Subsurface suitability maps for spatial planning

BRECHT WASSING[1] ROB VAN DER KROGT[2]

[1] *TNO Built Environment and Geosciences. (e-mail: brecht.wassing@tno.nl)*
[2] *TNO Built Environment and Geosciences. (e-mail: rob.vanderkrogt@tno.nl)*

Abstract: Much of the shallow surface of the Netherlands consists of unconsolidated deposits with low strength, high water content and low consistency, especially in the western and northern coastal zones where the upper 20 m of the subsurface is made of soft and water-saturated Holocene clay, peat and sand. Nowadays, it is well understood that the shallow subsurface of the Netherlands shows varied geotechnical behaviour, contains mineral resources, and also provides potential for underground space that may be needed for economic expansion. A sustainable development and use of the subsurface of the Netherlands can only be guaranteed when the geological characteristics and geotechnical constraints are considered in the context of public planning for land-use, building infrastructure, and exploitation of natural resources, environmental development and use of underground space.

In the Netherlands there is now a growing attention for the role of the subsurface within spatial planning of traffic infrastructure, business parks and urban extensions. The consequences of relevant aspects of the subsurface (i.e. land subsidence, mineral resources, water quality) for these functions are presented in geographical maps by means of GIS. These maps are integrated into so-called "subsurface suitability maps" depicting the suitability of areas for a certain spatial development, viewed from the perspective of the subsurface. These techniques are used for the quantification of environmental effects and construction purposes, in a regional and local scale. In the Province of Zuid-Holland, these "subsurface suitability maps" have been applied within decision support systems to compare spatial alternatives for a number of scenarios.

Résumé: Cet article décrit une méthode pour introduire de l'information géologique et geohydrologique dans le l'aménagement du territoire.

Keywords: Planning, engineering geology maps, hydrogeological maps, landuse, geographical information systems.

INTRODUCTION

The provincial authorities of Zuid-Holland wish to extend the area for business parks to a total area of 500 hectare. Zuid-Holland is a densely populated region, which means the authorities are confronted with a scarcity of space. In the process of planning several spatial and socio-economical factors should be taken into account, such as the accessibility of the sites in relation to the main infrastructure and main ports and the distance to the urban areas. In addition, in the Netherlands there is a growing recognition of the importance of the subsurface within spatial planning. The Province Zuid-Holland is well-known for its thick, unconsolidated and water saturated clay and peat deposits. City councils in this region, like Gouda, are confronted with high maintenance costs of both infrastructure and underground mains and services due to the continuous subsidence of the shallow soil layers. Both older and newly built building estates suffer from the inconvenience or even damage caused by flooding and high water tables. On the other hand, the shallow subsurface also offers some opportunities for development; like the potential for underground space needed for economic expansion, the presence of mineral resources and the potential for thermal energy storage in shallow aquifers by means of cold and heat storage systems. It is realised that both the geological constraints and potential benefits of the subsurface should be considered in spatial planning.

This paper describes a method that has been developed to combine both spatial, socio-economical and geological information to support the planning process (see figure 1).

THE CONSTRUCTION OF SUBSURFACE SUITABILITY MAPS FOR SPATIAL PLANNING

Engineering geological basemaps

First, all engineering geological and geohydrological aspects relevant to the development (and maintenance) of the business parks were inventoried. The following aspects were considered relevant:

- Foundation depths, i.e. depth of soils layers with sufficient bearing capacity. Foundation design and construction costs depend on the bearing capacity of the shallow soil layers. Foundation depths and foundation levels were defined for ‘ordinary’ buildings. Thick deeper compressible clays and peats below these foundation levels may cause settlement of high, heavy buildings with large foundation pressures; in areas with deep thick clay deposits heavy buildings may need deeper piled foundations.

