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A Simulation of the Oxygen Profile in the Han River

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ABSTRACT

The stochastic profile of variability of biochemical oxygen demand (BOD) and dissolved oxygen (DO) in the Han River has been considered with Streeter-Phelp's equation.

According to the nature of the Han River, the BOD removal coefficient, K_1, and the reaeration coefficient, K_2 values, were calculated at an average of 0. 157 and 0. 97 respectively at 20°C in the spring.

Where the levels of BOD would be high in relation to the standard of water quality, the treatment for sewage and industrial wastes from tributaries of Seoul City should be performed with proper efficiency. Before 1985 plants with 90% efficiency should be installed at every outlet of the tributaries. The level of DO is not a relevant parameter to assess the pollution in the Han River. The description of the oxygen profile of the Han River also suggests monitoring points for inspection of water quality.

INTRODUCTION

The Han River is one of the big rivers in Korea. Its downstream portion is used as a resource for water supply as well as the receptacle for domestic sewage and industrial wastes of the capital city of Korea, Seoul, which has more than 6 million inhabitants (Fig. 1) In Seoul City along the river side, there are five plants for city water supply, producing 1. 2 million tons per day. In 1970[1] the pollution level was already 13. 0 ppm of BOD at Kwangjang Kyo which is on the upper border of Seoul along the Han River, 30. 5 ppm at the first bridge of the Han River and 36. 7 ppm at the second bridge of the Han River which are both in the middle of Seoul. The situation is growing worse day after day, and since 1960 swimming in the river in the Seoul area has been prohibited by the authorities. In 1974, moreover, the pumping stations for tap water which had been located in the Seoul area were being moved to the Pal-dang Dam site upstream, about 30 Km from the Seoul City boundary. If the effluent discharge from Seoul City is left untreated, the river will be greatly polluted and will become worse and worse because of the increasing population and industry along the Han River especially in the Seoul-Inchon area, a heavily industrialized zone, since 1960. Recently a plant for sewage treatment has been built at the outlet of the Chung-Kae stream and it has a 50% efficiency of treatment for this stream.

Table 1. Discharge of Sewage and Industrial Wastes from Seoul into the Han River

Stream	Catchment area (ha)	1971		Projected for 1985	
		Population (×1000)	Discharge (×1000 MTD)	Population (×1000)	Discharge (×1000 MTD)
Chung Kae S.	5, 634	1, 750	380	1, 700	730
Jung Ryang S.	23, 740	830	172	1, 206	490
Uk S.	1, 237	365	78	300	128
Kong Duk S.	227	180	39	105	46
Bong Won S.	652	275	59	200	85
Hong Jae S.	2, 696	281	61	330	141
Bull Kwang S.	2, 354	294	63	350	150
Tan S.	24, 150	165	16	305	108
Yang Jae S.	6 340	14	2	285	102
Ahn Yang S.	28, 278	1, 020	230	1, 862	795
Sa Dang S.	1, 552	157	33	387	171
Ban Po S.	1, 630	40	8	270	119
Sung Nae S.	3, 200	140	30	390	159
Ku Yee-Sung Soo Area	1, 020	135	28	250	100
Yee Chon- Eung Bong Area	1, 165	349	76	317	130
Ro Ryang Area	626	157	35	157	65
Ryo Eu-Jam Sil	650	—	—	200	81
Total	105, 151	6, 152	1, 310	8, 614	3, 600

(Data from Seoul City, Oct. 1972)

This study was undertaken to learn the effects of discharge from the dwellings and industrial areas in Seoul upon the quality of the water in the river and to evaluate the efficiency of the sewage treatment plants to be installed at the outlets of the tributaries which discharge sewage and waste, causing pollution of the river.

