Coastal Education & Research Foundation, Inc.

Correlation between freshwater discharge and salinity intrusion in the Han River Estuary, South Korea

Author(s): Byung Il Yoon and Seung-Buhm Woo

Source: *Journal of Coastal Research*, Special Issue 65: Proceedings of the 12th INTERNATIONAL COASTAL SYMPOSIUM ICS 2013, Volume 2 (2013), pp. 1247-1252
Published by: Coastal Education & Research Foundation, Inc.
Stable URL: https://www.jstor.org/stable/26490958

Accessed: 11-03-2024 14:46 +00:00

REFERENCES
Linked references are available on JSTOR for this article:
https://www.jstor.org/stable/26490958?seq=1&cid=pdf-reference#references_tab_contents
You may need to log in to JSTOR to access the linked references.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at https://about.jstor.org/terms

Coastal Education & Research Foundation, Inc. is collaborating with JSTOR to digitize, preserve and extend access to *Journal of Coastal Research*

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

Correlation between freshwater discharge and salinity intrusion in the Han River Estuary, South Korea

Byung Il Yoon† and Seung-Buhm Woo†

†Department of Oceanography,
University of Inha, Incheon, Inha-ro 100,
South Korea
obangss@hanmail.net
sbwoo@inha.ac.kr

www.cerf-jcr.org

www.JCRonline.org

ABSTRACT

Yoon, B.I. and Woo, S.B., 2013. Correlation between freshwater discharge and salinity intrusion in Han River Estuary, South Korea *In:* Conley, D.C., Masselink, G., Russell, P.E. and O'Hare, T.J. (eds.), *Proceedings 12th International Coastal Symposium* (Plymouth, England), *Journal of Coastal Research*, Special Issue No. 65, pp. 1247-1252, ISSN 0749-0208.

The salinity distributions of estuaries and tidal rivers exhibit unique characteristics due to the effects of various external forces, such as tides, freshwater discharge, wind, and topographic effects. The interpretation and understanding of the structure of salinity profiles in coastal and estuarine areas is necessary for addressing issues related to oceanography, water quality, ecology, and engineering. To identify the salinity distribution of Han River Estuary (HRE), South Korea the surface salinity of the southern and northern regions of Yeomha Channel were observed from May to June, 2007. Variations in the salinity were clearly correlated with long- and short-term tidal fluctuations. Furthermore, the salinity strongly decreased when additional freshwater was discharged relative to the dry period, and more than 25 days were required following a high-discharge period to restore the salinity to that of the normal flow conditions. The characteristics of the axial salinity distribution in the Yeomha Channel of the HRE were studied using data from the National Marine Monitoring Network of the National Fisheries Research and Development Institute, and the length of the salinity intrusion relative to the tidal range, the amount of freshwater discharge, and topographic effects were expressed using an empirical equation. A correlation between the saltwater intrusion limit at the HRE and the freshwater discharge rate was expressed using an empirical equation. Based on this simple analytical approach, we believe that the structural characteristics of the salinity distribution in estuaries and tidal rivers vary not only due to freshwater discharge and tidal mechanisms but also due to topographic effects.

ADDITIONAL INDEX WORDS: *Salinity intrusion, Freshwater discharge, Empirical equation, Han River Estuary, South Korea.*

INTRODUCTION

An estuary is a brackish water zone where freshwater and saltwater mix; it is also an area where various artificial activities occur. The salinity distribution in estuaries is controlled by temporal and spatial variations in several factors, including the freshwater discharge rate, tidal amplitude and phase, wind, vertical and lateral mixing effects, and friction at the bottom and side boundaries (Savenije, 2005). The vertical and lateral variations in the salinity distribution in estuaries, which result from the mixing of tidal and freshwater discharge, stratification or changes in baroclinic flow, are among the major factors that determine the saltwater circulation and transport of materials throughout estuaries. The temporal and spatial variations of salinity significantly affect the survival and distribution of organic matter, bacteria, animals, and plants; the salinity distribution is also important for the acquisition and management of water resources as well as the engineering and installation of structures (Haas, 1977; Conomos *et al*., 1979; Kuo and Neilson, 1987).

Research on the vertical and lateral salinity distribution and saltwater intrusion in an estuary, which changes due to various causes, is typical performed using observational techniques, analytical methods and numerical models (Ippen, 1966; Officer, 1973; Prandle, 1981; Garvine *et al*., 1992; Huang and Spaulding, 2000; Savenije, 2005; Brockway *et al*., 2006). However, studies of the salinity distribution in the study area have been restricted in terms of access and the observation period for military reasons, and there has been a lack of research using different methods, such as analytical methods or numerical models, for simple and effective analyses.

