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Interactive Water Quality Simulation of the Han River Using Computer Graphics

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The water quality simulation of the Han River was performed by computer-aided design methods using interactive computer graphic routines. The model used to simulate water quality in the Han River was based upon the U.S. Environmental Protection Agency's QUAL-II program. The constituents which were simulated include temperature, conservative substances, coliform bacteria, BOD and DO. Discretization of the model over space was done using the Galerkin finite element method. Data input requirements for the model included rate constants, meteorological data, and headwater, point and non-point source concentrations. The point and non-point source waste loadings were assumed to be constant over time.

Several options for dealing with simulation results were available. These included listings or graphs showing the concentration values by constituent, either for all sites at one point in time, or for one site at all times. By merging spatial and temporal data, a three-dimensional surface of concentration as a function of site location and time of day could be plotted for any constituent. A pictoral display of water quality throughout the Han River, using various colors to indicate different concentrations of constituents or degrees of temperature, also is possible.

Water quality profiles of the Han River were developed using 1981 waste loadings. These results were compared to observed data in order to determine the best values for model parameters. Calibration of the model was aided by the interactive use of statistical tests, including linear regression analysis and t-tests of two means.

Using estimates of population and industrial growth for the Han River Basin, simulations for expected 1986 and 1991 conditions were undertaken. Results indicate that without increased investments in wastewater treatment facilities and associated collection systems, most of the river will contain BOD concentrations which greatly exceed the maximum 6 ppm allowed. In addition, the number of coliform bacteria will be substantially more than the maximum permitted number, 10,000 MPN/100 ml, for water supply sources requiring highest levels of treatment.

These results also suggest where monitoring stations should be established, and where

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proper management practices will have the greatest impact on controlling the extent of river pollution resulting from the discharge of waste effluent from urban communities, industries, and agricultural land along the Han River.

Key Words: Water Quality, Han River, Computer graphics

One of the four major rivers in Korea, the Han River flows through the capital city of Seoul. Since this portion of the river and its tributaries serve both as sources of water and as recipients of domestic and industrial waste, the water quality of the Han River is of vital concern to the more than 8 million people in the Seoul city area. Pollution in the Han River has been steadily increasing in recent years, especially since the initiation of the economic development plan in 1962. Since 1976, only one plant for sewage treatment has been built at the outlet of the Chung Kae Stream, the largest tributary upstream of Seoul. The plant treats about 20% of raw sewage discharged from Seoul with an efficiency of about 50%. As a result, the level of BOD in the Han River downstream of this treatment plant is more than 6 mg/1, the maximum legal standard for urban water supply sources. Therefore, the need for systematic planning for water quality management of the Han River is an urgent problem that requires immediate attention.

Korea's water quality management program began in earnest in 1980 when the Office of Environment was established. One of the objectives of this office is to develop a comprehensive plan for water quality management of the Han River. Water quality simulation models will play in important role in the development of the plan.

The work discussed in this paper involves an examination of alternative water quality management plans for the Han River utilizing a water quality simulation model. This model is incorporated within an "Interactive Water Resources Planning Graphic Display System." This system, developed at Cornell University (French, *et al.*, 1978, 1979, 1980), combines a number of water resources planning models with interactive computer graphic displays.[1-4]

Computer graphic input and display methods, when coupled with water quality management models, are shown to have a number of advantages for the user as well as for those who must understand and make decisions based on the results of these models. The ability to graphically input spatial data bases can substantially reduce input time, and visual feedback substantially reduces the changes of undetected errors in the input data. Also, when graphics are used as the communication medium, the capability for interactive man-machine dialogue is enhanced. Once established, this interactive capability makes it much easier to incorporate into the analysis both changes in data and assumptions or preferences of planners and decision makers. The advantages to the decision maker stem from a fast response to "what if" questions and a clearer graphical and/or pictorial presentation of the results and impacts of the water quality management alternatives being simulated.

This paper illustrates the application of interactive computer graphics to water quality management planning in the Han River. Water quality profiles of the Han River were simulated and the best parameters were determined by calibration of the model results. The proper management practices are suggested by the extent of pollution in the river.

METHOD

Equipment

The "Interactive Water Quality Simulation Graphic Diplay System" was implemented using relatively inexpensive minicomputer and storage tube technology. The minimal equipment required was a central processing unit (CPU), a display terminal with alphanumeric keyboard, an electronic pen and digitizing tablet, and a hard copy device.

The CPU initially used was a PDP-11/45 minicomputer, which later was replaced by a VAX /780(Digital Equipment Corporation). Data input was made via a digitizing tablet with an electronic pen which was used to "point to" selected commands, or to draw the desired image (Fig. 1). Output was displayed on a Tektronix 4014-1 display terminal or on an Evans and Suterland Picture System II. Copies of any graphics displayed on these devices are obtainable from a 4631 Tektronix hard copier.

Software Program

The software required to run and support the system is divided into three sections: system routines, low-level graphics, and water resources routines. The low-level graphics routines were developed at the Cornell Laboratory of Computer Graphics, Cornll University, Ithaca, U.S.A. All of the water resources routines were written in FORTRAN.

Structure of the Program

The "Interactive Water Quality Simulation Graphic Display System" can be divided into two major modules:

1) River Basin Definition Module
2) Water Quality Analysis Module

These two modules subsequently have been disaggregated into submodules, each designed to perform a particular activity. The overall structure of the program is summarized by the flow

Fig. 1. Interactive Display Terminal, Digitizing Tablet and Pen (Cursor).

