Mass Balance Simulation for Wetlands and Estuaries Management

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Abstract

The closed bay formed by a tidal power plant on the west coast of Korea has caused water quality to change due to nutrient increase and salinity alternation. The nutrients of the inner bay are often kept a balance with the aid of the outflow at the mouth of the bay. Hence it is necessary to minimize the environmental effects by forecasting the potential environmental changes caused by a tidal power construction. Seasonal observations of mass balance in the inner and outer Garolim Bay were performed. The low quality nutrients released from sediments, land and river were more dominant than the nutrients released from the outer bay in the study area. It was observed that the tidal power plant construction made water exchange ratio 57%.Various mitigation strategies such as water gates were studied so that the water exchange rate can be reduced. The change in the water exchange ratio is significantly reduced as the cross-section and the number of water gates is increased. The water exchange ratio was decreased by 8%, which increased nutrients in the inner bay. Results of numerical the nutrients decreased with the 7% increase in the inflow while the decrease in outflow discharges. However, it is considered only 0.2% increase in the entire mass balance of Garolim Bay relatively inadequate to mitigate the environmental impact.

Keywords: Tidal Power Plant, Mass Balance, Numerical Model, Tidal Flat

Introduction

With the global warming and depletion of fossil energy, the world is focusing on natural energy development In particular, as the inexhaustible ocean energy is new renewable energy, it decrease the risk of causing the secondary environmental problems unlike polluting natural energies. Korea, surrounded by oceans, has a very beneficial topographic trait of taking an advantage of environment-friendly ocean energy, including wave-power and tidal energy generation at the eastern and western coasts. In particular, since the West Sea of Korea has a large tidal range, it has a favourable condition for creating a large-scale new renewable energy from tidal-power generation, which leads to continuous studies on it in Korea. There were validity tests on tidal-power generations at Garolim Bay, Saemangum, Chonsu Bay and Incheon Bay. The reason is that they have larger tidal ranges and stronger tidal currents than other areas in Korea. According to the results of previous studies, the requirements for efficient tidal-power generation are a large tidal range, big water-reserving area and narrow mouth. Garolim Bay has a maximum tidal range of 7.9m, comparatively bigger water-reserving area and only 2km wide mouth. Such conditions led to a first choice for building a tidal-power plant with high expectations. Although the availability of tidal energy at Garolim Bay has been reviewed, a close investigation is still necessary for more efficient tidal-power generation. It might include concrete locations of the plant, tidal ranges and locations of sluices, among other factors. In this study, Environmental Fluid Dynamic Computer Code (EFDC) was used to assess the three-dimensional intertidal zone in neritic region and the validity of building a plant at Garolim Bay Note that EFDC is easily applicable to the West Coast with a large intertidal zone. Moreover, the tidal ranges and the locations of sluices for efficient tidal-power generation were reviewed by identifying external forces of coastal hydraulics, which provides much information on the characteristics of ocean circulation in the site.

Methods

It is well know that over 77% pollutant that has adverse effect on marine environment comes from contaminant released from lands (GESAMP 1990). In particular, the water quality and ecological environment of Garolim Bay and semi-closing coast are vulnerable to be polluted. The reason is that they have the high population density, and low exchange ratio of seawater volume. Therefore, various factors that decrease the seawater exchange ratio are assessed using Mass Balance equation. Such parameters in this study are tidal power plant, pollutant released from lands and sludge at the bottom of the Sea.

Study Area

The study area (site) is located at the north of Taean Peninsula at the west of Korea. The mouth of the bay is 2.2km wide and the distance from the mouth to the inner bay is 22.4km. Its mouth is narrow with a shape of gourd bottle, i.e., a semi-enclosed back bay (Ministry of Land, Transport and Marine Affairs, 2006).

