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The potential pollution index as a tool for river water quality management

6

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WORLD HEALTH ORGANIZATION
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THE POTENTIAL POLLUTION INDEX AS A TOOL FOR RIVER WATER QUALITY MANAGEMENT

BY

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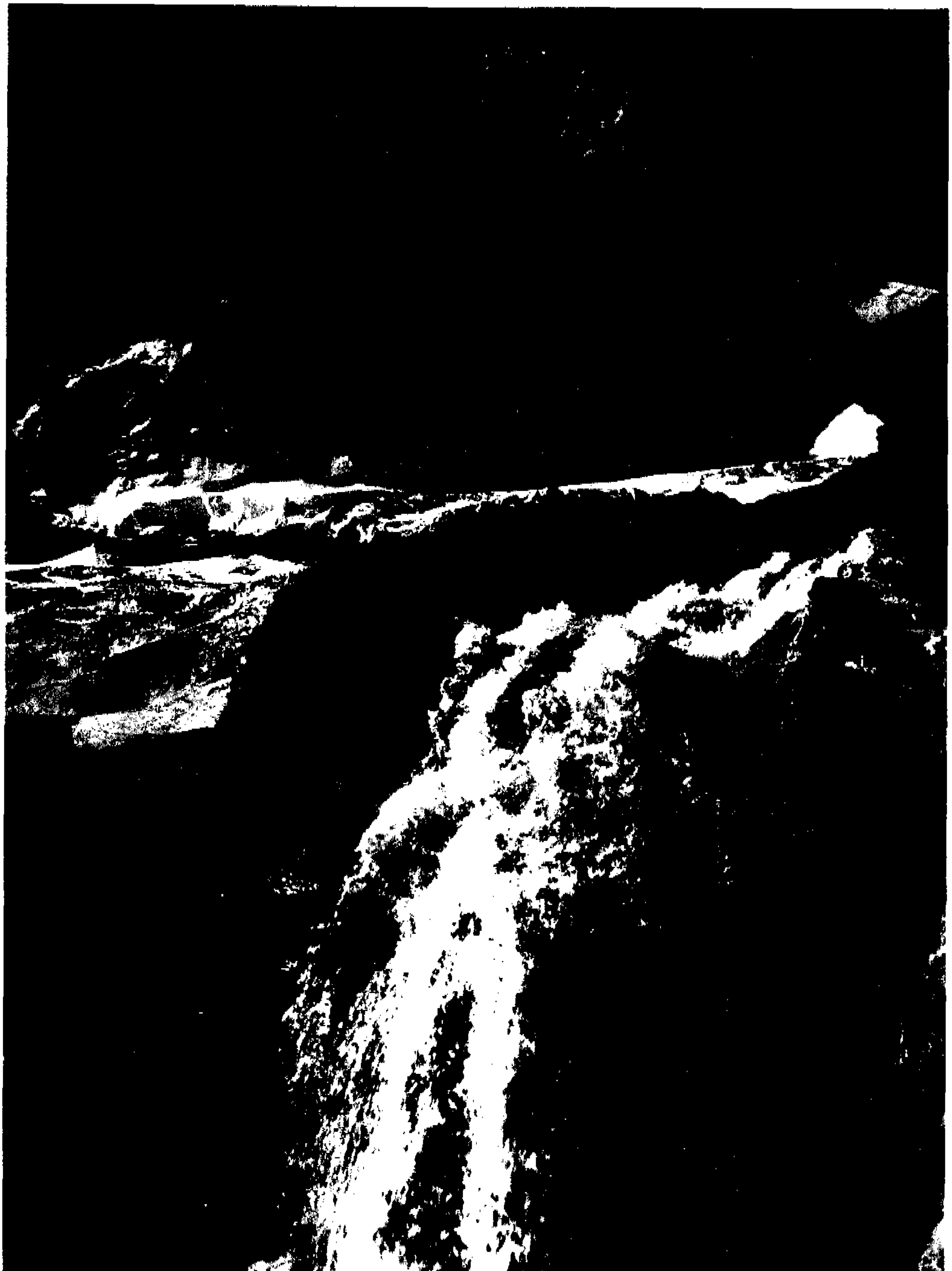


Waterfall at the source of a river near the Matterhorn in Switzerland.
(Photo from Wasser-bedrohtes lebenselement)

SYNOPSIS

The lack of quality data over long periods for different parameters and different rivers has up till now been prohibitive for the formulation of a mathematical relationship between the changes in river water quality and the changes in human activities which are responsable for it. A model is proposed which is based on a Potential Pollution Index (P.P.I.). The P.P.I. depends on size of population in the river drainage area, the economic activity in the river basin and the average waterflow of the river. The relation of this P.P.I. and actual river water quality is derived from river water quality data of 160 riversites from all over the world. Based on the concept of a Potential Pollution Index a classification of rivers is given and general water pollution trends are presented. From these general water pollution trends a reconstruction of natural pollution levels of rivers as well as a prognosis of water quality for rivers in general and for the specific case of the river Rhine in the year 1980 and the year 2000 are derived.

Finally the usefulness of the P.P.I. as an indicator for sanitation programming and P.P.I.'s possibilities for the communication of information on river water quality are considered.

It is hoped that the preliminary results of this paper will stimulate others, especially in Latin-America, Africa and Asia, to make available more information on water quality of rivers in these regions.

INTRODUCTION

Rivers have always been very important to human society. From ancient history names are known to us like the Ganges in Pakistan, the Jordan in Israel and the Nile in Egypt. Rivers consitute for mankind as a whole the principle source of water although they contain only about 0.01% of the water of the globe. This importance of river water is a result of the easy accessibility and the superior quality as compared with stagnant water.

When the population density in the drainage area of a river increases, the use of river water for different purposes will be also intensified: transport of agricultural and industrial materials, irregation, fishery, community water supply, waste disposal and recreation. As soon as the discharge of wastes into the river is trespassing a certain threshold, whereby the dilution of pullutants and the self-purification capacity of the river are no longer sufficient to restore natural water quality, man is confronted with a multitude of problems. The most important implications of river water quality deterioration are:

1. increasing risk of breakouts of infectious diseases (pest, cholera, etc.);
2. fishkills by decreased dissolved oxygen content;
3. increased eutrofication;
4. increasing quantity of substances exerting a chronic toxicity to the ecosystem (carcinogens, organochloropesticides, heavy metals etc.).

Up till now the lack of quality data over long periods for different parameters and different rivers has been prohobitive for the formulation of a mathematical relationship between the changes in river water quality and the changes in human activities that were responsible for it. Such a relationship would possibly give an answer to questions like:

1. what might be the water quality at a specific riversite in the year 2000 or what has been the "natural" water quality e.g. 100 years ago;

2. at what time should specific measures of pollution abatement be programmed and how should the results be judged.

The key to the proposed mathematical relationship is an index which depends on the size of the population and its economic activity. The effect on water quality of the potential pollution charge of a river that is represented by these two factors, will mainly depend on water discharge of the river and the degree of sewage treatment. Not taking into account the effect of waste water purification a Potential Pollution Index can be defined as follows:

$$P.P.I. = \frac{N \times G.N.P./cap.}{Q \times 10^6} \qquad (1)$$

where:

P.P.I. = Potential Pollution Index for a specific riversite and year of observation

N = Number of people living in the considered drainage area

G.N.P./cap. = Average Value of the Gross National Product/Capita (U.S.$) applying to the population of the considered drainage area

Q = Yearly average discharge (m^3/s)

It is of interest to mention a similar concept here: the GNP/Area Ratio, that has been proposed in the meantime by GOLDBERG AND BERTINE (1971) as an approximate but useful measure of the potential pollution of a country.

The establishment of a model, that describes changes in river water quality as a function of time, will become possible by correlating P.P.I. values with actual water quality data. For this purpose a questionnaire was sent in 1971 to about 300 environmental agencies, river authorities, research instutions, universities etc. all over the world. A general specification of the available information is given in the Appendix. An evaluation of the data and some preliminary conclusions that can be derived from this material will be presented in this paper. Finally the results will be tested on a case history of the river Rhine.

SPECIFICATION OF AVAILABLE INFORMATION

As a result of responses to the questionnaire a total number of more than 1000 yearly average values for about 50 water quality parameters at 160 riversites have been gathered. Most of the data originate from the United States of America and Western Europe, in particular the United Kingdom (see Figure 1). For each of the following parameters more than 40 values have been obtained: Chloride, Fluoride, Phosphate (ortho), Total Hardness, B.O.D.5, Coliforms, Iron, Manganese, Zinc and Copper.