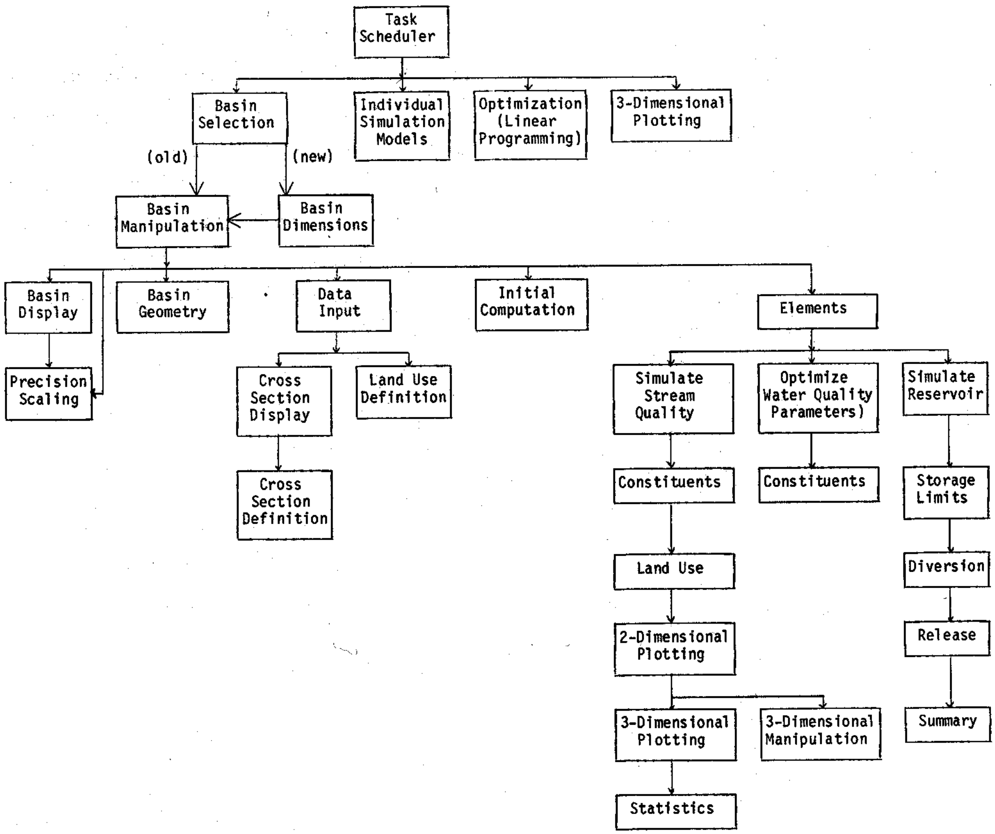


Fig. 2. Menu Page Flow Chart.

chart of Fig. 2. Each box on the chart represents a menu page, or set of menu pages, with which the user can accomplish a particular activity. A schematic representation of the interactive modeling process is shown in Fig. 3.

MODELING

Water Quality Prediction

This module allows the user to predict water quality over time, throughout any confirguration of streams that is defined during the Basin Definition portion of the program. The procedure utilized for modeling stream quality is a three-step process involving simulation, calibration, and verification. Conjunctive operation of these three steps permits the model to be used as a tool for both planning and research.

Simulation: The simulation component allows the user to set the concentration of all constituents entering the basin, either as headwater boundary values, point source inflows, or non-point source runoff from the various land uses. Constituents which were simulated include: temperature, conservative substances, coliform bacteria, BOD and DO. Water quality prediction was based on the coupled, partial differential equations used in QUAL-II, the U.S. Environmental Protection Agency's (EPA) stream quality simulation model[5].

The general predictive equation describing the convection, dispersion, growth and decay of the constitutents, over time, is:

$$A\,dx\,\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left[A\,D\,\frac{\partial C}{\partial x}\right]dx - \frac{\partial}{\partial x}\,[A\,UC]\,dx$$

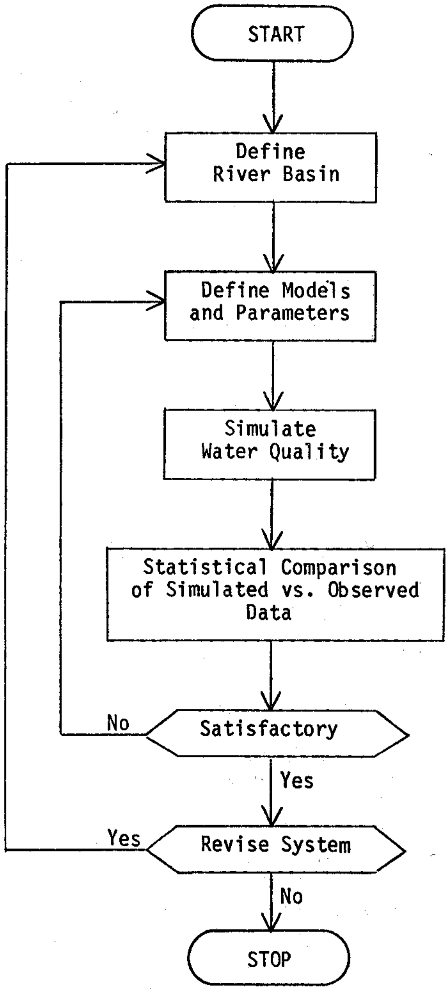


Fig. 3. Flow Chart of Interactive Methodology for Derivation and Refinement of Water Quality Simulation.

$$+ A\,dx \frac{dC}{dt} + S \qquad (1.0)$$

where:
- A = the cross-sectional area at a site, m^2,
- D = dispersion, m^2/hr,
- U = velocity, m/hr,
- C = concentration or gm/m^3,
- $\frac{dC}{dt}$ = A source/sink term which is specific to each constituent, and
- S = a waste loading component, gm/hr.

Although the model utilizes steady-state flows and loadings, the simulation was performed dynamically over a 24-hour period to illustrate the diurnal aspect of water quality. Since most reaction rates used in the model are temperature dependent, it is possible to show diurnal variations for all non-conservative constituents.