This study explored the temporal and spatial distribution of salinity according to the tidal fluctuation and the freshwater discharge rate using long- and short-term observational salinity data. Furthermore, an empirical equation was applied for a simple and effective analysis of the cause of the saltwater intrusion phenomenon. The results were analyzed, and the correlation between the presented empirical equation and the freshwater discharge rate was examined. We believe that this study will be useful as a basis for coastal research and engineers on the salinity distribution.

STUDY SITE

Complex and unique salinity distribution properties are expected in the Han River Estuary (HRE) of Gyeonggi Bay, South Korea because it is connected to the Han River, the Yeomha Channel east of Ganghwado and the Seokmo and Gyodong channels to the west (Figure 1). The main stream of the Han River has maintained a steady water level during streambed excavation, the construction of submerged dams (e.g., the Singok and Han River submerged dams), and a blockage of freshwater outflow to

DOI: 10.2112/SI65-211.1 received 07 December 2012; accepted 06 March 2013.
© Coastal Education & Research Foundation 2013

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

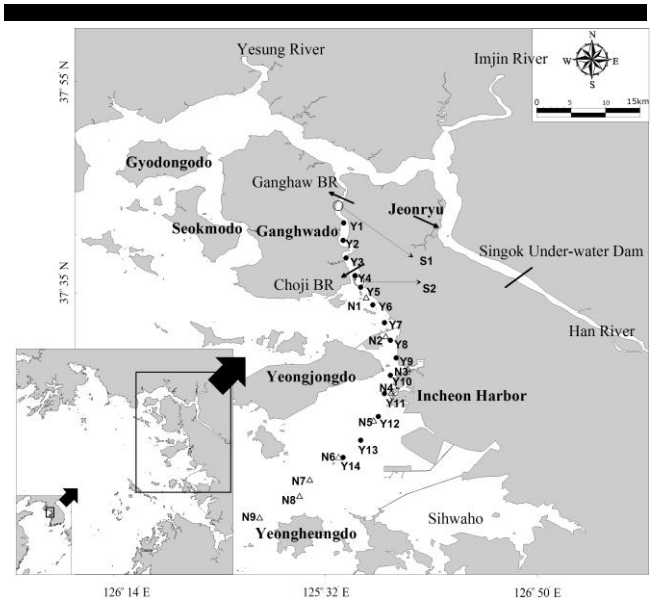


Figure 1. Map of the study area, Gyeonggi bay, and the HRE. The stations Y1-Y14 (●) indicate the location of the salinity profiling observations, and stations N1-N9 (△) were sampled by the NFRDI. The salinity was measured over 50 days at the fixed stations (○) S1 and S2 located near the Ganghaw and Choji bridges, respectively.

the open sea as a part of the Han River Development Project (1982-1986). However, the tidal range upstream of the submerged dam was significantly reduced because the tides extending from the open sea were blocked from entering the upper stream (Chang and Oh, 1991).

According to salinity data collected prior to the Han River Development Project, the salinity ranged from 15.8 to 35.5 psu and 12.1 to 20.1 psu for normal and wet river discharge condition, respectively, of 1966 at Noryangjin (16 km upstream of the Singok submerged dam) and Haengju Bridge (near the Singok submerged dam) (Kim, 1972). Although differences in salinity occurred depending on the extent of the offshore tide, according to the data observed after the construction of the submerged dam, the intrusion of high-salinity water upstream of the Singok submerged dam was nearly absent, and salinity values of less than 1.7 psu were observed in the section between Jeonryu-ri and the Singok dam (Chang and Oh, 1991; Kim, 2002; Park, 2004).

DATA and METHODS

The National Fisheries Research and Development Institute (NFRDI [1]) have established a marine environment-monitoring system for coastal and offshore areas in South Korea and have regularly conducted surveys 4 times per year since 1996. Using the National Marine Environmental Monitoring System data obtained from the Korea Oceanographic Data Center [2], we gathered salinity data from 1997 to 2009 for 9 stations in the Incheon coastal area (Figure 1; sites N1-N9). For this dataset, samples of salt water from the surface and the bottom layer were collected 4 times per year (February, May, August and November), and the salinity was analyzed using a standard method for water-quality analysis. Because these observational data from the NFRDI form a limited dataset based on quarterly observations, it is difficult to assess salinity variations due to tidal fluctuations, such as semidiurnal and diurnal tides. However, because the timing of the salinity observations was within ±2 hours of the high tide (Park, 2004), the tidal effects can be assumed to be constant; in addition, because the data were collected over a long period of time, we believe that the use of this data is reasonable for an analysis of the correlation with the freshwater discharge (which varies seasonally).

