IMPROVEMENT OF FRESHENING PROCESS BY MEANS OF UNDERDRAINAGE CONDUIT

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ABSTRACT/This paper is concerned with the actual comparison analysis for the freshening process in the two selected experimental reservoirs. At the deep freshening reservoir, salinity and depth of the freshwater layer were estimated by simulation technique using the quantitative equation for the two layered flow structures. First of all, it is shown that the effects of underdraiange conduit in the lower layer were reported more effective for the control of upper layer salinity comparing with the case of no underdrainage conduit. Further the results of computation were later compared with the real observed values and the relating parameters of the salt balance equation are conformed even though approximately. Finally it was represented that the salinity of upper layer is easily diluted not only by the tidal gate but also by the underdraiange conduit in the lower layer of the freshening reservoir.

I. INTRODUCTION

Recently in Korea, many freshening reservoirs have been constructed for the development of new water resources aiming at the irrigation water supply to the reclaimed lands. After sea dike was consolidated, salt water in the reservoir change to freshwater by the operation of tidal gate or other hydraulic structures. This reservoir is so called freshening reservoir$^{15)}$. Most of freshening reservoirs take one of the two general types,$^{3,4,5)}$ shallow or deep freshening reservoir. The deep freshening reservoir, so called standard type freshening reservoir, is characterized by occurrence of a distinguish saline interface. These reservoirs are complicate on salinity control problems compare with shallow ones concerning to the design period of freshening process for the water supply. Jansen$^{10)}$ and Okuda$^{11,12,13,14)}$ developed the salt balance equation for the freshening reservoir, considering only convective freshening mechanism in the effective storage of freshwater layer or in the shallow freshening reservoir. Minami$^{2)}$ considered three kinds of hydraulic mechanisms in the freshening process comprising the convective salt transport in the upper layer, the vertical diffusion of salinity through

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* Rural Development Corporation, Doctor of Agriculture

** Seoul National Polytechnic Univ., Dept. of Civil Eng., Professor saline interface and salt dispersion from the bottom soil of the reservoir. These mechanisms are based on the stratified flow defined as more important factor. The saline interface layer in the standard freshening reservoir has a complex state in which salinity diffusion by the convective movement in the upper layer and mixing velocity by the turbulence, also fluctuation of vortex with eddy in viscosity[1,6,8,9]. In order to improve the above mechanism, real experimental reservoirs were simulated for the freshening process. The selected freshening reservoirs have an underdrainage conduit for the withdrawal of the lower saltwater and observed data could be compared with the simulated results. The experimental reservoirs were selected in the Dai-ho and Nam-yang reclamation projects which are located in the western part of Korean peninsula as shown in Fig.1.

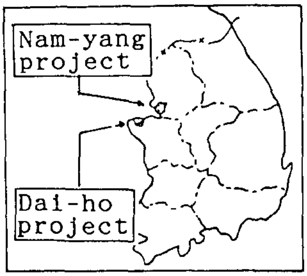

Fig. 1 Key map

II. GENERAL OUTLINE OF THE SELECTED RESERVOIRS

The Nam-yang reservoir is one of the first freshening reservoir in Korea which was constructed by the large scale projects for the comprehensive agricultural land development. This reservoir was being constructed during the period of April of 1971 to May of 1975. After construction of sea dike, salinity damage was happened many times to the crops in the cultivated paddy field during the period of irrigation. The main reasons of the this damage can be guessed that the effective storage of this reservoir is too small compare with amount of the irrigation water demand even though supplementary water is received from the A-san reservoir which is located near the south part of the Nam-yang reservoir, and in addition the freshening process is prevented by saltwater supplies from the outside sea, e.g., leakage from tidal gate or seepage of the sea dike. The saltwater below saline interface many times ascended to the surface of reservoir due to intake of irrigation water during the summer season. To solve this bad condition, the underdrainage conduit of the lower layer was newly designed in 1982 and built in 1983. Fig.2 represents the real plan of the Nam-yang project.

