Development of a knowledge base to support the consideration of groundwater protection in land-use planning

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Abstract
Groundwater is an essential resource for water supply, but it is vulnerable to the potential impacts of contaminant emissions from human activities. It is widely recognized that the effects of human activities on groundwater quality and quantity can be mitigated, in large part, by appropriate land-use planning because it plays a central role in groundwater protection and conservation. However, groundwater-related issues are not commonly considered in the land-use decision-making process. The main objective of this paper was to develop a decision-support system (DSS) to fill the gap between groundwater resources management, territorial development and the land-use institutional framework. To achieve this objective, it was necessary to establish a dialogue with decision makers to identify their needs. Then, by linking human activities and their related contaminants and impacts, it was possible to identify land-use planning actions that could support groundwater protection. This research resulted in a tool named "Base de connaissances – aménagement du territoire et eau souterraine" (BC-ATES) [Knowledge base – Land use planning and groundwater]. This tool was tested using Microsoft Access. It includes all the information identified as relevant by land-use planners in the decision process regarding groundwater needs.

Keywords
Land-use planning; groundwater management; decision-support system; knowledge/data base.

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1. Introduction

The use of groundwater resources for water supply is widespread. Compared to surface water, groundwater offers many advantages in terms of quality and quantity (Gleeson et al. 2010; Zektser et al. 2004). For example, groundwater supplies drinking water to more than 37% of the US population (estimated by Maupin et al. 2014) and more than 75% in Europe (European Union et al. 2008). In the province of Québec, Canada, 20% of the population depends on groundwater for their water supply (MDDELCC 2015). Furthermore, the use of groundwater resources is common for industrial activities and agriculture (Zektser et al. 2004).

However, groundwater faces many pressures from human activities (e.g., Changming et al. 2001; Custodio 2002; Gleeson et al. 2010; Trabelsi et al. 2005). Indeed, it is sensitive to overexploitation and vulnerable to potential contamination by surface activities (Granato and Smith 2002). Moreover, its regeneration capacity is slow and this aggravates the pollution impacts on a resource for which the assessment of quantity and quality is already complex and costly (Zektser et al. 2004). Thus, terrible consequences could occur when a groundwater supply is contaminated. One example in the province of Ontario (Canada) is the contamination of Walkerton's municipal groundwater supply by E. coli bacteria in May and June 2000. It was a public health disaster with 7 deaths and 2,300 people infected in a municipality with about 5,000 inhabitants (Driedger et al. 2014; Hrudey et al. 2002; Mullen et al. 2006; O'Connor, 2002). The economic impact of this tragedy was estimated at CDN $64.5 million (Livernois 2002; Vicente and Christoffersen 2006). Because the bacteria from agricultural activities were spread by floods, this example points to the need for better land-use planning to adequately protect groundwater upstream of its withdrawal.

Indeed, as early as 1991, UNESCO issued a warning regarding the decline in groundwater quality resulting from inadequate land-use planning (Vrba et al. 1991). Several authors demonstrated a causal link between human activities and the quality and quantity of groundwater, including case studies (Collin and Melloul 2001; Conacher 1994; Foster and Cherlet 2014; Foster 2001; Haase 2009; Hayashi et al. 2009; Lerner and Harris 2009; Onodera et al. 2008; Scanlon et al. 2005; Tang et al. 2005; US EPA 2013). Yet, the integration of groundwater into land-use decision making continues to lag behind in the province of Québec, Canada (Caron et al. 2016; Lavoie, 2013). The problem persists, despite the existence of a regional groundwater resources assessment program (*Programme d'acquisition de connaissances sur les eaux souterraines* [PACES]) that covered more than 75% of municipal land in Québec between 2009 and 2015 (MDDELCC 2015; RQES 2012). There are many reasons for this lack of integration of available data: inadequate human and financial resources; lack of cooperation between the water stakeholders; and, available hydrogeological data too technical and not adapted to the needs of land-use decision makers (Lavoie 2013). This echoes Armstrong's (1990) assertion that groundwater data have been collected on a large scale, but from a variety of independent sources and organized without links that could exist between them. Accordingly, these databases fail to answer the multidisciplinary problem of groundwater management and, *de facto,* are of little use to decision makers.

Thus, the current situation may be summarized as follows: there are available data on groundwater resources in Québec, a dynamic land-use framework exists, and groundwater supplies a large part of the population. The question that must then be asked is how might we interconnect the information to help land-use planners develop their territory while minimizing the potential risk of pollution of their main source of drinking water? The aim of this study was to develop a decision-support tool in a relational database management system (RDBMS) that could be applied to a multidisciplinary activity such as land-use planning and groundwater protection. The model introduced by Codd (1970) is still the standard in databases. It is a collection of logically connected data without redundancy (Gabillaud 2009) that allows the storage of data and links, but also the manipulation and interrogation of the data while ensuring their protection, backup and access (Akoka and Comyn-Wattiau 2001; Favennec 1998; Nguyen and Meier 2006; Ponniah 2003; Welling and Thomson 2009). These advantages appear to have been adapted, since land-use planners do not have the time to develop a database from scratch, but do have the time to modify and use a database in their daily practice.

2. Design

2.1. Description of the case study

This study is part of a research project undertaken in the Chaudière-Appalaches region located to the South of Quebec City (province of Québec, Canada), which deals with the integration of groundwater into land-use planning. Groundwater data in this region were derived from a regional groundwater resources assessment program (*Programme d'acquisition de connaissances sur les eaux souterraines* [PACES]) supported by the Government of Québec between 2009 and 2015, with projects in different areas carried out by universities (INRS in the case of Chaudière-Appalaches) in collaboration with regional water stakeholders. The purpose of this program was to provide a picture of groundwater resources across municipal land in Québec. Data were published in the PACES-Chaudière-Appalaches (PACES-CA) project report in March 2015 (see Lefebvre et al. 2015). This PACES project covered the entire Chaudière-Appalaches region (excluding the city of Lévis), an area of 15,601 km^2.

Figure 1: Maps of the Chaudière-Appalaches study area showing:(a) Topography represented by the digital elevation model (DEM) (Lefebvre et al. 2015, p.9); (b) regional rock aquifer confinement conditions (based on the nature and thickness of surficial sediments) (Lefebvre et al. 2015, p.92); (c) recharge of the regional rock aquifer (Lefebvre et al. 2015, p.108), (d) Vulnerability of the regional rock aquifer based on the DRASTIC index (Lefebvre et al. 2015, p.116)

The Chaudière-Appalaches region comprises three hydrogeological contexts: the St. Lawrence Lowlands, the Appalachian Valleys and the Appalachian Highlands. The topography of the area varies between 0 m to 1043 m (Figure 1a). The region is characterized by a continuous regional aquifer formed by naturally fractured rock and some local granular aquifers. Over most of the area, the regional rock aquifer is unconfined, but confined conditions are dominant in the St. Lawrence Lowlands (Figure 1b). The average annual recharge of the fractured rock aquifer is 166 mm/year (Figure 1c), with recharge far exceeding the groundwater exploitation rate, which is generally less than 10% of recharge except in some municipalities where it exceeds 20% in the St. Lawrence Lowland. The maximum DRASTIC vulnerability index (Aller et al. 1987) is between 160 and 180, which is considered as a medium to high vulnerability (Figure 1d). With a maximum of 168, the aquifers in the area does not reach a very high vulnerability. The most vulnerable areas are found where the aquifer is unconfined (Figure 1b) and has a high recharge (Figure 1c). Groundwater is also an important part of water supply in the region. Nearly 42% of the water used comes from groundwater and 32% of the population is supplied by private wells. Furthermore, nearly 60% of municipal systems are supplied by groundwater.