Status of the Han River Basin

Topographical situation

The Han River is located in the middle of the Korean peninsula; It springs from Mt. Tae-baek and reaches the Yellow Sea. This river, consisting of the union of two streams, the North Han River and the South Han River, which merge 35 Km north east of Seoul, flows through Seoul City. From the origin of the North Han River to the conflux with the

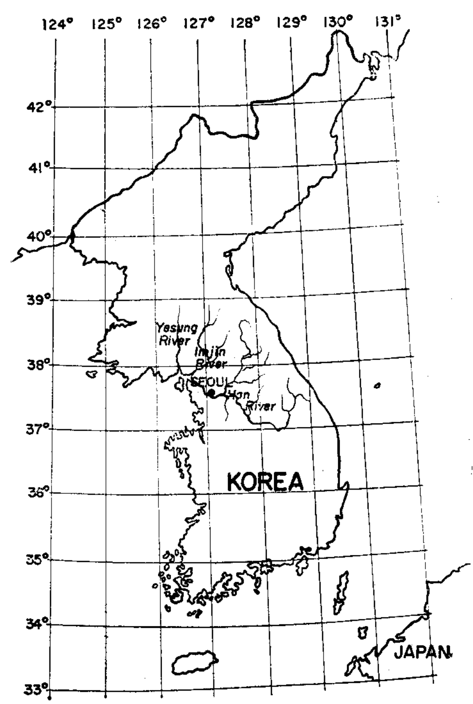

Fig. 1. Situs of the Han River.

Im-jin River, the boundary of North Korea (DMZ), it is about 180 Km long and from the DMZ to the estuary of the Yellow sea it about 80 Km.

The Han River Basin of which 3,248 Km^2 belongs to North Korea occupies a total of 26,219 Km^2, which is equal to about one-fourth of the area of South Korea. The area of the catchment of the North Han River is 10,652 Km^2; the South Han River, 12,514 Km^2; and the main Han River, a segment extending from the conflux to the estuary, is 3,053 Km^2. The slope of the river upstream is about 4 m per Km and in the main Han River, about 20 Cm per Km. This study was done in the main Han River downstream from Seoul City and industrial areas. The main Han River has been polluted largely by discharge from the Seoul area. The amount of discharge of sewage and industrial wastes from the tributaries of the Han River around Seoul City is shown in Table 1.

Climate and Hydrology

The Korean peninsula has four distinct seasons, affected by the tropical weather of the South Pacific Ocean in the summer and by the dry cold weather of Siberia in the winter. The temperature reaches a maximum of 40°C in summer and a minimum of −30°C in winter. The temperature variations for Seoul in the Han River Basin are shown in Fig. 2.

In the Han River Basin, there is an average amount of precipitation (1,200 mm annually), which has a direct relationship to the amount of river flow. During the rainy seasons, from the beginning of July to early September, more than 70% of the year's precipitation occurs (Table 2).

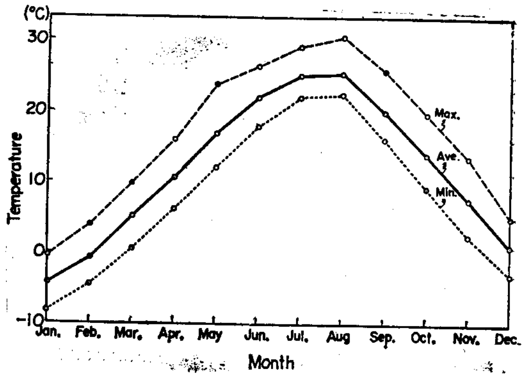

Fig. 2. Temperature of Seoul (1957~1969).

The main Han River flow averages 17,860 $\times 10^6 m^3$ a year at the first bridge of the Han River, with maximum discharges of 32,450 $\times 10^6 m^3$ the rainy season and minimum discharges of 7,160 $\times 10^6 m^3$ in the dry season, with a 300~500 m range in width and a 2~10 m range in depth (Table 3, Fig. 3).

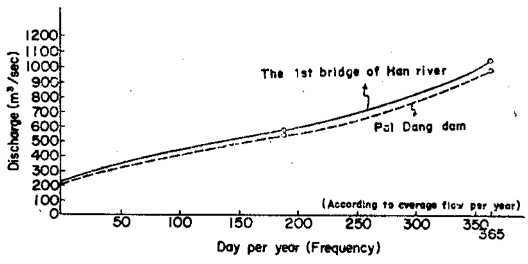

Fig. 3. Discharge Duration of the Han River.