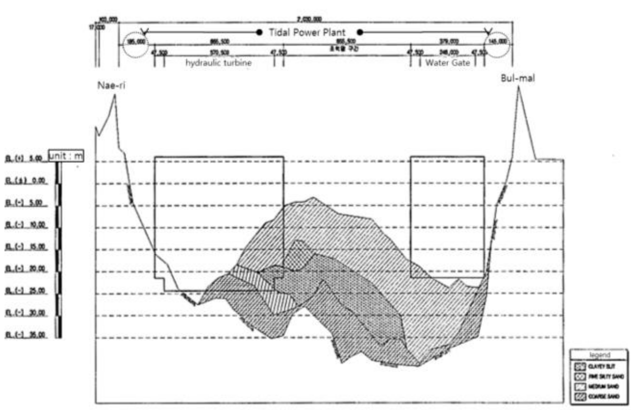

Figure 1. Location of Study Area

The length of the coast line is 161.84km and there are several small islands at the inner bay. Garolim Bay reserves a natural-state mud field of 70km^2 created by a large tidal range of 7.9m with abundant biota. From the viewpoint of fisheries science, the region is vital for fish spawning and habitats (Park, et al., 2009). It is generally known that the most impact factors for efficient tidal power generation are 1) a large volume of reservoir area 2) water head difference determined by the water-level changes in the reservoir 3) and open sea tides (Baker, 1991). From this point of view, it was estimated that Garolim Bay is the most appropriate to an effective tidal power plant. The reason is that it has the largest reservoir area in Korea, consisting 112.57km^2 reservoir areas with a mouth less than 2km. Garolim Bay has a large tidal range with a gourd bottle shape as shown in Figure 1. Its narrow bay entrance and broad surface extent of the inner bay indicate that it has one of the best geographical conditions in the world for a tide power generation. The annual maximum tidal range at the bay entrance reaches 851cm and the tidal range is amplified towards the inner bay. The tidal current is observed to have noticeable semidiurnal tide components with maximum flow speed of approximately 1.5m/s during flood tide.