CONTINENT	COUNTRY	NUMBER OF RIVERSITES WITH WATER QUALITY DATA
AFRICA	SOUTH AFRICA	1
	SUDAN	1
AMERICA (NORTH.)	U.S. OF AMERICA	60
ASIA	IRAN	2
	ISRAEL	1
	NEW ZEALAND	2
	PHILIPPINES	1
	VIETNAM (SOUTH)	3
AUSTRALIA	AUSTRALIA	3
EUROPE	BELGIUM	3
	FED. REP. OF GERMANY	2
	FINLAND	9
	FRANCE	1
	GREECE	3
	HUNGARY	2
	NETHERLANDS	2
	NORWAY	2
	SWEDEN	10
	SWITZERLAND	1
	UNITED KINGDOM	51
TOTAL		160

FIG.1 ORIGIN OF RIVER WATER QUALITY DATA

The average river in this study has a yearly discharge of about 100 m^3/s, while only 10% of the considered rivers have a yearly discharge of more than 1000 m^3/s (see Figure 2). Although it may be stated that the size of the considered rivers is rather representative, this does not at all apply to the economic situation in the considered drainage areas. About 7.5% of the drainage areas have an average G.N.P./Cap. of U.S. $ 1000 or less, while about 75% of the world population belong to this category. Especially in this respect the available information needs to be completed by data from South America, Asia and Africa. On the other hand a more extended list of parameters has to be aimed at, that includes organic pollutants like mineral oil and synthetic detergents as well as micropollutants like polynuclear aromatic hydrocarbons, pesticides, taste and odour substances and metal compounds.

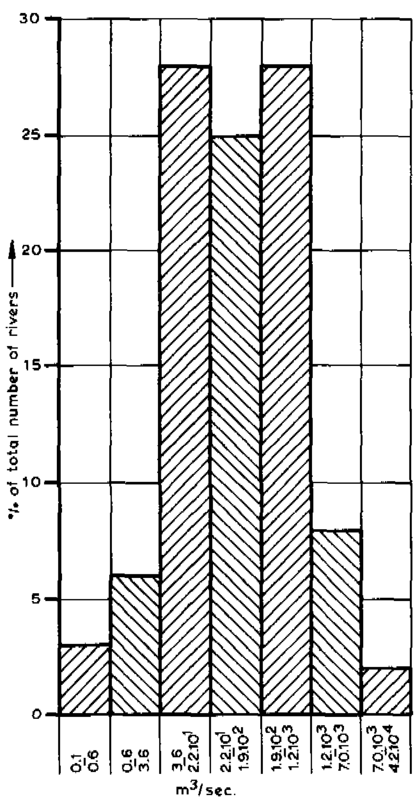


FIG. 2 FREQUENCY DISTRIBUTION OF YEARLY AVERAGE RIVER DISCHARGES.

CLASSIFICATION OF RIVERS IN VIEW OF THEIR POTENTIAL POLLUTION

The potential pollution of rivers as indicated by the P.P.I. can vary considerably. The lowest P.P.I. value found up till now, amounted to approx. 0.01 for the Angat River at the Ipe Dam in the Philippines, while the maximum value amounted to approx. 1000 for the Santa Ana River at the Prado Dam in California.

POTENTIAL POLLUTION INDEX	RIVER	LOCATION	DISCHARGE (m^3/s)	COUNTRY
RIVERS WITH MAXIMUM P.P.I. VALUES				
980	SANTA ANA	PRADO DAM	13.0	U.S.A. (CAL.)
270	SANTA CLARA	SANTA PAULA	8.0	U.S.A. (CAL.)
265	LEE	CHINGFORD	6.5	UN.KINGDOM
200	BLYTHE	BLYTHE BRIDGE	0.5	UN.KINGDOM
130	MERSEY	HOWLY WEIR	42	UN.KINGDOM
110	CHELMER/BLACK WATER	LONGFORD	3.2	UN.KINGDOM
110	SKILLET FORK	WAYNE CITY	1.3	U.S.A. (ILL.)
110	SAMBRE	NAMUR	15	BELGIUM
100	TRENT	NOTTINGHAM	82	UN.KINGDOM
90	NORTH CANADIAN	OKLAHOMA	19	U.S.A.(OKLA)
RIVER WITH MINIMUM P.P.I. VALUES				
0.34	CAM-LE	DA-NANG	125	S.VIETNAM
0.30	STORSJÖN	ÖSTERSUND	240	SWEDEN
0.20	JAJRUD	LATIAN	5.4	IRAN
0.15	BLEU NILE	KHARTOUM	1.640	SUDAN
0.13	TOWY	TY CASTELL	46	UN.KINGDOM
0.13	LULE ÄLV	BODEN	500	SWEDEN
0.11	KARAJ	SIERA	10	IRAN
0.07	MÉKONG	CHAU-DOC	14.500	S.VIETNAM
0.06	DENMARK	DENMARK WEIR	4	AUSTRALIA
0.009	ANGAT	IPE DAM	40	PHILIPPINES

FIG. 3 TEN RIVERS THAT ARE MAXIMAL/MINIMAL CHARGED WITH POTENTIAL POLLUTION

Figure 3 shows 10 rivers respectively having the highest and the lowest P.P.I. registered. The highest potential pollution is found in relatively small rivers in the U.S.A. and Western Europe. Low P.P.I. values are registered for rivers of different size in Asia, Africa and parts of Scandinavia. Among the larger rivers of the world with an average yearly discharge of more than 2000 m^3/s the Rhine proves to be potentially the most polluted one. (Table 1.)

Table 1. P.P.I. values for rivers with more than 2000 m^3/s discharge.

P.P.I.	Discharge x 1000 m^3/s	River	Location	Country
39	2.2	Rhine	Lobith	Netherlands
13	2.2	Missouri	St. Louis	U.S.A. (Miss.)
7.6	15.8	Mississippi	Vicksburg	U.S.A. (Miss.)
5.5	7.3	Ohio	Cairo	U.S.A. (Ill.)
3.8	2.4	Danube	Budapest	Hungary
2.3	6.8	St. Lawrence	Ogdensburg	U.S.A. (N.Y.)
2.2	5.5	Columbia	Bonneville	U.S.A. (Ore.)
0.068	14.5	Mékong	Chau-Doc	S. Vietnam

A more detailed classification can be developed by comparing the actual P.P.I. value of a river with the P.P.I. value of its natural state of pollution. The natural pollution will mainly depend on geological and hydrological characteristics. Rivers with a relatively low discharge will naturally be more polluted than rivers with relatively high discharges. Figure 4 shows the tentative relationship for the P.P.I. of naturally polluted rivers (G.N.P./Cap. smaller than U.S. $ 1000 in the drainage area) and the drainage area/discharge ratio. From these relatively few data the following general definition of the natural potential pollution index ($P.P.I._N$) of a river can be tentatively derived:

$$\log (P.P.I._N) = 2.2 \log (D.A./DISCH.) - 4.8 \qquad (2)$$

where:

D.A. = Drainage Area in km^2
DISCH. = Discharge in m^3/s

Based on this natural P.P.I. value the following classification of rivers to their degree of potential artificial pollution is proposed:

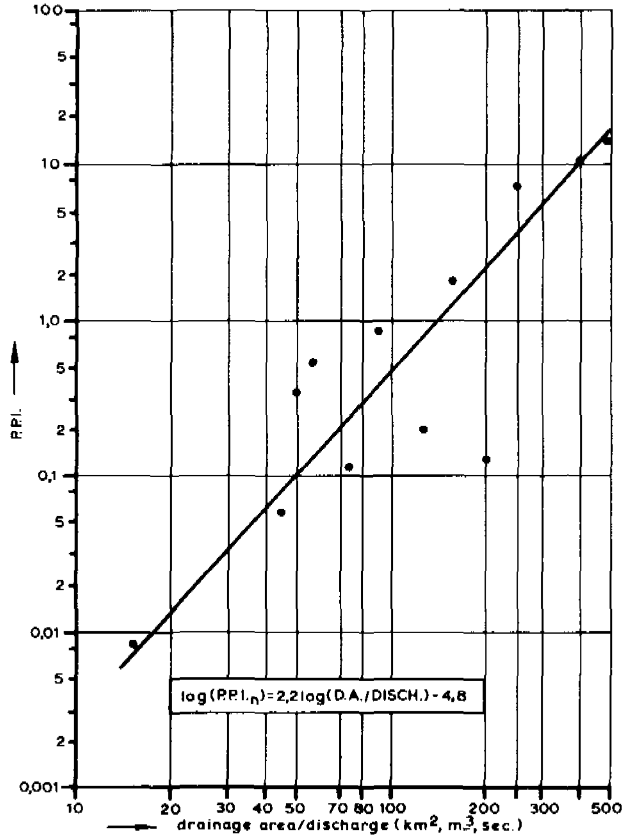
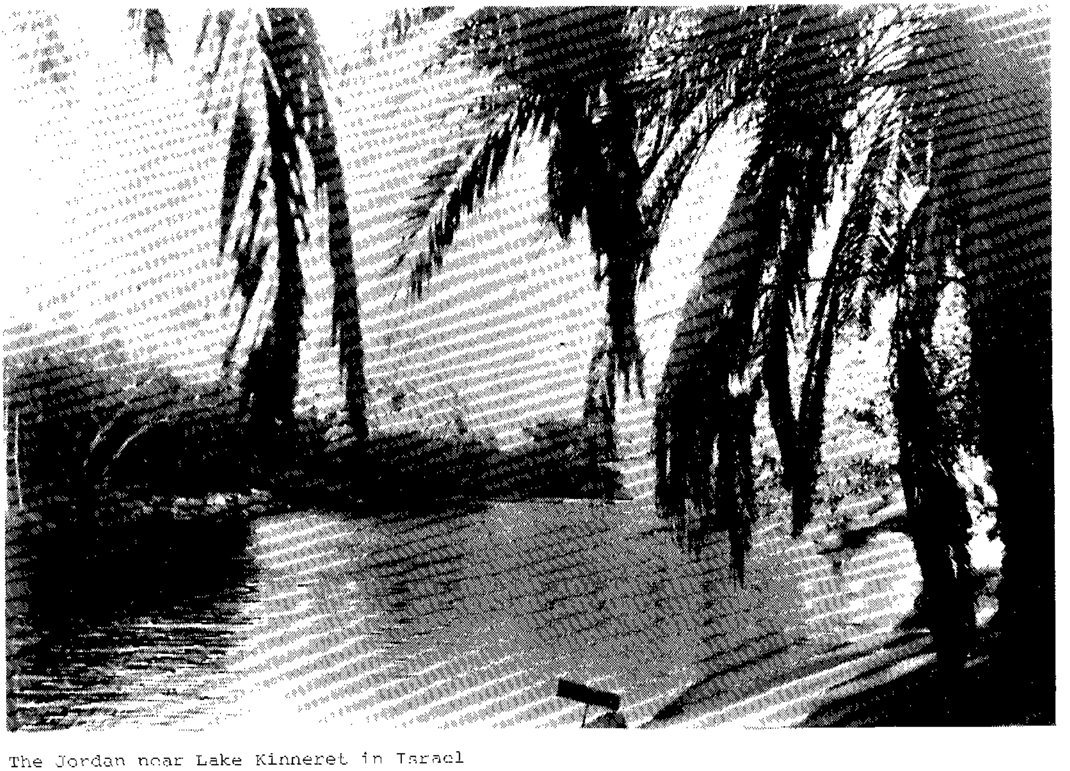


FIG. 4 TENTATIVE RELATIONSHIP FOR P.P.I. AND DRAINAGE AREA/ DISCHARGE RATIO OF NATURALLY POLLUTED RIVERS (G.N.P./CAP. <1000 U.S. $)

Table 2. Classification of rivers to artificial pollution.

P.P.I.	Class
>5 x $P.P.I._N$	Naturally/Slightly Artificially Polluted
5 x $P.P.I._N$ - 50 x $P.P.I._N$	Moderately Artificially Polluted
<50 x $P.P.I._N$	Strongly Artificially Polluted

The result of this type of classification is given in Figure 5, which also proves that the river Rhine is one of the best examples of artificial river water pollution.



The Jordan near Lake Kinneret in Israel
(Photo by J.M.G. van Damme)

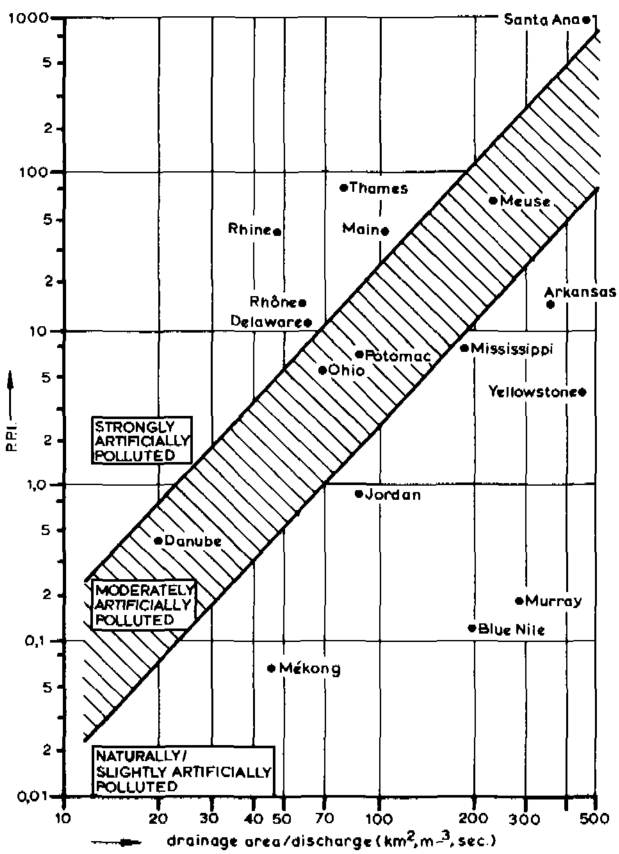


FIG. 5 CLASSIFICATION OF RIVERS TO THEIR DEGREE OF POTENTIAL ARTIFICIAL POLLUTION

GENERAL WATER POLLUTION TRENDS

A detailed presentation of the obtained results for the water quality trends of five parameters in relation to the P.P.I. is given in Figure 6.

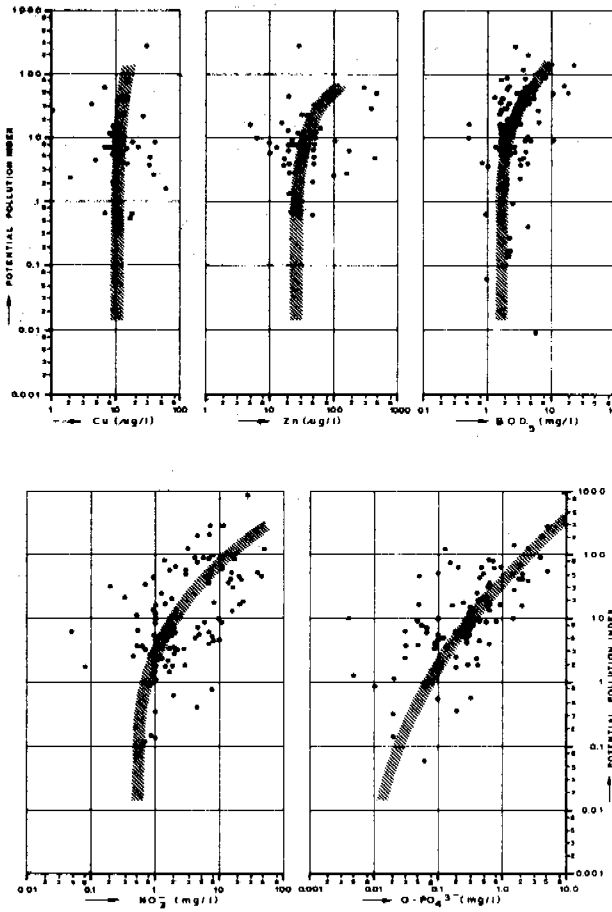


FIG.6 RELATION POTENTIAL POLLUTION INDEX OF RIVERS AND FIVE WATER QUALITY PARAMETERS

The overall result concerning those 11 parameters for which more than 40 data are available is presented in Figure 7. Tentatively some general trends can be distinguished.