Long-term monitoring of the salinity was conducted from May to June of 2007 for a total of 50 days using an Ocean Seven 304 CTD logger (IDRONAUT) was moored on the surface at the south entrance (near Choji Bridge) and the north entrance (near Ganghwa Bridge) of Yeomha Channel, which is located between the Incheon coast and Ganghwado (Figure 1; sites S1 and S2).

Figure 2 presents the daily mean discharge data recording at Paldang Dam from 1974 to 2009, as provided by the Han River Flood Control Office (HRFCO). The daily mean discharge rate at Paldang Dam averaged 527 m^3s^{-1} over 36 years, and the median was 243 m^3s^{-1}. For the months of February, May, August, and November, the average discharge rates were 165, 408, 1478, and 205 m^3s^{-1}, respectively. Because the seasonal freshwater discharge rates appear to differ significantly, it is preferable to consider the seasonal variations due to differences in freshwater discharge rates for the salinity data provided by the NFRDI. For the correlation between the salinity and freshwater discharge rate during the analysis of a long-term salinity monitoring dataset, HRFCO provided flow-rate data for the Han River (Paldang Dam) and the Imjin River (Jeokseong) during the same period as the 2007 salinity observations. Because Paldang Dam, which is located 55 km upstream from the Singok submerged dam, is at the upper limit of the tidal reach at the Jamsil submerged dam (37 km upstream of the Singok submerged dam), its flow rate is thought to be largely unaffected by tides. The rate of discharge from the tributaries of the main stream of the Han River was excluded from the analysis of the correlation between salinity and freshwater because the tributary flow was less than 10% of the total flow from Paldang Dam. The flow rate at Jeokseong, located upstream of the Imjin River, was specified as the flow rate of Imjin River.

RESULTS

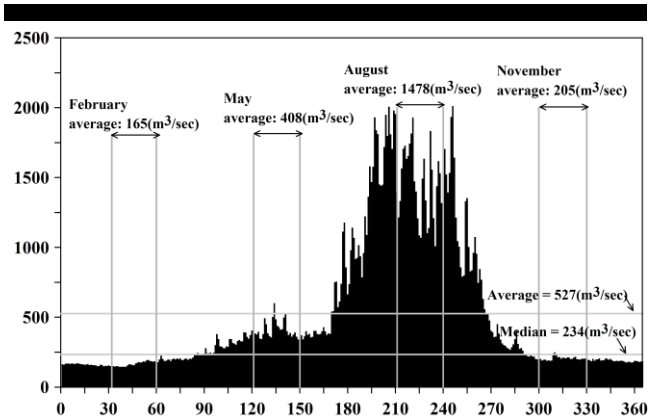


Figure 2. Daily mean discharge rates at Paldang Dam in the Han River averaged over 1974-2009.

[1] National Fisheries Research & Development Institute, http://www.nfrdi.re.kr/en
[2] http://kodc.nfrdi.re.kr/

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

Variation in Salinity

The time-series of the tides at Incheon Harbor, the freshwater discharge rates, the surface salinity observed at stations S1 and S2, and the horizontal salinity differences between the two stations are presented in Figure 3. During the salinity observation period, the discharge for Paldang Dam was in the range of 10-797 m^3s^{-1}, and the total freshwater discharge rate, including the flow rate from Imjin River, was in the range of 57-1542 m^3s^{-1} (Figure 3A). There were 2 occurrences during the observation period where the freshwater discharge was greater than 1,000 m^3s^{-1}: from May 18 to 21 and from May 28 to 31.

When the variations in salinity at Incheon Harbor are compared to the tidal fluctuations, it is apparent that the salinity values increased or decreased depending on the high or low state of the tides (Figure 3B). The surface salinity values for stations S1 and S2 during the entire observation period ranged from 0.5 to 22.2 psu and 4.0 to 30.8 psu, respectively. To identify the long-term salinity variation, a low-pass filter using a cutoff frequency of 48 hours was applied. The variation in salinity with the short-term tide components removed clearly showed an increase or decrease in salinity depending on the tidal period (spring or neap), and the salinity clearly decreased sharply when the freshwater discharge rate rapidly increased. At station S1, the rate of reduction in the salinity was larger and the recovery period was longer relative to station S2, which was downstream of S1.

