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The role of models in assessing the impact of sewage overflows on fecal water contamination

P Riou[1], JC Le Saux[2], F. Dumas[2], F. S Le Guyader[2], R. Le Goff[1], F. Maheux[1], L. Lamort[1] and M Pommepuy[2]

[1]Ifremer, Port-en-Bessin, Avenue du Gal De Gaulle, 14520 Port-en-Bessin, France

[2]Ifremer, Centre de Brest, BP 70, 29280 Plouzané, France

Abstract:

Climate change contributes to local weather modifications such as storm events and heavy rainfall, and in particular, changes in the frequency and intensity of extreme storm and rainfall events. Observations have indicated that rainfall-runoff processes, like sewage overflow may induce fecal contamination in coastal water. Pathogens present in runoff water could therefore contaminate shellfish and be responsible for food-borne disease outbreaks.

Mathematical models for this were used to predict the effect of climate modifications on shellfish quality. Using a hydrodynamic model, simulations of water quality conditions under a variety of storm event scenarios were run and are presented here for a harvesting area in France. Major storm events occurring in the watersheds were selected to estimate the critical fecal loads which could be due to overflow. Escherichia coli fluxes were calculated for these scenarios. Norovirus fluxes were estimated from data in the literature. The hydrodynamic model was then used to calculate the impact of hydraulic load and wastewater inputs on seawater quality. Our results indicated that major rainfall events generated relatively high runoff volumes and high pathogen loadings to the sea which led to shellfish contamination. After an extreme contamination event, the time needed to recover good water quality as calculated using the model, depended on the sectors in question.

Keywords: Modeling, seawater fecal contamination, *E. coli*, virus, shellfish, climate change

1. Introduction

Coastal water quality is important for various activities such as shellfish harvesting, bathing or other recreational activities. Likewise, coastal water quality is directly affected by the amount of sewage reaching the marine environment. To protect the environment and consumers, EU Directives regulate activities with respect to the water quality. For instance, EU regulations (ED/91/492/EEC, 854/2004) define the sanitary quality of shellfish harvesting areas and aim at preventing outbreaks of illness due to shellfish. In France since 1989 the national shellfish monitoring network called REMI, piloted by Ifremer, surveys fecal contamination levels as required by EU regulations. Levels of *E. coli* are used to categorize harvesting areas and the prescribed types of treatment required before the shellfish from them are consumed. However, shellfish which meet standards have been implicated in outbreaks (Le Guyader, 2006, Lees, 2000). In fact, the risk of shellfish contamination is linked to the presence of pathogens in the community and the potential of contaminated sewage to impact shellfish growing areas. The most common route for fecal contamination of shellfish is through overflows of untreated sewage into the aquatic environment (Pommepuy et al., 2005). In areas classified as A, the occurrence of viral contamination is rare, but heavy and short rainfall events can lead to shellfish contamination. Until, there have been few events of the sort. However, some authors have reported observations related to climate changes. In Canada, Chen and his colleagues (2005) recently indicated that temperatures have risen by 0.45°C and that there has also been an increase in the number of rainy days and extreme events over the past century. Predictive models have shown that extreme rainfall events will become more intense and frequent in the coming century (He et al. 2005). The same climate changes were already predicted in Europe by Van Luijtelaar (2002). These predictions raise the issue of the impact of recurrent intermittent rainfall events on the sustainable development of shellfish production. To investigate it, hydrodynamic models were used to assess the role of rainfall on water and shellfish quality in terms of fecal contamination. The study area is located in Normandy (France) in an A-classified area under the EU regulation for shellfish farming. The first objective of this study was to determine the main inputs and fluxes (*Escherichia coli* and norovirus) under "normal" and "storm" conditions. Secondly, it aimed to run a hydrodynamic model to simulate the impact of rainfall events on water quality, and finally to evaluate the risk period and the recovery time for water and shellfish quality.