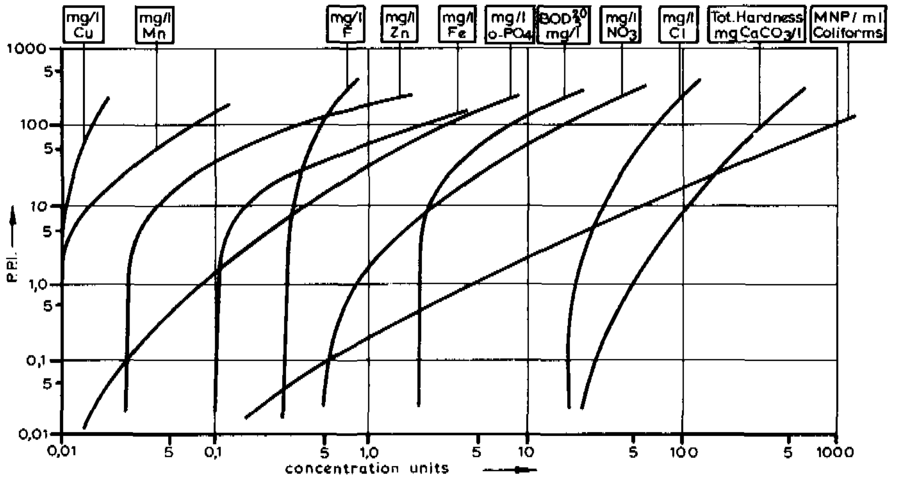


FIG. 7 TENTATIVE GENERAL WATER QUALITY TRENDS IN RELATION TO THE P.P.I.

The most sensitive parameter for increasing P.P.I. values is the Coliform number, followed by respectively the o-Phosphate content, the Nitrate content and the Total Hardness of the water. Most parameters are in general rather insensible to changes in P.P.I. when the P.P.I. values are below 1.0. Above P.P.I. values of 10, Chloride and Fluoride content are distinctly increasing while an abrupt increase appears in this P.P.I. range for the B.O.D.5 and the content of metals like Iron and Zinc. For P.P.I. values of 10 and more, a less sharp increase is found for Manganese and Copper.

The Henry Mountains in the drainage area of the Colorado, Utah, U.S.A.
(Photo from Water, Time Inc.)

RECONSTRUCTION OF NATURAL POLLUTION LEVELS

Using the information of Figure 7 it is generally possible to approximate the natural pollution levels of rivers for the individual parameters. This can be of practical importance for the establishment of water quality standards. (ZOETEMAN, 1973). Because of the insufficient knowledge on dose-effect relations for water pollutants a tendency exists to attach much importance to the natural quality of water. Although considerable deviations for individual rivers do occur, which will be of decisive significance for establishing local water quality standards, the natural water quality of an average river will be in general of value for river water quality management. For this purpose concentration levels of several parameters for naturally polluted rivers are summarized in table 3.

Table 3. Quality specification for the natural state of rivers.

Parameter	Concentration Range (mg/l)	Concentration for an average river (mg/l)
Phosphate (ortho) (P04)	0,005 - 0,1	0,02
Copper	0,001 - 0,05	0,01
Manganese	0,002 - 0,08	0,01
Zinc	0,005 - 0,1	0,025
Iron	0,005 - 1,0	0,1
Fluoride	0,05 - 0,8	0,25
Nitrate (NO_3)	0,005 - 8	0,5
BOD5	0,5 - 5	1,5
Chloride*)	1 - 35	17
Total Hardness (CaCO3)	10 - 100	25

*) Brackish Waters excluded

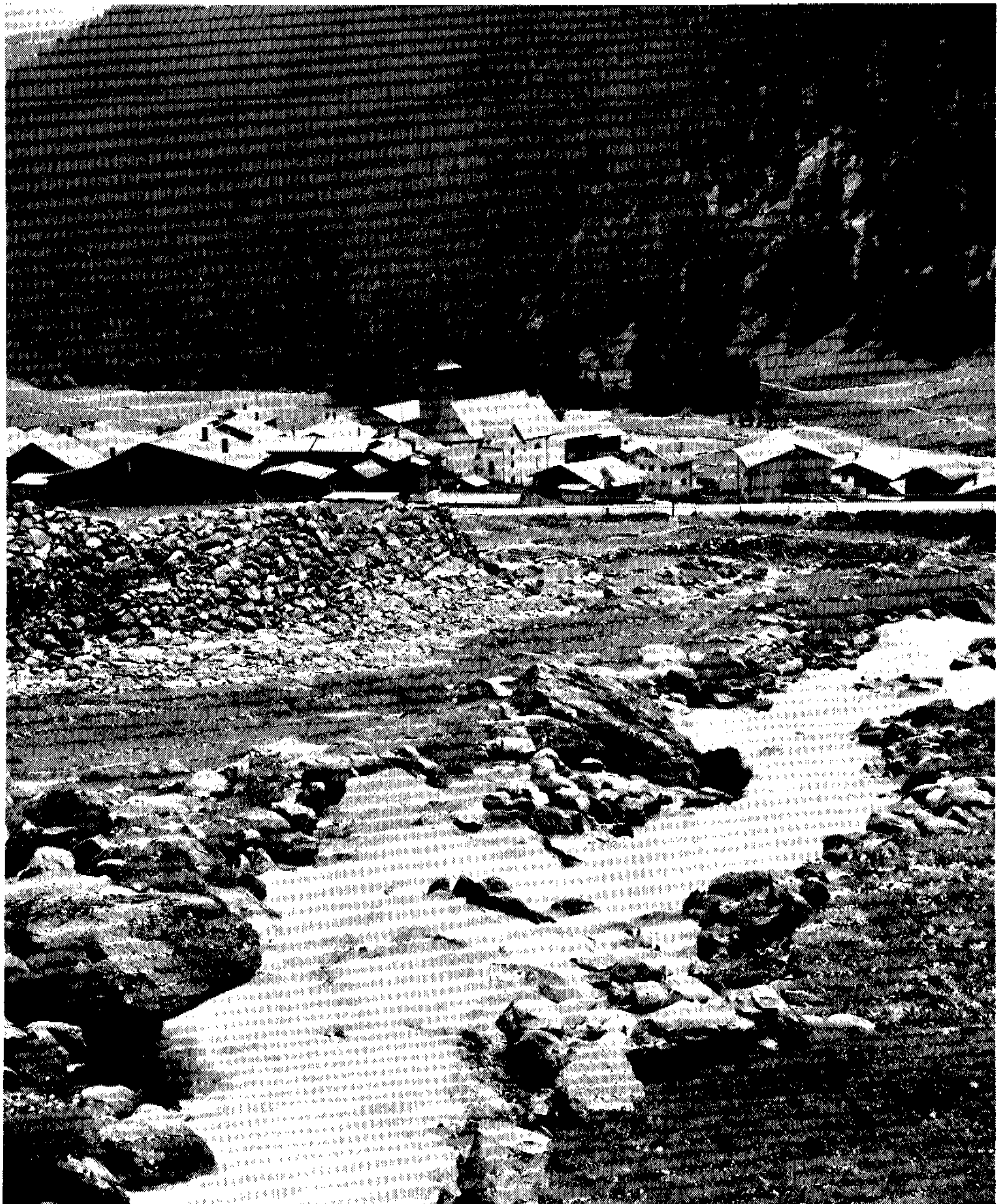
THE P.P.I. AS AN INDICATOR FOR SANITATION PROGRAMMING

From Figure 7 it is evident that even in the case of rivers with P.P.I. values as low as 0,01 the presence of coliform and pathogenic bacteria will be prohibitive for the direct use of river water as drinking water. Any community water supply using river water should at least apply chlorination or slow sand filtration. As the content of faecal organisms increases very rapidly with increasing P.P.I. values a disinfection of municipal effluents should be strived after starting at P.P.I. levels of 10 - 100. This is specially important both in view of water supply, and of recreational purposes.

As plant nutrients like Phosphate and Nitrate depend even at low P.P.I. ranges on P.P.I. it is recommendable to start eutrofication abatement already at P.P.I. values of 0.1, as far as Phosphate removal from municipal waste water can reduce the total Phosporous input considerably and for those cases that river water stagnates. At higher P.P.I. values of 10 - 100 the river water will become very eutrophic and reduction of the potential phosphorous input (e.g. by a tertiairy treatment at sewage treatment plants) is absolutely necessary for rivers with stagnating parts. Rivers with a P.P.I. of 10 - 100 will potentially be threatened by anaerobic conditions. Exhaustion of dissolved oxygen in a river is absolutely unacceptable and must be prevented by biological sewage treatment plants. As the content of various heavy metals and probably also the content of toxic organic micropollutants will be considerable above the natural level at P.P.I. values of 10 and more, water works should not only apply coagulation, softening and sand filtration processes, but also ozoniation and activated carbon filtration to minimize the risk of chronic toxic effects. As concerns waste water discharge, a stringent control of the discharge of individual pollutants like pesticides, mercury compounds etc. must be executed.

At P.P.I. levels of rivers above 100 a very rigorous sanitation program must be realized by an extensive and effective organization for river water quality management and examination. Even then it will be difficult to establish a healthy river water quality that can support a well-balanced ecosystem. At these high P.P.I.-values community water supply will be confronted with new problems like concentrations of parameters as Fluoride, Nitrate and Chloride that exceed the standards for drinking water. Unless the discharge of these pollutants is reduced these heavily polluted rivers might become excluded as sources for community water supply. In this situation mixing with possibly available good quality water from other sources is one possibility and application of desalination techniques is another to arrive at drinking water quality.