The observed salinity data included 4 spring periods (SP) and 3 neap periods (NP) (Figure 4B), and each period was classified according to the spring and neap period as well as the freshwater discharge rate. When the first spring period (SP1) was compared with the second spring period (SP2+River), during which the freshwater discharge rate increased, the differences in the average horizontal distribution of salinity between stations S1 and S2 were 5.2 and 2.4 psu, respectively. When the NP1 period and the NP2+River period were compared, S1 station showed a salinity difference of 15.4 psu, and S2 station showed a salinity difference of 11.3 psu. Thereafter, a salinity distribution similar to the SP1 and NP1 periods was not observed during the SP3 and NP3 periods. Because a difference of 2-3 psu occurred between the SP1 and SP4 periods, we cannot consider the estuary to have been completely restored to the freshwater discharge state during a normal flow period after experiencing two discharge events of 1,000 m^3s^{-1}. We believe that the estuary is restored to the salinity distribution characteristics of a normal flow period after at least 20 days following the NP2+River period.

Figure 3C presents the temporal variation of the salinity differences in the axial direction between the two stations as well as the salinity difference of long-term components when the short-term tide components were removed. Although the variations were clearly correlated to the tidal period (i.e., spring or neap), the differences between the two stations were highly dependent on the freshwater discharge rate. For variations from SP1, where less than 300 m^3s^{-1} of flow was discharged, to NP1, the difference in the surface salinity between the two stations in the axial direction during the neap periods was approximately 7.4 psu, on average; this difference was smaller during the spring periods (approximately 6 psu). In addition, the salinity variations between the two stations when more than 1,000 m^3s^{-1} of freshwater was discharged were 8.9 and 10.4 psu for the spring period and the neap period, respectively. It was apparent that the salinity differences in the axial direction were not sufficiently restored even during the SP4 period, which is consistent with the average salinity data.

Although the surface data are limited, and we cannot accurately calculate the influence of the Yeomha Channel on the total freshwater discharge rate, this freshwater discharge has a direct and indirect influence on the total discharge upstream of the S1 and S2. The water column near the S1 station, which is located upstream of S2, has a large gradient between the surface and bottom layer salinity values because this site was more directly affected by the freshwater input than the S2 station. In addition, both the S1 and the S2 stations have larger vertical gradients in salinity during the neap periods than during the spring periods. The patterns of salinity variation differ depending on how the freshwater flow and tide conditions are combined. If the flow is greater (1000 m^3s^{-1}) than normal flow conditions, a more drastic salinity gradient than that caused by tidal fluctuations alone would occur, and the salinity difference in the axial direction would become larger than that found during the normal flow period. Following an increase in the freshwater discharge rate, the estuary requires more than 20 days to return to the salinity distribution that is characteristic of the normal flow period.

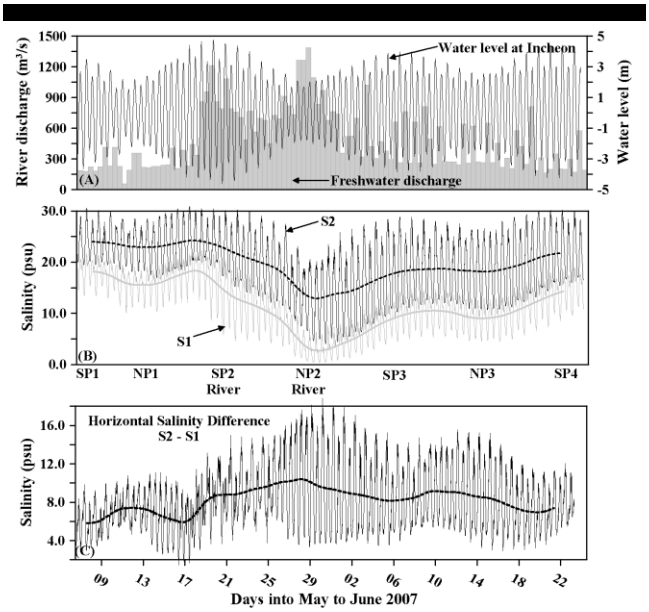


Figure 3. The top panel is a time series of the water level at Incheon Harbor as well as the rates of freshwater discharge from the Han and Imjin rivers. The middle panel is a time series of the surface salinity at stations S1 and S2. The bottom panel is the horizontal difference in salinity between stations S1 and S2. The solid and dotted lines are salinity and salinity of low-pass filtered with 36hour cut-off frequency, respectively.