The specific differential equations to be solved are as follows:

Conservative Substances (C):

$$\frac{\partial C}{\partial t} = \frac{\partial (A D \frac{\partial C}{\partial x})}{A\ \partial x} - \frac{\partial (A\ UC)}{A\ \partial x} + \frac{S_C}{A\ dx} \qquad (1.1)$$

Biochemical Oxygen Demand (L):

$$\frac{\partial L}{\partial t} = \frac{\partial (A D \frac{\partial L}{\partial x})}{A\ \partial x} - \frac{\partial (A\ UL)}{A\ \partial x}$$

$$- (K_1 + K_3)\, L + \frac{S_L}{Adx} \qquad (1.2)$$

Dissolved Oxygen (ϕ):

$$\frac{\partial \phi}{\partial t} = \frac{\partial (A\ D \frac{\partial \phi}{\partial x})}{A\ \partial x} - \frac{\partial (A\ U\phi)}{A\ \partial x} + K_2(\phi^* - \phi)$$

$$- K_1 L - \frac{K_4}{A} + \frac{S_\phi}{A\ dx} \qquad (1.3)$$

Coliform (F):

$$\frac{\partial F}{\partial t} = \frac{\partial (A D \frac{\partial F}{\partial x})}{A\ \partial x} - \frac{\partial (A\ UF)}{A\ \partial x} - K_5 F + \frac{S_F}{Adx} \qquad (1.4)$$

where:
- K_1 = carbonaceous BOD decay rate, day^{-1}
- K_2 = reaeration rate, day^{-1}
- K_3 = carbonaceous BOD sink rate, day^{-1}
- K_4 = benthos source rate for BOD, mg/day-ft^{-1}
- K_5 = coliform die-off rate, day^{-1}
- ϕ^* = concentration of DO at saturation, mg/ℓ

Table 1. Input parameters for water quality model

Name in Equation	Description	Units	Values at 20°C	Remark* (proper value)
K_1	Carbonaceous BOD decay rate	day^{-1}	1.0	0.1 ~ 2.0
K_2	Reaeration rate	day^{-1}	1.0	0.0 ~ 100
K_3	Carbonaceous BOD sink rate	day^{-1}	0.0	
K_4	Benthos source rate for BOD	$mg/day\text{-}ft^{-1}$	0.0	
K_5	Coliform die-off rate	day^{-1}	2.4	0.5 ~ 4.0

*Reference (5)

Although the effects of algal growth, respiration and nitrogenous oxygen demand can be simulated by the model, insufficient data were available to warrent their inclusion in this study.

All rate constants that are known to be temperature-dependent are formulated according to the relationship

$$X_T = X_{T_s} \theta^{(T-T_s)} \tag{1.5}$$

where: X_T = the value of the variable at the local temperature, T

X_{T_s} = the value of the variable at the standard temperature, T_s

θ = an empirical constant for each system variable.

Table 1 lists the values of the input parameters defined in equations 1.1 through 1.4. These parameters were estimated fron data of the water pollution survey of the Han River[6~9]. To provide the best results for streams having depths greater than 0.6 meters[10], the reaeration coefficient at each node was computed using Churchill et al's. equation[11].

$$K_2 = 5.026\, U^{0.969} H^{-1.673} \tag{1.6}$$

Where: U = the velocity (fps)

H = the depth (ft).

Discretization of the Model

Each partial differential equation was discretized, over space, using the Galerkin finite element method, where each reach becomes an element and each site becomes a node. The type of shape function used for the simulation, either linear or quadratic, was user-selected. For the quadratic shape function, a node invisible to the user was located at the midpoint of each reach. There results a system of linear equations which is expressed in matrix notation by:

$$[A]\{\dot{c}\} + [H]\{c\} = \{f\} \tag{2}$$

where: [A] = a time step transfer matrix,

[H] = a matrix of convective, dispersive and decay terms,

{f} = a vector of point and non-point loads[32], and

{c} = concentration, mg/ℓ.

The temporal derivative c is approximated by a backward implicit differencing method to yield:

$$[\frac{A}{\Delta t} + H]\{c\}^{t} = [\frac{A}{\Delta t}]\{c\}^{t-1} + \{f\} \tag{3}$$

This system of linear algebraic equations was solved using a packed storage, Gaussian elimination algorithm developed by Gupta and Tanji[13].

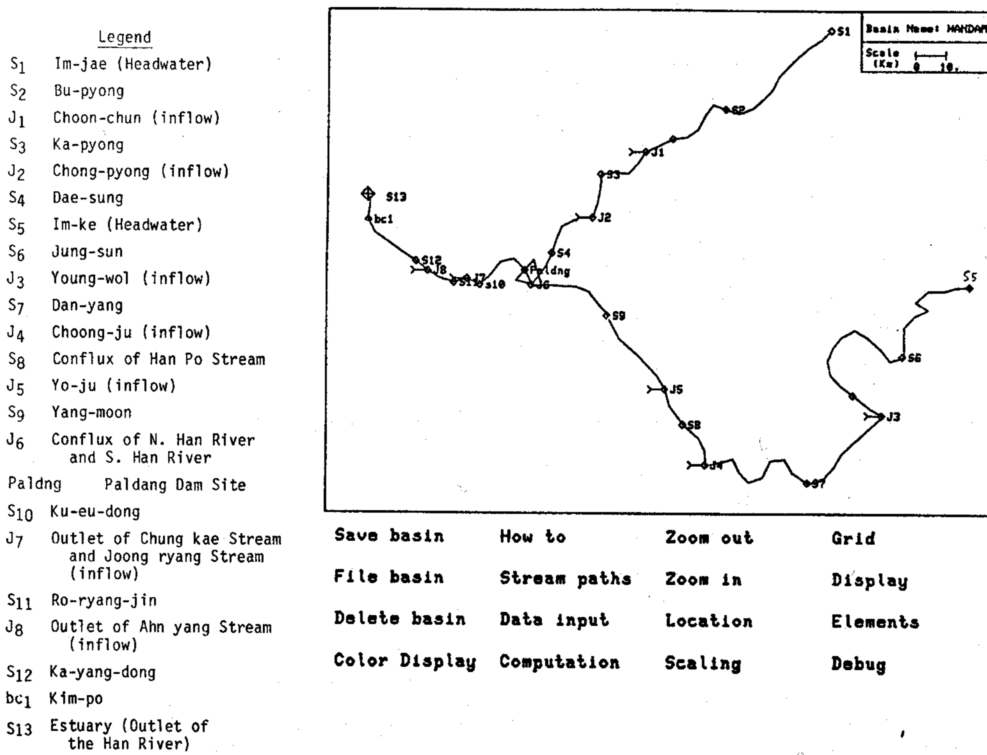


Fig. 4. Map of the Han River Basin to be Drawn in and Modeled.

Calibration and Verification

In the context of the interactive water quality modeling program, verification refers to the use of statistical tests to compare simulated data to observed data. These comparisons were made to examine the effect of parameter changes on simulation results (calibration), as well as to verify the calibrated model.