Table 2. Precipitation and Evaporation in Seoul (1931-1966)

Month / Item	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average and total
Temperature (°C)	−4.9	−1.9	3.6	10.5	16.3	20.8	24.5	25.4	20.3	13.4	6.3	−1.2	11.1
Precipitation (mm)	17.1	21.0	55.6	68.1	86.3	169.3	358.0	224.2	142.3	49.2	36.0	32.0	1259.2
Evaporation (mm)	42.0	48.9	80.2	121.9	155.8	147.2	130.2	140.8	114.8	92.8	59.8	42.0	1176.0

Table 3. Discharge of the Han River

Point \ Item	Catchment area (Km^2)	Average flow ($10^6 m^3/yr$)	Average flow per unit area ($10m^3/Km^2/yr$)	Max. Flow ($10^6 m^3/yr$)	Min. Flow ($10^6 m^3/yr$)
The 1st bridge of the Han River	25, 047	17, 860	713	32, 450	7, 160
Pal dang dam	23, 713	16, 916	713	30, 691	6, 775
So yang dam	2, 703	1, 856	663	3, 099	781
Chung ju dam	6, 648	4, 428	665	7, 760	1, 715
Yo ju dam	10, 319	7, 300	707	15, 818	2, 578
Hong chun dam	1, 473	1, 094	744	2, 041	438
Dal chun dam	1, 348	1, 058	784	3, 192	293
Kan Yun dam	1, 180	926	784	2, 796	253
Im jae dam	461	316	692	655	89

Method

The computation of oxygen profile

The execution of a program for the computation of DO and BOD at several points in the polluted river was carried from the Streeter-Phelp's equation[2~4]. The relationship existing among the various factors involved in oxygen dynamics can be expressed in the following greatly simplified differential equations:

$$\frac{dL(t)}{dt}=\begin{cases}-K_1L(t), & \text{when } DO>0 \\ 0 & DO=0\end{cases} \quad \cdots\cdots(1)$$

$$\frac{d}{dt}DO(t)=K_2(Ds-DO(t))\begin{cases}K_1L(t), & \text{when } DO>0 \\ 0 & DO=0\end{cases} \quad \cdots\cdots\cdots\cdots(2)$$

Where $L(t)$: BOD load concentration(mg/l)

$L(o)$: Initial BOD concentration (mg/l)

K_1: BOD removal coefficient(day^{-1})

$DO(t)$: Dissolved oxygen concentration(mg/l)

$DO(o)$: Initial dissolved oxygen concentration(mg/l)

Ds: Dissolved oxygen concentration at saturation(mg/l)

K_2: Reaeration coefficient(day^{-1})

t: Residence time from source of pollution(day)

The exact solution of the differential equations(1) and (2) is:

(1) $L(t)=L(o)\,e^{-K_1t}$

(2) $DO(t)=Ds-\frac{K_1L(o)}{K_2-K_1}(e^{-K_1t}-e^{-K_2t})$

From these two equations and both differential equations the expression for the time that the minimum DO value occurs can be found:

$$t_{min}=\frac{\ln(A)-\ln(B)}{K_2-K_1}$$

with $A=\frac{K_1\cdot K_2}{K_2-K_1}L(o)-K_2\{Ds-DO(o)\}$

$B=\frac{K_1}{K_2-K_1}L(o)$

This time can also be converted to distance. At differential temperature, the conversion formulae of K_1 and K_2 values are used[5]:

$$K_1=K_1(20)\cdot 1.047^{(T-20)}$$

$$K_2=K_2(20)\cdot 1.0159^{(T-20)}$$

This computation of the oxygen profile was worked out by using a computer, terminal IBM.

Calculation of K_1 and K_2 values

The rate of up-take of oxygen can be written[5]:

$$-\frac{dL}{dt}=K_1L$$

Table 4. The Calculation of K_1

Station	Distance(Km)	L(ppm)	Lo(ppm)	t*	$K_1(d^{-1})$
Kwang Jang kyo	0	20.7	14.2	4	0.194
Duk do	7.5	43.7	29.7	6	0.129
Bo Kwang dong	12.0	38.4	26.3	5	0.157
The 1st bridge	14.5	33.9	23.2	5	0.157
The 2nd bridge	19.0	69.5	47.6	7	0.112
Ryum Chang dong	21.0	48.1	32.9	6	0.129
Average				5	0.157

(t* could be assumed by the graphical estimation)

Where: L is the ultimate first-stage oxygen demand at anytime, t.
and K_1 is the rate-constant of oxidation, referred to as the deoxygenation constant.

