Influence of Rainfall and Combined Sewerage Overflow on Odaiba Area in Tokyo Bay

Student ID: 47-076957
Name: M.M. Majedul Islam
Name of the supervisor: Asst. Prof. Yukio Koibuchi
Dept. of Socio-cultural Environmental Studies
31 July 2009

1. Introduction: Big cities have long been developed near coastal zones, which is a dynamic area of natural change and of increasing human use. Tokyo Bay is a semi-enclosed coastal sea, surrounded by one of the world's most urbanized areas. Thus, it receives enormous pollutant load. Effluents released into the bay water pose a risk of pathogen contamination. This risk is increased for Tokyo Bay as it receives combined sewer overflows (CSO's) during storms.

Tokyo's Bureau of Sewerage employs a combined system in which both storm water and sanitary waters are flows through the same pipelines. During storms, enormous amounts of raw sewage have been overflowing directly into Tokyo Bay without being treated at the Sewage Treatment Plants (STPs). CSO contain pathogens which may cause many human diseases like diarrhea, respiratory, skin, ear and eye infections.

Background and purpose of the study

Though the sewerage system of Tokyo metropolitan is well established, water quality degradation of Tokyo Bay is still taking place. The reason is CSO. But So far very little is known about the influences of storm water or CSO on Tokyo Bay. Moreover, it is difficult to accurately estimate CSO and the consequent flux. In addition, the physical environments of urban coastal zones vary widely depending on time and location. Their complicated geographical features border both inland and outer oceans, affect widely. Consequently, the frequent monitoring of pathogens is needed to discuss the risk pathogens pose in coastal zones but that appears to be impossible.

Present study aimed to understand the dynamic processes of CSO and modeling approach to support public health risk management. To achieve the goal, a three-dimensional hydrodynamic model coupled with a pathogen model was applied. Field observations were also conducted to monitor the influences of CSO and to validate the model. The main objectives of study are as follows:

- To understand the dynamics and distribution (timing & extent) of CSO by numerical simulation using *E. coli* and Adenovirus (AdV) as an indicator.
- To determine the conditions (tide, wind, rainfall) that are dominant factor for variations of pathogen concentration and distribution.
- To provide a guideline (i.e safe time and location) for the sea surfers and swimmers.

2. Materials and Methods

Site description: The study site is the upper area (Odaiba) of Tokyo Bay (Fig.2.1).

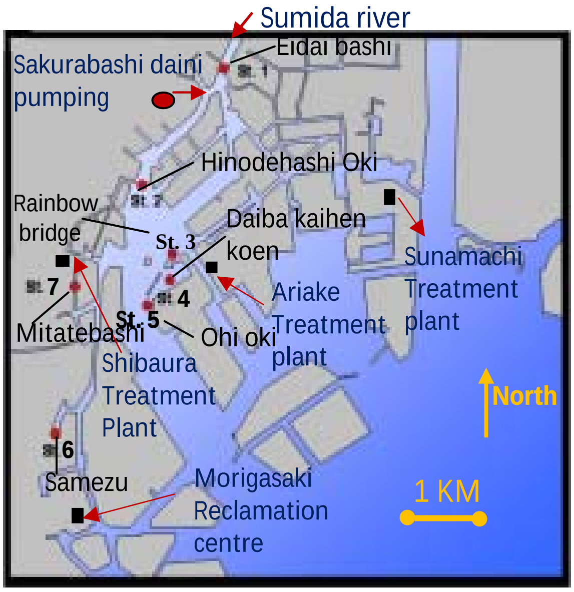

Fig. 2.1. Study site and sampling locations

Field sampling: Total 5 days sampling done at November, 2007 (11th 12th 14th 21th 28th) just after 26.5 mm rainfall on Nov10th. Sampling was done to know the following water quality parameters: bacteria (Coliform, *E. coli*) Adenovirus, nutrients (TN, NH_4-N, NO_2-N, NO_3-N, PO_4-P, TP), SS, TOC, turbidity, salinity, temperature, EC, DO and pH. Numerical simulation was performed only at station 3, 4 and 5 due to lack of observed data.

Analytical methods: Table 2.1 shows the types of instruments used for sampling and analysis. Bacterial and viral data were kindly provided by Furumai-lab, Department of Urban Engineering, UT. To validate numerical modeling *E. coli* and Adenovirus data from August to October 2004 were collected from Mr. Onozawa (previous student, UT).

