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Designing sustainable and economically attractive brownfield revitalization options using an integrated assessment model

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ABSTRACT

We describe the development of an integrated assessment model which evaluates redevelopment options of large contaminated brownfields and we present the application of the model in a case study. Aiming to support efficient and sustainable revitalization and communication between stakeholders, the presented assessment model integrates three pinnacles of brownfield revitalization: (i) subsurface remediation and site preparation costs, (ii) market-oriented economic appraisal, and (iii) the expected contribution of planned future land use to sustainable community and regional development. For the assessment, focus is set on the early stage of the brownfield redevelopment process, which is characterized by limited data availability and by flexibility in land use planning and development scope. At this stage, revealing the consequences of adjustments and alterations in planning options can foster efficiency in communication between the involved parties and thereby facilitates the brownfield revitalization process.

Results from the case-study application indicate that the integrated assessment provides help in the identification of land use options beneficial in both a sustainable and an economical sense. For the study site it is shown on one hand that brownfield redevelopment is not automatically in line with sustainable regional development, and on the other hand it is demonstrated that additional contributions to sustainability are not intrinsically tied to increased costs.

1. Introduction

1.1. Brownfield revitalization

Different definitions in both Europe and the US similarly describe brownfield sites as abandoned or underused properties, for which intervention is required to ensure beneficial reuse because of the real or suspected presence of hazardous substances, pollutants or contaminants (CABERNET, 2005; USEPA, 2002). The health and economic threats of brownfields as well as the challenges and potential of their reuse are recognized world-wide and international literature describes concerns related to brownfields e.g. in Africa (e.g., Haylamicheal and Dalvie, 2009; Kaufman et al., 2005), Asia (e.g. Cao and Guan, 2007; Zhang and Wong, 2007), Australia (e.g., Apostolidis and Hutton, 2006; Toms et al., 2008), and Canada (e.g., DeSousa, 2001; NRTEE, 2003). Estimated costs for restoration of large brownfield sites in the US range from $100 billion (USEPA, 2003) to over $650 billion (NRTEE, 2003) and for the European Union amount to almost €100 billion (EEA, 2000).

When brownfields are especially large in terms of area, prominence, relevance, seriousness, regional significance, complexity of contamination and of stakeholder networks, they are typically referred to as megasites in more recent literature (Agostini et al., 2007; Bardos, 2004). The revitalization process of such sites may be complicated e.g. by extensive investigation efforts, intricate negotiation among stakeholders with potentially differing interests, large uncertainties, and time-consuming and costly clean-up that may outrun any market interest by far (Bardos, 2004; NRTEE, 2003). The consequence of this is that many of the most complex brownfields to date remain undeveloped.

On the other hand, successful brownfield revitalization can benefit from the typically prominent location of the sites and of already existing infrastructure and it can drastically enhance sustainable regional development (Bardos et al., 2000) by contributing to a reduction of land consumption and urban sprawl (Nuissl and Schroeter-Schlaack, 2009). Large sites additionally provide developers with a wide scope of planning for the design of future land use options, i.e. the use types considered and their allocation on the site.

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Only if this freedom is exploited in order to optimally trade-off between the partly conflicting goals of maximizing land value (i.e. realization of valuable land use types), minimizing remediation costs (i.e. by optimal definition and allocation of land use types with respect to exposure to contaminants), and at the same time contributing to a sustainable urban and regional development, revitalization of large brownfields can be successful (DeSousa, 2006).

1.2. Necessity for appropriate decision support systems

The concept of spatial decision support systems (sDSS) evolved from the need to make decisions based on quantitative and qualitative spatial data in geographic information systems (GIS) (Densham and Goodchild, 1989). Interest in sDSS research has been continuously increasing (Malczewski, 2006) and so has their use for comparative analysis of environmental management alternatives (Ascough et al., 2008), when the high uncertainty associated with forecasting consequences to future actions (Walker et al., 2003) could otherwise result in inaction or improper action like excessive data collection (Reichert and Borsuk, 2005; Smit and Smit, 2003; Wang and McTernan, 2002).

