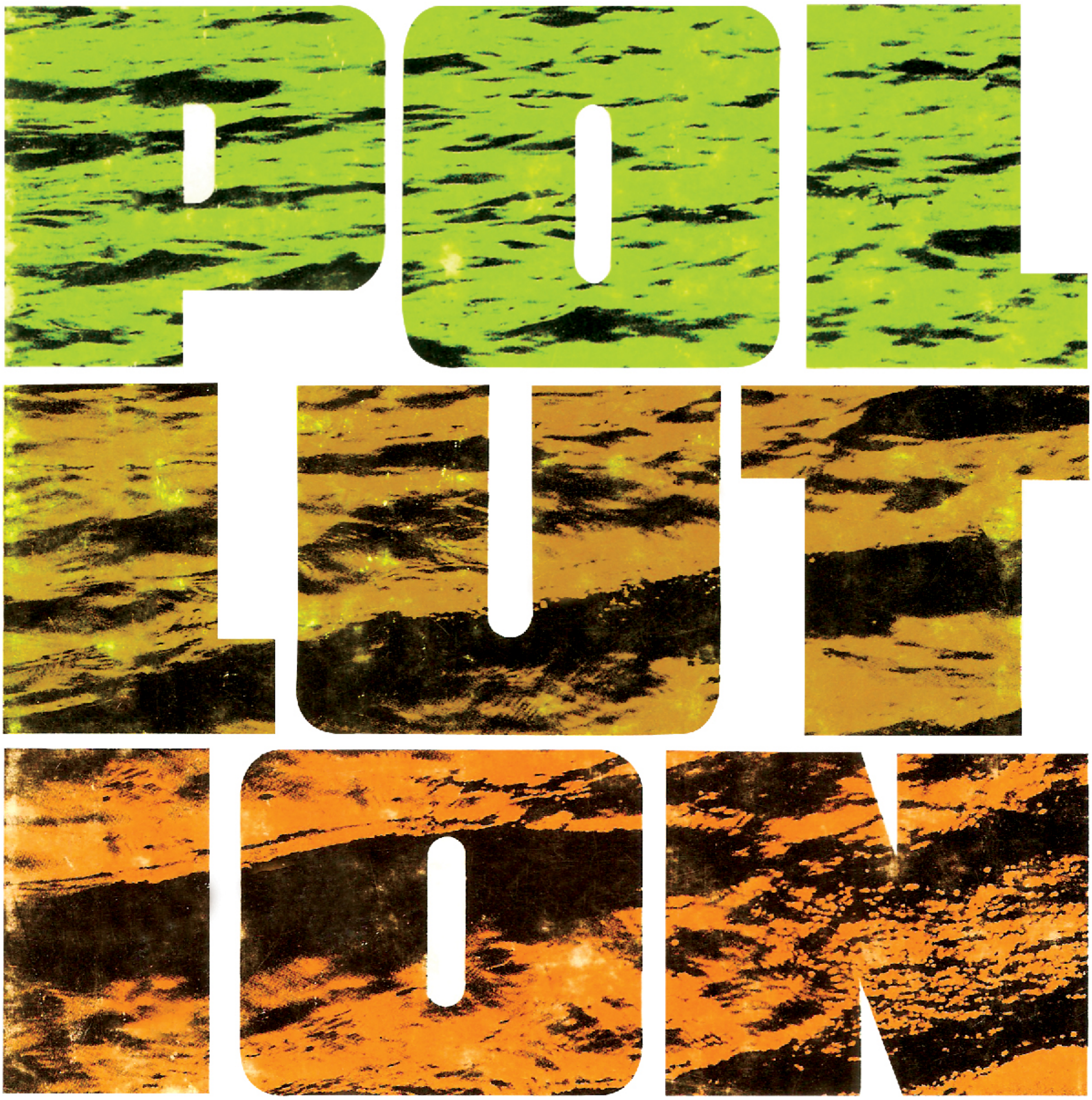
advances in

WATER POLLUTION RESEARCH

Proceedings of the 6th International Conference held in Jerusalem, 1972

Edited by S.H.JENKINS



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WATER POLLUTION RESEARCH

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Proceedings of the Sixth International Conference held in Jerusalem June 18-23 1972

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S. H. JENKINS

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FOREWORD

The 71 papers published in this volume represent those selected by the Programme Committee of the International Association on Water Pollution Research for discussion at the Jerusalem Conference out of the 176 completed papers that were submitted. Attention is drawn to the fact that each of the papers offered was adjudicated by five referees drawn from different countries and their assessments provided the basis of selection. The choice of papers for the Conference was therefore made by a system which is quite as thorough as that used for the selection of papers for the International Association's Journal "Water Research". The International Association would like to take this opportunity of recording its appreciation of the assistance that has been rendered by all the referees in the selection of papers.

In view of the Association's policy to publish in the Proceedings only those papers that were selected for discussion, the referees were also requested to assess the suitability for publication in Water Research of all the papers that were submitted for the Conference. A proportion of those not included in the Conference Proceedings were recommended for publication and some of these, with the consent of the authors, will appear in Water Research in due course.

The International Association on Water Pollution Research is indebted to the publishers, Pergamon Press Ltd., who have made every effort to include authors' last minute alterations to their texts so as to reduce corrections and amendments to papers to a minimum and who have delayed publication of the Proceedings in order to include discussions that were delayed in arrival.

The Israel Host Committee by their efficient organization of the Jerusalem Conference and the provision of editorial office facilities greatly contributed towards the successful presentation and discussion of papers and particularly in the collation of discussions.

In the order in which the sessions were held the Session Chairmen were:- R. Canham, USA., N.E. Cooke, Canada., G.R. Rivas-Mijares, Venezuela., W.J. Weber, USA., S. Arlosoroff, Israel., C.H. Plümer, FRG., L. de W. Henry, Australia., W.H. Wiseley, USA., N.de Baenst, Belgium., R.P. Mathur, India., G.R. Rivas-Majares, Venezuela., F. Josa, Spain., R.D. Sylvester, USA., I. Zohar, Israel., W.A. Murray, South Africa., O. Jaag, Switzerland., G. Jamme, France., A. Wiener, Israel., E. Kuntze, FRG., E. Balasha, Israel., A. Shemtov, Israel., E. Vasseur, Sweden., B. Bergmann-Paulson, Norway., G. Rousse, France., S. Iwai, Japan., J.P. Lagnesse, USA., K.J. Lunn, USA., S. Kishoni, Israel., H.J. Eggink, Netherlands., M. Fleisher, Israel., T.E. Larson, USA., Mrs. O.D. Brockett, New Zealand., A. Sorathesn, Thailand., K. Mudrack, FDR., G. Ainsworth, U.K.,

The Editor's thanks are due to authors and discussors for their acceptance of his amendments to manuscript. He would also like to place on record the appreciation of the International Association on Water Pollution Research to the Upper Tame Main Drainage Authority for the facilities it has provided and to Miss I.M. Herrick for her continued service as editorial secretary.

It is a pleasure to recognise the assistance that has been given by Mr. J. Ian Waddington, Clyde River Purification Board, in compiling the index and to the Chairman of that Board, Councillor D.M. Wardley, J.P., D.L., for permitting the facilities of the Board to be used for the purpose.

In addition to the 71 papers and the discussions that are printed in this volume a further 26 papers were prepared by invitation of the Programme Committee. These papers and all the discussions that resulted from their presentation have been published separately under the title "Management and Pollution Control Problems (Jerusalem Workshop Papers)" as volume 3 of a new series of publications by Pergamon Press Ltd., on behalf of the International Association on Water Pollution Research. This new series, "Progress in Water Technology", will in future include the proceedings of Workshop Sessions at the biannual conferences in addition to the proceedings of specialised conferences and books on special subjects written on the invitation of the International Association on Water Pollution Research. Volume 1 in this new series is "Applications of New Concepts of Physical-Chemical Wastewater Treatment (Nashville Conference), and volume 2 is "Phosphorus in Fresh Water and the Marine Environment (London Conference), and volume 4 entitled "Toward a Unified Concept of Biological Waste Treatment (Atlanta City Conference) will appear in 1973.

S.H. Jenkins
Chairman of the Programme Committee
and Executive Editor

ACKNOWLEDGEMENTS

The Israel Host Committee headed by Dr. G. Shelef worked unsparingly to arrange every detail so that the Conference could proceed in a smooth and efficient manner. Special mention must be made of the superb work done by the Conference manager, Mr. G. Rivlin, Director of Kenes-Organisers of Conferences and Special Events Limited together with his devoted assistants Mrs Elana Shapiro and Mrs Katrin Tchechik. Mrs. Ruth Tamar, Conference Secretary, applied her usual skills in helping to see to it that all things were arranged properly and ran smoothly. Many other people contributed actively to the successful organization of the Conference and it would be impossible to mention them all but their efforts are nonetheless fully appreciated and acknowledged.

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OPENING ADDRESS TO THE SIXTH INTERNATIONAL CONFERENCE ON WATER POLLUTION RESEARCH

BINYANEI HAOOMA – JERUSALEM – JUNE 19, 1972

PROFESSOR HILLEL I. SHUVAL
Conference President

CHALLENGES FOR THE FUTURE IN WATER QUALITY MANAGEMENT

Since the first Conference of the International Association on Water Pollution Research a decade ago in London, our organization has truly circled the globe, having held conferences in Tokyo, Munich, Prague, San Francisco and Hawaii, and now completing the cycle here in Jerusalem. In many ways this is symbolic since Jerusalem, one of the world's most ancient cities, has struggled to solve problems of water for some three thousand years. Here one can find the remains of marvellous ancient water engineering works side by side with the most modern developments in water technology. Israle is mainly a semi-arid country, but the vision of plentiful flowing water sources has been echoed from the earliest of times. The prophet Isaiah yearned: "... for in the wilderness shall water break forth and there shall be streams in the desert ..." (Isaiah 35, 6).