To compare between the actual and the simulated data, linear regression analyses were performed either over space or over time. To assist in determining the closeness of the comparison, the plotted regression line was accompanied by a confidence interval and the target line. A quantitative estimate of the reliability of the simulated data was provided by a t-test. To examine the hypothesis that the means of the two data sets were equal, an F-test was performed.

RIVER SYSTEM DESCRIPTION AND DATA INPUT

Mapping

A map of the Han River system to be studied was placed on the digitizing tablet. Scaling parameters for basin dimensioning were entered directly via the terminal's keyboard. The stream paths defining the river system were entered into the computer by using the digitizing pen to point to the appropriate command and then tracing the appropriate path. Various sites along the river were located and named as desired by the user (Fig. 4). Drainage areas were traced and the area enscribed was computed automatically. Superimposed on the drainage areas were land use patterns or other cultural data for which intersecting areas were computed automatically. The vertical dimension (i. e.

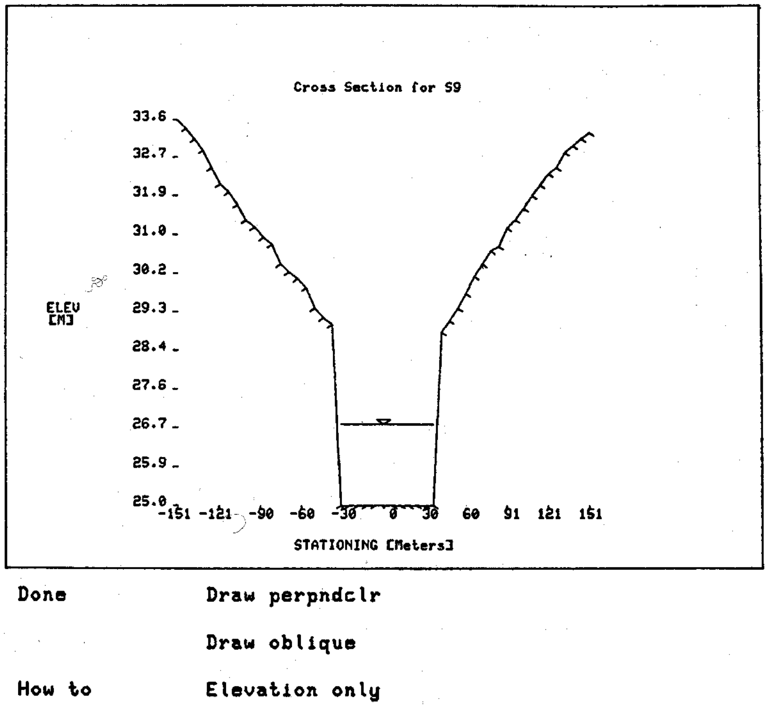


Fig. 5. Cross-Sectional Display of Elevation vs. Horizontal Position After Being Drawn with Cursor and Tablet.

elevation) was entered into the computer by drawing in cross-sectional data at each appropriate site, as illustrated in Fig. 5.

The Han River System to be studied was defined with three branches, one reservoir, and seven inflows. The branches were the North Han River (from Im jae, S_1, to Yang soo ri, J_6), the South Han River (from Im ke, S_5, to Yang soo ri, J_6) and the Main Han River (from Yang soo ri, J_6, to the estuary of the Yellow Sea, S_{13}). The reservoir system was located at Paldang Dam[14]. The inflow sites correspond to tributaries of the Han River which have been shown to exert a significant impact on river quality[15].

A flow gaging station was defined for the basin, and the average September flow was entered. Based upon flows, drainage areas and the cross-sectional data, water surface elevations at each site were computed automatically. These results are summarized in Table 2.

Water Quality Data Input

Initialization: The first step toward simulation is to initialize the system and to select the classes of parameters (operational, system, or meteorological) which are to be changed. A quadratic shape function was utilized, thus adding an additional node at the midpoint of each element (stream reach). Based upon previously defined data, nodal values were determined for the average depth, velocity, cross-sectional area, dispersion rate, and the oxygen reaeration rate.

Calculation of the nodal logitudinal dispersion coefficient, D_L, was based upon Fisher's equation[16]:

$$D = 0.3 \frac{U^* \ell^2}{k^2 R} \qquad (4)$$

where: U^* = shear velocity, $\bar{U}\sqrt{f/8}$

$\bar{U}$ = average velocity

f = Darcy-Weisbach friction coefficient

Table 2. The Geographical and physical input data in the Han River basin

Site	Flow Amount* Q (m^3/sec)	Flow Velocity* V (m/sec)	Cross Section (m)** W	$\bar{w}$	h	$\bar{h}$	Elevation Sea Level (m)
S_1	5	1.5	1.6	1.6	2.1	2.0	521.6
S_2	10	1.5	2.0	1.4	2.0	1.5	353.6
J_1	59	1.5	10.1	7.1	3.7	3.0	105.6
S_3	150	1.5	25.1	21.6	3.6	3.5	70.0
J_2	250	1.5	37.7	33.7	4.4	4.0	42.2
S_4	250	1.0	45.0	40.0	>5.0	5.0	35.0
S_5	10	1.5	6.8	5.3	1.8	1.5	229.1
S_6	20	0.8	15.2	13.7	1.6	1.5	180.0
J_5	230	0.8	93.0	90.0	>3.0	3.0	29.1
S_9	250	0.8	74.0	70.0	>4.0	4.0	15.0
J_6	536		102.0	97.0	>5.0	5.0	1.6
S_{10}	540	0.5	266.0	262.0	>4.0	4.0	1.5
S_{13}	580	0.5	144.4	137.4	>7.0	7.0	0.0

* = Average Flow

Table 3. Boundary conditions and non-point loads

Loads \ Item		Conservative Material (mg/1)	Coliform Bacteria (MPN/100 ml)	BOD (mg/1)	DO (mg/1)
Boundary Condition		10	10	0.2	9.2 at 10°C 8.5 at 15°C
Non-Point Loads	'81	50	100	2	6.0
	'86	100	1000	5	6.0
	'91	100	1000	5	6.0

ℓ = distance from the deepest part of stream to the more distant shore

k = von Karman's constant, 0.40, and

R = hydraulic radius.