- The compressibility of the soils and the risk of settlement. Both construction and maintenance costs of infrastructure, sewer and mains systems will be high in settlement prone areas with thick peat and clay deposits. Experience with building estates constructed in areas with thick peat deposits showed that sewer systems have to be replaced once every 10 years, as opposed to sewer systems in sandy soils which may have a lifetime of almost 30 years.
- Geohydrological aspects such as depth of groundwater, seepage- and infiltration rates and storage capacity, which will influence the future risks of groundwater related problems. Due to climate changes in future higher amounts of precipitation are expected; water storage capacities on sites should be sufficient. Also, the groundwater system is a dynamic system. The construction of a business park itself will have an impact on the groundwater system (changing water tables, changing seepage rates, increased amount of paving, etc.)) on site but also in the vicinity of the site. At this stage, however, it has not been possible to fully incorporate the dynamics of the groundwater system in the planning process and decision making. For this project a pragmatic choice was made to use only the information on seepage and infiltration rates, which are relevant to both construction costs (seepage pressures and intensity of drainage) and the risk of spreading of contamination. Also the quality of the groundwater was taken into account. Sulphates and chlorides may lead to a rapid deterioration of construction materials such as concrete.
- The suitability of the soil structure for underground constructions. Both geotechnical design and related construction costs of underground constructions depend on the geology and geohydrology of the site. Often in the Netherlands building pits are used for underground construction, to overcome the problems with (soft) soil conditions and high ground water tables. The construction costs of underground constructions mainly depend on the design of the building pit and the measures that are necessary to guarantee stability and prevent the inflow of groundwater. Both design and measures strongly depend on the geology and geohydrology of the site (Herbschleb et al., 2003).
- Presence or absence of sand and gravel resources. Though shallow sand and gravel resources in close vicinity of the sites can be used for construction purposes on site, in this case it was decided that for a sustainable use of the subsurface and development of the business parks the accessibility of mineral resources should be retained. Building sites should not be planned on top of valuable mineral resources.
- Possibilities for the storage of thermal energy in aquifers by means of cold and heat storage systems. Cold and heat storage can be used as a sustainable energy source for office buildings.
- The presence of contaminated soils; though the presence of contaminated soils may cause some delay in the development of the sites, the Provincial authorities consider a simultaneous sanitation (or immobilisation and isolation on business parks) of contaminated soils and development of the sites as positive.

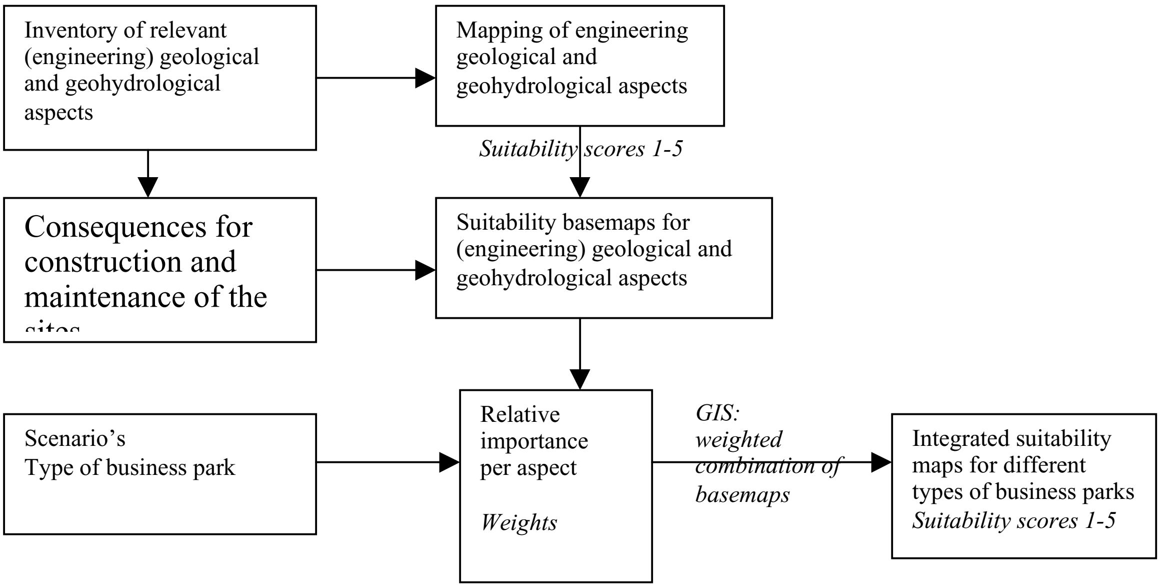


Figure 1. Outline of the use of (engineering) geological and geohydrological information in integrated suitability maps.

Integrated subsurface suitability maps

For all the above engineering geological and geohydrological aspects base maps were constructed at a regional scale of 1:250,000. Based on the base maps an integrated subsurface suitability map was obtained. The engineering geological and geohydrological characteristics of the individual base maps were first transformed into 'suitability scores' (for example see figure 2). For all maps suitability scores ranged from 1 (''very unsuitable') to 5 ('very suitable'). For example, with respect to the engineering geological aspect of foundations, a site with shallow foundation levels which allows for pad and strip foundations will obtain a high score of 5 and a site with deep foundation levels of 20m below surface level will be assigned a score of 1. To combine all base maps into an integrated subsurface suitability map weights had to be assigned to all base maps.

