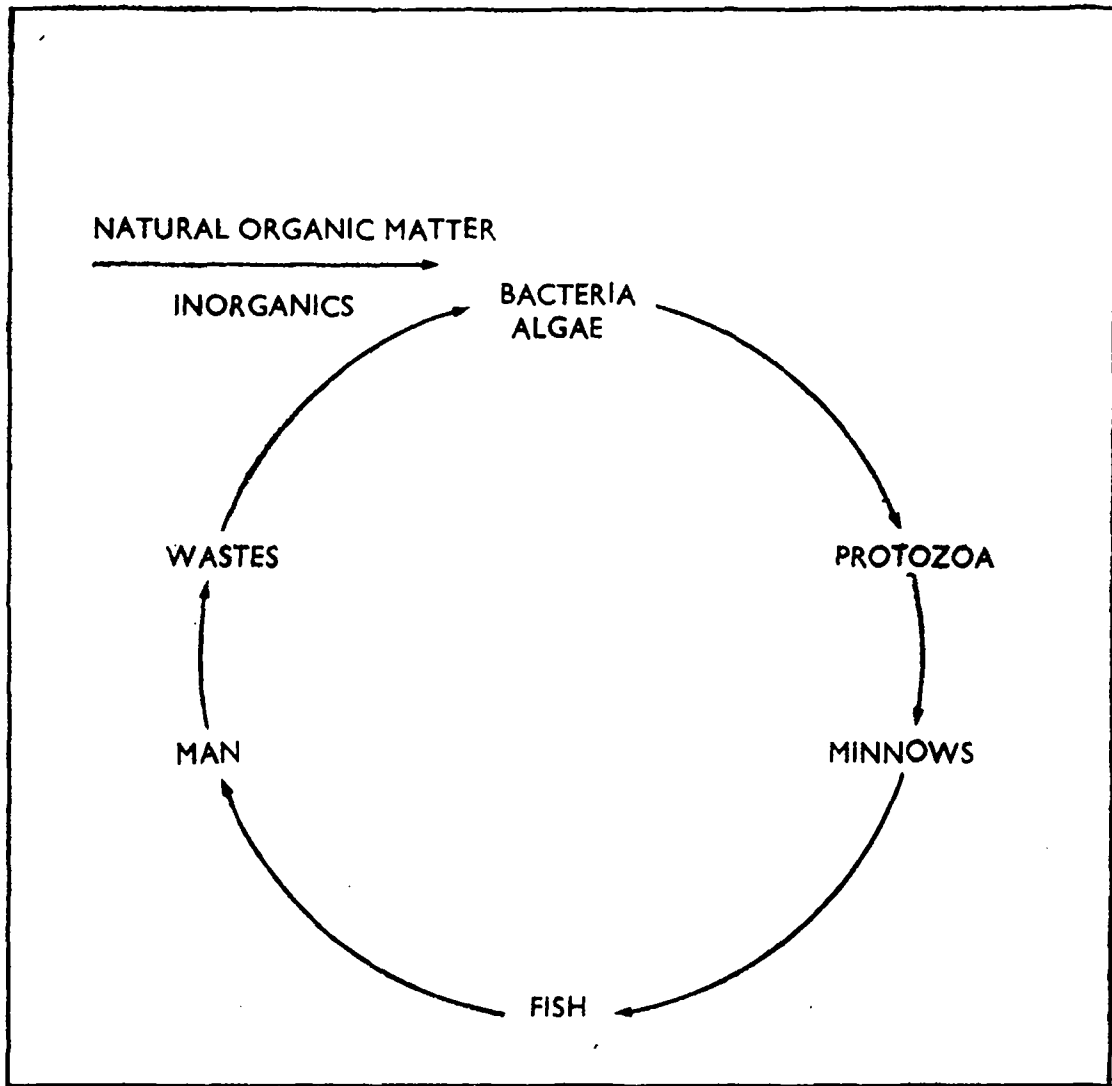


Fig. 1. NATURAL BIOLOGICAL CYCLE IN STREAM

bacteria undergo anaerobic metabolism with the resultant odours and black colours. Even man is unable to live close to such polluted rivers.

Biological Effects of Organic Matter

When sewage is introduced into a river, there begin sequences of events in time and distances of flow that lead to different environmental conditions and different aquatic communities in successive reaches of the river, until natural processes eventually return the river to something like its original condition. Some of the important successional changes occurring in a river when sewage is introduced are shown in Fig. 2.

The bacteria are at first abundant and then decline as the organic matter is used up, sewage fungus appears, increases, and then declines in the same way. When oxygen conditions permit, large numbers of protozoa are build up and most of them belong to species which feed on the bacteria. The algae at first decrease in numbers, but then, as nutrient salts are released from the organic matter and condition improves, they increase greatly in numbers, and then decline as the supply of nutrient salts is diminished. Cladophora appear very abundantly as recovery begins, and then decline like the other algae.

Fishes and clean water invertebrates decline rapidly in numbers and usually all disappear as they are overcome by lack of oxygen, the blanketing effects of suspended solids and sewage fungus or release of poisons. They then reappear in small numbers and little variety and their numbers and variety increases steadily as recovery takes place. In the badly polluted zone the clean water animals are replaced by a very abundant pollution fauna consisting of sludge worms (Tubificidae) blood worms (chironomas) and water louse (Asellus). These three types of animals succeed one another in importance as one proceeds downstream from the outfall. A point that should be stressed is that although it is legitimate in this context to speak of a pollution fauna, none of the animals which belong to it are confined to pollution water. All are indeed normal inhabitants of river muds and ponds, and they merely happen to be favoured by organic pollution.

Fish

Fish are usually eliminated for long distances by severe organic pollution but the reason why this is so is not always clear obviously toxic substances particularly ammonia sulphides and cyanides, kill them, as do very low oxygen tensions. Also low oxygen concentrations enhance the toxicity of most poisons. But fishes often disappear without apparently being killed. They are repelled by low oxygen concentrations, particularly at high temperature (Jones, 1952) and if they are prevented from leaving relatively de-oxygenated water they develop clear sign of distress. Several investigations have observed, however, that fishes were absent below the out-falls of organic effluents even though the oxygen content of the water always remained well above their lower limit of tolerance. At first sight it would be seen that organic matter is repellent to them, and this may to some extent be true. But it is often noted that fishes often congregate around sewage-works outfalls and apparently thrive on the rich food supply which is available there, in the form of worms and insects from filters and particles of sewage fungus. It has often been noted, however, that they tend to leave such places in warm weather. Perhaps this indicate that organic matter becomes repellent only when it is actively decaying. Some recent work by Albaster (1975) also supports this idea. He demonstrated that the concentration of CO_2 in the water has a great influence on the oxygen requirements of fishes CO_2 is produced in large amounts by the breakdown of organic matter, and concentrations of the order of 50 mg/l may occur in polluted water. Such amounts have been shown to

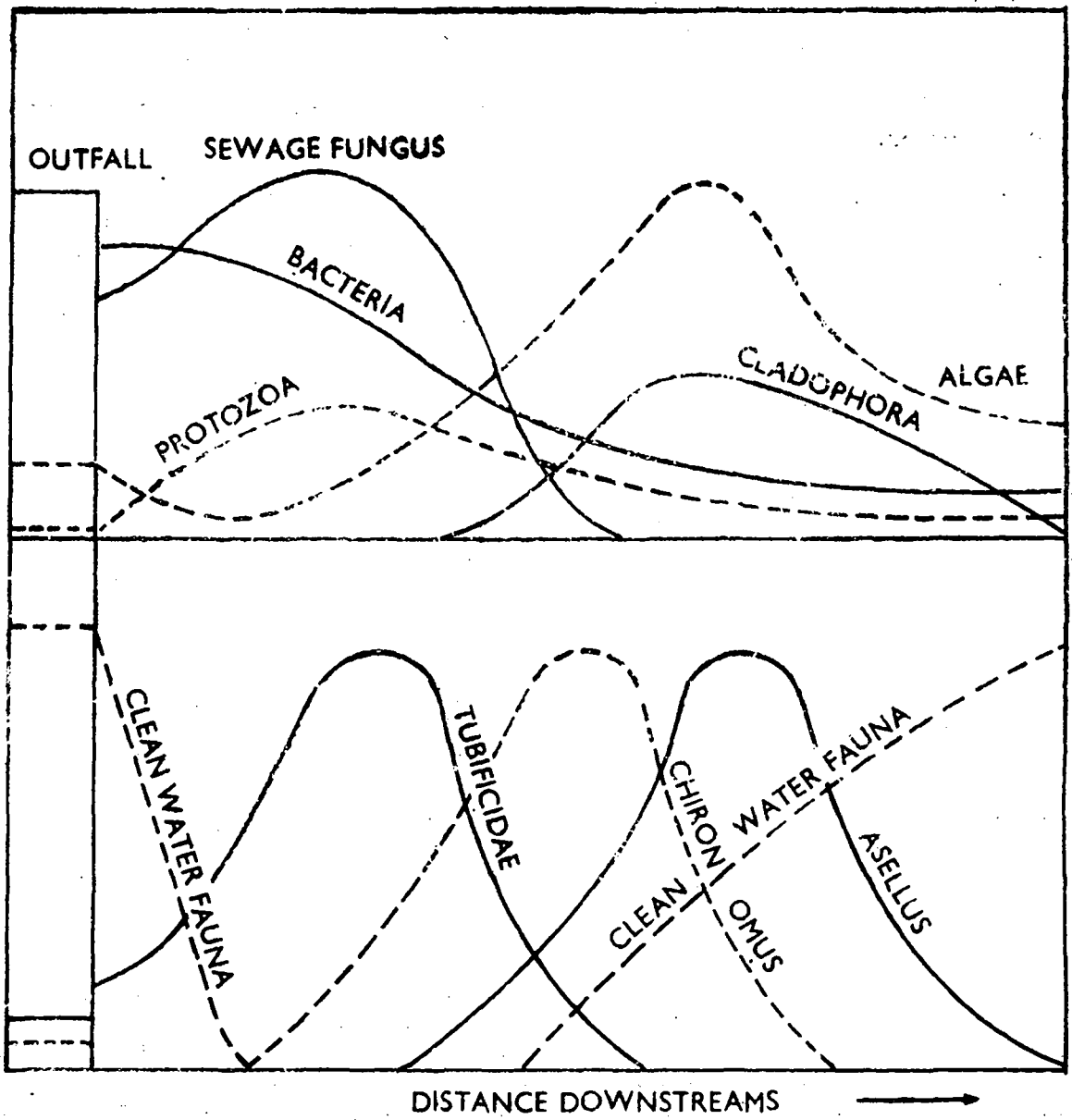


Fig. 2. DIAGRAMMATIC PRESENTATION OF THE EFFECTS OF AN ORGANIC EFFLUENT ON A RIVER AND THE CHANGES IN MICRO-ORGANISMS AS ONE PASSES DOWNSTREAM FROM THE OUTFALL.

double the minimum concentrations necessary for the survival of fishes, and doubtless also they have similar effect on their avoiding reactions.

Distribution of Biological Life in the River Bed

The major controlling factors in the distribution of invertebrates is the nature of river bed. This is either 'eroding' in which event it is rock, stone or gravel, or 'depositing', in which event it is silt or mud. The intermediate condition, sand, forms a convenient dividing line as it is a particularly unsuitable habitat for animal life, and is often almost barren. Superimposed on any of these types of bottom one may find weed beds, which provide a third type of substratum.

Both the oxygen content of the water, and its temperature, tend to be correlated with the types of river bed. Eroding substrata occur in turbulent waters. They are well oxygenated and usually cool. Depositing substrata occur only in sluggish water, they are therefore liable at times to be deficient in oxygen. Extensive weed beds tend to occur in silted regions of slower current and are similarly occasionally exposed to oxygen deficiency and high temperatures.

The inhabitants of the 'eroding' river beds are a rich assortment of worms, leeches, shrimps, insects mites and molluscs; they have varied ways of life, but they all have in common the ability to withstand the force of the current. Many, such as the flatworms, segmented worms, the Nymphs of the stoneflies *Isonychia* and *Chloroperla* and the crane-fly larva *Dicranta*, avoid exposure by creeping down amongst the stones and gravel, which they are able to do because of their elongate and supple bodies.

Most of the inhabitants of eroding substrata are cold loving animals and cannot tolerate very warm water. Some of them, such as the flat worms can withstand very little rise in temperature, and so are confined to high or cool streams. And others such as many of the stoneflies, mayflies and caddisflies get over this problem by doing all their growth in the winter.

The inhabitants of 'depositing substrata' are less varied and interesting, and apart from a few carnivores, such as the fishes and the olderfly, they are scavengers. Silt and mud are unsuitable substrata for algae, and the main food stuff available is the silt itself, dead leaves and other decaying organic matter. The normal inhabitants are, in fact nearly all creatures which also live in stagnant water, such as lakes and ponds. On the surface of the mud one finds the water-slug *Asellus*, which feed on dead leaves and bacterial growth, and in the mud, burrowing creatures and sometimes large numbers of little beam shrimps occur. The burrowers include segmented worms particularly those of the family Tubificidae which feed like earthworms on the mud itself. Also to be found in such places are the large mussels *Anodonta* and *Unio*. Another important group of burrowing animals are the larvae of several species of the midge *Chironomus* which like the tubificidae have red blood, hence their popular name "blood worms." They make tubes in the mud and feed on the particles of silt, bacteria and detritus on the surface.

Biological Effects of Poisons in a River

The biological effects of poisonous substances are basically very simple. Generally speaking the individuals of each species of animals or plants can stand a certain amount of a particular poison, and if more is administered they die. From Fig 3 it is noted that after a poison enters the river its concentration slowly declines, either because of dilution, precipitation or destruction. The animal species are eliminated and then slowly reappear in small numbers. The algae are at first reduced, and the species that survive as dominants

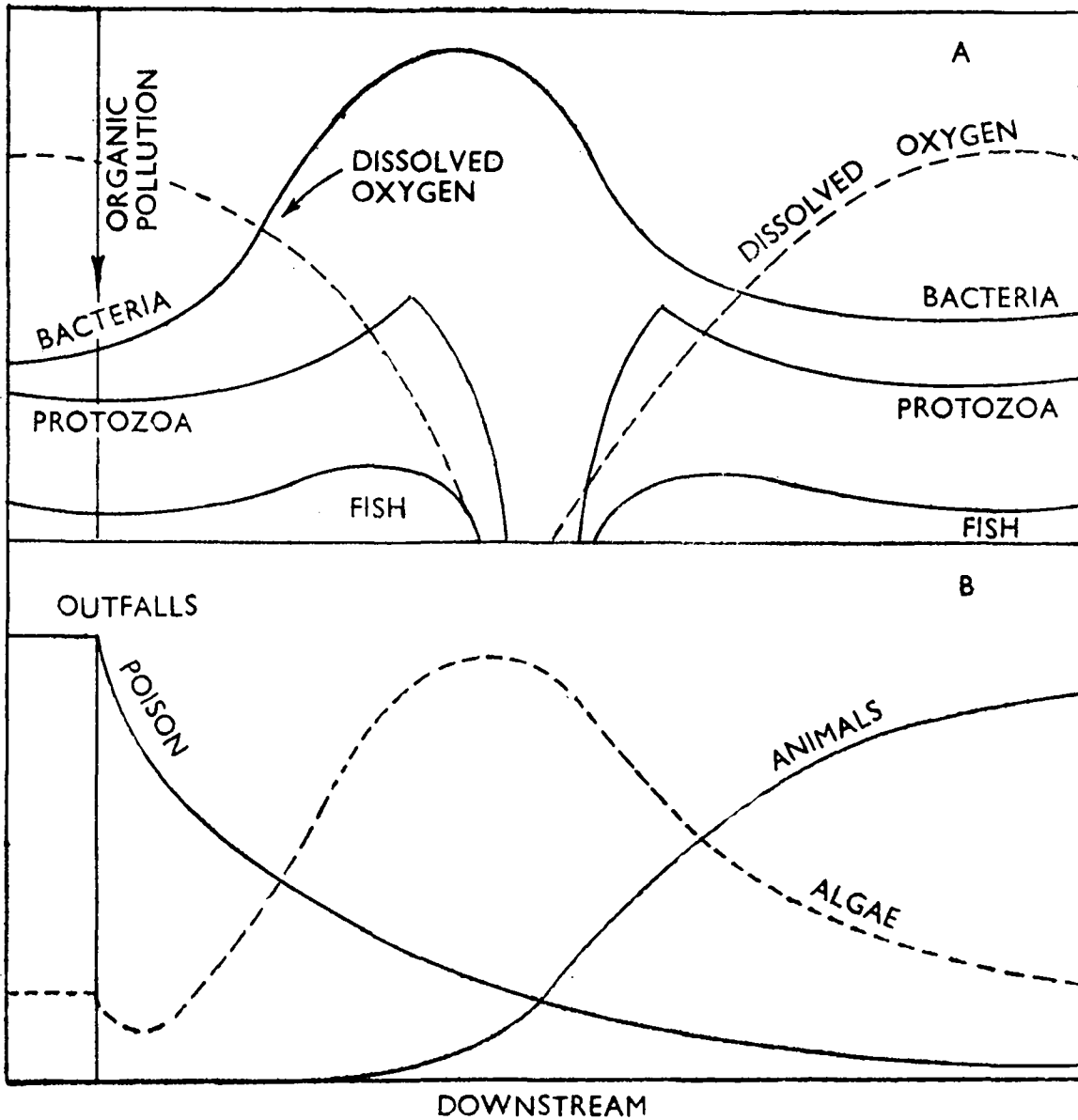


Fig. 3. (A) EFFECT OF POLLUTION ON BIOLOGICAL LIFE IN A STREAM.

(B) DIAGRAMMATIC PRESENTATION OF THE DECREASE IN CONCENTRATION OF A POISON IN A RIVER AND THE CORRESPONDING CHANGES IN MICRO-ORGANISMS.

may be unusual. They may then build up to large numbers, because of the absence of animals to eat them, and slowly decline. Under special circumstances, however, this algal increase may not occur, and there may of course, be poisons which affect the algae as much as, or more than, the animals. It is for instance known that species of cladophora is sensitive to iron salts (Blum 1957) and there is no evidence that this applies to most animals.

The actual effects of poisonous substances on rivers have been investigated by a number of workers. It has many times been noted that sensitive fishes are absent for some distance below outfalls, but much less work has been done on invertebrates and very little on plants. In the United States Wiebs (1972) found that at one point in the upper Mississippi river far from a gas plant had eliminated all life. In Germany it was found that where the river Pleisse contained 20 ppm of phenol there was also no oxygen, presumably because of the oxygen demand of the phenol, and no life at all, but further downstream, where the phenol content was lower, various protozoa returned, but not those species which are ordinarily associated with organic pollution (Muller, 1964).

Biological Assessment of Pollution

Pollution is essentially a biological phenomenon in that its primary effect is on living things. Biological study has moreover several advantages over chemical analyses. It takes less time, because a single series of sample reveals the state of the animal and plant communities, which themselves represent the results of a summation of the prevailing conditions. The advantage of biological investigation therefore lies in the fact that the animals and plants provide a more or less static record of the prevailing conditions and that they are not affected by a temporary amelioration, nor usually by a transient deterioration, of the effluent. But biological investigation does not have all the advantages. It is to some extent true indictment to say that its results are not always easy to interpret. Biological study can reveal only the general type of the pollution; it does not indicate the exact substances involved. It can distinguish between organic and poisonous pollution, but it does not identify, except in certain cases, the particular poison which is causing damage.

Kolkwitz and Marsoon developed their well known Saprobien system for the assessment of organic pollution. They postulated that when a river received a heavy load of organic matter the normal process of self purification would result in a series of zones of decreasing severe conditions succeeding one another downstream and each containing characteristic animals and plants. They divided the system into three zones: Polysaprobic, Mesosaprobic and Oligosaprobic.

Polysaprobic zone is the zone of gross pollution with organic matter of high molecular weight, very little or no dissolved oxygen and the formation of sulphides. Here bacteria are abundant, as are other organisms, but there are few species of animals, and these all live on decaying organic matter or feed on Bacteria. Mesosaprobic zone with simpler organic molecules and steady increasing oxygen content, is divided into an upper (L) zone still with many bacteria and often fungi, and with more types of animals but few algae, and a lower B Zone where mineralization has proceeded further and conditions are suitable for many algae, and tolerant animals and some rooted plants may occur.

Oligosaprobic Zone is the zone of recovery where mineralization is complete and the oxygen content is back to normal and a wide range of plants and animals may occur.

They listed a large number of species of plants and animals which are said to be characteristic of each zone and suggest that identification of those which are present in a river or lake will enable its pollutional status to be assessed.

River Ravi—A Biological Survey

A biological survey of River Ravi was carried out under a planned programme. Samples were collected on a monthly basis covering an area of about 53 km. As the flow of the river varied widely during summer and winter, observations were therefore recorded for both the seasons.

The following Biological flora and fauna were identified from the samples collected.

Algae	Oscillatoria, Lepocinclis, Phacus, Chlorococcum, Nitzschia, Melosira Ankisprodesmus, Navicula, Rhizoclonium ulothrix and surirella.
Midge (deptera)	T. attenuatus, T. reparius, T. stoegeri, T. paganus. T. Blumosus, T. tentan, (T=Tendipedidae).
Stoneflies (placoptera)	N. isoperla, N. teronarcy's, N. acron-euria (N=Nymph).
Caddisflies Oligochaetes	Larvae triaenodes, Helicoplyche Tubifex Tubifex, Tubifex tempelion's Lemnodrelus hoffmeisteri, lemnodrilus undekemianus, Eullyodrilus bavariaus Aulodrilus bluriseta.
Molluscs (Molluscs)	Vireiparodae, Amnicolodae, Pleurocerodae Littorinidae,
Fish	Rohu (Labeorohita), Mori (cirrihnus mrigala, Thaila (Catla Catca), Khagga (Ritarita) Mahasheer (Murrels), Cinghara (Mystus).

Most of the algae species identified from the river were polluted water algae. Species of chlorococcum and diatoms showed a high tolerance range for organic pollution. During summer due to an increase in the flow rate, the algae species showed a decline, indicating better condition of the river. Few species of midge were also identified. They seem to be quite resistant to temperature and sensitive to pollution. An increase in the quantity of midge in summer indicated the return of healthy conditions in the river. Very few species of stoneflies and caddisflies were present in the river. Because of their preference for clean and well aerated water, presence of stoneflies and caddisflies can be regarded as absence of pollution. Species of oligochaetes were also identified. They were quite resistant to organic pollution as most of the species were identified from sewage samples, their number decline during summer. Fish were also identified from the river. From literature survey on Fish of the river Ravi it was concluded that this fauna is decreasing at an alarming rate indicating increase in the pollution load of the river.

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SAMPLING STATION SELECTION

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Sampling stations should be selected with great care and special considerations given to sources of pollution, dilution by branch stream changes in surrounding topography, and slope of the river. Significant river side features should also influence the choice of sampling points, a municipal water intake, a state park, an industrial area, a good fishing spot, a hotel, or a camping site, as each have a definite bearing on the usage of the stream. Since the acceptable pollution limits for waters vary according to usage, samples should be collected and a record made of the condition of the stream just above and just below all such points of stream use or change.

Factors Governing Location of Sampling Stations

Major factors that influence the locations of a sampling station are the relative position of waste effluent outfall, the channel characteristics, river development, and the self purification characteristics of the stream.

Waste Effluent Outfalls

If a sampling station is established at or immediately below a source discharge, it is very probable that sample results influenced by stream pollution will be highly erratic. The station should be some distance down stream, where dispersion throughout the section is essentially complete. If the stream is sluggish and wide, care should be taken to test for significant variability. If variability is detected, it may be necessary to sample at more than one position in the cross-section.

An initial upstream station should be located as a control above the zone of pollution to reflect the residual stream quality from sources of upstream waste and from land drainage and surface wash. There can be a significant organic BOD load and lowered DO as the river arrives at the head of the reach to be analysed.

Channel Characteristics and River Developments

Configuration of the stream channel, irregularity of cross-section, depth, bends and gradients should be considered in locating a sampling station. Wherever feasible, a single sampling position in the cross-section is desirable, but the position must be representative of the main body of flow. Sampling from shore is seldom satisfactory, particularly in an irregular section with shallow beach and deep channel. A good location is a reach of straight, regular cross-section without excessive turbulence down stream of bends and irregular reaches that have produced good mixing and uniformity throughout the section. Bridges may afford a convenient location, if other features are satisfactory. Generally a

boat is necessary for most stations ; however, a boat offers the advantage of flexibility—it is possible to check transversely at a given section and longitudinally between sections for the occurrence of any abnormalities.

Physical characteristics of the channel of a wide, deep river may make it necessary to locate sampling points at several positions transversely in the section and at different depths. This greatly adds to the number of samples necessary to obtain a reliable mean for the section. Station should not be located immediately below the junction of a major tributary. A better measure of the influence of the tributary is to locate the station on the main stream just above the junction and to establish a secondary station on the tributary above its mouth. Otherwise the sampling station in the main stream should be located sufficiently down stream to ensure adequate intermixing of the tributary.

Power dams, storage pools, and navigation works drastically alter the natural channel of a river and may introduce short circuiting and stratification, with accompanying variation in water quality in the cross section. One of the most trouble some variations in sampling introduced by man-made development is the hydroelectric power plant. Radical diurnal variations in stream discharge are induced by heavy release to meet the peak power demands for a few hours of the day with curtailed flow at off-peak hours. This sets up a series of pulsations in discharge that persists down the course of the stream and make representative sampling exceedingly difficult. Arrangements should be made with the power company to stabilize the flow. Usually cooperation can be made if the survey is of short duration. Otherwise intensive sampling on 1 to 2 hr. schedule (or continuous monitoring is necessary to reflect the cycle. As the pulsation of flow passes down stream, it smooths somewhat, and the integration of the cycle will provide a mean condition.

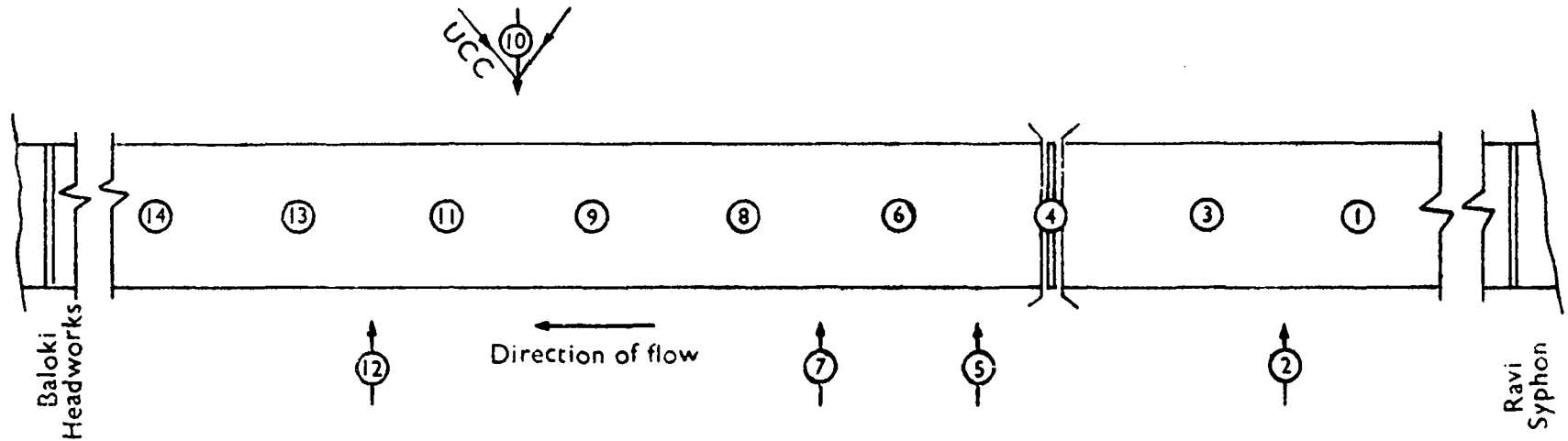
Self Purification Characteristics

In the evaluation of the organic self purification the major objective is to describe the shape of the entire DO profile along the river course, and particularly the critical low point in the sag. Hence more sampling stations are located through the zone of depletion than along the recover reach. If the waste loading is concentrated in a single reach, the DO profile will normally be quite regular and a minimum of sampling stations will suffice. If waste loadings occur along extensive reaches, the DO profile may be composed of primary and secondary sag with intermediate recovery zones and in such cases a considerable number of sampling stations are required.