Dai-ho project is also a deep one with a long sea dike as shown in Fig.3 but has a small catchment area with no main river. The total storage of this reservoir is too big compare with the catchment area and then the freshening process is much restricted due to this relatively less river inflow. Hence, according to the designed schedule, installation of the underdrainage conduit was considered for the withdrawal of lower layer salinity. The sea dike of the Dai-ho project was completed at the end of 1983, and operation of the underdrainage conduit was started from 1984. Now the tidal land is under consolidation for the diversification of paddy field.

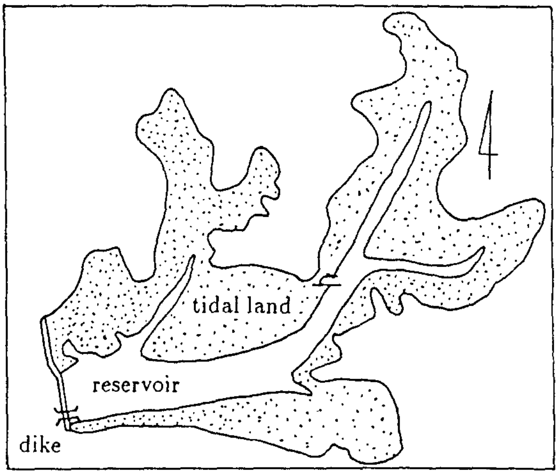

Fig. 2 Map showing of the Nam-yang project

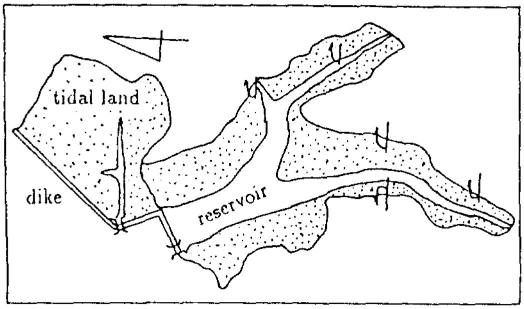

Fig. 3 Map showing of the Dai-ho project

Vertical salinity distributions for the two selected freshening reservoir were observed several times in a year to obtain their time histories as illustrated in Fig.4 and Fig.5. Scale dimensions of the two projects are listed in Table 1.