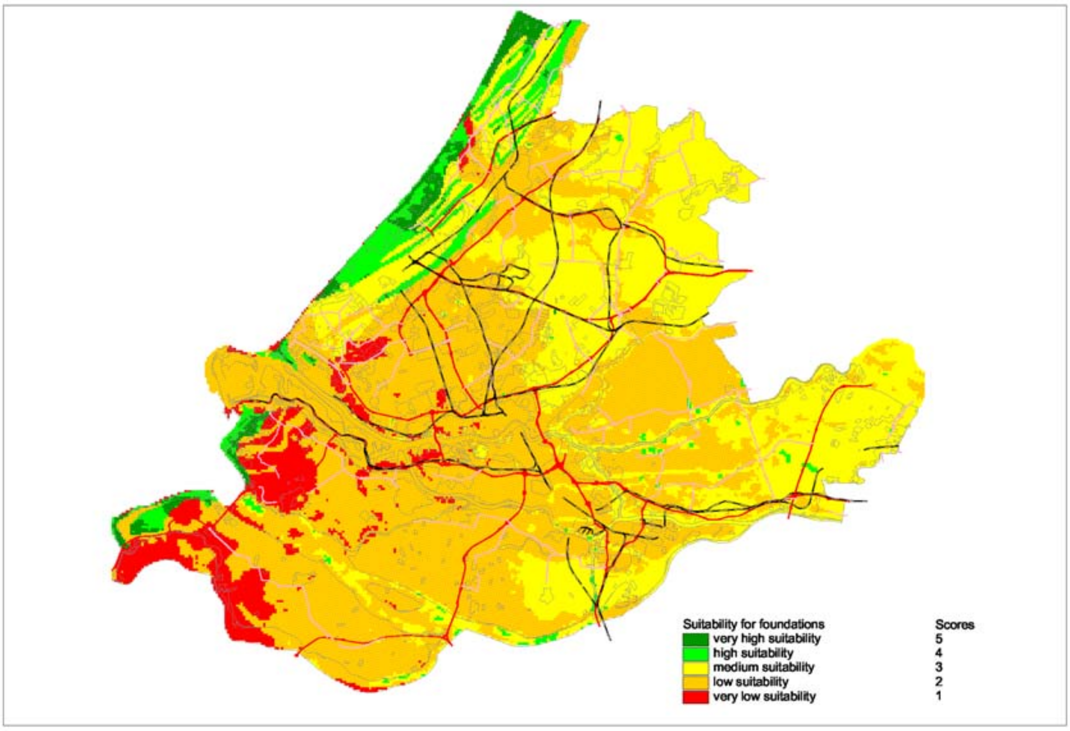


Figure 2. Example of an (engineering) geological base map of the Province Zuid-Holland : suitability for foundations.

Weighting of base maps

The classification of a specific location as either 'suitable' or 'unsuitable' and the weights assigned to all individual engineering geological aspects depend on the type of business park considered. For this study three types of business parks were distinguished (see table 1.)

Table 1. Types of business parks distinguished.

Type of business park	Characteristics
Type I. Offices – general	Offices. Low Floor Space Index. Average area of paving.
Type II. Offices – intensive	Offices. High floor Space Index. Large area of paving.
Type III. Transport and distribution facilities. Production facilities with low and medium environmental impact.	Low Floor Space index. Large area of paving. Heavy transport. Various types of buildings for production, storage space, laboratories, some offices. Use of contaminants (agro-business parks).

The main characteristics of the three types of business parks are used to assess the relative importance of the engineering geological information. For example, the distinguishing feature of the type II business park type – offices, intensive - will be the high Floor Space Index (FSI). Offices in a type II park will in general be high multi-storey buildings, causing high foundation loads. Here, the presence of thick clay layers below shallow bearing soil layers may cause an unacceptable settlement of the foundations and buildings. High, heavy buildings should be founded on strata below these clay layers, and the information on the potential presence of deep clay layers is very relevant. On the other hand, this specific information is less relevant to the type I and III business parks. In type III business parks a lot of heavy traffic can be expected both on site, as on the access roads. Therefore, in case of a type III business park more weight is assigned to the engineering geological base map on settlement.

Often the relative weights assigned to the various engineering geological base maps are somewhat arbitrary and subjective. Though some of the individual engineering geological aspects can be quantified into costs, i.e. construction costs for foundations and construction and maintenance costs for infrastructure, other aspects such as the value of sustainable energy are much harder to quantify. Furthermore, the relevance of all the engineering geological aspects (which is also true for the spatial and socio-economic aspects) depends on the perception of the planner. Depending on such perspective, the outcome of the integrated suitability map will be different. In consultation with the planners four scenario's were defined:

Scenario 'sustainability'

The scenario 'sustainability' aims at a sustainable planning and development of the business parks. Adverse effects on nature open space and environment should be prevented. Referring to spatial and socio-economic factors, this means for example that business parks are concentrated in urbanized areas. As for subsurface aspects the scenario aims, amongst others, at a sustainable use of mineral resources and (thermal) energy and a sustainable design of infrastructure (minimizing settlement).