Axial Salinity Distribution

Secondary flow due to a lateral salinity gradient in estuaries is controlled by factors such as estuary tidal motions, wind, channel width and the shape of the channel (Wong, 1996). However, this study only discusses the salinity distribution in the axial direction due to limitations in observational data, and we plan to present variations using the laterally observed salinity data and the numerical model results in the future.

The monthly averaged salinity distribution for the surface layer (Figure 4B) and the bottom layer (Figure 4A) at the 9 stations provided by NFRDI are presented; the vertical differences (Figure 4C) and the variations from the offshore to the upstream regions are also shown. The salinity difference between the surface and bottom layers at station N9, which is the furthest offshore observation site, was less than 1 psu, whereas the salinity

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

difference was greater than 5 psu between the surface and bottom layers in upstream locations (e.g., at station N1). The vertical salinity difference varied by season: the differences in the axial direction and the vertical salinity were smallest in February when the freshwater discharge rate was relatively low, whereas the differences in the axial direction and the vertical salinity were relatively large in August when the freshwater discharge was the greatest. There may have been variations in salinity in the vertical, lateral and axial directions due to the tidal influence, wind effects and topographic effects; however, because the data were averaged over 13 years and show variations similar to the freshwater discharge rate, we believe that the variations in the salinity distribution were caused by variations in the rate of freshwater discharge.

Stations N4 to N7 are thought to have strong variations during August when the freshwater discharge is strong, whereas the stations between station N4 and the upstream station at N1 are thought to be always directly affected by freshwater during the normal flow period (May) and the flood period (August). The salinity at stations N8 and N9 varied within the range of 29.7-31.5 psu each month, thereby indicating that the range of freshwater discharge did not greatly vary in the offshore direction from Palmido. Therefore, based on the long-term seasonal variations in the salinity in the axial direction, the entrance of the Yeomha Channel estuary appears to be located near Palmido.

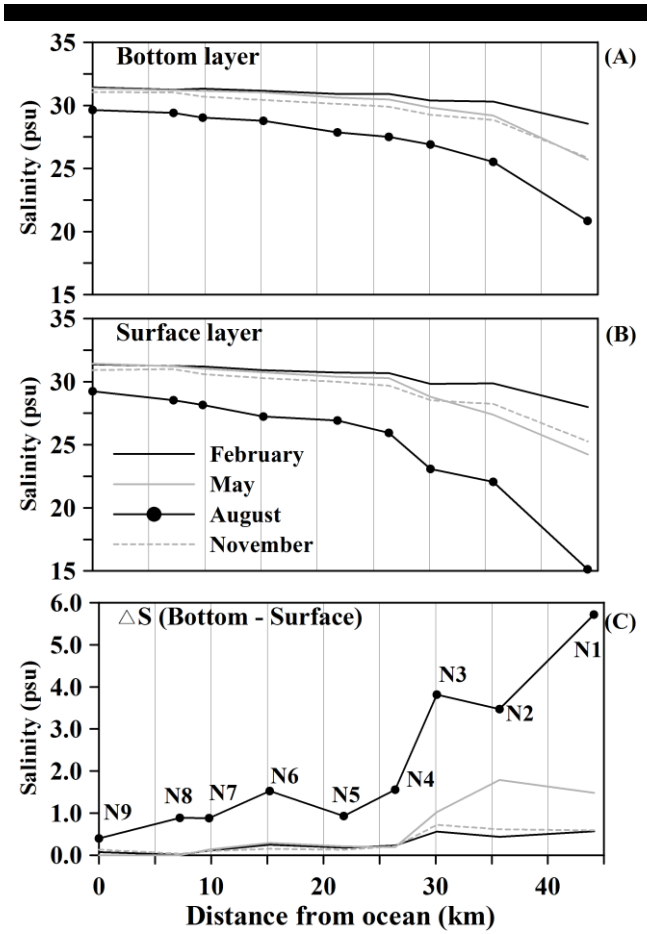


Figure 4. Axial salinity distribution based on data from NFRDI. The salinity data were calculated monthly (February, May, August, and November) and averaged for 13 years (1997-2009) at each station.