Meteorological parameters were defined as follows:

Latitude (LAT), 37.5°N; Longitude (LONG), 127.5°E

Dry bulb temperature (DRYBLB), 20°C in September, 10°C in March

Wet bulb temperature (WETBLB), 15°C in September, 7°C in March

Atmospheric pressure (ATMPR), 760 mmHg

Wind speed (WIND), 1.5 Km/hr; Fractional cloud cover (CLOUD), 5%.

The length of the time step chosen for the simulation model was 1 hour.

Waste Load Inputs: Following initialization, the waste input concentrations were defined and entered via the alphanumeric keyboard, or

Table 4. Point loads

Site	Item Year	Inflows (m^3/sec)	Loads Conservatives (mg/1)	Coliform (NPN/100 ml)	BOD (mg/1)	DO (% saturation)
Choon Chun J_1	1981	4.83	10^2	10^4	100	50
	1986	7.25	10^3	10^6	200	0
	1991	10.00	10^3	10^6	200	0
Chong Pyong J_2	1981	3.30	10^2	10^3	50	60
	1986	5.00	10^3	10^4	100	30
	1991	7.50	10^3	10^4	100	30
Young Wol J_3	1981	3.30	10^2	10^3	50	60
	1986	5.00	10^2	10^4	100	30
	1991	7.50	10^2	10^4	100	30
Choong Ju J_4	1981	12.00	10^2	10^4	80	60
	1986	18.00	10^3	10^6	150	30
	1991	20.00	10^3	10^6	150	30
Yo Ju J_5	1981	1.45	10^4	10^6	300	0
	1986	2.18	10^4	10^8	300	0
	1991	2.50	10^4	10^8	300	0
Chung Kae Stream, J_7	1981	15.70	10^4	10^8	300	0
	1986	23.60	10^4	10^8	300	0
	1991	25.0	10^4	10^8	300	0
Ahn Yang Stream, J_8	1981	11.10	10^4	10^8	300	0
	1986	16.60	10^4	10^8	300	0
	1991	20.00	10^4	10^8	300	0

by the penactivated number pad. Table 3 shows the input loads associated with either headwater boundary conditions or non-point sources. The type of land use draining to each reach was defined; for the North and South branches, the predominant land use type is agricultural.

The point loads at each inflow site were estimated from available data[6-9,15], and entered into the computer. These data are shown in Table 4. The water temperature at all inflow sites was defined as 15°C in September and 10°C in March. For dissolved oxygen (DO), inflow concentrations were determined from the temperature and the percent saturation, as defined in the literature[6-9].

RESULTS AND ANALYSIS

Simulations were performed for the Han River, over time, on water temperature, a conservative substance, coliform bacteria, DO and BOD. The initial simulation was for the year 1981; waste load information was based upon available data[6,7,9]. In order to examine the impact of population growth, industrial development and land use changes on water quality,

Table 5. 1981 Water quality profile during average flow (September)

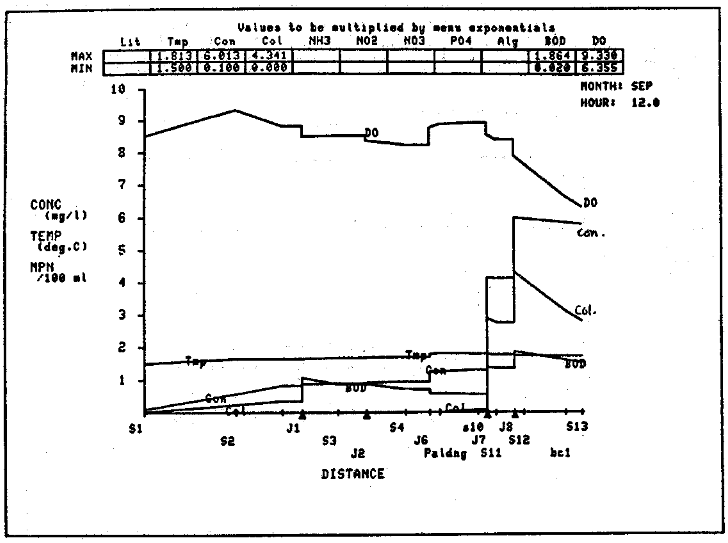
Stream	Site	Coliform Bacteria (MPN/100 ml)	DO (mg/1)	BOD (mg/1)
North Han River	S_1	10	8.5	0.2
	S_2	350	9.4	0.3
	J_1	759	8.5	10.6
	S_3	515	8.5	8.7
	J_2	391	8.4	8.7
	S_4	248	8.2	7.1
South Han River	S_5	10	8.5	0.2
	S_6	18	8.9	1.4
	J_3	130	8.1	8.1
	S_7	73	7.7	5.3
	J_4	563	7.3	9.2
	S_8	339	7.2	7.4
	J_5	5,910	7.0	8.3
	S_9	3,112	7.2	6.5
Conflux	J_6	1,351	8.8	5.8
Main Han River	Paldang	4,082	8.9	5.7
	S_{10}	76,781	8.9	5.6
	J_7	2,881,900	8.6	13.9
	S_{11}	2,753,500	8.4	13.6
	J_8	4,341,000	7.9	18.6
	S_{12}	4,114,200	7.7	18.2
	S_{13}	2,814,500	6.4	15.4

simulations using projected waste loadings were performed for the years 1986 and 1991. Using an average flow month, September, the simulation results for 1981 are shown in Table 5 and Figures 6 and 7.

To illustrate water quality variations over time, results for S_{10}, Kwang Chang Kyo, are shown in Fig. 8. Although coliform bacteria and BOD do not exhibit much variation throughout the day, the diurnal temperature variation has a significant effect on DO.

