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Study on the assessment of environmental impact indicators on concentrated effluent from desalination facility

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ABSTRACT

Concentrated effluent from desalination facility constantly impacts on near-ocean ecosystem by changing physicochemical characteristics such as temperature and salt. To minimize damage from the effluent, its effect on the ecosystem should be figured out by predicting and monitoring through modeling as well as on-site investigation. This study used four steps of environmental impact assessment; pollutant source identification, analysis of the acceptor ecosystem, analysis of the links between source and acceptor, and mitigation suggestions. In each step of the assessment, pollution sources were identified and affected ecosystem was analyzed. Their correlation was also analyzed to propose efficient facility operation methods to reduce environmental impacts. On-site water quality survey and Environmental Fluid Dynamics Code modeling were also performed to predict and assess the environmental impacts of the effluent discharge to the Yeongil Bay region. The result showed that T-N and T-P in region near to the effluent outlet increased, resulting in rapid growth of chlorophyll-a, which might lead to a red tide.

Keywords: Environmental impact indicator; Desalination facility; Concentrated effluent; Ocean ecosystem; Mitigation suggestion

1. Introduction

Introduction of a desalination facility has been actively promoted over the world as an alternative of water source to regions of insufficient water supply. However, concentrated seawater generated by the desalination process is coming to the fore as a new problem. The desalination concentrate has high salinity, high temperature, and high nitrogen concentration, but it is known to have an extremely low level of external carbon sources that are necessary for microbial growth [1]. Inflow of various types of by-products discharged from desalination facilities into the sea has been reported to have a lasting impact on not only the physicochemical properties of the nearby marine waters, including water temperature and salinity, but also the marine ecosystem [2]. In this regard, some of the countries operating a desalination facility are investigating the impacts of the by-products on the nearby ecosystems under the greatest impact with the goal of minimizing the impacts [3]. In addition, the countries are preparing measures to minimize the damage from the substances discharged from the desalination process by predicting the impacts through modeling and by performing continuous monitoring with the consideration of the environment. For example, the impacts of the discharged substance on representative producers and primary consumers have been assessed with respect to phytoplanktons and zooplanktons. The impacts on the benthic ecosystem have been investigated by monitoring the changes in the annelids and seaweeds species as well as their distribution [4].

Generation of high-salinity concentrate from desalination facilities is an unavoidable problem, and most of the high-salinity concentrate is currently discharged to the near sea. Since the salinity of the discharged concentrate is extremely high to be about 70,000 ppm, the impact of the concentrate

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on the adjacent marine ecosystems has been controversial for several years. However, it is currently known that the high-salinity concentrate forms a high-salinity layer at the bottom due to its high density, affecting the marine ecosystems severely [5,6]. In particular, the desalination facilities broadly located at the seashores of the Middle East have been reported to destroy the near-ocean environment seriously [7]. The severity of the impact of the concentrate discharge on the environment is dependent particularly on the chemical composition of the concentrate among the many properties of the desalination process, but it is also dependent on the hydrodynamic properties, water depth, and biological properties of the discharged marine regions [8].

At present, more than 90% of large-scale desalination facilities discharge the concentrate directly to the sea. Direct discharge of the concentrate to the sea is performed either by directly discharging at a coast or by using a pipe to discharge to offshore waters separated from a coast [9]. Large-scale facilities generally employ the method of directly discharging at a coast, while small-scale facilities (400 m^3/d or less) transfer the concentrate to a point of 100 m away from the coast underwater and then discharged by using distribution equipment [10]. The flow rate of discharged concentrate is generally from 1.5 to 3.7 m/s, and the common design value is 3 m/s [11]. Choosing a region where the concentrate may be rapidly mixed with the seawater to be diluted is important in both of the methods. Marine organisms are generally known to tolerate salinity change of ±1,000 mg/L from the existing salinity [12]. Since the average salinity of seawater is 35,000 mg/L, a change of salinity within 3% may not give an adverse impact on marine organisms. For example, if the seawater salinity is 35,000 mg/L and the salinity of concentrate is 70,000 mg/L (the concentration ratio is two in cases of 50% recycling rate facilities), the minimum dilution ratio should be 35 to maintain the salinity after mixing at 36,000 mg/L, or lower.

The damage of the environment by the discharge of concentrate from desalination facilities is well illustrated in the case of Spain, where *Posidonia oceanica* was lost due to the concentrate resulting in the destruction of the ecosystem [13]. The problem began to be severe as many desalination facilities were established in the region of Alicante where *P. oceanica* was widely distributed. *P. oceanica* grassland is significant in the Mediterranean ecosystem, and thus its conservation is emphasized in many laws for environmental protection. *Posidonia* grassland serves as a foundation for ecosystem maintenance since it fixes sand dunes to supply oxygen to the sea and provides food to various marine organisms. Therefore, loss of *Posidonia* grassland causes deterioration of water quality and enhances sludge formation to increase the turbidity and produce sedimentation. Other impacts of the loss of *Posidonia* grassland include change of the marine food chain and blocking of food sources for many marine species [14].