Each of the monthly averaged salinity datasets for the surface and the bottom layers were used to calculate the salinity variations from the estuary entrance toward the upstream locations in a non-linear regression model, which is presented in Figure 5. In this regression model, X-intercept (i.e., where Y = 0) is defined as the maximum length of the saltwater intrusion, and the saltwater intrusion length based on the freshwater discharge rate for each month is presented in Table 1. The freshwater discharge for each month averaged over 36 years was approximately identical to the average freshwater discharge rate from 1997 to 2009 (i.e., the period when the NFRDI data were collected). Moreover, the average freshwater discharge based on the flow rate on the first day of each month and the 2 days prior, which was the salinity observation period for the NFRDI data, also showed a similar flow rate for each season (Table 1).

The correlation between the freshwater discharges rates (Q), which was compared to the monthly average freshwater discharge rate using the equation obtained by Brockway *et al*. (2006), is shown in Figure 5. The length of saltwater intrusion is presented in Figure 6. The correlation coefficient for the relationship between the length of the saltwater intrusion and Q calculated using Equation (1) was 0.89.

$$L = 234.6Q^{-1.6/10} \quad (1)$$

Oey (1984) reported a high level of correlation between the length of saltwater intrusion and $Q^{-1/5}$ at the Hudson River, whereas Monismith *et al*. (2002) presented a correlation with $Q^{-1/7}$ by defining the area showing a range less than 2 psu as the limit to the length of the saltwater intrusion. Monismith *et al*. (2002) reported that the cause of the relatively low correlation between the observed salinity and the freshwater compared to the correlation of Oey (1984) was the effects of stratification and variation in depth due to vertical mixing. The correlation equation calculated in this study was $Q^{-1.6/10}$, which indicates that the correlation between freshwater and saltwater was lower than those in the studies by Monismith *et al*. (2002) and Oey (1984). This result indicates that the length of the saltwater intrusion was affected to a lesser extent than in other studied areas, although the distribution of salinity was determined by the effects of freshwater.

Empirical Relationship

The application of an empirical equation for calculating the length of a saltwater intrusion that takes into account the freshwater, tidal, and topographical effects is a simple and useful method, and many researchers have presented various methods and empirical equations to calculate the length of saltwater intrusions. The limitation of the length of the saltwater intrusion in this study was defined as the point of 2 psu, and we calculated the length of the saltwater intrusion using Equation (2) proposed by Brockway *et al*. (2006). This equation takes into account the effects of freshwater and the topographic shape of the estuary, as presented by Savenije (2005).

$$x_L = \left(\frac{1}{\beta}\right)\ln\left(\frac{4.6A_0\beta\kappa_x}{Q} + 1\right) \quad (2)$$

Here, A_0 is the cross-sectional area of the entrance of estuary, and β is the reduction factor or the extent of topographical convergence of the estuary. This study used the cross-sectional area A_0 (~46,945 m^2) and topographical convergence β (~0.028