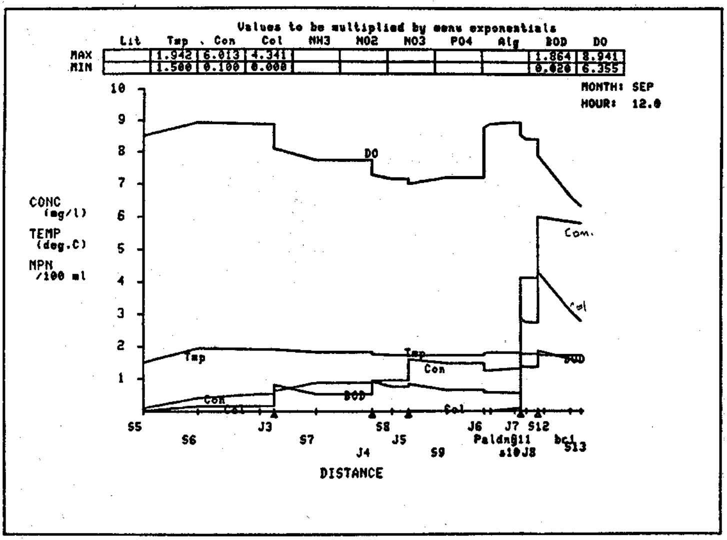
By merging the spatial data and the temporal data, a three-dimensional graph of concentration vs. distance downstream vs. time of day can be plotted. Fig. 9 shows a three-dimensional plot for DO during average flow (September) and 1981 waste load conditions.

An attempt was made to calibrate the model using statistical analyses and survey data. Linear regression analyses and t-tests of two means were used to compare survey data for the simulated 1981 data. The calibration process was difficult to perform successfully due to inconsistencies in the survey data. Linear regression analyses for BOD are shown in Fig. 10 for Hong's data[17)] and for data from the Korean National Environmental Protection Instiute[18)]. whereas Hong's data indicates that the BOD decay rate used in the simulation model was too low, the KNIEP data indicates that



Done	Lite	NH3-N	Algae
New Plot	Temp E+ 1	NO2-N	BOD E+ 1
How to	Cons E+ 2	NO3-N	DO E+ 0
Hard copy	Coli E+ 6	PO4-P	F<-Dynamics->S

Fig. 6. Water Quality Profiles in the Han River in 1981 (1). (from S_1 to S_{13} during average flow)



Done	Lite	NH3-N	Algae
New Plot	Temp E+ 1	NO2-N	BOD E+ 1
How to	Cons E+ 2	NO3-N	DO E+ 0
Hard copy	Coli E+ 6	PO4-P	F<-Dynamics->S

Fig. 7. Water Quality Profiles in the Han River in 1981 (2). (from S_5 to S_{13} during average flow)

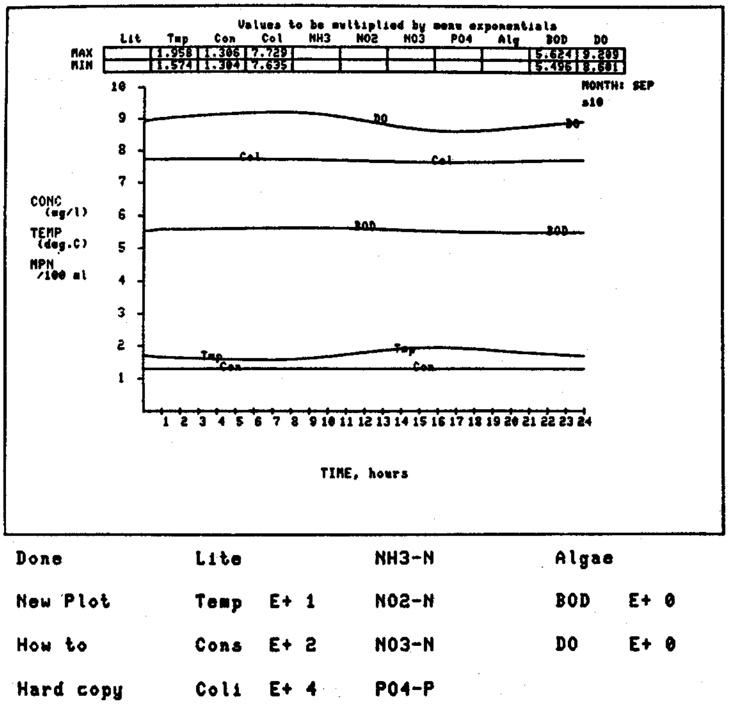


Fig. 8. Water Quality Variation over Time at Kwang Chang Kyo (S_{10}) Site in 1981.

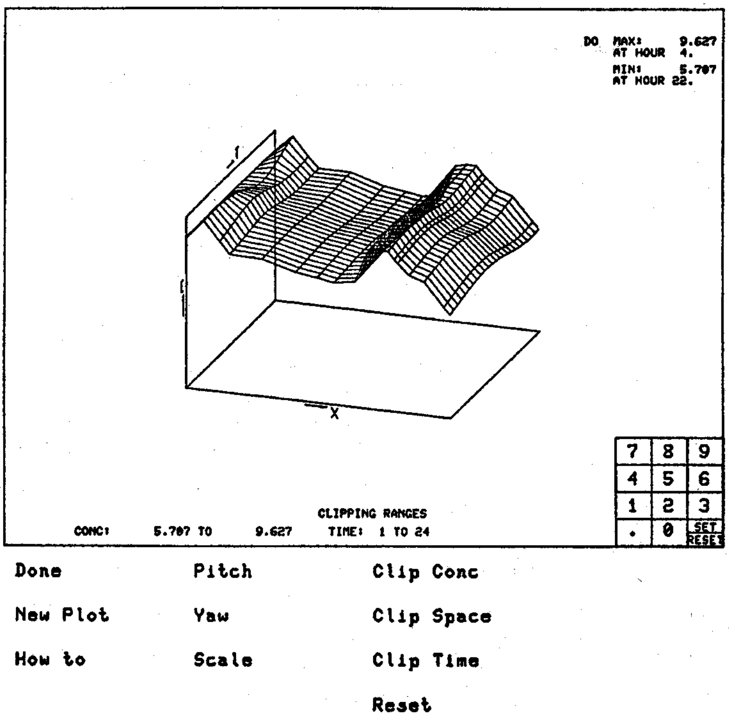


Fig. 9. Three-Dimensional Plot for DO During Average Flow in 1981 (from S_5 to S_{13}).