From an institutional and land-use planning perspective, the Chaudière-Appalaches region is made up of nine regional county municipalities (*Municipalité régionale de comté* [MRC]) comprising 135 municipalities with a total population of 278,234 inhabitants (MAMROT, 2016). The region is predominantly rural and farming occupies two thirds of the inhabited area (Services Québec, 2015). As part of this research, five MRC land-use planners (regional stakeholders) volunteered to participate in the development of the decision support tool (Table 1). Their interest in participating in this research stems mainly from the recent availability of groundwater data covering their region, but also from a lack of available tools to consider groundwater in land-use planning.

Table 1—Portrait of participating regional county municipalities (MRC). (Data: final report and deliverable 26B of PACES-CA, 2015; MAMROT, 2016).

Based on the methodological examples of Connolly and Begg (2005), Akoka and Comyn-Wattiau (2001), and some elements of Ponniah (2003), the design of the knowledge base was completed in three phases: conceptual, logical and physical. The main classes of the knowledge base were first developed, followed by secondary classes. Classes are data tables that group information categories (attributes) composed by data. For example, the class "Reference" is composed of attributes such as the name of the document used, the name of the organization that created the document and its year of publication. To identify this information, the participation of regional stakeholders was continuous and represents a benefit for this study. Indeed, the meetings with stakeholders made it possible to learn more about their relationship with groundwater resources found within their territory. Furthermore, the discussions also identified their needs and expectations in order to make the tool as functional as possible.

2.2. Conceptual design

2.2.1. Identifying the purpose of the tool and its potential uses

First, this study defined the basis of the tool (purpose and uses). Its purpose is to reduce the impact of human activities on groundwater through sustainable land-use planning (Figure 2).

Figure 2 - Dynamics considered to reduce the impact of human activities on groundwater resources through land-use planning

Then, three purposes for the tool were identified through exchanges with the participating regional stakeholders. Two of the purposes concern actions taken to prevent contamination; the third purpose is in response to a proven problem (Figure 3).

Prevention: If the regional or local authorities had projects and developments that they would like to implement within their territory, they would use the knowledge base to:

- Identify the activity that represents the lowest risk or the most tolerable potential impact on groundwater resources.
- Identify the measures to be implemented during the development of a project to reduce potential impacts on groundwater.

Reaction: If the regional or local authorities observed any degradation of groundwater quality (on infrastructure, in the environment, etc.), they would use the knowledge base to:

- Identify the probable sources of contamination by identifying activities releasing this type of contaminant.

Figure 3 – The purposes of the tool: Prevention and reaction illustrated by the example of vegetable farming

2.2.2. Identification of Primary, Secondary and Attribute Classes

After the identification of the purpose and uses of the tool, key elements emerged and were used to define the different classes of the tool. For example, the need for knowledge about the available action tools or the actors at the origin of the classes “Tool” and “Actor”. The identification process of the tool classes was achieved during individual meetings with participating regional stakeholders. This process was carried out from the inside out, starting with primary classes—considered as absolutely necessary by stakeholders—, followed by secondary classes—considered as interesting information—, and including the “PACES” classes that make a link between tool and the data from the governmental program (Figure 4). For validation, identified key elements were regrouped and sent by email to stakeholders. Through discussions and consensus between all stakeholders, primary and secondary class were thus validated.

Figure 4 — The twelve classes identified for the tool

The primary classes are:

- “Actor”: lists the actors who have the legal competence or who participate in the implementation of an action. These actors are government agencies and organizations, the population, but also private companies. The information comes from provincial laws and regulations, ministerial directives and examples of actions implemented by other regional or local stakeholders at the provincial scale.
- “Action”: lists actions that the land-use planner could implement to avoid or correct a case of contamination. These actions are identified through legislative sources, ministerial directives and planning documents at the provincial scale.
- “Activity”: identifies the activities present in the territory on the basis of the land-use code (*Code d’utilisation des biens-fonds,* CUBF) from Québec’s property assessment manual (*Manuel d’évaluation foncière du Québec* [MAMROT 2010a]) edited by the provincial government. This kind of property codification is the key to making this tool work. The CUBF takes the physical and economic inventory of the provincial territory by identifying its different uses (MAMROT 2010b). The CUBF has different degrees of accuracy from one to four digits. Each usage has a unique four-digit code. For example, the code CUBF 1542 corresponds to the use “orphanage” categorized in 154 “House of retreat and orphanage”, in Category 15 “dwelling in common”, all classified in the use Type 1 “residential”. In order for the tool to be adapted to day-to-day practices, meetings with land-use planners concluded that the four-digit CUBF code was the most accurate level of precision regarding human activities.
- “Impact”: identifies the potential impact of contaminants categorized by types of impacts (infrastructure, environment, human health, etc.). This information was identified through various sources, such as governmental health agencies or the scientific literature.
- “Contaminant”: identifies the main contaminants that can be found in groundwater. The data from PACES Protocol 23 are used to produce an index of the density of potentially groundwater-polluting human activities (Audet-Gagnon et al. 2013). The aim of this protocol is to assess the potential impact of anthropogenic activities in terms of the perceived risk on the quality of groundwater resources.
- “Tool”: lists the tools with which actions can be implemented, such as awareness raising, financial incentives and fines, planning documents and legal regulations. These tools were identified through the provincial legislation and examples of actions were based on other regional or local stakeholders at the provincial level.

Secondary classes are used mainly to add information. It is possible to subdivide the secondary classes into sub-classes resulting from PACES Protocol 23. The level of threat to groundwater quality represented by a CUBF activity is calculated according to PACES protocol 23 as follows: potential impact (class “Risk”) = (toxicity of contaminants [class “Toxicity”] + quantity of contaminants [class “Quantity”] + activity area of impact [Class “Zone”]) × recurrence of contaminant releases (class “Recurrence”) (Audet-Gagnon et al. 2013). The knowledge base does not allow users to calculate the risk. It serves only to integrate the information produced by the protocol to inform land-use planners. Secondary classes include:

- "Reference": lists examples of the implementation of actions and the legal documents used as a basis for the action. These are planning documents from regional and local land-use planners having implemented the same action, or a similar action. "Reference" also contains articles of law requiring the implementation of certain actions, or ministerial directives that advise on the implementation of these actions.
- "Toxicity": indicates the toxicity of contaminants associated with an activity. PACES Protocol 23 uses the toxicity classification of pure products listed in an information system for hazardous materials in workplaces (*Système d'information sur les matières dangereuses utilisées au Travail*, SIMDUT) developed by the provincial government. Pure products are classified under three sub-categories according to their quantity in the contaminant. For each of the three products, they are categorized as *nontoxic*, *toxic* or *very toxic*.
- "Quantity": indicates the quantity and concentration of contaminants associated with the activity. The quantity of contaminants can be *small*, *large*, or *very large*. Contaminant concentration may be *low*, *medium* or *high*.
- "Zone": refers to the potential impact area of the activity. It is subdivided into three spatial scales: *punctual* (10 m^2), *local* (100 m^2) and *regional* (1 km^2).
- "Recurrence": indicates the potential contamination of an activity over time. If the releases are systematic and related to the nature of the activity, they are considered as *recurrent*. In other cases, they are considered as *accidental*.
- "Risk": indicates the potential impact of each CUBF activity on the quality of groundwater. Activities are divided into four risk classes: *low*, *moderate*, *high*, *very high*.