It is therefore helpful to have fore knowledge of the shape of the expected DO profile in establishing sampling stations. Previous survey data may suffice, but if they are not available it is desirable to take a test run under a runoff regime approximating that contemplated for the sampling programme.

Abnormalities in self purification such as immediate demand, sludge deposits, and biological extraction can radically alter an otherwise normal DO profile. Such abnormalities can be usually anticipated from the reconnaissance survey, the onshore waste survey, and the channel cross-sectioning, from these sampling stations can be located to reflect any distortions. Sampling in tidal estuaries is a difficult and controversial problem, and engineers answers to it have ranged from complete mathematical formulations to simple grab samples. The problem arises from the fact that pollution in tidal streams ebbs and floods with the tide, so that a portion often remains in the reach below the source of pollution for many days rather than hours. One method of sampling which has been found effective, is to determine the tide cycle of the particular stream, then to sample on the high and low, as well as the mean tide. This method provides the analyst with a consistent and overall picture of the tidal pollution situation. Jenkins has indicated how analytical methods may have to be modified for such location because of salinity variations.

Fig. 1. Schematic Sketch of Sampling Stations



- 1 Yar Pur Village.
- 2 Shad Bagh Pumping station.
- 4 Ravi Bridge gauging station.
- 5 Main Outfall.
- 7 Babu Sabu pumping station.
- 9 D/S of Babu Sabu pumping station.
- 10 Degh Nallah outlet.
- 12 Hudiara Nallah outlet.
- 14 D/S of Hudiara Nallah.

Sampling stations 3, 6, 8, 11 & 13, are located approximately where sanitary or industrial waste water intercepts the main body of the river.
River length between station 1 and station 14 = 52 Km.

LEGEND

- River water sample
- ⊕ Waste discharges
- || Gauging station

In evaluating alternative sampling positions in a waste-water stream, the first consideration should be to decide at what points problems may exist and where mixing will be adequate to allow taking representative sample. In some cases it may be necessary to conduct experiments involving the sampling of various cross-sections of a stream and to inspect for bottom deposits or floating scum in streams.

The frequency of monitoring and the type of monitoring will also significantly effect the choice of the monitoring site. If composite samples are to be taken and certain parameters measured and recorded continuously, then the monitoring station should be at a point easily accessible and in an environment suitable for the operation of the required instruments. Because no sampling and monitoring equipments is maintenance free, it should be as close as possible to areas where plant personnel can frequently check on the operation. Hazardous locations which would require installation of special explosion proof instruments might be rejected in favour of areas where such special precautions would not be necessary.

Ravi River Pollution Study

The proposal of this Institute to conduct programme of fields sampling and laboratory analysis of Ravi River was finalised with Water and Sanitation Agency LDA, in 1976. Although Planning and reconnaissance survey, for the same had been started much earlier.

The stretch of Ravi river selected for the study is about 23 km between the first and last sampling station along the river starting from a point about 3 km upstream of the Shad Bagh Sewage Pumping Station which is the first of several locations along the river where municipal sewage from Lahore is being discharged into it. The end of selected stretch is just downstream from the outlets of the Deg and Hudiara Nallahs. The average daily flow of Lahore sewage estimated for 1976 is 213 cusecs. It is stated that almost 50 percent of this quantity is presently used directly for irrigation and the remaining discharged to the river. The average daily sewage flow is estimated almost to double its 1976-value by the year 2000.

Fourteen sampling stations have been selected. A schematic sketch of the river stretch indicating the relative position of the sampling station is given in Fig. 1. The estimated river distance in kilometers with station 1 as the starting point is as follows. Sampling Station 1 Yarpur Village—0 Km ; Sampling Station 4 Ravi Railway Bridge 11 Km ; Sampling Station 5 Main Outfall 17 Km ; Sampling Station 6 Downstream of Main Outfall 18 Km ; Sampling Station 7 Outfall of Babu Sabu Pumping Station 25 Km ; Sampling Station 8 Downstream of Outfall of Babu Sabu Pumping Station 26 Km ; Sampling Station 9—38 Km ; Sampling Station 10 Deg Nallah Outlet 40 Km ; Sampling Station 11 Downstream of Deg Nallah 41 Km ; Sampling Station 12 Hudiara Nallah Outlet 47 Km ; Sampling Station 13 Downstream of Hudiara Nallah Outlet 47 Km ; Sampling Station 13 Downstream of Hudiara Nallah 48 Km ; Sampling Station 14—53 Km.

Major factors which influenced the location of these sampling station in the Ravi River Pollution Study were the relative position of different waste effluent outfalls, the channel characteristics and the anticipated assimilation capacity of the stream. Stations are also located some distance downstream where it was expected that the dispersion throughout the section would be available. Similarly configuration of the Stream Channel, irregularity of the cross-section, depth and bends were considered in locating the sampling station. The reconnaissance survey for the purpose of locating sampling stations was conducted during the months of May, June and December, 1975 to examine municipal waste effluent points, Nallah outlets, sites for flow measurements ; creeks and their points of confluence with the main body of the river.

SAMPLING PROCEDURES

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Introduction

An analysis is always carried out on a sample and it can be no more representative of the liquid under investigation than is that sample. If the liquid is of relatively uniform composition in both time and space then any sample should suffice and there is no problem. But if the composition varies with time or is not uniform at the place where it is decided to take the sample, then no single sample will be truly representative. It then becomes a question either of taking and analysing a number of samples or taking a number of sub-samples, combining them suitably to form one composite sample and analysing that. The number of samples to be taken and the time and exact place of sampling depends on the importance of the analysis, the accuracy required, and the resources available, but skilled judgement will be valuable and there may even be a case for simple-cost-benefit analysis.

The analysis is generally intended to reveal the composition of the liquid at the time of (or even the period of) sampling. Consequently errors are introduced if changes will occur in most of the liquids and in some cases the changes could be substantial or profound. The arrangements should be such that these are prevented or at least minimized. One method of doing this is to carry out the analysis immediately after sampling, though this is often an impossible ideal. There should always, however, be the very minimum of delay and if biological action is likely, storage should be at as low a temperature as possible (usually about 3 to 4°C) consistent with there being no risk of the sampling freezing and breaking the bottle. For some determination other actions can be taken such as the addition of preservatives or immediately fixing the constituent of interest, but the possibilities of doing this depend on the type of analysis required. If preservatives are used the fact must be recorded on the sample bottle and on the analyst's report. Samples for the analysis of metals are best collected in a separate clean glass bottle and acidified with hydrochloric acid to pH 1 to minimize precipitation and adsorption. Care must be taken, however, if cyanide is present.

Thus the whole sampling technique will depend upon what is being sampled, why it is being analysed, and what constituents are to be determined. The man who takes the sample should either be competent to decide this for himself or be thoroughly instructed about it, otherwise the analysis may be either useless or positively misleading.

Objective of Sampling

Quality characteristics of sewage, waste water or polluted wastes are not uniform from one body of water to another, from place to place in a given body of water or even

from time to time at a fixed location in a given body of water. A sampling programme should recognise such variations and provide a basis for interpretation of their effects.

The purpose of collection of samples is the accumulation of data which can be used to interpret the quality or condition of the waste water investigation. Ideally, the sampling programme should be so designed that a statistical confidence limit may be associated with each element of data.

Waste water quality surveys are undertaken for a great variety of reasons. The overall objectives of each survey greatly influence the location of sampling stations, sample type, scheduling of sample collections, and other factors. This influence should always be kept in mind during planning of the survey.

The sampling and testing programme should be established in accordance with principles which will permit valid interpretation. The collection, handling, and testing of each sample should be scheduled and conducted in such a manner as to assure that the results will be truly representative of the sources of the individual samples at the time and place of collection.

The locations of sampling stations and the schedule of sample collections for the total sampling programme should be established in such a manner that the stated investigational objectives will be met. Sampling should be sufficiently repetitive over a period of time to provide valid data about the condition or quality of the water.

Sample Variations

Interpretation of survey data is based on recognition that variations will occur in results from individual samples. The following can be identified as factors producing variations in data and should be considered in planning the sampling programme

Apparent Variations :

- (a) Variations of statistical nature, due to collection of samples from the whole body water, as contrasted with examination of all the water in the system.
- (b) Variations due to inherent precision of the analytical procedures.
- (c) Apparent variations are usually amendable to statistical analysis.

True Differences

- (a) Variations of a cyclic nature

Diurnal variations, related to alternating periods of sunlight and darkness ;

Diurnal variations related to waste discharges from communities ;

Seasonal variations, related to temperature and its subsequent effects on chemical and biological processes and interrelationships ;

Variations due to tidal influence, in coastal and estuarine waters.

(b) Intermittent variations

Dilution by rainfall and runoff ;

Effects of irregular or intermittent discharges of wastewater, such as "sludges" of industrial wastes ;

Irregular release of water from impoundments, as from power plants.

(c) Continuing changes in water quality

Effects downstream from points of continuous release of wastewater ;

Effects of confluence with other bodies of water ;

Effects of passage of the water through or over geological formations of such chemical or physical nature as to alter the characteristics of the water ;

Continuing interactions of biological, physical, and chemical factors in the waste water, such as in the process of natural self-purification following introduction of organic contaminants in a body of water ;

(d) Similarly, vertical mixing may not be rapid. This is noted particularly in tidal estuaries, where it may be necessary to make collections both from near the bottom and near the surface of the water.

(e) Collection of multiple samples from a station requires close coordination with the laboratory, in terms of the number of samples that can be examined. Some types of samples may be composited. The decision must be reached separately for each type of sample.

Time of Year

In short-term water quality investigations, particularly in pollution investigations, there often is need to demonstrate the extremes of pollution effects on the aquatic environment. For this reason, many short-term surveys are conducted during the warmer season of the year, at such times as the water flow rate and volume is at a minimum and there is minimum likelihood of extensive rainfall.

In a long-term investigation, sampling typically is conducted at all seasons of the year.

Daily Schedules

As shown in an introductory paragraph, waste water quality is subject to numerous cyclic or intermittent variations. Scheduling of sample collections should be designed to reveal such variations.

In short-term surveys it is common practice to collect samples from each sampling site at stated intervals through the 24-hours day, continuing the programme for 1—3 weeks. Sampling at 3 hours intervals is preferred by many workers, though practical considerations may require extension to 4 or even 6 hour intervals.

In an extended survey there is a tendency to collect samples from each site at

not more than daily intervals or even longer. In such cases the hour of the day should be varied through the entire programme, in order that the final survey show cycle or intermittent variations if they exist.

In addition, sampling in tidal waters requires consideration of tidal flows. If samples are collected but once daily, many workers prefer to make the collections at low slack tide.

In long-term or any other survey in which only-daily samples are collected, it is desirable to have an occasional period of around-the-clock sampling.

Sample Collection

Types of Samples

"Grab" Sample—a grab sample is usually a manually collected single portion of the wastewater or stream water. The analysis of a grab sample shows the concentration of the constituents in the water at the time the sample was taken.

"Continuous" Sample—when several points are to be sampled at frequent intervals or when a continuous record of quality at a given sampling station is required, an automatic or continuous sampler may be employed. Some automatic samplers collect a given volume of sample at definite time intervals: this is satisfactory when the volume of flow is constant. Other automatic samplers take samples at variable rates in proportion to changing rates of flow. This type of sampler require some type of flow measuring device.

"Composite" Sample—a composite sample is the collection and mixing together of various individual samples based upon the ratio of the volume of flow at the time the individual samples were taken to the total cumulative volume of flow. The desired composite period will dictate the magnitude of the cumulative volume of flow. The more frequently the samples are collected, the more representative will be the composite sample to the actual situation. Composite samples may be obtained by:

- (a) Manual sampling and volume of flow determination made when each sample is taken.
- (b) Constant automatic sampling (equal volumes of sample taken each time) with flow determinations made as each sample is taken.
- (c) Automatic sampling which takes samples at pre-determined time intervals and the volume of sample taken as proportional to the volume of flow at any given time.

TYPE OF SAMPLING EQUIPMENT

Manual Sampling

Equipment is specially designed for collection of samples from the bottom muds, at various depths or at water surfaces. Special designs are related to protection of sample integrity in terms of the water characteristic or component being measured.

Manual sampling equipment has very broad application in field work, as great mobility of operation is possible, at lower cost than may be possible with automatic sampling equipment.

Automatic Sampling Equipment

Automatic sampling equipment has several important advantages over manual methods. Probably the most important consideration is the reduction in personnel requirements resulting from the use of this equipment. It also allows more frequent sampling than is practical manually, and eliminates many of the human errors inherent in manual sampling.

Automatic sampling equipment has some disadvantages. Probably the most important of these is the tendency of many automatic devices to become clogged when liquids high in solids are being sampled. Individual portions of composite samples are usually quite small which may in some cases be disadvantageous. In using automatic samples, sampling points are fixed, which results in a certain loss of mobility as compared to manual methods.

Automatic sampling equipment should not be used indiscriminately for some types of samples—notably bacteriological, biological, and DO samples—should not be composited. In cases of doubt, the appropriate analyst should be consulted.

Different devices Available for use as Samplers are :

Composite samplers, Jar and tube sampler scoop type, Pumps Solenoid valve arrangement, Vacuum operated, Air vent control, Drip sampler.

In continuous recording equipment instruments have been developed which provide direct measurement of temperature, pH, conductivity, colour, and dissolved oxygen. Such instruments may be equipped for continuous recording. Instruments of this type are quite expensive and their installation is often difficult. They are best adapted to permanent installations, although good portable non-recording instruments are available for measurement of temperature, pH, and conductivity. Some Considerations in Sampling Operations.

All procedures in care and handling of samples between collection and the performance of observations and tests are directed toward maintaining the reliability of the sample as an indication of the characteristics of the sample source.

Sample Quantity

Sampling for a series of chemical analyses requires determination of the total sample volume required for all the tests, and should include enough sample in addition to provide a safety factor for laboratory errors or accidents. Many workers collect about twice the amount of sample actually required for the chemical tests. As a rule of thumb, this is on the order of 1 litre.

Bacteriological samples, in general, are collected in 250-300 ml sterile bottles ; approximately 150-200 ml of samples is adequate in practically all cases.

Sample Identification

Sample identification must be maintained throughout any survey. It is vital, therefore, that adequate records be made of all information relative to the source of the sample and conditions under which the collection was made. All information must be clearly understandable and legible.

Every sample should be identified by means of a tag or bottle marking, firmly affixed to the sample bottle. Any written material should be with indelible marking material.

Minimum information on the sample label should include identification of the sample site, date and time of collection, and identification of the individual collecting the sample.

Supplemental identification of samples is strongly recommended, through maintenance of a sample collection logbook. If not included on the sample tag (some prefer to duplicate such information) the Log book can show not only the sample site and date and hour of collection, but also the results of any tests made on site (such as temperature, pH, dissolved oxygen). In addition, the Log book should provide for notation of any usual observations made at the sampling site, such as rainfall, direction and strength of unusual winds, or evidence of disturbance of the collection site by human or other animal activity.

Care and Handling of Samples

As a general policy, all observations and tests should be made as soon as possible after sample collection. Some measurements require performance at the sampling site, such as temperature, light intensity (if determined), flow-rate, etc. Some tests are best made at the sampling site because the procedures are simple, rapid, and of acceptable accuracy. This may include such determinations as pH and conductivity.

Some additional determinations, such as alkalinity, hardness, dissolved oxygen and turbidity may be made in the field, provided that ease, convenience, and reliability of results are acceptable for the purposes of the study.

Samples to be analyzed in the laboratory require special protection to assure that the quality measured in the sample represents the condition of the source. Many samples, especially those subjected to biological analysis, require special preservation, protection, and handling procedures. In case of doubt, the appropriate analyst should be consulted. Most common procedures for sample protection include : temperature control, protection from light and addition of preservative chemicals. However early examinations of the samples is always desirable.

Temperature Control

All biological materials for examination in a living state should be iced between collection and examination. Bacteriological samples, according to "Standard Methods" should be maintained at the same temperature as the source of the sample between collection and starting the laboratory tests. Most survey workers, however, continue to ice samples and start laboratory tests within 6 hours after collection. Chemical samples often require icing. Samples for dissolved oxygen can be maintained several hours if kept iced, and protected from the light. BOD samples can be held several hours in an iced condition. Quick freezing will permit retention of many samples for upto several months prior to laboratory examination.

Protection from Light

Any constituent of water which may be influenced by physio-chemical reactions involving light should be protected. DO samples brought to the iodine stage, for example, should be protected from light prior to titration. In addition, any water constituent (such as dissolved oxygen) which may be influenced by algal activity should be protected from light.

Addition of Chemical Preservatives

Bacteriological samples never should be "protected" by addition of preservative agents. The only permissible chemical additive is sodium thiosulphate, which is used to neutralize free residual chlorine, if present.

Samples for biological examination should be protected by chemical additive only under specific direction in a water quality study. For chemical tests, preservatives are useful for a number of water components which are given in Table I.

TABLE I
Recommendation for Sampling and Preservation of Samples
according to Measurement

Measurement	Volume required (ml)	Container	Preservative	Holding Time
1	2	3	4	5
<i>Physical Properties :</i>				
Colour	50	P,G	Cool 4 °C	24 Hrs.
Conductance	100	P,G	Cool 4 °C	24 Hrs.
pH	25	P,G	Det. on site	6 Hrs.
Turbidity	100	P,G	Cool 4 °C	7 days
Temperature	1000	P,G	Det. on site	No Holding
Hardness	100	P,G	Cool, 4 °C HNO ₃ to pH<2	—
Residue filterable	100	P,G	Cool 4 °C	7 days
Non-filterable	100	P,G	Cool 4 °C	7 days
Total	100	P,G	Cool 4 °C	7 days
Volatile	100	P,G	Cool 4 °C	7 days
Settleable matter	1000	P,G	Non Req.	24 Hrs.

1	2	3	4	5
<i>Inorganic, Non-Metallics :</i>				
Acidity	.. 100	P,G	Non req.	24 Hrs.
Alkalinity	.. 100	P,G	Cool 4 °C	24 Hrs.
Chloride	.. 50	P,G	Non req.	7 days
Fluoride	.. 300	P,G	Non req.	7 days
Nitrogen (Ammonia)	.. 400	P,G	Cool 4 °C H ₂ SO ₄ pH<2	24 Hrs.
Kjeldahl, Total	.. 500	P,G	Cool 4 °C H ₂ SO ₄ to pH<2	24 Hrs.
Nitrate	.. 100	P,G	Cool, 4 °C	24 Hrs.
Dissolved Oxygen probe	300	G. only	Det. on site	No handling.
Winkler	.. 300	G. only	Fix on site	4—8 Hrs.
Phosphorus ortho	.. 50	P,G	Filter on site Cool, 4 °C	24 Hrs.
Sulphate	.. 50	P,G	Cool, 4 °C	7 days
COD	.. 50	P,G	H ₂ SO ₄ to pH<2	7 days
Oil & Grease	.. 1000	G. only	Cool, 4 °C H ₂ SO ₄ or Hcl to pH<2	24 Hrs.

NOTE : Plastic (P)
Glass (G)

STANDARD WATER SAMPLER, ACC. TO RUTTNER

With this handy and versatile apparatus, water samples can be taken from any desired depth. The closing mechanism of the sampler has proved itself to be most satisfactory over many years ; the water sampler itself is of simple and practical design and guarantees reliable results.

The Standard Water Sampler, still open, is lowered by rope into the water. Upon reaching the desired depth, the drop messenger is let down on the rope. When it strikes the Standard Water Sampler, the closing mechanism is released and the lids of the sampling tube close. A thermometer ranging from -2 to $+30^{\circ}\text{C}$, divided in $0,2^{\circ}\text{C}$, indicates the temperature of the sample ; the temperature can easily be read through the plastic tube of the sampler. The water sample can be drawn off through the discharge cock in the lower lid for the various analyses.

INDUSTRIAL WATER SAMPLER

The Industrial Water Sampler is an improved version of the Standard Water Sampler and was developed to comply with the demands of the industrial world for more exact analytical tests. In the Industrial Water Sampler the sample no longer comes into contact with metal and thus tests for the determination of trace elements are possible. Operation is the same as for the Standard Water Sampler Acc. to Ruttner excepting that a thermometer is not built in.

Transport

The water samples should reach the laboratory as soon as possible. On no account should storage exceed 72 hours. Cooling of samples during transport is not mandatory, but if it is possible, it would be an advantage. No samples should be collected on days preceding week-ends or public holidays.

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LABORATORY TECHNIQUES

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SUSPENDED SOLIDS

Principle

There are two ways to determine suspended solids, also known as "total suspended matter."

(a) The total residue of a water sample by evaporation and the residue of the filtered sample (filtrable residue) are determined. The difference of the two results represents the amount of suspended solids.

(b) Suspended solids are removed from the sample by filtration and directly measured.

Method (b) will be described in the following :

Procedure

(1) For polluted water, a glass fibre filter disc has been found very suitable to remove suspended particles. It does not get easily clogged. The disc has to be dried, weighed, and placed on a filter holder.

(2) The sample size should be such that a non-filtrable residue from about 50 to 200 mg remains on the filter. The sample is filtered through the disc while suction is used. The residue should then be washed with distilled water.

(3) The filter disc is dried for one hour in an oven at 103—105 °C.

(4) After drying, the disc should be cooled to room temperature in a desiccator and weighed on an analytical balance.

(5) The calculation for expressing the result in mg/l is as follows :

$$\text{mg/l suspended matter} = \frac{A \times 1000}{B}$$

A = mg suspended solids weighed

B = ml sample

TOTAL DISSOLVED SOLIDS

Principle

Total dissolved solids, known as TDS, are determined as filtrable residue of a water sample. The water sample is filtered and the filtrate evaporated, dried and weighed.

General

Strictly speaking, the filtrable residue is not accurately the amount of solids that were dissolved in the original water sample. Depending on the pore size of the filter used suspended and colloidal matter might have passed through it. During evaporation, bicarbonates precipitate as carbonates and this conversion results in a loss of carbon dioxide. When the residue is dried, some of the salts retain water of crystallization and may also include some water mechanically. Slight weight gains may occur due to oxidation and weight losses to volatilization of organic matter. For these and other reasons, the filtrable residue represents only an approximate value of, but a practical approach to, TDS. Any method aiming at a higher accuracy would make the procedure exceedingly complex.

Procedure

(1) The sample is passed through a filter, which may be a hard finished paper filter, glass fibre filter, membrane filter or a suitable crucible. The sample volume should be so chosen that it will presumably yield a residue between 100 and 250 mg. The volume to be filtered can be estimated from the value of the specific conductivity.

(2) The measured volume is poured into a weighed evaporating dish and evaporated slowly on a steam bath. The dish may be porcelain which is satisfactory for most purposes. High pH waters, however, require a platinum dish.

(3) After complete evaporation, the dish is transferred to an oven, where a temperature of 103-105°C is maintained, and dried to constant weight. To avoid frequent checking of the weight the dish may be dried overnight. Another standard temperature for drying is 180 °C but this is less commonly used.

(4) The dish should then be allowed to cool briefly in air before it is placed into a desiccator. After it has completely cooled it should be weighed on an analytical balance.

(5) The calculation for expressing the result in mg/l is as follows :

$$\text{mg/l filtrable residue (TDS)} = \frac{\text{mg residue weighed} \times 1000}{\text{ml sample}}$$

The temperature at which the sample was dried should always be reported.

TDS may also be obtained by difference between the total residue and total suspended matter.

NITRATE

General

The determination of nitrate in water with classical methods is not very easy. Several ions interfere and the procedures are complex. There are many methods, but none

of them is really satisfactory. There are the zinc reduction and the cadmium reduction method, the brucine and the phenol-disulphonic acid method, the salicylate, the chromotropic acid, the 2, 6 xyleneol, the parafluorophenol and the ultraviolet spectrophotometric method. A specific ion electrode method has been developed recently which seems to be quite promising. The great number of methods shows that analysts have intensively searched to find the ideal way for nitrate determination. Hence, the phenol-disulphonic acid method will be described, because this method is popular in many laboratories.

Principle

The method is based on the fact that a yellow colour is produced by the reaction between nitrate and phenol-disulphonic acid. The colour intensity can be measured by the aid of a photometer. The main interference in this method is chloride, even small concentrations effect the result and should therefore be removed. Nitrite and coloured ions and materials, as well as turbidity, also interfere.

Procedure

(1) Colour and turbidity have to be removed by treatment of the sample with an aluminium hydroxide suspension. Activated carbon can also be used for the removal of colour by adsorption.

(2) Nitrite (if present) has to be converted into nitrate by an oxidant such as potassium permanganate or hydrogen peroxide. At the end of the nitrate determination, a proper deduction has to be made for the nitrite originally present, which has to be estimated separately.

(3) The chloride content of the water must be known, and the sample is then treated with an equivalent amount of standard silver sulphate solution. Insoluble silver chloride is formed which can be removed by centrifugation or filtration after the sample has been allowed to stand for some time preferably over night.

(4) The neutralized sample has to be evaporated to dryness.

(5) The residue is thoroughly mixed with a certain amount of the phenol-disulphonic acid reagents. (This reagent is not commercially available ; it has to be prepared by dissolving pure phenol in fuming concentrated sulphuric acid).

(6) After the reagent is added and the mixture diluted with distilled water, an addition of ammonia or potassium hydroxide is made, and colour develops.

(7) Any residual turbidity should be removed and the clear solution transferred into a volumetric flask.

(8) A photometric reading is made in cells having a light path of 1 cm or longer at a wavelength of 410 nm.

(9) With the aid of a calibration curve, prepared by using various dilutions of a standard nitrate solution, nitrate concentration is found.

The calibration curve may be calibrated in nitrate (NO_3^-), mg/l or in nitrate nitrogen (N), mg/l. The latter way is often chosen to facilitate the comparison of the amounts of the various forms of nitrogen (organic N, ammonia N, nitrite N and nitrate N). For conversion, the factor 4.43 may be used :

$$\text{mg/l NO}_3^- = \text{mg/l nitrate N} \times 4.43$$

ORTHO-PHOSPHATE

General

Phosphate in streams occurs as ortho-phosphate, condensed phosphates including poly-phosphates and organic phosphate. Only the determination of ortho-phosphate (PO_4^{-3}) is described here. One of the standard methods for ortho-phosphate is the vanado-molybdate method. There are also two modifications of it, the stannous chloride and the ascorbic acid method, which will not be covered here.

Principle

Ortho-phosphate reacts under acid condition with ammonium molybdate to form molybdo-phosphoric acid. In the presence of vanadium, a yellow compound, the vanado-molybdo-phosphoric acid, is formed. The intensity of the yellow colour is proportional to the phosphate concentration in the sample. There are a number of ions that can cause interference but only if their amount is unusually high.

Procedure

(1) Any excessive colour present in the sample is removed by shaking it with activated carbon followed by filtering the sample through filter paper.

(2) A certain sample size is measured, 10 ml of the vanadate—molybdate reagent is added, and the solution diluted to the mark of the flask with distilled water. A blank should be prepared in which the sample is substituted by the same volume of distilled water.

(3) After 10 minutes from the time of adding the reagent, the absorbance of the sample versus the blank is read on a photometer at a wavelength of 400-490 nm, depending on the sensitivity esired.

(4) The final result is obtained by the aid of a calibration curve, which has to be prepared for a particular wavelength, using various dilutions of a standard phosphate solution. It is practical to plot a family of calibration curves for various wave-lengths for various sensitivities.

ATOMIC ABSORPTION SPECTROPHOTOMETRY

General

Atomic absorption spectrophotometry (AAS) has in recent years become valuable tool for the determination of heavy metals and other elements in water and wastewater. The method is sensitive, rapid, and relatively free from interference, which makes it attractive also for stream pollution surveys. However, the apparatus necessary for it is very costly.

Principle

When an element in the atomic state is subjected to extreme heat, a portion of the atoms becomes thermally "excited", meaning raised to a state of energy in which they emit radiation. The wavelength of the radiation is characteristic of that element. At the temperature of the flame, however, most of the atoms remain unexcited or, as it is called, in their "ground-state." In this condition they do not emit, but are able to absorb radiation of the same frequency.

Adopting this phenomenon for analytical purposes, the decrease in the intensity of the characteristic radiation is measured after it has passed through a flame containing atoms of an element to be determined. This decrease is a function of the concentration of the element in the flame and hence in the water sample.