Scenario 'economy and costs'

In the scenario 'economy and costs' much attention is paid to the construction and maintenance costs of the sites, which means aspects as foundation depths, settlement risks and high construction costs due to unfavourable groundwater conditions obtain relatively high weights. On the other hand, from an financial perspective the use of underground space is unappealing and the presence of soil contamination will always result in higher construction costs – both will be weighted less. Reserving space for water storage will preclude the economical development of the area, which means this aspect obtains little weight.

Scenario 'multiple use of space'

This scenario concentrates on an efficient layout of the business park and an efficient use of the (scarce) space. Relatively large weights are assigned to the suitability of the geology for underground construction. With respect to the spatial and socio-economic factors, this scenario aims at a concentration of business parks near infrastructural junctions and within urbanized areas.

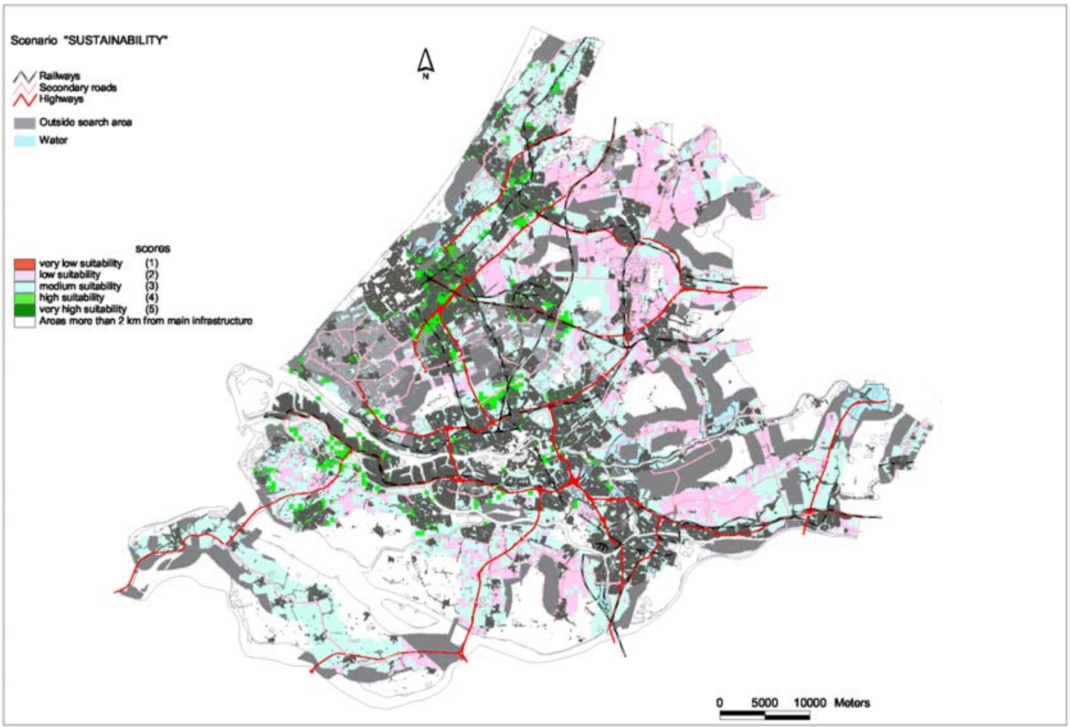
In addition to these three specific scenarios a 'neutral' reference scenario was defined. In table 2 for each scenario the relative importance of the subsurface, spatial and socio-economic factors is presented.

The final weights of all the engineering geological, spatial and socio-economic factors were assigned during a workshop with the planners. These weights were used in a GIS-environment to combine the information of the various base maps in integrated suitability maps for different types of business parks and different scenario's (see figure 1).

