An optimisation approach for groundwater monitoring network augmentation- a ‘detection’ monitoring case study

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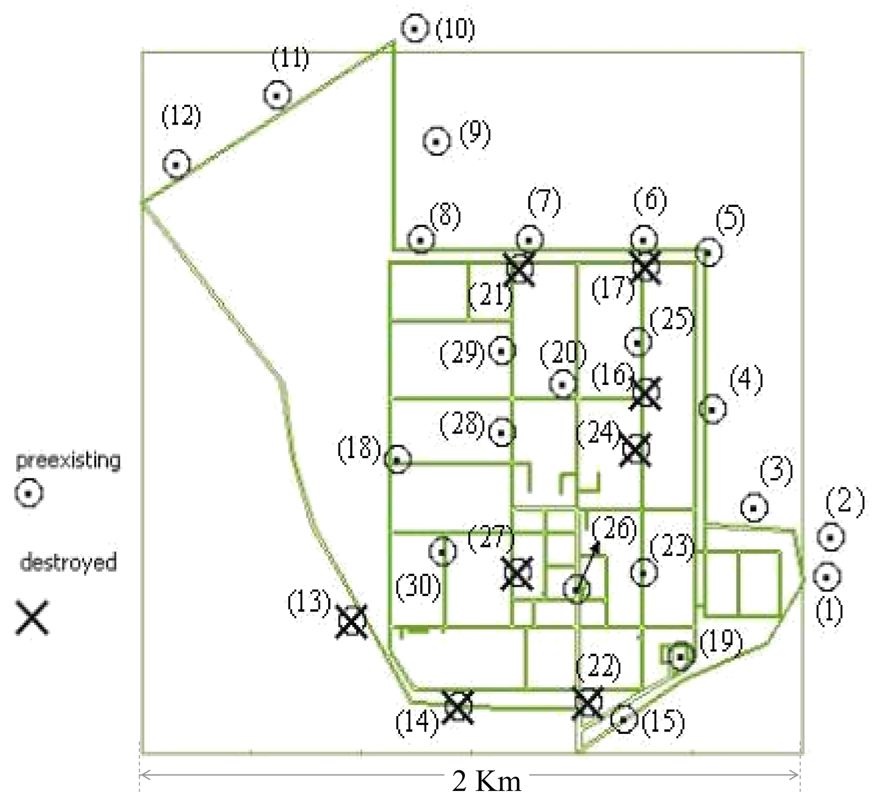
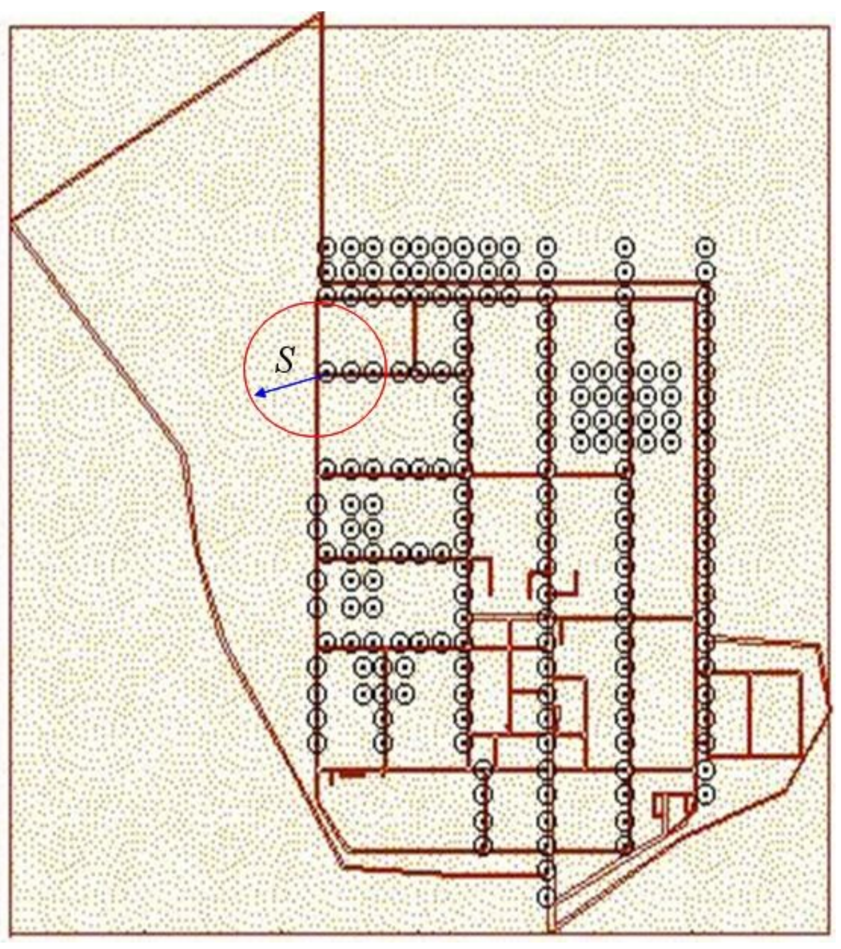
Background