The Hudson near New York, N.Y., U.S.A. (Photo by J.M.G. van Damme)



The origin of the Rhine in Switzerland (Photo from VEWIN)

CASE-STUDY OF THE RHINE

As the river Rhine has already a long history of pollution, it is interesting to check the P.P.I.-concept on its case. A prognosis of the increase of the P.P.I. for the river Rhine at Lobith (Dutch-German border) over the period 1850 - 2000 is given in Figure 8. This prognosis is based on the situation in 1970 with a total population in the drainage area of 41 million, a G.N.P./Cap. of U.S. $ 2100 and a P.P.I. of 39. Using data of Statistische Jahrbuch für die Bundesrepublik Deutschland (1972), Annulaire statistique de la France (1967), Statistisches Jahrbuch der Schweiz (1972) and of KAHN AND WIENER (1967) the following growth rates have been derived: population growth 1%/year for 1850-1970 and 0.8%/year for 1970-2000; growth of the G.N.P./Cap. 1.8%/year for 1850-1950 and 3.8%/year for 1950-2000.

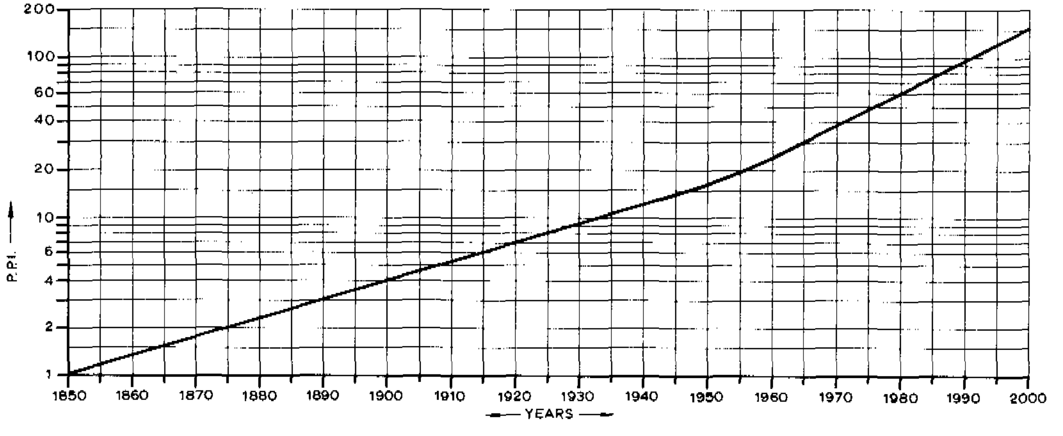
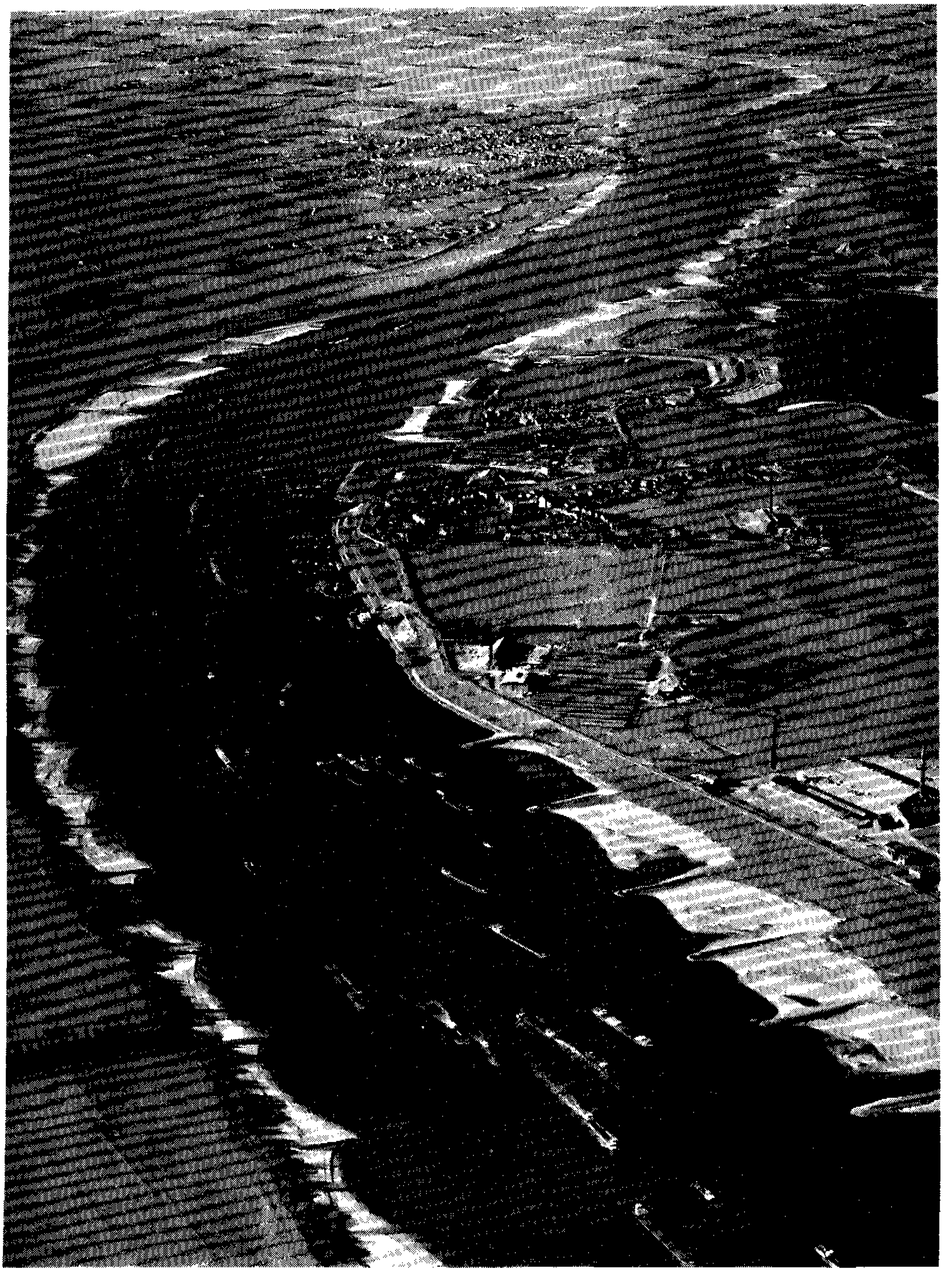


FIG.8 POTENTIAL POLLUTION INDEX FOR THE RIVER RHINE AT LOBITH (PERIODE 1850-2000)



The Rhine at the Dutch-German border (Photo from VEWIN)

Considering water quality data from MOLT (1961) and the International Commission for the Protection of the river Rhine against Pollution some trends are calculated and presented in Figure 9. Although Phosphate concentrations are somewhat below the average level, concentrations of other parameters and especially of Chloride are considerably above the average trend. Table 4 gives a survey of future concentrations that must be expected in case adequate sanitation measures are not realized.