A wide variety of methods to date deal with one or a number of aspects of brownfield revitalization such as risk assessment (e.g., Carlon et al., 2008; Semenzin et al., 2006; Strenge and Chamberlain, 1995), policy analysis (e.g., Linkov et al., 2006), optimization of remediation (e.g., Ahlfeld et al., 1995; Bürger et al., 2007; Wang and McTernan, 2002), remediation cost assessment (e.g., Kaufman et al., 2005), general success factors for brownfield redevelopment (e.g., Lange and McNeil, 2004; Nijkamp et al., 2002), infrastructure redevelopment (Attoh-Okine and Gibbons, 2001), urban planning and site prioritization under budget constraints (e.g., Alvarez-Guerra et al., 2009; Stevens et al., 2007) and mediation of negotiation (Sounderpandian et al., 2005).

Despite the variety of models, several authors have recently described additional need for DSS for contaminated land reuse, which integrate the manifold relevant topics into one system and manage the complicated balance between complexity of information and transparency of results (e.g., Agostini et al., 2007; Agostini and Vega, 2007; Bardos et al., 2001; Tam and Byer, 2002), and that provide guidance to stakeholders while analyzing the huge number of factors that influence optimal future land use on large contaminated sites (Carlon et al., 2007). In particular further development of DSS that integrate an assessment of sustainability has been claimed (Hassan, 2004). Although several definitions of sustainability criteria are described in literature, as well as models to assess the sustainability of land use options (e.g., Wedding and Crawford-Brown, 2008; Zavadskas and Antucheviciene, 2006), most DSS today still do not integrate such assessments. This is explained by the topic's abstract notion (Esty et al., 2005), its multidimensionality (Doick et al., 2009; Jakeman et al., 2008), and a perceived lack of transparency and objectivity.

1.3. Objectives

The objective of this work was to provide an integrated assessment model, which is based on the use of screening-level data and serves as a spatial decision and communication support system for the comparative evaluation of alternative brownfield redevelopment options. The following key factors (modified from Tam and Byer, 2002) were considered in this sDSS:

(1) Examine alternative clean-up goals.
(2) Examine alternative site use options.
(3) Examine the social, economic, and ecological sustainability of land use alternatives.
(4) Estimate all of the economic implications, including clean-up costs, liability, and site use benefits.
(5) Examine uncertainties.
(6) Be computationally feasible and accessible to stakeholders.
(7) Generate results that are understandable to stakeholders (not only to experts in the respective fields).

By encouraging stakeholders to communicate their different expectations towards brownfield redevelopment, the model is meant to promote concerted, constructive and site-specific compromises, thereby fostering the optimal exploitation of the sites' physical planning scope which enables successful revitalization. The focus of this paper is the description of the framework of methods that underlie the integrated assessment, as well as the discussion of results from their application to a case-study site.

2. Description of methods

2.1. Data requirements

The proposed integrated assessment requires a set of general site-specific data and subsurface conditions including aquifer geometry, properties and contamination (Table 1). In addition to this, the redevelopment options of the site need to be specified in terms of land use maps (i.e., the spatial allocation of defined land use types on the site). Redevelopment options that shall be assessed may stem from proposals made by the local authority's planning board or from the investor's plans, but can also be the result of stakeholder discussions and/or iterative re-planning guided by the results of an assessment model as is presented herein. The description of the redevelopment options is complemented by a set of parameters that characterize the particular land use types being considered. The parameter set is composed of reference values for the price of clean land in order to reflect the land use-specific potential revenues from revitalising the site, and compliance criteria for contaminant concentration in soil and groundwater. These compliance criteria define levels of environmental quality, which need to be achieved in order to permit the planned future use of the site. Levels may be defined using human health risk assessment methods (e.g., Marsland, 1999; Strenge and Chamberlain, 1995; USEPA, 1991) or based on regulatory remediation goals (Rügner et al., 2006), and they should always be established in cooperation with local authorities in order to achieve the commensurate and reasonable levels required by law (Begley,

Table 1
Required input data for the integrated assessment model.

		Spatial data	Non-spatial data
Site-specific	Location and extent of site	x	
	Digital elevation model	x	
	Depth and thickness of contamination in soil and groundwater	x	
	Aquifer top and bottom	x	
	Hydraulic conductivity	x	
	Distribution of contaminant(s)	x	
	Contaminant properties		x
	Unit cost data for remediation		x
	General conditions of the site (social, economic, ecological)	x	x
Option-specific	Reference values for price of clean land		x
	Compliance criteria for contaminant concentration		x
	Planned allocation land use options	x	
	Buildings to be deconstructed		x
	Information on site features, attributes, and attractions		x