2. Material and methods

Study area and sampling plan

The area studied (fig1a) includes a large harvesting zone near the coast. About 14,000T of oysters (*Crassostrea gigas*) are grown there in shallow waters in bags on trays set 50cm above the bottom. The oysters are left about 18 months in the same place before being sent to other regions in France for their grow-out. Two rivers called the Saire and the Sinope input the main freshwater runoff (fig 1b). Between these sub-catchments, a coastal sub-catchment (28 km^2), is drained by the small Bonde, Vaupreux and Godey tributaries which flow directly into the shellfish growing area (fig 1c). The human population is approximately 11,300 inhabitants, with a low density (51 inhabitants/km^2). The catchment is an important agricultural area for livestock, mainly cattle. During the study, oysters (*Crassostrea gigas*) were collected monthly from March 2001 to March 2004 at four shellfish bed locations (fig. 1c) to evaluate the extent of fecal contamination (*E. coli*). Field data also included monthly water sampling from the main rivers (Saire, Bonde, Vaupreux, Godey and Sinope) and during heavy rainfall events (16 October 2002, 2 July 2003 and 12 January 2004). All these results were also used to validate the dispersion parameters of the hydrodynamic model.

E coli counts were taken using the ISO 9308-3 technique in water and the NF V 08-106 impedancemetry method in shellfish (Dupont et al., 2004) The flow rate was measured in rivers and tributaries using flow-meter sensors (OTT type). Weather forecast data were obtained from the Météo-France station at Carteret, which is representative of weather conditions for the upstream drainage area and the marine coastal sector. Finally, the risk period of viral input to the littoral was assessed on the basis of data from the Inserm's monitoring network (http://rhone.b3e.jussieu.fr/senti/). This network indicates the regional occurrences of gastro-enteritis cases in the population.

The hydrodynamic model used here was described in Riou et al. (2007). In short, it is a 2D horizontal model which has been validated for the hydrodynamic features of the region, i.e., shallow, non stratified water. The numerical model solves the Saint Venant equations. These equations were obtained by integrating the Navier-Stokes equations under the Boussinesq and hydrostatic assumptions over the vertical. To run the microbiological model, the dynamical equations were coupled with a transport equation for any dissolved matter, expressed in the conservative form. The model takes bacterial and viral behavior into account.

The site's ability to recover safe status was estimated using a flushing time calculation, based on the Continuously STirred Reactor (CSTR) concept described in Monsen et al. (2002). The CSTR flushing time (T_f) reflects the average time a mass of a compound spends in the system and was assessed as follows: in a given volume (defined by its area of 4 km² here, marked A, B, C, D and E (fig. 1c) and the water depth), at an initial time called t0, a mass of a conservative tracer was homogeneously introduced. For everywhere outside of this volume the tracer concentration was set to 0. Changes in the mass over time were mostly driven by tidal currents and meteorological forcing. Afterwards, the mass of the tracer in the tagged volume was computed at each step. In each sub-area, the flushing time T_f was computed for the following conditions: real tide variation (alternately high and neap tides); with and without wind (respectively south-westerly, north-easterly and south-easterly at speeds of 7.5 and 5 m.s^{-1}).