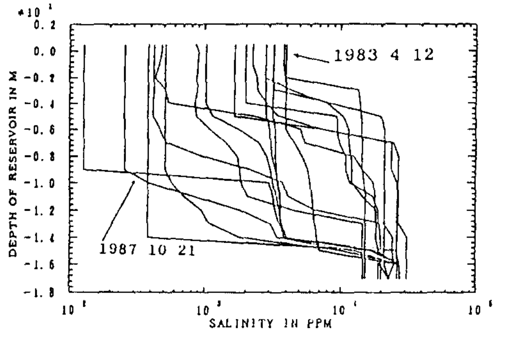

Fig. 4 Observed salinity distribution at the Nam-yang reservoir

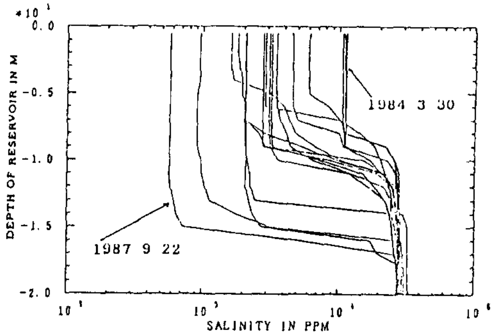

Fig. 5 Observed salinity distribution at the Dai-ho reservoir

Table.1 Scale dimensions of the selected freshening reservoir

Contents	Unit	Dai-ho	Nam-yang
Catchment area	ha	27800	20900
Reservoir surface area	ha	2150	800
Total storage	ha-m	12200	3150
Dead water storage	ha-m	7550	1300
Effective storage	ha-m	4650	1850
Flood water level	EL;m	+0.40	+2.10
Dead water level	EL;m	-3.70	-3.50
Maintenance water level	EL;m	-0.50	+0.50
Sill elevation of gate	EL;m	-6.00	-2.50
Scale of tidal gate	B×H×EA	10×6×6	3×5×12
length of sea dike	m	3253	2060
Drainage conduite			
1) diameter	mm	2200	1440
2) length	m	690	505
3) EL. of outlet	EL;m	-7.0	-3.5
4) EL. of inlet	EL;m	-14.0	-15.0
Tide			
1) higher sea level	EL;m	4.45	4.45
2) mean sea level	EL;m	0.033	-0.009
3) lower sea level	EL;m	-4.58	-4.58

Ⅲ. CONCEPTS OF THE DEEP FRESHENING RESERVOIR

1. General characteristics of the standard freshening reservoir

As most of standard freshening reservoir in Korea have small catchment areas, with less inflow through the small tributaries in comparison with effective storage of the reservoir volume, and stratified flow in the upper and lower layers appear due to salinity and temperature differences during a few months after construction of sea dike.

Since the tidal gate of standard freshening reservoir is located on a good foundation with relatively shallow depth, the lower part below its sill will be filled with original saltwater. Therefore analysis of the freshening process must be performed based upon the concept of two layered density stratification. Elevation of the interface water level can be assumed, as shown in Fig.6, the same as sill elevation of tidal gate at the initial stage of the freshening process. But instantaneously the feature of interface be changed by convective transport in the upper layer and diffusion phenomena from the interface between upper and lower layers. Also during the flood season, the saline interface will represent a convex curve and the salt wedge will be pushed to the down stream direction, but in most cases the saline interface recovers again to a horizontal line due to saltwater leakage through the sea dike and tidal gate during the dry season. Therefore it can be assumed that the saline interface remains as horizontal water level during the long term simulation of the freshening process.

2. Geomorphological aspects of the standard freshening reservior

Effective storage of the freshening reservoir can be defined as the volume between saline interface and surface of the reservoir, i.e., V_1 in Fig.6. In most cases of the upstream reservoir in mountains, the big effective storage is defined between surface elevation and dead water level. But in the freshening reservoir, though the interior mixing occurs, the upper layer is easily diluted by the river inflows compared with interface variation. In general cases, the designed initial effective storage of freshwater layer is taken as the volume from the sill elevation of the tidal gate to the surface of reservoir.

The area of interface layer(A_1) is generally the same as the horizontal area at the sill elevation of

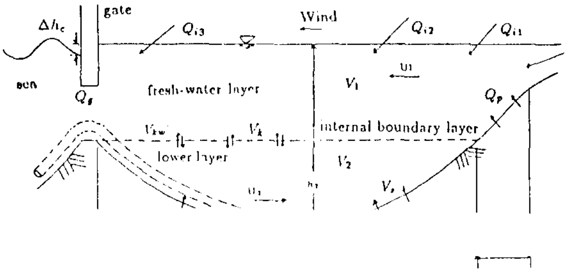

Fig.6 Tow layered freshening reservoir model

gate. This area can be calculated using the Area-Elevation curve provided by field survey, and is also used for the calculation of vertical mixing salinity from the lower layer as shown in Fig.6. In order to calculate the salinity dispersion from the bed soil, the bottom area(A_2) wetted by the freshwater layer which is also assumed horizontal level must be calculated. After freshening reservoir was constructed with the tidal land reclamation, saltwater of the ground A_2 will be mixed into the freshwater layer. Therefore the initial value of A_2 can be taken as the difference between the overall surface area of freshening reservoir(A) and interface area (A_1), $A_2=A-A_1$.