Following the identification of the different classes that make up the knowledge base, the attributes of each class were defined (Appendix 1). Finally, the validation of the attributes within the classes was carried out with participating land-use planners through emails.

2.3. Logical design

During the logical design, the associations – link – and the multiplicity – how the elements are linked – between each class were identified. Figure 5 illustrates those elements using an example (vegetable farming). This phase was carried out in three parts to ensure better readability.

Figure 5: Associations ("Links") illustrated with the example of the activity "Vegetable Farming"

The purpose of the first part (non-illustrated in Figure 5) was to establish a link between the PACES and the activities inside the database. All the PACES classes are characterized by a *one-to-many* multiplicity with the class "Activity". For example, a degree of risk may involve several activities, but an activity can only be associated with a single degree of risk. A "Moderate risk" is associated with activities such as “Vegetable farming”, “Lumbering industry” or “Golf course”, but “Vegetable farming” is only associated with “Moderate” risk and not “Very High”, “High” or “Low” risk.

The purpose of the second part was to link the activities and the solutions (actions) through the causalities made by the contaminants. Each association between these classes is characterized by a *many-to-many* multiplicity. For example, “Vegetable farming” is associated with contaminants such as “Nitrate”, “Phosphate” or “Coliform and non-coliform bacteria”. “Nitrate” is also associated with other activities such as “Chalet or vacation house” or “Cereals, oilseed and leguminous plant crops”. The same logical process was repeated for each element to establish association and multiplicity between them.

The purpose of the third part was to link the solutions to the right tools and actors. Each association is characterized by a *many-to-many* multiplicity. For example, an action may be implemented by several tools and a tool can implement several actions.

Finally, the verification and validation of the links between classes were carried out with database professionals during dozens of meetings. The objective was to identify on paper the problems that could occur before implementing the concept in the database management system. Moreover, this step aimed to be sure about the logical construction of the concept.

2.4. Physical design

The physical design served to identify the type (numerical, textual, etc.) of each attribute. These elements are presented in Appendix 2. The knowledge base was validated during meetings with database experts to ensure that all the concept did not contain logical mistakes and to verify if the links between classes were well designed. Then the concept was implemented according to the model shown in Figure 6, which illustrates how the previously described blocks fit together.

Figure 6 – The BC-ATES physical implementation model

3. Application

Results of the design produced the “Base de connaissances – Aménagement du Territoire et Eau Souterraine” (BC-ATES) [Knowledge base – Land use planning and groundwater] decision support tool. To test the decision-support system, it was implemented in the Microsoft Access software.

3.1. The choice of data

During meetings, regional stakeholders were asked to identify the activities they would like to see in the knowledge base test (Table 2). Participants highlighted agricultural activity, which represents a large part of the land-use present within their territories. Then, other elements that could have an impact on groundwater in their territories were discussed, such as resorts, oil pipelines, industries, golfs, logging, and the road network. Thus, we can consider that these elements represent as many territorial realities as elements of concern for the regional stakeholders. According to the wishes of stakeholders, twelve activities were selected based on three criteria: the activity had to exist in at least two of the five regional county municipalities; the potential risk of the activity; and, its impact area. For the potential risk and the impact area, the selected activities had to be as heterogeneous as possible in order to provide a variety of scenarios to the knowledge base. The presence of the activities was noted through land-use planning documents and economic portraits of the region; the risk and the impact area were identified by PACES Protocol 23 as previously described.

Table 2 – The twelve activities selected for the BC-ATES test

Following the choice of activities, all the data were inserted sequentially for one activity at a time. For the 12 activities, it was possible to identify 24 actions, 16 actors, 33 contaminants, 25 impacts and 22 tools (Appendix 3).

3.2. Information Filtering

After implementing information inside the knowledge base, the first queries - a request for information from a database - revealed that the information had to be filtered. Indeed, to avoid inexact information in the results of the query, specific criteria (the filters) had to be added inside the query. For example, it is necessary to filter the information for activities releasing the same contaminating product and having the same impact in order to obtain the appropriate action to apply to the activity. For instance, the action of "Reduce the spread of de-icing salt" should not concern the activity "Vegetable farming". Thus, two filters must be inserted to correctly identify the Activity-Action and Activity-Actor combination (Figure 7). These filters may take many forms and can be inserted directly into coding. However, as part of this research, they were implemented in Microsoft Access by adding the "Code_CUBF" attribute in the "Action" and "Actor" classes. These attributes allowed to create associations between the classes and acted as filters. As a list of choices, this attribute retrieves the information from the "Activity" class and makes it possible to associate an activity with an action and an activity with an actor.

Figure 7 – Illustration of the use of query filters inside the tool.

3.3. Access to information

After formatting and implementing the knowledge base, access to information was put in place. After meetings with regional stakeholders, a form was developed within the knowledge base to gain access to the information (Appendix 4). The first version of the form consisted of drop-down lists and search fields, which only allowed the user to browse the information with no possibility to modify or creating data inside the knowledge base. Therefore, it could only be used to query information and minimize the risk of untimely changes made to the data.

In the first part of the form, in a fixed header, water stakeholders can quickly find general information about activities such as the code of the activity (attribute “Code_CUBF”), the category of the activity (attribute “Category_CUBF”), the name of the activity (attribute “Name_Activity”) and the level of risk linked to the activity (class “Risk_Codification”). Users can search for an activity by its code CUBF or by its name. Using a fixed header allows users to scroll down the page without losing sight of the activity to which the data relate.

Then, in the second part of the form, users have the final part of the general information about the activity such as the frequency of contaminant releases (attribute “Frequency_Name”) and the impact area of the activity (attribute “Name_Impact_Zone”). Two main tables are visible through sub-forms. First, the contaminants rejected by the activity and their impacts (class “Contaminant”). Inserted as a sub-sub-form, users have details regarding identified impacts (class “Impact”) for each contaminant. Then, another sub-form makes the synthesis of all the impacts (class “Impact”) linked to the activity.

Lastly, in the third part of the form, information about land-use planning actions and how to implement them are shown. The same process of sub-sub-form is reproduced as this process allows precise access to information. A sub-form listing the actions (class “Action”) is inserted, allowing users to have a clear and quick information about all the actions that can be implemented regarding the activity. Then, a first sub-sub-form indicates which tool (class “Tool”) is necessary to implement the action and, for each action, it is possible to consult the various tools available. Finally, the second sub-sub-form indicates the actor (class “Actor”) that is legally responsible or related to the tool necessary to implement the action.

Thanks to filtering, the information from the form, sub-form and sub-sub-form allows users to find the right actions to implement according to the activity sought. Moreover, when it comes to awareness, the actors are filtered according to their competence with regard to the activity.