3. Results and discussion

When microbial concentrations in the inputs were measured during “normal” weather conditions, the average counts were less than 2,900 *E. coli*/100ml (table1). These results were in agreement with those found in rivers or in treated urban waters (Garcia-Barcina et al., 2006; Rose et al., 1996). Under "storm" conditions, concentrations at the same inputs reached 12,830 *E. coli*/100ml. and they were multiplied by a factor of 4.5 for the Morsalines tributaries, (table 1), probably due to an overflow of untreated water. Table 2 shows the calculated fluxes obtained by multiplying *E. coli* concentrations with the river flow measured at the same time. The average fecal fluxes varied from 0.1 to 4 10^7 cfu/m^3/s under normal winter conditions and maximal fluxes ranged from 0.007 to 2.5$10^9$ cfu/m^3/s during the storm events. The major fecal fluxes for *E. coli* come from the rivers. Norovirus concentrations were estimated from data obtained using real-time PCR (Le Guyader, personal com.). These concentrations go from 10^2 to 10^4 RNA copies/100ml, depending on the origin of the water sample (river and effluent respectively). This concentration range is consistent with those obtained by authors in influent and effluent waters (Laverick et al. 2004; Lodder et al. 2005, Pusch et al. 2005). Estimated norovirus fluxes fed into the model went from 0.16 to 4. 10^7 RNA copy/m^3/s. This included the maximal values in Morsalines inputs, where overflow from a wastewater treatment plant was observed during intermittent rainfall periods. The occurrence of normal and storm events and the associated fecal input in the bay were then estimated from Météo-France data. 10 mm/day were considered as a threshold limit between “normal” and “storm” conditions for fecal contamination. Current Health Ministry observations indicate that in Normandy, more than 50% of coastal contamination is due to rainfall reaching 10 mm/day. The rainfall data recorded by Météo-France allowed us to determine the occurrence of the potential overflow periods during the period of the study (March 2001 to March 2004). (See Figure 2.) Fecal fluxes corresponding to these selected periods were put into the model.

The second objective was to assess the “risk period” for viral contamination. This was based on monitoring of cases of gastro-enteritis in the population (Figure 2). Winter epidemics largely attributable to viruses are regularly reported in Europe and in the United States. When an epidemic occurs, viruses are detected in wastewater samples taken during and for several weeks after the epidemic due to viral shedding by the population (Svraka et al., 2007). The epidemic data provided by the medical practitioners' network shows seasonal peaks of viral gastro-enteritis in the local population. In this study, the “risk period” for viral input in harvesting areas was determined by the simultaneous occurrence of a large outbreak in the population and rainfall exceeding 10 mm/day. This worst condition corresponds simulating a viral storm input in the bay.

During the four year study, only two fecal events were observed, with one “high viral risk period”, because only one storm event occurred at the same time as gastro-enteritis in the population. Most of the time, the epidemic peak was associated with a relatively low amount of rainfall and "normal" situations, i.e. a few cases of gastroenteritis and dry weather were observed during this period. We considered that the "risk" conditions were representative of the local periodicity. During the period from 1997-2000, high viral risks were rarely seen, i.e. once at the end of 1999 and again with a major potential flux during the 2000-2001 winter season.

The impact of tributaries on fecal water contamination was then simulated by the model. Under normal fluxes, water contamination was weak and was in agreement with sampling data (not shown). Therefore, this result was in agreement with the class A EU regulations classification assigned to this area. The model also demonstrated the deterioration of water quality when a storm event was simulated. The shellfish beds were quickly covered by a fecal plume (fig 3a and 3b). In case of viral contamination (fig3b), the impact of such events could more dramatically affect shellfish farms, because of the long persistence of viruses in the environment (Loisy et al., 2005)

The model was then used to understand the hydrodynamics of the sector and the time required for water quality recovery. Using particle trajectories, we had previously demonstrated (Riou et al., 2007) that, when the starting position of a particle was located in the bay near the mouth of a river, the particle was trapped in the bay and the water mass was confined in the area. In the case of pollution by fecal contamination, it was of essential to evaluate the time needed for the recovery of water quality. The two main factors influencing the speed of recovery of water quality are dilution and the T90 (parameter taking into account the resistance of bacteria or viruses in the model). The flushing time, - i.e. the average time the mass released in the sub-area will spend inside the system- was calculated under various wind conditions, and included the tidal effect. The model showed that flushing times are different according to the sub-areas (Table 3). Outside the bay, the flushing time was very short due to the efficiency of the dilution in decreasing the pollution. On the contrary, it was found to be very long in the bay, due to poor dilution. It takes several hours for the water inside the bay to recover its quality. Therefore, a storm rainfall event may have a greater impact in a confined sector. Furthermore, viruses in the environment survive for a long time in the environment and take much longer than *E. coli* to disappear**.** This means that the water quality recovery time for viruses will take 2 or 3 times longer than *E. coli* (Riou et al. 2007).