A few kilometers from this building where we sit today, the water engineers of King Hezekiah some 2,700 years ago, laid out a complex subterranean water supply tunnel dug in solid rock, bringing living water from the Gihon spring into the walled city of Jerusalem. This water supply tunnel functions to this day. The crowning glory of the ancient Israeli water engineers of two thousand years ago was the construction of an intricate system of aqueducts, tunnels and siphons bringing water to the city over a distance of seventy kilometers with some two-hundred thousand cubic meters of capacity in storage reservoirs. Following in this ancient tradition of water engineering, modern Israeli engineers have drilled thousands of wells, built reservoirs and have transported water by aqueduct and pipeline hundreds of kilometers from the Jordan River in the north to the parched deserts of the south, fulfilling the vision of Isaiah of bringing streams of water to the desert – to make it bloom.

The problem that we shall be dealing with at this Conference is the protection and maintenance of the quality of our vital water resources. A paradox of modern technological society is that more and more water is required as populations grow and the standard of living increases, resulting in greater and greater withdrawals from ground and surface sources. With the growing urban and industrial use of water, greater amounts of organic and inorganic wastes are spewed back into the water sources so that less and less pure water becomes available at the quality required as a result of the self-destructive process of pollution.

By the time one of Europe's major rivers, flowing from its sources in the mountains reaches the sea, its entire flow may be almost wholly made up of water used once or more times by upstream cities. Six million people draw upon this river as their main source of water supply. How long may we continue at this pace? Will all of the surface waters of the world eventually face this fate?

Another paradox of our modern technological world is the fact that our society "is hooked" on the use of a vast array of agricultural chemicals and fertilizers to ensure the plentiful food supply for our growing population. But some of these essential chemicals are polluting our water resources or leading to unexpected ecological imbalances. The situation has reached almost crisis dimensions in Israel, a country which is presently utilizing almost all available ground water. Nitrate levels have been increasing at the rate of two milligrams per liter per year for the past fifteen years and today some five hundred wells already show nitrate concentrations equal to or above the standard recommendation for drinking water by the World Health Organization. It appears from research results which will be presented at this Conference by an Israeli scientist, that the very high use of inorganic fertilizers rich in nitrogenous chemicals may be a major factor in this type of ground water pollution. Can we find a solution to this problem which will both provide protection of ground water while maintaining the right level of food production essential to our existence?

Not all water pollution is a result of the disposal of urban and industrial wastes into the environment. The buildup of naturally occurring inorganic salts in the aquifer as a result of incautious water resources management could in some cases provide an extremely serious threat of water pollution, particularly in arid zones. Heavy pumping of ground water coupled with intensive irrigation practises could cause this problem. While substantial amounts of water are lost by evaporation in irrigation practise, the dissolved salts are completely returned to the aquifer resulting in a slow buildup of minerals in the ground water. Here in Israel, this increase amounts to a few miligrams per liter per year. The full impact will be felt only in twenty or even fifty years from now, by which time major portions of our ground water may no longer be suitable for agricultural or domestic use. Do our water quality management programs face up to the severe implications of such creeping water pollution, or will we pass this problem on to the next generation when it may be too late to reverse the process?

It would be a disservice to our profession to imply that we are recklessly riding an uncontrolled path to total pollution of our water resources and that nothing is being done to reverse this trend. At this Conference we shall emphasize not only the new and often ingenious technology developed in our research institutes aimed at overcoming the problems of pollution, but the real accomplishments achieved with the aid of these innovations. Many of the papers to be presented here this week will report on real progress.

An outstanding example is the paper of Gameson and his colleagues of the U.K. They report on the dramatic improvements in the Thames River over the past twenty years. In 1950, a reach of some thirty-five kilometers of the river was at times devoid of oxygen and fish life was extinguished, while today after major investments in modern wastewater treatment, the river is entirely aerobic once again and more than fifty species of fish inhabit this rehabilitated waterway. From the other end of the world, Fujiki of Japan will report later this week that Minamota Bay – once heavily polluted with deadly mercury wastes has been cleaned up by the construction of plants to remove mercury from industrial wastewater and by technological changes in other plants which avoid the use of mercury entirely. Fish caught in the bay in 1961 showed mercury concentrations of 23 mg/kg, more than forty times the concentration considered safe for human consumption. By 1970, only 0.2 mg/kg of mercury was found in the fish of that once ill-fated bay. This is well within safe limits.

We all rejoice in these historic accomplishments which have been achieved by the co-operative efforts of research scientists and practical engineers who actually went ahead and did the job.

May this Conference serve as a turning-point in the successful campaign to reduce the pollution of our water environment. Let us learn not only to warn of the dangers of uncontrolled pollution, but to point to the successes that can result from the planned and judicious application of our research efforts. Nothing breeds success more than success itself.

With a growing shortage of water in many parts of the world, we will be seeking new sources of water supplies. Can we afford to throw away a vital resource such as water that has been used only once and is still 99.9% pure water? Engineers talk freely of the utilization of seawater, but it is worth noting that seawater contains thirty times more contaminants than municipal wastewater. Israel is one of the few countries in the world that is already utilizing almost all of its ultimate, natural water resources and must look for maximum conservation of its existing supplies. We are already renovating 25% of our urban wastewater for agricultural and industrial purposes. The challenge of the future will be to develop systems to purify wastewater so that they will be safe for unlimited urban use. This issue will be discussed at some length at this Conference.

This international Conference with representatives from thirty-five countries from all continents, from various political, social and economic systems, is symbolic of the role that science and scientists can play in breaking down the barriers of communication that are sometimes artificially placed in our way. The free exchange of ideas is a sine-qua-non for peaceful co-operation of the type that is necessary to assure the proper management of the quality of the world's water resources. Many of the major rivers of the world pass through three or four countries on their twisting path to the sea. Only the most exacting co-operation among the nations sharing the use of the river can guarantee that the maximum benefit can be derived for all concerned. The seas are shared by all nations and here only full international control can prevail in preventing their degradation. May I add that our own region could benefit immeasurably by peaceful co-operation among the nations of the area in developing the limited water resources and to take the measures necessary to prevent their pollution and preserve their quality. May this Conference provide the forum for the meeting of the minds necessary to achieve such true co-operation among nations.

Our profession is called upon to provide scientific answers to the current and future problems involved in preserving the quality of our water. However, technology is not enough. We must guide our administrators and statesmen as to the optimal application of the new technology capable of preventing the deterioration of the environment. On the one hand, insufficient preventive action today may lead to irreversible damage that cannot be corrected at any price in the future. On the other hand, an irrational use of limited financial resources today to achieve unreasonable goals such as a level of absolutely zero pollution as has been recently proposed by some influential ecologists, may lead to a state of disenchantment or even revolt among the public who have so far enthusiastically supported environmental improvement programs. Will they blindly support expenditures to achieve an exaggerated degree of environmental pollution control at the expense of other worthwhile social needs such as housing and education? Concepts of costs and benefits and maximum social gain must be introduced into our formula for improving the environment.

The task that lies ahead is not an easy one and no single mathematical formula will provide the answer to the complex problems of science and society as far as the management of man's environment is concerned. Here I can only suggest a philosophy which I have found useful in my own career of public service: an eminent British scholar suggested these thoughts as a guideline for the public servant: "Give me the strength and fortitude to change those things which can be changed – the patience and peace of mind not to attempt to change those things that cannot be changed – the good judgement and wisdom to tell one from the other . . ." May this Conference provide us with improved knowledge of how to protect our environment for the betterment of man and the wisdom required to guide ourselves and our leaders on the rational use of this new science and technology so as to achieve the most beneficial social gains for mankind from our efforts.

WHAT PRICE - WATER POLLUTION CONTROL

ABEL WOLMAN
The Johns Hopkins University, Baltimore, Maryland

It is axiomatic that water pollution, in its popular connotation, is sinful. In the climate of public discussion, in the last ten years, the term "pollution" has taken on an absolute character in place of its relative nature. To the specialist, pollution is related to what, where and how. Since water is never static, its ingredients, even without the impact of man and his works, have always been varied. When we speak, therefore, of pollution, it becomes necessary to quantify, to define, and to assess positive and negative values of corresponding methods of abatement.

To the professional, these tasks are complex. To the layman, they are simple – water should be of pristine purity and its ingredients should be zero. The price or the value of these political dicta necessarily places the members of this group in an uncomfortable situation of choosing between supporting the unwise or struggling to maintain the logical. Temptation is always high to bend with the winds of political doctrine, particularly when we have spent a century trying to spark public interest in our discipline. Suddenly, that interest is dominant, even if at times hysterical. Are we then to temper this burst of enthusiasm to re-make the environment in the image of distilled water? The challenge is real. The risk is even greater if that challenge is not discerned and the decision how to meet it is not equally clear. The indecision, so far characteristic of our stance, may result in our being trampled under the charge that we are ecologically immature, are in the eternal business of destroying nature, or are slow in disclosing or implementing sane correctives.

ON OBLIGATIONS

The debate is old as to whether a good end justifies a bad means. Some have recently contended that falsifying scientific data may be justified, if the ultimate purpose is for the common good. The late Leo Szilard has been quoted as suggesting: "don't lie, if you don't have to." De Toqueville, on the other hand, had long maintained that the intellectual's guidance has been very limited in determining public behavior. In general, that behavior has been simplistic, gross and often contradictory.