4. Discussion

One of the most important issues in the development of BC-ATES was the identification of the most relevant stakeholder who might use the knowledge base. The choice was directed towards regional county municipalities (MRC) for three reasons. First, MRCs are at the crossroads between the ministries (who make the decisions) and the municipalities (which have most of water competencies). Secondly, the ministerial level is too far removed from local realities and the municipal level cannot act outside its administrative boundaries. Thirdly, municipalities would not have had sufficient financial and human resources to use such a tool. The second challenge was to identify the easiest tool that spatial planners could use. Relational database management systems (RDBMS) were chosen because they offer flexibility which, as part of this study, enables the effective link between information from the territory, the groundwater resources and the land-use institutional framework. Thus, land-use planners have quick access to the information they need concerning the potential impact of activities on groundwater. However, many limitations were identified.

The most important limitation of BC-ATES is the need to have a land-use planning institutional framework and a property codification, without which it would be impossible to adjust this tool. Another main limitation is the availability of groundwater data and the knowledge transfer of these data to land-use planners. Indeed, such a tool requires programs producing knowledge on groundwater resources that have been carried out previously. In Québec, the PACES has produced such knowledge in most regions, including the test region used to develop the tool. This implies a significant investment by governmental agencies. Moreover, even after obtaining the data on the resource, it is necessary to efficiently transfer the knowledge to water stakeholders who must exploit these complex hydrogeological data. In Québec, a groundwater knowledge transfer program was initiated in 2014. By 2018, it will have covered all regions where PACES projects have previously been carried out (RQES 2016). Another limitation is the need to continuously update the knowledge base. Indeed, the institutional framework is in constant evolution and the tool must be dynamic to be relevant in the long term. Thus, this implies that human resources must be allocated to update the tool. The last limitation regards aspects such as mentalities towards groundwater resources that are struggling to evolve or the lack of political will which hampers the use of such a tool. Indeed, protection and conservation of groundwater can be seen as a constraint on the development of municipalities, even though groundwater resources often represent an important part of their water supply.

Finally, the knowledge base could be enriched by the integration of economic components such as the cost of the actions and the quantification of the economic losses due to the pollution of the water resources. During meetings with the MRCs, the addition of an economic variable was requested in order to support action proposals presented to elected representatives. However, given the complexity of integrating economic components, it was proposed to integrate similar implementation examples offering an idea of the costs of an action. Furthermore, the association class linking the “Contaminant” and “Impact” classes could contain a “Reference” attribute that would allow the user to know where the information originates from.

5. Conclusion

The objective of this research was to develop a decision-making support tool to fill the gap between information about groundwater resources, territorial development and the institutional framework of land-use planning. To achieve this objective, three major methodological steps were followed to develop a decision support system. First, a conceptual design identified the purpose of the tool, its uses and the content of the primary classes, secondary classes and attributes. This was followed by a logical design to identify the associations and the multiplicity between each class. In other words, this stage made it possible to identify the links between the classes. Finally, a physical design identified the type of each attribute within the class. The result of this research is a tool known as "Base de connaissances – Aménagement du Territoire et Eau Souterraine" (BC-ATES) [Knowledge base – Land use planning and groundwater]. BC-ATES was tested using Microsoft Access software.

The development of BC-ATES would not have been possible without the participation of land-use planners from the Chaudière-Appalaches region. Indeed, as regional stakeholders, their participation was crucial to the conceptual design and different stages of validation. Thanks to their help, it was possible to adapt the tool as closely as possible to their land planning practices. Furthermore, the participation of database professionals resulted in the development of a user-friendly tool.

BC-ATES faces some limitations. Indeed, for the development of such a decision-making tool, a land-use planning framework is crucial, as is the existence of groundwater information. Furthermore, the tool must be updated continuously. This limitation is important because it involves identifying the organization responsible for these updates and setting aside the necessary resources to work on the updates. Finally, this type of tool can faces political and social obstacles, which would limit its usefulness.

Despite these limitations, BC-ATES is a promising tool because it integrates, in one location, a set of information that can help land-use planners to consider groundwater in their planning. Not only is BC-ATES making users aware of the source of groundwater contamination, but it also proposes solutions through actions that can be implemented in land-use planning to prevent or reduce contamination. Moreover, BC-ATES indicates the legal tool with which it would be possible to implement an action, as well as the actor having the legal competence to carry out the action. Therefore, this tool offers significant potential to help protect and conserve groundwater in the context of land-use planning.

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Table 1—Portrait of participating regional municipalities (MRC). (Data: final report and deliverable 26B of PACES-CA, 2015; MAMROT, 2016).

Name of the MRC	Number of municipalities	Population (2016)	Surface area (km^2)	Groundwater use (relative to total water use)
Appalaches	19	42 970	1912,38	47,8 %
L'Islet	14	18 320	2098,80	72,1 %
Lotbinière	18	31 266	1663,49	67,1 %
Montmagny	14	22 750	1692,84	39,1 %
Nouvelle-Beauce	11	37 037	904,78	31 %

Table 2 – The twelve activities selected for the BC-ATES test

CUBF codification	Name of the activity
1100	Cottage or vacation house
4510	Highways and streets
4855	Garbage dump
4880	Snow dump
5811	Restaurant and establishment with full service, without terrace
7412	Golf course, with chalet and other sports facilities
8121	Beef cattle breeding
8122	Dairy cattle breeding
8132	Cereal, oilseed and leguminous plant crops
8199	Vegetable farming
8311	Lumbering industry
8511	Iron ore mining