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

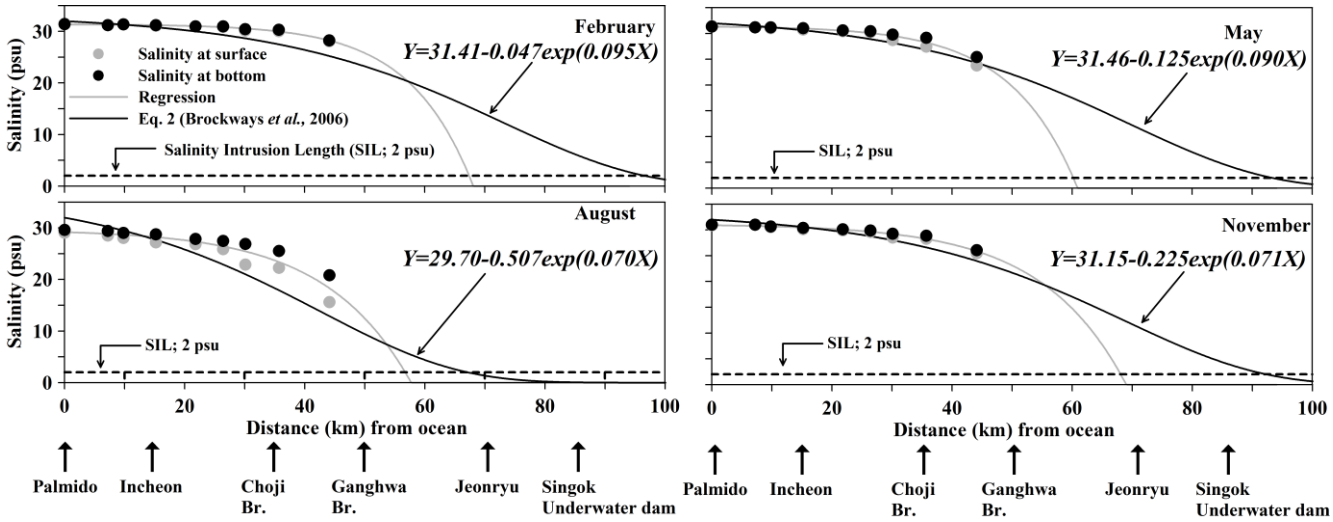


Figure 5. The black circle and gray circle indicate bottom and surface averaged salinity during 14 years (1997~2009) from NFRDI, respectively. Non-linear regression lines (gray line) and salt intrusion length (2 psu; dotted line) according to seasonal freshwater discharge. The black line is empirical relation (Brockway, *et al*., 2006) from Equation (2).

km-1) for the estuary entrance at Yeomha Channel, as presented by Woo and Yoon (2011). κ_x is the mixing coefficient for the axial direction, and $\kappa_x = -Q/(\beta A_0 \text{slope})$. The reduction value obtained using the non-linear regression model for each month (Figure 5) was used as the slope.

The mixing coefficient and the saltwater intrusion length obtained using the freshwater discharge rates for each month are shown in Table 2. The range of the saltwater intrusion in all of the months was greater than the values presented in Table 1. The results based on the freshwater discharge rate as well as the tidal conditions and topographical effects are thought to be more reasonable based on comparisons to previously published results because the salinity was in the range of 0-2 psu at Jeonryu-ri, which is 80 km upstream from the entrance of estuary (Palmido), whereas there was almost no saltwater intrusion at the Singok submerged dam, which is 100 km upstream.

CONCLUSION

Based on the observed water level for the HRE, which is the only estuary on the west coast of South Korea without a sea dike, together with previously published data, the Jamsil submerged dam is considered to be the limit of the tidal reach, whereas the Singok submerged dam is considered to be the limit of the salinity

Table 1. Freshwater discharge from 1974 to 2009 and 1997 to 2009 in addition to the NFRDI salinity observations. The length of the saltwater intrusion was calculated based on the non-linear regression shown in Figure 5. (SIL*: Salt intrusion length)

M	River (m^3s^{-1})			SIL* From ocean (km)
	'74-09 Monthly mean	'97-09 Monthly mean	Observation mean	
2	165	154	164	68
5	408	400	381	61
8	1,478	1,714	1,255	58
11	205	206	199	69

Table 2. Characteristics of the saltwater intrusion based on empirical relationships (SIL*: Salt intrusion length; S*: Slope)

M	SIL* (km) Non-linear regression	River (m^3s^{-1})	S*	κ_x m^2s^{-1}	SIL* (km) Empirical relation
2	68	164	0.05	5.6	101
5	61	381	0.13	11.1	95
8	58	1,255	0.5	20.1	74
11	69	199	0.23	4.7	89

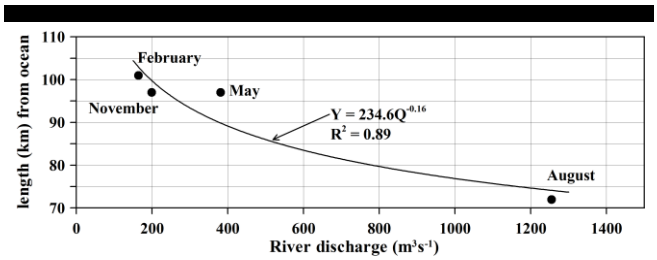


Figure 6. Correlation between the freshwater discharge rate Q and the length of the saltwater intrusion (using equation by Brockway *et al*. (2006)) from the ocean.

caused by the saltwater intrusion. The correlations between the tidal conditions and freshwater discharge rate as well as the degree of variation of the salinity were analyzed using a long-term salinity observational dataset. The average salinity for each month (season) in the axial direction of the Yeomha Channel based on the National Marine Monitoring Network database were used with the regression curve obtained from a non-linear regression to calculate the length of the saltwater intrusion. The length of the saltwater intrusion varied depending on the freshwater discharge rate, although the shape of the saltwater intrusion generally remained unchanged. When we examined a power-law regression for the calculated length of the saltwater intrusion and the freshwater discharge rate for each month, a correlation of

