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Seawater intake system in Test Bed seawater reverse osmosis (SWRO) project

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ABSTRACT

The Test Bed for seawater reverse osmosis desalination plant having a capacity of 10 million imperial gallons per day, located in Gijang-Gun, Busan, South Korea, is under construction by Doosan Heavy Industries and Construction. Generally, beach well-type intake system furnishes a good seawater quality, but the amount of water which can be extracted from each well is limited by the geological formation surrounding the wells. In case of the Test Bed, unfortunately, beach well-type intake could not be adopted, therefore, in order to achieve asimilar level of seawater quality, as being able to get by adopting the beach well intake, the Test Bed intake system is directly connected with a newly developed dissolved air flotation with ball filtration system. The Test Bed intake system consists of passive offshore screen, intake pipe, and air-burst cleaning system. In order to avoid possible clogging of the offshore screen by oceanic substances, compressed air-bursting system is installed onshore. In addition, underground tunnel is adopted to minimize the environmental impact during construction. Also, to avoid possible brine recirculation, a simulation study on the recirculation of brine discharge was carried out. The simulation study has been conducted using Environmental Fluid Dynamics Code model which is a three-dimensional hydrodynamic and water quality model. Grid generation is arranged 11.5 km horizontally and 15.5 km vertically. Mesh is varied from 20 to 200 m with 10 layers. Using tidal current and tide data of Korea hydrographic and oceanographic administration (KHOA), this model was verified. The result shows that if the distance between intake and outfall is 50 m, brine is induced to intake and excessive salinity at intake increases to 800 ppm in summer. If the distance between intake and outfall is increased to 70 m, the resulting maximum excessive salinity is 340 ppm. Finally, the outfall is displaced 70 m from intake.

Keywords: Test bed; Seawater reverse osmosis (SWRO); Desalination; Intake; EFDC; Brine; Recirculation; Offshore screen

1. Instruction

Seawater reverse osmosis (SWRO) desalination plant is highly sensitive to the feed seawater quality, which is the key factor to decide the configuration of its pretreatment system and operation directly. Therefore, in a SWRO desalination plant, the intake system has to ensure sufficient quantity and acceptable quality of seawater. And nowadays, minimization of

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environmental impacts is highly required. Also, public interest becomes one of the key execution factors.

To ensure a good quality of seawater feed before reverse osmosis system, a careful study on the location of the intake as well as its type is very important during its design stage. Deeper location of intake head would guarantee better quality of seawater: however, it could result in the increase of capital cost [1]. And recently, because of the difficulty in getting good feed seawater quality, due to more offshore contamination, the cost for seawater intake and outfall is continuously increased, and becomes a substantial portion of EPC cost for SWRO desalination plant. In case of 35 million gallons per day SWRO desalination plant, Gold Coast, Australia, the cost of providing intake and outfall was 50% of that of the SWRO facility. If sub-surface types of intake are adopted, the cost for the intake is considerably increased. In case of 50 million gallons per day Carlsbad SWRO desalination plant, California, the cost for new open intake is 150 million United State Dollars (USD). But that of beach well intake is 650 million USD [2]. Therefore, an economic design of the seawater intake is very important.

Presently, the Test Bed SWRO desalination plant is under construction in Gijang-Gun, Busan, South Korea. Its designed quantity of permeate is 10 million imperial gallons per day (45,460 m^3/day) and the produced potable water will be supplied to the town of Gijang-Gun.

The plant is being constructed on the skirt of a mountain which is inside a nature reservation area. In addition, seaweed farms are located within 1,000 m. Therefore, in the design stage, the environmental characteristics of intake and brine discharge were carefully reviewed.

This paper presents the introduction of the intake system of the Test Bed SWRO desalination plant.

2. System description

Beach well-type intake usually furnishes better water quality in terms of suspended solid, oil and grease, natural organic contamination and aquatic microorganisms as compared to open seawater intake. But it is necessary to have good transmissivity of the seashore's geological formation [3]. Unfortunately, geological survey shows that this site and its coastal area are rock-based soil. Therefore, beach well-type intake cannot be adopted in the Test Bed SWRO desalination plant. In order to achieve the similar level of seawater quality as being able to get by adopting the beach well intake, the Test Bed intake system is directly connected with a newly developed dissolved air flotation with ball filtration system (DABF). The combination of intake system and the DABF is the most innovative designs of Test Bed SWRO desalination plant.

To minimize the foot print of the site, offshore screen is chosen instead of installing conventional bar screen and travelling band screen. Intake pipe is directly connected to the DABF. Suspended solids and some organisms which are contained in influent seawater are filtered by ball media. The DABF is installed under the ground level, and seawater flows into the DABF by gravity. And a pumping station is located downstream the DABF. The layout of the Test Bed SWRO desalination plant is shown in Fig. 1.

Intake system consists of passive offshore screen, intake pipe and air-burst cleaning system. The designed capacity is 4,500 m^3/h. The size of the offshore screen is 5,540 mm in length and 1,675 mm in diameter. This screen is made of V-wired mesh and its slot size is 3 mm. The current velocity passing through the slot is less than 0.13 m/s and the initial pressure drop of the clean screen is as low as 0.25 m of water pressure (Fig. 2(a)).

Offshore screen can be clogged with oceanic substances. To remove them, a compressed air-bursting system is installed on shore. It consists of a compressed air receiver tank, pneumatic valves which are controlled by a distributed control system. The pressure of this tank is 8 bars. During the cleaning cycle, compressed air is supplied to the screen for 20 s.

Chlorination pipe is connected downstream from the screen. Chlorination affects not only outside the screen, but also inside the intake pipe. Shock dosing will be carried out every two weeks.

Underground tunnel is designed to minimize the environmental impact during construction. For the same reason, five desalination plants in Australia adopted tunnelling intake and brine outfall [4]. Both seawater intake piping with 1,200 mm diameter and brine disposal piping with 800 mm diameter are installed in this tunnel with 3,000 mm diameter. The tunnel is located at −35 m from the ground level and extends 400 m from the seashore (Fig. 2(b)).