Apparatus

An apparatus for AAS consists basically of the following units :

(a) A light source for the radiation characteristic of the element to be determined. This is usually a so-called hollow-cathode lamp, an electrical discharge tube fitted with a silica window. It contains electrodes constructed of the element for which it is to be used. For each element a different lamp is necessary.

(b) A hot flame into which the sample is sprayed. Gas mixtures are used for the flame, air-acetylene being suitable for most elements and nitrous oxide-acetylene for those that require a higher flame temperature. Controls for the flow of these gases are necessary.

(c) A nebulizer or "atomizer" that forms an aerosol of the element to be determined. Only a very fine spray of the sample should reach the flame.

(d) A monochromator to isolate the desired wavelength from that of neighbouring wave-lengths emitted from the source.

(e) A detector to measure the intensity of the radiation both the original intensity and its decrease after the radiation has passed through the flame. The detector is usually a photomultiplier tube.

(f) Electronics for the amplifying, processing and converting the detector signal into absorbance, which is presented digitally in modern instruments.

Procedures

It is not possible here to outline the detailed procedure for the determination of each element because they are so numerous. Only a few important points may be mentioned.

- For the determination of metals in water, samples are to be acidified with nitric acid at the time of collection to ensure they remain in solution.
- If suspended solids are present, which are to be analyzed, a digestion procedure has to be employed.
- After complete dissolution, the following metals can be determined (directly or after addition of a reagent to counteract interferences) in an air-acetylene flame : Nickel, chromium, cobalt, copper, silver, lead, calcium, magnesium, iron, manganese, zinc, and cadmium.
- For very low concentrations of cadmium, chromium and lead an enrichment process involving organic reagents is necessary prior to their determination in the air-acetylene flame.

—For the elements aluminium, silicium, beryllium, barium and vanadium, a nitrous oxide-acetylene flame is required, and very low concentrations of them need to be enriched first.

—To convert the absorbance into concentration units a calibration curve is needed.

The detection limit by AAS for various metals differs very much from metal to metal. For aluminium, the limit is 0.1 mg/l whereas for mercury, it is as low as 0.0002 mg/l.

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LABORATORY TECHNIQUES

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TURBIDITY

Principle of the Nephelometric Method

The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. The results are expressed in Nephelometric Turbidity Units, NTU. Maximum turbidity to be measured is 40 NTU.

Formazin polymer, which is easy to prepare, is used as the turbidity standard reference suspension. Formazin standards in sealed vials are also supplied by the manufacturers of turbidimeters, but their limited lifetime must be kept in mind.

Various makes of turbidimeters are available. The HACH turbidimeter, which is used at this Institute, is equipped with 5 separate scales 0-0.2, 0-1.0, 0-100, and 0-1000 NTU. The upper scales serve only as indicators of required dilution volumes to reduce reading to less than 40 NTU.

Procedure

(1) Calibrate the turbidimeter with a turbidity standard in the range in which the turbidity of the sample is expected to fall.

(2) Turbidity less than 40 units : Shake the sample thoroughly to disperse the solids. Wait until air bubble disappear, then pour the sample into the turbidity tube. Read the turbidity directly from the instrument scale.

(3) Turbidity exceeding 40 units : Dilute the sample with one or more volumes of turbidity free water until the turbidity falls below 40 units. The turbidity of the original sample is then computed from the turbidity of the diluted sample and the dilution factor.

pH VALUE (HYDROGEN ION CONCENTRATION)

General

pH is defined as the negative logarithm (to base 10) of the hydrogen-ion concentration expressed in g-ions/l;

$$\text{pH} = \log_{10} (\text{H}_3 \text{O}) +$$

Instruments are available which can record the pH of a solution by electrometric methods. There is also a rapid, inexpensive method sufficiently accurate for many purposes which makes use of chemical indicators. These substances are usually dyestuffs which change colour when the solution in which they are placed reaches a certain pH value. In the following, only the electrometric method will be described.

Principle

The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference electrode or a combination electrode.

Apparatus

(a) Electronic pH meter laboratory or field model. A wide variety of instruments are commercially available with various specifications and optional equipments.

(b) Glass electrode.

(c) Reference electrode. A calomel, silver—silver chloride, or other reference electrode of constant potential may be used. The glass electrode and the reference electrode are also supplied in one unit, known as combination electrode.

(d) Magnetic stirrer and teflon coated stirring bar.

(e) Thermometer or temperature sensor for automatic compensation.

Interferences

(1) The glass electrode, in general, is not subject to solution interferences from colour, turbidity, colloidal matter, oxidants, reductants or high salinity.

(2) Coating of oily material or particulate matter can impair electrode response. These coating can usually be removed by gentle wiping or detergent washing, followed by distilled water rinsing. An additional treatment with hydrochloric acid may be necessary to remove any remaining film.

(3) Temperature effects on the electrometric measurement of pH arise from two sources. The first is caused by the change in electrode output at various temperatures. The second source is the change of pH inherent in the sample at various temperatures.

Procedure

(1) Samples should be analyzed as soon as possible preferably in the field at the time of sampling.

(2) Calibrate the electrode system against standard buffer solutions of known pH.

(3) Place the sample or buffer solution in a clean glass beaker using a sufficient volume to cover the sensing elements of the electrodes.

(4) If field measurements are being made the electrodes may be immersed directly in the sample stream to an adequate depth and gently moved.

(5) If the sample temperature differs by more than 2°C from the buffer solution the measured pH values must be corrected.

(6) After rinsing and gently wiping the electrodes, if necessary, immerse them into the sample beaker or sample stream.

(7) Note and record sample pH and temperature. pH meters read directly in pH units.

THE EXAMINATION FOR MEMBERS OF THE COLIFORM GROUP

General

The organisms most commonly used as indicator of faecal pollution are the coliform group as a whole, and *Escherichia Coli* or faecal coliforms in particular.

The term "Coliform organisms" refers to Gram-negative, oxidase-negative, non-sporing rods capable of growing aerobically on an agar medium containing bile salts and able to ferment lactose within 48 hours at 37 °C with the production of both acid and gas. *Escherichia Coli* is a coliform organism, which is capable of fermenting lactose with the production of acid and gas at both 37 °C and 44 °C in less than 48 hours. E-Coli is undoubtedly of faecal origin.

Since coliform bacteria are present in large numbers in faeces and sewage, they are the most sensitive indicators for demonstrating the excretal contamination of water. For this reason careful estimation has to be made of the numbers of coliform organisms and of *E. Coli* present before deciding whether the pollution is severe enough to render the water potentially dangerous.

The coliform examination is usually performed either by adding measured volumes of water to suitable liquid media or by filtering measured volumes of water through membrane filters.

(A) MPN PRESUMPTIVE AND CONFIRMED TEST

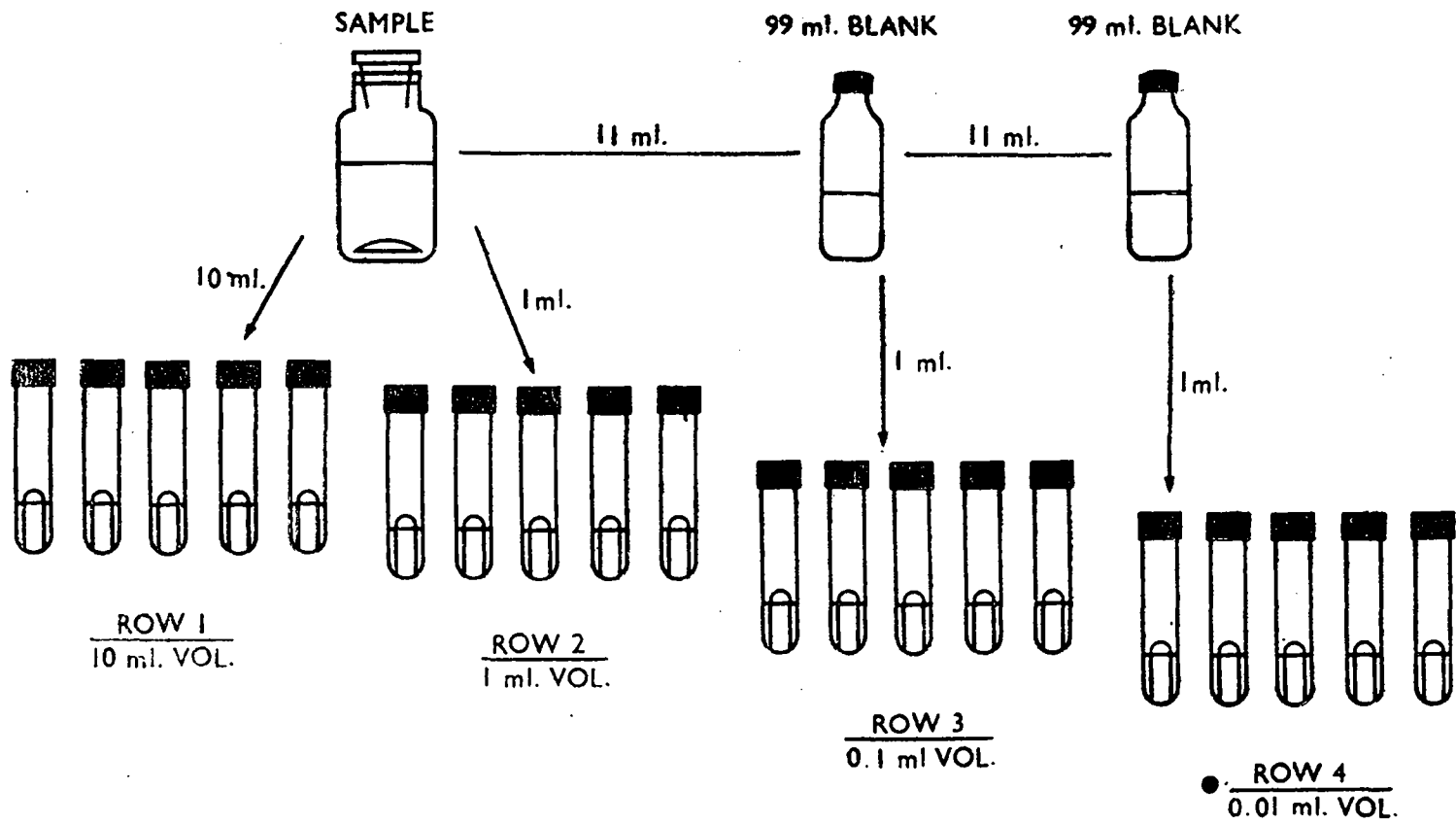
Principle

Measured volumes of the water or its dilutions are added to tubes containing a liquid differential medium. It is assumed that, on incubation, each tube which received one or more viable organisms in the inoculum will show growth and the differential reaction appropriate to the organisms sought and the medium used. The most probable number (MPN) or organisms in the original sample may be estimated from the number of tubes giving a positive reaction. Statistical tables of probability are normally used for this purpose.

Procedure of Presumptive Test

1. Shake sample bottle vigorously several times and pipet 1 ml of sample into a 99 ml dilution blank. This constitutes 1/100 dilution of the sample.

2. Pipet 10 ml of sample into each of the 5 double strength presumptive broth tubes in row "1."

Fig. 1. Preparation of Dilutions for MPN Procedure

3. Pipet 1 ml of sample into each of the 5 single strength presumptive broth tubes in row "2."

4. Shake the bottle containing a 1/10 dilution of the sample vigorously and pipet 1 ml into a 99 ml dilution blank. This constitutes a 1/100 dilution of the sample.

5. Pipet 1 ml of the 1/10 dilution into each of the 5 single strength broth tubes in row "3."

6. Shake the bottle containing the 1/100 dilution vigorously and pipet 1 ml into each of 5 single strength presumptive broth tubes labeled row "2."

7. Incubate all tubes at 37 °C for 48 hours.

The production of acid and gas in these tubes incubated at 37 °C for 48 hours, indicates the presence of coliform-organisms. This reaction is generally referred to on a "Presumptive Positive Coliform reaction."

Procedure of Confirmed Tests

Using a sterile metal loop 3mm in diameter, transfer one loopful of medium from all 24 hours and 48 hours gas positive tubes to fermentation tubes containing 1 per cent lactose ricinoleate broth or brilliant green lactose bile broth and incubate for 24 hours at 37 °C, for coliform. At the same time inoculate 1 percent lactose peptone water and incubate at 44 °C for 24 hours, for the rapid indication of the presence of E-Coli.

(B) MEMBRANE FILTRATION

The alternative method of estimating coliform organisms in water is by filtering a measured volume of the sample through a membrane composed of cellulose esters. All the bacteria present are retained on the surface of the membrane which is then put into a Petri dish on an absorbent pad. This pad is saturated with a nutrient, which is a differential selective medium. For the determination of total coliforms, M-Endo medium is used and the Petri dish is incubated for 22 to 24 hours at 35 ± 0.5 °C in an air-incubator.

Colonies that have a pink to dark-red colour with a metallic surface sheen are counted. A colony counter with a magnifying lens may be helpful.

The membrane filtration method can also be employed for the determination of faecal coliforms. In this case M-FC medium is used and the cultures are incubated for 24 hours at 44.5 ± 0.2 °C. Since incubation temperature is critical for the selectivity of this test, an air incubator is undesirable because of its unavoidable temperature fluctuation. The greater need for temperature control must be met with an electronic water bath which can maintain the maximum permissible variation of ± 0.2 °C.

Colonies produced by faecal coliform bacteria are blue and can easily be distinguished from the back-ground and the non-faecal coliforms.

Membranes have the advantage that the condition of incubation can be easily varied to encourage the growth of attenuated or slow growing organisms. By this technique it is possible to obtain within a total incubation time of 18 hours direct presumptive coliform and direct faecal coliform counts which do not depend on the use of probability tables. The media used with membrane filters usually differ in composition from those used in the multiple tube method.

Limitation use of Membrane Filtration

Membranes are unsuitable for use with waters of high turbidity in association with low counts of coliform organisms. In these circumstances the membrane will become blocked before sufficient water can be filtered. Membranes are also unsuitable for water containing few coliform organisms in the presence of many non-coliform organisms which are capable of growth on the media used and are thus liable to cover the whole membrane and interfere with the growth of coliform organisms. If non gas-producing lactose fermenting organisms are predominant in the water, membranes will be unsuitable because of the high proportion of false positive results.

LABORATORY TECHNIQUES

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General

Dissolved Oxygen, Biochemical Oxygen demand, Chemical Oxygen demand and Organic Nitrogen are among the important parameters used for evaluating stream characteristics.

DISSOLVED OXYGEN

All the gases of the atmosphere are soluble in water to some degree. Both nitrogen and oxygen are classed as poorly soluble. The solubility of atmospheric oxygen in fresh water ranges from 14.6 mg/l at 0 °C to about 7 mg/l at 35 °C. High temperature conditions, when dissolved oxygen is least soluble, are of greatest concern to Sanitary Engineers. Most of the critical conditions related to dissolved oxygen deficiency occur during the summer months when temperatures are high and solubility of oxygen is at a minimum. For this reason it is customary to think of dissolved oxygen levels at about 8 mg/l as being the maximum available under critical conditions.

The low solubility of oxygen is the major factor that limits the purification capacity of natural waters and necessitates treatment of wastes to remove polluttional matter before discharge to receiving streams. Dissolved oxygen is one of the most important single tests that the Sanitary Engineer uses. It is desirable to maintain conditions favourable for the growth and reproduction of a normal population of fish and other aquatic organisms. It serves as the basis of the Biochemical Oxygen Demand test.

Principle of the Winkler Method

The Winkler method and its modifications are the standard procedures for determining dissolved oxygen at the present time. The test depends upon the fact that oxygen oxidizes divalent manganese to a higher state of valence under alkaline conditions and that manganese in higher states of valence is capable of oxidizing iodide to free iodine under acid conditions. Thus the amount of free iodine released is equivalent to the dissolved oxygen originally present. The iodine is measured with standard thiosulphate solution and interpreted in terms of dissolved oxygen.

Reagents

1. Standard sodium thiosulphate
2. Manganese sulphate
3. Alkali iodine azide
4. Sulphuric acid
5. Starch

Procedure

- (1) To the BOD bottle with sample add 2 ml manganese sulphate solution.
- (2) Add 2 ml of Alkali iodine azide reagent.
- (3) Mix by inverting the bottle for at least 20 times.
- (4) Allow the coloured precipitate to settle, leaving about 100 ml clear supernatant above.
- (5) Add carefully 2 ml conc. sulphuric acid, mix again to redissolve the precipitate.
- (6) Titrate 203 ml of the clear sample with sodium thiosulphate using starch as an indicator.

Calculation

Amount of sodium thiosulphate used is equivalent to mg/l of dissolved oxygen.

Principle of the Membrane Electrode Method

Oxygen-sensitive membrane electrodes are basically composed of two solid metal electrodes in contact with a certain volume of supporting electrolyte which is separated from the test solution by a selective membrane. Polyethylene and Teflon membranes are commonly used, since they are permeable to molecular oxygen and possess a certain degree of ruggedness. In all these instruments the "diffusion current" is directly proportional to the concentration of molecular oxygen in the test solution. The current can be converted easily in concentration units (i.e. mg/l) by a calibration procedure.

The electrode method minimise the effects of interferences since the sensing element is protected by the membrane, which serves as a diffusion barrier against impurities. Membrane electrodes provide an excellent method for DO analysis in polluted waters, highly coloured waters, and strong waste effluents. An additional advantage of the method is that most of the DO meters available are portable and can be used in the field. In this case, no collection of samples is necessary, and therefore errors caused by sampling handling and storage are eliminated.

Procedure

- (a) The DO meter has to be calibrated against air or, more accurately, by using a water sample of known DO concentration (determined by the Winkler method) as well as a sample with zero DO.
- (b) The instrument is now ready to be used for DO measurements in samples or directly in natural water bodies. Sufficient flow of the test solution across the membrane surface should be provided by either stirring the sample or moving the electrode
- (c) Readings are made directly from the DO meter scale in mg/l.

BIOCHEMICAL OXYGEN DEMAND

General

Biochemical Oxygen Demand (BOD) is usually defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. The BOD test is widely used to determine the pollutional strength of domestic

and industrial wastes in terms of the oxygen that they will require if discharged into natural water courses in which aerobic conditions exist. The test is one of the most important in stream pollution control activities.

Principle

The test is based upon determination of dissolved oxygen at zero days (immediate) and after incubation at 20 °C for 5 days. The method is based upon the fundamental concept that the rate of biochemical degradation of organic matter is directly proportional to the amount of undegraded material existing at that time.

Procedure

Preparation of dilution water:

- (a) Distilled water (pre-aerated)
- (b) Phosphate buffer solution
- (c) Magnesium sulphate solution
- (d) Calcium chloride solution
- (e) Ferric chloride solution
- (f) Acid or alkali solution (for neutralization)
- (g) Sodium sulphate solution
- (h) Seed

For each litre of distilled water 1-ml solution is used.

The following dilutions are suggested for samples to be added in BOD bottle:

TABLE I

<i>Sample Volume in 300 ml BOD Bottle</i>	<i>Range of BOD, mg/l</i>
0.50	1,200—4,200
1.00	600—2,100
2.00	300—1,050
5.00	120—420
10.00	60—210
20.00	30—105
50.00	12—42
100.00	6—21
300.00	0—7

1. Fill half of the required BOD bottles with standard dilution water.
2. Add measured samples whose BOD is to be estimated with the help of the Table I.
3. Complete remaining volume of the BOD bottles with the same dilution water.
4. Analyse of BOD bottle of similar dilution for dissolved oxygen (DO_0 day).
5. Incubate the rest of the bottles at 20 °C for 5 days.
6. Analyse the rest of the BOD bottles for D.O. after 5 days (DO_5 day) calculate BOD.

Calculation

$$\text{B.O.D}_5 \text{ mg/l} = (DO_0 - DO_5) \times \frac{300}{\text{ml of sample}} - (DO_0 - DO_1)$$

DO_0 is the dissolved oxygen originally present in the undiluted sample.

DO_0 is the dissolved oxygen present at 0 days.

DO_5 is the dissolved oxygen remaining after 5 days of incubation.

CHEMICAL OXYGEN DEMAND

General

Chemical Oxygen Demand (COD) is also used as a means of measuring the pollution strength of domestic and industrial wastes. This test allows measurement of a waste in terms of the total quantity of oxygen required for oxidation to carbon dioxide and water. During the determination of COD, organic matter is converted to carbon dioxide and water regardless of the biological assimilation of the substances. As a result, COD value are greater when significant amounts of biologically resistant organic matter is present.

The major advantage of the COD test is the short time required for evaluation. The determination can be made in about 3 hr. rather than the 5 days required for the measurement of BOD. One of the chief limitations of the COD test is its inability to differentiate between biologically oxidizable and biologically inert organic matter.

Principle

The test is based upon the principle that most types of organic matter are destroyed by a boiling mixture of chromic and sulphuric acids. A sample is refluxed with known amounts of potassium dichromate and sulphuric acid and the excess dichromate is titrated with ferrous ammonium sulphate. The amount of oxidizable organic matter, measured as oxygen equivalent, is proportional to the potassium dichromate consumed.

Reagents

1. Standard potassium dichromate 0.250 N
2. Sulphuric acid reagent
3. Standard ferrous ammonium sulphate titrant

4. Ferriin indicator
5. Silver sulphate
6. Mercuric sulphate

Procedure

- (1) Place 0.4 g mercuric sulphate in a refluxing flask and add 20.0 ml sample and mix.
- (2) Add 10.0 ml std. potassium dichromate solution and several glass beads, connect the flask to the condenser.
- (3) Slowly add 30 ml sulphuric acid reagent through the open end of the condenser, mixing thoroughly while adding the acid.

NOTE : Mix the reflux mixture thoroughly before heat is applied, otherwise the mixture will be blown out.

- (4) Reflux the mixture for two hours, cool and then wash down the condenser with distilled water.
- (5) Dilute the mixture to about 150 ml with distilled water, cool to room temperature and titrate the excess dichromate with standard ferrous ammonium sulphate, using ferriin indicator.
- (6) Reflux in the same manner a blank consistency of 20 ml distilled water, together with the reagent.

Calculation

$$\text{mg/l COD} = \frac{(a-b) N \times 8000}{\text{ml of the sample}}$$

a = ml of titrant used for blank, and b ml titrant used for sample, and

N = Normality of the titrant.

ORGANIC NITROGEN

General

The Chemistry of nitrogen is complex because of the several valence states that nitrogen can assume and the fact that changes in valence can be brought about by living organisms. To add even more interest, the valence changes by bacteria can be either positive or negative, depending upon whether aerobic or anaerobic conditions prevail.

All nitrogen present in organic compounds may be considered organic nitrogen.

This includes the nitrogen in amino acids, amines, amides, nitro derivatives, and a number of other compounds.

Most of the organic nitrogen that occurs in domestic wastes is in the form of proteins and their degradation products, polypeptides and amino acids. Therefore the methods employed have been designed to ensure measurement of these forms without particular regard to other organic forms.

Principle

Most organic compounds containing nitrogen are derivatives of ammonia and destruction of the organic portion of the molecule by oxidation frees the nitrogen as ammonia. The Kjeldahl method employing sulphuric acid as the oxidizing agent is standard procedure. A catalyst is ordinarily needed to hasten the oxidation of some of the more resistant organic materials. The oxidation proceeds rapidly at temperature slightly above the boiling point of sulphuric acid (340°C). The boiling point of the acid is increased by addition of sodium or potassium sulphate.

Reagents

1. Digestion reagent
2. Phenolphthalein
3. Sodium hydroxide-sodium thiosulphate reagent
4. Mixed indicator solution
5. Indicating boric acid and standard sulphuric acid titrant

Procedure

- (1) Place a measured sample into an 800 ml Kjeldahl flask. If necessary dilute the sample to 300 ml and neutralize to pH 7.
- (2) Add 25 ml phosphate buffer solution and a few glass beads and boil off 300 ml.
- (3) Cool and add carefully 50 ml digestion reagent.
- (4) Mix and digest until clear solution is obtained.
- (5) Cool, dilute to 300 ml with ammonia free distilled water and add 0.5 ml phenolphthalein indicator solution and mix. Also add sufficient hydroxide-thiosulphate reagent to form an alkaline layer to the bottom of the flask.
- (6) Connect the flask to the distillation apparatus and collect 200 ml distillate below the surface of 50 ml boric acid solution.

(7) Titrate the ammonia in the distillator with standard 0.02 N sulphuric acid until the indicator turns a pale lavender.

(8) Also carry out a Blank Test.

Calculations.

$$\text{mg/l organic N} = \frac{(D-E) \times 280}{\text{ml of sample}}$$

D = sulphuric acid titration for sample.

E = ml sulphuric acid titration for Blank.

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STREAM FLOW MEASUREMENT AND ANALYSIS OF FLOW DATA

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Introduction

Magnitude of stream flow at any point and time is a dominant characteristic affecting pollutant concentration in a stream, therefore, systematic collection of stream flow data is very important in stream pollution surveys. Two types of stream flow data are generally required ; Flow data at the time of sampling for pollution surveys, and past flow data extending over a period of time. The former is utilized in analysing the stream water quality under the prevailing condition at the time of the surveys whereas the later is needed to estimate the critical flow conditions so that the effect of waste discharges under such critical flow can be determined.

In Pakistan flow data are available with the Irrigation and Power Departments, and Water and Power Development Authority (WAPDA). The discharge data are reported as daily average discharge. The daily discharges are generally recorded three times a day ; at 060, 1200 and 1800 hours and averaged. Hourly observations are also made during periods of floods.

Generally past flow data are readily available at different gauging stations maintained by the above mentioned departments. However in case the discharge data are not available at desired locations in the stream, the measurement of discharge becomes the part of stream pollution surveys. In any case records of past flow will have to be referred to existing gauging stations and projected to the locations of interest. Since at times discharge measurement are to be made during stream pollution surveys a brief description of some of the stream discharge measurement methods is given.

METHODS OF FLOW MEASUREMENT

Velocity Area Methods

Using the velocity area methods, the flow rate is determined by multiplying the velocity by the cross sectional area through which the flow is occurring. Methods and instruments for the measurement of cross-sectional area and velocity of flow are briefly described below.

Measurement of Cross Section

To measure the cross section of the stream, a rope or cable, is stretched across the stream above the maximum water level in the stream. Marks are made at fixed point

point intervals to divide the width of stream into a number of sections such that not more than 10 percent or preferably more than 5 percent of the discharge should occur in each section. The depth of water below these marks is taken with the help of sounding pole if the depth is less than 10 ft and with the help of a sounding cable if the depth is more than 10 ft. Knowing the depths of water at the beginning and end of each compartment, the cross-sectional area of that compartment can be computed. The velocity is then measured in each section and multiplied by the area to obtain discharge from that section. The flow in the stream is obtained by adding the flow in each section.

Measurement of Velocity

The following methods and instruments are commonly used for the measurement of velocity :

Current Meters

Current meter measurement can be used to determine accurately the velocity of flow. Since the velocity is *not uniform throughout the depth of each section of the stream*, the current meter is held at 0.6 of the depth measured from the water surface to get the average velocity of the stream in the vertical section. For more precise measurements, the velocity is observed at 0.2 and 0.8 of the depth and the average of these two values is taken to represent the average velocity in the vertical section. In using the current meter, observations of the rates of revolution of the meter wheel are made within a selected cross-section of a stream and are converted into velocities by means of a meter rating table that has been prepared from observations made in a rating flume. The accuracy attained depends on the integrity of the rating of the meter and on the sufficiency and competency of the observations of depth and velocity.

Float Measurements

In this method of velocity measurement, the timing of the floats over a measured course is noted which constitutes a direct observation of the average velocity of that filament of water in which the float has travelled over that course. The accuracy depends on the *uniformity of the velocities throughout the length of the runs* as well as on the sufficiency of float runs. The surface velocities observed on the timing of floats must be adjusted on the basis of vertical velocity curves to mean velocities.

Surface Slope Measurements

In a determination of velocity by a measurement of surface slope, the average slope over the reach of the stream is measured and is converted into an average velocity in that reach by means of a formula which expresses the relation of slope to velocity, like the chezy formula

$$V = C \sqrt{RS}$$

or the Manning formula

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

where V is the velocity, R is the hydraulic radius of the stream and S is the slope. C and n are coefficients and their values depend on the condition of the stream channel. The accuracy of the method depends upon the uniformity of slope throughout the reach of the

stream in which the slope is measured and the applicability of the coefficients selected for use in the slope formula to the channel conditions where the slope is measured.