Ⅳ. GOVERNING EQUATIONS

1. Freshwater layer

For the practical simulation approach, Minamis' formular[7] is employed here in which allows for the vertical diffusion from the interface and dispersion salinity from the bottom soil of the reservoir. The representative equation of the freshening process for the freshwater layer above of the interface can be expressed as

$$\frac{dC_1 \cdot V_1}{dt} = [Q_{i1} C_{i1} + Q_{i2} C_{i2} + Q_{i3} C_{i3} + A_1(C_2-C_1)V_k + A_1(C_2-C_1)V_{kw} + C_2 Q_l E_l + A_2 V_s(C_2-C_1)$$
$$+ C_2 Q_p E_p + C_2 Q_b E_s - Q_{01} C_1 - Q_{02} C_1 - Q_{03} C_1 - Q_g C_1] \qquad (1)$$

where $C_1=$ Salinity of freshwater layer(ton/m^3), $C_2=$ Salinity of lower layer (ton/m^3), C_{i1}, C_{i2}, C_{i3} $=$ Salinity of river inflow, domestic use, industrial use water(ton/m^3), Q_{i1}, Q_{i2}, $Q_{i3}=$ Inflow of river, factory waste water, from domestic use(m^3/sec), $V_k=$Vertical mixing velocity due to turbulent shear stress(m/sec), $V_{kw}=$Vertical mixing velocity due to wind (m/sec), $Q_l=$Leakage from tidal gate (m^3/sec), $E_l=$Diffusion rate of gate leakage(%), $V_s=$Diffusion mixing velocity from bed soil (m/sec), $Q_p=$Ground water inflow (m^3/sec), $E_p=$Diffusion rate of ground water(%), $Q_b=$Seepage of the Sea dike (m^3/sec), $E_s=$Diffusion rate of dike seepage(%), Q_{01}, Q_{02}, $Q_{03}=$Intake water for irrigation, for domestic use, for industrial use(m^3/sec), $Q_g=$Outflow from tidal gate(m^3/sec). The term of left-hand-side of Eqn.(1) shown the variance in salinity of the effective storage during the unit time dt and the right side includes various factors by which the freshening process in the upper layer is influenced. Here the value of inflow Q_i and its salinity C_i are assumed nearly constant during the short period of simulation, and C_2 also be assumed the constant value under a stable condition of the lower layer. Now we can define the two parameters D and E as

$$D=\frac{-1}{V_1}[A_1(V_k+V_{kw})+V_s A_2+Q_{01}+Q_{02}+Q_{03}+Q_g] \qquad (2)$$

$$E=\frac{1}{V_1}[Q_{i1} Q_{i1}+Q_{i2} C_{i2}+Q_{i3} C_{i3}+A_1 C_2(V_k+V_{kw})+Q_l E_l C_2 V_1+A_2 V_s C_2$$
$$+E_p Q_p C_2+ E_s Q_b C_2] \qquad (3)$$

Thus Eqn.(1) can be rewritten as

$$\frac{dC_1}{dt} +C_1 D=E \qquad (4)$$

Integrating Eqn.(4) under the initial condition $t=0$ and $C_1=C_2$, we arrive at the solution as follow

$$C_1=\frac{E}{D}+(C_2-\frac{E}{D})e^{-D\cdot t} \tag{5}$$

and for the simulation purpose, we have

$$C_1(I)=\frac{E(I)}{D(I)}+[C_2(I-1)+\frac{E(I)}{D(I)}]e^{-D(I)t} \tag{6}$$

where I = the simulation interval constant, t = time interval.

2. Lower layer

In the standard type freshening reservoir, the saltwater remains in the lower layer due to density difference, forming a distinguish interface layer. The salt balance equation for the lower layer become

$$\frac{dC_2\cdot V_2}{dt}=[C_2(1-E_1)Q_1+C_2\,Q_p(1-E_p)+C_2\,Q_b(1-E_s)-A_1(C_2-C_1)(V_k+V_{kw})-Q_c\,C_2\,E_{fc}] \tag{7}$$

where Q_p = Ground water inflow(m³/sec), E_p = Diffusion rate of ground water(%), Q_c = Discharge of the underdrainage conduit (m³/sec), E_{fc} = Efficiency of drainage conduit(%). The term on the left-hand-side of above equation shows the variance in salinity of the lower volume V_2 below sill elevation of the tidal gate during the unit time dt and the right-hand-side term contains the relating factors for the salt layer. Let us consider the nearly constant value of C_2 during a short simulation period, then two parameters D_2 and E_2 can be defined as follows.

