# An IDSS to identify and implement actions to protect drinking water sources in land use planning: Exploration and use of knowledge and past experiences

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**Abstract.** Protecting source water is an important step in maintaining high drinking water quality. This involves the implementation of various actions, on the territorial level, aimed at reducing the impact of anthropogenic activities on water sources. Acting on the territory involves many organizations with different goals and responsibilities resulting in knowledge fragmentation within a decision-making process. In this research summary, we describe a doctoral research project aimed at designing a knowledge-based decision support system (KB-DSS) using case-based reasoning (CBR), in the province of Quebec (Canada). The system is meant to recommend source water protection actions based on past experiences. It is divided into two phases: 1) knowledge acquisition and structuring; 2) technical design, implementation and testing of the KB-DSS. The knowledge gathering methodology consists of a mixed method approach using online surveys, interviews and focus groups. The structuring process uses concept maps and coding analysis in Nvivo to create a graph-based edition process.

**Keywords:** Source Water Protection, Land Use Planning, Knowledge-Based System, Decision Support System, CBR application.

## 1 Challenges in Implementing Source Water Protection

Various anthropogenic activities (land uses) such as agriculture, residential, manufacturing or electricity production can have environmental impacts on soil, water quality and quantity [1]. This calls for better land use planning [2] aimed at ensuring safe drinking water. In such a context, source water protection (SWP) is a fundamental part of a multi-barrier approach [3] and several countries have implemented it within their regulatory water management frameworks (e.g. the Source Water Assessment Plan from the State of New York [USA] in 1999, the European Water Framework Directive in 2000, etc.).

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Nonetheless, SWP in a land use planning perspective may face various challenges due to multi-scale, multi-stakeholder and multi-objective decision processes [4], where overlays of administrative boundaries do not always coincide with the drinking water catchment area (i.e. a watershed) [5], leading to complex water-related problems solving processes. A water-related problem can be defined as “an event representing a risk for a water source or a desire to prevent any risk.” Examples of such problems are “lack of water,” “eutrophication of a lake,” etc. Solutions are answers to a problem and are defined as “any action that aims at reducing the impacts of anthropogenic activities on the quality and / or quantity of water for environmental protection purposes.” Examples of actions are “construction of water retention ponds along highways,” “implementation of pesticide management plans” or “awareness campaign on water consumption.”

This discrepancy between boundaries has also contributed to the multiplication of actors [6], who produce a great diversity of unstructured, fragmented and often unshared knowledge [7]. For example, universities and research centers produces technical data, technologies or processes; watershed organizations are responsible for developing water master plans; regional offices and municipalities have legal legitimacy to act on the territory and produce technical documentation or data, etc. Nonetheless, this often redundant and dispersed knowledge is a key ingredient for identifying and implementing remedial or preventive actions.

In order to address SWP related challenges, a research project was defined where the objective is to design a knowledge-based system, using Case-Based Reasoning (CBR), that can facilitate knowledge sharing in Quebec (Canada). The following research questions were formulated: Who are the stakeholders? What knowledge is useful? Who produces it? How can we collectively learn from past experiences?

## 2 Gathering, Structuring and Sharing Source Water Protection-Related Knowledge

A decision process encompasses a set of activities that start with problem identification and may go beyond solution implementation [8]. It involves several phases of acquisition, reuse and creation of knowledge [9]. Although knowledge is a key element of decision-making, its overload can influence the quality of decisions made [10, 11] and one possible solution is to use a Decision Support System (DSS). A DSS may have five different types of focus: communications, data, documents, knowledge and models [12–14]. The problem addressed here calls for a knowledge-based system (KBS).