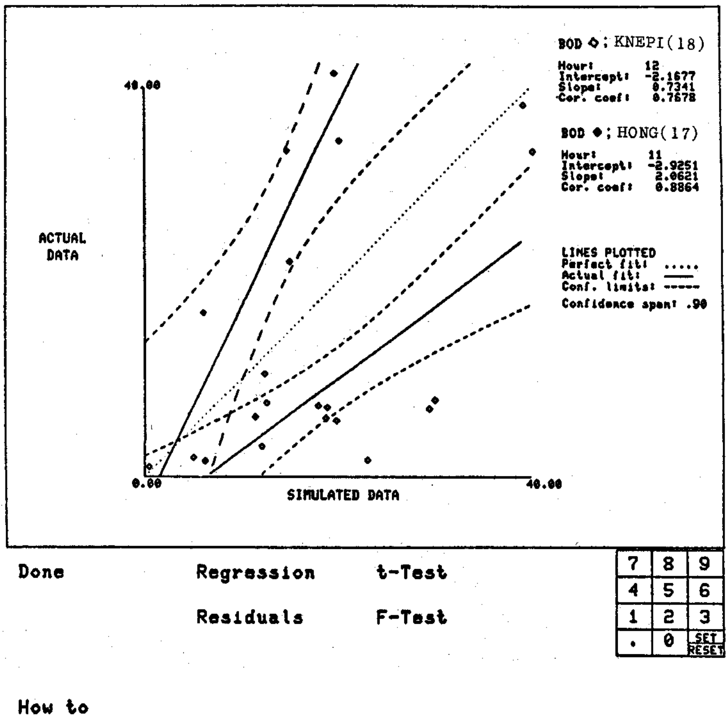


Fig. 10. Regression Analyses of Observed Data.

the rate was too high. Since the two sets of regression lines and 90% confidence limits were almost symmetric about the "perfect fit" line, the BOD decay rate was not adjusted[19].

During the dry season of 1981 (March), the water quality is worse than that during the average season (September), as shown in Table 6. The low flow during the dry season resulted in 250 cu.m/sec at S_{13}, the terminal point of the Han River. Since the low flow is approximately half of the average, higher values of BOD and coliform bacteria are manifested throughout the Han River, and especially in the main stream. This is caused by the effluent from the Seoul City urban area, having more than 8 million people, which continues to discharge constantly, or increasingly, regardless of the seasonal river flow.

Since the assimilative capacity of a stream depends upon the flow of the stream, the calculation of allowable waste load discharge also is stream flow dependent. The flow commonly used in the determination of allowable waste loadings is the lowest average flow for seven consecutive days, having a recurrence frequency of once every 10 years. This often is referred to as the 7-day, 10-year low flow or 7Q10[20]. Therefore, in setting up the proper policy for water quality management in the Han River, the assimilative capacity of the stream should be considered.

According to the current water resources classification[21], the Han River would be divided into four categories: A-water for the upper streams, S_1 and S_5; B-water for the middle streams, S_2 to S_4 for the north stream and S_6 to S_8 for the south stream; C-water for the downstream, J_5 to Paldang; and unsanitary water for S_{10} to S_{13} (Table 7).

The Environmental Preservation Law of Korea prescribes a quality standard for rivers and lakes which is consistent with water utilization[21]. For water supplies, the maximum legal standards are: BOD lower than 6.0 mg/1, DO higher

Table 6. 1981 Water quality profile during low flow (March)

Stream	Site	Coliform Bacteria (MPN/100 ml)	DO (mg/1)	BOD (mg/1)
North Han River	S_1	10	9.2	0.2
	S_2	600	9.3	0.5
	J_1	1,669	9.3	19.5
	S_3	1,067	9.4	14.7
	J_2	722	9.1	14.4
	S_4	392	9.1	10.5
South Han River	S_5	10	9.2	0.2
	S_6	20	10.2	1.7
	J_3	299	7.4	15.0
	S_7	256	8.2	7.0
	J_4	914	6.9	14.6
	S_8	372	6.8	10.8
	J_5	12,664	6.5	12.6
	S_9	4,931	7.0	8.3
Conflux	J_6	1,781	9.3	7.3
Main Han River	Paldang	7,234	9.4	7.1
	S_{10}	276,680	9.3	7.2
	J_7	6,762,500	8.3	26.5
	S_{11}	6,318,300	7.8	25.8
	J_8	9,463,800	6.3	36.4
	S_{12}	8,785,800	5.6	35.2
	S_{13}	4,728,600	1.9	26.7

Table 7. Classification of water quality standards of Korea

Classification	Water Use	BOD (mg/1)	DO (mg/1)	Coliform (MPN/100 ml)	Remark
A	Urban water supply source (Class I)	< 1.0	> 7.5	< 100	available for public supply after simple treatment
B	Urban water supply source Swimming and fisheries (Class II)	< 3.0	> 6.5	< 1,000	available for public supply after filtration and sedimentation
C	Urban water supply source Industrial water (Class III)	< 6.0	> 3.0	< 10,000	available for public supply after high-grade treatment
All Waters	Water source for Irrigation	< 10.0	> 2.0		

Table 8. Water quality of the Han River predicted in 1986

Stream	Site	Coliform Bacteria (MPN/100 ml)		DO (mg/1)		BOD (mg/1)	
		Average Flow	Minimum Flow	Average Flow	Minimum Flow	Average Flow	Minimum Flow
North Han River	S_1	10	10	8.5	9.2	0.2	0.2
	S_2	850	1,600	9.4	10.2	0.7	0.8
	J_1	10,577	24,851	8.0	8.4	24.6	52.5
	S_3	9,471	15,958	8.1	8.4	18.5	38.6
	J_2	27,526	94,557	7.7	7.4	18.8	37.1
	S_4	7,650	50,195	8.5	7.4	13.9	25.8
South Han River	S_5	10	10	9.0	9.2	0.2	0.2
	S_6	76	150	7.3	9.8	1.6	6.2
	J_3	1,880	78,270	7.3	5.8	20.8	42.4
	S_7	575	46,300	5.9	7.3	9.5	16.9
	J_4	77,536	93,523	5.8	3.8	20.1	37.2
	S_8	44,671	58,512	5.5	3.6	15.4	27.1
	J_5	889,620	1,952,200	5.6	3.4	15.3	27.0
	S_9	470,300	809,060	6.0	4.7	11.2	17.4
Conflux	J_6	200,880	299,970	8.5	8.8	10.2	16.2
Main Han River	Paldang	194,220	282,160	8.6	9.0	10.0	15.8
	S_{10}	268,540	642,030	8.6	8.8	9.7	15.5
	J_7	4,492,000	10,464,000	8.1	7.3	22.0	44.0
	S_{11}	4,295,100	9,808,700	7.8	6.5	21.5	42.7
	J_8	6,608,200	14,309,000	7.1	4.4	28.7	57.3
	S_{12}	6,268,300	13,377,000	6.7	3.5	28.0	55.6
	S_{13}	4,312,700	7,713,200	4.7	0.0	23.7	43.4