$$D_2=\frac{1}{V_2}[A_1(V_k+V_{kw})] \tag{8}$$

$$E_2=\frac{1}{V_2}[C_2\cdot(1-E_1)\cdot Q_1+C_2\cdot Q_p(1-E_p)+C_2\cdot Q_b(1-E_s)-A_1\cdot C_2(V_k+V_{kw})-Q_c\cdot C_2\,E_{fc}] \tag{9}$$

In consequence, the differential equation for the lower salt layer becomes

$$\frac{dC_2}{dt}+D_2\cdot C_2=E_3 \tag{10}$$

Integration of Eqn.(10) under initial condition $t=0$ and $C_2=C_s$, where C_s = sea water salinity, yields the solution

$$C_2=\frac{E_2}{D_2}+(C_s-\frac{E_2}{D_2})e^{-D_2\cdot t} \tag{11}$$

For the simulation procedure, Eqn.(11) can be expressed as

$$C_2(I)=\frac{E_2(I)}{D_2(I)}+[C_2(I-1)+\frac{E_2(I)}{D_2(I)})e^{-D_2\cdot t} \tag{12}$$

where I = simulation time interval.

3. Drainage condition for the underdrainage conduit

In the two layered freshening reservoir, a conduit of underdrainage system on a syphon type can be apply for the withdrawal of lower layer salinity. In order to improve for the freshening process, the condition of drainage must be considered in the head difference between sea water and reservoir water level.

The case of following condition,

$$\triangle h_c < \frac{\rho_2 - \rho_1}{\rho_2}(h_2) \tag{13}$$

discharge in the underdrainage conduit will be generate. Where $\triangle h_c$=head difference between sea water and reservoir water level, ρ_1, ρ_2=density of the fresh and sea water, h_2=inlet depth of conduit in the reservoir. Most of the inlet position of the conduit be installed the deepest position in the deep freshening reservoir.

V. SIMULATION PROCEDURE

The simulation period is a total of 1461 days(1984–1987) for the Dai–ho reservoir, and 1826 days (1983–1987) for the Nam–yang reservoir. In the process of simulation, interpolation method is used for the conversion from storage(V) to water surface area(A), from storage to water level(H), also from water level to storage. For the calculation of hourly drainage discharges from the tidal gate or syphon type of the underdrainage conduit, the actual tidal data as shown in Fig.7, is used. During the entire calculation, the reservoir water level is limited to that the value of lower than a given normal retention level. Thus the discharge released from the reservoir are evaluated by the difference between tidal and reservoir water level. Fig.8 shows the inflow of river and intake water for the Nam–yang reservoir and Fig.9 shows the river inflow for the Dai–ho reservoir. It should be note that for the Dai–ho reservoir no intake waters are considered since the reclaimed lands which require for the supply of irrigation water were completed after the simulation period of interest. Concerning the supplementary water supply during the irrigation period, the actual situation is adopted to the Nam–yang reservoir. Namely supplementary water from the A–san reservoir is supplied to the Nam–yang reservoir, resorting to pumping equipment with the capacity of 660ha–m per 10 days. The time–varying properties of the used data are summarized in Table 2.