3. Physical oceanographic conditions

Fig. 3 shows the sectional drawing of intake and outfall areas. The depth of seawater is less than 30 m within 1,000 m from the shoreline. After that point, it is sharply down. From the coast to 200 m, the seabed is made of rock. And the slope of the seabed is slightly down. Seawater level at the intake and outfall ranged from 10 m to 20 m.

If a heavy amount of high salinity brine is continuously discharged, it can be fatal for marine life.

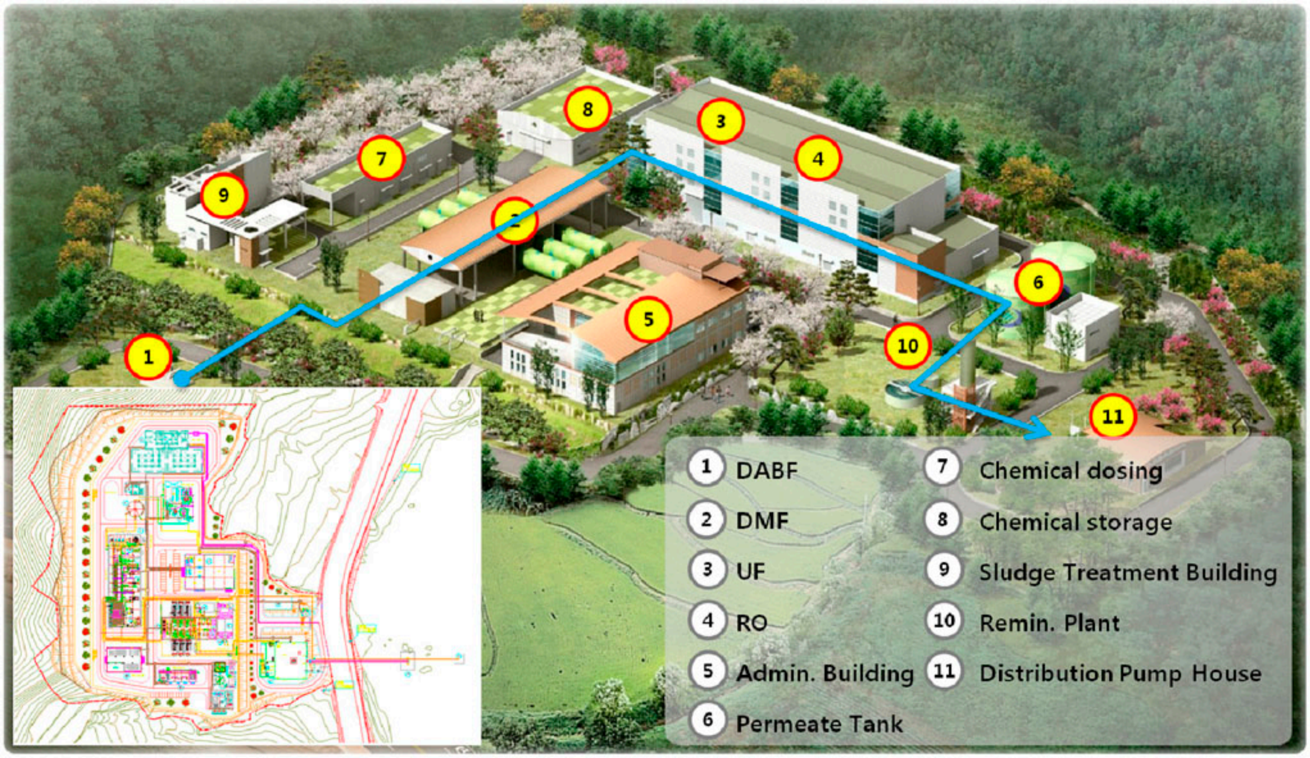


Fig. 1. Layout of Test Bed SWRO desalination plant.

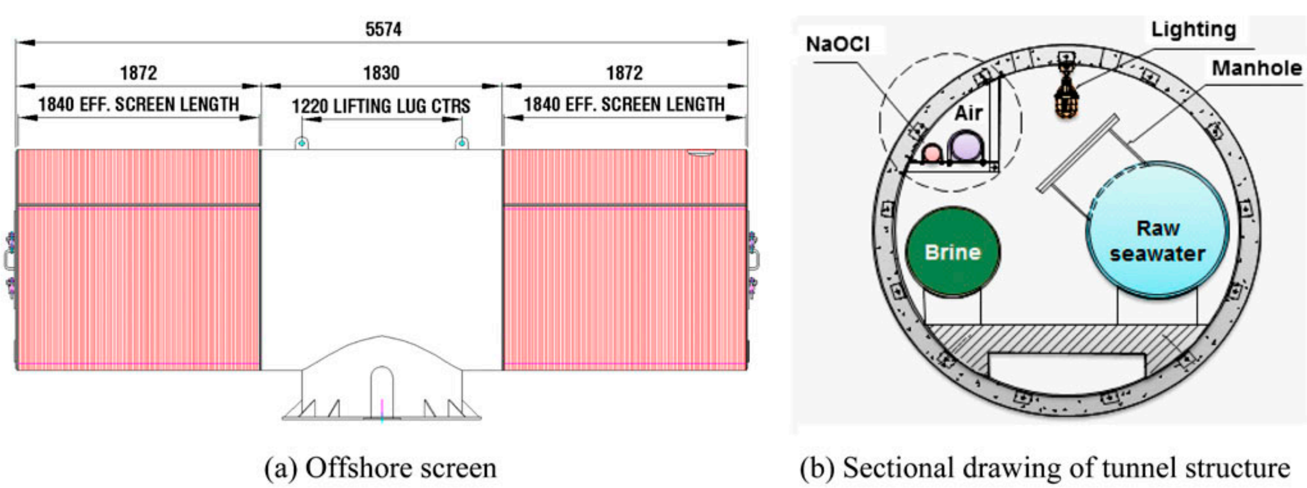


Fig. 2. Intake system descriptions.

Salinity is the controlling factor for the distribution of marine species. To encourage brine dissipation, a diffuser system having multiple nozzles is installed at the end of the discharge pipe. Due to the brine density, the discharge brine from the SWRO plant will spread over the sea floor [5]. Therefore, nozzles have a discharge angle of 45° above horizontal and faced the ocean (Fig. 4).