4. Conclusion

The model demonstrated that under normal conditions the water quality in the sector is good, but that it is very sensitive to rainfall events in terms of fecal contamination. Moreover, on a few occasions a viral flux from an ill population may reach shellfish beds through raw-water overflows. For the moment, this sort of event is still quite rare, occurring only once every 8 years, as shown in Figure 2. However, depending on the hydrodynamic conditions, contaminated water where viruses are present could stay for several days on shellfish beds. If climate changes increased the number of extreme rainfall events, this would dramatically lead to long periods of shellfish bed closures. In fact, shellfish can be contaminated in a few hours (Plusquellec et al., 1990). But the depuration time for shellfish in natural water (at low winter temperatures) is very long, exceeding several weeks (Loisy et al. 2005). During our study, shellfish were contaminated once by viruses and monitoring showed that 3 to 4 weeks were needed before the different contaminated areas tested negative for viruses (data not shown). If rainfall storm events increased significantly in the future, they would have a direct impact on the sustainability of aquaculture. The model demonstrated this area's sensitivity to pollution and the need to reduce the fecal load entering the bay. Management options to limit the fecal load must also take into account the possibility that river flows may increase in future.

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References

Chen Z., Grasby S.E., Osadetz K.G., Fesko P., 2005. Climate and Stream Flow Trends and. Future Water Demand Analysis in the Calgary Region, Canada. *Wat. Sci. Tech.,* 53, 1-11.

Dupont J., F. Dumont, C. Menanteau, M. Pommepuy, 2004, Calibration of the impedance method for rapid quantitative estimation of *Escherichia coli* in live marine bivalve molluscs. *J. Appl. Microbiol.* 894-902

Garcia-Barcina, J.M., Gonzalez-Oreja, J.A., De la Sota, A. 2006. Assessing the improvement of the Bilbao estuary water quality in response to pollution abatement measures. *Wat. Res*., 40, 951-960.

Griffin, D.W., Donaldson, K.A., Paul, J.H., Rose, J.B., 2003. Pathogenic Human Viruses in Coastal Waters. Clin. Microbiol. Rev., 16, 129-143.

He J., Valeo C., Bouchart J.C., 2005. Enhancing urban infrastructure investment planning practices for a changing climate, Water science & technology, vol 53, 10, 13-20.

Laverick, M. A., A. P. Wyn-Jones, and M. J. Carter. 2004. Quantitative RT-PCR for the enumeration of noroviruses (Norwalk-like viruses) in water and sewage. Lett. Appl. Microbiol. 39:127-136.

Lees, D. N., 2000. Viruses and bivalve shellfish. Int. J. Food Microbiol. 59, 81-116.

Le Guyader F.S., Loisy F., Atmar R.L., Hutson A.M., Estes M.K., Ruvoen-Clouet N., Pommepuy M., Le Pendu J., 2006. Norwalk virus specific binding to oyster digestive tissues. *Emerg; Inf. Disease.* 12 : 931-936.

Le Guyader F.S., Bon F., De Medici D., Parnaudeau S., Bertome A., Crudeli S., Doyle A., Zidane M., Suffredini E., Kohli E., Maddalo F., Monini M., Gallay A., Pommepuy M., Pothier P., Ruggeri F. 2006. Detection of noroviruses in an international gastroenteritis outbreak linked to oyster comsumption. *J. Clin. Microbiol.* 44: 3878-3882.

Le Guyader F., Neill F.H., Dubois E., Bon F., Loisy F., Caprais M.P., Kohli E., Pommepuy M., Atmar R. 2003, A semi-quantitative approach to estimate Norwalk-like viruses contamination of oysters implicated in an outbreak. *J. Food Microbiol.*, 87: 107-112;

Lipp, E.K., Kurz, R., Vincent, R., Rodriguez-Palacios, C., Farrah S.R., Rose, J.B., 2001. The effects of seasonal variability and weather on microbial fecal pollution and enteric pathogens in a sub-tropical estuary. Estuaries. 24, 238-258.