The integrated form of this equation is;

$$Lt = Lo\ e^{-k_1 t} = Lo\ 10^{-K_1 t}$$

Where: Lo is the initial first stage BOD, L is the ultimate first stage BOD, which can be calculated as $1.46 \times Lo$[3] and Lt is BOD remaining at any time, (L − Lo).

The value of the coefficient in the model equation is dictated by the observed data. From the BOD determined at the various points in the Han River[6], the K_1 value was predicted to average 0.157(Table 4).

The rate of reaeration, K_2, could be worked out according to the prediction method of Churchill, Elmore and Buckingham[7].

The magnitude of K_2 at 20°C can be expressed with reasonable success by the observational relationship:

$$K_2 = 5V/R^{5/3}$$

Where: V is the mean velocity of flow in a given river stretch and R is its mean hydraulic radius, often referred to as depth of the river.

According to hydrologic data of the Han river, the various results of K_2 could be obtained as follows (Table 5).

The study area and its division

The stretch of the Han River under consideration is from Kwang Jang Kyo to an area down stream Hang Ju, a distance of some 41 Km, which exhibits considerable pollution by Seoul City. The direct inputs to this system are more than 16 untreated tributaries (Table 1 and Fig. 4-1).

For the purpose of simplifying the constru-

Table 5. The Calculation of K_2

Seasonal Division	Discharge ($Q, m^3/sec$)	Average depth(R, m)	Average with(W, m)	Average velocity (V, m/sec)	K_2(20°C) (day^{-1})	Remark
Winter	567	2	400	0.6	0.95	Jan.-March
Spring	228	1.5	300	0.5	0.97	April-June (Dry Season)
Summer	1,031	3	500	0.7	1.02	July-Sept. (Rainy Season)
Autumn	567	2	400	0.6	0.95	Oct.-Dec.

Table 6. The Amount of Sewage Discharge by Sectional Areas

Section	Year	A	B	C	D	E
Discharge (m^3/sec)	1971	0.671	7,584	0.880	2,039	4,015
	1985	2,998	16,530	4,110	3,953	12,510

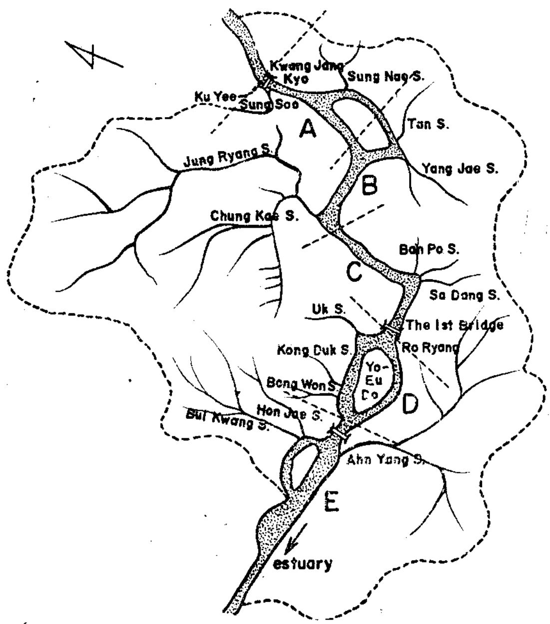

Fig. 4-1. Sewerage System in Seoul.

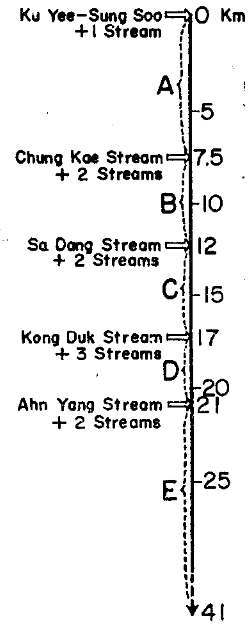

Fig. 4-2. The Simplified Stretch of the Han River.

ction of the model, this stretch was divided into five sections, taking under consideration the amounts of discharge and the distances related to input points of sewage effluent from tributaries, as shown in Fig. 4-2.

The amount of effluent from sectional areas is shown in Table 6.