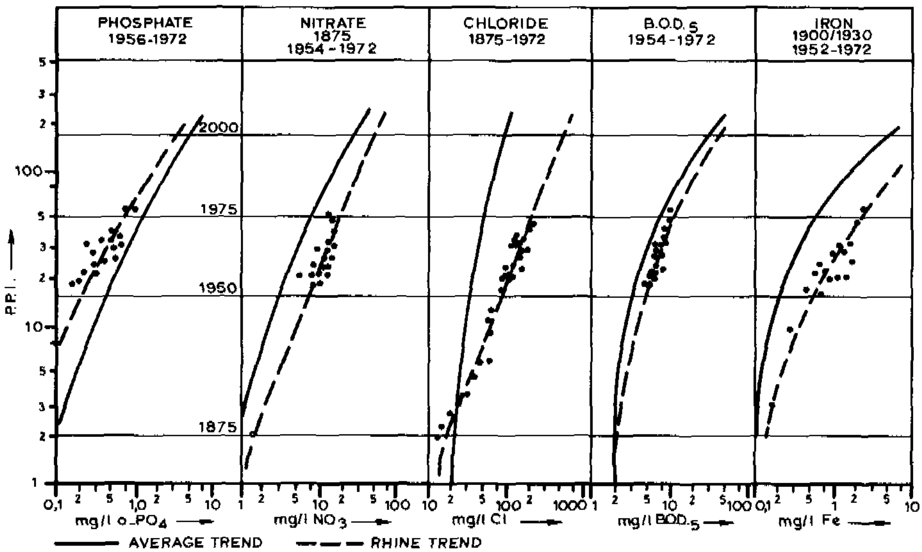
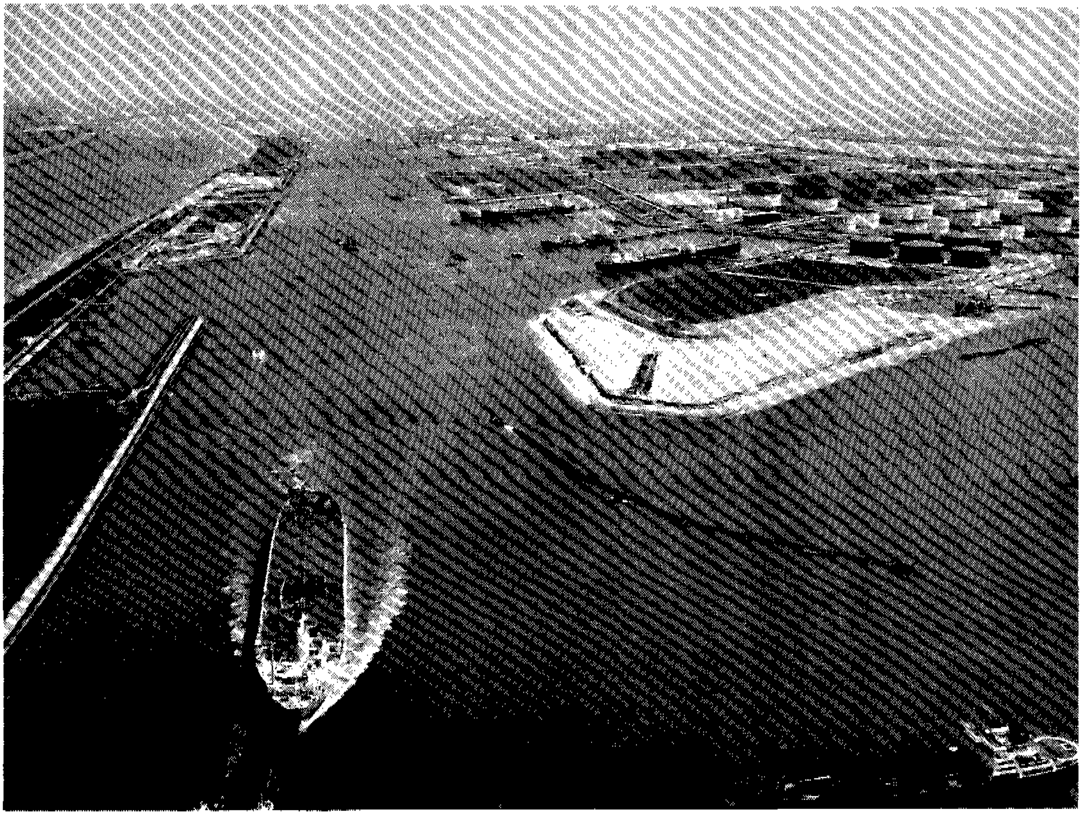


FIG. 9 RELATION P.P.I. AND FIVE PARAMETERS FOR THE RHINE (YEARLY AVERAGE VALUES)



The Rhine-delta, harbours and chemical industry near Rotterdam, The Netherlands. (Photo from Bart Hofmeester)

Table 4. Prognosis for five parameter concentrations in 1980 and 2000 in case sanitation measures are omitted in the drainage area of the river Rhine (values for average discharge of 2200 m^3/s).

Parameter	Concentration			
	1875	1970	1980	2000
Ortho-Phosphate (mg/l)	0.05	0.70	1.0	3.0
Nitrate (mg/l)	1.5	13	20	45
Chloride (mg/l)	12	160	250	500
BOD_5 (mg O_2/l)	2.0	9.0	13	40
Iron (mg/l)	0.15	2.0	3.5	20

These values emphasize once again the need to establish in an early stage of pollution the construction of treatment plants and the necessary legislation and enforcement for pollution abatement. In this context it is useful to confront the general sanitation profile with history and plans for the river Rhine as shown in Fig.10.

GENERAL PPI. RANGE	WASTE WATER TREATMENT		TREATMENT FOR WATER SUPPLY		YEAR FOR THE RHINE
	PROCESSES	REALISATION AT RHINE-PPI.	PROCESSES	REALISATION AT RHINE-PPI.	
<0.1	NON		CHLORINATION SLOWSAND FILTRATION	2.0	1875
0.1-10	P-REMOVAL RECOMMENDED		BREAKPOINT CHLORINATION COAGULATION-SOFTENING RAPID SAND FILTRATION	15	1945
10-100	SEDIMENTATION BIOLOGICAL OXIDATION DISCHARGE RESTRICTIONS	50	MIXING BIJ STORAGE RESERVOIRS OZONIZATION ACTIVATED CARBON ABS.	50	1975
	P-REMOVAL-TERT.TREATM. EFFLUENT DISINFECTION	(75)		(75)	1985
>100	ADVANCED TREATMENT ADVANCED DISCH. RESTR.	(150)	(DESALINATION)	(150)	2000

FIG. 10 GENERAL SANITATION PROFILE AND THE CASE OF THE RHINE

FINAL CONSIDERATIONS

As has been elaborated in this paper the P.P.I. concept offers a general matrix for water quality data of different origin, different kind and different time. From this matrix general trends can be derived to deduce river water quality in the past and to extrapolate quality trends to the future. Furthermore the P.P.I. concept can be extended to a scientific yardstick in the process of decision making concerning sanitation programming. The more data on water quality are available the more precise this yardstick will be. For this purpose a detailed study has to be undertaken on the relation of P.P.I. with the presence of micropollutants, with specified sanitation programs and with biological parameters like quantity and quality of algae and fishes. Last but not least P.P.I. can be used for the communication of information on water quality. The Water Quality Index of BROWN, MCCLELLAND AND DEININGER (1972) of the National Sanitation Foundation, Ann Arbor, Michigan that has been developed for this purpose might be supplemented by an "Actual Pollution Index". An Actual Pollution Index can be derived from P.P.I.-concentration relations (see Figure 9) by calculating for each parameter the P.P.I. value that corresponds with the actual concentration. The Actual Pollution Index can be defined as the average of the sum of these "appearant" P.P.I. values for the different parameters. Like the Water Quality Index the Actual Pollution Index (A.P.I.) represents the actual river water quality. The difference between P.P.I. value and A.P.I. value of a river can be considered as a measure for the effect of sanitation programs. The lowest attainable value for A.P.I. will be the already mentioned Natural Potential Pollution Index ($P.P.I._N$).

It is sincerely hoped that the P.P.I. concept will stimulate people's imagination concerning the extend of future water quality problems and that it will contribute in this way to people's willingness to support the many activities that are needed now for the restoration and preservation of a healthy water quality in the rivers on earth.

ACKNOWLEDGEMENT.

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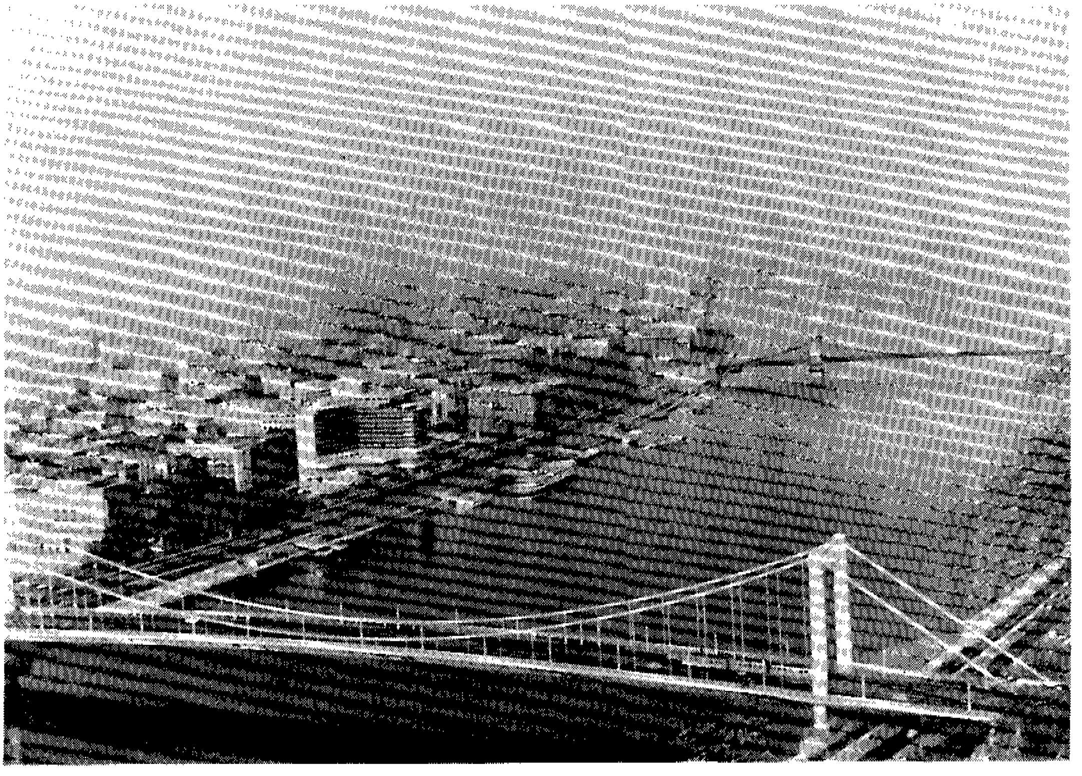