Buceta et al. [15] studied the impacts of high-salinity concentrate on the *Posidonia* grassland and concluded through an experiment that *Posidonia* grassland is vulnerable to an increase of salinity. An increase of salinity inhibits the growth, permanently detaches the foliage, and causes necrosis of cells to change the structural pattern of *Posidonia* grassland, increasing the mortality. The mortality of the *Posidonia* grassland was found to be proportional to the increase of the salinity. The mortality started to increase from a salinity level of 40,000 ppm, and it reached 50% within 15 d at the salinity level of 45,000 ppm.

In South Korea, almost no study has been conducted on the effect of desalination facilities on near ocean. The ecological toxicity assessment in relation to desalination facilities has been studied at a molecular or cellular level. However, the impacts of desalination facilities on the sea are beyond a molecular or cellular level. Therefore, research at levels of individual organisms, population, and ecosystem should be conducted to figure out the exact effect. A comprehensive environmental impact index is also necessary to take an ecosystem into account. In this study, as a method of assessing the impacts of concentrate discharged from a desalination facility on a nearby ecosystem, four steps of environmental impact assessment method were used, and the requirements at each step were discussed. The environmental impact assessment method was applied to an installation stage of a desalination facility to investigate the sensitivity of the nearby environment as well as a method for minimizing the impact. Finally, the impact of high temperature, which is one of the impact factors of concentrate on the nearby seawater region, was simulated by predicting the power generation coolant discharge on the basis of an Environmental Fluid Dynamics Code (EFDC) model, and the results were compared with actual measurement values.

2. Environmental impact assessment protocol for concentrate discharged from desalination facility

Although the environmental impact assessment procedures were already proposed in another research [16], the relevant standards, codes, and technical solutions are still in their infancy. So far, there is no single environmental impact assessment method that is internationally recognized with respect to desalination facility, but environmental impact assessment codes to be applied to desalination facilities are currently under development. However, such a legal boundary is necessary in the stage of determining the most appropriate water supply means.

In Spain, the number of desalination facilities is anticipated to drastically increase in future, and a high-salinity concentrate of about 730 hm^3/year is expected to be produced additionally. Therefore, construction of these facilities should undergo strict environmental impact assessment. Considering the ecological values of the ecosystem mentioned earlier, its conservation should be highly appreciated. When a critical value is recommended, the preventive principle for securing a minimum level of safety is important to guarantee the survival of the polluted grassland [17]. In addition, the limiting values of salinity should be provided as not a reference value but a frequency distribution. For example, the salinity should not exceed 38,500 ppm at 25% or more of the measurements obtained at any positions of the grassland, or should not exceed 40,000 ppm at 5% or more of the measurements [15].

2.1. Procedures of environmental impact assessment

The procedures of environmental impact assessment follow the minimum guidelines, including (1) analysis of sources of impacts, (2) analysis of ecosystem under impacts, (3) definition of cause-and-effect relations, (4) recommendations for reducing impacts, and (5) substantiality of environment conservation means [18]. Step 1 is about 10 components of an ecosystem when concentrate is discharged to the sea, which is environmentally important. In Step 2, the 10 are further divided according to the marine ecosystems sensitivity. Steps 3, 4, and 5 are general information, not about specific plants or regions. Any norms applied include several central and mandatory steps that should draw attention, to which the following five items belong.

- Environmental impact assessment requires analysis of pollutants (pollution sources). The analysis should be performed with a desalination facility causing the environmental impacts, not a specific version of desalination process or an independent plant [19]. Another constraint is that only the discharge to the sea should be taken into account. Air pollution is not considered.
- Environmental impact assessment requires analysis of an affected ecosystem (subject). For the purpose of the present study, a typical coastal region was selected as the ecosystem to be analyzed, which was the southwestern coastal region of Arabian Gulf [20]. Detailed marine ecosystems were characterized and classified according to the sensitivity.
- The relation between pollution sources and the subject should be defined. Environmental impacts are analyzed at different sensitivities of the detailed ecosystems. No matter how similar an ecosystem may be to the typical region selected in the step, actual field investigation is insufficient and thus scientific experience is scarce [21].
- A method of reducing the impact should be proposed, that is, alternatives are developed, and the best and the worst alternatives are evaluated and selected.
- Environmental impact assessment is finalized with recommendations for the present and the future. Some recommendations may be appropriately carried out only with specific subjects, but several general recommendations may be included in the conclusion.

2.2. Procedures of environmental impact assessment for desalination facility construction and operation

The system for assessing the environmental impact of constructing and operating a desalination facility on a marine ecosystem employs four consecutive steps of environmental impact assessment methods (Fig. 1).

Step 1 is the process of investigating all tangible and intangible pollution sources created by the construction and operation of a desalination facility as well as the types and quantities of the pollutants [22]. The substantial change of a habitat caused by the facility site formation in the facility construction process, and the introduction of suspended particles and sands during the construction works are monitored in Step 1 (Table 1). Step 1 also requires the continuous monitoring hazardous chemicals such as high-salinity water, cleaning solutions, facility wastewater, disinfection solutions, and biocides produced during the process of operating of the facility.