Chemical and Radioactive Tracers

In this method, the tracers are usually injected into the stream upstream of two control points. The time of passage of the prism of water containing the tracer is noted at these control points and the velocity is then computed by dividing the distance between the control points by the travel time. The time of passage is the difference between the times where peak concentrations of tracers are recorded at each control point.

Dilution Methods

These methods are based upon the principle of introducing a known quantity of substance into the river and of measuring the concentration of that substance after it has been uniformly mixed in the water and thus the discharge can be calculated. A chemical or radioactive substance is added continuously, at a constant rate, to the stream in which the discharge is to be measured. At a distance downstream sufficient to ensure complete mixing of the substance and stream, the stream is sampled and the concentration of the tracer or chemical substance is determined. The flow of the stream can be determined using a material balance equation

$$Q_s = \frac{Q_t (C_t - C)}{C - C_s}$$

where Q_s is the stream discharge, Q_t is tracer discharge, C_t is the concentration of the tracer being added C_s and C are the concentration of the tracers in the stream before and after injection of the tracer.

In order to get good results from this method, it is essential that there is a good mixing of the injected substance with the river water. For this reason this method may be more useful in rocky streams where other methods of measurement have not been found possible and good mixing of stream water is ensured. The application of this method to large rivers has the disadvantage that it is not easy to secure good mixing and if the injected substance remains in the river too long a period before samples are taken for an analysis, changes may take place due to various causes which can upset the results.

Measurement with the help of Structures

In these methods structures are built across a stream like weirs, flumes etc., and using the mathematical relationships to calculate the discharge is calculated. Weirs are much used for measuring discharge, with a high degree of accuracy under proper conditions. They vary widely in crest profile, in cross-section and in placement in the stream channel. The basic method is the same for all types of weirs except variation in the terms, coefficients, and exponents used in the weir formulas. The simplest weir formula is $Q = C l h^{3/2}$, where Q is the discharge over a rectangular weir without end contractions, C is coefficient, h is energy head and l is the length of the crest. All other weir formulas are variations of this simple equation, with difference in the coefficient C and in the exponent of h and if appropriate, the addition of a term or terms to provide in the decrease in effective length due to end contractions and for departures from the simple rectangular weir. The formula values of coefficients and exponents must be carefully studied in order that the formula adopted may be appropriate to the situation.

The use of a weir in measuring stream flow involves a considerable loss of head, since a definite drop in the surface of the water as it passes over the weir is necessary, even if the weir is submerged. Whereas the venturiflume has an important advantage due to its ability to function with a relatively small loss of head. It is based on the well known venturi principle and is a structure which provides a short constricted portion, or throat for the passage of water between an upstream contracting approach and a downstream diverging exit. The discharge may be calculated with the help of formulas or it can be rated in the laboratory and reproduced in the field. The parshall flume is an improved modification of the original venturi flume. The flumes are principally used for the distribution of irrigation water and in very small streams.

Discharge Rating Curves

In stream pollution survey a continuous and accurate record of discharge and time is required. The principle commonly used to secure this is to relate stage (elevation) to discharge with the help of rating curve and thus converting the record of stage into a record of discharge with the help of such a curve. In other words the discharge measurements are indirectly taken by recording the elevation of water surface behind some relatively stable control in the channel. In turn gauge height is related to the actual measurement of the mean velocity and cross-section taken at the location of stable channel below the control over a range of river flow and thus rating curve is developed for converting gauge height to stream flow. The rating curves are verified and adjusted after floods which might disturb the control and thus affect gauge height corresponding to a specific stream discharge which might alter the stream, cross-section where velocity measurements are made. Also the flow measuring stations should be cited where the geometry of the stream is not subjected to alterations and where the flow of the stream is contained in the a single channel at all stages.

The records of stage are taken with the help of gauges, principally of two types non-recording gauges and recording gauges. Non-recording gauges may be a staff gauge, on which the readings of stage are made directly or chain, wire-weight, float tape and hook gauges, in connection with which readings of stage are made indirectly by measurement to the water surface from fixed points. Float type gauges and hook gauges are used almost exclusively as auxiliary or reference gauges in connection with the operation of water stage recorders. Staff gauge may be vertical or inclined. Stilling wells are utilized to avoid the difficulty of gauge reading due to waves. Automatic stage recording gauges can also be used to have a continuous record of stage.

Instruments of Measuring and Recording Stream Flow

The principal instruments for measuring and recording the discharge of rivers at velocity area stations are gauges for indicating and recording stage and current meters for measuring velocity. Accessories include hand lines and Reel lines for suspending weights and meters, weights for making soundings and holding meters in position, reels and cranes for handling heavy weights, taps for measuring depths and distances, and stop watches for registering time as an element in the measurement of velocity. The major pieces of equipment of a gauging station include the support and shelters for the gauges, and a bridge, cable or boat to enable the Engineer to make the requisite observations of depth and velocity at any part of the measuring section of the stream.

For float stations, in addition to gauges, there must be surface and perhaps sub-surface and tube or rod floats and the equipment needed for releasing them at selected points in the current upstream from the selected course, for timing their passage over the

course and for measuring the length of the course and the areas of cross-section of the streams, at the end of the course and at intermediate points.

For slope stations and for slope-area measurement, their must be available in addition to the necessary gauges, an Engineer's level for measuring the slope of the water surface at peak or other stage and the instruments needed for measuring the distance along the river between the gauges or between the ends of the reach and the cross section of the stream at the end and intermediates points of the reach.

For all types of stations, transits equiped with stadia wires for making necessary areal surveys and Engineer's levels and levelling adds for setting gauges and for referencing and checking their datums must be available.

Discharge Functions

The discharge along the course of a stream in variable. The exact quantification of the variations involves complicated mathematical relationships. However simple formulation can be used in stream pollution data analysis to estimate such variations and to calculate discharges at points other than at the ganging stations. The following three formulations may be quite useful in this regard.

$$Q = Q_0 + Ax$$

$$Q = Q_0 e^{Bx}$$

$$Q = Q_0 x^c$$

where Q is the discharge at any point at a distance X downstream of the gauging station and Q_0 is the discharge at the ganging station. A , B , and C are parameters to be determined under field conditions for each reach of the river, for which discharge data from the existing gauging stations can be used.

Analysis of Drought Flow

Where Urban and Industrial development relies on the natural unregulated stream runoff, the characteristic of the minimum flow (drought flow) is the element in growth potential. Any level of development carries a risk of unsatisfactory stream condition related to the probability of drought severity. Decisions as to the level of community and industrial development, the required degree of waste-water treatment, and down stream water quality objectives rest on the definition of minimum flow expectancy.

Two basic time elements are important in the definition of low flow : the base unit time from which a low flow is selected from the record and the length of time over which a low flow is averaged.

The fundamental approach to the statistical evaluation of the drought flow characteristics stems from the theory of extreme values. The theory is predicted on base unit of time such that any extreme value selected in one of a large number of observations and such that extreme value selected from consecutive time units are independent of each other. It is a common practice in dealing with stream flow data to employ the year as the basic time unit. Since runoff records are reported as daily average discharge, the unit provides on extreme value as one most sever among 365 measurements. However this does not always forms a series of extremes values that in successive years are completely independent of each other. The time lag factor in hydrologic cycle influencing drought

may even extend over 2 or more years. Consequently, to obtain a true series of completely independent minima, the base time unit should perhaps be greater than one year. However considering the relatively short record available, practical considerations dictate the adoption of the base time unit as one year, recognizing that on this time basis some of the less severe flows selected in the series in a true sense are not drought flows.

The second time element, the period over which the low flow is averaged, may be taken on a calendar basis of a day, week, or month or preferably on the basis of a consecutive period without record to calendar. For refined analysis it is desirable to select four separate drought flows; the minimum daily average, the minimum consecutive 7, 15 and 30 days averages. For many practical problems it is adequate to employ the minimum daily, minimum monthly average and minimum consecutive 7 days average.

Length of Record

How long should a continuous record extend in years to warrant analysis by the theory of extreme values, is a difficult question to answer. The longer the record, the more reliable the estimates of expected severity at various probability of occurrence. However a flow record extending over a period of the order of about 20 years may be adequate for practical purposes.

Frequency Distribution of Drought Flows

It is well known that extremes of hydrological phenomena do not follow a normal distribution but are skewed. Records of this kind can be generalized roughly as geometrically normal distributions, or more closely as Gumbel distribution. With the application of these distribution to the flow data, any probability of low flow severity can be calculated.

Analysis of such distributions can be expedited with the help of probability papers. The probability paper used in such a case is log-probability paper or preferably log-extremal probability paper which is more commonly recommended. The analysis of low flows by such a method involves arranging the low flows in the order of severity irrespective of the year in which they occur and the expectancy of occurrence of K th low flow magnitude can be calculated to be once in $(n+1)K$ years of time, where n is the number of years for which record is available.

To illustrate the approach, 19 years of flow data of Ravi River at Shahdara gauging station is used to obtain minimum daily, minimum monthly and minimum 7-day consecutive flow. The low flows are arranged in the order of severity in Table I and the calculations of expectancy of occurrence of each flow are made. The results are plotted in Fig. 1, from where any probability of drought flow severity can be calculated. For example a minimum 7-days consecutive flow with a probability of once in 10 year is 450 cusecs.

The Drought Flow Reference Frame

From the probability distribution plots of drought flows, a reference frame of expected drought flow severity can be constructed, which constitutes a useful summary. From the probability plots of minimum, 1, 7, and 30 days averages in Fig. 1, the most probable low flow, the low flow severities expected once in 5, 10, and 20 years are obtained and plotted in Fig. 2. Curve A represents the most probable drought expected as an average over any number of consecutive days from 1 to 30, similarly curves, B, C and D represents the drought severities expected on the average once in 5, 10, and 20 years respectively.

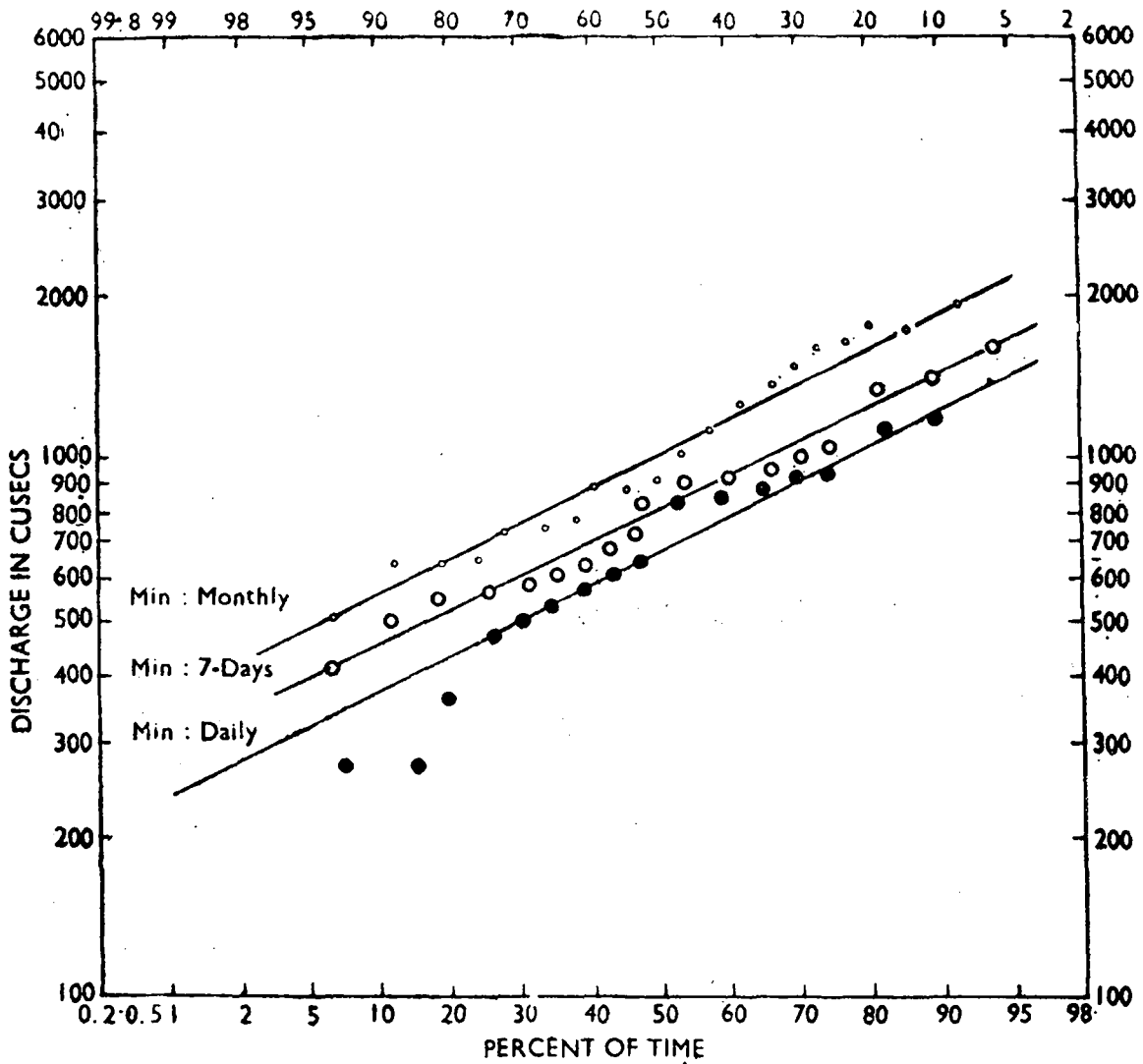
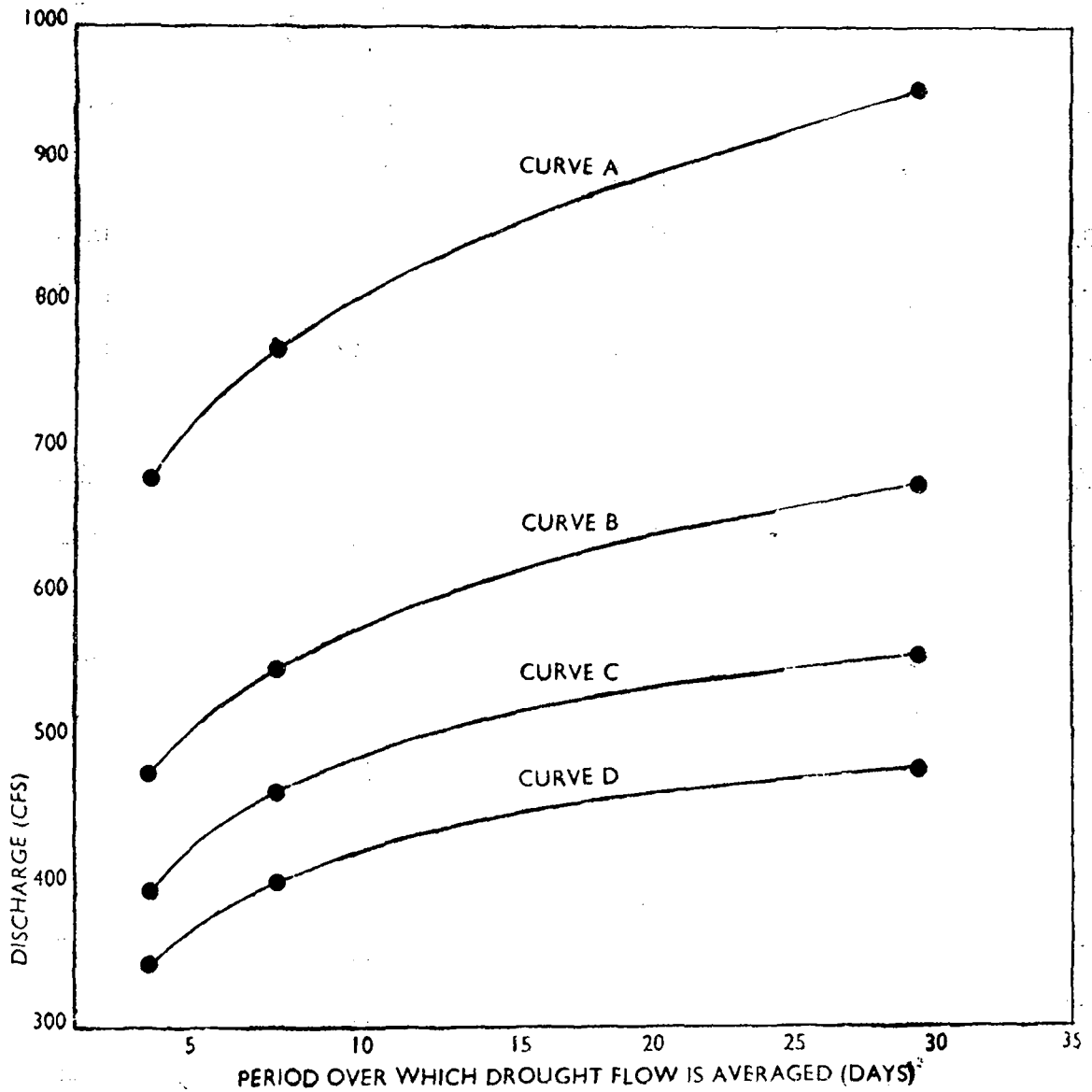


Fig : 1 RAVI AT SHAHDARA



CURVE A : MOST PROBABLE DROUGHT
 CURVE B : ONCE IN 5 YEARS
 CURVE C : ONCE IN 10 YEAR
 CURVE D : ONCE IN 20 YEARS

FIG -2. DROUGHT FLOW REFERENCE FRAME

TABLE I
Drought Flows at Shahdara (Ravi River)

S. No.	Percent of time flow equals or exceeds	Minimum 7-days discharge (cusecs)	Minimum 7-days consecutive discharge (cusecs)	Minimum monthly discharge (cusecs)
1.	5	1375	1418	1833
2.	10	1080	1252	1616
3.	15	1050	1200	1590
4.	20	883	978	1527
5.	25	869	916	1398
6.	30	850	872	1364
7.	35	808	862	1228
8.	40	797	847	1062
9.	45	761	827	989
10.	50	640	802	890
11.	55	622	758	869
12.	60	595	682	853
13.	65	555	620	744
14.	70	525	654	742
15.	75	493	555	737
16.	80	454	551	658
17.	85	350	507	625
18.	90	240	486	613
19.	95	240	398	484

As one shortens the period over which the discharge is averaged, drought flow severity increases. Conversely, extremely low flows do not prevail for extended periods. From the stand-point of pollution control, consecutive low flow over a period equal to the time of passage through the critical reaches of the stream is a significant interval. This

will vary from stream to stream depending on the physical characteristics of the channel and the distribution of pollution loads along the course. Droughtflow reference frames afford a convenient means for interpolating severities as an average for any number of consecutive days appropriate to the situation.

In reaching decisions about pollution control requirements, it is essential to take position at some point within the drought flow reference frame. This position must be defined in terms of both co-ordinates, horizontally by the consecutive number of days over which the flow will be averaged and vertically by the drought flow severity within the range from the most probable to say once in 20 years. Although generally in pollution control problems, 7-days low flow expected once in 10 years is selected, it is desirable to take a rational and reasonable position within the drought flow reference frame and evaluate the consequences of that position since it has bearing on the decisions regarding level of community and industrial development and the required degree of waste treatment.

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DISSOLVED OXYGEN SAG IN A RIVER

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Dissolved-Oxygen Sag Equation

A wastewater treatment facility that discharges its effluent into a stream usually is designed to meet a variety of stream quality requirements. Very often one of these requirements is the maintenance of at least a minimum acceptable concentration of dissolved oxygen in the stream. The equation developed by Streeter and Phelps (1) expressing the relationship between initial concentration of BOD and dissolved oxygen and the resulting dissolved oxygen profile has found wide acceptance and use in such design situation. The Streeter-Phelps formulation assumes that BOD removal in a stream consists only of aerobic biological degradation and that reaeration is simply absorption of atmospheric oxygen. It applies for channels of uniform cross-section where effect of algae and sludge deposits are negligible. The dissolved oxygen deficit at any time of flow downstream from an initial point is given by the Streeter-Phelps equation as :

$$D = \frac{K_1' L}{K_2' - K_1'} (e^{-K_1' t} - e^{-K_2' t}) + D_0 e^{-K_2' t} \dots\dots\dots (1)$$

where D is the dissolved oxygen deficit at time t in mg/l

t is the time of flow, in days, from the initial point, expressed as, $t = \frac{x}{v}$

where x is distance from the initial point in miles,

v is the velocity of flow, miles/day,

L is First stage ultimate BOD at $x = 0$,

K_1' is deoxygenation constant in days⁻¹ (base e),

K_2' is reaeration constant (base e) in days⁻¹,

and D_0 is initial oxygen deficit in mg/l.

The form of the Streeter-Phelps equation is shown in Fig. 1, which shows the dissolved-oxygen—sag curve for a river. Active biological decomposition begins immediately after discharge. This decomposition utilizes oxygen. Because atmospheric reaeration is proportional to the dissolved-oxygen deficit, its rate will increase with increasing deficit. Finally a point is reached at which the rate of oxygen utilized for waste decomposition

equals the rate of atmospheric reaeration. This is the point X_c . Downstream from this point, the rate of reaeration is greater than the rate of utilization and the dissolved oxygen begins to increase. This is the phenomenon of natural stream purification.

The value of X_c , the critical distance, can be determined by differentiating equation (1) with respect to X and setting dD/dX equal to zero.

$$X_c = \frac{v}{K_2' - K_1'} \ln \frac{K_2'}{K_1'} \left[1 - \frac{D_o (K_2' - K_1')}{K_1' L} \right] \dots \dots \dots (2)$$

As $t_c = \frac{X_c}{v}$, therefore

$$t_c = \frac{1}{K_2' - K_1'} \ln \frac{K_2'}{K_1'} \left[1 - \frac{D_o (K_2' - K_1')}{K_1' L} \right] \dots \dots \dots (2A)$$

The critical dissolved oxygen deficit D_c at point X_c is of engineering significance, and it can be determined :

$$D_c = \frac{K_1' L}{K_2'} \left[e^{-K_1' \left(\frac{X_c}{v} \right)} \right] \dots \dots \dots (3)$$

Sometimes it is desirable to use log with 10 as a base, the Streeter-Phelps equation becomes ;

$$D = \frac{K_1 L}{K_2 - K_1} \left[10^{-K_1 \left(\frac{X}{v} \right)} - 10^{-K_2 \left(\frac{X}{v} \right)} \right] + D_o 10^{-K_2 \left(\frac{X}{v} \right)} \dots (4)$$

where $K_1 = \frac{K_1'}{2.303}$ $K_2 = \frac{K_2'}{2.303}$

Relationship between 5-days BOD and First-Stage BOD

Biochemical oxidation is a slow process and theoretically takes an infinite time to go to completion. In the 5-days period used for BOD test, oxidation is from 60 to 70 percent complete. The 20°C temperature used is an average value for slow moving streams in temperate climates and is easily duplicated in an incubator.

The kinetics of BOD reaction, for practical purposes may be expressed as :

$$\frac{dL_t}{dt} = K_1' L_t \dots \dots \dots (5)$$

where K_1' = coef. of deoxygenation

L_t = amount of the first-stage BOD remaining in water at time t .

The equation can be integrated as

$$\int_L^{L_t} \frac{dL_t}{L_t} = K_1' \int_0^t dt$$

$$\ln \frac{L_t}{L} = -K_1' t$$

$$\frac{L_t}{L} = e^{-K_1' t} = 10^{-K_1 t}$$

L is Total or ultimate first-stage BOD initially present

The amount of BOD remaining at any time t :

$$L_t = L (10^{-K_1 t}) = L (e^{-K_1' t}) \dots\dots\dots (6)$$

and y, the amount of BOD that has been exerted at any time t (see Figure 2) :

$$y = L - L_t = L - L (10^{-K_1 t}) = L (1 - 10^{-K_1 t})$$

$$\text{or } y = L (1 - e^{-K_1' t})$$

Note that the 5-day BOD equals

$$\begin{aligned} y_5 &= L (1 - 10^{-5K_1}) \\ &= L (1 - e^{-5K_1'}) \dots\dots\dots (6A) \end{aligned}$$

Example 1

Determine the ultimate first-stage BOD for a sewage whose 5-days, 20° BOD is 200 mg/l

If reaction constant, $K_1' = 0.23$

From equation (6A) $y_5 = L (1 - e^{-K_1' t})$

$$\begin{aligned} L &= \frac{y_5}{1 - e^{-K_1' t}} = \frac{200}{1 - e^{-5(0.23)}} = \frac{200}{1 - 0.316} \\ &= 293 \text{ mg/l} \end{aligned}$$

Value of Reaction Constant K_1

The value of K_1 varies significantly with the type of waste. The range may be from 0.05 day⁻¹ to 0.3 day⁻¹ or more. For polluted water and sewage a typical value of K_1 (base 10, 20°C) is 0.10 day⁻¹. For the same ultimate BOD, the oxygen uptake will vary with time and with different K_1 values. The effect of different K_1 values is shown in Fig. 3.

Determination of K_1' (or K_1) Value

The value of K_1' is needed if the BOD₅ (y_5) is to be used to obtain L, the ultimate first-stage BOD. The usual procedure followed is to determine K_1' and L from a series of BOD measurements. There are several ways of determining K_1' and L from the results

of a series of BOD measurements only the least—squares method is explained and illustrated here.

The least square method involves fitting a curve through a set of data points, so that the sum of the squares of the residuals (the difference between the observed value and the value of fitted curve) must be a minimum. For a time series of BOD measurements on the same sample, the following equation may be written for each of the various n data points :

$$\text{From eq. } \frac{dL_t}{dt} = K_1' (L_t) \text{ or } \frac{d(L-y)}{dt} = K_1' L_t$$

$$\frac{dy}{dt} = K_1' (L_t)$$

$$= K_1' (L - y)$$

In this equation K_1' and L are unknown. Due to experimental error, the two sides of the equation will not be equal but will differ by an amount R .

$$R = K_1' (L - y) - dy/dt$$

$$= K_1' L - K_1' y - y, \text{ where } y = \frac{dy}{dt}$$

$$\text{Let } K_1' L = a, -b = K_1'$$

$$R = a + by - y$$

Now if sum of squares of the residual R is to be a minimum, the following equations must hold,

$$\text{for } R = R(a, b)$$

$$\frac{\partial}{\partial a} \sum R^2 = \sum 2R \frac{\partial R}{\partial a} = 0$$

$$\frac{\partial}{\partial b} \sum R^2 = \sum 2R \frac{\partial R}{\partial b} = 0$$

$$\text{or } (a + by - y) = 0$$

$$(a + by - y') y = 0$$

If there are n observation points, the following equations result :

$$na + b \sum y - \sum y' = 0 \dots\dots\dots (7)$$

$$a \sum y = b \sum y^2 - \sum yy' = 0 \dots\dots\dots (8)$$

Where $K_1' = -b$ (base e)

$$L = -a/b$$

Illustrative Example 2

Given BOD data as follows :

t days	2	4	6	8	10
y, mg/l (BOD)	11	18	22	24	26

Calculate L and K_1 using the least— squares method.

Solution :

1. Set up a computation Table :

Time	y	y ²	y'	yy'
2	11	121	4.50	49.5
4	18	324	2.75	49.5
6	22	484	1.50	33.00
8	24	576	1.00	24.0
Σ	75	1505	9.75	156.0

The slope y is calculated as follows :

$$\frac{dy}{dt} = y_n = \frac{Y_{n+1} - Y_{n-1}}{2 \Delta t}$$

for ex. at t = 2 days

$$y_{n+1} = \frac{11 + 18}{2} = 14.5$$

$$y_{n-1} = \frac{11 + 0}{2} = 5.5$$

$$t = 1$$

$$y' = \frac{14.5 - 5.5}{2} = \frac{9}{2} = 4.5$$

2. Substitute the values from the table into Equations (7) and (8) :

$$4a + 75b - 9.75 = 0$$

$$75a + 1505b - 156.0 = 0$$

3. Solve the equations simultaneously

$$b = -0.271$$

$$a = 75$$

Therefore

$$K_1 = -b = 0.271 \text{ (base e)}$$

$$L = \frac{a}{b} = \frac{7.5}{0.271} = 27.7 \text{ mg/l}$$

Relationship between K_1 (or K_1') and Temperature

The temperature at which the BOD of a wastewater sample is determined is usually 20°C. It is possible, however, to determine the reaction constant K_1 (or K_1') at a temperature other than 20°C by the following formula :

$$K_T = K_{20} [\theta^{(T-20)}] \text{ or } K_T' = K_{20}' [\theta^{(T-20)}] \dots\dots\dots (9)$$

where K_T (10 as base) = reaction constant at temperature T°C

K_T' = reaction constant with e as base at temperature T°C

θ for K_1 varies from 1.056 in temperature range from between 20°C and 30°C to 1.135 in the temperature range between 4°C and 20°C. θ for K_2 is equal to 1.024.