Lodder, W. J., and A. M. D. Husman. 2005. Presence of noroviruses and other enteric viruses in sewage and surface waters in The Netherlands. Appl. Environ. Microbiol. 71:1453-1461.

Loisy, F., Atmar, R.L., Le Saux, J.C., Cohen, J., Caprais, M.P., Pommepuy, M., Le Guyader, F., 2005. Use of rotavirus virus like- particles as surrogates to evaluate virus persistence in shellfish, Appl. Environ. Microbiol. 71, 6049–6053

Miossec, L., Le Guyader, F., Haugarreau, L., Comps, M.A., Pommepuy, M., 1998. Possible relation between a winter epidemic of acute gastroenteritis in France and viral contamination of shellfish. J. Shellf. Res. 17, 1661-1664.

Monsen, N.E., Cloern, J.E., Lucas, L.V., 2002. A comment on the use of flushing time, resident time, and age as transport times scales. Limnol. Oceanography. 5, 1545-1553.

Pommepuy M, Hervio-Heath D, Caprais M. P., Gourmelon M., Le Saux J. C., and Le Guyader F., 2005. Feacal contamination in coastal areas: an engineering approach. *In* Oceans and Health, Pathogens in the Marine Environment*.* S Belkin & R. R. Colwell edt. Sringer N.Y., 331- 359.

Pusch, D., D. Y. Oh, S. Wolf, R. Dumke, U. Schroter-Bobsin, M. Hohne, I. Roske, and E. Schreier. 2005. Detection of enteric viruses and bacterial indicators in German environmental waters. Arch. Virol. 150:929-947.

Riou P, Le Saux J.C., Dumas F., Caprais M.P., Le Guyader S.F., Pommepuy M, 2007. Microbial impact of small tributaires on water and shellfish quality in shallow coastal areas. *Wat.Research* (on line).

Rose, J.B., Dickson, L.J., Farrah, S.R., Carnahan, R.P.. 1996. Removal of pathogenic and indicator microorganisms by full-scale water reclamation facility. Water Res. 30, 2785- 2797.

Svraka, S., E. Duizer, H. Vennema, E. de Bruin, B. van der Veer, B. Dorresteijn, and M. Koopmans. 2007. Etiological Role of Viruses in Outbreaks of Acute Gastroenteritis in The Netherlands from 1994 through 2005. Journal of Clinical Microbiology 45:1389-1394

Van Luijtelaar H., Albert H. Dirkwager., 2002. Quickscan Climatic Change and Urban Drainage. Proceeding Conference Hydraulic Modeling, Newswire 3 September 2002 Edition 6/2002.

Table 1: *E. coli* /100ml concentrations measured in the rivers and the tributaries flowing into the three main shellfish farming areas.

	Saire Bay input	**Morsalines Bay inputs**	**Sinope input**
5. Normal weather	2500	2850	2000
Storm event	4500	12830	3600
factor	1.8	4.5	1.8

Table 2: *E. coli* fluxes in the main inputs under normal weather conditions and during a storm event

	Summer mean ($cfu/m^3/s$)	***Winter mean ($cfu/m^3/s$)***	***Max ($cfu/m^3/s$)***
Saire bay inputs	$3.5\ 10^6$	$3.9\ 10^7$	$2.5\ 10^9$
Morsalines bay	$3.6\ 10^5$	$9.8\ 10^5$	$6.7\ 10^6$
Sinope	$3.5\ 10^6$	$1.7\ 10^7$	$1.4\ 10^9$

Table 3: Flushing times (hours) in the different sub-areas as function of wind conditions

	A	**B**	**C**	**D**	**E**
Without Wind	28	73	13	13	5
South-westerly wind 7m/s	10	14	5	6	6
South-easterly wind 5m/s	23	51	6	6	6
North-easterly windt 5m/s	20	50	41	56	6