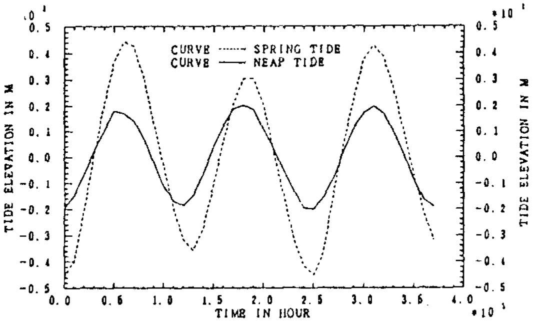

Fig.7 Sampling data of the tide

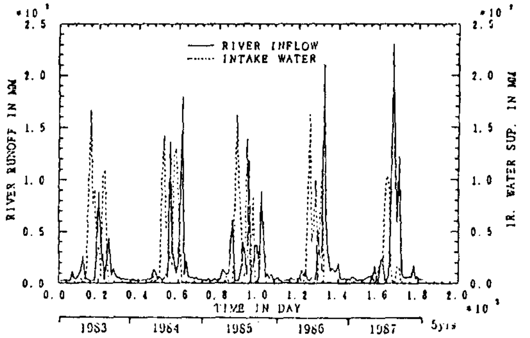

Fig.8 Inflow and intake water for the Nam–yang reservoir

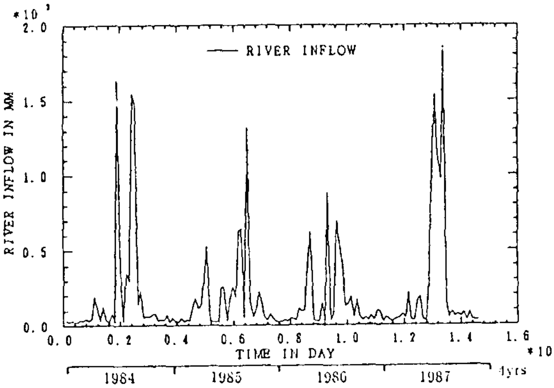

Fig.9 Inflow for the Dai-ho reservoir

Table.2 Main data for simulation

Component	Nam-yang	Dai-ho
Met. station	Su-won	Suh-san
Rainfall	Daily data of 5yrs	4yrs
Evaporation	Daily data of 1yr	1yr
Tide	Hourly data of 30days	30days
Wind velocity	Daily data of 1yr	1yr
Suppl. water	10 days data of 5yrs	Noting

VI. SIMULATION RESULTS AND DISCUSSION

1. The effects of underdrainage conduit

For the Dai-ho freshening reservoir : Because of no intake waters for irrigation, the salinity and interface water level slowly vary with time, as shown in Fig.10 and Fig.11. Up to 1985, the effect of underdrainage facility is not so great on salinity variation, but after 1985 the difference in salinity between two case, underdrainage and no underdrainage, becomes distinguishable. Use of underdrainage conduit is indeed much effective on lowering the saline interface and thereby increasing the fresh water storage, terminally producing its relative difference of 7.0m deep.

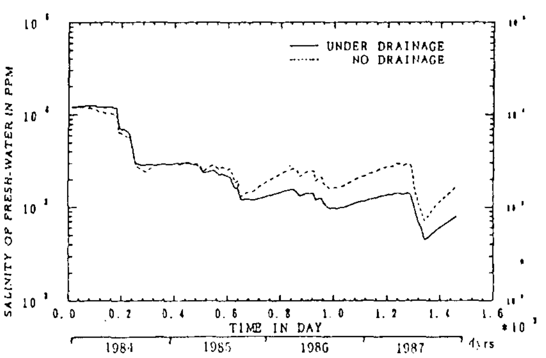

Fig.10 Salinity of freshwater layer in the Dai-ho reservoir

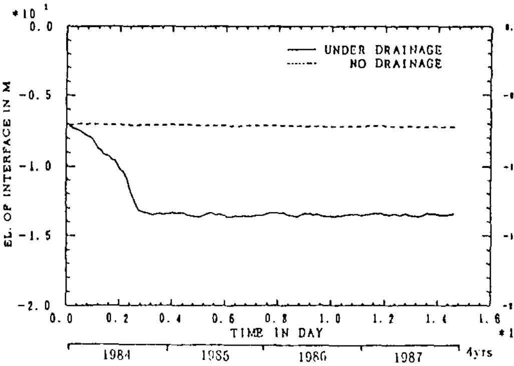

Fig.11 Interface water level in the Dai-ho reservoir

For the Nam-yang freshening reservoir : As was previously described, the water quality in this reservoir had been controlled by the operation of tidal gate only until the underdrainage conduit was installed in 1983. If the conduit was not added for the water quality improvement, the salinity of freshwater layer would remain higher than 1000 ppm during the irrigation season, as shown in Fig. 12, and further the saline interface would be positioned around 4.0m deep, as shown in Fig.13.