Figure 1 - ArcGIS / Adobe Indesign

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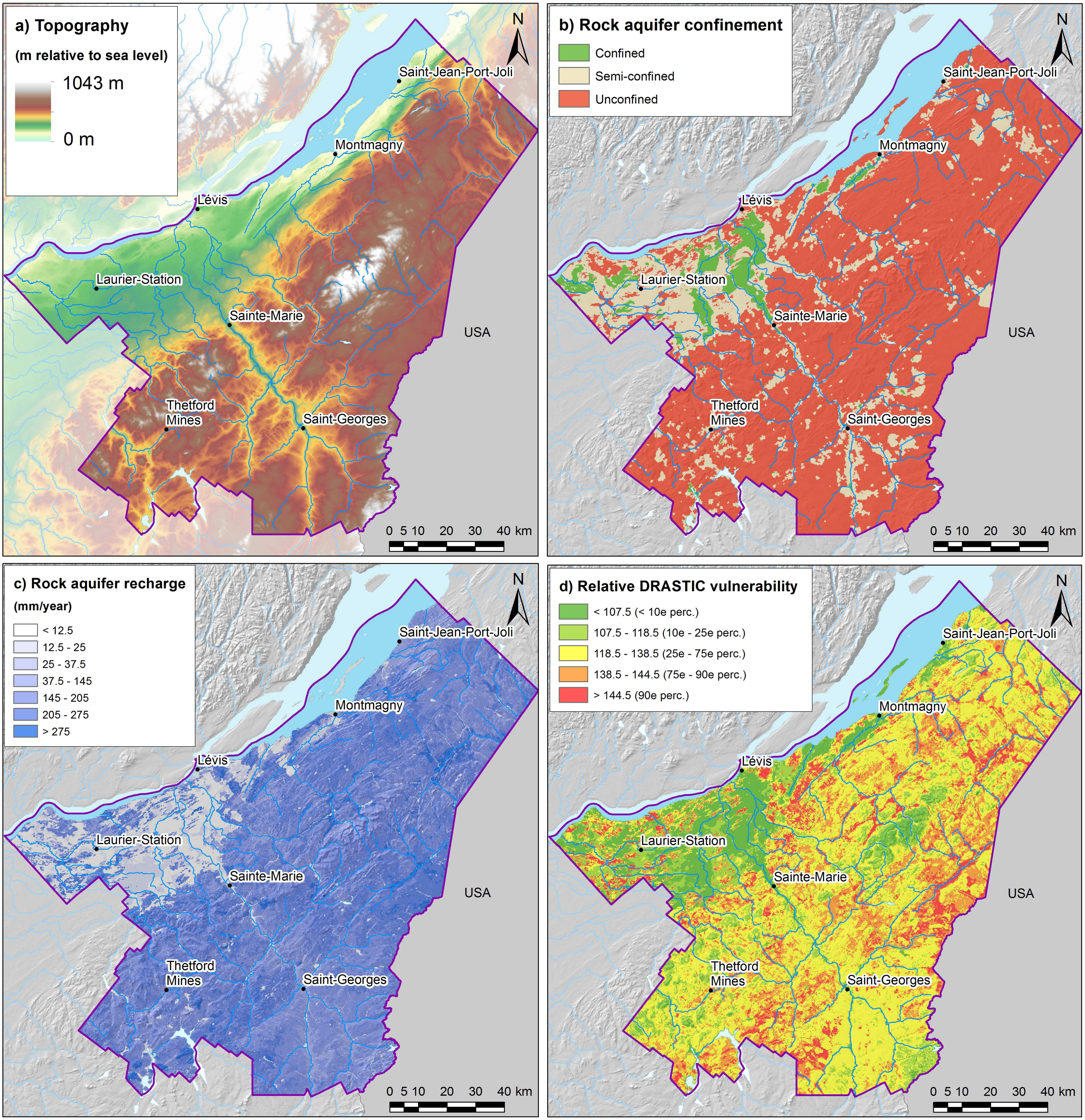

Figure 2 - Adobe Illustrator

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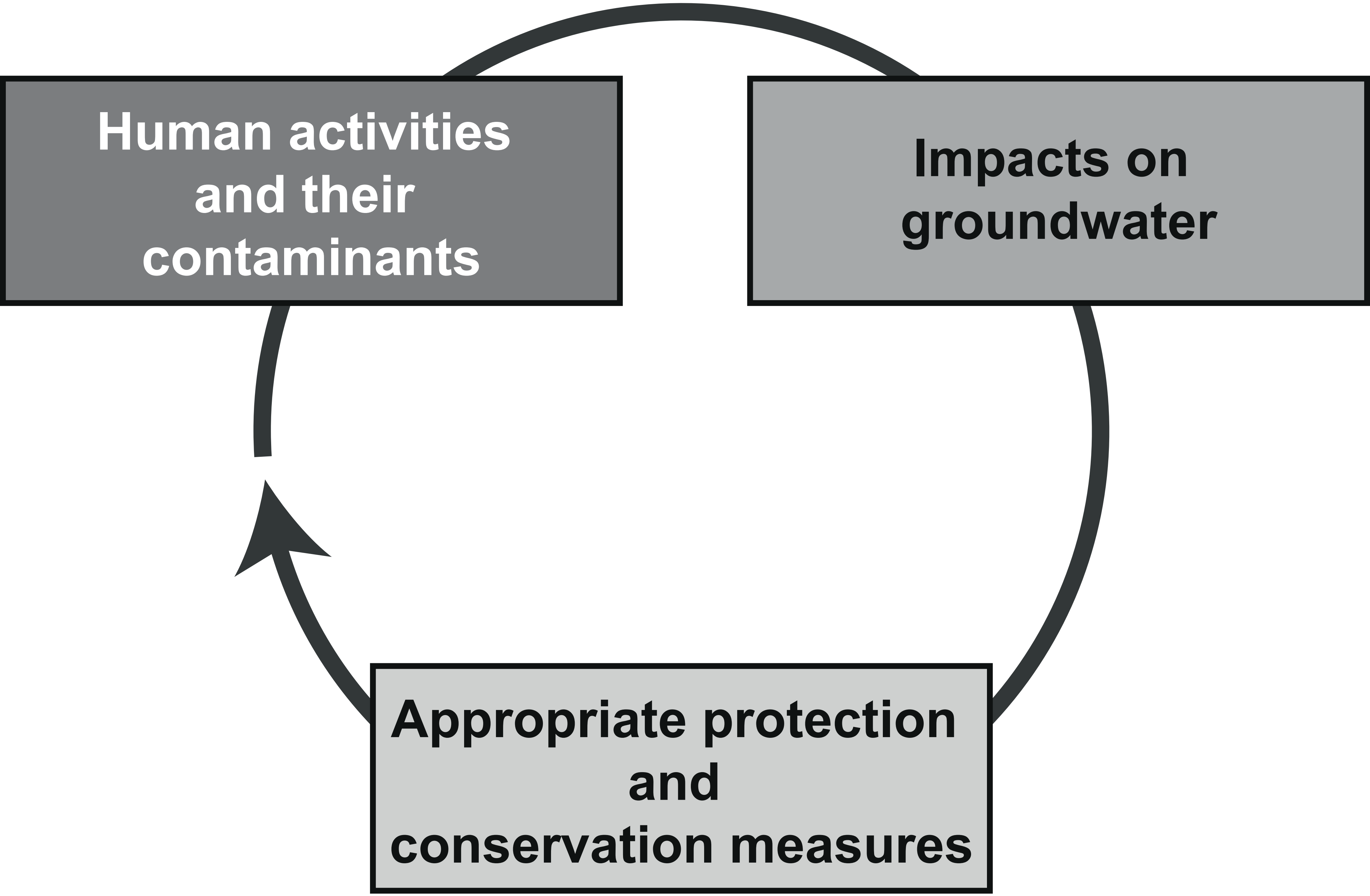