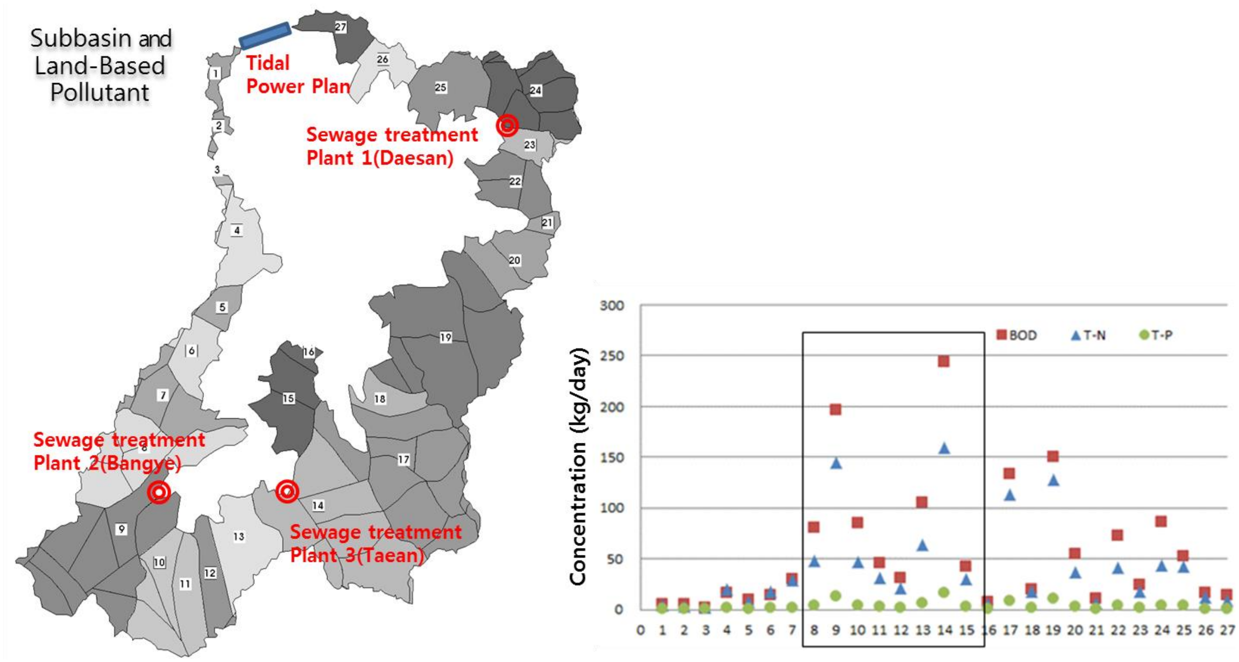

Figure 2. Sub basins and Land-Based Pollutants in Garolim Bay

Numerical Simulations of Tidal Current and water quality

A water quality model with twenty-one state variables has been developed and integrated with EFDC to form a three-dimensional Hydrodynamic-Eutrophication Model (HEM-3D) of the VIMS. The model, upon receiving the information of physical transport from EFDC, simulates the spatial and temporal distributions of water quality parameters including dissolved oxygen, suspended algae (3 groups), various components of carbon, nitrogen, phosphorus and silica cycles, and fecal coliform bacteria. A sediment process model with twenty-seven state variables has also been developed. The sediment process model, upon receiving the particulate organic matter deposited from the overlying water column, simulates their diagenesis and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate and silica) and sediment oxygen demand back to the water column. The coupling of the sediment process model with the water quality model not only enhances the model's predictive capability of water quality parameters but also enables it to simulate the long-term changes in water quality conditions in response to changes in nutrient loadings.

The EFDC Model, developed by VIMS(Virginia Institute of Marine Science), is a numerical model for multi-variable finite difference simulating transport and flow which is authorized by

Environmental Protection Agency. EFDC Model is very suitable to measure two or three dimensions vertically and horizontally. In particular, it is designed to deal with a three-dimensional intertidal zone in neritic region by using mass-conserving scheme. It can be easily applied in the western coast where a large intertidal zone exists. However, there are weaknesses of the model along with the easy application. First, a lot of calculation data is required considering with the multiple processes of hydrodynamics, sediment transport, water quality and toxics. Second, it requires a length of time to calculate which needs to be resolved in future. Since the grid system for this model uses cartesian or curvilinear coordinate system horizontally and can express a proper topography with the minimum number of grids through vertical coordinate system, it enables us to get the numerical solution effectively and decreases the calculation time. The theory of EFDC Model and its numerical analysis are similar to those of Chesapeake Bay of US Engineer Corps. The governing equations are the three-dimensional Reynolds average continuity equation, momentum equations, equation of state and mass conservation equations (Hamrick, 1992). The horizontal turbulent viscosity coefficient at the horizontal turbulent viscosity term and the turbulent diffusion term used to express the turbulent mixing of a smaller scale than the model grid is calculated through the equation determined by the gird size and the velocity gradient. In general, considering the horizontal turbulent viscosity coefficient and the horizontal turbulent diffusion coefficient are the same, as the calculated grid size and the velocity gradient gets smaller, the horizontal turbulent viscosity coefficient decreases and can be ignored if the grid is small enough. Tide level and velocity component at the open boundary of the open sea were assumed to be represented around the targeted waters. In addition, coordinate system was comprised to include the numerical traits by layers since the inner water of Garolim Bay consists of intertidal zone due to different water depths between the edge and the center. Table 1 shows the conditions of ocean circulation numerical model experiment. The governing mass-balance equation for water quality state variables consists of physical transport, advective and diffusive, and kinetic processes. When solving Eq., the kinetic terms are decoupled from the physical transport terms. The mass-balance equation for physical transport only, which takes the same form as the salt-balance equation, is:

$$\frac{\partial C}{\partial t}+\frac{\partial (uC)}{\partial x}+\frac{\partial (vC)}{\partial y}+\frac{\partial (wC)}{\partial z}=\frac{\partial}{\partial x}\left(K_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right)+S_C$$

Table 1. Simulation Condition of EFDC

Grid System	Grid Size 40 ~ 750m / 189 × 256 (Grid Number 26,493)
Layer	3Layer(surface, middle, bottom)
Tide	M2, S2, K1, O1
Duration	16day
Time Step	2sec