In such conflicting dilemmas, where should we sit? In my own mind, our position is clear – it is on the side of honesty, logic and wisdom. Our purpose should be to disclose scientific verity, to develop sound technologic implementation, to provide alternative solutions, to clarify choices, and to list tangible and intangible costs and benefits. All of these obligations need to be met to be most useful to society and its political mentors. The politican-statesman, of course, ultimately determines public policy – sometimes wisely and sometimes contrary to the scientists' myopia. Our task remains, however, one of illumination of issues and choices. This has not always been our universal position. The ecologists' contribution has certainly extended the depth and breadth of our horizons, in spite of their tendencies, on occasion, to over-emphasize the evils of science and technology.

This Conference gives us an opportunity to rehearse the considerations which should guide us in making our best contribution to the health and welfare of society. A few months ago, Dr. H. E. Stokinger, in the United States, presented several guidelines for investigators. Parenthetically, Dr. Stokinger is the chief of the Laboratory of Toxicology and Pathology of the National Institute for Occupational Safety and Health, of the United States Department of Health, Education and Welfare. He dignified his suggestions in a series of commandments,* as follows:

"1. Standards must be based on scientific facts, realistically derived, and not on political feasibility, expedience, emotion of the moment, or unsupported information.

"2. All standards, guides, limits and so on, as well as the criteria on which they are based, must be completely documented.

"3. Avoid the establishment of unnecessarily severe standards. This admonishment runs against the current tide of boiling popular enthusiasm for cleaning up pollution completely. But it is time that popular enthusiasm cool down, to recognize the consequences of establishing goals instead of standards.

"4. Determine realistic levels.

"5. Interpret the 'Delaney clause' with informed scientific judgment. This much maligned clause has become an excuse for oncologists to use inappropriate and unrealistically high levels in testing for carcinogenic potential.

"6. Determine trends, not pro tempore monitoring. The most flagrant violations of this commandment are the recommendations . . . regarding mercury . . . One moment's reflection would reveal that the concentration of mercury in the oceans has not changed perceptibly since the white men reached these shores, and that men have eaten these fish and lived and died without signs or symptoms of mercury poisoning. This is not to say that local, aqueous mercury or other excess pollutants should not be spotted, and, when possible, controlled, but that the thoughtless and irrational extension of a local finding to global dimensions is inconceivable in persons of sound mind!

"7. Delimit banning. . . . The banned food additives were either unnecessary or could be readily substituted with less harmful substances. Not so the totally banned DDT† and alkyl mercury compounds. First, DDT does not present an 'imminent hazard' to public health, despite misstatements to the contrary; second, its use for controlling the spread of malaria and African trypanosomiasis is unexcelled, and equivalent substitutes are not available at this time."

To these precepts, other cautions should be recorded. It is unfortunate that rarely are the consequences of decision making so set forth as to make clear, not only monetary costs and benefits, but the far more subtle resultants. Remote and intangible consequences are rarely assessed, because these so often lend themselves to exaggeration both for good and evil results. For example, the purification of water is often in a low cost category, while the processes for waste treatment of very high efficiency are more expensive. Choices between them are too often determined by emotion rather than by reasonably familiar quantitive parameters.

Similarly, threats of economic disaster due to abatement measures and costs are

*H. E. Stokinger. How to Achieve a Realistic Evaluation. Science, 174, 662-665 (November 12, 1971). Jour. American Water Works Association, 64, No. 4 (April 1972).

†The ban has so far been lifted by the Environmental Protection Agency. (A.W.)

perennially debated. Estimates of such debacles vary widely, depending upon who makes them and for what ends. Yet impartial evaluations are increasingly required in order to determine the economic consequences of political action. In this area of activity, our members have a high responsibility for intelligent input, provided they can maintain some kind of intellectual equilibrium in the modern maelstrom of environmental excitement.

The program this week is illustrative of both the positive and the negative contributions of which we speak. The workshops cover wide ranges of significant topics. The public defender, looking over our shoulders, however, might well find it difficult to discover relevance, to determine priority and to evaluate direct and indirect social costs and benefits. One might argue, of course, that these determinations are not within the purview of our assigned purpose or of the disciplines here engaged. The omissions need to be noted, even if perpetuated, because already rumblings regarding the balancing of equities may be detected in various quarters.

In many countries, officials, responsible for public and private expenditures, complain that the lists of research undertakings are not only great in number, but most often lacking in delineation of relative importance or priority. Hundreds of areas of exploration are noted, often with the tacit assumption that all the inquiries are of equal weight and necessity. It is easy to understand why this is so. Every investigator, if he is worth his salt, has his own set of "articles of faith", whether engineer, biologist, chemist, or economist. There should be room, somewhere in this assembly, to debate the merits of short and long range relevance, tangible and intangible costs and benefits, and good and bad externalities.

One of these contradictions is strongly brought to mind as an immediate consequence of the Stockholm meetings. Simply stated, the basic questions are whether pollution is in fact global in nature, whether waters are worse in quality today than 20 years ago, and whether universal monitoring is necessary or not. Are answers to these salient questions part of our deliberations this week? One might raise reasonable doubts as to each of these significant questions. Answers to all of them are already erroneously embedded in the current political literature.

Global pollution, with some important exceptions, is probably not demonstrable. Universal deterioration of waters over past decades is likewise subject to considerable question. Unfortunately, with the exception of recent studies in the United States* and England,** documentation is rare on this score. The studies need to be widely, geographically extended.

Of even greater importance to this group is to engage in a realistic appraisal of the significance of our activities in relation to the problems and policies of the populations of two-thirds of the world. How far, how fast, and how costly are the research findings applicable to developing countries? Is universal implementation desirable and at what price in those countries hungry for moving upward by agricultural and industrial expansions? Are unadjusted standards and goals, now appropriate to developed countries, applicable to the rest of the world? Again, the agenda are relatively bare on these pressing political issues.

*M. Gordon Wolman. The Nation's Rivers. Jour. Water Pollution Control Federation, 44: 5 (May 1972), pp. 715-737. Science, 174: 905 (November 26, 1971).

**Report of a River Pollution Survey of England and Wales, 1970, Volume 1. Her Majesty's Stationery Office, 1971. London, England.

The sheer comprehensiveness of our interests and tasks makes selectivity difficult. It has been said, with some truth, that comprehensiveness of plan stands in the way of quanta of implementation. On a broader scale, in some countries the peculiar situation has developed where action is at least temporarily stalled while waiting for total environmental impact coverage and diagnosis. For developing countries, this restraint is a source of increasing concern.

Even at the risk of sermonizing, this occasion appeared an appropriate one at which to suggest modest undertakings in post-auditing our activities, and in stock-taking of our future objectives and goals. In these days of suspicion of science and technology – in the recent colorful semantics of "the careless technology" – our precepts may well be examined, without indulging in self-flagellation! In so doing, the highly pertinent conclusions reached in the United Nations Conference at Founex, Switzerland, just one year ago, give valuable guidance.

"The major environmental problems of developing countries are essentially of a different kind. They are predominantly problems that reflect the poverty and very lack of development of their societies. . . . In both the towns and in the countryside, not merely 'the quality of life', but life itself is endangered by poor water, housing, sanitation and nutrition, by sickness and disease and by natural disasters."*

The quest for pure water is centuries old. The definition of purity has gone through continuous up-grading, until, in fact, truly tailor-made water is the product. In this practice, social choice has been a dominant factor. The guidance and implementation of such choices remain our primary responsibility.

*Development and Environment. United Nations Conference on the Human Environment. Founex, Switzerland. June 4-12, 1971.

THERMAL POLLUTION AND O_2 TRANSFER

STREAM TEMPERATURE RESPONSE TO THERMAL POLLUTION

V. NOVOTNY and P.A. KRENKEL*
*Dept. of Sanitary and Water Resources Engineering,
Vanderbilt University, Box 1670 – Station B, Nashville, Tennessee 37203, U.S.A.

INTRODUCTION

It is expected that by the year 2000, the production of electric energy in the United States will be about nine times that of 1970. Both fossil fuel and nuclear power plants require large amounts of cooling water for the dissipation of waste heat, the latter discharging the greater amount of heat on an equivalent capacity basis. Because of the relatively low thermal efficiency of either type of thermal power station, the larger part of the heat produced is released through the cooling system into the aquatic and atmospheric environment. Resulting increased temperatures in the receiving water may have harmful effects, such as a shift in population of the ecosystem, death of aquatic organisms beyond certain limiting temperatures, decreased waste assimilative capacity, etc.

It is obvious that this problem requires immediate attention, and furthermore, that all consequences of heated water discharges should be investigated. Major considerations are the determination of river assimilative capacity for heat, the thermal behavior of water in rivers, and the response in water temperature that can be expected from added waste heat with respect to certain meteorological conditions.

BASIC TEMPERATURE RELATIONS IN STREAMS

Although heat transfer in flowing waters differs in some respects from that occurring in lakes and reservoirs, it has been common practice to apply the results obtained in studying evaporation and heat transfer in lakes (e.g. the classical Lake Hefner Study – U.S. Geological Survey – 1954) to those in streams. The following simple comparison demonstrates significant differences between heat dissipation and evaporation in lakes and rivers:

Lakes	*Rivers*
Little turbulence in water body	High degree of turbulence
Lower turbulence level at water surface	High degree of turbulence at water surface
Water body is thermally stratified	Minimal thermal stratification
Low degree of uniformity	High degree of uniformity

Topographical differences
Size difference

The equation describing heat transfer in rivers can be written as:

$$\frac{\partial T}{\partial t} - D_L \frac{\partial^2 T}{\partial x^2} + U \frac{\partial T}{\partial x} - \frac{\alpha}{H}(T_s - T) - \frac{Q_s}{H \rho_w C_p} = 0 \qquad (1)$$

where D_L is longitudinal mixing coefficient, H is the depth of the flow, a is a surface renewal coefficient, U is the velocity of flow, T is the bulk temperature, T_s is the surface temperature, Q_s is the short wave radiation input, ρ_w is the density of water, C_p is the heat capacity at constant pressure, t represents time, and x is distance.