Figure 3 - Adobe Illustrator

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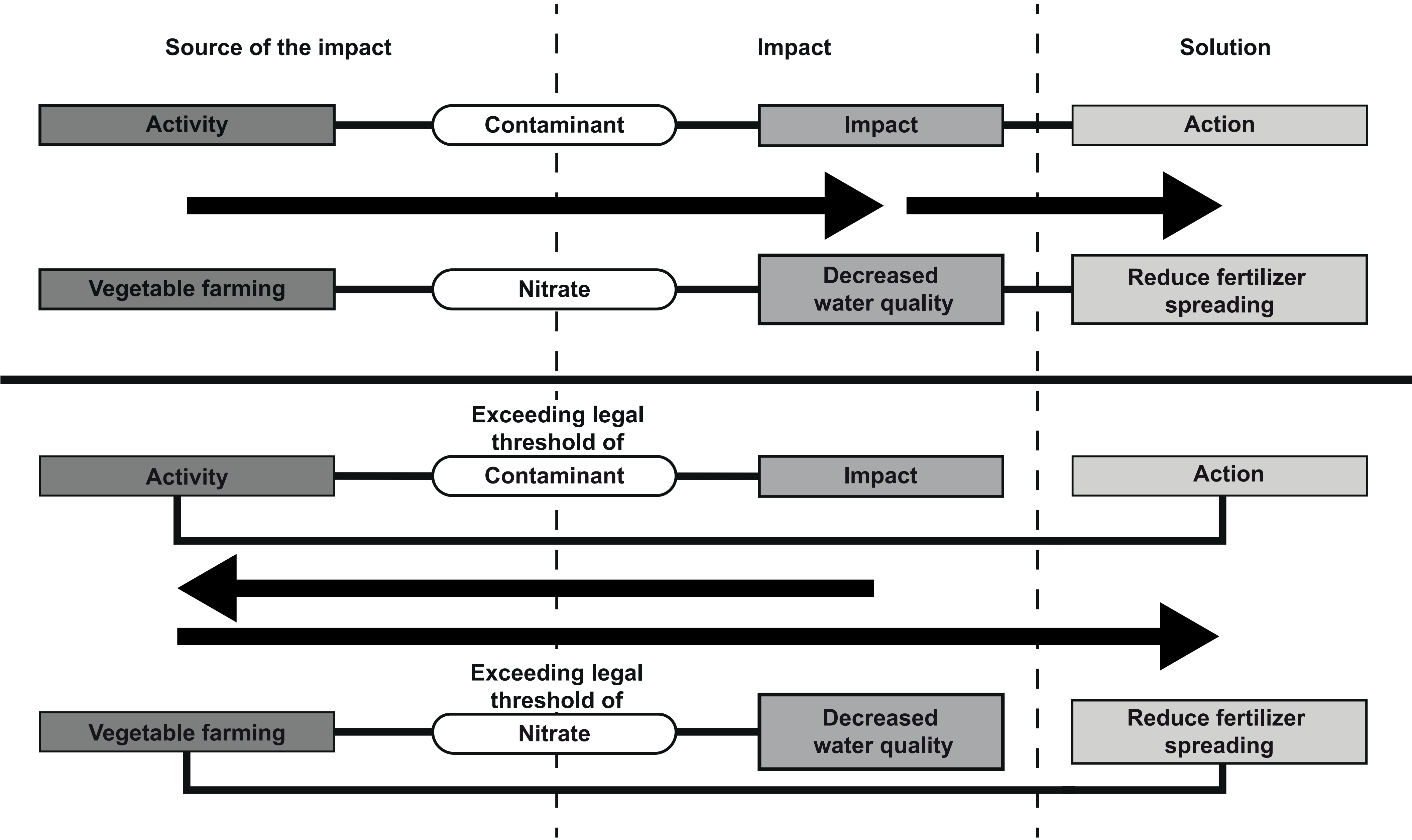

Figure 4 - Adobe Illustrator

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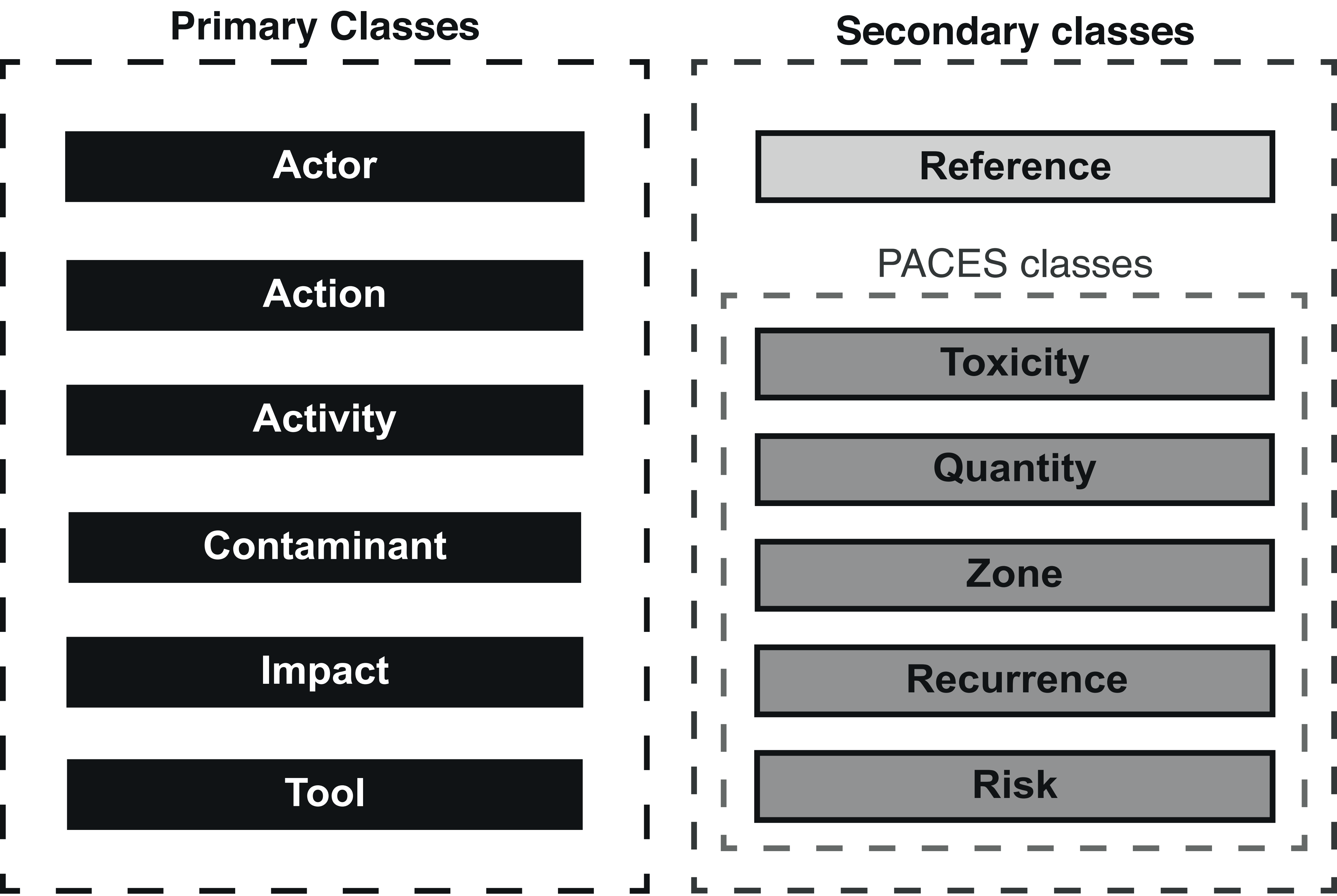