Table 2.1 Instruments for measurement

Instrument	**Parameter**
Alec Compact-CTW	Salinity, Temperature
Multisensory (HORIBA U-10)	Turbidity, DO, EC, pH
TOC analyzer (SHIMAZDU TOC-V)	TOC, DOC, and TN
Potassium peroxydisulfate decomposition method	TP
AACS -III Auto Analyzer (BRAN+LUEBBE)	NH_4-N, NO_2-N, NO_3-N, PO_4-P

Numerical Modeling: The present numerical model (developed first by Sasaki and Isobe (1996) and later by Koibuchi and Isobe, 2001) is a three dimensional, hydrodynamic model which solves equations for Navier-Stokes, conservation of mass, momentum, temperature, salinity and turbulence kinetic energy. In the present study simulations performed with two nested domains to fit the complex geographical feature around the Odaiba area (Fig. 2.2). A detail configuration of the model is summarized in table 2.2.

Table. 2.2. Boundary conditions and grid

	Domain 1	**Domain 2**
Area	50km×66km	5km×12.7km
Grid size	2000m	100m
Grid no	25×33×10layer	50×127×10layer
Total grid no	2920	22740
Computational duration	2004/August/1~ October/15	2004/August/1~ October/15
Time step	10 minutes	30 seconds

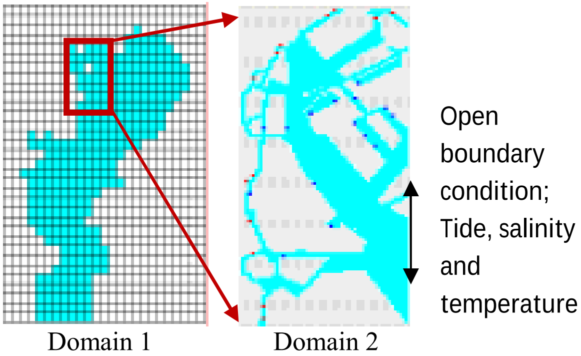

Fig. 2.2 Two nested computational domains with pumping stations

Pathogen modeling

The mathematical framework employed in the pathogen model to reflect the fate and transport process of *E. coli* and AdV is expressed as follows:

$$\frac{\partial C}{\partial t}+u_i\frac{\partial C}{\partial x_i}+(-Sink)\frac{\partial C}{\partial z}=\frac{\partial}{\partial x_i}\left(\varepsilon_i\frac{\partial C}{\partial x_i}\right)-sal\cdot C$$

Where *C* denotes conc. of *E. coli* or AdV (CFU/100ml), and t is time. *Sink* represents the sinking speed of *E. coli.* and AdV, u_i denotes flow speed for the calculation of the advection term. ε_i denotes the diffusion coefficients. *sal* denotes the salinity-dependent die-off rate (/ppt-day). Here, the die-off due to decay process was included using a constant decay rate, 2.3 $day^{-1}$for *E. coli* and 0.792 $day^{-1}$for AdV. The study area has high turbidity that rapidly absorbs UV rays at the sea's surface. So effect of solar radiation has been ignored in this model. As there was no evidence of resuspension found in the observed data, so it is ignored in the model.

Input Boundary Conditions: It includes discharge from pumping stations, STPs and rivers. Threre are 4 STPs (Shibaura, Sunamachi, Ariake and Morigasaki) in the study area which have a total of 28 pumping stations (Fig. 2.2). A constant CSO concentration of 33 × 10^6 CFU/ 100 ml for *E. coli* and 1.0× 10^4 for AdV was used to calculate pathogen discharge is shown by formula below:

Rain water runoff= Rainfall Amount× Treating Water Area (ha) × Water Flow co-efficient (0.8)

E.coli (CFU/100ml) = (33×10^6) × (Dry weather sewage)÷Water Runoff)

3. Result and Discussion:

Model calibration: The hydrodynamics in the Bay-wide model (domain 1) were first simulated and the results of temperature, salinity and water level were used as an open boundary to simulate domain 2 (fine grid). The simulation and observed results (Fig. 3.1) show stratification, mixing, and an upwelling phenomenon.

Calibration of pathogen: Fig.3.2 and Fig.3.3 shows a comparison between modeled and measured *E. coli* and AdV respectively. St.3 and 5 show relatively higher concentration than St. 4. It may be due to the enclosed bathymetry of St.4 which is located more land locked position. Again St. 3 and 5 contains higher discharge from river and STPs, due to their closest proximity and open position. The temporal variability of concentration occurred due to mainly storm with CSO discharge. The main rainfall induced CSO discharge were occurred on Aug 15 (32mm), Aug 29 (17mm), Sep 4 (106mm), Sep 30 (15mm), Oct 5 (65mm) and the biggest one on Oct 9 (180mm) leaded to higher conc. The result also reveals that the increasing rates of pathogen do not agree with levels of precipitation. Even in small rainfall, pathogen significantly increased.