Equation (1) is based on the assumption that energy inputs at the air-water interface consist of the components depicted in Fig. 1 and described by Equation (2) as follows:

$$\Delta Q = Q_s - Q_{rs} - Q_a - Q_{ra} - Q_b - Q_e - Q_h - Q_w \qquad (2)$$

where:

Q_s = the rate of heat flow into a control volume from solar radiation,
Q_{rs} = the rate of heat flow out of the water surface, or the reflected solar radiation,
Q_a = the rate of heat flow into the surface layer from atmospheric radiation,
Q_{ra} = the rate of heat reflected from the water surface, or the reflected atmospheric radiation,
Q_b = the rate of heat flow from the water surface by back radiation,
Q_e = the evaporative heat loss from the water surface,
Q_h = the rate of heat loss by conduction at the air-boundary layer,
Q_W = the rate of heat flow by surface layer renewal.

In addition, it is assumed that only short wave radiation can penetrate into the water body. Other heat inputs contribute only to surface heating, the heat of which is then transferred into the main body of the water by the turbulent surface renewal phenomena.

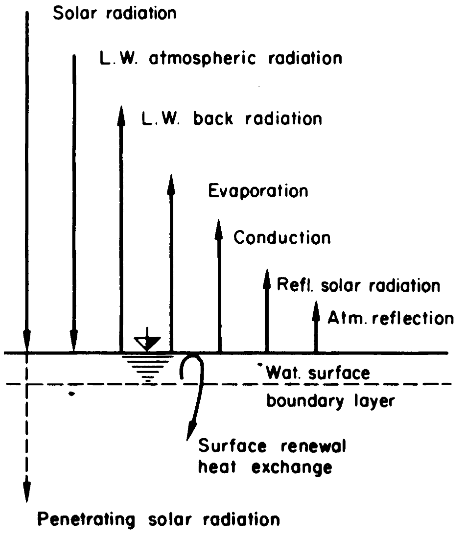

Fig. 1. Heat energy inputs at the air-water interface

SURFACE TEMPERATURE COMPUTATIONS

The surface temperature differs from that of the main bulk of the water, the difference being possibly as much as several tenths degrees celsius. Using an energy budget approach, the surface temperature can be calculated by assuming that $\Delta Q = 0$ at the boundary interface. Then,

$$Q_a - Q_{ra} - Q_b - Q_e - Q_h + \frac{\partial Q_s}{\partial y}_{air} \delta_{air} = Q_w + \frac{\partial Q_s}{\partial y_{wat}} \delta_{wat} \quad (3)$$

In the air boundary, $\partial Q_s/\partial y \to 0$ and in the water boundary layer, $\partial Q_s/\partial y = Q_{s(H)} (1-e^{-\eta \delta_w})$, where Q_s (H) is the solar radiation reaching the water surface, η is the extinction coefficient of short wave solar radiation in water, and δ_w is the thickness of the water surface boundary layer.

It has been found that with a high degree of accuracy, the long wave radiation input, evaporative energy input, and head conductivity input can be approximated as follows (Novotny, 1971).

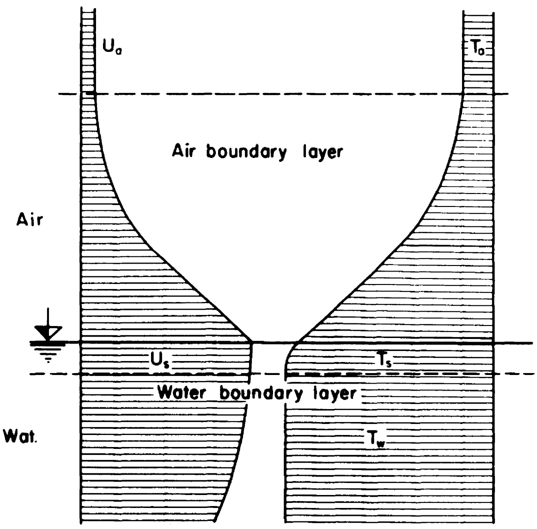

Fig. 2. Temperature and velocity distribution at the air-water interface

Total long wave radiation flux: All equations describing the long wave radiation input at the boundary are based on the Stefan-Boltzman fourth power radiation law and are quite similar. It is possible to combine equations and approximate the net long wave radiation input by:

$$\Delta Q_a = Q_a - Q_{ra} - Q_b = A_a + B_a (T_A - T_S) + C_a T_A \quad (4)$$

where:

$A_a = 695.04 \quad (\beta - 0.874) \quad \text{cal cm}^{-2} \text{ day}^{-1}$
$B_a = 11.42 \quad \text{cal cm}^{-2} \text{ day}^{-1} \text{ °C}^{-1}$
$C_a = 10.18 \quad (\beta - 1.123) \quad \text{cal cm}^{-2} \text{ day}^{-1} \text{ °C}^{-1}$

β is a coefficient accounting for cloud cover and humidity as defined by Raphael (Raphael, 1962), and T_A is the air temperature.

Evaporation: Knowing the relative humidity, f, and the air temperature, T_A, the evaporative heat flux can be approximated as follws:

$$Q_e = A_e + K_e (T_s - T_A) \tag{5}$$

where:

$A_e = 0.625 \ h_r e^{0.0625 \ T_A} (1-f) \quad \text{cal cm}^{-2} \text{ day}^{-1}$
$K_e = 0.0166 \ h_r e^{0.0625 \ T_A} \quad \text{cal cm}^{-2} \text{ day}^{-1} \text{ °C}^{-1}$

Applying the Harbeck formula (Harbeck, 1962), the vapor transfer coefficient, h_r, can be computed from:

$$h_r = \frac{E\phi}{e_w - e_a} = 392 \ X^{0.1} \ U \tag{6}$$

Where X is a characteristic length expressed in meters, and U is a relative water surface velocity expressed in meters per second. For the velocity, U, the vector subtraction, $U = |\vec{U}_A - \vec{U}_S|$ is understood. In the preceding discussion, U_A is the air (wind) velocity, U_S is the water surface velocity, e_w is the saturation vapor pressure, e_a is the vapor pressure of air, ϕ is a conversion factor, and E is the evaporation rate.

Heat conduction in Air boundary layer: Since the Prandtl numbers for both evaporation and conduction are similar and follow the same laws, both processes have approximately the same transfer coefficients, or:

$$h_{vapor} \approx h_{heat}$$

In this case, the heat conductivity can be computed using the same transfer coefficient, or:

$$Q_h = h_{heat} \, \rho_A \, c_{pA} (T_S - T_A) = K_h (T_S - T_A) \tag{7}$$

where ρ_A is the density of air, and C_p is the heat capacity of air.

The surface renewal heat transfer: This factor can be approximated as

$$Q_w = \frac{\alpha \, \rho_w \, c_{pw}}{H} (T_S - T) = K_w (T_S - T) \tag{8}$$

The surface temperature then becomes:

$$T_S = \frac{Q_S (1 - e^{-\eta \delta w}) + A_e - A_e + T_A(B_a + C_a + K_e + K_h) + K_w T}{B_a + K_e + K_h + K_w} \tag{9}$$

Inserting Equation 9 into Equation 1 and defining a tentative base temperature, T_O, as

$$T_o = T_A + \frac{A_a - A_e + C_a T_A}{K_A} + \frac{Q_s(K_w + K_A)}{K_w + K_A} \tag{10}$$

where the overall air heat transfer coefficient is defined as:

$$K_A = B_a + K_h + K_e$$

One can obtain an equation describing the heat transfer as:

$$\frac{\partial T}{\partial t} - D_L \frac{\partial^2 T}{\partial x^2} + U \frac{\partial T}{\partial x} + \frac{K_w K_a}{H\, c_p \rho_w (K_w + K_A)} (T - T_o) = 0 \tag{11}$$

Since in turbulent streams, the magnitude of K_w is more than two orders of magnitude greater than K_A, the value of K_w has little influence on the process of turbulent heat transfer in streams, and the heat transfer coefficient can be simplified as follows:

$$K = \frac{K_w K_A}{H\, c_p\, \rho_w\, (K_w + K_A)} \approx \frac{K_A}{H\, c_p\, \rho_w}$$

APPLICATION OF THE MODEL TO A RIVER TEMPERATURE COMPUTATION

It is obvious that the general type of temperature equation, Equation 11, is also valid for describing the temperature occurring in streams under natural meteorological conditions. This enables one to relate the temperature increase due to a thermal pollution load to the natural temperature which would occur in the stream if no thermal pollution was present. Mathematically:

$$\frac{\partial (T - T_N)}{\partial t} - D_L \frac{\partial^2 (T - T_N)}{\partial x^2} + U \frac{\partial (T - T_N)}{\partial x} + K (T - T_N) = 0$$

Where T_N is a natural temperature with no thermal pollution.

