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Integrating groundwater into land planning: A risk assessment methodology

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ABSTRACT

Generally, groundwater is naturally of good quality for human consumption and represents an essential source of drinking water. In Canada, small municipalities and individuals are particularly reliant on groundwater, since they cannot afford complex water treatment installations. However, groundwater is a vulnerable resource that, depending on its characteristics, can be contaminated by almost any land use. In recent decades, governments have launched programs to acquire more information on groundwater, in order to better protect it. Nevertheless, the data produced are rarely adequate to be understood and used by land planners. The aim of this study was to develop a method that helps planners interpret hydrogeological data in the Province of Quebec, Canada. Based on the requests and needs of planners during semi-directed interviews, a methodology was developed to qualitatively evaluate groundwater contamination risk by land uses. The method combines land planning data and hydrogeological data through the MACBETH multicriteria analysis method, to obtain maps of groundwater contamination risk. The method was developed through group and individual meetings with numerous hydrogeology, land planning, water's economics and drinking water specialists. The resulting maps allow planners to understand the dynamics of groundwater within their territory, identify problem areas where groundwater is threatened and analyse the potential impact of planning scenarios on the risk of groundwater contamination.

RÉSUMÉ

L'eau souterraine est généralement d'une bonne qualité naturelle pour la consommation humaine. Elle représente donc une source essentielle d'eau potable pour plusieurs petites municipalités et individus qui n'ont pas les moyens financiers pour des installations de traitement de l'eau complexes. L'eau souterraine est toutefois une ressource vulnérable qui, dépendamment de ses caractéristiques, peut être contaminée par pratiquement n'importe quelle utilisation du sol. Dans les dernières décennies, plusieurs gouvernements ont lancé des programmes d'acquisition d'information sur les eaux souterraines, dans le but de mieux la protéger. Par contre, les données produites sont rarement adéquates pour être comprises et utilisées par des intervenants en aménagement du territoire. L'objectif de cette étude est de développer une méthode qui aide les aménagistes à interpréter les données hydrogéologiques. En se basant sur les demandes et les besoins d'intervenants évoqués lors d'une série d'entretiens semi-dirigés, une méthodologie pour évaluer qualitativement le risque de contamination de l'eau souterraine par les utilisations du sol a été développée. La méthode combine des données hydrogéologiques et des données d'aménagement du territoire, à l'aide de la méthode d'analyse multicritère MACBETH, pour obtenir des cartes du risque de contamination de l'eau souterraine. La méthode a été développée à l'aide de rencontres individuelles et de groupe avec de nombreux spécialistes de l'hydrogéologie, de l'aménagement du territoire, de l'économie de l'eau et de l'eau potable. Les cartes résultantes permettent entre autres

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aux intervenants en aménagement du territoire de comprendre les dynamiques de l'eau souterraine sur leur territoire, d'identifier les secteurs problématiques où l'eau souterraine est menacée et d'analyser l'impact potentiel de scénarios d'aménagement sur le risque de contamination de l'eau souterraine.

1. Introduction

Groundwater is naturally of good quality for human consumption. It often requires less treatment than surface water and is a vital source of drinking water. In Canada, small municipalities and individuals are particularly reliant on groundwater since they cannot afford complex water treatment installations. However, groundwater is also a vulnerable resource. Depending on the conditions, it can be contaminated by almost any land use. When groundwater quality is affected, devastating consequences can occur. For instance, in 2000, in Walkerton, Ontario, microbial contamination from manure spread on nearby agricultural lands seeped through the soil and reached the municipal well. This led to the death of seven people and made 2300 others sick (O'Connor, 2002). Along the US/Mexican border, incidences of waterborne diseases such as cholera, amoebiasis, hepatitis A and giardiasis have occurred because of inadequate solid waste treatment leading to contaminated groundwater (Kidd, 2002). Groundwater quality and quantity are also imperatives for agriculture and irrigation (Giordano, 2009; Siebert et al., 2010). Then again, groundwater is not only necessary for anthropogenic use, it is also crucial to ecological dynamics. Indeed, groundwater feeds wetlands, rivers and lakes, affecting base flow and leading to significant impacts on riparian habitats and species (Candela et al., 2009; Falke, 2009). Substances present in groundwater will reach such environments. Consequently, poor groundwater quality can lead to wetland eutrophication (Smolders et al., 2010) or changes in nutrient input in lakes (Sanders et al., 2011).