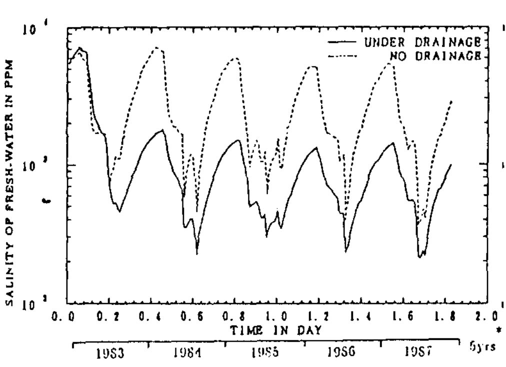

Fig.12 Salinity of freshwater layer in the Nam-yang reservoir

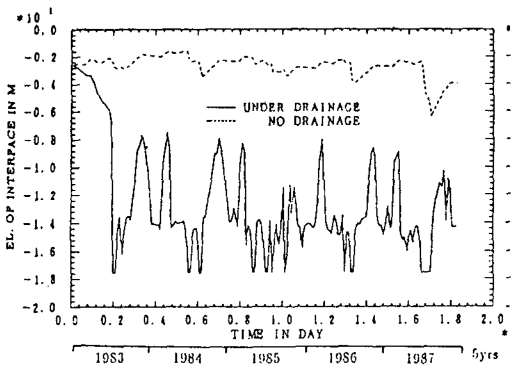

Fig.13 Interface water level in the Nam-yang reservoir

2. Comparison with observed data

The Dai-ho reservoir : On-the-spot surveys for the measurement of vertical salinity distribution were carried out only 20 times during the period under consideration. Initial condition for the computation is set up based upon the distribution of firstly observed. According to the results as shown in Fig.14, the computed salinity is as a whole lower than the observed ones, though their variation tendencies are nearly the same. On the other hand, as shown in Fig.15, computed result for the variation of saline interface level are well adjusted with the observed ones, except for the limited period of extreme deviation from the observed values. This deviation is considered to be a results of irregular operation of the tidal gate, that is, of the unexpected saltwater intrusion through the tidal gate.

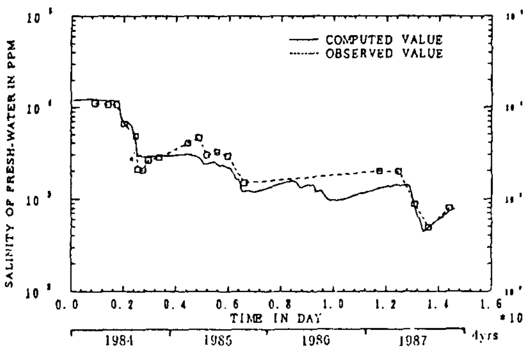

Fig.14 Salinity variation for the Dai-ho reservoir

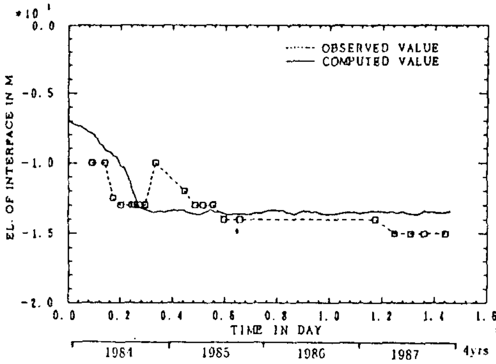

Fig.15 Interface variation for the Dai-ho reservoir

The Nam-yang reservoir : As the computed results in Fig.16 indicate, the upper layer salinity is periodically raised correspondingly to the absolute reduction of the freshwater inflow during the winter season. Clearly the observation justified this feature. However the computed values considerably deviate from the observed ones. Similarly to the Dai-ho reservoir, this seems to be a result of the excess supply of saltwater through the tidal gate and/ or sea dike. Meanwhile it can be seen from Fig.