Step 2 is the process where the desalination facility construction site candidates are selected to investigate the habitats that may be affected by the desalination facility operation, and habitats that are inadequate as a desalination facility construction site candidate are excluded. In Step 2, the types of habitats that are preferred for desalination facility construction are the sites where marine energy of wave and tidal current is high, coasts composed of rocks and gravels, and coastal region with water springs. Geographical features inappropriate for desalination facility construction include the sites where marine energy of wave and tidal current is low, a closed bay, sea jungle, salt marsh, intertidal forest, and coral reef. In the present study, 15 habitats were classified into different types to propose habitat survey and environmental investigation, given the marine water environment. Table 2 shows the data used for the determination of vulnerability of each habitat for a desalination facility construction.

In Step 3, the correlation between pollutants and ecosystems is studied to investigate the impacts of pollutants generated from the desalination process on the ecosystem of the water region and to suggest a method of identifying the ecological impact of desalination facility. Step 3 requires a physical study (water depth, ocean current, flow discharges, etc.), investigation of water quality (water temperature, dissolved oxygen (DO), pH, salinity, chloride, ammonia, etc.), a biological

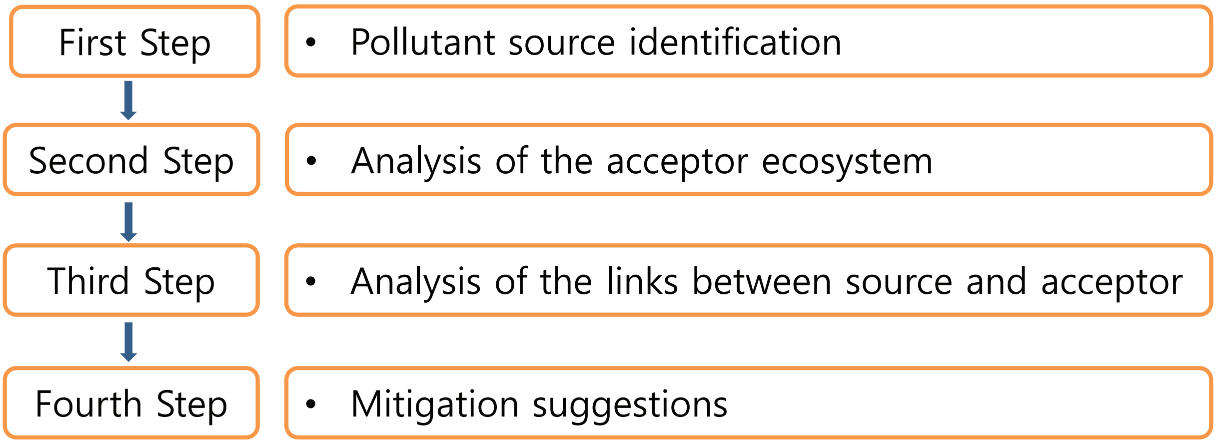


Fig. 1. Environmental impact assessment method on desalination facility.

Table 1
Hazardous chemicals using by desalination facility

Additive categories	Chemicals
Biocides	Chlorine, halogenated hydrocarbons (THMs), chloramine
Coagulants	Ferric chloride, aluminum chloride, polyelectrolytes
Scale control additives	Polyphosphates, polymer antiscalants
Antifoaming agents	Polyethylene glycol
Metals by corrosion	Copper, nickel, iron, chromium, molybdenum, benzotriazole derivates
Membrane cleaning chemicals	Formaldehyde, isothiazole, sodium dodecylbenzenesulfonate, sodium dodecyl sulfate, ethylenediaminetetraacetic acid, sodium perborate

Table 2
Environmental sensitivity according to habitat types of desalination facility

Habitat types	Sensitivity
High energy oceanic coast, rocky, or sand with coast-parallel coast	Lowest
Exposed rocky coast	
Mature shoreline	
Coastal upwelling	
High energy soft tidal coast	
Estuary and estuary-similar system	
Low energy sand-, mud- and beach rock flat	
Coastal sabkhas	
Fjords	
Shallow low energy bays and semienclosed lagoons	
Algal (cyanobacterial) mats	
Seaweed bays and shallows	
Coral reefs	
Salts marshes	↓
Mangrove flats	Highest

assessment (ecological toxicity, population structure, etc.), and a study on the concentrate diffusion pattern using a mathematical model. To identify the impact on the ecosystem, regular monitoring of the environment near to a desalination facility should be performed at least four times a year, and a marine ecological toxicity test should be performed with the pollutant by using at least three biological organisms.

In Step 4, methods of reducing environmental impacts and effectively operating the facility are proposed to derive a socioeconomic agreement with the environment. Methods of operation, discharge, by-product reduction, and monitoring were suggested to minimize the environmental impacts of the desalination facility and propose a sustainable operation method (Table 3). In Step 4, measures to reduce environmental impacts should be established with regard to the vulnerability of ecosystems and the most sensitive subgroups. For example, measures should be urgently prepared for the management of the water region under the direct impact of high-salinity plum and for the conservation of benthic ecosystem, particularly adherent biota. Table 4 shows common pollution sources involved in the desalination process as well as the methods of reducing the pollution.