Environmental effects on water quality due to a tidal power generation

It is expected that the closed bay formed by a tidal power plant construction causes nutrient and salinity to fluctuate, thus leads to water quality changes. The nutrients of the inner bay are often kept a balance with the aid of the outflow at the mouth of the bay. Hence it is necessary to minimize the environmental effects by forecasting the potential environmental changes caused by a tidal power construction. Seasonal observations of mass balance in the inner and outer Garolim Bay were performed. The low quality nutrients released from sediments, land and river were more dominant than the nutrients released from the outer bay in the study area. It was observed that the tidal power plant construction made water exchange ratio 57%.Various mitigation strategies such as water gates were studied so that the water exchange rate can be reduced. The change in the water exchange ratio is significantly reduced as the cross-section and the number of water gates is increased. The water exchange ratio was decreased by 8%, which increased nutrients in the inner bay. The changes in the water quality were evaluated using the Mass Balance Equation. Table 1 shows the simulation results obtained from the Mass Balance Eq.. As shown in Table 1, discharging of water in Garolim Bay is higher than the water inflow. It is also found that the reduction of the seawater exchange rate due to construction of tidal power plant made the increase of nutrient salt: nitrogen (1.526ton) and phosphorus (0.102ton).

S1 : Input-output budgets from Bay entrance

Volume Transport (kg) = ∑ [Cross Sectional Area (m2) × Velocity(m/s) × Time (s) × Concentration (mg/l)]

S2 : Input-output budgets from groundwater

Volume Transport (kg) = Discharge (Q, m^3/sec) × T-N or T-P(C, mg/L) × Time(s)

S3 : Input-output budgets from Nutrient release

Volume Transport (kg) = Nutrient release (T-N or T-P)(C, mg//day) × area × Time(day)

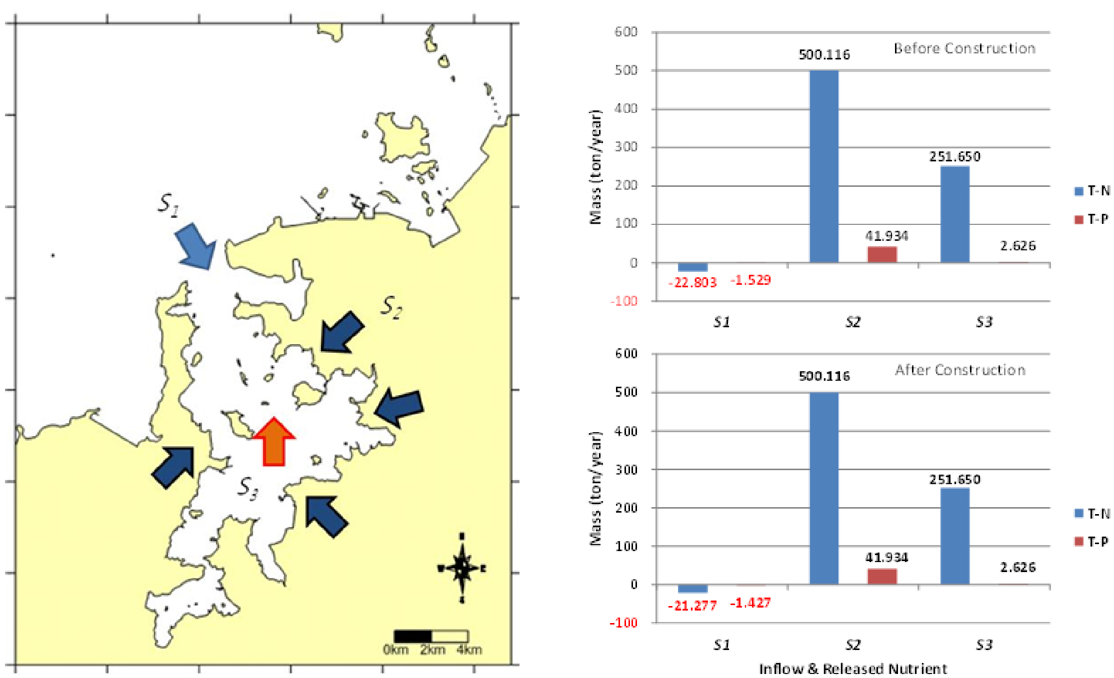

Figure 3. Mass Balance in Garolim Bay(ton/year)