Flow characteristics of flood current and ebb current are shown in Fig. 5. Flood current flows from northeast to southwest. Contrarily, ebb current flows from southwest to northeast. Their maximum velocities are 0.463 and 0.514 m/s, respectively.

Seawater temperature and salinity for winter are measured near the site offshore. Data of surface layer and bottom layer are averaged. The surface layer is

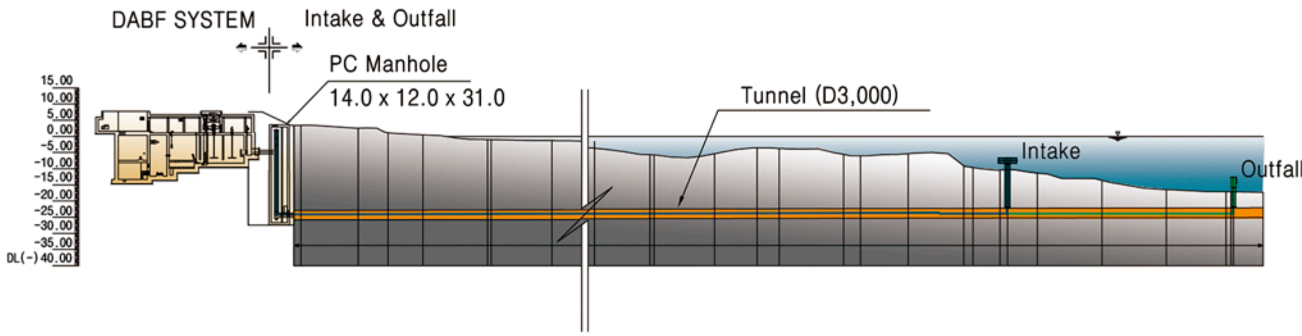
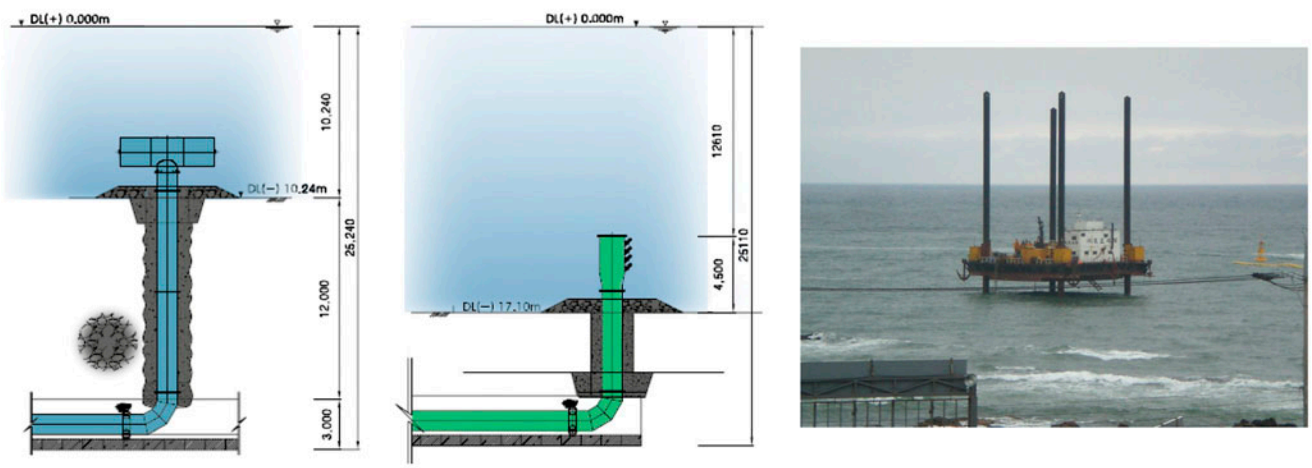


Fig. 3. Longitudinal sections drawing of intake and outfall.



(a) Intake (b) Outfall (c) Jack-up Barge

Fig. 4. Detail drawing of intake and outfall and jack-up barge.

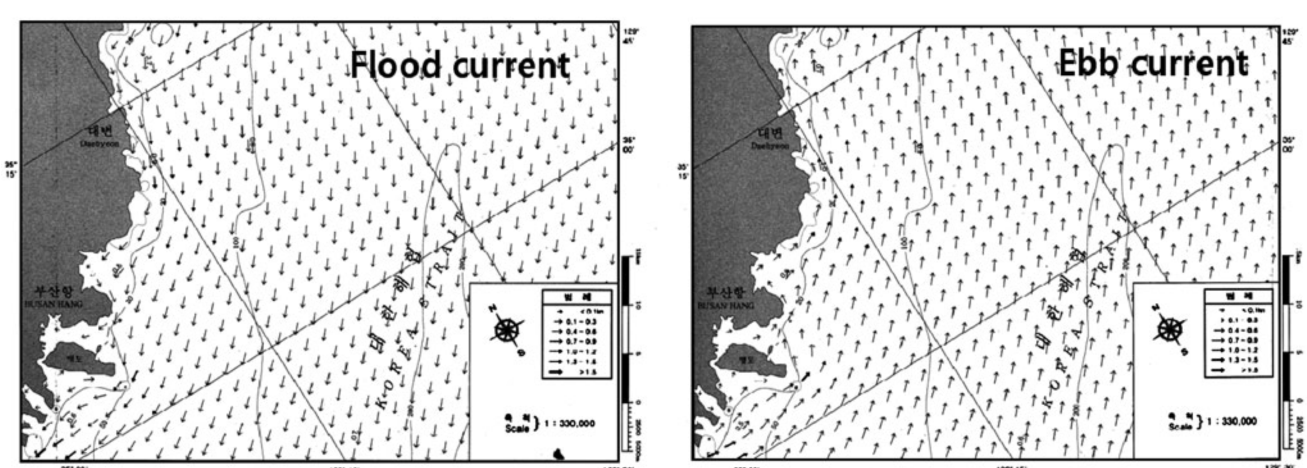


Fig. 5. Current flow near the site.

defined from surface to 1 m below. The bottom layer is from the seabed to 1 m above. Temperatures of the surface layer vary between 14.47 and 14.63℃ and temperatures of medium layer are 14.42–14.59℃. The temperatures of the bottom layer vary between 14.18 and 14.42℃. The measured temperatures slightly vary within 0.24℃. Salinities vary between 34,420 and 34,460 ppm. Temperatures and salinities for the other seasons have been surveyed from the database of National Fisheries Research & Development Institute.