According to Liu et al. [15], there are four main KBS designs approach: Rule-Based Reasoning (RBR), Case-Based Reasoning (CBR), Network-Based Reasoning (NetBR) and Narrative-Based Reasoning (NBR). Since CBR approach can be easier to design, can avoid knowledge acquisition problems (e.g. the "knowledge acquisition bottleneck" such as knowledge inaccuracy [16]) and are ideal for problems that do not require an optimal solution and that are based mainly on human expertise, we have chosen to design a CBR-KBS [17]. As a technique that captures and reuses experimental knowledge, CBR has great potential for modeling decision-making in the selection of alternatives in a complex dynamic environment [18]. It is therefore a promising approach in a context such as ours, where no explicit rule can be easily extracted to build, for example, a rule-based system. In addition, the use of machine learning techniques is out of the question because of the nature of our problem and in the absence of large sets of data.

Three main types of CBR for case representation and reasoning can be found in the literature: structural, textual and conversational [19]. This project uses a mixed conversational CBR (CCBR) and structural CBR (SCBR) approach. According to Lamontagne and Lapalme [17], a CCBR system consists of three parts: 1) A problem P that textually describes the nature of the problem; 2) A series of QA questions and answers used to obtain more information about the problem, where each question has a weight representing its importance in similar cases identification; 3) An action A that is a textual description of the solution to be implemented. The "interaction" between the user and the system progressively defines the problem to be solved [20]. In this project, interaction is guided by a conditional branching questionnaire represented as a graph-based editing process. Such a process has the advantage of building a structured model while allowing for flexibility [21]. It uses both open-ended questions (text) and closed-ended questions (predefined answer set) to instantiate pre-defined attributes (SCBR logics) such as "the presence of water treatment plants", "regulatory protection zones" or "type of source water intake". Characterization of knowledge types [22] will also be used to structure the various knowledge sources within the case base (e.g. the water management plan as a Document, the geolocation of a private water supply facility as Data, etc.) as well as the stakeholder's category who is the knowledge creator.

Our knowledge acquisition phase is based on a sequential mixed-method approach (quantitative and qualitative), well adapted to complex and interdisciplinary problems [23]. It is similar to the interactive knowledge acquisition and modeling found in the CBR literature [20, 24] and follows the key steps of identification, conceptualization and codification [25]. Our first step was to conduct an online survey to identify: stakeholders involved in the protection of water sources (municipalities, regional authorities, private companies, citizens, watershed organizations, etc.); knowledge about water (documents, data, know-how, etc.) and past experiences. This survey was aimed at everyone (from government agents to citizens) who considered themselves involved in the implementation of SWP in Quebec. To date, more than 200 responses have been validated. A large number of interviewees (from regional or municipal offices) answered questions related to cases they have faced in recent years. The survey provided preliminary information on cases (for example, "water shortage"), geolocation of cases and the decision-making process used by stakeholders to find a solution. The information being incomplete, semi-directed interviews were subsequently conducted to better understand the cases. For example, some respondents wrote "water shortage" without context or cause. However, this could have been caused by different events such as drought or the construction of an upstream water dam. Each case being unique, we had to find a link between them. This led us to define some attributes based on the geo-socio-demographic situation (e.g. the population of the city, the presence of a municipal drinking water distribution network, etc.), the regulations around source water protection (e.g. protection zones, etc.) or the characteristics of the water supply (e.g. presence of a treatment plant, artesian wells, etc.).

Since the acquisition and structuring of cases is the main challenge in this project, the implementation of a KB-DSS is still in its infancy. The prototype will be developed using myCBR tool and will be accessible online to government stakeholders (e.g. municipalities) and watershed organizations. Adjusting the solutions and reusing them will be a challenge because the people who design solutions are not necessarily the ones who have the power to implement them.

## 3 Progress to Date

The knowledge acquisition and structuring process is ongoing. We have almost completed the questionnaire's data analysis that provides a snapshot of water protection-related knowledge in Quebec. We are currently conducting knowledge analysis and categorization using NVivo to produce conceptual maps. The first semi-directed interviews have been completed. These interviews allowed us to identify precise elements related to water protection. They contributed to the design of the first graph-based edition process identifying similar characteristics between the experiences.

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