Given their awareness of these threats to groundwater and the significance of this resource, many provincial and state governments in North America have decided to produce more information on the resource for the purpose of protecting it. As of 2013, groundwater information is now available almost everywhere in Canada and the United States (Lavoie et al., 2013b). In Quebec, the Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs (MDDEFP) launched the *Projet d'acquisition des connaissances sur les eaux souterraines* (project for the acquisition of knowledge on groundwater, hereafter referred to as PACES) in 2008. Its purpose was to produce detailed groundwater atlases for the most densely populated southern portion of the province (MDDEFP, 2012). The first round of projects ended in 2013 and the second round should release their data in 2015. In land planning, the information from PACES should be taken into account in order to protect and preserve groundwater; for instance to direct land use development where the quantity of groundwater is deemed sufficient (Acker and Lynch, 2004; Idaho Department of Water Resources, 2009; Wehrmann and Knapp, 2006) or to develop strategies to prevent groundwater contamination through land use planning (Collin and Melloul, 2003, 2001; Giupponi et al., 1999a; Thomsen et al., 2004). The data available could be of great use to planners. However, it has been noted that in many North American states and provinces, there is a gap between the production of groundwater data and its use in planned decision making (Lavoie et al., 2013b). Several stakeholders are aware of this problem and are working on means such as guidelines (Jatel et al., 2009; New Hampshire Department of Environmental Services, 2008; U.S. Department of Agriculture, 2010) or aquifer classifications (Kreye et al., 2001; New Hampshire Department of Environmental Services, 2011) to fill the gap. Indeed, field surveys in 22 territories in the Province of Quebec, Canada, have shown that planners often lack the ability to understand and interpret the data. Moreover, there is a general lack of awareness of groundwater vulnerability, not only among planners, but also among the population, and the consequences of a shortage or contamination. It also appears that existing data had been poorly publicized. Atlases for two regions encompassing 103 municipalities and 11 regional county municipalities (RCMs are groups of municipalities) have been produced. One of the atlases was simply sent through mail and the other was launched at a press conference, but in both cases, there was no support for their use. Therefore, planners did not understand the data or what they were expected to do with it. Furthermore, there is confusion as to who is responsible for protecting the groundwater among planners from different organizations (municipalities, RCMs, provincial government and watershed organizations). Finally, convincing local politicians to take action to protect a resource that they believe is devoid of problems is proving to be a challenge (Lavoie et al., 2014).

Addressing the issues identified through the field surveys will require awareness campaigns, regulatory schemes and training (Lavoie et al., 2014). There is also a need for support for data interpretation. Many municipalities cannot afford to hire a hydrogeologist. Therefore, in their decision-making processes, planners need to be able to understand the data themselves and develop a global appreciation of the characteristics of groundwater within their territory. The main purposes of this research project is to develop a methodology to interpret and integrate hydrogeological data for land planning and to test it through two land use change simulation scenarios. More precisely, the project will serve to produce maps to ascertain the risk of groundwater contamination through land use. This methodology based on a multi-criteria approach will have an impact on several of the aforementioned obstacles. For example, it will help the planners better understand the dynamics of groundwater and facilitate the analysis and interpretation of data. It will also serve to produce maps that can be used to discuss with elected representatives or citizens the risks within their territory and the consequences of potential groundwater contamination. To our knowledge, after an exhaustive literature review, no other method or process allows planners to easily incorporate groundwater into their planning.

This study presents a new methodology for assessing the risk of groundwater contamination and two land use simulations to estimate land planning risks. Initially, preliminary steps in the development of this methodology will be presented: a survey was conducted in North America and semi-directed interviews took place in the Province of Quebec. Both studies served to draw a portrait of the current integration of groundwater into regional planning and gain a better idea of planners' concerns, competences, resources, needs and interest in groundwater. Then, some concepts associated with the assessment of groundwater contamination risks are presented. The proposed methodology will be explained and maps resulting from the land use scenarios will be analysed and discussed with regard to their helpfulness for land use decision-making purposes.