4. Simulation for brine recirculation

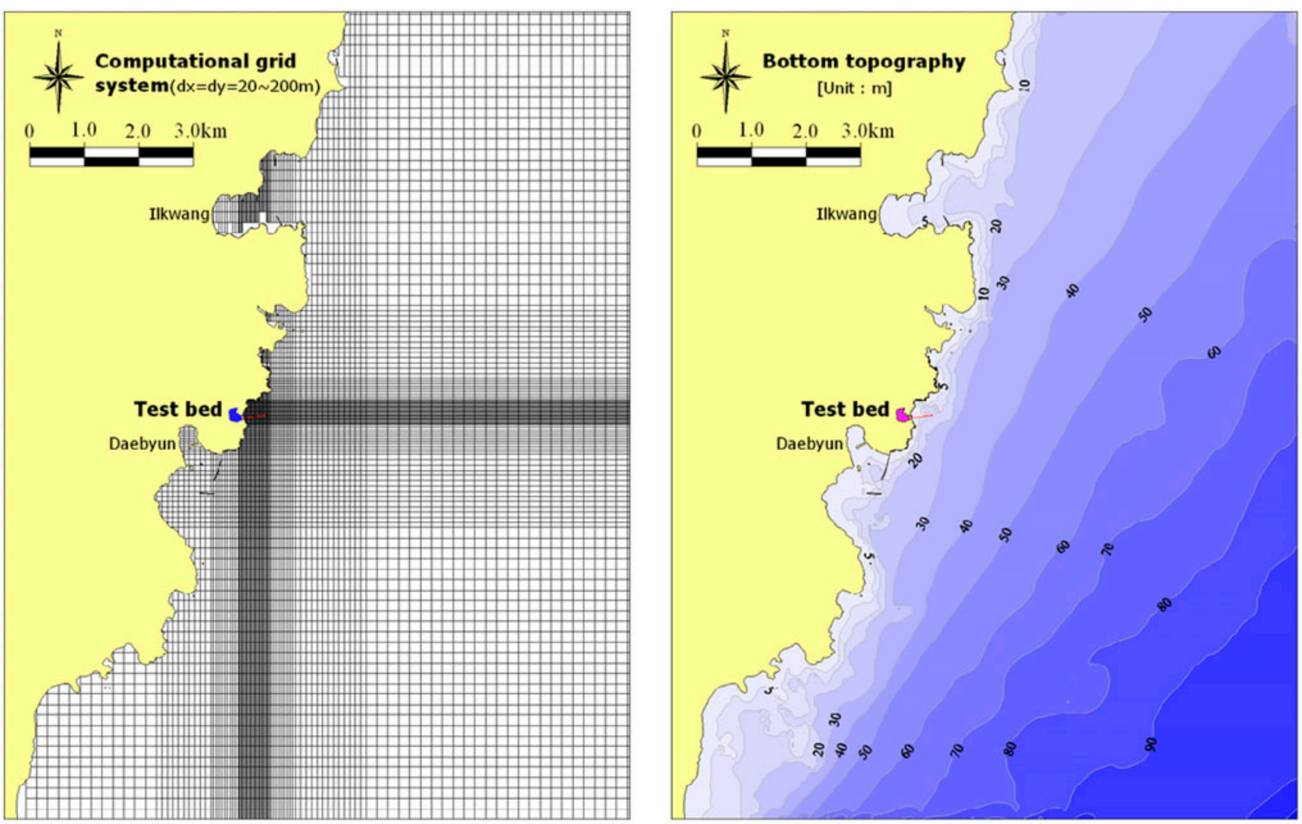
To avoid brine recirculation, the simulation study of recirculation of brine discharge was carried out. The concentration of brine from RO building is 66,400 mg/l. If brine flows into the intake, RO membrane performance decreases. Therefore, the intake shall be located far from the brine discharge.

4.1. Model verification

Many previous researches were conducted using the software programs: CORMIX, VISUAL PLUMES, VISJET, CORJET and MEDVSA. They are focused on nozzle and localized field for simulation. Though discharged brine is affected by the current, tide and local bottom topologies, they were not considered [6–10]. In this study, environmental fluid dynamics code (EFDC) model, which is a three-dimensional (3-D) hydrodynamic and water quality model, was adopted to simulate the current flow and brine recirculation. This model has been applied to a large range of conditions from near shore dynamics, estuaries/bays, lakes/reservoirs and river systems. Grid generation are ranged 11.5 km horizontally and 15.5 km vertically. Mesh varies from 20 to 200 m with 10 layers. Bottom topography is initiated from Korea hydrographic and oceanographic administration (KHOA) (Fig. 6).

Using tidal current and tide data of KHOA, the model was verified. Previous tide data were measured at the Daebyeon fishing port ("PT-1"). Also, tidal current was measured at the outside of that port ("PC-1") of which location is 35˚12´33´´ of longitude and 129˚ 14´24´´ of latitude (Fig. 7).

Fig. 8 shows the seawater level data at PT-1. Ebb and flow currents are repeated twice a day. Calculated



(a) Grid (b) Bottom topography

Fig. 6. Grid generation and bottom topography for computation.