The Danube at Budapest (Photo by J.M.G. van Damme)

APPENDIX

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
AFRICA	BLUE NILE	KHARTOEM	SUDAN	1970	1640	325.000	0.12
	TEGULA	NEAR MOUTH	S. AFRICA	1960	184	29.000	1.8
AMERICA (NORTH)	ALTAMAHA	DOCTORTOWN	U.S.A. (GA.)	1968	253	35.000	5.6
	MERICAN	EL DORADO	U.S.A. (CAL.)	1965	100	8.000	68
	APALACHICOLA	CHATTAHOOCHEE	U.S.A. (FLA.)	1968	628	44.000	2.8
	ARKANSAS	LITTLE ROCK	U.S.A. (ARK.)	1965	1140	410.000	14
	CIMARRON	PERKINS	U.S.A. (OKLA.)	1970	32	46.000	69
	COLORADO	COLOR. RIV. AQUAD. INT.	U.S.A. (CAL.)	1969	730	640.000	10
	COLUMBIA	BONNEVILLE	U.S.A. (ORE.)	1965	5520	614.000	2.2
	CONNECTICUT	THOMPSONVILLE	U.S.A. (CONN.)	1965	451	25.000	9.1
	CUMBERLAND	CHEATHAM LOCK	U.S.A. (KY.)	1965	779	46.000	4.6
	DELAWARE	TRENTON	U.S.A. (N.J.)	1965	327	18.000	11
	ESCAMBIA	CENTURY	U.S.A. (FLA.)	1965	173	10.000	3.5
	GRAND NEOSHO	FT. GIBSON	U.S.A. (OKLA.)	1970	178	32.000	8.6
	GREEN	DUTCH JOHN	U.S.A. (UTAH)	1965	181	105.000	5.5
	ILLINOIS	PEORIA	U.S.A. (ILL.)	1965	425	33.000	16
	KASKASKIA	SHELBYVILLE	U.S.A. (ILL.)	1965	11	2.500	19
	KASKASKIA	NEW ATHENS	U.S.A. (ILL.)	1965	345	13.000	4.5
	KLAMATH	KLAMATH	U.S.A. (CAL.)	1970	505	26.000	0.57
	LOWER ARKANSAS	TULSA	U.S.A. (OKLA.)	1970	835	383.000	22
	LOWER RED	DENISON DAM	U.S.A. (OKLA.)	1970	333	123.000	18
	MAUMEE	TOLEDO	U.S.A. (OHIO)	1965	127	16.000	10
	MERRIMACK	LOWELL	U.S.A. (MASS.)	1965	205	12.000	2.3
	MISSISSIPPI	ALTON	U.S.A. (ILL.)	1965	2620	444.000	6.9

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
AMERICA (NORTH)	MISSISSIPPI	EAST ST. LOUIS	U.S.A. (ILL.)	1965	5000	1800.000	21
	MISSISSIPPI	VICKSBURG	U.S.A. (MISS.)	1965	15800	3000.000	7.6
	MISSOURI	CULBERTSON	U.S.A. (MONT.)	1966	252	237.000	7.5
	MISSOURI	YANKTON	U.S.A. (S.D.)	1965	689	724.000	8.1
	MISSOURI	ST. LOUIS	U.S.A. (MISS.)	1965	2200	1370.000	13
	NORTH CANADIAN	OKLAHOMA	U.S.A. (OKLA.)	1970	19	36.000	89
	OHIO	TENNEYSON	U.S.A. (OHIO)	1970	2800	200.000	6.0
	OHIO	LOUISVILLE	U.S.A. (KY)	1965	3120	240.000	6.2
	OHIO	CAIRO	U.S.A. (ILL.)	1965	7300	500.000	5.5
	OUACHITA	BASTROP	U.S.A. (LA.)	1965	507	40.000	4.8
	POTOMAC	GREAT FALLS	U.S.A. (MA.)	1970	300	29.000	8.1
	RED	GRAND FORKS	U.S.A. (N.D.)	1965	69	78.000	23
	RED	ALEXDRIA	U.S.A. (LA.)	1965	880	175.000	5.9
	RIO GRANDE	LAREDO	U.S.A. (TEX.)	1965	123	352.000	11
	ROCK	COMO	U.S.A. (ILL.)	1965	175	22.000	10
	SABINE	RULIFF	U.S.A. (TEX.)	1965	239	24.000	6.1
	SACRAMENTO	FREEPORT	U.S.A. (CAL.)	1970	870	69.000	7.4
	SACRAMENTO	SACR. DELTA	U.S.A. (CAL.)	1965	650	70.000	7.4
	SAN JOAQUIN	VERNALIS	U.S.A. (CAL.)	1970	248	31.000	9.2
	SANTA ANA	PRADO DAM	U.S.A. (CAL.)	1970	13	6.300	980
	SANTA CLARA	SANTA PAULA	U.S.A. (CAL.)	1970	8	4.000	270
	SATILLA	ATKINSON	U.S.A. (GA.)	1968	24	7.000	12
	SAVANNAH	CLYO	U.S.A. (GA.)	1968	280	25.000	3.6
	SKILLET FORK	WAYNE CITY	U.S.A. (ILL.)	1960	1.3	1.200	110
	SNAKE	ICE HARB. DAM	U.S.A. (WASH.)	1965	1390	267.000	3.7
	SOUTH CANADIAN	OKLAHOMA	U.S.A. (OKLA.)	1970	150	122.000	3.9

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
AMERICA (NORTH)	SUSQUEHANNA	CONOWINGO	U.S.A. (MA.)	1965	963	63.000	8.0
	ST. LAWRENCE	OGDENSBURG	U.S.A. (N.Y.)	1971	6760	765.000	2.3
	UPPER ARKANSAS	KEYSTONE RES.	U.S.A. (OKLA.)	1970	126	140.000	53
	UPPER RED	DENISON RES.	U.S.A. (OKLA.)	1970	80	78.000	4.6
	VERDIGRIS	INOLA	U.S.A. (OKLA.)	1970	109	20.000	8.8
	WABASH	RIVERTON	U.S.A. (IDIAN.)	1965	236	33.000	11
	WASHITA	DENISON RES.	U.S.A. (OKLA.)	1970	39	18.000	2.2
	WILLAMETTE	PORTLAND	U.S.A. (ORE.)	1965	665	19.000	0.60
	YELLOWSTONE	SIDNEY	U.S.A. (MONT.)	1965	365	178.000	2.0
ASIA	ANGAT	IPE DAM	PHILIPPINES	1965	40	600	0.009
	CAM-LE	DA-NANG	VIETNAM (SOUTH)	1970	125	6.300	0.34
	DONG-NAI	BIEN-HOA	VIETNAM (SOUTH)	1970	400	22.000	0.59
	HUTT	HUTT CITY	NEW ZEALAND	1972	83	650	26
	JAJRUD	LATIAN	IRAN	1970	5.4	710	0.20
	JORDAN	GESHER BENAT YAAFEV	ISRAEL	1968	17.5	1.530	0.86
	KARAJ	SIERA	IRAN	1970	10	725	0.11
	MEKONG	CHAU-DOC	VIETNAM (SOUTH)	1966	14500	650.000	0.068
	WAIKATO	HAMILTON	NEW ZEALAND	1972	235	8.200	0.86
AUSTRALIA	DENMARK	DENMARK WEIR	AUSTRALIA	1971	11	500	0.062
	MURRAY	MANNUM	AUSTRALIA	1970	310	92.000	0.18
	ONKAPARINGA	MT. BOLD RES.	AUSTRALIA	1970	4	390	2.1
EUROPE	AURAJOKI	TURKU	FINLAND	1969	18	2.000	45
	AVON	LODDISWELL	UN. KINGDOM	1968	1.3	100	24
	AXE	WHITFORD	UN. KINGDOM	1968	1.8	290	32