CONCLUSIONS

From the integrated subsurface suitability maps a general insight in the suitability of the sites for the development of business parks is obtained. Those sites classified as very suitable for business parks obtain a score of 5. Sites very unsuitable obtain a score of 1. In figure 3 two examples of integrated suitability maps are presented. As stressed earlier the weights chosen and the results of the final integration, i.e. the integrated suitability map, depend on the perception of the planner. Defining a number of scenarios gives us some idea of the sensitivity of the results to the various engineering geological, spatial and socio-economic factors. In all scenarios some robust patterns of very suitable and very unsuitable sites are distinguished. The above method enables planners to handle, weight and combine a large amount of information in one system and to translate policy measures into spatial overviews and possible planning decisions. The instrument is developed in a way that it is also possible to perform this type of analysis in workshops, where participants can assign weights to base maps in a 'real time' setting, and the resulting spatial overviews can be presented after only a few minutes.

At the moment it is still difficult to take full account of the impact of interventions in the subsurface on the dynamics of the groundwater system and vice versa. Further research will concentrate on a better implementation of the groundwater dynamics. Furthermore future research will also focus on a better quantification of costs and benefits.



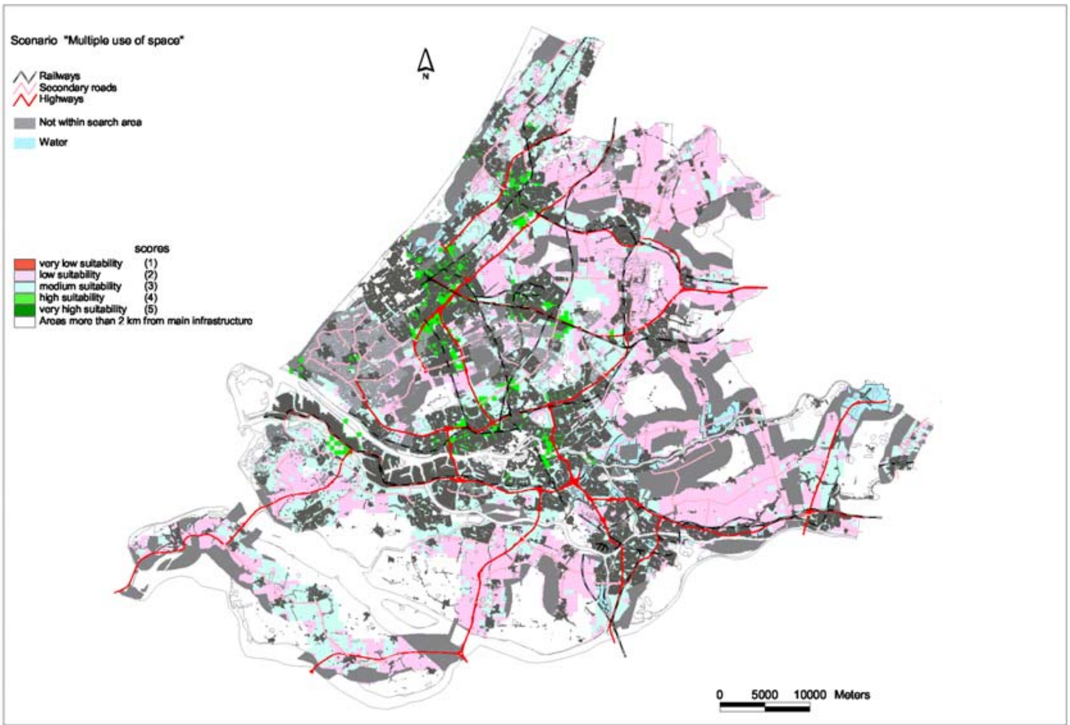


Figure 3. Example of integrated suitability maps for business parks. The maps presents the suitability for type I business parks, from the perspective of sustainability (upper) and 'multiple use of space' (lower).

Table 2. Relative importance of engineering geological factors for 3 scenarios, as compared to a reference scenario. +=high importance, 0=neutral importance (same as reference), -/-=low importance as compared to reference scenario.

	Reference	Sustainability	Economy and costs	Multiple use of space
Subsurface factors				
Foundations (ordinary buildings)	0	-/-	0	0
Deep foundations (presence deep clays)	0	-/-	+	0
Geohydrology: Chlorides and sulphates	0	0	0	-/-
Geohydrology: Seepage and infiltration, contamination	0	+	0	-/-
Geohydrology: Construction costs	0	-/-	+	-/-
Mineral resources	0	+	-/-	-/-
Thermal energy storage	0	+	0	+
Soil contamination	0	+	-/-	0
Spatial and socio-economic factors				
Distance to existing business parks	0	0	0	+
Distance to main junctions infrastructure	0	0	0	+
Groundwater protection area	0	+	0	0
Contours urbanized area	0	+	0	+
Search area for water storage (reduction risk of flooding)	0	+	-/-	+
Areas with valuable geological features	0	0	-/-	-/-
Areas with noise restrictions	0	+	-/-	-/-

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