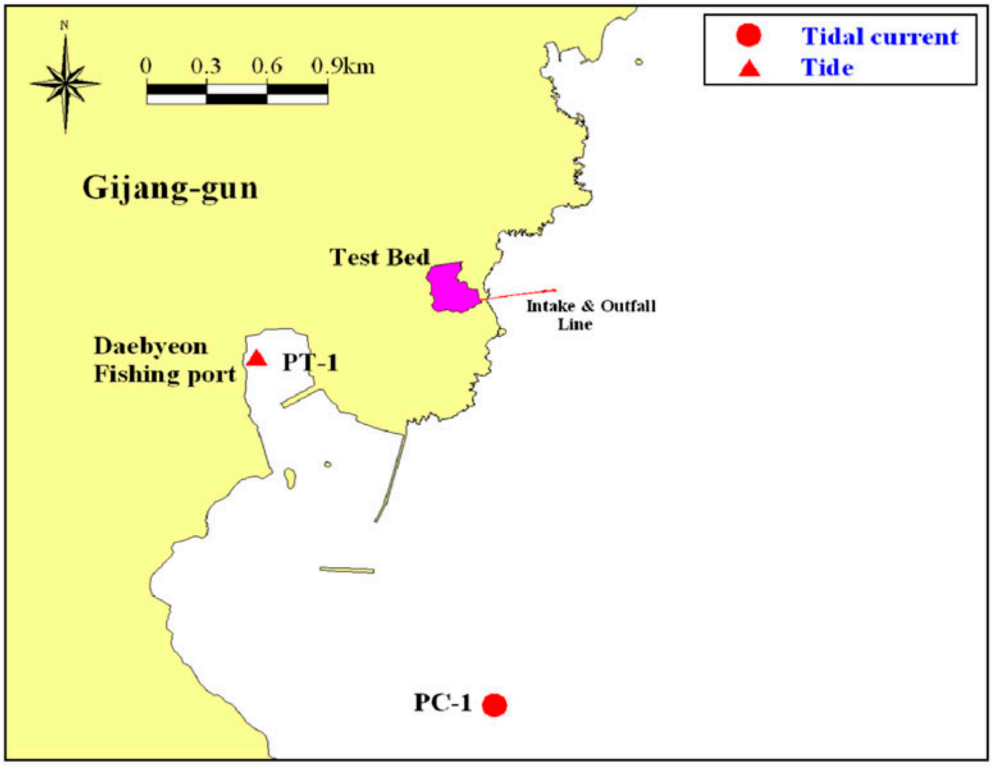


Fig. 7. Measuring points for tide and tidal current.

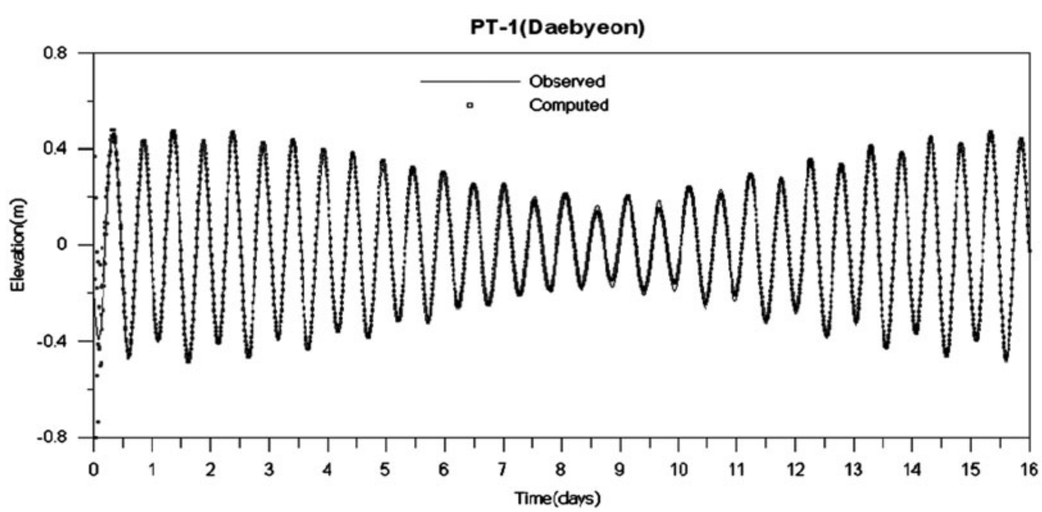


Fig. 8. Comparison of tide data between observation and computation.

data coincided well with the observed ones. Fig. 8 shows the scattered diagrams of tidal current data between observation and computation at PC-1. Observed data indicate that the direction of flood current is southwest and that of ebb current is northeast. Their maximum velocity is 47 cm/s. The direction and velocity of the calculated one are nearly the same, but the shapes of observed and calculated are different. The calculated data are wider than the observed one. It is because the observed data are measured at a point, but the calculated are area data which are averaged at specific grid (Fig. 9).

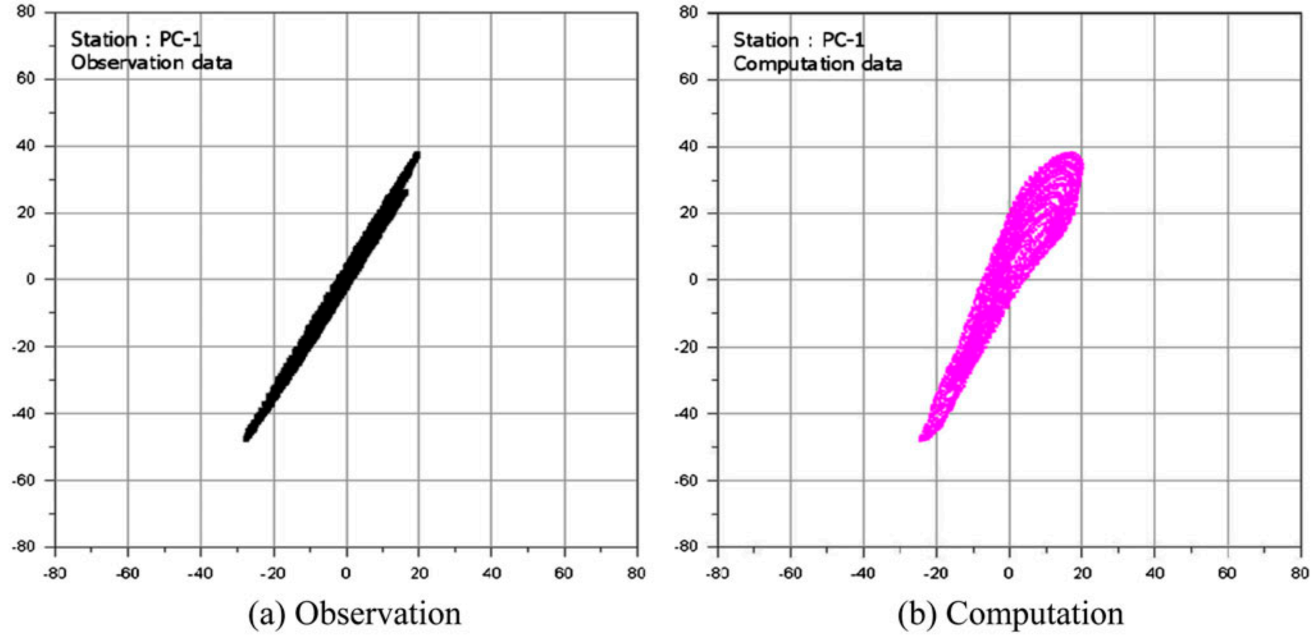


Fig. 9. Comparison of scattered diagrams of tidal current data between observation and computation (unit: cm/s).