Reaeration Constant K_2 (or K_2') Determination.

The rate of reaeration, K_2 , varies with surface exposure and volume of water and the rate at which the water is mixed by vertical and horizontal currents that distribute absorbed oxygen and bring fresh volumes undersaturated water into contact with the atmosphere. Churchill, Elmore, and Buckingham (8) have concluded that the magnitude K_2 at 20°C can be predicted with reasonable success by the observational relationship :

$$K_2 = 5.02 \bar{V}^{0.969} / \bar{R}^{-1.673} = 5\bar{V} / \bar{R}^{-5/3} \dots\dots\dots (10)$$

Where \bar{V} is the mean velocity of flow in a given river stretch

\bar{R} is its mean hydraulic radius

From Manning's formula

$$\bar{V} = \frac{1.49}{n} \bar{R}^{2/3} S^{1/2}$$

$$K_2 \cong 7.5 S^{1/2} (\bar{R} / n) \dots\dots\dots (11)$$

Where S = head loss or drop in water surface

n = Coef. of roughness

Illustrative Examples

A large stream about 400 ft wide with a mean hydraulic radius $R = 5.66$ ft. flows at a velocity $V = 2.78$ fps. Predict the rate of reaeration at 11.9°C

$$\begin{aligned} \text{Solution : } K_2 &= 5 \times 2.78/5.66^{5/3} \\ &= 0.773/\text{day at } 20^\circ\text{C} \end{aligned}$$

Using equation (9)

$$\begin{aligned} (K_2)_{11.9^\circ\text{C}} &= 0.773 (1.135)^{(11.9 - 20)} \\ &= 0.634/\text{day} \end{aligned}$$

The reaeration constant K_2 can be also determined by the values of self-purification ratio $f = K_2/K_1$. The information on self-purification constant f at 20°C is listed in Table 4.

TABLE 4

Values of self-purification Ratio $f = K_2/K_1$

Nature of receiving water	Magnitude of f
Small ponds and backwaters	0.5 — 1.0
Sluggish streams and large lakes or impoundments	1.0 — 1.5
Large streams of low velocity	1.5 — 2.0
Large streams of moderate velocity	2.0 — 3.0
Swift streams	3.0 — 5.0
Rapids and waterfalls	5.0

With f known, and K_1 determined, K_2 can be calculated.

The classification of different bodies of water is not sharply defined. Each class merges into its adjoining classes, and there is appreciable variation within the types described, as well as within different reaches of the same body of water.

ILLUSTRATIVE EXAMPLE 4

Example of Dissolved-oxygen Sag in River

A city of 3,00,000 population produces sewage at the rate of 100 gpcd. The sewage is discharged into a stream whose minimum flow rate is 300 cfs.

The velocity of the stream is about 2 mph. The temperature of the sewage is 20°C, while that of the stream is 15°C. The 20°C BOD₅ of the sewage is 200 mg/l, while that of the stream is 1.0 mg/l. The sewage contains no dissolved oxygen, but the stream is 90 percent saturated upstream of the discharge. At 20°C, K₁' is estimated to be 0.30 per day while K₂' is 0.7 per day. Determine the critical oxygen deficit and its location. Also estimate the 20°C BOD₅ of the sample taken at the critical point.

Solution :

1. Determination of sewage flow.

$$(100 \text{ gpcd}) \times 3,00,000 = 30 \times 10^6 \text{ gal/day} = 30 \text{ MGD}$$

2. Determination of dissolved oxygen in the stream before discharge. Saturation concentration at 15°C (from solubility of oxygen in water table) = 10.2 mg/l.

$$\text{Dissolved oxygen in stream} = 0.9 (10.2) = 9.2 \text{ mg/l.}$$

3. Determination of temperature, dissolved oxygen and BOD of the mixture :

$$\text{Temp. of the mixture} = \frac{30 (1.55) (20) + 300 (15)}{30 (1.55) + 300} = 15.7^\circ\text{C}$$

$$\text{Dissolved oxygen of the mixture} = \frac{30 (1.55) (0) + 300 (9.2)}{30 (1.55) + 300} = 8.0 \text{ mg/l}$$

$$Y_5 = \text{BOD}_5 \text{ of mixture} = \frac{30 (1.55) (200) + 300 (1)}{30 (1.55) + 300} = 27.7 \text{ mg/l}$$

Using equation (6A), find BOD_L

$$L = \frac{Y_5}{1 - e^{-5K_1'}} = \frac{27.7}{1 - e^{-0.3 (5)}} = 35.6 \text{ mg/l}$$

4. Correct the rate constant to 15.7°C, using equation (9) :

$$K_1' = 0.3 (1.135)^{15.7-20} = 0.174 \text{ per day}$$

$$K_2' = 0.7 (1.024)^{15.7-20} = 0.63 \text{ per day}$$

5. Determine t_c and x_c

From solubility of oxygen in water table, the saturation oxygen concentration at 15.7°C = 10.1

$$D_o = 10.1 - 8.0 = 2.1 \text{ mg/l}$$

From equation 2A.

$$t_c = \frac{1}{K_2' - K_1'} \ln \left[1 - \frac{D_o (K_2' - K_1')}{K_1' L} \right]$$

$$= \frac{1}{0.63 - 0.174} \ln \frac{0.63}{0.174} \left[1 - \frac{2.1(0.63 - 0.174)}{0.174(35.6)} \right]$$

$$= 2.45 \text{ days}$$

$$X_c = Vt_c = 2(24)(2.45) = 117 \text{ miles}$$

6. Determine, D_c by equation (3)

$$D_c = \frac{K_1'}{K_2'} L(e^{-K_1' t_c}) = \frac{0.174}{0.63} (35.6) e^{-0.174(2.45)}$$

$$= 6.4 \text{ mg/l}$$

$$DO_c = 10.1 - D_c = 10.1 - 6.4 = 3.7 \text{ mg/l}$$

7. Determine BOD_5 of a sample taken at X_c by equation (6) :

$$L_t = L(e^{-K_1' t})$$

$$L_t = 35.6 [e^{-0.174(2.45)}] = 23.3 \text{ mg/l}$$

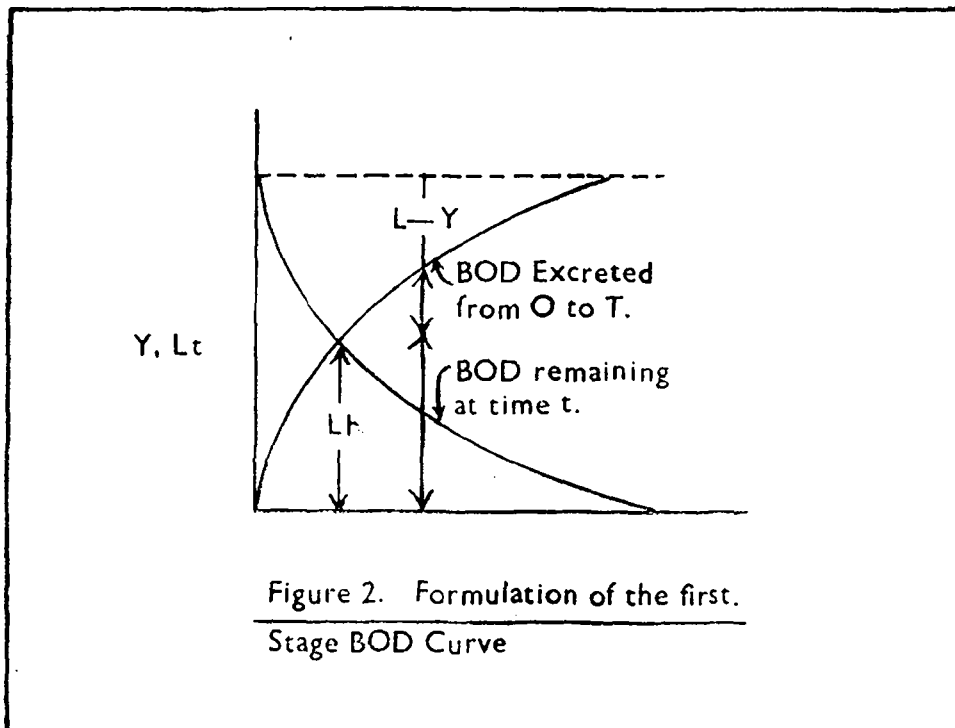
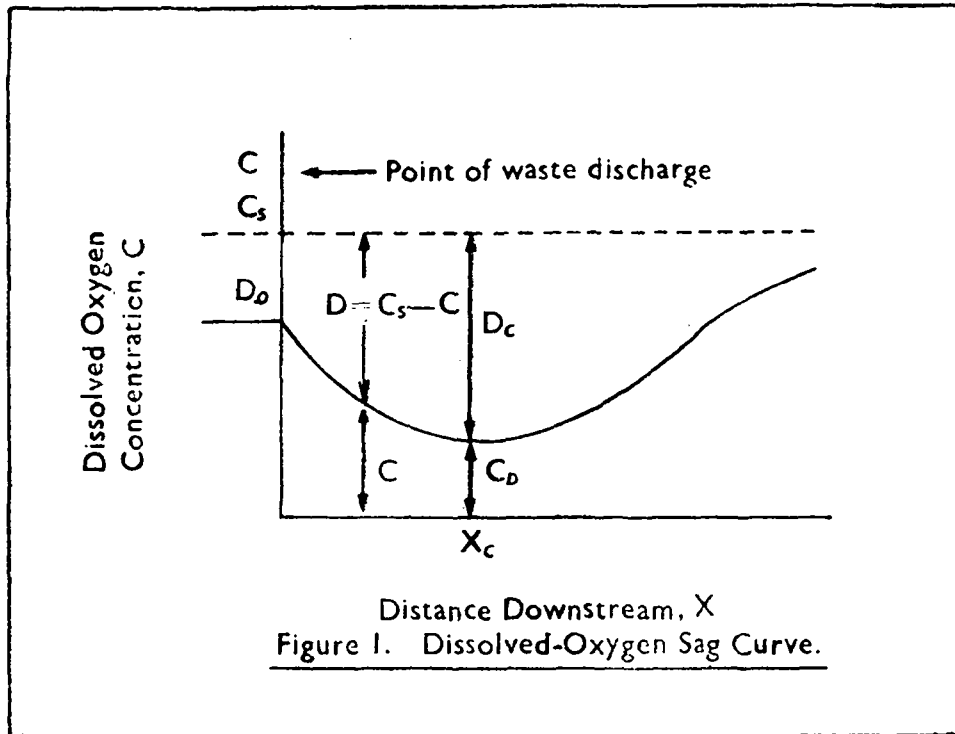
From equation 6A.

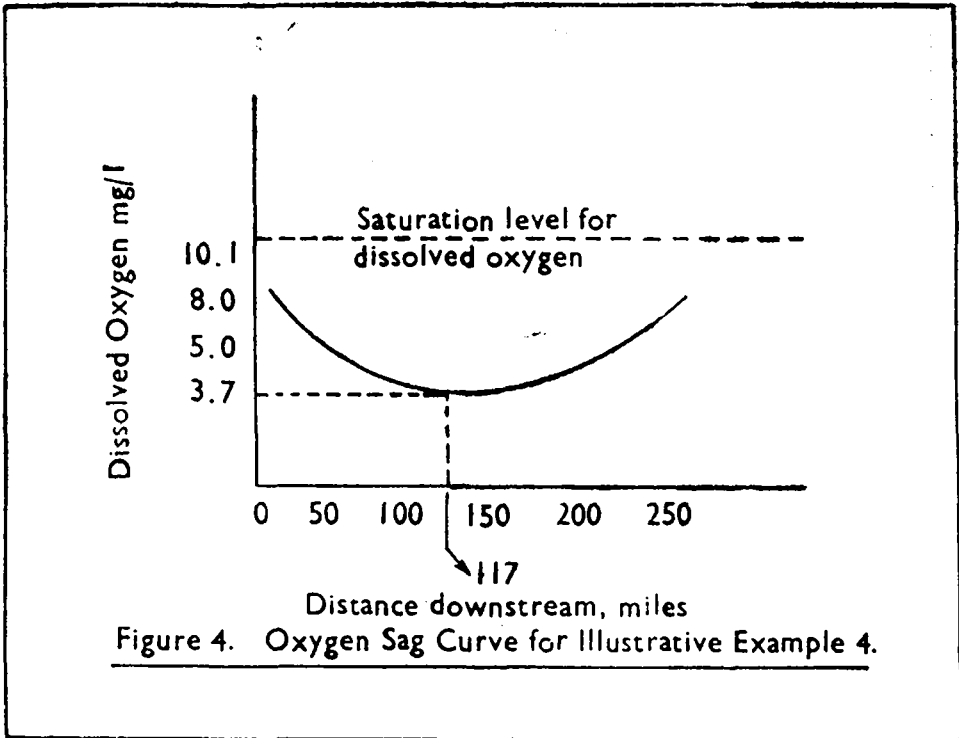
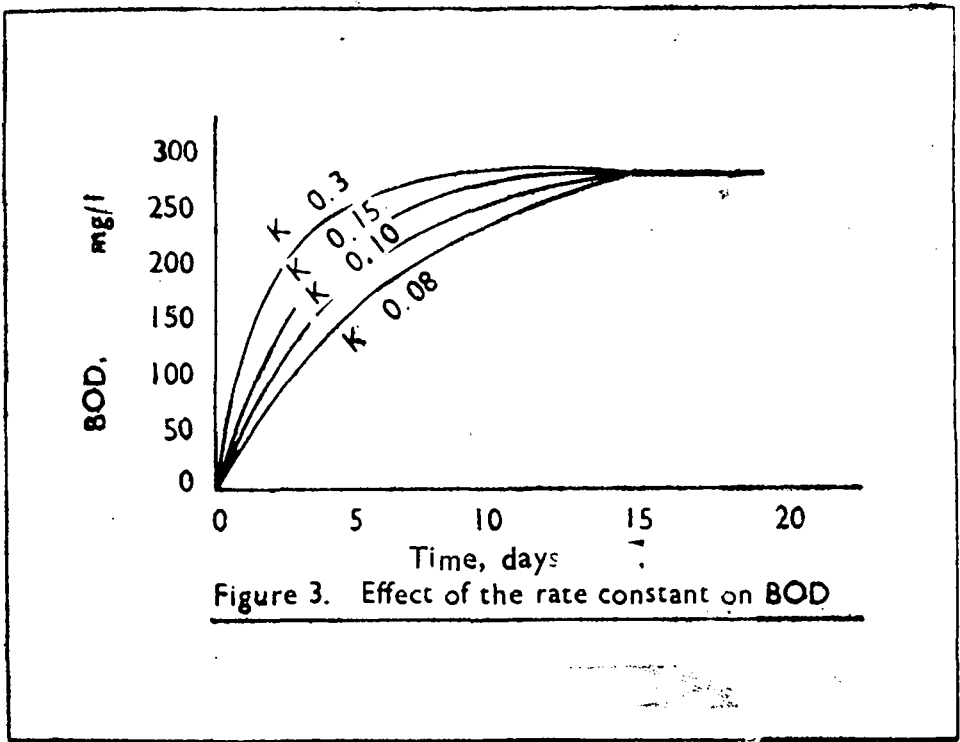
$$20^\circ\text{C}, BOD_5 = y_5 = L(1 - e^{-5K_1}) = 23.3(1 - e^{-0.3(5)}) = 18.1 \text{ mg/l}$$

From this example, it can be seen that the critical dissolved oxygen occurs not at the immediate vicinity of the discharge, but at a point quite some distance downstream from the point of discharge.

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ANALYSIS OF STREAM POLLUTION DATA

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Introduction

The data collected during any stream pollution survey must ultimately be reduced to some simple, expressive form for presentation. Unless the data is presented in a convincing manner so that it communicates the real findings and interpretation of the actual field conditions, the data is useless. Just as it is not very practical to expect a layman to understand complex technical results, neither can one expect a field engineer working 98% of his time with technical aspects suddenly to communicate adequately in layman terms.

For this reason, there is need to develop expertise within water pollution control agencies by which this communication can occur. However, the engineer must have a working knowledge of statistics and mathematics in order to convey his information to the layman.

Results obtained by regularly performed water quality investigations, summarized and presented in a concise form, give a clear idea of water quality and its changes at a given point or a given reach of water course. Once this data is available, the changes of water quality occurring at points important from the view point of water use and pollution can be taken into account.

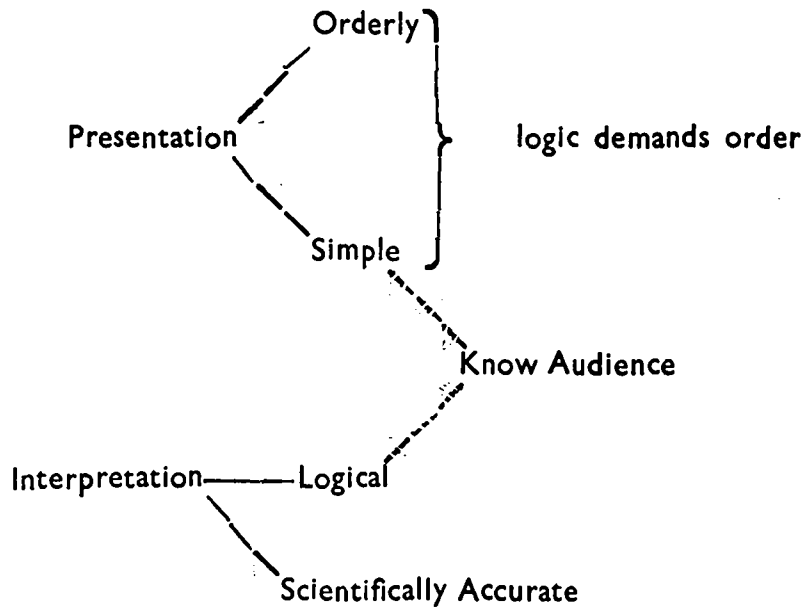
Data analysis includes data evaluation and statistical analysis. Adequate data in a continuing and updated basis is fundamental to the analysis process.

The value of results obtained by water quality investigations depend on several factors. Apart from hydrological and meteorological factors, the method and frequency of the investigations play an important role.

2. Analysis of Data

2-1. Before one analyzes any information, the data must be set into logical order and the analyst must present the information to himself in developing this order, the analyst should keep in mind the objectives of the survey, and the variables encountered during the study.

2.2.



3. Presentation of Data

This is one of the most important areas of report writing and unfortunately is often neglected or overlooked.

3.1. Common Methods of Presenting Data

1. Single value
2. Single value plus related information
3. Graphic methods

3.2. Single value Approach

I Methods commonly used :

- (a) Arithmetic mean
- (b) Geometric mean
- (c) Median value
- (d) mode value

For example, when studying the "Most Probable Number" (MPN) of coliform bacteria present in a stream, the arithmetic mean would not clearly describe and emphasize this number, whereas the geometric mean, or mode, may well illustrate it accurately. In addition, considerable variation can, and often does, exist between the arithmetic mean and the mode in biological systems. The following example illustrates the difference between the arithmetic mean and the mode for a series of coliform bacteria counts:

A sample of calculations:

SAMPLE OF CALCULATION

Sample Number	Coliform Count MPN/100 ml
1	0
2	0
3	0
4	9.0
5	3.6

$$\text{Arithmetic mean : } \frac{12.6}{5} = 2.52$$

$$\text{Mode} = 0$$

Advantages of using Single Value Approach

(a) *Economical* : Engineering design criteria is often based on average value. In some instances minimum and maximum values are more critical. Statistical handling of municipal sewage and industrial-waste data is just as important as statistical handling of river data. The Sanitary Engineer should realize, for example, that figures on peak waste flows are significant under certain conditions, but the arithmetic mean BOD values are the figures required when one is designing facilities for treating these wastes.

(b) *Instrumentation* : Advanced analytical techniques and instrumentations are accounting for the collection of tremendous amounts of information. The tendency is to use sophisticated statistical methods to arrive at representative mean values.

(c) *Audience* : Since some readers (local federal legislators) do not have the technical background or (specially), interest to read through many pages of numbers, it becomes convenient to summarize the numerous observations by using single representative values. In effect, the analyst is a salesman, his report being his product.

3.3. Single value Plus Related Information

1. Methods commonly used:

(a) single value plus maximum or minimum value.

(b) single value plus percentage range (usually 80%) of survey or laboratory results.

(c) single value plus standard deviations from the mean.

(d) distribution and frequency distribution tables.

2. Advantages of using value Plus Related Information

(a) eliminates some misinterpretation caused by extremely high or low results that occur rarely.

(b) gives an idea of what type of distribution is occurring (normal, skewed, etc).

(c) average values are extremely useful but it is usually the maximum or minimum values that pose serious problems.

In computing treatment plant efficiencies, the Engineer can obtain a more complete picture of the plant's operation by using the standard deviation from the arithmetic mean than by using the mean value alone. Also, when comparing the efficiency of one treatment plant with another, he may find it desirable to use the coefficient of variation.

4. GRAPHIC METHODS

4.1. Graphs Commonly used

(a) *Normal graph paper* (Cartesian coordinate paper)—this is the most generally used graph paper and is most useful in obtaining an idea of the trend the numerical observations are taking. This type of paper is most useful in preliminary plotting of information to decide if semi-log, log-log, or other types of functional graph papers would be more desirable to use.

(b) *Functional graph paper* (semi-log, log)—use of this paper allows for the plotting of results in straight line fashion that would appear on normal graph paper (Cartesian coordinate paper) as a curved line.

(c) *Arithmetic or geometric (log) probability paper*—this type of graph plots the normal frequency curve (Bell shaped curve) as a straight line.

(d) *Nomograph*—used where complex equations or complicated mathematical manipulations and calculations are involved. Nomographs have been developed for numerous applications.

Data on water quality investigations in surface water can be processed by the following methods:

1. Setting up of annual-time-series concerning points where samples are generally taken weekly.

(a) Synoptic resume of all survey results obtained from samples investigated during the year, with separate headings for the best, worst and critical values.

(b) Representation in columns of the time-series (measured values) of the most important water quality parameters.

(c) Plotting of duration figures on the water quality factors mentioned in point (b)

The processing of the annual-time-series covers water quality components, depending on the water quality requirements of uses.

(a) The synoptic resume includes the following components :

— Type of water, stage changes (flow fluctuations)

— Flow

- Weather
- Temperature of water
- BOD₅
- Oxygen saturation
- Alkalinity
- Total suspended solids
- TDS
- NO₄⁺
- NO₃⁻
- PO₄⁻³
- Phenols
- Conservative minerals (Cl⁻, SO₄⁻⁻)

(b), (c) The setting up of time-series and duration figures covers the following components :

- Daily mean flow (mean daily flow) investigated during the year.
- Plus water pollution parameters indicated under as above.

2. Longitudinal Representation: Of survey results taken at several points along the watercourse.

- (a) Computation of the values of water quality changes and loads due to waste water effluents and their synoptic resume on the basis of the characteristics of water quality components.
- (b) Representation of water quality along the water-course on the basis of samples taken at different points on the same day.

The computation and representation of water quality changes along the water-course covers the component important from the view point of the type of pollution and from the view point of uses.

The study (computation) of water quality changes along the water-course compared to the boundary section should be performed on the basis of survey results obtained from samples taken at places below important discharge points and effluent inlets. For this investigation, it is necessary to compute an average value, weighed proportionally to water flow according to the following relationship.

$$\bar{Y} = \frac{\sum YQ}{Q}$$

\bar{Y} = average value weighed with water flow.

Y = measured value of water quality component.

Q = water flow.

The connection of the results of water quality studies to quantitative conditions is more suitable for a numerical demonstration of water quality changes, than a characterization without water quality.

The changes shown by the comparison of two sampling points on the basis of average values of water quality components weighed with water flow can be negative or positive, depending on the wasteloads (effluent load) and self-purification, and the changes in water quality can be determined in a given reach of the water course (between the entering and exit-border sections).

(b) Representing the changes in water quality along the water course (longitudinal section) figures may cover the following components :

— BOD₅

— DO

— total dissolved matter

— total suspended matter

— conservative minerals.

The selected components may be different in accordance with the function of the stream and stream local condition.

CASE STUDY

Ravi River Pollution Study

In Figure 1, the arrows shown at the top of longitudinal section indicate the more important discharge points. BOD₅ and DO data for a study period of 2/77 to 4/78 are also plotted in Fig. 2. This data information will be utilized in determination of the assimilative capacity of the stream. Minimum, average and maximum measured values of DO and BOD at different sampling points in the river during the sampling period of 2/77 to 4/78 are also presented in Tables 2 and 3. The same are plotted under longitudinal sections in Fig. 2 and 3.

SUMMARY OF BOD-DO DATA INTERPRETATION

I. Temperature and Dissolved Oxygen

From Table 1 it is apparent that temperature in the river reach under study varies between 15°C to 23°C with an average value of 19.8°C which for all practical purposes may be approximated as 20°C. Minimum, average and maximum values of DO and BOD are presented in Table 2 and 3 respectively.