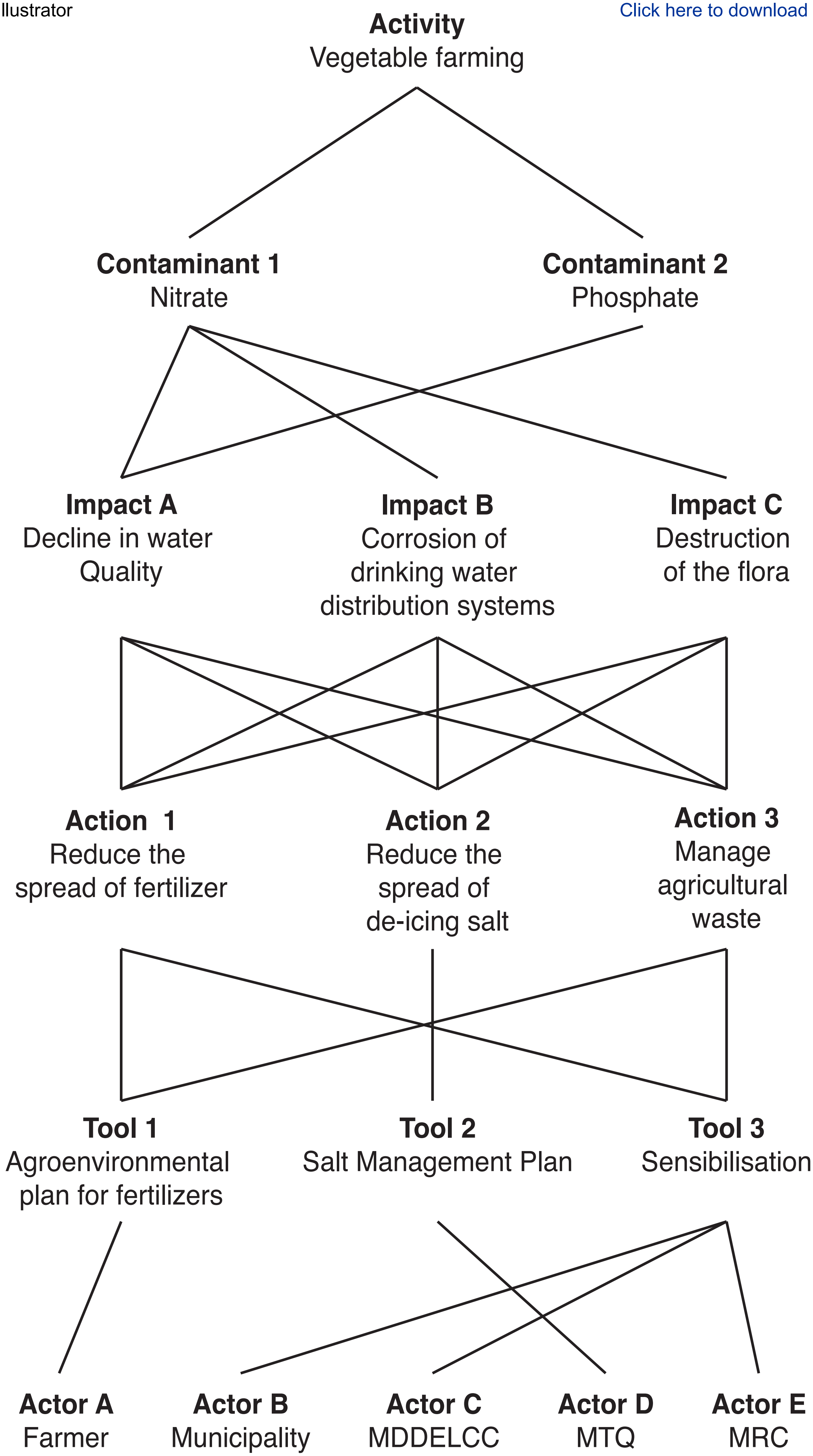
Activity
Vegetable farming
Contaminant 1
Nitrate
Contaminant 2
Phosphate
Impact A
Decline in water Quality
Impact B
Corrosion of drinking water distribution systems
Impact C
Destruction of the flora
Action 1
Reduce the spread of fertilizer
Action 2
Reduce the spread of de-icing salt
Action 3
Manage agricultural waste
Tool 1
Agroenvironmental plan for fertilizers
Tool 2
Salt Management Plan
Tool 3
Sensibilisation
Actor A
Farmer
Actor B
Municipality
Actor C
MDDELCC
Actor D
MTQ
Actor E
MRC

Figure 6 - Enterprise Architect

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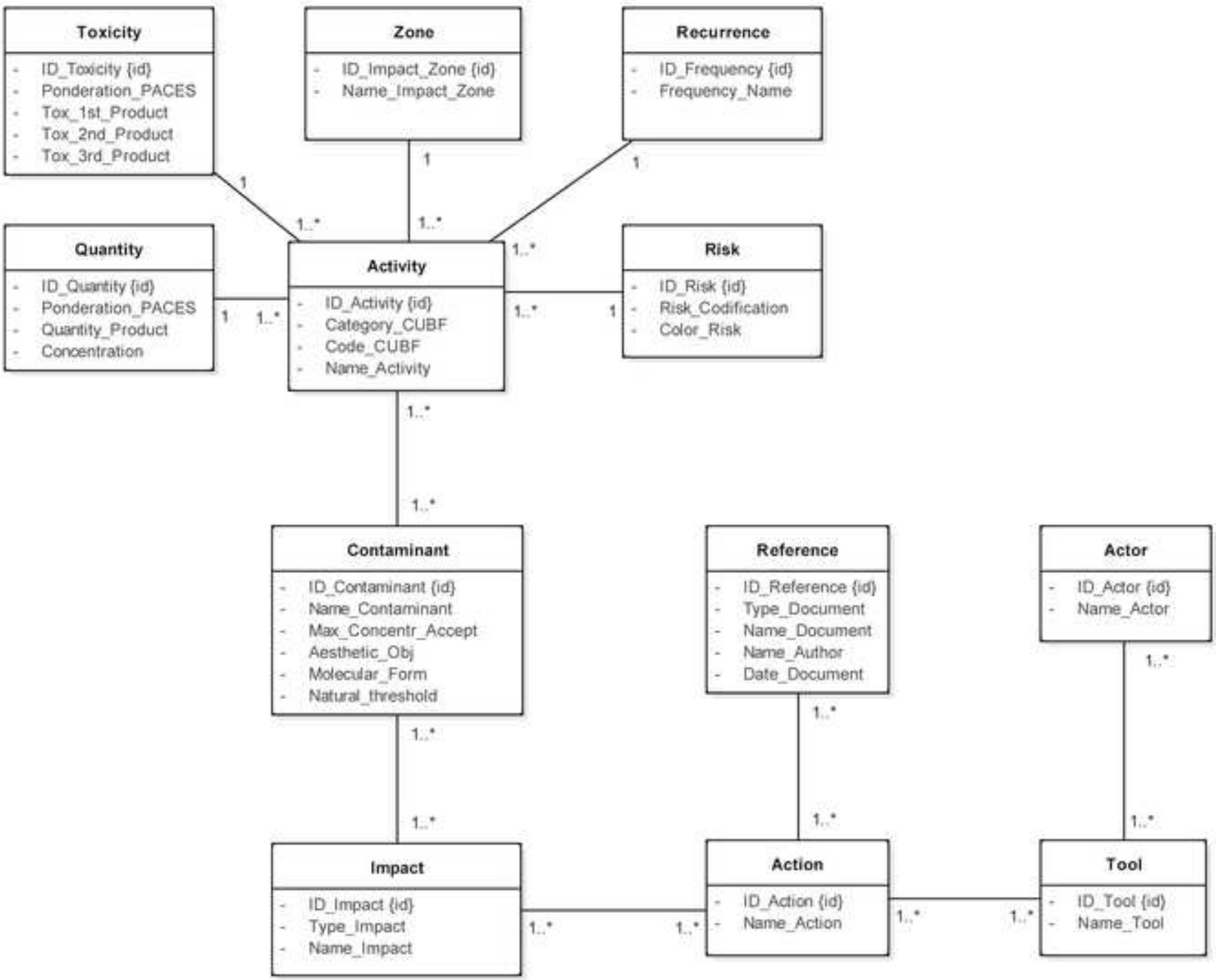