In most engineering considerations, the heat load (e.g. from thermal power plants) is constant and $T_i - T_N$ = constant, where T_i is the initial temperature of the reach under consideration. It should be noted that this is a steady state condition only if the natural temperature is considered as being a base temperature and the only time varying input is the natural temperature. Thus, the time varying solution can be divided into two parts; (a) the time varying natural temperature, and (b) the steady state decay of $\Delta T = T - T_N$, which is superimposed on the naturally occurring temperature. Therefore:

$$T(t) = \Delta T_{ss} + T_N(t)$$

This approach differs from generally accepted practice, which uses the so-called equilibrium temperature as defined by Edinger and Geyer (1965). When the course of the natural temperature is known, computation of the heat load decay is quite simple, and a computation of the equilibrium temperature is not necessary. Since Equation 12 is generally valid, the methodology developed herein may also be applied to cooling ponds, etc.

The model was tested using both laboratory flume data and field measurements (Novotny, 1971). The results obtained were quite satisfactory as can be seen on Fig. 3, where the model was tested utilizing field data obtained on the Cumberland River below Wolf Creek Dam near Burkesville, Kentucky.

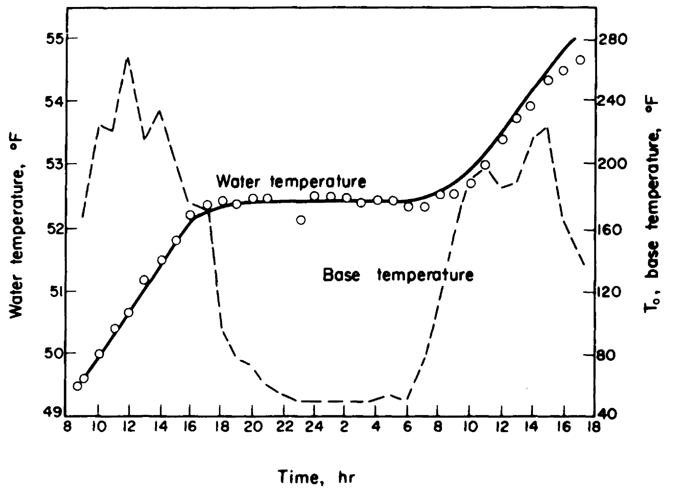

Fig. 3. Comparison of base temperature, T_o, and measured water temperature – Cumberland River – July 29-30, 1970
o measured values, —— predicted by the model

CONCLUSIONS

A mathematical model describing temperature changes in rivers was developed which takes the differences between stream flow and lakes and reservoirs into account. There are many basic differences between these two types of the heat transfer phenomena; the most significant one being the dynamic character of the air-water interface where both boundaries are moving.

The results of this investigation lead to the following conclusions:

(1) Since the surface renewal coefficient for the water boundary layer is several orders of magnitude greater than the exchange coefficients in the air boundary layer, the turbulence intensity in the water surface layer or in the water body has very little influence on the heat exchange rate between the water and the air. Therefore, in most cases, the heat exchange between air and flowing water is governed by the heat, vapor, and radiation exchange rate in the air boundary layer.

(2) The heat (vapor) exchange coefficient in the air boundary layer is to some extent dependent on a characteristic length of the boundary layer formation.

(3) The value of the heat (vapor) exchange coefficient in the air boundary layer is dependent on the vectoral subtraction of the wind and water surface velocities.

(4) The initial thermal load to the stream, $\Delta T_i = T_i - T_n$, may be assumed to be constant

during a certain time period. This assumption leads to the division of the equation of heat transfer in streams into two simultaneous equations, one describing the natural temperature and the other depicting the steady decay of the thermal load. If the behavior of the natural temperature is known, the entire computation is significantly simplified, even when the thermal load to the stream is not at a steady state condition. It is significant to note that costly and sometimes inaccurate measurements of cloud cover, solar radiation, and humidity are not necessary inasmuch as the overall heat exchange coefficient, K, is dependent only on wind velocity, stream surface velocity, air temperature and, to a lesser extent, on the area of the water surface.

ACKNOWLEDGEMENTS

This study was partially supported by the Environmental Protection Agency, under the auspices of the National Center for Research and Training in the Hydraulic and Hydrologic Aspects of Water Pollution Control at Vanderbilt University and by Vanderbilt University.

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Discussion *by* H. Fasoli, Italy

Attention is drawn to eq.8 which should read

$$\alpha \rho C_p = K_W \qquad 8')$$

from which eq. 10) becomes

$$T_O = T_A + \frac{A_a - A_e + C_a T_A}{K_A} + \frac{Q_S (K_W + K_A)}{K_W K_A} \qquad 10')$$

observing that eq. 10) is valid only if we put

$$Q_s (1 - e^{-\eta \sigma_w}) = O$$

and remembering that for the authors also $\left.\frac{\delta Q_s}{\delta y}\right|_{air} = O$

that means there is no solar radiation both in the air and in the water.

It seems right to criticize also the 5) taken from Harbeck jr and the 7).

Correlation between mass and heat transfer is expressed by the largely corroborated Chilton-Colbrurn's formula:

$$\frac{K}{U_\infty \cdot \rho C_p} P_r^{2/3} = \frac{h}{U_\infty} S_c^{2/3}$$

where U_∞ represents velocity at boundary layer limit and Pr and Sc are respectively the Prandtl's and Schmidt's numbers. K and h are, according to authors nomenclature respectively heat and mass transfer.

If Pr = Sc (as in the case of air-water) and if the flow condition is unique, Lewis' equation is valid:

$$\frac{K}{h} = \rho C_p$$

Then it will be written

$$Q_h = K (T_s - T_A) \; (7' \text{ and } Q_e = [\lambda + C_p (T_s - T_A)] \frac{K}{\rho C_p} (H_s - H_A) \qquad (5'$$

where λ is the heat of vaporization and H the humidity. It becomes (ever using author's nomenclature) $K_e = K_h$ so that $Q_h = K_h (T_s - T_A)$ seems to be computed twice: one in the 5) and once in the 7).

An important question to debate may be the starting mathematical model.

The authors' model may be represented in fig. 1

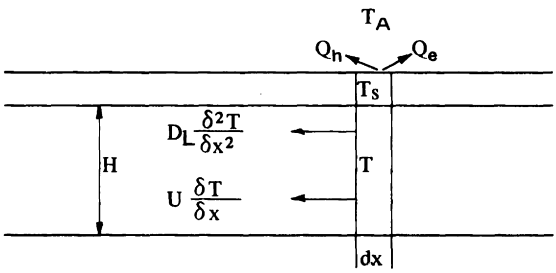

fig. 1

In this model it is supposed that in a cross section having a thickness dx there is a uniform temperature calculated supposing dynamic equilibrium among the over lying air, the boundary layers and the bulk of liquid.

As the authors later, in considering the natural temperature as the base temperature admit that this is the steady state condition, the term $\frac{\delta T}{\delta t}$ in the formula 1) may be cancelled.

In this case we can consider another model represented in fig. 2 and formula 1').

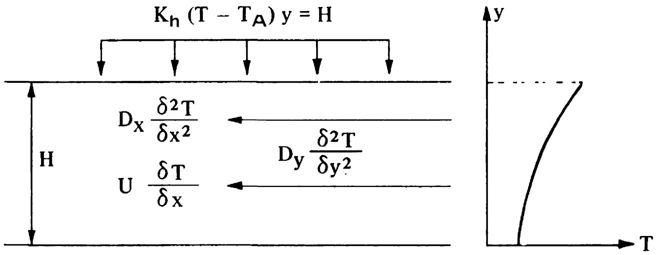

fig. 2

$$U\frac{\delta T}{\delta x} + K_x\frac{\delta^2 T}{\delta x^2} + K_y\frac{\delta^2 T}{\delta y^2} = O \qquad 1')$$

with the limits

$$y = O \qquad \frac{\delta T}{\delta y} = O$$

$$y = H \qquad D_y\frac{\delta T}{\delta y} = K_h (T - T_A)$$

$$x = O \qquad T = T_i$$

where y is the variable height.

In this model it is considered the temperature distribution along the height.

The formula 1') with its limit does not have a simple solution. It has been tried to examine the applicability of the simplification $Q = K_r (T-T_A)$ where K_r is an overall heat transfer coefficient. It is seen to be applicable only in the range $0, 12\ T_i < T < 0{,}5T_i$ when $K_A \gg K_W$ and this range becomes smaller and smaller as much K_W approaches or overlaps K_A.

The position $K_A \gg K_W$ of the authors does not seem to be very real.

Reply

The equations presented in the paper are expressed in Lagrangian coordinate system which is a common way of treating diffusion problems. In this system the differential element moves with the stream. The original differential equation of the diffusion or heat transfer contains parameters for all coordinate directions, i.e. X, Y and Z. However, such an equation cannot be mathematically solved and therefore, some simplifications are necessary. One very common simplification is the assumption that the temperature distribution (or concentration distribution) in a turbulent stream is uniform which fact has been proven by several field and laboratory measurements, e.g. measurements performed by the authors on impounded Tennessee River (depth || 20–25m, velocity <0.3m/sec) showed that even in such conditions the vertical turbulence mixing was high enough to equilibrate the vertical temperature profile. Thus, Dy, can be neglected. For faster turbulent streams the longitudinal mixing coefficient, D_L can be neglected too, which operation converts the energy equation into a single exponential function.

The equations presented in the paper are linear differential equations and as such the superimposition is mathematically possible.