Table 3
Recommendation according to discharge

Discharge	Recommendation
discharge to surface	Increase dilution rate by lowing depth of channel and widening width
single outlet	Increase dilution rate by increasing discharge line
multiple outlet	Increase dilution rate by aligning dilution line perpendicular to surrounding ocean current

3. On-site water quality survey

Two times on-site surveys were performed on August 11 and November 14, 2016. Fig. 2 shows 13 sampling positions for on-site water quality survey, which were 5 in Hyeongsan river near POSCO (Pohang Steel Company) power plant coolant outlet and 8 in nearby sea. The sampling positions were carefully selected to monitor the effect of the power plant coolant effluent (about 1 million tons everyday) on nearby ecosystem. When the on-site surveys were conducted, a red tide occurred at the P4 position where the POSCO power plant coolant is discharged. Seawater temperature and salinity of the surface layer and the bottom layer were measured at each position. Five water quality item of T-N, T-P, chemical oxygen demand (COD), chlorophyll-a, and DO were measured through standard method. In addition, a flowmeter was used to measure the flow speed of the surface layer and the bottom layer.

3.1. Result of first on-site water quality survey (August 11, 2016)

The first on-site water quality survey performed at 13 sampling positions. P1 to P5 were in Hyeongsan river and outlet of the power plant coolant is located near P4. The sampling positions of P6 to P11 were selected to investigate the effect on near sea and the positions of P12 and P13 were on further effect. The P5 to P13 positions, where the warm effluent is discharged and is mixed with the seawater, were directly affected. And P2 to P4 positions were expected to have an indirect impact from warm water. The flow speed at P4 position where the warm effluent is discharged was 0.87 m/s, and the density Froude number at the P1 to P5 positions were 12.46 with a discharge flow speed of 0.87 m/s.

Table 5 shows the results of the water quality survey. As shown in Table 5, the water temperature at the position

Table 4
Mitigation plan according to environmental impact factor

Environmental impact factor	Desalination method	Mitigation plan
Low pH	Mainly SWRO	Increase pH before discharge
Residual brine	MSF	Remove salt and improve facility before discharge
Temperature increase	MSF	Use mixing, cooling, or cooling tower
Metal increase	MSF	Improve facility(use polyethylene or titanium pipes instead of metal pipe)
Salinity increase	SWRO/MSF	Discharge after dilution/mixing

Note: SWRO — seawater reverse osmosis, and MSF — multiple-stage flash distillation.

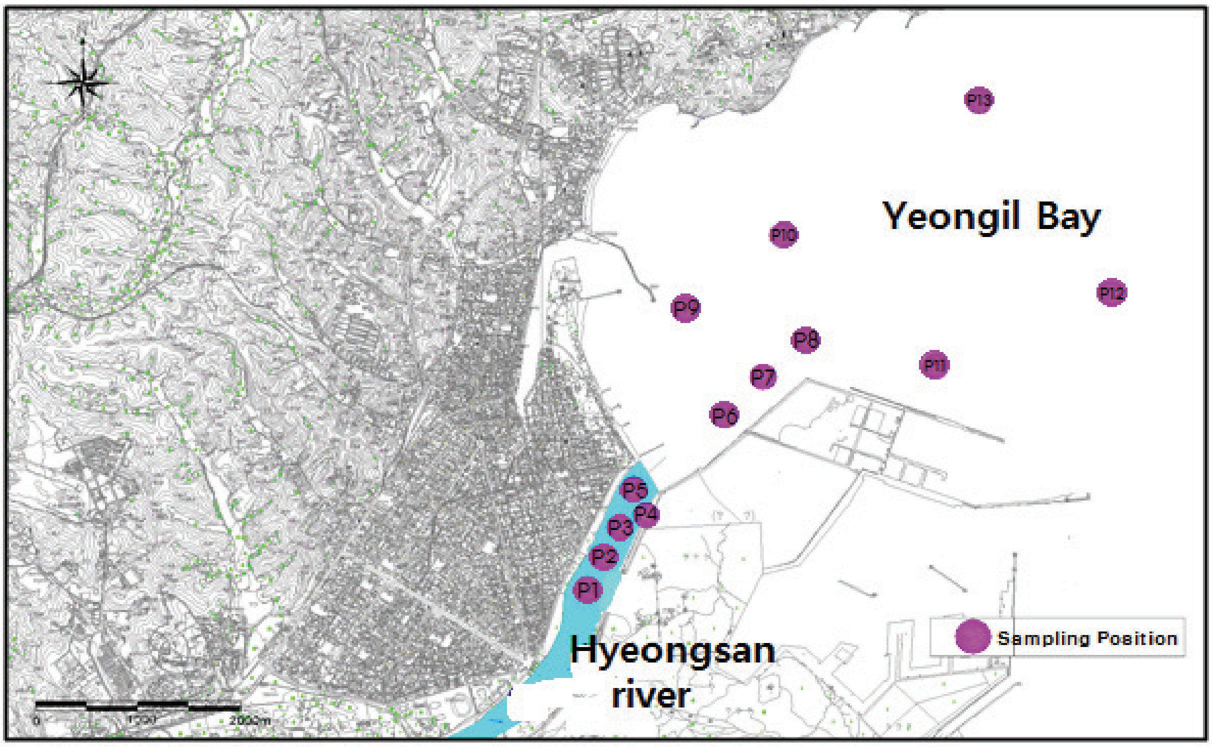


Fig. 2. Sampling positions for on-site water quality survey.