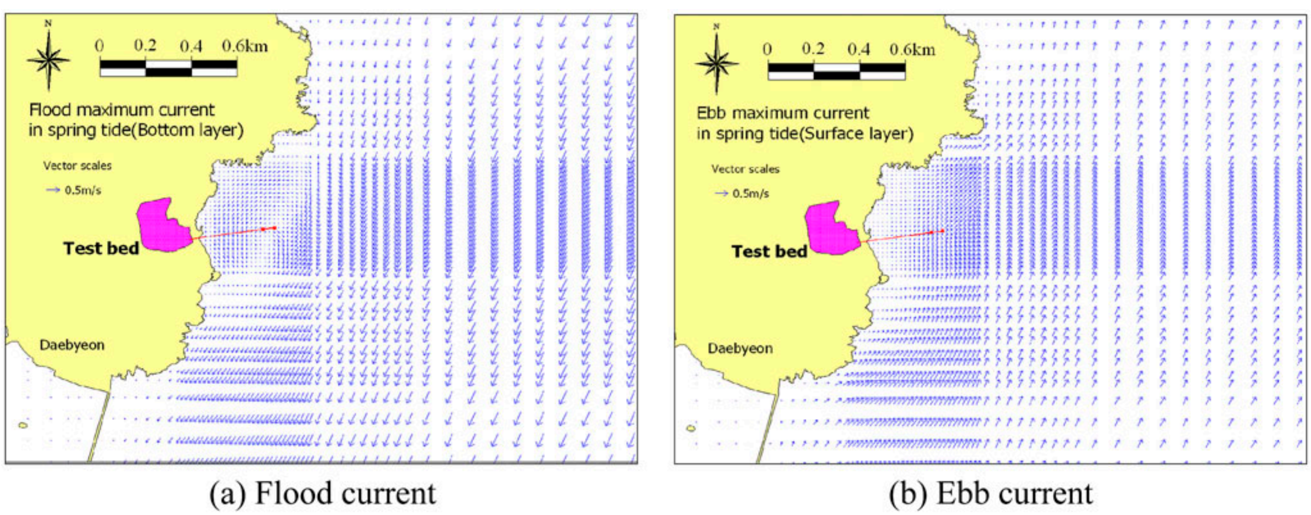


Fig. 10. Velocity vector field during maximum current condition.

4.2. Current flow calculation

Using a model, current flow was calculated. Main stream current is similar to that of Fig. 10. In case of flood current, northerly cape makes eddy flow in front of the site. But in the case of ebb current, the eddy flow does not appear.

In front of the site, maximum velocities of the surface layer are 40.0 cm/s of flood current and 42.0 cm/s of ebb current. Those of bottom layer are 27.0 cm/s for both the currents. In the case of flood current, intake and outfall are placed at the centre of the eddy flow. Maximum velocities at the intake and outfall are 10.0 cm/s. In case of ebb current, they show higher values which range from 11.0 to 18.0 cm/s.

4.3. Calculation of brine recirculation

To calculate the brine dispersion, the initial conditions are set as follows:

- Flow rate of brine: 2,500 m^3/h.
- Salinity of brine: 67,000 ppm.