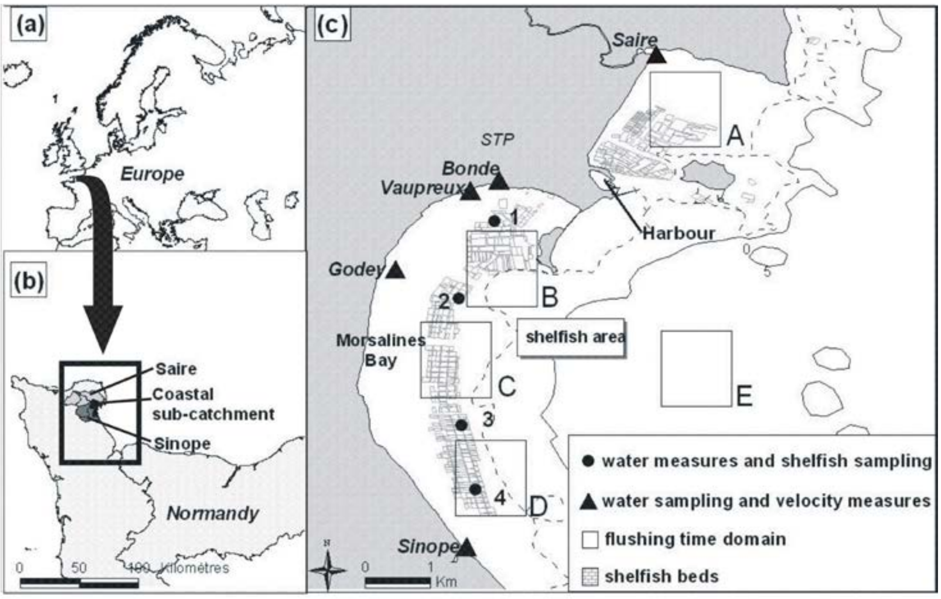

Figure 1: (a) Location of the study area; (b) Domain included in the hydrodynamic model and the three sub-catchments (Saire, Sinope and coastal area sub-catchments); (c) Position of the tributaries; shellfish sampling locations 1, 2, 3 and 4;and sub-areas A, B, C, D and E for flushing time calculation.

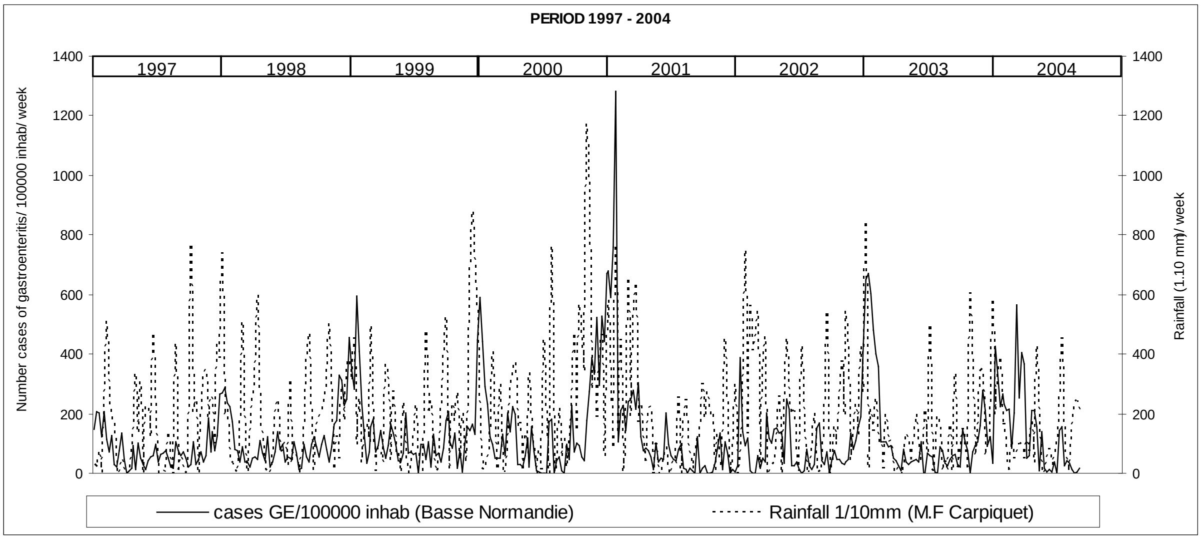

Figure 2: Occurrence of viral gastro-enteritis in the local population (Health Ministry survey) compared to rainfall (Météo-France data)