PREDICTIONS OF TEMPERATURE IN STREAMS RECEIVING THERMAL DISCHARGES BY USING A DETERMINISTIC MODEL AND COMPUTER TECHNIQUE

FRANZ BERGER, Biologische Station Lunz der Osterreichischen Akademie der Wissenschaften, Lunz am See, Osterreich.
WOLFGANG SCHMITZ, Landesstelle fur Gewasserkunde und wasserwirtschaftliche Planung Baden-Wurttemberg, 75 Karlsruhe, Hebelstr. 2, B. R. Deutschland.

INTRODUCTION

The effect of a thermal discharge into a river on the temperature of the water is not only due to mixing, but to interference with the natural heat budget of the flowing water. The elements of the heat budget are subject to considerable diurnal and seasonal fluctuations and are dependent on the temperature of the water itself. Therefore calculations of the resulting temperatures are laborious and require the aid of a computer technique. The principle of including the heat budget into the calculations was applied by the authors in a study to predict temperature changes expected to occur in the River Rhine between the mouth of the tributary Aare and the city of Basel (Switzerland) after installation of power plants in future. Detailed results were laid down in an internal report prepared by Berger (1) in 1966, which has not been published. Further use has been made from the experiences of this study in the development of a general plan to manage thermal discharges into the Rhine river between Aare confluence and the Dutch-German border. This plan was prepared by Landesstelle für Gewässerkunde Baden-Württemberg and has been approved and edited by the joint Commission of the German States on Sanitation of the River Rhine in 1971 (2).

DETERMINISTIC MODEL OF THERMAL SITUATION IN STREAMS

The deterministic model used is based on the proposals of Eckel and Reuter (3). In this procedure the calculations of temperatures are made in the form of a one-dimensional deterministic model assuming some simplification of the natural events. The assumptions are as follows:

a) the water is homothermic in the cross-section of the stream;
b) the cooling water is totally mixed with the water of the receiving river immediately;
c) the distortion of bodies of flowing water by longitudinal dispersion during their transport downstream is neglected.

Under these conditions the temperature of the water TW will undergo a deviation of temperature dTW according to the following equation during each small period of flowtime dt.

$$dTW = \frac{1}{H \cdot \rho \cdot c} (GLR \pm EBR \pm EV \pm HCA \pm HCS) \cdot dt$$

where:

- H = depth of water during interval of flow time dt
- ρ = density of water at TW

c = specific heat of water at TW
GLR = global radiation (solar + diffuse skylight radiation)
EBR = effective long wave radiation of water at TW
EV = heat exchange by evaporation (–) or by condensation (+)
HCA = heat exchange by (turbulent) heat conduction with air
HCS = heat exchange by heat conduction with soil of the river bed.

The dimensions used in the calculations of ΔTW are:

$$\frac{[\mathrm{cal}\,.\,\mathrm{cm}^{-2}\,.\,\mathrm{h}^{-1}]\,.\,[\mathrm{h}]}{[\mathrm{cm}]\;[\mathrm{g}\,.\,\mathrm{cm}^{-3}]\;[\mathrm{cal}\,.\,\mathrm{g}^{-1}\,.\,{}^{\circ}\mathrm{C}^{-1}]} = {}^{\circ}\mathrm{C}$$

This equation may be simplified for gradual solution:

1) ρ and c are made unity;
2) HCS is neglected, since it is not relevant to short-time fluctuations of water temperature;
3) dt is replaced by Δt = 1 hour. dTW hence will become temperature deviation ΔTW after 1 hour;
4) R is a coefficient of GLR, which considers the losses of GLR at the water surface by reflection and by incomplete absorption;
5) H is considered as the average depth of that particular range of the stream through which the river water flows during the corresponding Δt.

The equation used for the calculation is hence:

$$\Delta TW = \frac{1}{H}\,(R\,.\,GLR - EBR \pm EV \pm HCA)\,.\,\Delta t$$

NUMERICAL CALCULATIONS

1) The calculations are started with the arbitrarily fixed initial temperature TWA.
2) H (in cm) is obtained for each hour step from a longitudinal stream profile in connection with hour step nomograms (Fig.1). Nomograms have been developed for different well defined cases of run-off. This information is generally taken from studies, tracing the flow by use of rhodamine WT technique or by calculations from known geometric data of the river bed.
3) GLR (in $\mathrm{cal.cm^{-2}.h^{-1}}$) is obtained as the average ordinate of single hour steps taken from global radiation diagrams (Fig.2). The information derives from actual observations with pyranometers.
4) R is either used as a constant R = 0.85 or it may be individually fixed for each daily hour on the basis of sun angle-reflection tables and data for reflection of scattered skylight as published by Sauberer and Ruttner (4).
5) EBR = 60 (BRW – BRA) . b (in $\mathrm{cal.cm^{-2}.h^{-1}}$), whereas BRW is long-wave back-radiation of the water and BRA long-wave counter-radiation of the atmosphere. BRW is calculated according to Stefan-Boltzmann as

$$BRW = 0.95\,\sigma\,.\,(TW + 273)^4 \text{ (in cal.cm}^{-2}\text{.min}^{-1}\text{)},$$

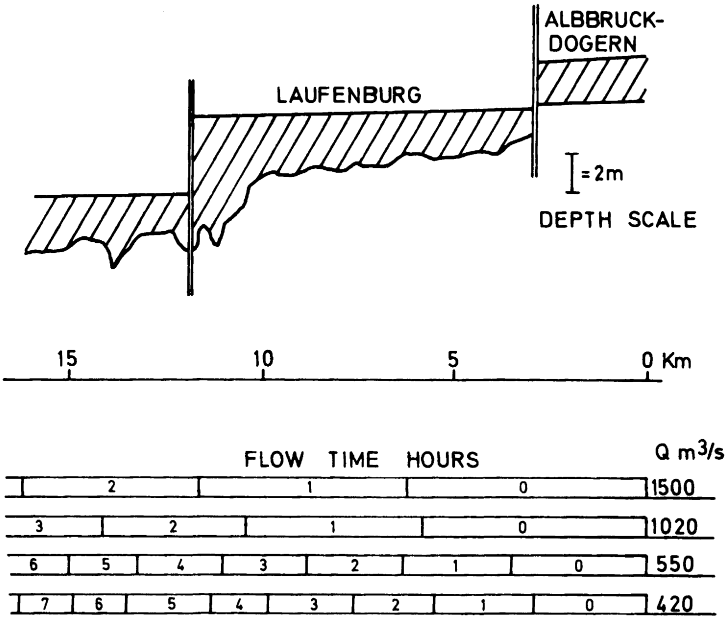

Fig. 1. Section of Stream Profile and Hour Steps of Flow in the River Rhine

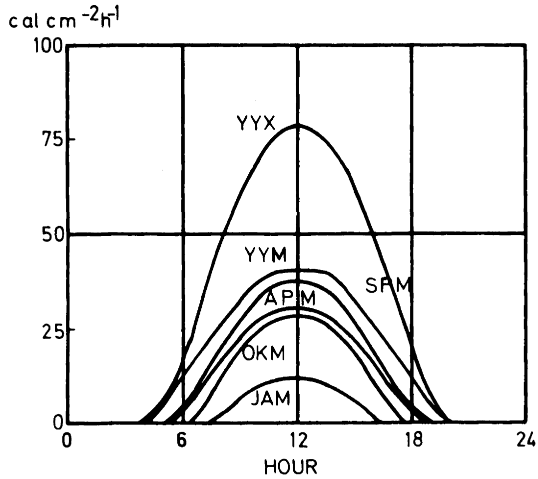

Fig. 2. Daily Fluctuation Global Radiation

and BRA is calculated according to Angstroem as

$$BRA = \sigma \, . \, (TA + 273)^4 \, . \, (0.806 - 0.236 \, . \, 10^{-0.069 \, EA}).$$

TA is temperature of the air (Fig.3) and EA is the water vapour pressure of the air (Fig.4).

$\sigma = 0.826. \, 10^{-10}$ cal. cm^{-2} . min^{-1}. Grad K^{-4}.
$0.95 \, \sigma \approx 0.7847$

b is a factor, depending on the degree and character of cloudiness, of the size between 1 (no clouds) and 0.5 (deep rain clouds).

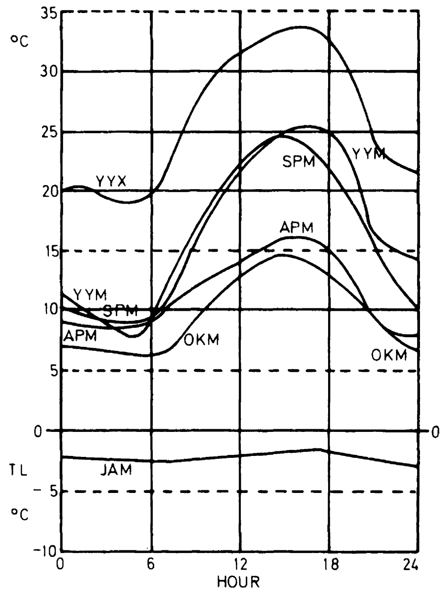

Fig.3. Daily Fluctuation of Air Temperature

6) EV = f . (EW – EA) . $\sqrt{C}$ (in cal . cm^{-2} . h^{-1}), whereas EW and EA are mean water vapour pressure of the water and the air (in mm Hg), and C the velocity of wind relative to the surface of the flowing water. EA is taken from meteorological humidity observations (hour step averages from Fig.4) and EA is calculated from EA = 760 . 10(–2300.2/(TW + 273) + 6.207).

f equals 10.2 to 9.8 for water temperatures between 0 and 35°C depending on the evaporation heat of water.

7) HCA = 0.50 . (TA – TW) . $\sqrt{C}$ (in cal.cm^{-2}.h^{-1}). Hour step averages of TA are taken from graphs (Fig.3), based on actual observations.

