An Empirical Method to Determine a low-risk fairway in the Gulf of Finland

Raul Isotamm, Bert Viikmäe, Nicole Delpeche

Institute of Cybernetics at Tallinn University of Technology
Akadeemia tee 21, 12618 Tallinn; bert@cens.ioc.ee

One of the aims of the BONUS+ BalticWay project it is to identify areas that are at high and low risk of current-transported coastal pollution in the Baltic Sea (Soomere and Quak, 2007). We describe first steps made towards creating a technology for identifying such areas for fairway designs. The basic tool for the analysis of current-driven pollution is a Lagrangian trajectory model, TRACMASS (Döös, 1995, de Vries and Döös, 2001) with the use of three-dimensional current velocity fields calculated by the Rossby Centre global circulation model (Regional Ocean model, RCO) with a resolution of 2×2 nautical miles. Trajectories of current-driven pollution are simulated for a few weeks and the simulations for each sea point are repeated over several years. A high risk to a coastal section is assumed when pollution reaches a sea point located at a distance of two or three grid points from the coast. The average time it takes for the pollutants to reach such points is a measure of risk associated with the starting point.

While the probability of coastal pollution for open ocean coasts can be reduced by shifting the fairway offshore, a central question for narrow bays is how to minimize the joint probability of hitting of either of the coasts. The first order solution is the equiprobability line, the probability of propagation of pollution from which to either of the coasts is equal. For wider sea areas there may appear an area, propagation of pollution from which to either of the coasts is unlikely. This line/area serves as an area of low environmental risk and indicates a safe fairway. We propose two methods for numerical estimation of the location of the equiprobability line. The first method is referred to as the linear method whilst the second method is referred to as the smooth method. The difference of the positions of the line/area can be interpreted as an estimate of uncertainty of their location.

The first method consists in the analysis of trajectories starting from each single cell. The Gulf of Finland area comprises of 3131 grid cells of 2×2 miles. For each grid cell, 4 starting positions of trajectory are defined. Thus the total amount of trajectories in the Gulf of Finland for this study was defined as 12524. The coastal zone is divided into a southern part and northern part.

The TRACMASS code is then run to simulate the movement of the trajectories for a particular time period. The hits of trajectories to each part are counted separately for each starting position and cell. A similar count is made for trajectories that are entirely located in the open sea area far from the coast. Trajectories were calculated over a five year time period in 1987–1992 using a time-window of 20 days from a variety of starting moments and the same pattern of initial positions of the trajectories. The time-step between these time-windows was one day The time scale of 20 days is about twice longer than the typical time scale for pollutant to hit a coast in this sea area and the calculations thus eventually reliably indicate which coast, if any, will be reached from a particular cell.

A statistical analysis is then performed on each grid cell. First, a count is made on if at least 50% of the trajectories travelled to either of the coast. If yes, the cell is marked as being a probable source of pollution for the particular coastal section. If not, the cell is marked as a part of the area, propagation of pollution from which to any of the coasts is unlikely. The latter area is called as an undefined area. The separation line of cells – probable sources of pollution to different coasts – evidently can be interpreted as the estimate of the location of the equiprobability line.

The described method generally leads to quite a large level of noise and not always results in a clear separation of sea areas in terms of propagation pollution to either of the coasts. For this reason, we use another method for specification of this line that implicitly involves a smoothing process. The method consists of dividing the sea area into clusters of 3×3 grid cells and considering integral properties of pollution propagation from these clusters. By tracing nine trajectories in each cluster (one from each cell) it is established whether the majority of the trajectories end up at one of the coasts or stays in the open sea area. This method allows for reduction of noise in the map of probabilities. This method can be viewed as an extended method of previous linear method, but instead of one grid cell we now use nine grid cells and from these nine grid cells we get one big grid cell which we call a cluster. The same procedure as above is then repeated for each cluster and the equiprobability line and the low-risk area is defined for the centres of the clusters.

Results indicate that increase in the simulation time causes an increase in the low-risk area. As the current fields in the Gulf of Finland exhibit strong seasonal variability, this feature suggests that a similar variability exists for low-risk areas. The equiprobability line was found to be substantially shifted northwards from the axis of the Gulf of Finland for both the methods. Most of the area between the coasts is the area with the larger probability of hitting the southern coast. The difference between the two methods estimates a measure of uncertainty related with this type of solution.

References

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