where the effluent is discharged (the P4 position) was 26°C. As the measurement position was farther from the P4 position, the water temperature was lowered, with the effluent being mixed with the relatively cold seawater at the Yeongil Bay and the freshwater from the upstream of the Hyeongsan river. No water temperature difference was found between the surface layer and the bottom layer at the P4 position where the effluent is discharged. At the P1 to P5 positions in the upstream of the Hyeongsan river, a significant difference was found in the salinity between the surface layer and the bottom layer, and the type of mixing was weak mixing due to the strong stratification caused by a saline wedge.

3.2. Result of second on-site water quality survey (November 14, 2016)

The flow speed at the P4 position where warm effluent is discharged was relatively high as 1.13 m/s. The density Froude number at the P1 to P5 positions were 18.12 with a discharge flow speed of 1.13 m/s. Table 6 shows the results of the water quality survey. The average values representing the water quality at the points were DO 6.93 mg/L, COD 1.85 mg/L, T-N 12.08 mg/L, T-P 0.140 mg/L, and chlorophyll-a 0.15 mg/L. The mixing type at the P2 to P4 positions, the upstream region of the Hyeongsan river, seemed to be strong mixing because the water temperature and salinity were not significantly different between the surface layer and the bottom layer.

4. Water quality prediction by modeling

In South Korea, seawater is generally used as power plant coolant. The used seawater whose temperature is increased by about 7°C–9°C is discharged to the coast after cooling the steam. Although it is different depending on sea regions, the temperature of the warm effluent discharged through the outlet generally becomes equal to that of the surrounding seawater as it moves to the offshore by being mixed with natural seawater or emitting heat to the atmosphere.

Table 5
Result of first water quality analysis

Point		DO (mg/L)	COD (mg/L)	T-N (mg/L)	T-P (mg/L)	Temperature (°C)	Salinity (ppt)	Chlorophyll-a (mg/m^3)	Depth (m)
P1	Surface	6.72	4.48	9.598	0.065	22.3	20.0	0.000	1
	Bottom	5.7	3.56	7.475	0.104	21.3	20.4	0.000	1.5
P2	Surface	5.68	7.32	13.588	0.149	22.6	12.8	0.822	1
	Bottom	4.38	3.72	3.886	0.127	17.5	20.6	0.000	3
P3	Surface	5.81	6.28	16.349	0.233	22.3	12.4	0.000	1
	Bottom	4.46	3.12	4.739	0.129	17.9	20.2	0.000	3
P4	Surface	4.88	5.88	33.209	0.369	26.0	9.6	0.000	1
	Bottom	5.93	5.44	10.538	0.196	26.0	18.5	0.000	1.5
P5	Surface	6.16	6.44	8.677	0.125	21.1	18.8	0.000	1
	Bottom	6.68	4.92	5.176	0.146	17.2	19.0	0.000	2.5
P6	Surface	5.85	4.84	4.907	0.091	19.3	13.8	0.000	1
	Bottom	7.13	0.76	4.792	0.131	17.9	18.3	0.000	2.5
P7	Surface	7.42	2.24	4.178	0.087	18.6	16.0	0.000	1
	Bottom	5.36	2.48	5.809	0.105	16.6	17.9	0.000	5
P8	Surface	6.84	1.60	5.314	0.058	18.9	14.6	0.000	1
	Bottom	5.2	1.64	6.031	0.102	15.6	14.8	0.000	12
P9	Surface	7.34	7.52	6.478	0.058	18.8	13.2	0.000	1
	Bottom	5.61	7.68	5.919	0.068	15.5	13.4	0.000	15
P10	Surface	7.25	7.80	5.450	0.074	19.5	16.3	0.000	1
	Bottom	4.52	8.64	8.290	0.269	16.3	16.1	0.000	6.5
P11	Surface	6.73	7.00	5.214	0.059	18.0	17.0	0.000	1
	Bottom	5.13	8.16	5.874	0.147	16.5	16.6	0.000	6
P12	Surface	7.36	3.88	5.815	0.050	18.3	10.7	0.000	1
	Bottom	6.25	3.64	4.835	0.061	14.9	10.5	0.000	15
P13	Surface	7.95	4.32	5.669	0.064	18.7	7.8	0.000	1
	Bottom	8.49	6.32	5.157	0.079	15.0	8.5	0.000	15

About 1 million tons of the POSCO power plant coolant is daily discharged in a constant amount over the year to the Hyeongsan river through the drains, as warm seawater effluent, at a temperature around 30°C. At the estuary of the Hyeongsan river, the seawater level is elevated to the water intake reservoir and then lowered twice a day by the impact of the tide. Therefore, the discharged warm effluent may be assumed to be immediately spread to the Yeongil Bay after the discharge. The warm effluent affects the coastal water quality environment and ecosystem by increasing the water temperature of the surrounding seawater. In this study, eight water quality items including water temperature, salinity, DO, COD, T-N, T-P, chlorophyll-a, and flow speed were measured to analyze the impact of the warm effluent at the estuary of the Hyeongsan river, and the on-site survey results were compared with the EFDC numerical analysis results.