than 3.0 mg/1, and coliform bacteria lower than 10,000 MPN/100 ml. These standards are applicable to public water supplies which provide both pretreatment and advanced treatment.

As mentioned in a previous report[8], DO in the Han River meets these legal standards for water supply sources[21-25]. This probably is caused by the steep slope of the river, which results in a higher reaeration rate (K_2). However, as shown in Figures 6 and 7, the levels of coliform bacteria and BOD increase rapidly at the inflow point at J_7, which is the outlet of Chung Kae stream. From the point downstream of S_{10}, Kwang Chang Kyo (Ku Eu Dong), the river quality is not suitable for water supply, swimming or fisheries.

The area of the Han River around Seoul is so unsanitary that its use as a recreation area has been prohibited since 1960. The pumping stations and raw water intake for Seoul were moved from this area to Paldang dam, about 30 Km upstream from the Seoul City boundary, in 1978. The level of sewage treatment in the Han River Basin varies widely. In rural areas no more than 6 percent of the population is served by a sewer system, while in the Seoul

Table 9. Water quality of the Han River predicted in 1991

		Coliform Bacteria (MPN/100 ml)		DO (mg/1)		BOD (mg/1)	
Stream	Site	Average Flow	Minimum Flow	Average Flow	Minimum Flow	Average Flow	Minimum Flow
North Han River	S_1	10	10	8.5	9.2	0.2	0.2
	S_2	960	4,600	9.6	9.8	0.9	0.8
	J_1	14,304	32,726	7.8	8.0	31.9	68.3
	S_3	9,505	21,664	7.8	7.8	23.9	51.2
	J_2	63,267	124,310	7.3	6.5	24.5	48.6
	S_4	37,621	68,880	7.1	6.4	18.0	34.6
South Han River	S_5	10	10	8.5	9.2	0.2	0.2
	S_6	150	263	9.1	9.2	1.7	11.0
	J_3	2,190	107,500	6.8	5.0	28.0	54.1
	S_7	965	74,200	7.0	6.6	12.0	22.5
	J_4	85,307	147,510	5.5	3.0	22.6	41.9
	S_8	49,295	63,952	5.4	2.8	17.2	30.8
	J_5	1,021,900	2,253,200	5.2	2.5	17.2	30.8
	S_9	541,320	936,450	5.7	4.0	12.5	19.9
Conflux	J_6	231,800	344,960	8.3	8.5	12.0	20.1
Main Han River	Paldang	223,970	324,260	8.5	8.8	11.8	19.6
	S_{10}	303,060	718,220	8.5	8.5	11.3	19.0
	J_7	4,788,900	11,188,000	7.9	6.8	24.3	48.9
	S_{11}	4,580,900	10,496,000	7.6	6.0	23.8	47.6
	J_8	7,405,500	16,001,000	6.7	3.8	32.4	64.8
	S_{12}	7,025,500	14,968,000	6.3	2.8	31.7	62.9
	S_{13}	4,837,000	8,663,900	4.1	0.0	26.7	49.2

area, about 40 percent are served[26].

In 1976, a sewage treatment plant was put into operation at Kun Ja Dong, the outlet of the Chung Kae stream. However, since the treatment efficiency is only 50%, and since the plant only treats 20% of Seoul's sewage, the main Han River continues to have BOD and coliform bacteria values much higher than the recommended standards. With respect to their potential use as water supply sources, the upper streams already are at the critical point for water quality.

If the effluent discharges from cities and non-point sources along the Han River are left untreated, the growth in population, industry, and agriculture will result in a deterioration of the already critical water quality conditions. To illustrate this effect, simulations were performed using projected waste loadings for 1986 and 1991. The results are presented in Tables 8 and 9, respectively. These simulations show that only the headwater areas of the North Han River (S_1 and S_2) and the South Han River (S_5 and S_6) will be suitable for use as Class II water supply sources.

Recommendations

Considering the severity of the water quality problems in the Han River, a water quality management plan is urgently needed. Such a plan should be developed in conjunction with the Fifth Five-Year Economic and Development Plan for the years 1982 to 1986, and should consider the following actions:

- Since the Paldang Reservoir is the water supply source for the 8 million people of Seoul and Kyung Ki Province, the water quality should be monitored and inspected.
- The Seoul area currently discharges more than 2.5 million metric tons of domestic sewage and 1.4 million metric tons of industrial effluent daily. With the trend of increased growth, the waste loads also will increase. Therefore, an urgent project should be the construction of waste collection and treatment facilities for the Seoul City area. Although abandoned several years ago, the plan developed by Seoul City authorities to construct a sewage canal parallel to the Han River, with terminal treatment plants, should be reconsidered.
- As a result of the water quality simulations, the following locations are suggested for monitoring points along the Han River:

N. Han
- S1 - Im Jae (Headwater)
- S3 - Ka Pyong
- S4 - Dae Sung

S. Han
- S5 - Im Ke (Headwater)
- S7 - Dan Yang
- S8 - Confluence with the Han Po Stream
- S9 - Yang Moon

Main
- Paldang
- S10 - Kwang Chang Kyo
- S11 - First Bridge Over the Han River
- S12 - Ka Yang Dong

- For the upper streams, non-point loads from agricultural and forested lands, low density urban areas and industrial zones should be controlled.
- As one of the communications media for water quality management, the utilization of interactive computer graphics makes it much easier to integrate analysis, planning and the decision-making process.

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