- Pre-existing network of monitoring wells had been installed to lower the groundwater table. 8 of the 30 wells were broken.
- Samples of groundwater from some of the existing wells showed free phase of hydrocarbon (visible LNAPL). Determination of the extent of contamination (i.e. mound(s) of floating hydrocarbon on the groundwater) beneath the refinery was the goal of the project.
- To gain further information on the spatial extent of the contaminant, augmentation of the network was deemed necessary.
- An integer programming approach, the Maximal Covering Location Problem (MCLP), was adopted to optimise the augmentation.

Maximal Covering Location Problem (MCLP)



Maximize coverage (population covered) within a desired service distance by locating a fixed number of facilities (Church and ReVelle, 1974). The mathematical formulation of this problem is presented below:

$$\text{Max } Z = \sum_{i \in I} w_i y_i$$

Subject to :

$$\sum_{j \in N_i} x_j \geq y_i \qquad (\forall i \in I)$$

$$\sum_{j \in J} x_j = P$$

$$x_j = (0,1) \qquad (\forall j \in J)$$

$$x_j = 1 \qquad (\forall j \in J_p)$$

$$y_i = (0,1) \qquad (\forall i \in I)$$

w_i : population at node i;

I : set of demand nodes in discretized network;

J : set of prospective nodes for siting facilities;

J_p : set of nodes j occupied by preexisting facilities;

$N_i : \{ j \in J \mid d_{ij} \leq S \}$;

d_{ij} : the shortest distance from node i to node j;

S : covering distance threshold (maximal service distance);

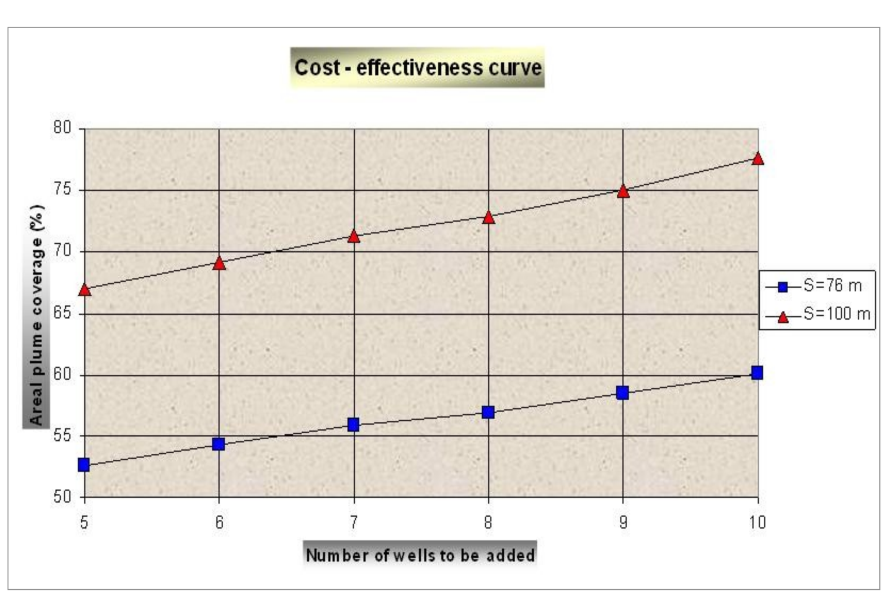
x_j : 1 if a facility is located at site j; 0 otherwise;