From stream sanitation point of view, the minimum temperatures are important as the DO concentration in the river is maximum to provide self purification. However, the flow in the river in winter is also low to put limits on the polluttional discharge. On

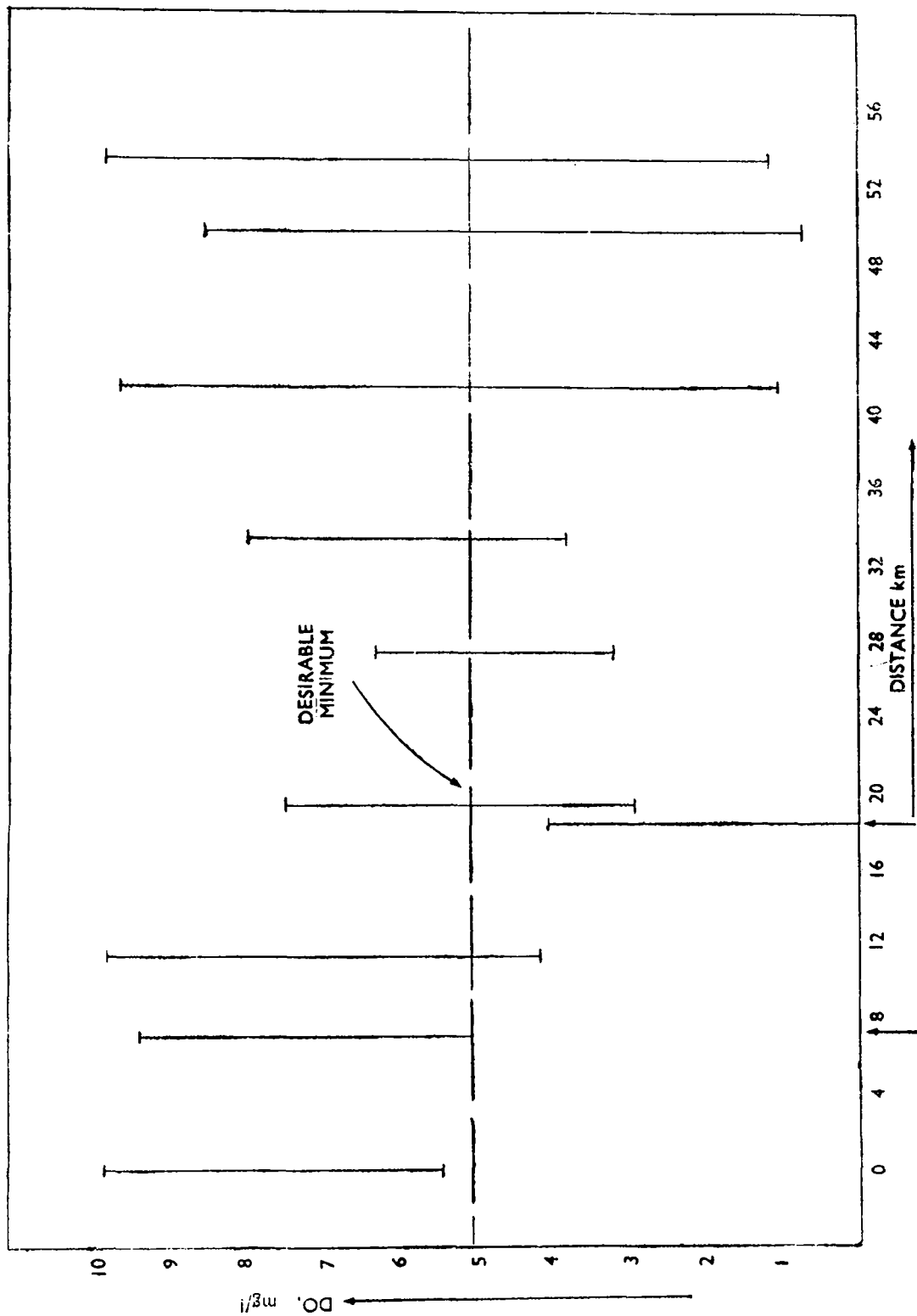
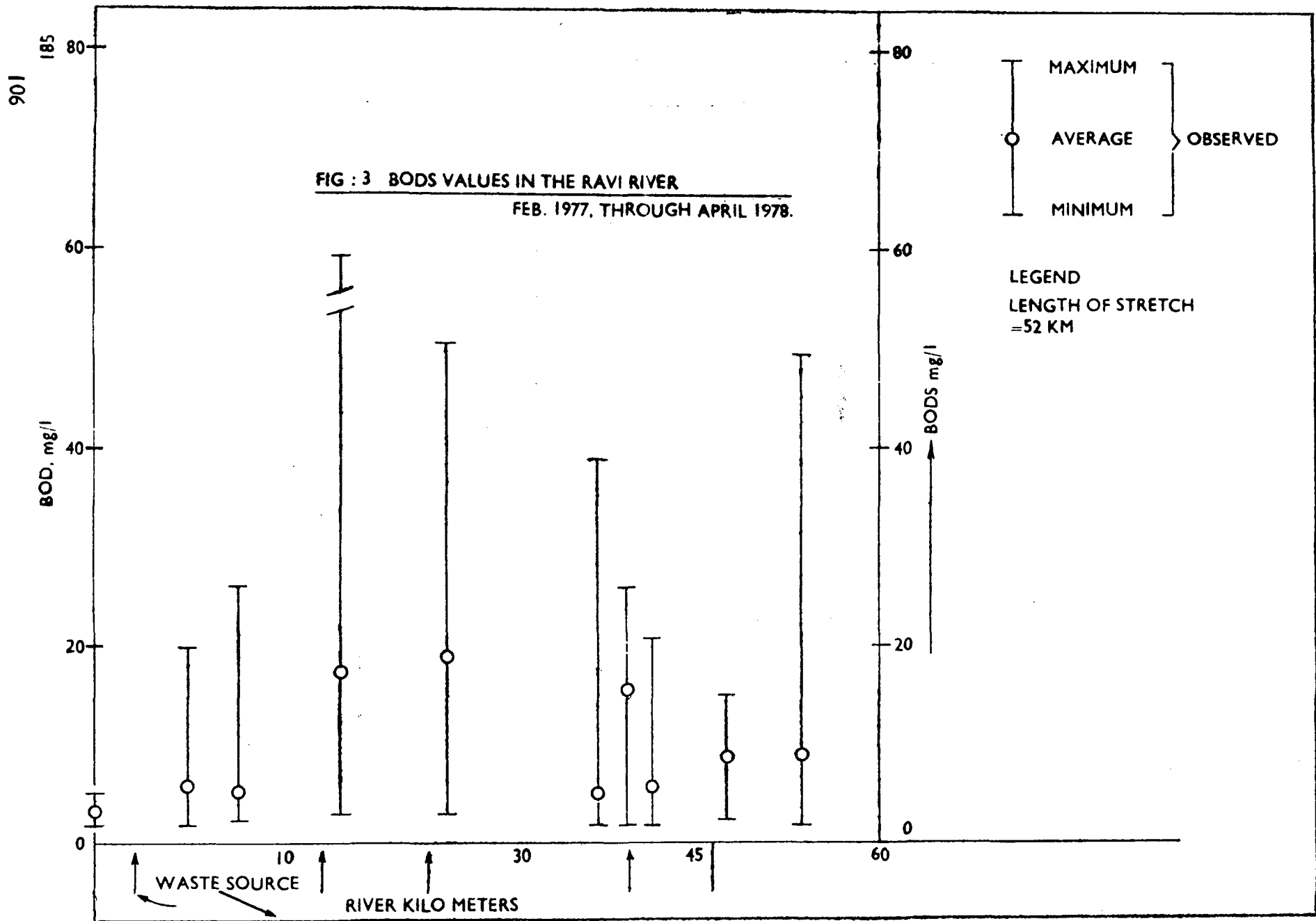


FIG. 2 DISSOLVED OXYGEN IN THE RAVI RIVER FEB. 1977 THROUGH APRIL 1978.



the other hand low DO content of the stream in summer time is balanced by heavy flood flows to provide adequate oxygen for the self purification of the river.

The sewage from the city of Lahore contains on average 1 mg/l of DO and its discharge to the river lowers the river DO level to 2.9 mg/l indicating a significant load on the oxygen resources of the stream. The dissolved oxygen concentration of the river falls below 1 mg/l after Deg and Hudiara Nallahs have joined the river. This situation therefore appears to be crucial for adequate life in the river reach stretch from sampling station 4 to 14 and perhaps for a considerable distance down stream. This view is based on the fact that most of water pollution control agencies adopt a minimum of 5 gm/l DO level as an objective to maintain a maximum potential warm water fish pollution. Camp Dresser and McKee, (1976) have reported that to maintain in healthy aquatic environment, DO content of the water at no time of the day should drop below 4 mg/l. On the other hand, quoting Ohio river standards in U.S.A. Metcalf and Eddy (1974) have reported that the DO level in the stream at no time of the day should drop below 3.0 mg/l. It can therefore be stated that the DO level in the river downstream of sampling station 6 are inadequate to support desirable fish life. Fig. (2) presents the variation in DO level in the river along its course of flow. The average DO level in the river downstream of sampling station 6 are inadequate to support desirable fish life. Fig. (2) presents the variation in DO level in the river along its course of flow. The average DO values do suggest somewhat adequate environment for fish life, which however is unrealistic. It is therefore necessary to take appropriate steps to reduce the pollution load on river Ravi, if adequate DO levels are to be maintained for fish population. This may be achieved by the provision of waste treatment facilities for Lahore city, Kala Shah Kaku Industrial Complex, Packages Ltd., and industries located on Sheikhpura Road.

TABLE I
Temperature °C DO (mg/l) BOD (mg/l) and Total Coliforms (per ml) Data

Sampling Station	Dt. in river miles	Temp.			Dissolved		Oxygen Av.	BOD			Total Min.	Coliform × 10 ⁶	
		Min.	Max.	Av.	Min.	Max.		Min.	Max.	Av.		Max.	Av.
1	0	15.0	22.0	19.5	5.4	9.8	9.4	0.6	4.0	1.8	0.01	170	17.5
2	3	16.6	26.0	20.8	0.0	4.1	2.9	145	270	202	0.8	230	27.5
3	7	15.5	22.0	19.9	5.6	9.3	7.0	0.6	19.5	6.5	0.14	70	13.2
4	11	15.7	21.5	19.8	4.1	9.7	7.0	2.0	26.0	5.3	0.01	160	16.8
5	17	16.0	25.5	20.6	0.0	4.0	1.0	125	315	197	0.11	700	107
6	18	15.4	22.4	20.0	2.9	8.4	5.8	3.1	90	17.3	0.05	240	25
7	25	15.0	26.1	20.6	0.0	3.8	1.0	69	330	185	0.01	300	41
8	26	15.0	22.0	20.0	3.2	6.2	4.2	1.0	51	18.9	0.15	290	34.5
9	38	15.2	23.0	19.9	3.8	7.8	4.6	0.8	39	5.0	0.02	20	3.5
10	40	15.3	22.0	19.4	0.0	9.6	6.9	0.6	25.5	14.2	0.08	260	33
11	41	15.6	23.0	19.9	1.0	9.5	6.9	0.5	21	6.0	0.07	280	38
12	47	15.2	23.0	20.3	0.0	8.6	6.0	1.0	300	11.4	0.05	300	36
13	47	15.2	21.5	19.5	0.7	8.4	5.1	1.4	13	7.7	0.05	170	27
14	53	15.1	22.4	19.5	1.1	9.7	5.5	1.3	12	8.9	0.17	70	14

TABLE 2

PROJECT RAVI RIVER POLLUTION STUDY PERIOD 2/77 TO 4/1978

Parameter : Dissolved Oxygen (DO) mg/l.

Sampling Station	River KM	Minimum	Average	Maximum
1	0	5.4	8.4	9.8
2	3	0.00	2.9	4.1
3	7	5.0	7.0	9.3
4	11	4.6	7.0	9.7
5	17	0.0	0.98	4.0
6	18	2.9	5.77	8.4
7	25	0.0	0.95	3.8
8	26	6.2	4.2	3.2
9	38	7.8	4.6	3.4
10	40	0.0	6.9	9.6
11	41	1.0	6.9	9.5
12	47	0.3	6.0	8.6
13	48	0.7	5.1	8.4
14	53	1.1	5.48	9.7

TABLE 3

RAVI RIVER POLLUTION STUDY PROJECT STUDY PERIOD : Feb. 1978 TO
APRIL, 1979

Parameter BOD (mg/l) Period : 2/77 to 4/1978

Sampling Station	River Kilo- Meters (km)	Minimum	Average	Maximum
1	0	0.6	1.79	4
2	3	145	202	258
3	7	0.6	6.47	19.5
7	11	2.0	5.26	26.0
5	17	125	197	315
6	18	2.1	17.3	90
7	25	69	185.96	330
8	26	1.0	18.9	51
9	38	0.8	5.0	39
10	40	0.6	14.23	25.5
11	41	0.5	6.06	21
12	47	1.0	11.37	300
13	48	1.4	7.71	13
14	53	1.3	8.9	12

2. BOD

BOD of the river water is a direct indication of the pollution load it carried. BOD values at station 1 indicate a satisfactory upstream river water quality. However this quality deteriorates significantly when the Lahore sewage is dumped into the river. Table I suggests that the average BOD of Lahore sewage varies between 185 to 202 mg/l. Tariq and Ahmad (1979) after a detailed study of Lahore sewage have reported an approximate mean value of 200 mg/l. As indicated in Table (I) BODs of the two tributaries to the river also show considerable variations during the year.

It can be calculated that Lahore sewage, on average basis, contributes 63.55 Kg. of BOD each day to the river. As a result a maximum rise of 18.9 mg/l of BOD was noted for river water, corresponding to a minimum of DO level as 3.2 mg/l. Fig. (3) shows the variation in river BOD for the stretch studied. The figure suggests that the river reach from sampling station 1 to 4 (i.e. 11 km) is relatively free from organic pollution. Further downstream, within station 4 and 8 BOD remains fairly high. The effect of self purification, further down-stream, is overmasked by the 164,900 kg./day of BOD discharged through Deg Nallah and 3345 kg/day of BOD through Hudiana Nallah.

The computations of deoxygenation coefficient from the collected data show extreme variations when individual sampling runs are considered. However considering the average values of BOD, the coefficient of deoxygenation appears to vary between 0.4 to 1.4 per day. Detailed analysis of the years data is required to arrive at definite conclusions.

Considering the average and maximum BODs of the river water in the reach, a general conclusion can be made that the river is significantly polluted and requires immediate attention not only to stop further degradation but also to improve the existing water quality.

WASTE ASSIMILATION CAPACITY OF STREAMS

KHADIM HUSSAIN ZIAI
Assistant Professor

Introduction

The law of oxygen absorption from the atmosphere has been formulated and can be expressed in terms of the initial oxygen deficit, the oxygen deficit at any latter time, and a reaeration coefficient. In a polluted stream, oxygen absorption will proceed simultaneously with satisfaction of the BOD : or the deoxygenation. Combination of the formulas of expressing the two relationships has been done by Streeter, to obtain the following expression :

$$D = \frac{K_1 L_0}{K_2 - K_1} (e^{-K_1 t} - e^{-K_2 t}) + D_0 e^{-K_2 t} \quad (1)$$

in which D_0 is the initial dissolved oxygen deficit in mg/l, D is the dissolved oxygen deficit in mg/l after t days, L_0 is the initial ultimate BOD in mg/l, K_1 is the coefficient of deoxygenation in per day, K_2 is the coefficient of reaeration in per day.

In the mathematical development of this equation it is assumed that K_1 and K_2 are constants, that only one source of pollution exists and there is no tributary inflow or pollution. Variations of these assumptions may be taken into account in any practical case.

From an engineering viewpoint, the DO sag indicates one point of particular significance ; the point of minimum DO concentration or of maximum deficit. The critical point is defined by the numerical equality of the two opposing rates, i.e., the point where the rate of change of the deficit is zero. The balance at this point may be written :

$$K_2 D_0 = K_1 L = K_1 L_0 e^{-K_2 t_c} \quad (2-a)$$

$$t_c = \frac{1}{K_2 - K_1} \log_e \frac{K_2}{K_1} \left(1 - \frac{D_0 (K_2 - K_1)}{K_1 L_0} \right) \quad (2-b)$$

Determination of K_1 and K_2 from observed Field Data

The deoxygenation coefficient K_1 , and the reaeration coefficient K_2 can be estimated from the field data. The field estimate of K_1 can be obtained from semi logarithmic

plots of observed long term ultimate BOD data (five day BOD stream data may also be used) as a function of distance down stream. Theoretically speaking, if both stream area and flow as constants in space.

$$L = L_0 e^{-K_1 X/U} \dots\dots\dots (3)$$

- L is BOD conc. mg/l,
- L_0 is BOD concentration at $X = 0$
- U is velocity in miles/day,
- K_1 is deoxygenation coefficient (day⁻¹), and
- X is distance in miles.

Thus in natural logs, equation (2) can be written as

$$\ln L = \frac{-K_1 X}{U} + \ln L_0 \dots\dots\dots (3-a)$$

A semi-log plot of field data usually results in a straight line, the slope of which is defined by :

$$\text{Slope} = \frac{-K_1}{U} \dots\dots\dots (3-b)$$

Mathematically :

$$K_1 = \frac{1}{t} \log \frac{LA}{LB} \dots\dots\dots (3-c)$$

- LA is ultimate upstream BOD,
- LB is ultimate downstream BOD, and
- t = time of travel in days.

This procedure provides the first estimate of deoxygenation coefficient.

The reaeration coefficient, K_2 may be estimated from depth and velocity data by the following formula developed by O'Connor from field studies :

$$K_2 = \frac{(D_t U^{1/2})}{H^{3/2}} \dots\dots\dots (4-a)$$

Where D_t is oxygen diffusivity at 20°C (0,000081 ft²/hr.)

- U is average stream velocity
- H is average depth

A more convenient form of this equation is :

$$K_2 = \frac{12.9 U^{1/2}}{H^{3/2}} \dots\dots\dots(4-b)$$

where U is velocity in ft/sec. and

H is depth in ft.

The reaeration coefficient is a surface controlled phenomenon and for all practical purposes, is independent of water quality. In view of this K_1 is usually the more variable unknown coefficient in the determination of assimilative capacity of the stream. Reaeration coefficient is also computed by the formula :

$$K_2 = K_1 \frac{\bar{L}_a}{\bar{D}} - \frac{\Delta D}{2.3 \Delta t \bar{D}} \dots\dots\dots (4-c)$$

utilizing the field data

where \bar{L}_a is average ultimate oxygen demand,

\bar{D} is average oxygen deficit in stream section,

t is time of stream flow from upstream to downstream sampling points (days),
and

D is change in oxygen deficit from upstream to down stream sampling points.

Stream Surveys

From the above discussions, it may be seen that data from controlled stream surveys are required for the determinations of the coefficients. The survey should be conducted as much as is practical and possible under a steady-state condition of river flow, waste flow and temperature. Cross-sectional measurements are necessary for the determination of the depths. With this information the velocity may be calculated from the continuity equation or it may be measured directly. Both depth and velocity are required for the reaeration coefficient and the velocity is also used to calculate the time of flow between stations.

Analysis of Data

Calculation of the stream constants K_1 is made in accordance with equations (3-c) using the BOD data from the respective stream sections. Equations (4-a-b) and (4-c) permits determination of K_2 .

Knowing the initial BOD and oxygen deficit, the DO sag curve (Eq. 2-b) may be computed and compared to the observed values. Adjustment of the coefficients, within statistical limits defined by the data, may be necessary to secure the best fit between the calculated and observed points. Having established coefficients for one set of flow and temperature conditions, they may be extrapolated to any other set of appropriate conditions. Calculation of the allowable BOD loading may be made in accordance with the equations (2-a) and (2-b).

The fundamental principles, as expressed by the above equations, may now be employed in the evaluation of the natural purification of a stream. Assuming knowledge of the rates of deoxygenation and reaeration in the receiving stream, the first important relationship to be developed is that of the DO concentration at the critical point for various river flows, for a given waste loading. The waste loading, which is used in developing this relationship, should be the average BOD of waste discharge from the plant. This relationship indicated in a quantitative manner the effect of the present pollutional load on the DO concentration in the river.

This may further indicate the need for waste treatment in order to maintain standards established for the receiving stream. One of the common and logical standards applies to a minimum allowable concentration of DO. For this minimum concentration, the allowable waste loading may be calculated for various river flows. This analysis will indicate the possible need to establish a probable seasonal plan of operation for the waste treatment plant.

Minimum Stream Flow

For a given waste discharge, the DO sag curve will vary in time and magnitude in accordance with the river flow. In this regard, some minimum stream flow is of particular significance. In selecting the minimum flow upon which to base a stream analysis, consideration should be given to stream usage, probability of minimum flow and its duration, (damage) if flow less than minimum occurs, and cost of increased treatment to meet more stringent requirements.

The existing water quality standards in the developing countries are presently involved to abate existing pollution and to prevent future pollution by providing design guidelines for waste treatment facilities. In the latter application, they are interpreted to apply during a critical draught stream flow equivalent to minimum average seven consecutive day flow with a probability of occurring once in ten years.

With this ground level, the waste assimilative capacity is defined as the maximum amount of treated waste that can be safely stabilised during critical stream conditions while maintaining assigned water quality standards without impairing legitimate water usages.

Illustrated Example

Example : The following abstract from a study of a river illustrates the steps in determining the oxygen balance and the resulting dissolved oxygen profile. The conditions for a 3 mile reach of river between point A and B are as follows :

RIVER :

Discharge	=	35 MGD
DO _r	=	9 mg/l
BOD ₅	=	3.2 mg/l
Velocity	=	1 mile per hour
K ₁	=	1.8-day
K ₂	=	5.3-day

(a) Industry :

- Efficiency = 70 %
- Discharge = 5 MGD
- DO = 2 mg/lit
- BOD = 70 mg/l

(b) Municipality :

- Efficiency = 60%
- Discharge = 10 MGD
- DO = 4 mg/l
- BOD₅ = 40 mg/l

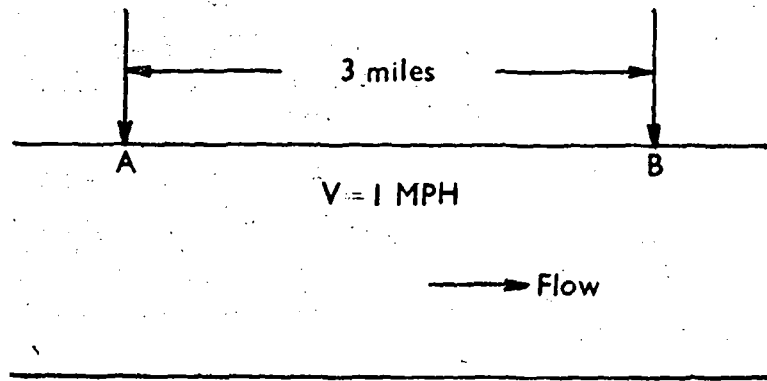


FIG. 1 River System

(a) Draw the 'DO PROFILE'

(b) Find the minimum 'DO' if industry treatment plant is expected to operate @ 90% efficiency.

(c) Find the efficiency of Municipal plant so that minimum 'DO' Sag, is 7.

Solution: Detailed computations are made and the computed dissolved oxygen profile is shown in Figure 2 and Figure 4. Part 'a'.

Computation of 'D' : After point of outfall of industry @ every 1/2 mile.

where D = The dissolved oxygen deficit in milligrams/litre

after an travel time *t* in days

Apply the formula :

$$D = \frac{K_1 L_o}{k_2 - K_1} (e^{-K_1 t} - e^{-K_2 t}) + DO e^{-K_2 t} \dots \dots \dots (i)$$

L_o = initial or first stage B.O.D. in milligrams per litre @ t : 0* @ point 'A'

$$L_o = \frac{3.2 \times 1.47 \times 35 + 70 + 1.47 \times 5}{35 + 5}$$

$$= \frac{165 + 515}{40}$$

$$= 16.95 \text{ mg/litre}$$

D_o = Oxygen deficite in mg/litre @ t : 0

*Multiplier used to convert 5 day BOD to ultimate first stage B.O.D.

Mixed DO_A @ point A is

$$= \frac{5 \times 2 + 9.0 \times 35}{5 + 35} = 8.125 \text{ mg/l}$$

DO_A @ point 'A' is

$$\begin{aligned} C_s - C_A \\ &= 10.2 - 8.125 \\ &= 1.075 \text{ mg/litre} \end{aligned}$$

Substituting these values in equation (1) after $\frac{1}{2}$ miles or travel time of 0.0208 days

$$\begin{aligned} D_t &= \frac{1.8 \times 1695}{5.84 - 1.8} \left(2.718^{-1.8 \times 0.0208} - 2.718^{-5.8 \times 0.0208} \right) \\ &\quad + 1.075 \times 2.718^{-5.84 \times 0.0208} \\ &= 1.499 \text{ mg/l} \end{aligned}$$

Similarly values of D_t at time of travel of 0.042, 0.0625, 0.104 days, and 0.125 days are 1.974, 2.14, 2.43, 2.60, and 2.917 mg/l respectively.

DO just before discharge of Municipal waste is $(9.20 - 2.917) = 6.283 \text{ mg/l}$.

Therefore Mixed DO @ point 'B' is

$$DO_{\text{Mix}} = \frac{10 \times 4 + 6.283 \times 40}{10 + 40} = 5.82 \text{ mg/l}$$

DO @ point 'B' = $9.20 - 5.82 = 3.38 \text{ mg/l}$

$$\text{Now } K_1 = \frac{1}{t} \log \frac{L_A}{L_B} \quad t = 3/24 = 0.125 \text{ days}$$

$$1.80 = \frac{1}{0.125} \log_{10} 16.95 / L_B \quad L_A \text{ is BOD @ point 'A' } = 16.95 \text{ mg/litre}$$

$$L_B = 10.14 \text{ mg/litre}$$

1st stage B.O.D. @ point 'B' is

$$L_{oB} = \frac{10.14 \times 40 + 40 \times 1.47 \times 10}{40 + 10}$$

$$L_{oB} = 19.85 \text{ mg/l}$$

Again substituting these values in relation (1) to calculate D_t after $\frac{1}{2}$ miles distance or travel time 0.0208 days beyond point B.

$$D_t = \frac{1.8 \times 19.85}{5.84 - 1.8} \left((2.718)^{-1.8 \times 0.0208} - (2.718)^{-5.84 \times 0.0208} \right) + 3.38 \times \frac{1}{(2.718)} 0.01215$$

$$= 3.62 \text{ mg/litre}$$

For a distance 1 mile D/S of B, t is 0.0416 day so

$$D_t = 8.85 \left((2.718)^{-1.80 \times 0.046} - (2.718)^{-5.84 \times 0.0406} \right) + 3.38 \times (2.718)^{-5.84 \times 0.0406}$$

$$= 3.92 \text{ Mg/l}$$

Similarly values of D_t at time of travel 0.062 days, 0.0833 days, 0.104 days, 0.125, days 0.1663 days, 0.1875 days are respectively 3.96 mg/l, 4.2 mg/l, 4.42 mg/l, 4.45 mg/l, 4.48 mg/l and 4.465 mg/l.

Computation of ' t_c '

$$t_c = \frac{1}{K_2 - K_1} \log_e \frac{K_2}{K_1} \left[1 - \frac{D_0}{K_1 L_0} (k_2 - K_1) \right]$$

$$= \frac{2.31}{5.84 - 1.80} + \log_{10} \frac{5.84}{1.8} \left[1 - \frac{3.38}{1.8 \times 19.85} (5.84 - 1.80) \right]$$

$$= \frac{2.31}{4.04} \log_{10} 3.246 \left[1 - 0.0946 (0.9) \right]$$

$$= 0.572 \log_{10} 3.246 (1 - 0.0382)$$

$$= 0.1731 \text{ days}$$

$$= 4.15 \text{ hours}$$

Point of Maximum Deficit = Velocity $\times t_c$

4.15 miles from point 'B'

Computation of $D_{t_{max}}$

Now $t = 0.1731$ days.

$D_{t_{max}}$

$$= \frac{1.80 \times 19.85}{5.84 - 1.80} \left[(2.718)^{-1.80 \times 0.1731} - (2.718)^{-5.84 \times 0.1731} \right] + 3.38 (2.718)^{-5.84 \times 0.1731}$$

4.16 mg/l

PART 'B'

COMPUTATION FOR 90% EFFICIENCY

Given operating efficiency of industry = 70%

$$.70 = \frac{(\text{B.O.D. in}) - (\text{B.O.D. out})}{(\text{B.O.D. in})}$$

$$\text{BOD}_{5\text{out}} = 70 \text{ mg/l}$$

$$\text{B.O.D.}_{\text{in}} = ?$$

$$0.70 = 1 - 70/\text{B.O.D. in}$$

$$\text{B.O.D.}_{\text{in}} = \frac{70}{0.3} = 233.7 \text{ mg/l}$$

COMPUTATION OF FIRST STAGE B.O.D. AT 90%

$$0.90 = \frac{233.7 - \text{B.O.D. out}}{233.7}$$

$$\text{BOD}_{\text{out } 90\%} = 0.1 \times 233.7 = 23.37 \text{ mg/l}$$

First stage B.O.D. of

$$\begin{aligned} \text{industry @ 90\%} &= 23.37 \times 1.47 \\ &= 34.38 \text{ mg/l} \end{aligned}$$

First stage B.O.D. of river = 1.47×3.2

$$= 4.7 \text{ mg/litre}$$

$$\text{MIXED B.O.D.}_{\text{out at point A for 70\%}} = \frac{34.38 \times 5 + 4.7 \times 35}{35 + 5}$$

$$L_o = 8.42 \text{ mg/litre}$$

COMPUTATION OF DO AT 90%

Since A lot of river data was missing for the exact computation of 90%, or for routing a good st. line variation

L_o is done by Rough Graphic method.