The numerical calculation of ΔTW is inaccurate in the first approximation because BRW, EV and HCA depend on the value of TW, which is not equal over the flow time Δt. Therefore the calculations of ΔTW were repeated, replacing TWA by TWA + $\frac{\Delta TW}{2}$, until in the course of iteration the results of subsequent calculations were equal within the

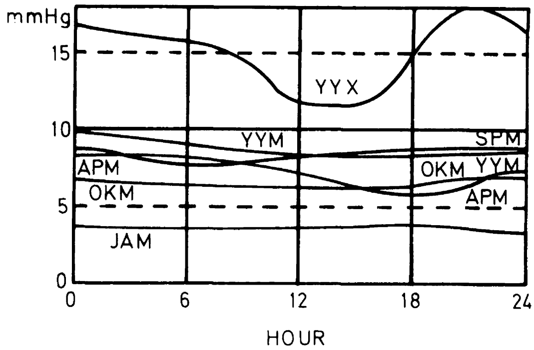

Fig.4. Daily Fluctuation of Water Vapour Pressure in Air

limits of 0.01 °C. The finally calculated end temperature of this hour step TWE = TWA + Δ TW enters the calculation of the next hour step as initial temperature TWA.

It is necessary to do this kind of calculation subsequently for the whole sequence of hour steps corresponding to the flow of the stream over the total distance under consideration. Such calculations also have to be made for different seasonal conditions of weather and also for flow time patterns of different run-off conditions. For simplification the calculations for the river Hochrhein (upper Rhine) were made using fixed standard weather types based on the monthly averages of observed daily fluctuations of GLR, EA and TA for January, April, June-July-August, September and October (JAM, APM, YYM, SPM, OKM in Figs.2, 3, 4). In the same way standard data for complete cloudless sky conditions during these months were arranged (e.g. YYX Figs.2, 3, 4). The calculations were made for 4 standard run-off conditions, 550, 710, 1020 and 1500 m^3/s, as far as they were relevant to the different seasons.

Another variable in the series of calculations was the initial temperature TWA at the Aare mouth, because it greatly influences the temperature development in the downstream direction. The range of alternate initial temperatures in the calculations was determined from observations of natural water temperatures and was extended to higher temperatures according to the additional thermal input assumed under future conditions, in this case the installation of successively 4, 8 and 12 power plant blocks, contributing each of them 600 megawatts.

The influence of wind on evaporation and heat conductance was investigated by calculating EV and HCA alternatively for a wind velocity of 1 and 3 m/sec.

It is also important to determine the initial starting hour of the day for the flowing water at the upstream station (Aare confluence), which will result in the daily maximum at the lower stream station concerned, in this case Basel. This is done by alternating calculations with different starting hours.

To include these different alternatives into the computer calculations, these were finally done as shown in the flow diagram of Fig.5.

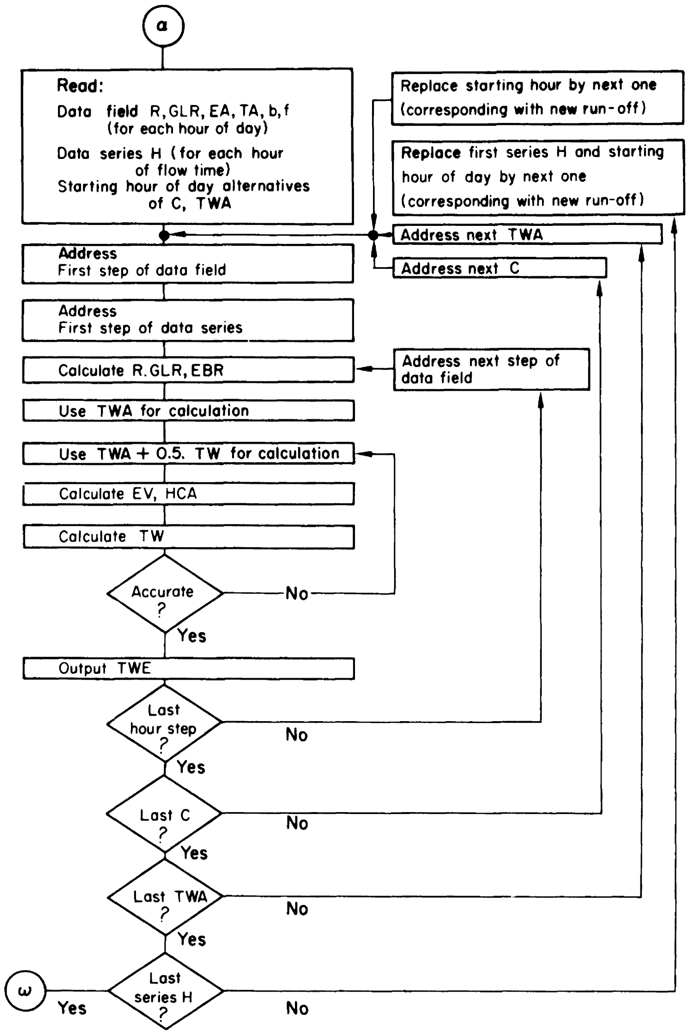

Fig.5.

PRESENTATION OF RESULTS

The calculated values of ΔTW between the initial position (Aare confluence) and the final position (Basel) were plotted separately for each weather condition and combination of run-off as ordinates in diagrams against the variables of initial water temperatures TWA

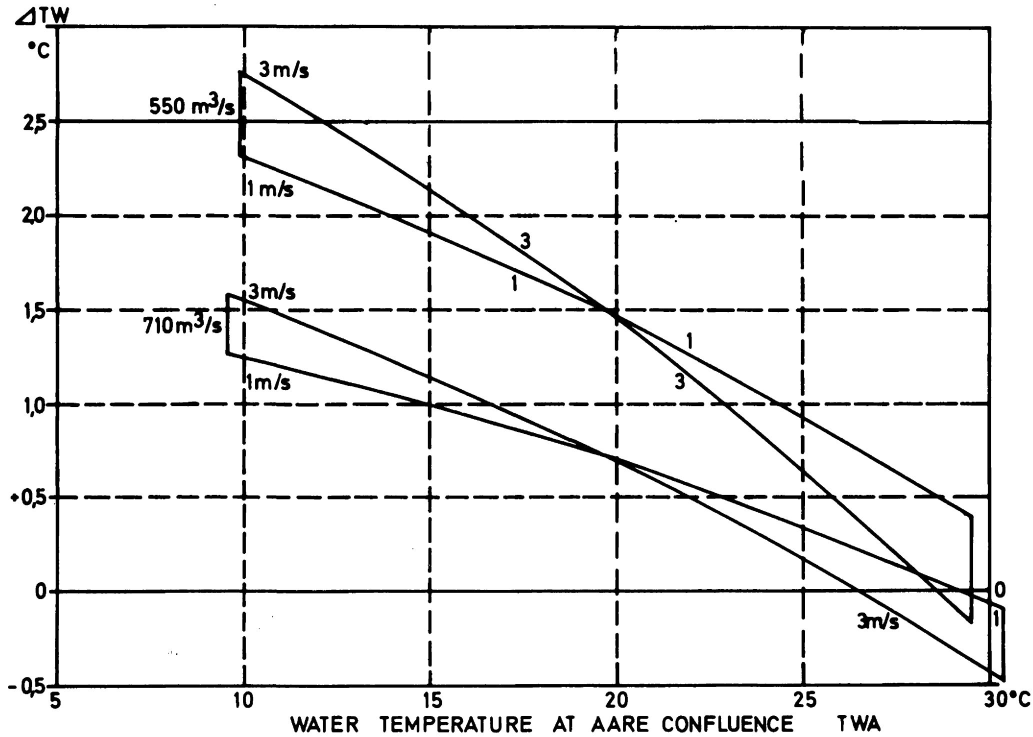

Fig.6. Expected Deviation of Water Temperature at Basel

as abscissae, for which an example is given in Fig.6. The two graphs express the range of the results differing from wind velocities assumed as 1 and 3 m/sec. We observe positive or negative values of ΔT depending on whether the initial temperature is below or above the equilibrium temperature of the water with the heat budget under the assumed standard weather conditions. The cross point for the two lines, referring to different wind velocities, demonstrates that situation where the effects of wind on evaporation are equal to the opposite ones on turbulent heat conduction. The analyses of all results of computations reveal many interesting aspects of the heat budget, which however cannot be discussed here.

To determine and predict the temperature situation at the lower reference point Basel for future conditions in relation to additional thermal discharge at the Aare confluence, graphs of the type of Fig.7 have been plotted. They show the frequency distribution of presently occurring temperatures at the Aare confluence, averaged from several years of observation (TP), and the frequency distribution, as expected after installation of 4, 8 or 12 power plant blocks at this place (solid lines, marked 4, 8, 12 in Fig.7). The shadowed areas in the bordering lines M and X represent the freqoency distributions at Basel expected under the same conditions and alternatively for the standard conditions "mean weather" (M) or "extreme sunshine" (X). From such a graph we may easily obtain the expectancy in number of days exceeding certain water temperatures at Basel and so have an estimate for what duration restrictions or precautions will become necessary on the power plants if a particular upper limit of water temperature is required at this place.