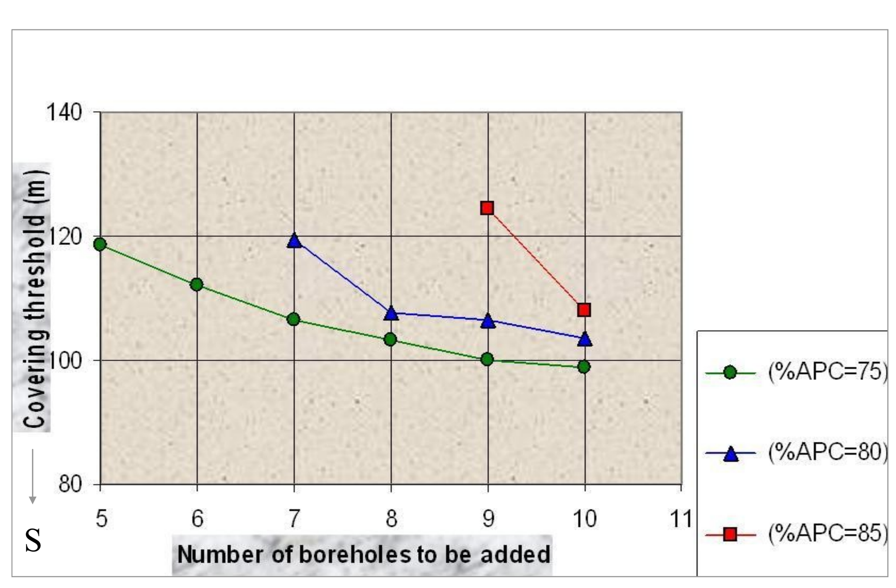
y_i : 1 if node i is covered; 0 otherwise;