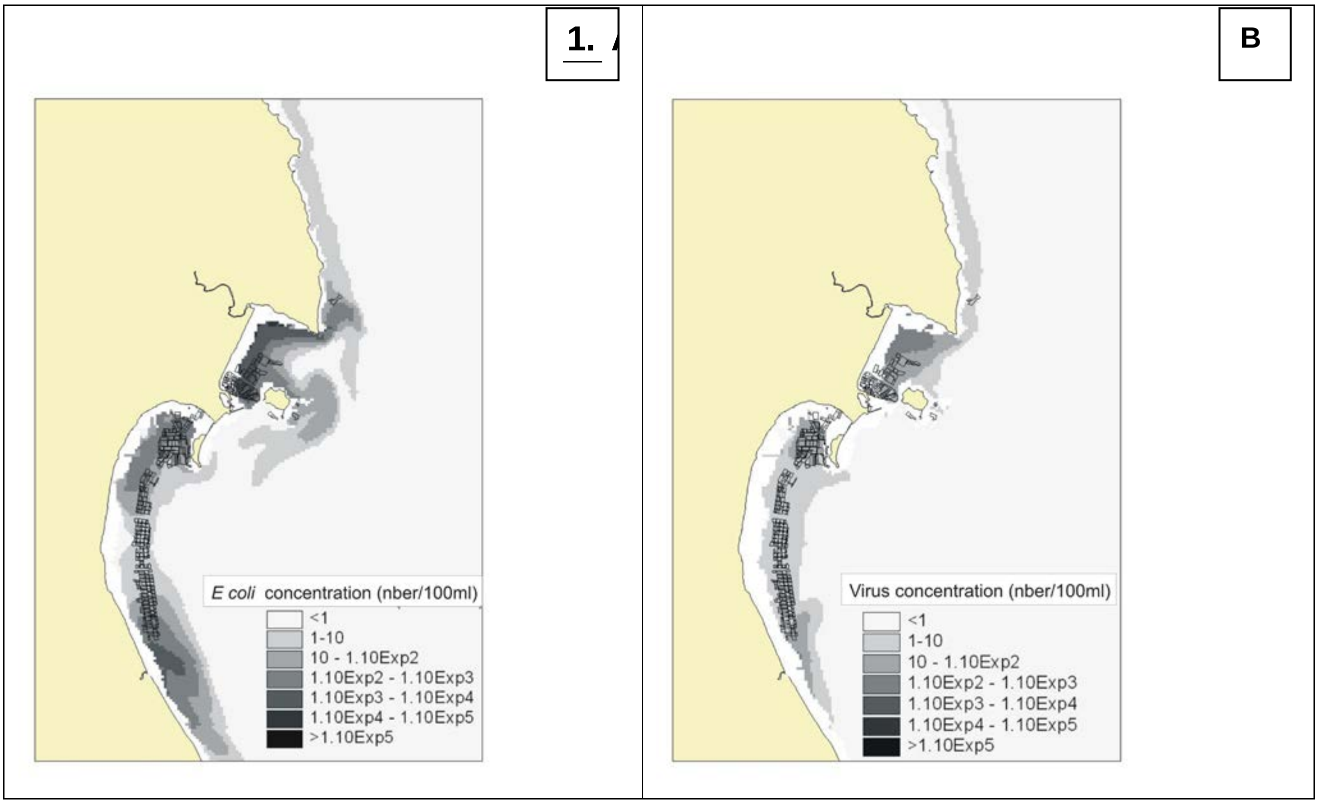

Figure 3: plume of E. *coli* (A) and viral (B) contamination