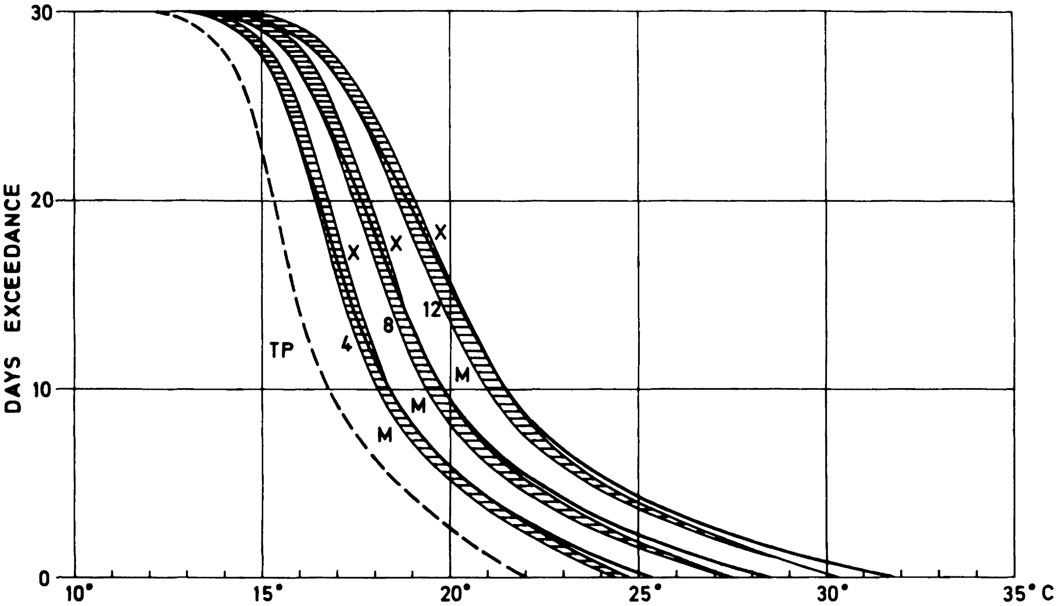

Fig.7. Frequency of Expectation of Water Temperatures for the Month of September

CONCLUDING REMARKS

It is realized that certain steps of the calculations of stream temperatures, as described here, give only approximately correct results and that for instance in the case of calculating evaporation or heat conduction other equations could be used as well, though probably with no better justification. As far as our own observations of water temperatures recorded at Aare confluence and Basel and of weather conditions are concerned, they are in good agreement with the temperatures calculated from our model. Furthermore, installations now have been made to record different parameters of the heat budget in relation to stream water temperatures above the water surface of the Neckar river near Gundelsheim (Baden-Württemberg). The parameters recorded there are global radiation and reflection, long-wave back-radiation of the water, long-wave atmospheric counter radiation, wind velocities, air temperatures with ventilated dry and wet sensors at 0.75, 1.5 and 3 m above the surface of the water. This is done to elucidate our still limited knowledge on this subject and achieve a better fit for the equations used in the calculation of ΔTW from meteorological data via the heat budget.

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Discussion *by* A. Goubet, France.

Water reuse is a relatively new subject, on which most work has been done in the last 10 years. It is true that the world consumption of electricity has doubled in 10 years, that waste heat from central generating stations has kept pace with power generation and that the prospect of massive nuclear power stations is likely to lead to a further doubling of power production in the next decade.

The research work in progress to study the problems arising from thermal pollution may be classified as (1) biological effects, which are not necessarily harmful, and (2) physical studies arising from mixing of warm with cold water, and the cooling of water.

The biological studies, because of the complexity of the phenomena involved in receiving rivers and the variety of the objectives of such work, are not yet capable of predicting results with any great accuracy, except perhaps where high temperature discharges are involved.

Mixing studies on heated water discharges have likewise made little progress. We know that mixing is poor and that heated water tends to remain at the surface but we are comparatively ignorant as to what will happen in an estuary or how recirculation currents will affect a discharge, although some progress has been made by the use of models.

However, so far as the study of temperature effects in rivers is concerned, principally the mixing of heated water, satisfactory progress has been made.

Several groups have worked independently and reported their results recently. In 1966 the mathematical model of Berger and Schmitz constituted the best of its kind in Europe if not the world, both as a contribution to research in this field and as a tool for the study of an actual problem.

These models express generally that the temperature of a river depends upon phenomena such as evaporation, condensation, radiation, convection etc., that have long been known although they also depend upon the use of coefficients or laws that may be insufficiently well defined, e.g., the influence of wind velocity. Furthermore, the calculations require the use of meteorological values that ought to appertain to the actual situation but which in reality only apply to the perhaps distant meteorological station where they were obtained.

For these reasons the use of such physical laws in theoretical studies may introduce inaccuracies. It is desirable that mathematical models relative to temperature, like all other models, may be compared with the results of actual situations. I do not think that the authors' model has been subjected to this sort of proof.

It also seems desirable that the model permits a probability study to be made of the reuse of water with a view to obtaining information about the maximum temperature likely to be obtained, expressed as a probable occurrence in terms of frequency per day or per annum. This would presuppose the availability of meteorological data daily or weekly and the use of such data in the model. The introduction of such data does not appear to be capable of being achieved in Berger and Schmitz's model, nor in any other described in 1966.

A model also ought to take account of the fact that it is possible for several heated discharges and many effluents to be discharged to a long river. This clearly was not the problem before the authors, who limited their investigation to one point (the city of Basle), the section of the Rhine situated between two points receiving an important effluent. It would be useful if models recently put forward would provide answers to questions arising from the complex problem of multiple discharges.

Thus, the model can be adjusted to agree with actual observations; what is the possibility of obtaining day to day temperatures based on true meteorological data, and what is the possibility of the model being used to represent complicated situations, particularly where several central power stations occur and variable additions of non-heated effluents may be made?

Reply

The correctness of the model was actually proven by observations. In these cases flowtime-distance relations of the stream were measured with the aid of fluorescent dye, water temperatures were recorded over a restricted period of time and likewise global radiation, total radiation budget, temperature and water vapor content and wind velocity above the surface of the water at a certain distance.

These studies were made at the Rase River, near Göttingen, Germany, a small stream deriving from a karst spring pool at a constant temperature of 9°C, on two occasions, one representing a cloudless summer day, the other during 24 hours on a bright and very cold day in winter. The first situation resulted in warming; the second one in cooling the water flowing out of the spring.[5]

Further studies were made in the Madison River at Yellowstone Park, U.S.A. The stream drains hot geyser effluents and therefore has summer temperatures above the equilibrium temperature. The cooling effect on the water whilst flowing downstream is remarkable because of the high altitude of the area. The temperatures observed in the streams were in good conformity with those ones computed from the observed meteorological data. Deviations for certain ranges of the Madison River could be explained by the penetration of ground water into the stream through the river bed or by shading effects of forests closely bordering the river banks.

Mixing of the geyser effluents in the Madison River was complete in the cross section. Mixing of discharged cooling water with the water in a steam occurs quickly in streams of medium size, if the amount of cooling water is not too far from the run-off of the river, even if the velocity of the current is rather low. For example in the Neckar River we found complete mixing achieved 2 km below a thermal discharge entering from one side at a temperature 6.5°C higher than in the river water, and the vertical temperature differences were only about 1°C after 1 km distance.[6] Larger streams may show delayed lateral mixing over very long distances, but vertical mixing occurs generally quickly. In such cases the one-dimensional model may be extended to a two-dimensional one, assuming different "parallel streams" flowing in the river bed, which join gradually according to the particular conditions of turbulent lateral dispersion. There was no need to do this for the Hochrhein calculations, because we could expect total mixing to occur.

No problem arises in extending our calculations to multiple discharge conditions. In fact the Hochrhein model has recently been extended to cover the ranges of the River Rhine between Lake Constance and the German-Dutch border, forecasting the effects of multiple thermal discharges to be expected in the future.[2] I admit that the one-dimensional model may not be correct for all locations on the River Rhine for reasons of incomplete lateral mixing. The water temperatures could actually be somewhat lower than those calculated. But regarding harmful effects by heating the water of the Rhine, in our calculations we are on the "right side" with our predictions.

I agree that model studies should include an approach to predict the probability of occurrence of different water temperatures during given periods of time or seasons. This can be done by regarding the weather situations as a set of defined singularities. The model calculations can be made for each weather singularity, possible alternatives of river run-off and initial water temperatures could be taken into account. If the frequency distribution of occurrence of special meteorological singularities is known, we are able therefrom to derive the expectation for the occurrence of certain water temperatures. In our example this approach was similar, but restricted to average monthly weather conditions. These are artificial weather conditions, derived from monthly averages of hourly values of global radiation, temperatures and humidity of the air at an observation station in the Hochrhein River Valley.

Surely it would be best to take the meteorological data for model computations from stations located at the river bank, and temperatures and water vapor content of the air, and wind from over the water surface at standardized distance. No observational system of this kind exists at the present time, but we are just starting installations of this kind along the River Rhine.

We expect further elucidation and verification or correction of the equations used in our computations from the test installations at the Neckar River, which I have already mentioned.

R.J. Davis, Israel

Has the temperature rise due to biotic metabolism been considered?

What are the effects of temperature variations due to either exothermic or endothermic chemical reactions caused by oxidation or reduction of either organic or inorganic substances?

What are the effects of terrestrial temperatures?

Data obtained during the course of an investigation of the pollution problem of Lake Kinneret (The sea of Galilee) during 1953-1964 showed that there was an increase in the lake water temperature while there had been a decrease in the ambient atmospheric temperature over the same period. It appears that an increase in temperatures occurred in association with ambient temperatures. I found that the ambient yearly temperature fluctuation, over a period of 20 years (1952-1972), showed a ratio of rise to fall of 7 to 5; that is a rise over 7 months and a fall over 5 months. I would welcome the authors' comments on this point.

Additional Literature:

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