RESULTS AND ANALYSIS

This simulation was carried out consecutively on dissolved oxygen (DO) and biochemical oxygen demand (BOD) in the main Han River. The study stations were chosen at various distances along the river from Seoul

Table 7-1. Information on the River Properties Just before the First Plant

Item	Description	Winter	Spring	Summer	Autumn
Q	Total discharge of the river, m^3/sec	567	228	1,031	567
RTE(0)	Water temperature, °C	5	15	20	10
L(0, 0)	BOD load, mg/l	3.0	5.0	3.0	3.0
D(0, 0)	Dissolved oxygen deficit with respect to saturation value, mg/l	0	0	0	0
X(0, 0)	Location of the first plant, Km	0	0	0	0

Table 7-2. Information on the Individual Reaches

Item	Description	Station 1	2	3	4	5	Remark
Q(J)	Discharge of the plant, m^3/sec.	0.671	7.584	0.880	2.039	4.095	in 1971
		2.998	16.530	4.110	3.953	12.570	in 1985
DTE(J)	Change of temperature of river flowing through the plant (°C)	0	0	0	0	0	
LP(J)	Total BOD load in the Water leaving the plant (mg/*l*)	230	495	490	300	230	in 1971[8]
		300	500	400	300	300	in 1985
Eff(J)	Efficiency of the Waste plant as a factor between 0 to 1	0	0	0	0	0	
		0	0.5	0	0	0	(Sewage plant at Chung-Kae stream)
		0	0.5	0	0	0.5	(Sewage plant at Chung-Kae st. and Ahn-Yang st.)
		0.3	0.3	0.3	0.3	0.3	Primary treatment
		0.6	0.6	0.6	0.6	0.6	Secondary treatment
		0.9	0.9	0.9	0.9	0.9	Tertiary treatment
DP(J)	Dissolved oxygen deficit with respect to saturation value of the leaving plant, (mg/*l*)	12.8	12.8	12.8	12.8	12.8	Winter
		10.0	10.0	10.0	10.0	10.0	Spring
		9.2	9.2	9.2	9.2	9.2	Summer
		11.3	11.3	11.3	11.3	11.3	Autumn
RL(J)	Reach length, (Km)	7.5	4.5	5.0	4.0	20.0	
Time(J)	Time required for the water to flow through the reach (day)	0.145	0.088	0.097	0.077	0.386	Winter
		0.174	0.104	0.116	0.093	0.463	Spring
		0.124	0.074	0.083	0.666	0.330	Summer
		0.145	0.088	0.097	0.077	0.386	Autumn
S(J)	Number of points in the reach where BOD and DO are computed	3	2	2	2	7	
K_2O(J)	Mean coefficient of biodegradation in the reach (K_1) at 20°C	0.157	0.157	0.157	0.157	0.157	
R_2O(J)	Mean Coefficient of reaeration in the reach (K_2) at 20°C	0.95	0.95	0.95	0.95	0.95	Winter
		0.97	0.97	0.97	0.97	0.97	Spring
		1.02	1.02	1.02	1.02	1.02	Summer
		0.95	0.95	0.95	0.95	0.95	Autumn

sewage outfall. The river profiles by seasons have formed the basis of much of this simulation by computer. In this data, the information given on the array boundaries in the program for the computer is that the JJ, number of reaches involved, is 5 and the Maxs, maximum number of S, which is the number of points in a reach where computation of BOD is required, is 7. The information on the river properties for the computer is given as follows (Table 7-1 and 7-2).

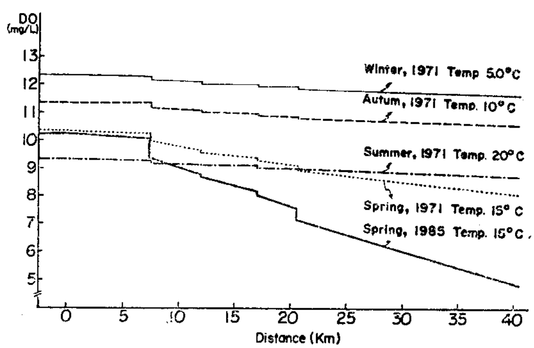

Fig. 5. The Profile of DO along Distance in the Han River.

DO and BOD Profiles

Ordinarily, as a result of the discharge from the various tributaries, DO would decrease slightly in relation to the distance along the river, compared with the DO value of the river at a location just before the first plant (Fig. 5).

The consquence is that the DO would be reduced to a large degree in the spring of 1971 as compared with other seasons, and by the spring of 1985, it will decrease greatly, especially in the 40 Km stretch near the estuary of the Yellow Sea, where it will be below 5.0mg/l of DO. It will not be desirable for fresh water use[9,10] in that area; that means it will be disturbing to the fish and wildlife as well as to the water supply and recreational usage in 1985.