Figs. 3 and 4 show the water quality modeling results of summer and winter, respectively, which indicates the water quality of horizontal and vertical distributions. The horizontal and vertical distributions of the water temperature and the salinity of the bottom layer in each season show that the bottom layer penetrated as a saline wedge from the outlet to the upstream of the Hyeongsan river. In particular, in some regions around the upstream of the Hyeongsan river, the water temperature was higher in the bottom layer than the surface layer in winter due to the density difference.

In summer, the penetration of the bottom layer as a saline wedge was decreased as the river flow was increased. However, the river water and the warm effluent were spread to the Yeongil Bay in a form of a typical estuary front with stratification. In winter, the water temperature distribution was inversed at the region near to the direct downstream from the POSCO outlet and the surface and bottom layers were strongly mixed to form a constant vertical density distribution. However, a type of front was formed in the downstream of the strong mixing region as a low density region was formed rather than a constant density distribution. Whether the front found in this study corresponds to so-called thermal front suggested by oceanography or not is uncertain at present, it is sure that the POSCO effluent affected a wider traverse region of the Hyeongsan river in winter when the river flow rate was decreased due to the winter drought than in summer, inhibiting the outflow from the upstream of the Hyeongsan river to the Yeongil Bay. As a result, when chlorophyll-a causing a red tide flourished, the stagnation of the flow by the front might have inhibited the spread of the effluent,

Table 6
Result of second water quality analysis

Point		DO (mg/L)	COD (mg/L)	T-N (mg/L)	T-P (mg/L)	Temperature (°C)	Salinity (ppt)	Chlorophyll-a (mg/m^3)	Depth (m)
P1	Surface	6	0.56	10.211	0.133	18.3	19.8	0.102	1
	Bottom	5.59	0.72	10.047	0.108	18	19.7	0.395	1.5
P2	Surface	6.63	3.04	22.687	0.189	21.2	16.1	0.000	1
	Bottom	6.6	0.52	7.522	0.105	18.8	19.4	0.010	3
P3	Surface	7.17	0.92	31.188	0.259	17.8	15.3	0.000	1
	Bottom	6.67	1.76	7.406	0.129	17.6	19.5	0.000	3
P4	Surface	6.5	2.04	33.727	0.292	23.5	14.4	0.102	1
	Bottom	5.8	1	13.717	0.158	23	17.9	0.102	1.5
P5	Surface	7.79	3.32	20.520	0.190	18.6	16	0.000	1
	Bottom	6.77	1	7.044	0.127	17.3	18.7	0.711	2.5
P6	Surface	7.2	1.88	17.372	0.176	19.3	15.9	0.000	1
	Bottom	7.79	0.2	7.747	0.109	18	18.3	0.000	2.5
P7	Surface	7.24	2.88	17.914	0.166	17.6	17.5	0.000	1
	Bottom	7.13	0.52	6.713	0.112	16.9	18.1	0.822	5
P8	Surface	6.30	2.32	18.638	0.192	18.3	15.5	0.000	1
	Bottom	6.69	2	7.616	0.129	18.8	16.9	0.000	12
P9	Surface	6.87	3.88	9.812	0.128	17.8	16.4	0.000	1
	Bottom	6.97	2.36	7.318	0.089	18.2	15.9	0.102	15
P10	Surface	7.17	1.84	7.986	0.085	18.3	17.4	0.000	1
	Bottom	7.61	1.88	6.392	0.093	18.3	17.5	0.000	6.5
P11	Surface	7.41	2.76	8.024	0.150	17.5	17.9	0.812	1
	Bottom	8.01	2.24	7.001	0.099	17.2	18.2	0.812	6
P12	Surface	7.04	0.72	8.950	0.162	17.5	15.4	0.000	1
	Bottom	7.01	2.6	7.294	0.082	16.6	15.5	0.000	15
P13	Surface	7.06	1.96	5.491	0.071	16.9	15.6	0.000	1
	Bottom	7.10	3.2	5.760	0.104	16	14.1	0.000	15

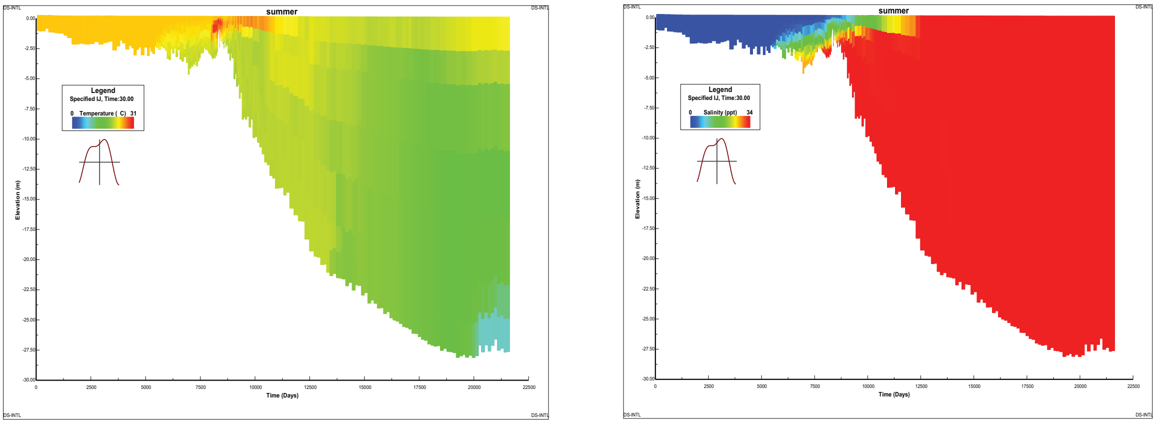
extending the red tide occurring in autumn and later in the Hyeongsan river. Such stagnation of the effluent flow is probably an important physical phenomenon causing the red tide in winter.