Table 2. Mass Balance Estimation due to the power generation

	T-N(ton/year)		*T-P(ton/year)*	
	Before	***After***	***Before***	***After***
S1 (Entrance)	-22.803	-21.277	-1.529	-1.427
S2 (River)	500.116	500.116	41.934	41.934
S3 (Bottom)	251.650	251.650	2.626	2.626
Total	728.963	730.489	43.031	43.133

Since the nutrient salts released from the sediments and river are dominant, the amount of nutrient salts was used as a parameter to investigate the water quality.

The experiment program is established as follows:

- Scenario 1(S1.): The condition is as it is now.
- Scenario 1(S2.): The reduction of the nutrient salts by 20%.
- Scenario 1(S3.): The reduction of the nutrient salts by 50%

Figure 4 compares the mass balance of the Scenario 1, 2, and 3. As shown in Figure 3, the proposed scenarios were not effective in reducing T-N and T-P: 1 ~ 2% mitigation.

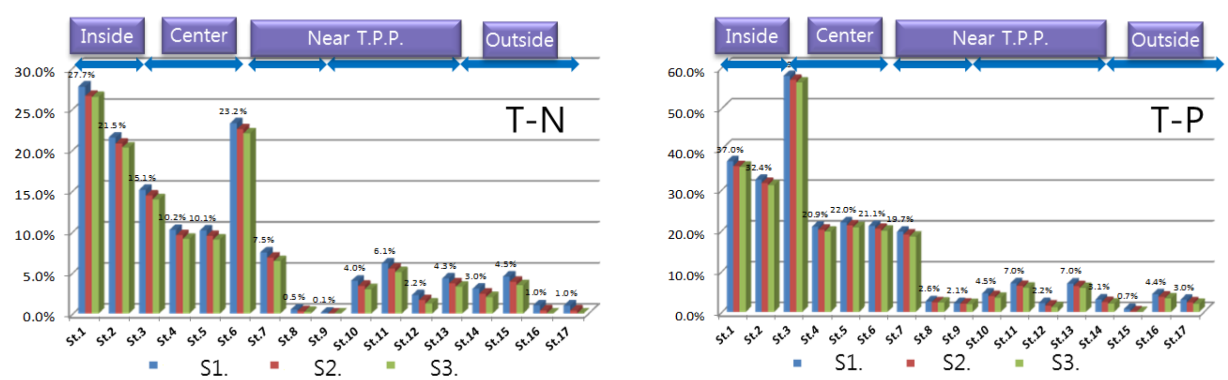

Figure 4. Mass Balance in Garolim Bay(ton/year)

As alternative approaches, the following scenarios were considered.

- Scenario 4(S.4) : The condition is as it is now
- Scenario 5(S.5) : 5% Increase of inflow loads from rivers and land
- Scenario 6(S.6) : 5% decrease of inflow loads from rivers and land

Figure 5 shows the simulation results. As shown in Figure 1, the control of inflow loads was more effective in reducing nutrient salts than the previous approach. When the inflow load was reduced by 5%, the nutrient salts were decreased by 5~7%; while as the inflow load was increased by 5%, the nutrient salts were increased by 3~4%.