But the Han River seems still to be of high quality in DO aspects related to some standards for the stream[9,10]. This would be caused by the high reaeration(K_2) of the river. In this case, the DO level would not be a relevant parameter to consider pollution in the Han River.

Chung Kae stream et als located at 7.5 Km distance from Kwang-Jang Kyo, in B section of this study, contributes more to the depletion of dissolved oxygen in the Han River than do other streams from Seoul City.

The BOD profile of the Han River is shown in Table 9, and Fig. 6 in which it appears that the value is increased in rapid steps from station two, the outlet of Chung Kae stream. Especially during the dry season in spring, a high value of BOD is manifested. It could also be imputed that the effluent from urban area, Seoul City, continues to flow constantly and/

Table 8. The Recommendable Water Quality for Fresh Water

DO(% sat.)	BOD (mg/l)	Coliform bacteria (MPN/100ml)	Reference
>50	<8.0	<5,000	9
>75		<1,000	10
>85	<2.0	<240	11

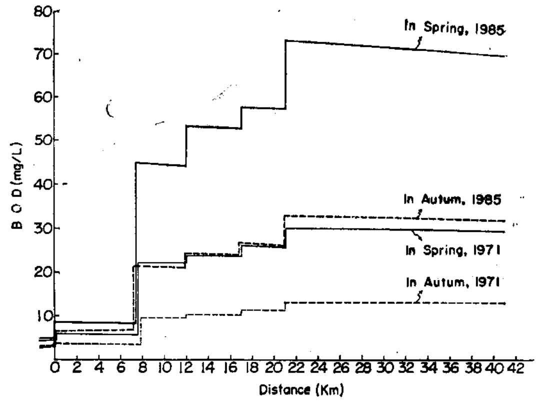

Fig. 6. The Profile of BOD in the Han River.

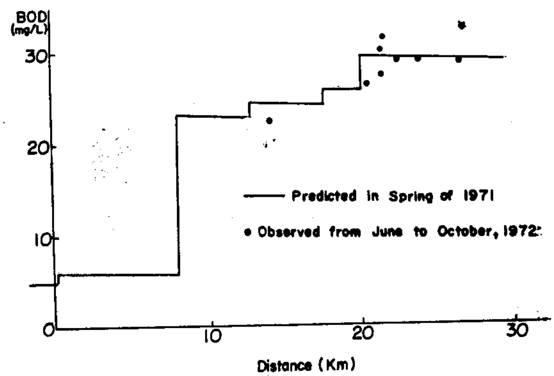

Fig. 7. Comparision of Actual and Predicted Values.

or increasingly, while the discharge from the river flows the least in spring as compared with any other season.

From some standards[9~11] of water quality recommended, unless the effluent from the tributaries of the Han River is treated with proper efficiency, we shall be forced to abandon usage of the river as a source of water supply.

By 1971 the Han River at Seoul had become so unsanitary that it had already been abandoned for use as a recreational area and as a source for potable water supply as well.

In the comparision in 1972, between the predicted and the actual values observed from

Table 9. The BOD profile in the Han River (mg/l)

Section	Distance	1971				1985	
	(Km)	Winter	Spring	Summer	Autumn	Spring	Autumn
	0	3.27	5.68	3.15	3.27	8.94	6.59
A	2.50	3.26	5.64	3.13	3.26	8.88	6.55
	5.00	3.25	5.60	3.11	3.24	8.82	6.52
	7.50	3.23	5.55	3.09	3.23	8.75	6.49
	7.50	9.86	22.02	6.73	9.85	45.00	21.07
B	9.75	9.82	21.88	6.69	9.80	44.71	20.98
	12.00	9.79	21.74	6.65	9.76	44.42	20.89
	12.00	10.55	23.63	7.07	10.52	55.44	24.52
C	14.50	10.51	23.46	7.02	10.47	53.05	24.39
	17.00	10.47	23.29	6.98	10.42	52.67	24.28
	17.00	11.55	25.97	7.57	11.50	57.87	26.33
D	19.00	11.51	25.82	7.53	11.46	57.53	26.27
	21.00	11.48	25.67	7.49	11.41	57.20	26.17
	21.00	13.14	29.80	8.41	13.07	73.74	32.82
	23.86	13.08	29.56	8.35	13.00	73.13	32.64
	26.71	13.02	29.31	8.28	12.93	72.53	32.46
E	29.57	12.97	29.07	8.22	12.86	71.94	32.28
	32.43	12.91	28.83	8.16	12.79	71.35	32.11
	35.29	12.86	28.60	8.10	12.72	70.76	31.93
	38.14	12.80	28.36	8.04	12.65	70.18	31.76
	41.00	12.74	28.13	7.98	12.58	69.60	31.58
Remark	Temp. (°C)	5.0	15.0	20.0	10.0	15.0	10.0
	Oxy. Sat. (mg/l)	12.35	10.35	9.35	11.35	10.35	11.35
	K_1	0.08	0.12	0.16	0.10	0.12	0.10
	K_2	0.75	0.90	1.02	0.81	0.90	0.81