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms

approximately 1.6/10 ($X_L \approx Q^{-1.6/10}$) was found, which is distinctly different from the typical value of 1/3. This result is due to the fact that the saltwater intrusion is determined by other conditions, such as tides and topographic effects, in addition to the freshwater discharge rate. The length of the saltwater intrusion calculated applying an empirical equation, which takes into account the freshwater discharge, topographic effects and tidal influence, was in agreement with that of the existing literature. The length of the saltwater wedge is determined by the freshwater discharge rate, whereas the shape of saltwater wedge is determined by many variables, such as the tide, freshwater discharge and topographic shape of the estuary.

ACKNOWLEDGEMENT

This research was a part of the project titled "Development of forecasting technology for sea water circulation and ecosystem change in the Gyeonggi bay" funded by the Ministry of Land, Transport and Maritime Affairs, Korea.

LITERATURE CITED

Brockway, R., Bowers, D., Hoguane, A., Dove, V. and Vassele, V., 2006. A note on salt intrusion in funnel-shaped estuaries: application to the Incomati estuary, Mozambique. *Estuarine, Coastal and Shelf Science*, 66, 1-5.

Chang, H.D. and Oh, J.K., 1991. Depositional sedimentary environments in the Han River estuary and around the Kyunggi Bay posterior to the Han River's development. *Journal of the Korean Society of Oceanography*, 26, 13–23.

Conomos, T. J., Smith, R. E., Peterson, D.H., Hager, S.W. and Schemel, L. E., 1979. Processes affecting seasonal distributions of water properties in the San Francisco Bay estuarine system, *In*: Conomos, T. J. (ed.), *San Francisco Bay: The Urbanized Estuary*. Pacific Division of the American Association for the Advancement of Science, San Francisco, CA, pp. 115-141.

Garvine, R.W., McCarthy, R.K., and Wong, K.C., 1992. The axial salinity distribution in the Delaware Estuary and its weak response to river discharge. *Estuarine, Coastal and Shelf Science*, 35, 157–165.

Haas, L. W., 1977. The effect of the spring-neap tidal cycle on the vertical salinity structure of the James, York and Rappahannock River, Virginia, U.S A. *Estuarine, Coastal and Marine Science*, 5, 485-496.

Huang, W. and Spaulding, M., 2000. Correlation of sub-tidal salinity and freshwater inflow in a tidal river. *Journal of Waterway Port Coastal and Ocean Engineering*, 126, 264-266.

Ippen, A. T., 1966. *Estuary and Coastline Hydrodynamics*. McGraw-Hill, New York. 744p.

Kim, D.H., 2002. *A Study of the Biogeochemical Interactions in the Han River Estuary*, Incheon, The Korean; University of Inha, MS thesis, 62p.

Kim, J.K., 1972. Taxonomy of the phytoplankton of the lower course of the Han River in Summer and its relation to sea water. *Korean Journal of Limnology*. 15, 31-41.

Kuo, A. Y., Neilson, B. J., 1987. Hypoxia and salinity in Virginia estuaries. *Estuaries*, 10, 277–283.

Monismith, S. G., Kimmerer, W., Burau, J.R. and Stacey, M. T., 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. *Journal of Physical Oceanography*, 32, 3003–3019.

Oey, L. Y., 1984. On steady salinity distribution and circulation in partially mixed and well mixed estuaries, *Journal of Physical Oceanography*, 14, 629-645.

Officer, C. B., 1976. *Physical Oceanography of Estuaries (and associated coastal waters)*. Wiley. 465p

Park, K.S., 2004. Salinity distribution and ecological characteristics in the Han River Estuary. Journal of Korean Wetlands Society, 6, 14-31.

Prandle, D., 1981. Salinity intrusion in estuaries. *Journal of Physical Oceanography*, 11, 1311-1324.

Savenije, H. G., 2005. *Salinity and Tides in Alluvial Estuaries*. Elsevier, Amsterdam. 194p

Woo, S.B. and Yoon, B.I., 2011. The Classification of Estuary and Tidal Propagation Characteristics in the Gyeong-Gi Bay, South Korea. *Journal of Coastal Research*, SI 64, 1624-1628.

This content downloaded from 165.246.122.121 on Mon, 11 Mar 2024 14:46:58 +00:00
All use subject to https://about.jstor.org/terms