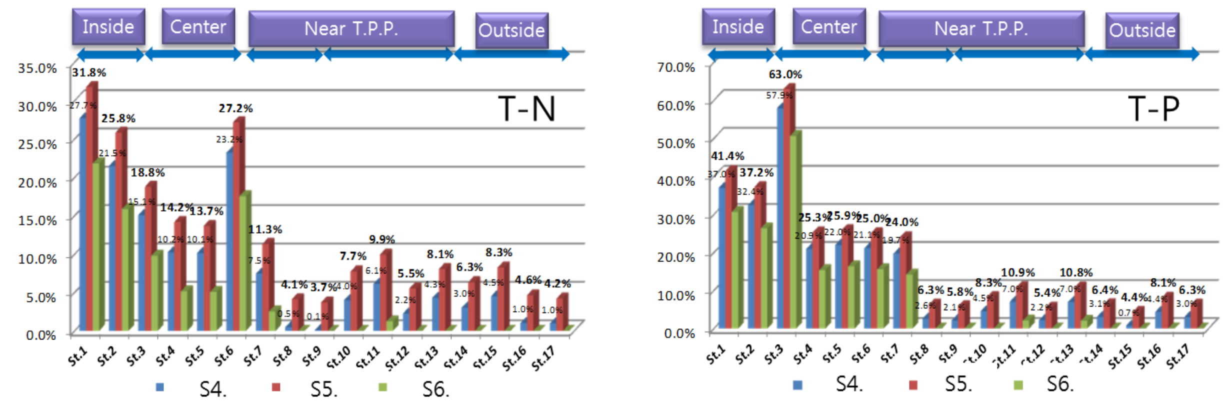

Figure 5. Mass Balance in Garolim Bay(ton/year)

Conclusion

For this study, concrete interpretation on the traits of ocean circulation at the study area was conducted for a tidal power plant by using the three-dimensional numerical model and field investigation. To investigate the effect element of water quality condition of the sea, flow field considering topographic and hydraulic characteristics was modelled. Based on the flow model, biochemical cycle of object sea area was evaluated using tidal power plant, land pollutant, and benthic flux in terms of T-P and T-N.

As Garolim Bay is narrow-mouthed and eutrophication influence factors could be divided mainly into inflow and discharging through the bay entrance, fall-line loads, benthic flux. Based on Mass Balance equations, it is observed that the discharging of water in Garolim Bay is higher than the water inflow. It is also found that the reduction of the seawater exchange rate due to construction of tidal power plant made the increase of nutrient salt: nitrogen (1.526ton) and phosphorus (0.102ton). However, nitrogen and phosphorus generated from land pollution and benthic flux 728.963ton, 43.031ton per year, respectively. It is expected that such conditions have a larger impact on the marine environment than the construction of tidal power plant.

Therefore, it would be urgent to quantitatively and qualitatively manage the land pollution that gets into coastal waters to control water quality condition. In addition, extensive studies on sources of land pollution should be carried out in order to maintain and improve values of coastal society and economy as well as coastal oceanic environment in a systematic ways

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References

Smagorinsky, J. (1963). "General circulation experiments with the primitive equation, Ⅰ. The basic experiment." Monthly Weather Review, 91, 99-164.

Baker A.C.,(1991), Tidal Power, Peter Peregrinus Ltd. London, United Kingdom

Hamrick, J. M.,(1992). A three dimensional environmental fluid dynamics computer code: Theoretical and computational aspects. Special report, The college of William and Mary, Virginia institute of marine science, Glouceslter point, VA

Seung Hoon Yoo, Joo Suk Lee (2008), Assessment of Environmental Value of Garolim Gulf, The Korean Economic Association, 56(3), 5-28

Park et al., (2009), Long-term Variation and Characteristics of Water Quality in the Garolim Coastal Areas of Yellow Sea, Korea, The Korean Society of Marine Environment and safety 15(4), 315-328.

Bum-Shin Shin, Kyu-Han Kim(2013), Effective tidal power generation with reduced environmental impact, *Journal of Coastal Research*, Special Issue No. 65, 1657-1662

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 1990. Report of the twentieth session, Geneva, 7-11 May 1990. Rep. Stud. GESAMP, No. 41.

Coastal management planning system for Garolim(2006), Ministry of Maritime Affairs and Fisheries

Harmonic and nonharmonic constant (http://www.khoa.go.kr, 2010) , Korea Hydrographic and Oceanographic Administration

Environmental Impact Assessment(EIA) for Garolim tidal power plant(2011), Garolim tidal power plant co.Ltd