the 2nd bridge of the Han River, the 15 Km point, to Hang-Ju, the 27 Km point of the stretch they closely coincide in Fig. 7. The actual samples were examined in 1972, from June in the dry season, to October.[12)]

The coincidence would imply that the predicted value for the spring of 1971 might represent the actual figures of an average year.

It might also be suggested that this model is not only applicable in estimating water quality, especially BOD, but also useful to the authorities in setting up the plants for sewage treatment at the outlets of tributaries.

At present a plant for sewage treatment with 50% efficiency is being installed at Kun Ja-Dong, the outlet of Chung-Kae stream. Even after it is in operation, the water of the Han River will still have a high BOD with respect to the recommended standard quality of water. Also, although still another

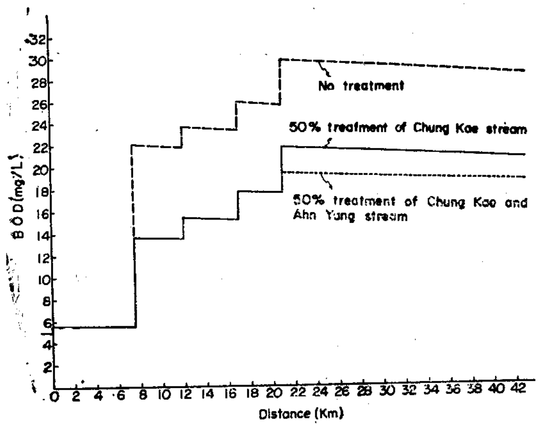

Fig. 8. The BOD Profile with Plant for Waste Treatment in the Han River (Spring, 1971).

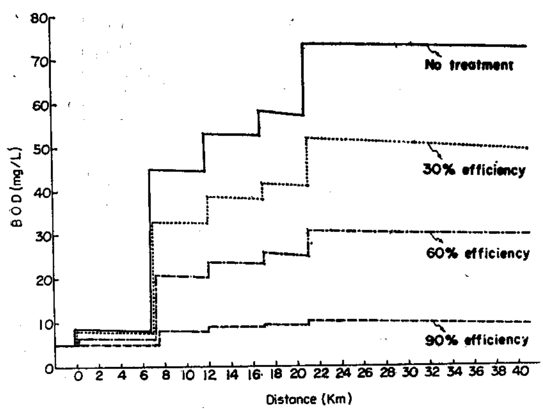

Fig. 9. The BOD Profile with Plant for Waste Treatment in the Han River (Spring, 1985).

plant is to be installed at the outlet of the Ahn-Yang stream, there will be no signficant change in the level of pollution (Fig. 8).

Considering the projected pollution level of the Han River in 1985 and how to recover the water quality, every tributary from Seoul city should be treated with 90% efficiency, which means resorting to the performance of tertiary treatment of effluent discharge(Fig. 9).

This simulation presents suggestions for the effective treatment of wastes and could be used in locating the monitoring points for inspection of water quality in the Han River. It is suggested that the optimum number of monitoring points in the Han River might be at the 5 Km point, upstream from Kwang-Jang Kyo, Kwong-Jang Kyo (0 Km), Duk-Do (5 Km downstream from Kwang-Jang Kyo), Keum Ho Dong (10 Km), Bo Kwang Dong (15 Km), the 2nd bridge of the Han River (20 Km) and Hang-Ju (25 Km).

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