MIXED DO AT POINT A

$$= \frac{5 \times 8.3 + 9.0 \times 35}{5 + 35}$$

$$= 8.913 \text{ mg/l}$$

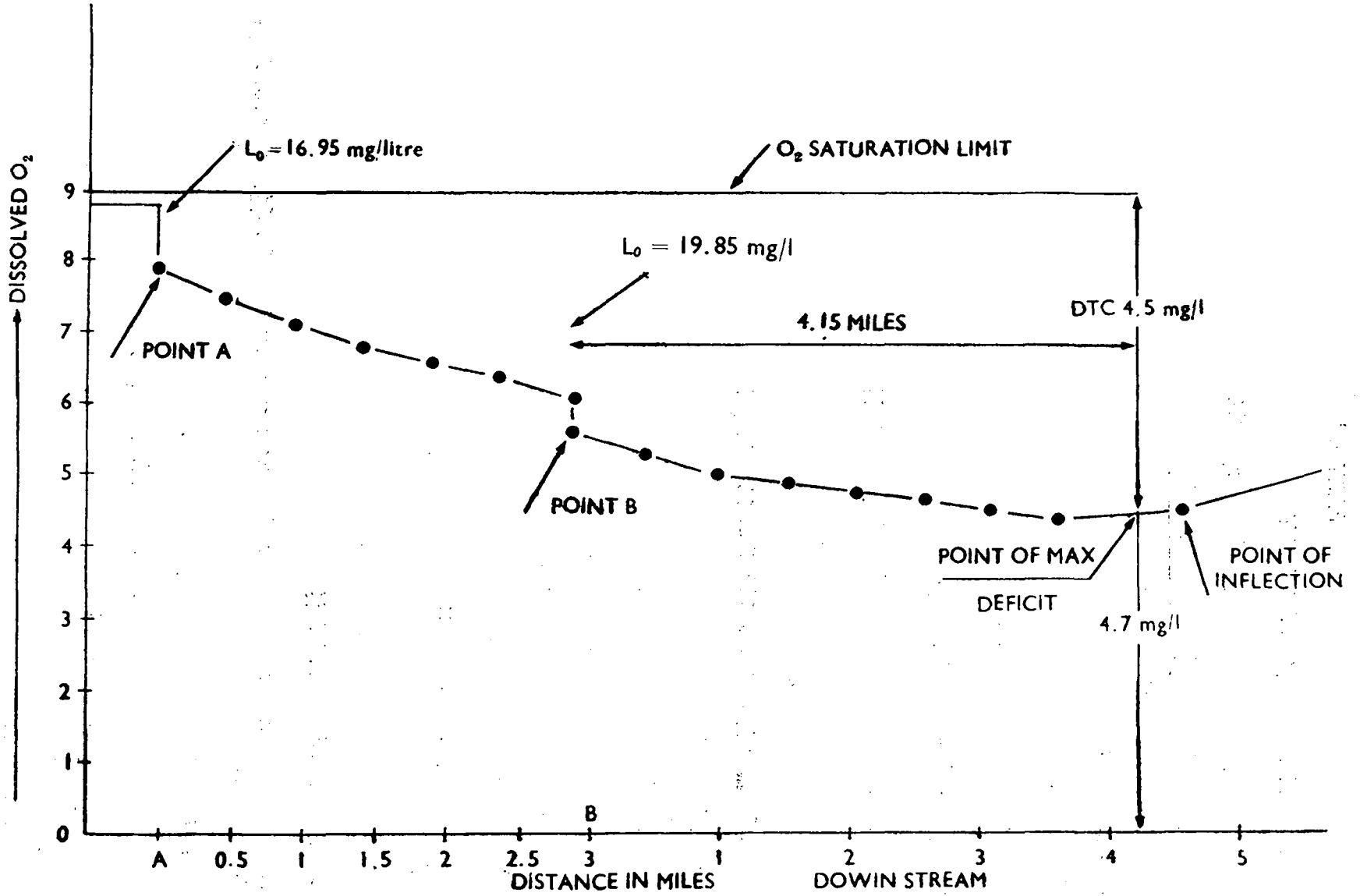


FIG. 2. DISSOLVED OXYGEN CURVE

Dissolved oxygen deficit at point A

$$D_o = 9.20 - 8.913$$
$$= 0.287 \text{ mg/litre}$$

COMPUTATION OF Dt AFTER EVERY $\frac{1}{2}$ M. @ 90%

$$t = 0.0208$$

$$Dt = \frac{1.80 \times 8.42}{5.84 - 1.80} \left((2.718)^{-1.80 \times 0.208} - (2.718)^{-5.84 \times 0.208} \right)$$
$$+ 0.287 (2.718)^{-5.84 \times 0.208}$$
$$= 0.575 \text{ mg/litre}$$

$$t = 0.0416 \text{ days (1 mile D/S w.r.t. Pt. A)}$$

$$Dt = 3.751 (2.718)^{-1.80 \times 0.0416} - (2.718)^{-5.84 \times 0.0416}$$
$$+ 0.287 (2.718)^{-5.84 \times 0.0416}$$

= 0.768 mg/litre similarly D_t at time of travel of 0.0625 days, 0.0833 days, 0.104 days, 0.125 days, are 0.89 mg/l, 1.096 mg/l, and 1.23 mg/l, and 1.327 mg/l respectively.

D_o @ 90% of just before Municipal discharge

$$= 9.20 - 1.327$$
$$= 7.873 \text{ mg/litre}$$

D_o of Municipal waste

$$= 4.0 \text{ mg/litre (given)}$$

$$\text{MIXED DO @ POINT 'B'} = \frac{4 \times 10 + 7.873 \times 40}{10 + 40}$$
$$= 7.098 \text{ mg/l}$$

DO @ Point B = 9.20 - 7.98

$$= 2.102 \text{ mg/l}$$

Computation of First Stage Mixed BOD @ B

$$K_1 = \frac{1}{t} \log_{10} \frac{LA}{LB}$$

$$1.8 = \frac{1}{0.125} \log \frac{8.42}{LB}$$

$$= 0.701$$

$$L_B = 5.03 \text{ mg/litre}$$

MIXED FIRST STAGE (ULTIMATE BOD) @ POINT 'B'

$$= \frac{10 \times 40 \times 1.97 + 40 \times 5.03}{10 + 40}$$

$$= 15.789 \text{ mg/litre}$$

Computation of Dt at every 1/2 mile from 'B' point.

$$t = 0.0208 \text{ days (1/2 mile D/S of point B)}$$

$$D_t = \frac{1.80 \times 15.784}{5.84 - 1.80} (2.718)^{-1.8 \times 0.0208} - (2.718)^{-5.84 \times 0.0208} + 2.102 (2.71)^{-5.84 \times 0.0208}$$

$$= 2.338 \text{ mg/l}$$

Similarly Dt at time of travel 0.0625 days, 0.0833 days, 0.104 days, 0.125 days, 0.1667 days, 0.1878 days, 0.208 days are respectively 2.75 mg/l, 3.019 mg/l, 3.16 mg/l, 3.34 mg/l, 3.35 mg/l and 3.294 mg/l, respectively.

COMPUTATION POINT OF MAXIMUM DEFICIT

$$t_c = \frac{l}{K_2 - K_1} \log_e \frac{K_2}{K_1} \left[1 - \frac{D_0}{KdL_0} (K_2 - K_1) \right]$$

$$= \frac{l}{5.84 - 1.80} \times 2.31 \log_{10} \frac{5.84}{1.80} \left[1 - \frac{2.102}{1.8 \times 15.78} (5.84 - 1.80) \right]$$

$$= 0.2037 \text{ days} \quad (5.8 - 1.80)$$

Point of maximum deficit in Part 'B'

$$= \text{Vel} \times \text{distance} = 1 \times 24 \times 0.2037$$

$$= 4.88 \text{ miles from point B (D/S)}$$

Computation of D_{max} in $t_c = 0.2037$

$$D_{t_c} = \frac{1.80 \times 15.784}{5.84 - 1.80} (2.718)^{-1.80 \times 0.2037} - (2.718)^{-5.84 \times 0.2037} + 2.10212 (2.718)^{-5.84 \times 0.2037}$$

$$= 3.373 \text{ mg/litre}$$

$$D_{max} = 3.369 \text{ mg/litre @ 4.38 miles D/S of point 'B'}$$

PART 'C'

For Municipal Plant Efficiency = 60 %

B.O.D.₅ = 40 mg/litre

$$\frac{1-C}{C_0} = 0.60$$

$C_0 = 100 \text{ mg/litre}$

COMPUTATION FOR DO SAG = 7 mg/litre

By Trial and Error Solution

Assume 70 % of Municipal plant

$$= \frac{\text{BOD}_{in} - \text{BOD}_{out}}{\text{BOD}_{in}}$$
$$0.70 = \frac{100 - \text{BOD}_5 \text{ out}}{100}$$

$$\text{B.O.D.}_5 \text{ out} = 0.3 \times 100 = 30 \text{ mg/litre}$$

$$\text{Municipal first stage ultimate B.O.D.} = 1.47 \times 30 = 44.10 \text{ mg/litre}$$

$$\text{B.O.D.}_5 \text{ Just before Municipal discharge} = 5.03 \text{ mg/litre}$$

$$\text{DO Just before Municipal discharge} = 7.873 \text{ mg/litre}$$

$$\text{DO @ 70\%} = 6.44 \text{ mg/l}$$

$$\text{Mixed DO @ point B} = \frac{10 \times 6.44 + 7.87 \times 40}{10 + 40}$$
$$= 7.586 \text{ mg/litre}$$

$$\text{DO deficit @ 70\%} = 9.2 - 7.586$$
$$= 1.619 \text{ mg/litre}$$

$$\text{Mixed B.O.D. @ Point B} = \frac{10 \times 44.10 + 40 \times 5.03}{50} = 12.84 \text{ mg/litre}$$

Computation of t_c Efficiency = 70%

$$t_c = \frac{1 \times 2.31}{5.84 \times 1.80} \log_{10} \frac{5.84}{1.80} \cdot \frac{1.614}{1.8 \times 12.84} (5.84 - 1.80)$$
$$= 0.2056 \text{ days ;}$$

$$D_{t_c} = \frac{1.80 \times 12.84}{5.84 - 1.80} (2.718)^{-1.80 \times 0.2056} - (2.718)^{-5.84 \times 0.2056}$$
$$+ 1.614 (2.718)^{-5.84 \times 0.2056}$$
$$= 2.63 \text{ mg/litre}$$

Also

$$.75 = \frac{C_o - C}{C_o}$$

$$0.75 = \frac{100 - C}{100} \quad C = 0.25 \times 100 = 25 \text{ mg/litre}$$

$$\text{Do at 75\%} = 6.90 \text{ mg/litre}$$

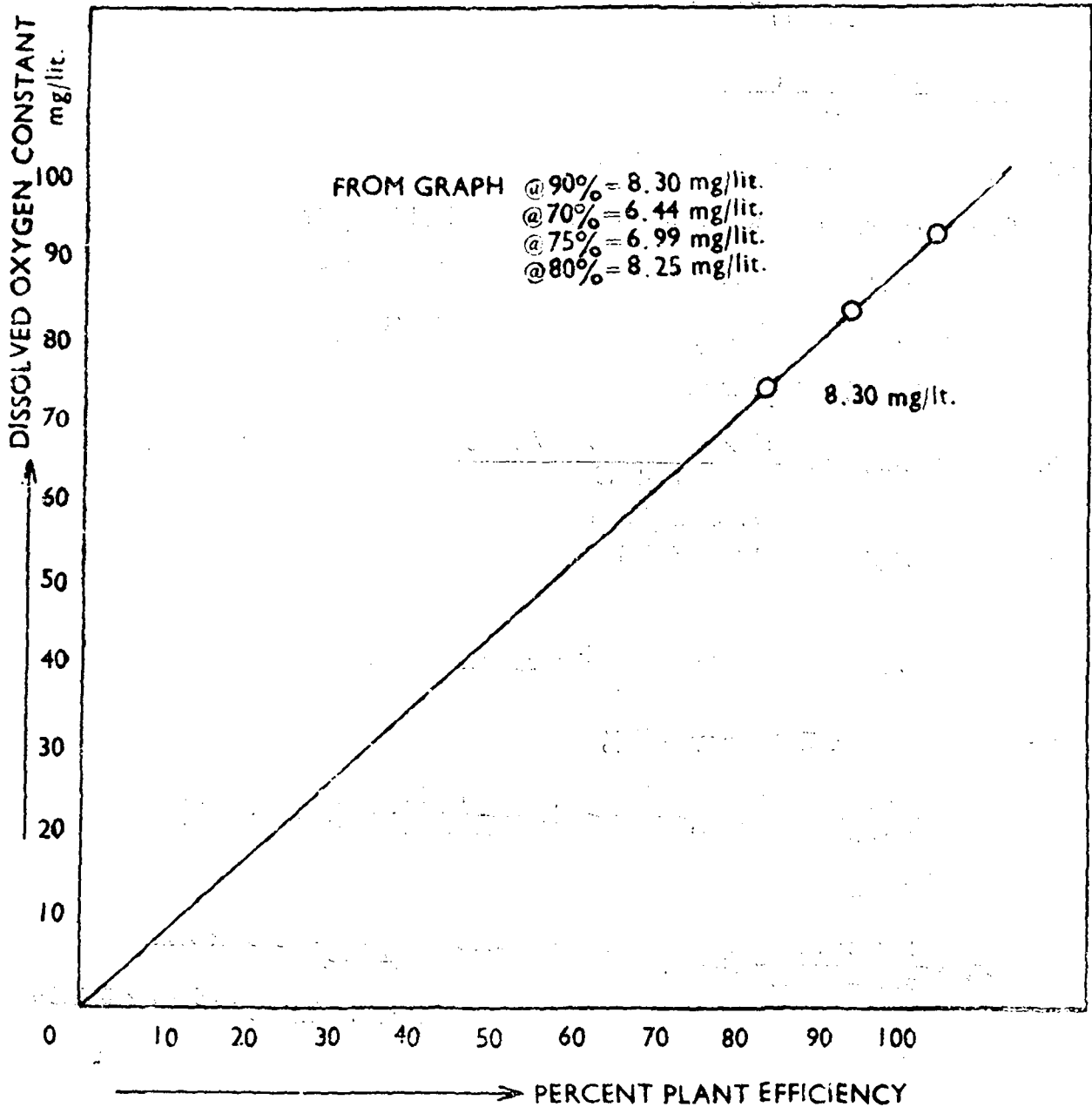


FIG. 3 EFFICIENCY VS DO CONCENTRATION

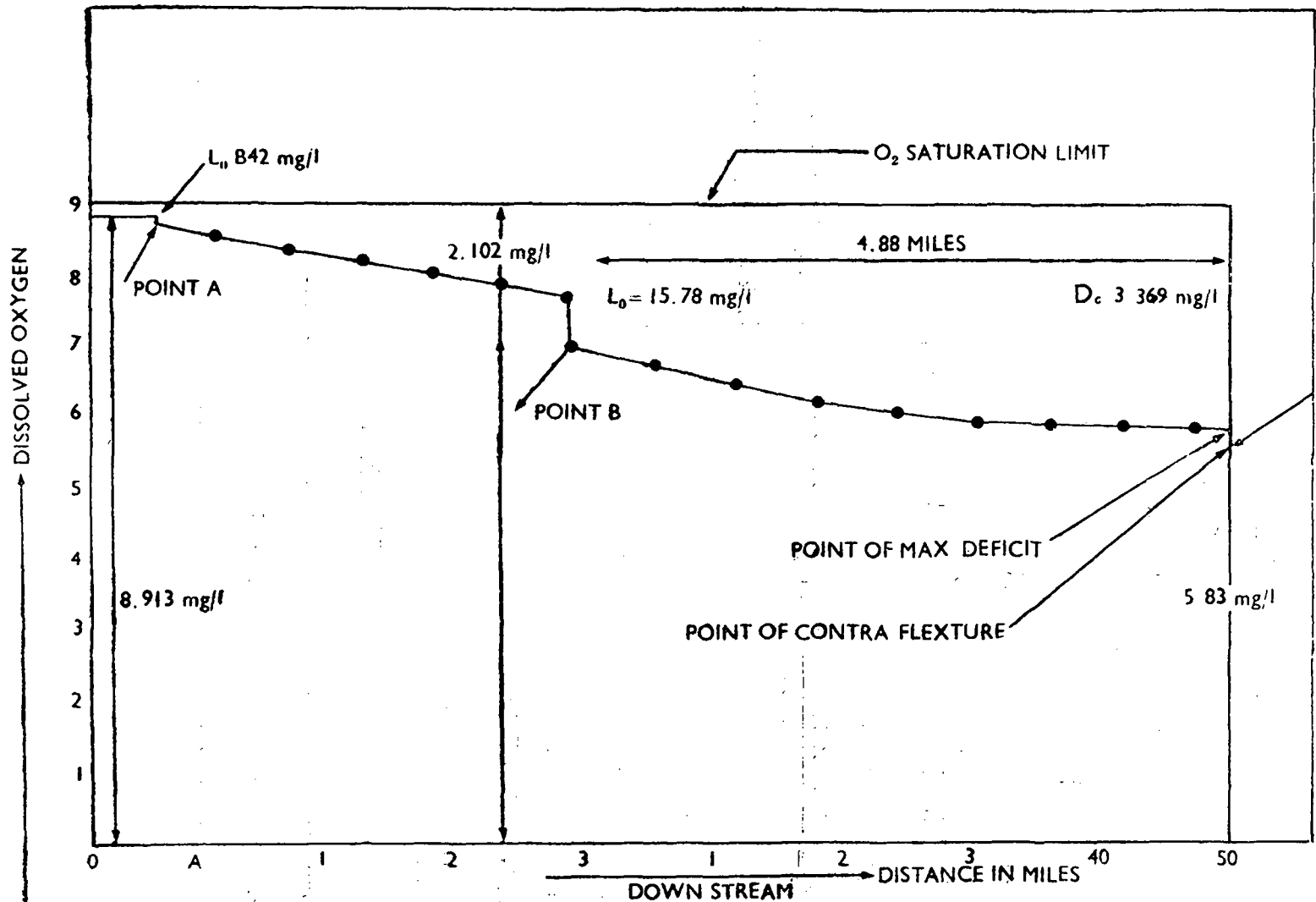


FIG. 4 DO PROFILE FOR 90% EFFICIENCY

$$\begin{aligned} \text{Mix DO @ Point B @ 75 \%} &= \frac{10 \times 6.90 + 40 \times 7.873}{40 + 10} \\ &= 7.678 \text{ mg/litre} \end{aligned}$$

$$D_o \text{ @ 75 \%} = 9.20 - 7.678 = 1.522 \text{ mg/litre}$$

Ultimate mixed B.O.D. @ point 'B' @ 75 %

$$\begin{aligned} &= \frac{10 \times 25 \times 1.47 + 40 \times 5.03}{10 + 40} \\ &= 11.37 \text{ mg/litre} \end{aligned}$$

COMPUTATION OF D_{t_c} at 75 %

$$\begin{aligned} t_c &= \frac{1}{5.84 - 1.80} \log \frac{5.84}{1.80} \left(1 - \frac{1.522}{1.80 \times 11.37} (5.84 - 9.80) \right) \\ &= 0.202 \text{ days} \end{aligned}$$

$$\begin{aligned} D_{t_c} &= \frac{1.80 \times 11.37}{5.84 - 1.80} (2.718)^{-1.8 \times 0.202} - (2.718)^{-5.84 \times 0.202} \\ &\quad + 1.322 (2.718)^{-5.84 \times 0.202} \\ &= 2.394 \text{ mg/litre} \end{aligned}$$

Similarly the values of t_c at plant efficiency of 80,79 % are 0.1958 days and 0.1977 days corresponding values of D_{t_c} are 2.176 mg/litre, and 2.208 mg/litre respectively.

At $D_{t_c} = 2.208$ mg/litre

$$D_o = 9.2 - 2.2 = 7.0 \text{ mg/litre}$$

Therefore 79% efficiency of the municipal plant gives the required D_o value of '7' mg/litre.

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MATHEMATICAL MODELLING IN STREAM POLLUTION CONTROL

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Introduction

The objective of a stream pollution control programme is to examine different alternatives in the light of effectiveness in the engineering context, efficiency in the economic context and reality in the social and political context. An important question in this regard is, to what level are we willing to invest money to protect, enhance or otherwise utilize a particular stream. In order to answer this basic question there is a need of a tool that can interplay relationships of the behaviour of a stream under different natural conditions and imposed constraints. The relationships between the quality of water and the contiguous environment is the domain of mathematical models in stream pollution control.

A mathematical model is an analytical abstraction of the real world and relates system responses with the inputs and parameters in the form of a mathematical relationship. As such it does not pretend to incorporate all phenomena but rather abstracts only those portions of the real world that are relevant to the problem under consideration. Mathematical models provide the means for the environmental planner to simulate the behaviour of the real system before the fact. He can test the effect of operating policies, control strategies and changes in the physical, chemical or biological conditions of stream without modifying the prototype. Of great importance, perhaps, is the capability given to the planner to compare alternatives to assess the incremental impact between two or more courses of action. It also aids in determining how much data to collect and where and of what type.

The use of mathematical modelling requires close liaison with the field sampling crew and the data analysis activities. Some streams vary in nature from place to place, therefore data should always be collected which can help shape the model and after proper verification can form the basis of making projections regarding the pollution control procedure.

Mathematical Modelling Procedure

Before any model of the physical environment can be used for control purposes, one must be reasonably satisfied that the mathematical model duplicates the major features of the prototype. This requires the degree of agreement between data as observed in the field and the model output. The agreement that is required will depend upon the nature of the problem under consideration. In any case, adequate model construction demands that the continual checks be made of the degree of agreement between computed and

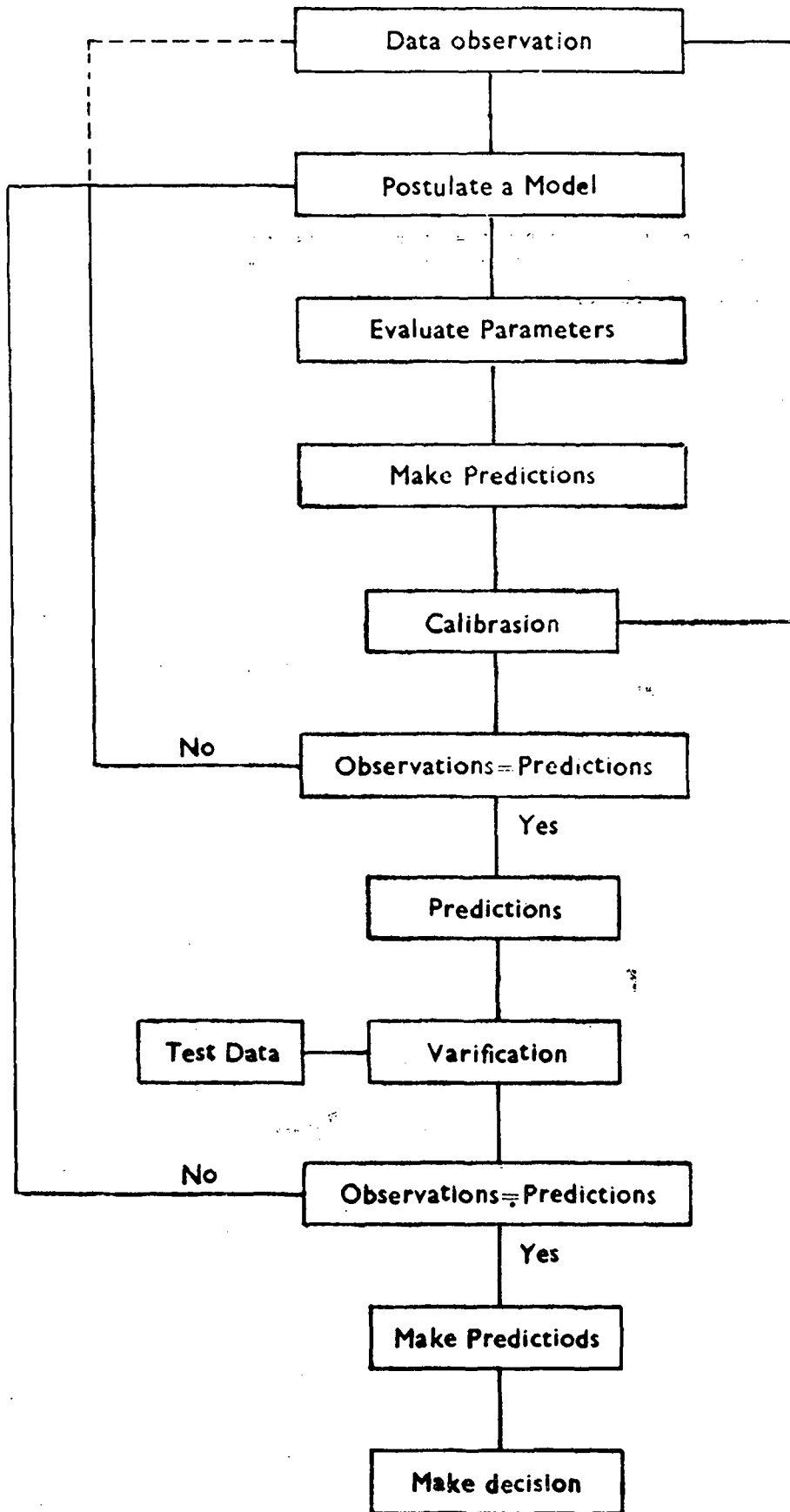


Fig. 1. MODELLING PROCEDURE

observed results. The objective of course is not just to get agreement with observed data but to obtain agreement with a model that has a physical rationale that is plausible and complementary to existing theory.

To obtain a reliable model, a schematic representation of the procedure is given in Fig. 1. On the availability of field data a reasonable mathematical model is postulated keeping in view the phenomena occurring in the stream. The model parameters are then determined using field data and related empirical relationships. Once the model parameters are known, the model is ready for use and outputs related to inputs can be calculated. If the results of the model are in close agreement with the field observations, the model is said to be calibrated, otherwise model needs reshaping verification of the model is done with the help of test data before it is used for the purpose of making decisions. In the process of verification, the agreement of the model output and the field test data is required. In case the agreement is achieved the model stands verified otherwise whole process is repeated again.

Development of Mathematical Models

The basic idea in developing a mathematical model is to write a mass balance equation for the elemental volume which is accounting for all the materials entering and leaving the infinitesimal cube. In most rivers and streams, the water body can be considered homogeneous with respect to water quality variables laterally and vertically. The concentration of waste material in such a case then varies only along the length of the stream. For many applications in stream pollution analysis, it is assumed that the transport of the materials is only due to advection and no mixing due to diffusion or dispersion of the material takes place. The mathematical models thus developed are referred as one dimensional advective models.

Models for Conservative Substances

A number of stream pollution problems involve the discharge of waste materials that for all practical purposes do not decay with time or disappear from the stream by settling, adsorption or other means. Such waste substances are termed conservatives and include total dissolved solids, chlorides, pesticides etc.

The mass balance equation of the material entering and leaving an elemental volume V represented by a cross sectional slice of thickness ΔX can be written as

$$\text{Accumulation} = \text{Inputs} - \text{Outputs}$$

or mathematically

$$V \Delta S = S \Delta t - (Q + \Delta Q) \left(S + \frac{\partial S}{\partial X} \Delta X \right) \Delta t$$

Where ΔS is the change in concentration and Δt is the time interval. Q is the discharge and V is the volume equal to $A \Delta X$, where A is the cross sectional area of the stream. Simplification and division by Δt and $V (A \Delta X)$ results

$$\frac{\Delta S}{\Delta t} = - \frac{Q}{A} \frac{\Delta S}{\Delta X} - \frac{Q}{X} \frac{S}{A} - \frac{\partial S}{\partial X} \frac{\Delta Q}{A}$$

when the infinitesimally small terms approach zero

$$\frac{\partial S}{\partial t} = - \frac{Q}{A} \frac{\partial S}{\partial X} - \frac{S}{A} \frac{\partial Q}{\partial X}$$

$$\frac{\partial S}{\partial t} = -\frac{l}{A} \left(Q \frac{\partial S}{\partial X} - S \frac{\partial Q}{\partial X} \right)$$

$$\frac{\partial S}{\partial t} = -\frac{l}{A} \frac{\partial(QS)}{\partial X} \dots\dots\dots (1)$$

under steady state conditions

$$\frac{\partial S}{\partial t} = 0$$

Therefore

$$\frac{l}{A} \frac{d(QS)}{dX} = 0$$

If area and discharge are constants

$$\frac{Q}{A} \frac{dS}{dX} = 0$$

or

$$\frac{dS}{dX} = 0 \dots\dots\dots (2)$$

The solution of equation 2, is $S = \text{constant}$. The value of the constant is determined by outfall boundary conditions of $S = S_o$. The concentration of S_o is calculated by making a mass balance at the outfall

$$S_o (Q_u + Q_w) = S_u Q_u + S_w Q_w$$

or

$$S_o = \frac{S_u Q_u + S_w Q_w}{Q_u + Q_w}$$

where S_u and Q_u represent the concentration and flow of the stream before entrance of the waste discharge and S_w and Q_w represent the concentration and flow of waste discharge.

Model for BOD

When the non-conservative substances like the organic matter are considered, the changes in the concentration of the materials are due to degradation of the material with micro-organisms as well as by transport mechanisms. Since BOD is the measure of the organic content of waste, a mathematical model in respect of BOD in the stream can be written as earlier, including the term for reaction as follows:

$$\text{Accumulation} = \text{Inputs} - \text{Outputs} \pm \text{sources/sinks}$$

The equation 1 after including the term for sink of BOD due to reactions can be written as

$$\frac{\partial L}{\partial t} = \frac{l}{A} \frac{\partial(QL)}{\partial X} \pm K, L \dots\dots\dots (3)$$

Where L is the BOD in the stream and K, is the BOD removal coefficient.