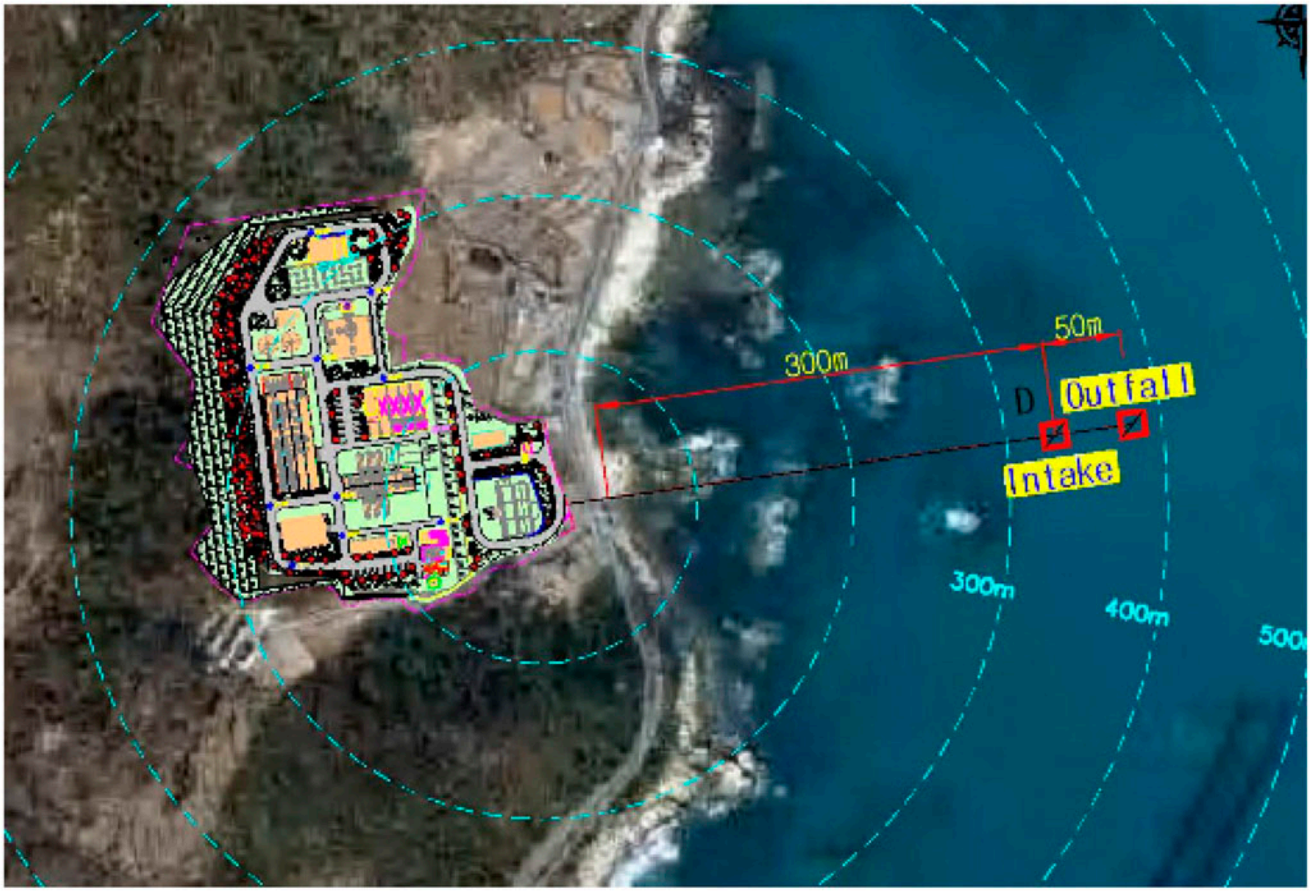


Fig. 11. Locations of intake and outfall.

- Salinity of seawater: 33,700 ppm (for winter) 34,000 ppm (for summer).

Using the current flow calculation, the dispersion of brine discharged was calculated. To select the points of intake and outfall, the depth of seawater and geologic formation were measured. The intake is placed at 300 m off the beach. The outfall is set further 50 m from the intake. Fig. 11 shows the locations of the intake and the outfall.

Fig. 12 shows the salinity distributions for winter and summer. Brine is mainly dispersed toward deep sea. It may be caused by the depth of the sea. From the beach to the intake, the seabed level is slowly down. But after the intake, it is rapidly down as shown in Fig. 3. The outfall is located on the seabed. The current velocity at outer sea is higher than that of the adjoining sea. The brine rarely flows into the adjoining sea but is dispersed with current flow. Concentration distributions both in winter and summer are similar in shape. The salinity at a distance of 500 m from the outfall is less than 34,000 ppm.

Fig. 13 shows the excessive salinity diagram at the intake when the distance between the intake and the outfall is 50 m. Salinity at the intake is affected all day long. Especially, during the flood current, brine has only influence on the intake. Eddy flow results in the increase of salinity at the intake. As the tidal deviation increases, excessive salinity is increased. The maximum excessive salinity at the intake is 800 ppm and the minimum is 100 ppm. For all seasons, excessive salinity is the same. In case of summer season, the maximum salinity at the intake reaches 34,800 ppm.

To reduce the increase of salinity at the intake, the distance between intake and outfall is changed from 50 to 70 m. With this relocation, maximum excessive salinity is reduced from 800 to 340 ppm. The affected period is reduced by 2 weeks per month. The effect of season is not found. Fig. 13 shows excessive salinity at the intake (Fig. 14).

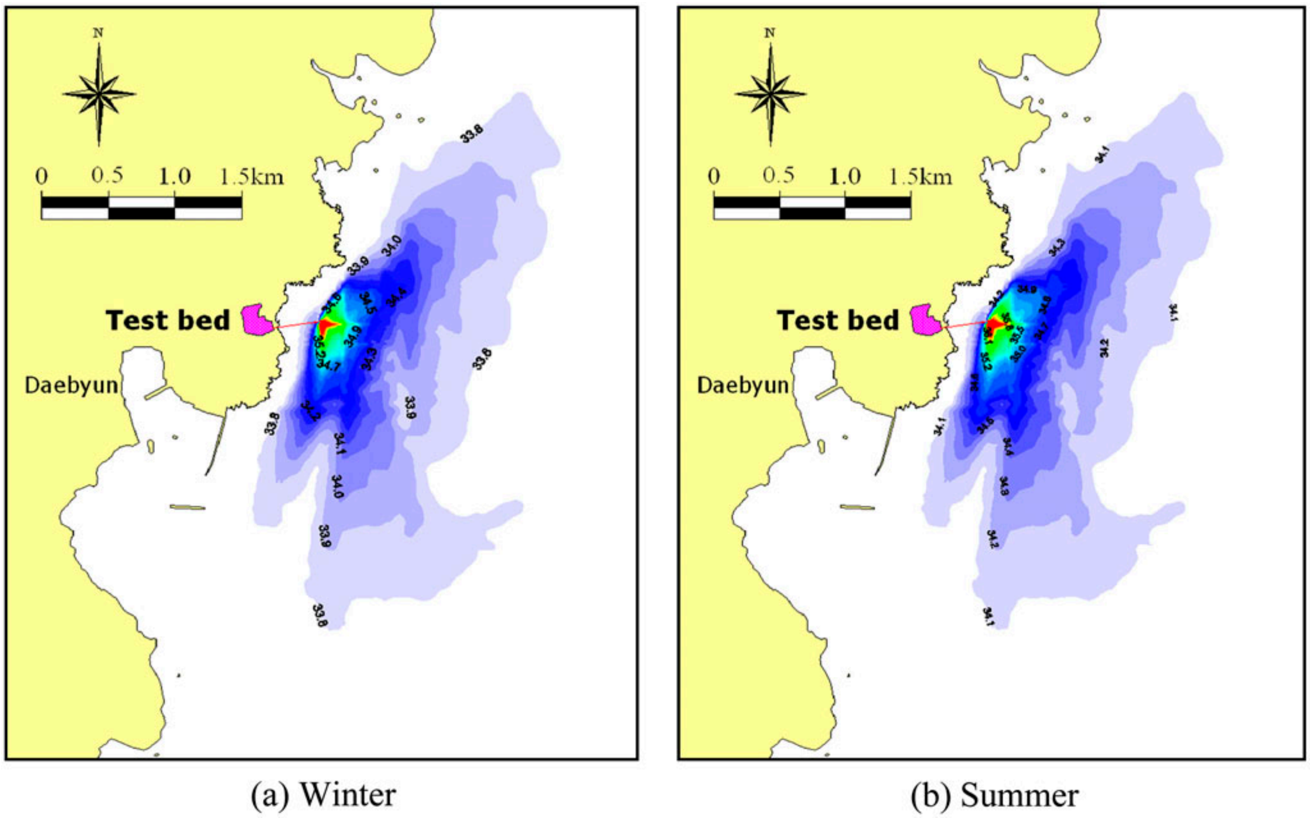


Fig. 12. Salinity distributions for winter and summer. [Distance between the intake and the outfall is 50 m.]