P : total number of facilities (pre-existing and added) to be located

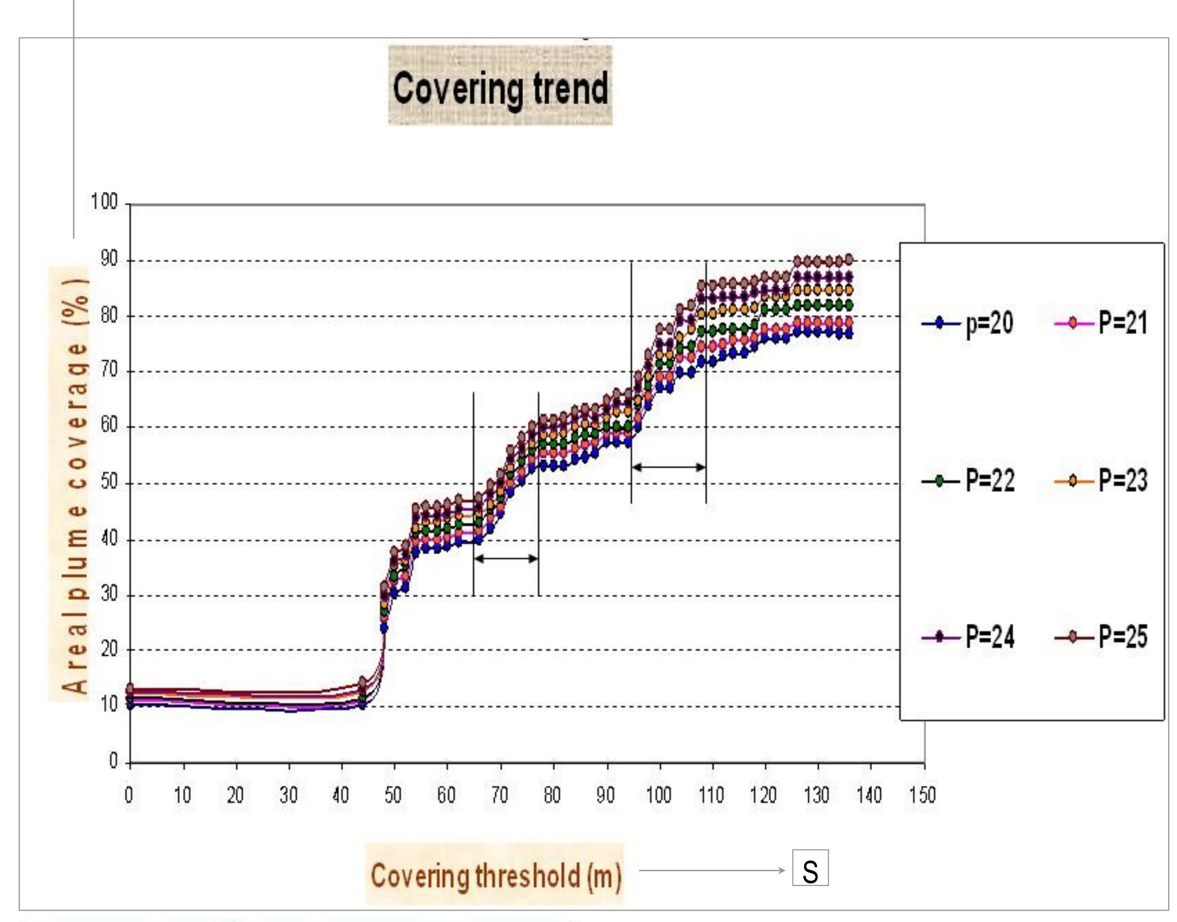
Implementation of the model

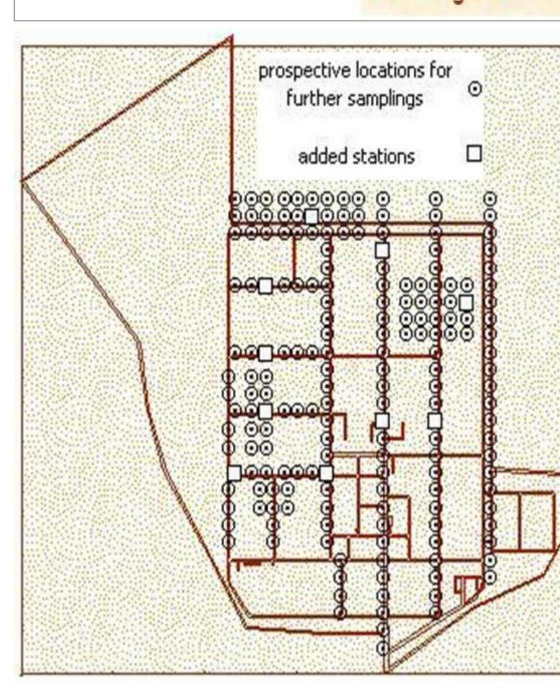
- Discretization of the study area into network of ‘demand’ nodes.
- Nodal weights calculation (estimation via a stochastic interpolator in this case).
- Solution of the integer programming problem (Lingo with supports from MATLAB).
- Further analysis and implementation of the outputs.





Percentage of nodes (with weight values above zero) that are covered by one or more wells (nodes i for which y_i=1)





Why the modelling was successful?

- Groundwater samples from 5 out of the 10 added monitoring wells showed free phase of hydrocarbon (i.e. captured the mound). Coverage of the mound by the augmented network was satisfactory.
- Clustering of added monitoring stations at areas with the highest weight (concentration) values was prevented. This was separately investigated through a ‘comparative’ study based on a purely geostatistical approach (i.e. ‘variance reduction analysis’). The results favoured the optimisation (MCLP) approach.
- Direction of geostatistical anisotropy in the analyses carried out to delineate the extent of the mound (using the data from the augmented network) was in agreement with the groundwater flow.