Mississippi River near New Orleans, La. U.S.A. (Courtesy of National Ocean Survey - NOAA)

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I
1	2	3	4	5	6	7	8
EUROPE	BLYTHE	BLYTHE BRIDGE	UN. KINGDOM	1970	0.5	190	200
	CHARADROS	CHARADROS	GREECE	1970	0.2	80	11
	CHELMER/ BLACKWATER	LANGFORD	UN. KINGDOM	1971	3.2	980	110
	COLNE	COLCHESTER	UN. KINGDOM	1971	1.1	256	41
	COQUET	WARKWORTH DAM.	UN. KINGDOM	1970	6.0	600	5.4
	CRAKE	SPARK BRIDGE	UN. KINGDOM	1971	4.3	73	2.3
	CUCKMERE	CONBEECH	UN. KINGDOM	1970	0.2	19	80
	DANUBE	BUDAPEST	HUNGARY	1970	2400	48.000	3.8
	DART	AUSTINS BRIDGE	UN. KINGDOM	1968	4.4	250	17
	DEE	CHESTER	UN. KINGDOM	1970	39	1.800	8.3
	DERWENT	WILNE	UN. KINGDOM	1970	20	1.180	38
	DERWENT	ELVINGTON	UN. KINGDOM	1970	16	1.630	54
	DOVE	MONKSBRIDGE	UN. KINGDOM	1970	15	890	17
	DUDDON	DUDDON BRIDGE	UN. KINGDOM	1971	4.8	78	7.5
	EAST CLEDDAU	CANASTON BRIDGE	UN. KINGDOM	1970	6.2	180	1.7
	ERME	ERMINGTON	UN. KINGDOM	1968	0.8	61	22
	ESK	RUSWARP	UN. KINGDOM	1970	4.0	300	6.7
	EURAJOKI	EURAJOKI	FINLAND	1969	11	1.300	6.8
	EXE	THORVERTON	UN. KINGDOM	1968	5.9	600	18
	GLOMMA	KONGSVINGER	NORWAY	1970	292	19.000	0.53
	GLOMMA	EIDSBERG	NORWAY	1970	683	40.000	1.2
	GOTA ALV	GÖTEBORG	SWEDEN	1970	320	25.000	3.5
	KEMIJOKI	KEMI	FINLAND	1969	540	51.000	0.65
	KENT	LEVELS BRIDGE	UN. KINGDOM	1971	11	220	4.3

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
EUROPE	KIFISSOS	BUKA KAPAÏDOS	GREECE	1970	4.8	2.300	14
	KOKEMÄENJOKI	PORI	FINLAND	1969	210	27.000	9.3
	KYMIJOKI	KARHULA	FINLAND	1969	280	37.000	4.9
	KYRÖNJOKI	MUSTASAARI	FINLAND	1969	43	4.800	5.4
	LEE	CHINGFORD, ESSEX	UN. KINGDOM	1970	6.5	1.200	265
	LEVENS	HAVERTHWAITE	UN. KINGDOM	1971	15	360	3.1
	LOUGHOR	TIR-Y-DAIL	UN. KINGDOM	1970	2.1	80	2.6
	LULE ÄLV	BODEN	SWEDEN	1970	500	24.500	0.13
	LUNE	HALTON	UN. KINGDOM	1971	36	1.000	3.9
	MAIN	KOSTHEIM	FED.REP.GERMANY	1970	237	27.000	45
	MÄLAREN-NORRSTRÖM	STOCKHOLM	SWEDEN	1970	170	23.000	10
	MERSEY	HOWLEYWEIR	UN. KINGDOM	1970	42	2.000	129
	MEUSE	LIEGE	BELGIUM	1971	100	21.000	60
	MEUSE	LITH	NETHERLANDS	1971	125	29.000	63
	MOTALA STRÖM	NORRKÖPING	SWEDEN	1970	90	15.000	9.8
	NECKAR	DOPPENWEILER	FED.REP.GERMANY	1970	189	14.000	49
	NENE	ORTON	UN. KINGDOM	1970	12	1.600	71
	OTTER	DOTTON	UN. KINGDOM	1968	1.2	200	33
	OURTHE	LIÈGE	BELGIUM	1971	30	3.600	32
	OULUJOKI	OULU	FINLAND	1969	230	23.000	1.8
	OUSE	BARCOMBE	UN. KINGDOM	1970	4.7	395	26
	OUSE	YORK	UN. KINGDOM	1970	63	3.315	9.5
	RHINE	BASEL	SUISSE	1969	965	36.000	9.3
	RHINE	LOBITH	NETHERLANDS	1970	3100	160.000	27

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
EUROPE	RHÔNE	BEAUCAIRE	FRANCE	1970	1700	96.000	13
	RIBBLE	PRESTON	UN. KINGDOM	1971	33	1.150	31
	RINGSJÖN	HÄLSINGBORG	SWEDEN	1970	4.0	400	6.5
	ROTHER	HARDHAM	UN. KINGDOM	1970	4.5	350	16
	SAMBRE	NAMUR	BELGIUM	1971	15	2.800	108
	STÄNGÄN	LINKÖPING	SWEDEN	1970	14	2.400	3.5
	STORSJÖN	ÖSTERSUND	SWEDEN	1970	240	12.000	0.30
	STOUR	STRATFORD ST. MARY	UN. KINGDOM	1971	3.0	850	50
	SVARTÅN	ÖREBRO	SWEDEN	1970	12	1.400	4.5
	TÂF	CLOGYFRAN	UN. KINGDOM	1970	7.3	220	2.0
	TAW	UMBERLEIGH	UN. KINGDOM	1968	6.3	830	12
	TAWE	YNYSTANGLWS	UN. KINGDOM	1970	13	230	0.95
	TEES	BROKEN SCAR	UN. KINGDOM	1970	20	2.000	54
	TEIFY	GLAN TEIFY	UN. KINGDOM	1970	34	890	1.4
	TEIGN	PRESTON	UN. KINGDOM	1968	3.7	380	32
	THAMES	TEDDINGTON	UN. KINGDOM	1970	96	7.900	52
	TISZA	SZEGED	HUNGARY	1970	815	45.000	5.7
	TORNIONJOKI	ALATORNIO	FINLAND	1969	370	40.000	0.51
	TORRIDGE	TORRINGTON	UN. KINGDOM	1968	5.5	660	11
	TOWY	TY CASTELL	UN. KINGDOM	1970	46	1.100	0.13
	TRENT	NOTTINGHAM	UN. KINGDOM	1970	82	7.500	97
	TYNE	WYLAM	UN. KINGDOM	1970	26	3.000	73
	USK	CHAIN BRIDGE	UN. KINGDOM	1970	29	900	16
	VANTAA	HELSINKI	FINLAND	1969	15	1.700	47

The frozen Potomac River at Washington D.C., U.S.A. (Courtesey of National Ocean Survey - NOAA)

CONTINENT	RIVER	LOCATION	COUNTRY	YEAR	DIS-CHARGE m^3/s	DRAIN-AGE AREA km^2	P.P.I.
1	2	3	4	5	6	7	8
EUROPE	VARNAVAS	VARNAVAS	GREECE	1970	0.2	50	7.4
	VÄTTERN	JÖNKÖPING	SWEDEN	1970	35	6.400	17
	VOMBSJÖN	MALMÖ	SWEDEN	1970	4	450	3.9
	WALLERSHAVEN	BOREHAM BRIDGE	UN. KINGDOM	1970	0.27	60	19
	WANSBECK	BELOW MITFORD	UN. KINGDOM	1970	1.4	350	90
	WEAR	COCKEN BRIDGE	UN. KINGDOM	1970	10	1.200	65
	WELLAND	TALLINGTON	UN. KINGDOM	1970	4.0	720	90
	WEST CLEDDAU	PRENDEGAST	UN. KINGDOM	1970	6.5	200	1.7
	WHARFE	ADDINGHAM	UN. KINGDOM	1970	15	440	8.0
	WYE	BELMONT	UN. KINGDOM	1970	47	1.900	3.4
	WYRE	ST. MICHAELS	UN. KINGDOM	1971	6.2	270	34

Finally a river delivers its pollution to the sea (Photo by J.M.G. van Damme)