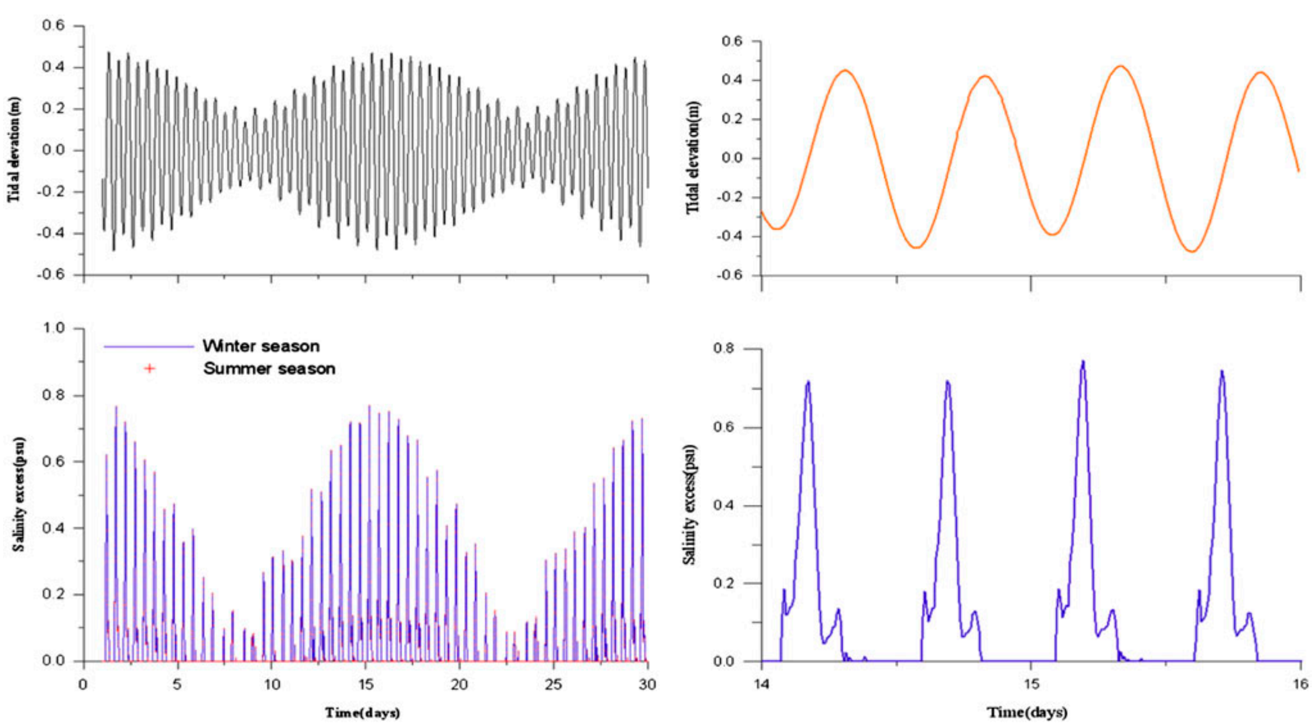


Fig. 13. Excessive salinity diagram at the intake. [Distance between intake and outfall is 50 m.]

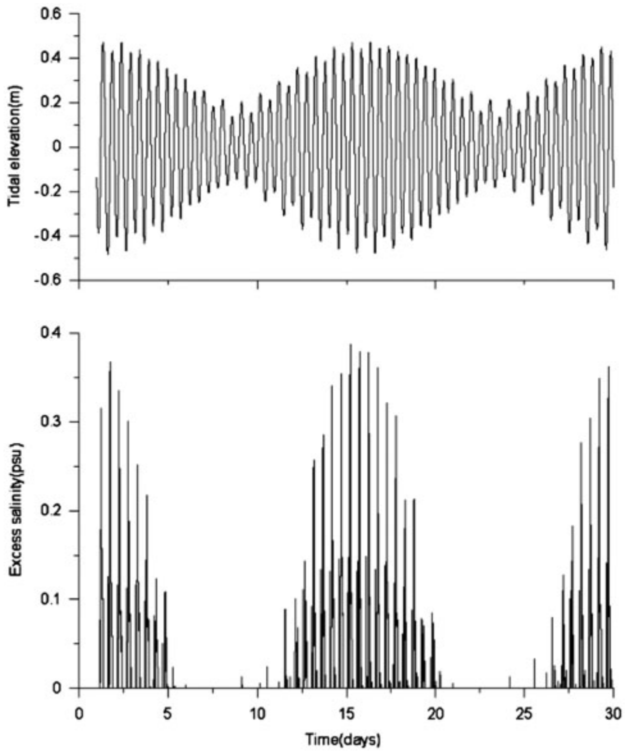


Fig. 14. Excessive salinity diagram at the intake. [Distance between intake and outfall is 70 m.]

5. Conclusions

To avoid brine recirculation, simulation study was conducted for the intake system of the Test Bed SWRO desalination plant. Using EFDC model, current flows were verified and salinity concentration was calculated. The results are:

(1) In case of flood current, eddy flow formed in front of the site. Location of intake and outfall is assigned at the centre of the eddy flow. Maximum velocities of intake and outfall are 10 m/s.
(2) Brine is mainly dispersed with current flow. There is no substantial brine influx to the intake because the seabed level is rapidly down from intake to outfall.
(3) If the distance between the intake and the outfall is 50 m, brine is induced to the intake and excessive salinity at the intake increases to 800 ppm in summer. If the distance between the intake and the outfall is increased to 70 m, excessive salinity becomes to 340 ppm. Finally, the outfall is displaced 70 m from the intake.

Acknowledgments

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