In addition, the type of mixing was different between winter and summer. As shown in the results of the on-site water quality survey, strong mixing occurred in winter, in contrast to the mixing type in summer. As the numerical calculation results suggest, the range of the discharged warm effluent spreading to the offshore was decreased due to the mixing type at the estuary region, and some of the discharged warm effluent was transferred to the upstream of the Hyeongsan river.

As can be seen from the numerical calculation results for chlorophyll-a, T-N, and T-P, the chlorophyll-a concentration was high in all the regions of the Hyeongsan river, indicating that the onset and expansion of a red tide may be explained on the basis of the chlorophyll-a concentration calculation results. Both the T-N and T-P values were higher in the region near to the POSCO warm effluent outlet than in other regions of the Hyeongsan river, which was the result of the increase of the T-N and T-P values due to the thermal front formed at the estuary of the Hyeongsan river. The increase of the T-N and T-P values might have resulted in the rapid growth of chlorophyll-a, leading to a red tide.

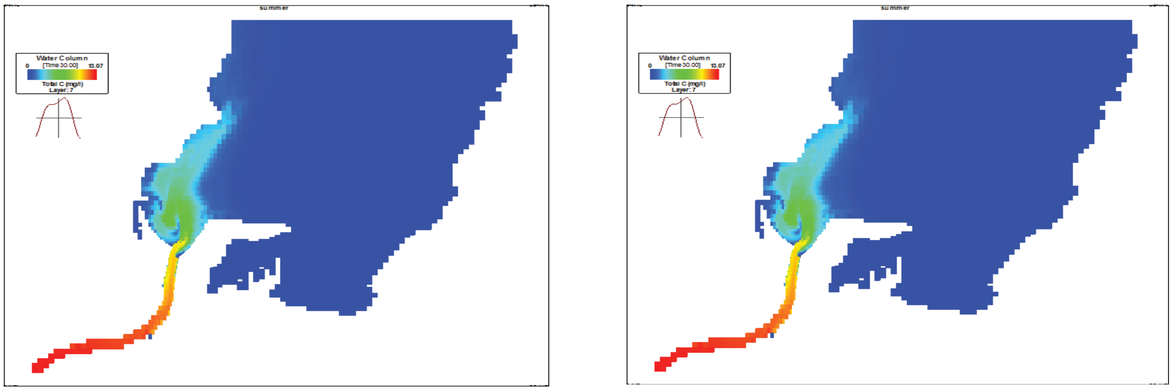
5. Conclusions

For the assessment of the environmental impacts of the concentrate discharge from a desalination facility on a marine ecosystem, five procedures were used in the present study, including the analysis of impact sources. In addition, four steps of environmental impact assessment were provided with regard to the construction and operation of a desalination facility. In each step of the assessment, the pollution sources were identified and the affected ecosystem was analyzed, and then their correlation was analyzed to propose methods to reduce environmental impacts as well as efficient facility operation methods. The impacts of the water temperature increase in the nearby sea region due to the concentrate discharge on the seawater quality were investigated to develop an index for the environmental impact assessment. On-site water quality survey was performed in summer and winter and an EFDC modeling was performed to predict and assess the environmental impacts of the power plant warm effluent discharge to the Yeongil Bay region by the POSCO power plant at a daily discharge rate of one million tons. The water quality modeling results showed that the POSCO effluent affected a wider traverse region of the Hyeongsan river in winter when the river flow rate was decreased due to the winter drought than in summer. As a result, the outflow from



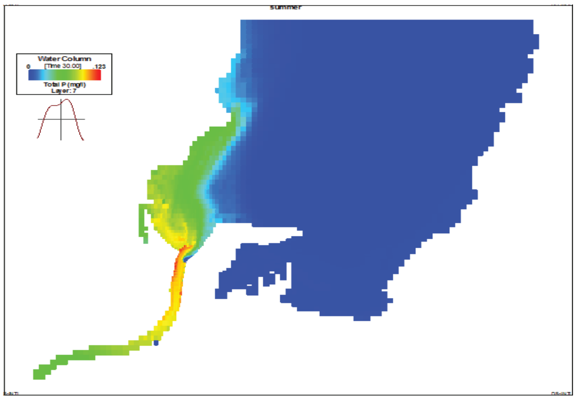
(a) Vertical distribution of water temperature