17 that like the case of the Dai-ho reservoir, the saline interface level is fairly well reproduced on a good fitted sense by computation.

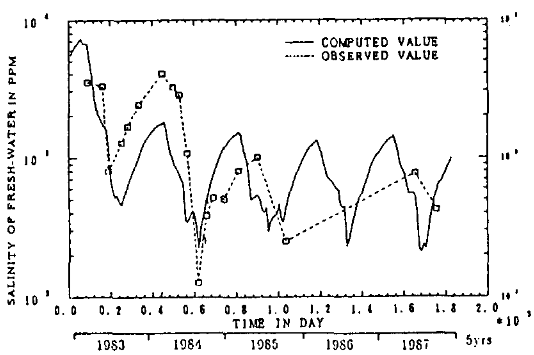

Fig.16 Salinity variation for the Nam-yang reservoir

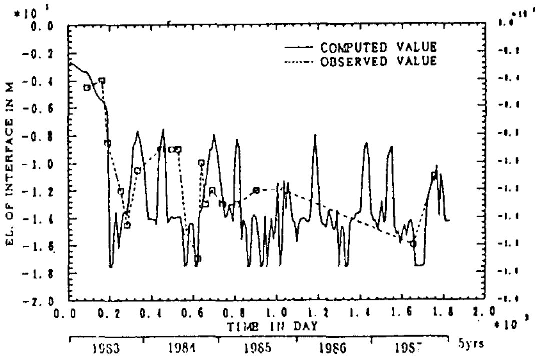

Fig.17 Interface variation for the Nam-yang reservoir

3. Conformed parameters for the selected freshening reservoir

During the simulation procedure for the Nam-yang reservoir, there is a difficult problem to conform the parameters for the salt balance equation. This reservoir was constructed a long time ago and leakage of the tidal gate or seepage of sea dike couldn't estimation. Therefore, first the parameters for the Dai-ho reservoir were conformed and thereafter these parameters were used for the initial values of the Nam-yang reservoir. Finally the conformed parameters in the two selected reservoirs were shown in Table 3. For the vertical mixing velocity due to wind, following values were adopted by interpolation method.

Wind speed(m/s)	2	4	6	8	10	12
Vkw(m/s)	0.25E-12	0.17E-9	0.45E-7	0.33E-5	0.11E-5	0.20E-5

Table.3 Conformed parameters for the selected freshening reservoir

Contents	Dai-ho	Nam-yang
V_k	0.3E-7	0.8E-7
Q_l	0.08	0.23
Q_b	0.08	0.23
E_l	0.2	0.2
E_s	0.1	0.2
E_p	0.1	0.2
C_k	0.000001	0.000001
H_o	20.0	22.0
H_K	25.0	27.0
E_{fc}	0.8	0.8

Ⅶ. CONCLUSIONS

Freshening process of two stratified layer in the estuarine reservoir was simulated using the salt balance equation. Even though this model is a lumped system based on the balance equivalent, it is very useful for the estimation of salinity and depth of the freshwater layer where the underdrainage conduit be installed for the improvement of water quality. In condition of the deep freshening reservoir with small catchment area in the western part of Korea, it is very difficult to use the upper layer as a freshwater storage since there is no underdrainage conduit in the lower layer. Because the saline interface level rises to the surface of the reservoir in many times during the dry season even though the salinity of upper layer becomes lower value. Therefore the deep freshening reservoir must be consider the underdrainage conduit for establishment of freshwater layer at the stable condition, and the place of big difference in tide as the western part of Korea, this underdrainage system was a suitable structure for the improvement of freshening process.

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