For constant area and discharge, under steady state condition, equation 3 taken the form

$$U \frac{dL}{dX} = -K_r L$$

or

$$\frac{dL}{L} = \frac{-K_r}{U} dX$$

upon integration

$$\ln L = K_r \frac{X}{U} + C$$

where C is a constant of integration and can be evaluated with boundary conditions

$$L = L_0 \text{ at } X = 0 \quad \text{as } C = \ln L_0$$

Therefore

$$\ln L = -K_r \frac{X}{U} + \ln L_0$$

or

$$L = L_0 \exp\left(-K_r \frac{X}{U}\right) \dots\dots\dots (4)$$

The equation 4 is a one dimensional steady state model of BOD under the assumption of constant parameters and no direct input of BOD except for a point source which can be included in the boundary conditions.

In case it is desired to evaluate the effects of distributed sources or sinks along the bottom of the stream resulting from some previous inputs as in benthal deposits L_d , the equation 3 becomes

$$\frac{\partial L}{\partial t} = -\frac{1}{A} \frac{\partial (QL)}{\partial X} - K_r L \pm L_d \dots\dots\dots (5)$$

The solution of equation 5 for steady state, constant parameters, and L_d as sink case is

$$L = \frac{L_d}{K_r} \left(1 - \exp\left(-K_r \frac{X}{U}\right)\right) + L_0 \exp\left(-K_r \frac{X}{U}\right) \dots\dots\dots (6)$$

Similarly here the effects of BOD from surface runoff (L_r) which contributes to flow are also considered, the equation 3 will become

$$\frac{\partial L}{\partial t} = -\frac{1}{A} \frac{\partial (QL)}{\partial X} - K_r L \pm L_d + L_r \frac{(\partial Q/dX)}{A} \dots\dots\dots (7)$$

In the same fashion any number of inputs and BOD removal mechanisms can be included in the model and then solutions of the resultant differential equations can be obtained.

Models for Dissolved Oxygen

The models for dissolved oxygen are generally expressed in terms of dissolved oxygen (DO) deficit and the procedure for their development is similar to that used for BOD. A mass balance equation in term of DO deficit D can be written as follows :

$$\frac{\partial D}{\partial t} = -\frac{1}{A} \frac{\partial(QD)}{\partial X} - K_a D - K_d L \dots\dots\dots (8)$$

where the term $K_a D$ represents the sink of DO deficit due to atmospheric reaeration and $K_d L$, the source of DO deficit due to BOD. The third term on the right hand side accounts for transport mechanisms as before. K_a and K_d are atmospheric reaeration rate and deoxygenation rate coefficients.

Under the assumptions of constant area and discharge, one dimensional steady state model can be written as

$$0 = U \frac{dD}{dX} - K_a D + K_d L \dots\dots\dots (9)$$

but $L = L_0 \exp\left(-K_r \frac{X}{U}\right)$

Substituting the value of L in equation 9 results

$$\frac{dD}{dX} + \frac{K_a D}{U} = \frac{K_d}{U} L_0 \exp\left(-K_r \frac{X}{U}\right) \dots\dots\dots (10)$$

Equation 10 is a first order, ordinary linear differential equation. By using integration factor method for boundry conditions, where

$$D = D_0 \text{ at } X = 0$$

$$D = D_0 \exp\left(-K_a \frac{X}{U}\right) + L_0 \left(\frac{K_d}{K_a - K_r}\right) \left(\exp\left(-K_r \frac{X}{U}\right) - \exp\left(-K_a \frac{X}{U}\right)\right) \dots (11)$$

Equation 11 accounts for sources and sinks of dissolved oxygen deficit only from point source of BOD and atmospheric reaeration. only. If other sources or sinks of DO deficit are to be included, the equation in general form can be written as

$$\frac{\partial D}{\partial t} = \frac{1}{A} \frac{\partial(QD)}{\partial X} - K_a D + K_d L + D_b - D_p + D_r + D_v \frac{(\partial Q / A)}{\partial X}$$

where D_b is due to benthal demand, D_p due to photosynthesis, D_r due to algal respiration, and D_v due to distributed surface runoff effect on dissolved oxygen deficit.

Models for Microbial Life

The death of micro-organisms like bacteria in an unfavourable environment has been generalized by Chick as to follows first order reaction Kinetics. Therefore, the mathematical expression for the number of bacteria remaining B can be written in the same way as that for BOD. So the steady state one dimensional model in terms of bacteria remaining will be

$$\frac{1}{A} \frac{d(QB)}{dX} + K_b B = Q \dots\dots\dots (12)$$

where K_b is the bacterial death rate coefficient

The solution of the equation 12 for constant parameter is

$$B = B_0 \exp \left(- K_b \frac{X}{U} \right)$$

where B_0 is the number of bacteria at the boundry where

$$X = 0$$

Due to many factors, the deviations of bacterial death rate from above has been reported in the stream environment. Two principal deviations commonly reported are: an initial lag phase and an after lag phase of apparent decreasing death rate. These deviations can be accounted for by assuming that the residual number of bacteria at any time consist of two fractions, one resulting from the application of a death rate K_{b1} to an initial bacterial population B_{o1} , and another from the similar application of the death rate K_{b2} to the initial population B_{o2} and thus the equation can be written

$$B = B_{o1} \exp \left(- K_{b1} \frac{X}{U} \right) + B_{o2} \exp \left(- K_{b2} \frac{X}{U} \right)$$

Practical Applications

Although it is possible to obtain solutions for the equations described earlier without assuming constant area, discharge and other parameters, however generally for the purposes of simplification, solutions are obtained for constant, area, discharge and other parameters for a particular reach of the stream and justifying it by the actual field data available to estimate the quantities. The resultant equations are used for each reach of the stream until one approaches a change in the functional form of one of the system parameters or reaches a new waste input or distributory. Thus a specific solution is obtained for a reach and a new initial value is computed for the next down stream reach and a solution is generated for the next reach continuing the process through the area of interest.

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STREAM STANDARDS

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Introduction

In today's environment streams are used to carry away pollution resulting from industries and municipalities. Other important uses of stream waters include fishing, irrigation, potable water supply, recreation, navigation, power and industry. A stream must therefore be protected so that it can serve the best interests of the people using it. Neglect of this aspect may have a significant impact on future development gains of the country.

To make a stream in acceptable conditions generally requires the enforcement of certain by laws specifying either effluent or stream standards. In water quality terminology, 'standard' denotes specific legal requirements for immediate compliance. Standards are based on some specific 'criterion' which denotes a method of measurement, a means of forming a judgement. Where, when, how and under what conditions measurements are made and how the data are interpreted are the criteria by which the compliance with a standard are judged. Stream standards must neither be too lax, and destroy a possible future use of the stream, not too strict, and require more waste treatment than necessary. Most of the developed countries have thus preserved the quality of their water bodies through the establishment of such standards. However, in the developing world only a few countries have adopted these standards. Nevertheless, practically no attempt has been made in these countries to adjust or modify the standards to suit local conditions.

Effluent Standards Vs Stream Standards

Controlling the stream condition through effluent standards simply requires that the waste discharged is kept below a certain maximum concentration of polluting matter. A disadvantage to this approach is that there is normally no control over the total volume of polluting substance. The large industry although providing the same degree of waste treatment as the small one may actually be responsible for a major portion of the pollution in the stream. Nevertheless, by virtue of their value, major industries should be allocated a larger portion of the assimilative capacity of the stream.

The effluent standard system is easier to control. No detailed stream analysis are needed to determine the exact amount of waste treatment required. In fact standards for effluent are based more on economics and practicability of treatment than an absolute pro-

tection of the stream and the best usage of stream is not the primary consideration. Rather the usage of stream will depend upon its conditions after industrial effluent standards have been satisfied.

The stream standard system is based on establishing classification or standard of quality for a stream and regulating any discharge into it to the extent necessary to maintain the established stream classification or quality. The primary motive of stream standards is to protect and preserve each stream for its best usage for both upstream and down stream users. The main advantage of the stream standard system is the prevention of excessive pollution regardless of the type and location of the industry. Loading is limited to what the stream can assimilate and this may impose hardships on an industrial plant located at a critical spot along the stream.

The disadvantage in establishing stream standards include the need for a complex and thorough stream survey prior to stream classification. This can be costly, cumbersome and result in delay. Similarly controversies over the proportion of the stream to be reserved for future use may rise. However, a precise knowledge of the stream condition is always helpful in determining the exact degree of treatment required by the industrial and municipal wastes to be discharged in the stream.

Stream Classification

Stream may be classified according to the probable use of their waters. New York State in America has employed the following classification for fresh water streams (Nemerow, 1971).

- Class AA — *Drinking Water* after approved disinfection, with additional treatment, if necessary, to remove naturally present impurities.
- Class A — *Drinking Water* if subjected to approved treatment equal to a minimum of coagulation, sedimentation filtration and disinfection, plus additional treatment for natural impurities, if necessary.
- Class B — *Bathing* or any lesser use
- Class C — *Fishing* or any lesser use
- Class D — *Agricultural, industrial cooling or industrial process water* or any lesser use

Stream Quality Criteria

In developed countries the Water Pollution Control Act provides for the establishment of water quality standards for various uses. In U.S.A. most states establish their own standards which the federal government accepts in turn. The standards are such as to protect the public health or welfare and enhance the quality of water. In establishing these standards, consideration is given to the use and value of stream for public water supply, propagation of fish and wild life, recreational purposes, agriculture and other legitimate use. The US federal government has established such quality guidelines, a summary of which is presented in Table 1 (Nemerow, 1971). Such standards have also been fixed for industrial use of stream water. However, each industry with its own process requirements usually evaluates the quality of water supply. It is therefore difficult to apply industry wide criteria when process requirements vary so widely.

World Health Organization (1971) has also recommended standards of quality for water sources. The summary of WHO standards has been given in Table 2.

With particular reference to the developed countries an important use of stream waters is that of recreation. The National Technical Advisory Sub-Committee for Recreation and Aesthetics (Thomann, 1972) has recommended that for general recreational

TABLE I
Water standards for various uses. (Nemerow 1971)

Water quality	Recreation and aesthetic	Public water supply		Fish and aquatic wildlife			Agriculture	
		Permissible	Desirable	Fresh water organisms	Wild life	Marine and estuarine organisms	Farm water supplies	Livestock	Irrigation
Colour, units		75	< 10	10% of light penetrating to bottom	10% of light penetrating 6 ft.			
Temperature, °F	< 85°	< 85°	< 85°	83—96° for 6 hr.	6 ft.			55—85°
Fecal coliform, no/100 ml.	2000—200	2000	20					4000
Alkalinity (CaCO ₃), ppm		30—500	30—500	> 20	35—200		35—203	
Chloride, ppm		250	25					
Hexavalent chromium, ppm		0.05	Absent				0.05	0.05 5—20
Copper, ppm		1.0	Absent				1.0	0.2—5.0
Dissolved oxygen, ppm		> 3.0	Near to saturation	> 4.0	Bottom	> 4.0 aerobic		
Hardness (CaCO ₃), ppm		300—500	60—120					
Iron, ppm		0.3	Virtually Absent				0.3	
Manganese, ppm		0.05	Absent				0.05	2.0—20
Nitrates, ppm		10.0 (N)	Virtually Absent				45.0	
pH	5.0—9.0	6.0—8.5		6—9	7.0—9.2	6.5—8.5	6.0—8.5	4.5—9.0
Sulphate, ppm		250	50					
Total dissolved solids, ppm		500	200				500—5000	10,000 0—5000
Carbon chloroform extractable, ppm		0.15	0.04				0.0001-0.02	
Pesticide, ppm		0.00—0.1	Absent	Varies with organism	Varies with organism	Varies with organism		
Phenol, ppm		0.001	Absent					
Gross beta radioactivity, $\mu\text{c/litre}$		1000	100	1000	1000	1000	1000	1000 1000
Cyanide, ppm		0.20	Absent				0.20	
Turbidity, ppm		Virtually Absent	10—50					

use of surface waters, the average fecal coliform count should not exceed 2000 per 100 ml and the maximum should not exceed 4000 per 100 ml except in the immediate vicinity of an outfall. It is also recommended that for swimming purpose, the fecal coliform content of the stream should not exceed geometric mean of 200 per 100 ml. In fact the use of water for direct contact recreation may dictate a more stringent coliform requirement than the Municipal water supplies.

Pescod (1974) has discussed the stream standards used in some of the developing countries of Southeast Asia and proposed standards for the region. It was pointed out that people in the region experience a significant degree of poverty and are not very sensitive to poor surface water quality. Thus the need for standardization of stream waters for the region would be restricted to fishing, irrigation and potable water supply.

Fishing

The main parameters that affect fish catch are dissolved oxygen concentration, presence of toxic compounds, temperature and the presence of non-biodegradable substances which are concentrated in the food chain (*i.e.* DDT). DO level reflects the general level and health of a water body. When DO levels are low the propagation of fish may be impaired and large mortalities may occur. The recommended levels of stream standards have been shown in Table 3. There appears to be difference in recommendations regarding the minimum DO level standards (Table 1). Infact a number of DO criteria are in use today and vary at different places. The National Technical Advisory Committee on Water Quality Criteria for fish and other aquatic life and wild life has recommended that for a warm water biological system, the DO concentration should be above 5 mg/l. It was suggested that under extreme conditions the DO concentration may range between 5 and 4 mg/l for short periods. Ohio River Valley Water Sanitation Commission (ORSANCO) (Nemerow, 1971) has suggested a DO level of not less than 5 mg/l during at least 16 hours of any 24-hour period, or less than 3 mg/l at any time.

TABLE 2

WHO STANDARDS FOR WATER SOURCES

Compounds affecting the Potability of Water.

<i>Substance</i>	<i>Maximum allowable limit</i>
Total dissolved solids	1500 mg/litre
Iron	50 mg/litre
Manganese—assuming that the ammonia content is less than 0.5 mg/litre	5 mg/litre
Copper	1.5 mg/litre
Zinc	1.5 mg/litre
Magnesium plus sodium sulphate	1000 mg/litre
Alkyl benzyl sulphonates (ABS : surfactants)	0.5 mg/litre

<i>Substance</i>	<i>Maximum allowable limit</i>
<i>Components Hazardous to Health</i>	
Nitrate as NO ₃	45 mg/litre
Fluoride	1.5 mg/litre
<i>Toxic Substances</i>	
Phenolic substances	0.002 mg/litre
Arsenic	0.05 mg/litre
Cadmium	0.01 mg/litre
Chromium	0.05 mg/litre
Cyanide	0.2 mg/litre
Lead	0.05 mg/litre
Selenium	0.01 mg/litre
Radionuclides	1000 $\mu\mu$ c/litre
<i>Chemical Indicators of Pollution</i>	
Chemical oxygen demand (COD)	10 mg/litre
Biochemical oxygen demand (BOD)	6 mg/litre
Total Nitrogen exclusive of NO ₃	1 mg/litre
NH ₃	0.5 mg/litre
Carbon chloroform extract	0.5 mg/litre
Grease	1 mg/litre
<i>Bacteriological Standards</i>	
	MPN/100 coliform bacteria
(i) Bacterial quality applicable to disinfection treatment only	0—50
(ii) Bacterial quality requiring conventional methods of treatment (coagulation, filtration, disinfection)	50—5000
(iii) Heavy pollution requiring extensive types of treatment	5000—50000
(iv) Very heavy pollution, unacceptable unless special treatments designed for such water are used: source to be used only when unavoidable	greater than 50,000

TABLE 3

Proposed Stream Standards for Fishing (Pescod 1974)

Quality parameter	Suggested levels of stream standard
CO ₂	12 mg/litre
pH	6.5 — 8.5
NH ₃	less than 1 mg/litre
Heavy metals	less than 1 mg/litre
Copper	less than 0.02 mg/litre
Arsenic	less than 1 mg/litre
Lead	less than 0.1 mg/litre
Selenium	less than 0.1 mg/litre
Cyanides	less than 0.012 mg/litre
Phenols	less than 0.02 mg/litre
Dissolved solids	less than 1000 mg/litre
Detergents	less than 0.2 mg/litre
Dissolved Oxygen	2 mg/litre or above

Irrigation

The main water quality parameter for irrigation water is the concentration of salts which damages plant cells. In addition, sodium salts if present cause the displacement of calcium ion from the soil causing permeability to decrease. A good drainage system lowers the contact period between the plant and saline water so that a well drained field may tolerate a lower irrigation water quality. A reliable index of the tendency of an irrigation water to form exchangeable sodium in the soil is the sodium-adsorption ratio (SAR).

It is defined as :

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}} \quad \text{where the}$$

concentration are in meq/litre.

Beside the above parameter, high temperatures increase water consumption of the plant thus demanding a better irrigation water quality. Also excessive concentration of metal ions retards plant growth and sometimes causes death. The stream standards for Irrigation use, as recommended by Pescod (1974) have been shown in Table 4.

Potable Water Supply

The standard water treatment usually includes coagulation, sedimentation, rapid sand filtration and disinfection. Assuming treatment level of this type, the recommended standards in the US have been shown in Table 1. For the Asian developing countries the proposed standards have been shown in Table 5 (Pescod, 1974). The quality requirements suggest that alternative sources of potable supply should be provided rather than attempt to maintain such a high quality for direct use of a surface stream.

TABLE 4

Proposed Stream Standards for Irrigation (Pescod, 1974)

Quality Parameter	Suggested Levels of Stream Standards
Total Dissolved solids (TDS)	<p>Not more than 400 mg/litre where there are poor drainage, saline soil and inadequate water supply.</p> <p>Not more than 1000 mg/litre where there are good drainage.</p> <p>Not more than 2000 mg/litre where there are salt-resistant crops, good drainage and low SAR of water.</p>
Sodium adsorption ratio (SAR)	<p>Not more than 10, where there is poor drainage.</p> <p>Not more than 18, where there is good drainage.</p> <p>Not more than 1.25 where there are sensitive crops.</p> <p>Not more than 4 where there are tolerant crops.</p>
Dissolved Oxygen	Greater than 2 mg/litre. A level of 2 mg/litre should not occur for more than 8 hours out of any 24 hours period.
Pesticides	
DDT	0.002 mg/litre
Endrin	0.004 mg/litre
B.H.C	0.21 mg/litre
Methyl Parathion	0.10 mg/litre
Malathion	0.16 mg/litre

TABLE 5

Proposed Stream Standards for Potable Water Supply (Pescod, 1974)

Quality Parameter	Suggested Levels of Stream Standards
Most Probable Number of Coliforms (MPN)	Effluent quality similar to the natural state of surface water
pH	6.5 — 8.5
Dissolved Oxygen	Greater than 2 mg/litre
Arsenic	Less than 0.05 mg/litre
Lead	Less than 0.05 mg/litre
Chromium	Less than 0.05 mg/litre
Cyanide	Less than 0.2 mg/litre
Phenolic substances	Less than 0.002 mg/litre
Chlorides	Less than 1000 mg/litre
Total dissolved solids	Less than 4000 mg/litre

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POLLUTION CONTROL PLANNING FOR RIVER

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In the area of water pollution control management, the application of system analysis techniques to improve the planning and decision-making processes, is becoming increasingly important. Systems analysis has provided a new dimension to man's analytical capabilities, and improvements of computer technologies have significantly improved man's computational abilities.

System analysis may be defined as an analytical study that helps a decision maker to identify and select a preferred course of action among several feasible alternatives. Quantitative methods are preferred in system analysis, and computers are almost mandatory if the system to be modeled is complex. In addition, model development needs expert intuition and judgment. This means that system analysis cannot replace experience—in fact, it augments it.

In the water quality prediction and control of a water and wastewater system, dissolved oxygen is an important and commonly used indicator. There have been well over 50 models proposed for defining and evaluating regional water-quality management programmes. No attempt will be made to describe in detail or to discuss the various mathematical programming techniques that have been used to solve the models. This paper will be limited to only the application of dissolved oxygen sag curve formula as a model for defining and evaluating wastewater reduction and treatment for the management of dissolved oxygen concentrations in regional surface water systems.

The following simple example is used as an illustration :

Illustrative Example

Two cities A and B with population of 30,000 and 20,000 respectively, 60 miles apart, discharge their wastewater into a river with a minimum flow rate of 300 cfs. The design sewage flow = 100 gpcd. 5-day BOD of the stream water above city A = 1 mg/l.

5-day BOD of the raw sewage = 200 mg/l.

No DO (Dissolved Oxygen) in the sewages.

Temperature of the sewages = 20°C

Temperature of the stream water above

City A = 15°C

(K_1) 20°C = 0.3 per day

(K_2) 20°C = 0.7 per day

The average velocity of the stream = 2 mph

Plan the degree of treatment for sewages from city A and B respectively in order to have a dissolved oxygen concentration more than 50% of saturation level.

Solution :

Three types of sewage treatment , are considered in this example. They are :

NT = No treatment

PT = Primary treatment, including machanized settling and heated digestion tanks.

ST = Secondary treatment, including machanized settling, activated sludge units heated digestion tanks.

The combinations of treatment can be represented by the following Table :

Type of Treatment	City	
	A	B
NT.		
PT.		
ST.		

Evidently, there are nine possible combinations of treatment as shown in Table I.

TABLE I

Combinations of Types of Treatment for Cities A and B

Treatment	City	
	A	B
1	NT	NT
2	NT	PT
3	NT	SS
4	PT	NT
5	PT	PT
6	PT	ST
7	ST	NT
8	ST	PT
9	ST	ST

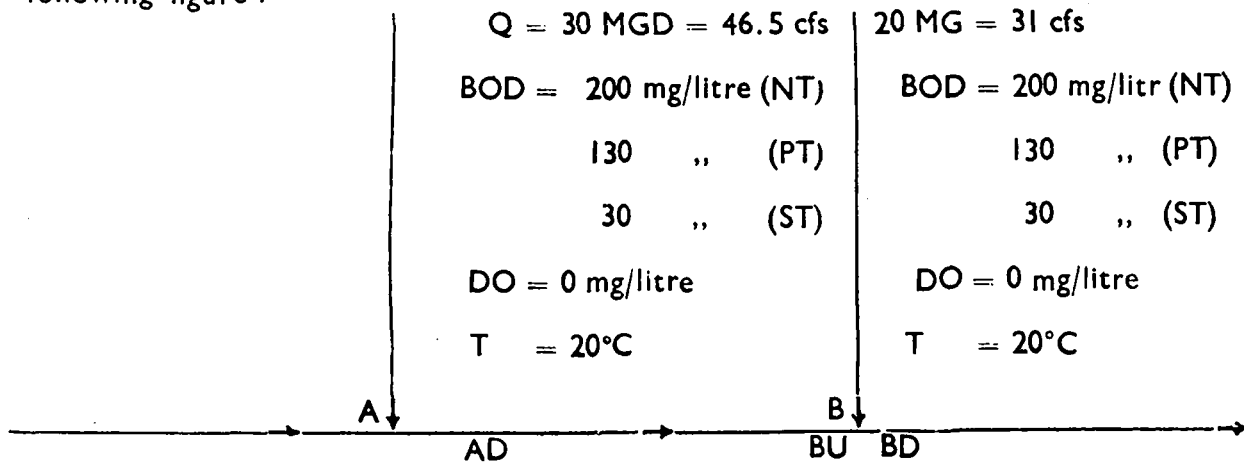
Assuming that there is 35% and 85% BOD reduction after PT and ST respectively, then the BOD of the sewage from PT Plant.

$$= 0.65 \times 200 = 130 \text{ mg/litre}$$

of the sewage from SS plant

$$= 0.15 \times 200 = 30 \text{ mg/litre}$$

The BOD, DO, temperatures and flow rates of the system are shown by the following figure :



Q = 300 cfs
 BOD = 1 mg/litre
 DO = 9.2 mg/litre
 D = deficit = 1 mg/litre
 T = 15°C

Q = 346.5 cfs
 T = 15.7°C

Q = 377.5 cfs
 T = 16.1°C

The analysis of DO budget of the river water for the various treatments is tabulated in Table 2.

TABLE 2
 Dissolved Oxygen (DO) Budget for River Water Calculation

Treatment (see Table 1)	AB									BC	
	DO _{AD}	BOD _s (y _s) _{AD}	L _{AD}	K ₁	K ₂	t _c	x _c	D _{BU}	DO _{BU}	DO _{BD}	D _{BD}
1.	8 mg/l	27.7 mg/l	35.6 mg/l	0.174/day	0.63/day	2.45/day	177 miles	5.7 mg/l	4.3 mg/l	3.9 mg/l	6.0 mg/l
2.	"	"	"	"	"	"	"	"	"	"	"
3.	"	"	"	"	"	"	"	"	"	"	"
4.	"	18.3 mg/l	23.5 mg/l	"	"	2.24/day	107 miles	4.08 mg/l	5.9 mg/l	5.4 mg/l	4.5 mg/l
5.	"	"	"	"	"	"	"	"	"	"	"
6.	"	"	"	"	"	"	"	"	"	"	"
7.	"	4.9 mg/l	6.3 mg/l	"	"	1.72/day	83 miles	1.8 mg/l	8.2 mg/l	7.5 mg/l	2.4 mg/l
8.	"	"	"	"	"	"	"	"	"	"	"
9.	"	"	"	"	"	"	"	"	"	"	"

TABLE 2 (continued)

Treatment	BC							
	(y_0) _{BD}	L_{BD}	K_1	K_2	t_c	X_c	D_c	DO_c
1.	36.8 mg/litre	61.3 mg/litre	0.182/day	0.637/day	2.13 hr.	102	11.8 mg/litre	—
2.	31.1 mg/litre	51.7 mg/litre	..	..	1.99 hr.	96	10.3 mg/litre	—
3.	22.8 mg/litre	38.0 mg/litre	..	..	1.64 hr.	79	8.03 mg/litre	1.92 mg/litre
4.	29.6 mg/litre	49.3 mg/litre	..	..	1.95 hr.	94	9.85 mg/litre	0.05 mg/litre
5.	24.2 mg/litre	40.2 mg/litre	..	..	1.72 hr.	83	8.38 mg/litre	1.57 mg/litre
6.	15.9 mg/litre	26.5 mg/litre	..	..	0.90 hr.	43	6.41 mg/litre	3.54 mg/litre
7.	20.0 mg/litre	33.4 mg/litre	..	..	1.43 hr.	68	6.63 mg/litre	3.32 mg/litre
8.	14.3 mg/litre	23.8 mg/litre	..	..	1.76 hr.	84	4.93 mg/litre	5.03 mg/litre
9.	6.1 mg/litre	10.1 mg/litre	..	..	0.75 hr.	36	2.50 mg/litre	7.47 mg/litre

From Table 2, it can be seen that treatments 6, 7, 8 and 9 can be considered for comparison. The cost analysis for these treatments are shown in Table 3.

TABLE 3

Cost Estimates* for Wasterwater Treatment Works

Treatment	Cost*
6 City A, PT. City B, ST.	$35 \times 10^{3/4} \times 30,000^{2/3} \times 47 + 10 \times 20,000^{3/4}$ = Dollars 981,260
City A, ST. 7 City B, NT.	$47 \times 10 \times 30,000^{3/4} = \text{Dollars } 1,306,600$
City A, ST. 8 City B, PT.	$47 \times 10 \times 30,000^{3/4} + 35 \times 10^{3/4} \times 20,000^{2/3}$ = Dollars 1,451,960
City A, ST. 9 City B, ST.	$47 \times 10 \times 30,000^{3/4} + 47 \times 10 \times 20,000^{4/3}$ = Dollars 2,097,140

*Cost estimate as of 1965 (7)

for PT = $35 \times 10^{4/3} P^{2/3}$

ST = $47 \times 10 \times P^{3/4}$, Where P = Population.

From Table 2, treatments 8 and 9 produce desired DO results, however, the cost of treatment 9 is relatively high from Table 3, and should not be used for economical reason.

The lowest cost is treatment 6, but this treatment produces DO_e slightly lower than the desired level. If this scheme is adopted, the sewage from city A, where PT is used, needs chlorination or other remedial measures such as artificial aeration, temporary storage, etc., at low river flow.

River and wastewater system planning is an art. The only way to develop and improve one's mastery of this art is to study the fundamentals of modelling and to practise and compare. There is an excellent chance that the information derived from the system analysis will prove very useful to the overall planning and decision-making process.

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