(b) Vertical distribution of salinity



(c) Plane distribution of Chl.-a

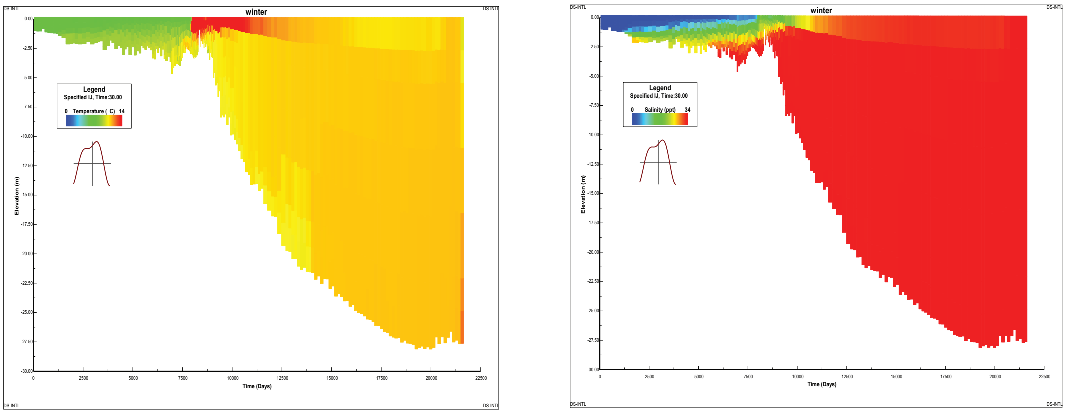
(d) Plane distribution of T-N



(e) Plane distribution of T-P

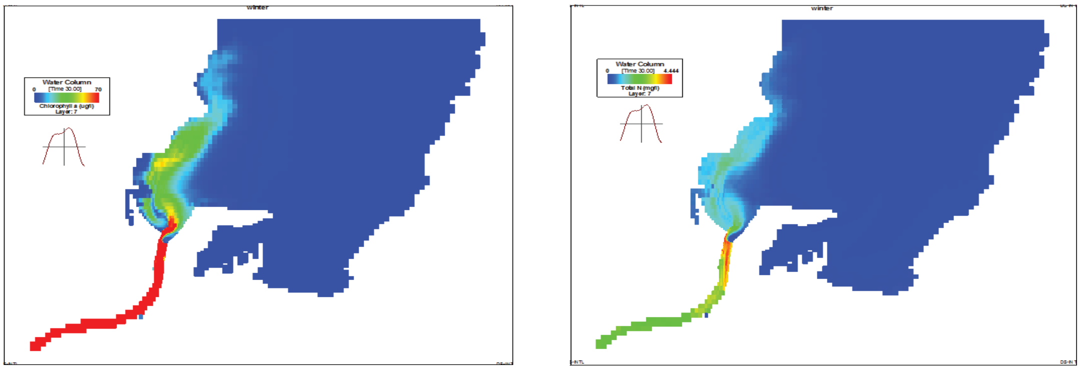
Fig. 3. Result of water quality modeling (summer situation after 30 d). (a) Vertical distribution of water temperature; (b) vertical distribution of salinity; (c) plane distribution of chlorophyll-a; (d) plane distribution of T-N; and (e) plane distribution of T-P.

the upstream of the Hyeongsan river to the Yeongil Bay was inhibited, and chlorophyll-a flourished, causing a red tide. As the numerical calculation results for chlorophyll-a, T-N, and T-P show the chlorophyll-a concentration was high in all the regions of the Hyeongsan river, suggesting that the onset and expansion of a red tide may be explained on the basis of the chlorophyll-a concentration calculation result. Both the T-N and T-P values were higher in the region near to the POSCO warm effluent outlet than in other regions of the Hyeongsan river, which was the result of the increase of the T-N and T-P values due to the thermal front formed at the estuary of the Hyeongsan river. The increase of the T-N and T-P values might have resulted in the rapid growth of chlorophyll-a, leading to a red tide.



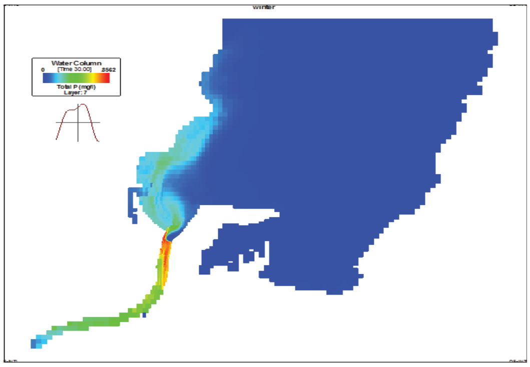
(a) Vertical distribution of water temperature

(b) Vertical distribution of salinity



(c) Plane distribution of Chl.-a

(d) Plane distribution of T-N



(e) Plane distribution of T-P

Fig. 4. Result of water quality modeling (winter situation after 30 d). (a) Vertical distribution of water temperature; (b) vertical distribution of salinity; (c) plane distribution of chlorophyll-a; (d) plane distribution of T-N; and (e) plane distribution of T-P.

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