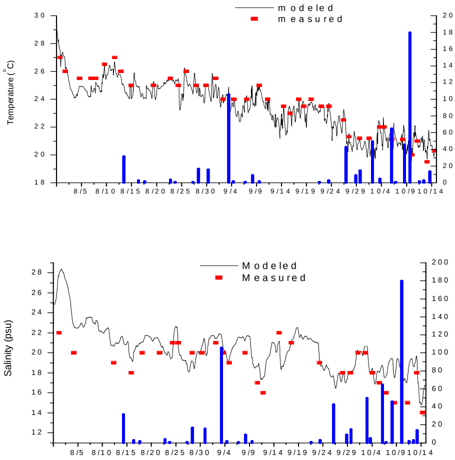

Fig.3.1. Calculated and observed temp and salinity at St.3 (2004).

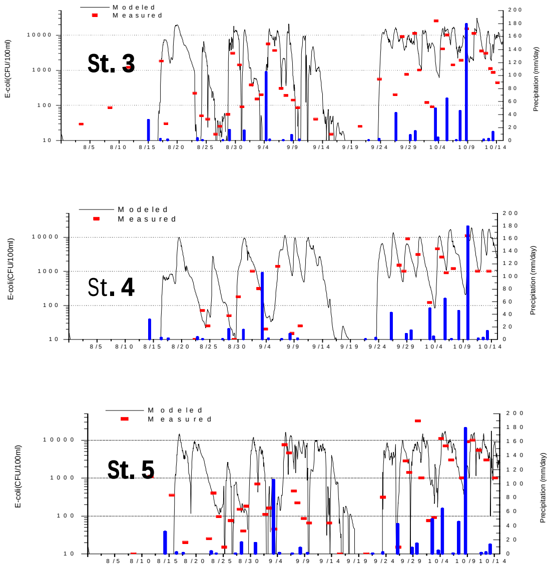

Fig. 3.2. Comparison between modeled and measured E. coli at surface water (2004)

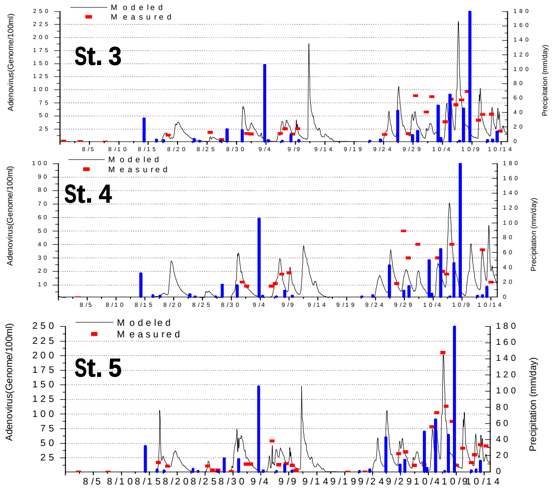

Fig. 3.3. Comparison between modeled and measured AdV at surface water of Odaiba (2004)

The current standard for acceptably safe beaches for swimming set by of the Ministry of the Environment, Japan is a fecal coliform rate of 1000 (CFU/100mL). The calculation results reveal that most of the time of the storm prone period (August-September) of Japan violates standard for swimming.

Numerical experiment: Numerical experiments were performed for without death rate and no wind action case. The model captures the increase in concentration when the death rate was omitted and concentration decrease when there was no wind (Fig. 3.4).

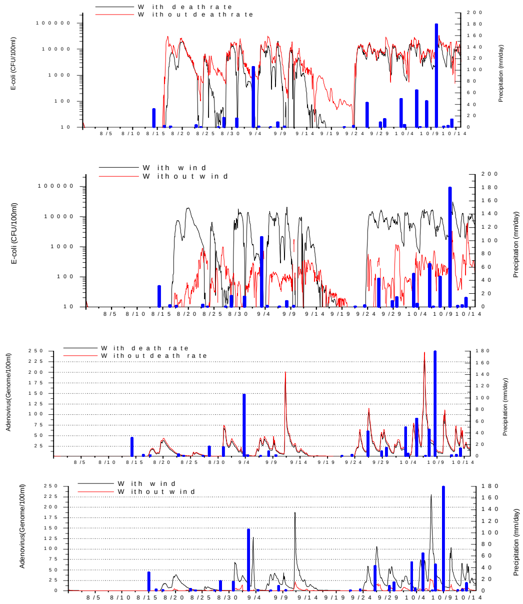

Fig. 3.4. Comparison between with and without death rate and with and without wind action at st.3.

Potential Model Improvements: Major areas of improvements are variable die-off rate (solar radiation), settling and re-suspension from sediment.

4. Conclusion and Recommendation:

From the present modeling results it is clear that the distribution and dynamics of pathogens is very complex and larger storm event is not so frequent. Construction of relatively small size of low cost storage can be effective to address most of the CSO problem caused by small storm events. For big storm case, awareness should create to avoid swimming until at least 3 days following a big storm.