Figure 7 - Adobe Illustrator

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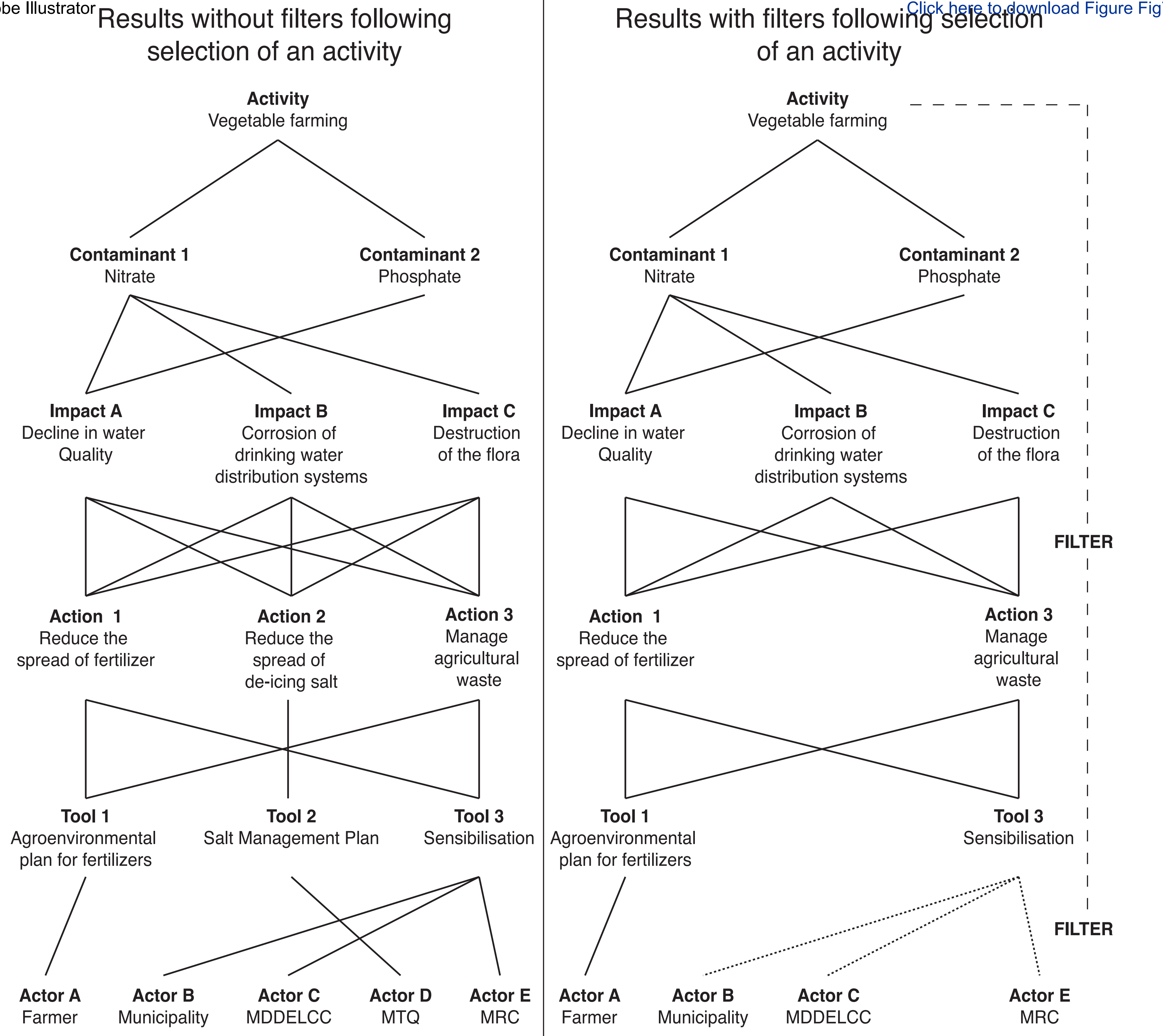

Actor	
Attribute	**Description**
ID_Actor	Number identifying the actor
Name_Actor	Name of the actor/stakeholder

Action	
Attribute	**Description**
ID_Action	Number identifying the action
Name_Action	Name of the action

Activity	
Attribute	**Description**
ID_Activity	Number identifying the activity
Category_CUBF	Name of the CUBF category
Code_CUBF	MEFQ code identifying the activity
Name_Activity	Name of the activity

Impact	
Attribute	**Description**
ID_Impact	Number identifying the impact
Type_Impact	Identify the type of the impact that could occur (environnemental, infrastructure, etc.)
Name_Impact	Name of the impact

Contaminant	
Attribute	**Description**
ID_Contaminant	Number identifying the contaminant
Name_Contaminant	Name of the contaminant
Max_Concentr_Accept	Indicates the maximum concentration of contaminant that is acceptable to be found in water as defined by current legislation
Aesthetic_Obj	Indicates the aesthetic indicators for water as defined by Health Canada
Molecular_Form	Identicates the molecular formula of the contaminant
Seuil_Naturel	Indicates the natural concentration of contaminant in water

Tool	
Attribute	**Description**
ID_Tool	Number identifying the tool
Name_Tool	Name of the tool

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Reference

Attribute	Description
ID_Reference	Number identifying the reference
Type_Document	Indicates the type of the document used as a reference (law, land-use planning document, etc.)
Name_Document	Name of the document in wich is proposed the action or a similar one
Name_Author	Name of the author (MRC, OBV, Municipalities, etc.) of the document used as a reference
Date_Document	Indicates the date of ratification or production of the document

Recurrence

Attribute	Description
ID_Frequency	Number identifying the frequency
Frequency_Name	Definition of the temporality

Quantity

Attribute	Description
ID_Quantity	Number identifying the quantity
Ponderation_PACES	Number linking the tool with PACES Protocol 23
Quantity_Product	Quantity of rejected contaminant
Concentration	Concentration of rejected contaminant

Risk

Attribute	Description
ID_Risk	Number identifying the risk
Codification_Risk	Degree of risk from *low* to *very high*
Color_Risk	Color related to a degree of risk

Toxicity

Attribute	Description
ID_Toxicity	Number identifying the toxicity
Ponderation_PACES	Number linking the tool with PACES Protocol 23
Tox_1st_Product	Toxic product in greater quantity in the contaminant
Tox_2nd_Product	Toxic product in medium quantity in the contaminant
Tox_3rd_Product	Toxic product in lowest amount in contaminant

Zone

Attribute	Description
ID_Impact_Zone	Number identifying the impact zone
Name_Impact_Zone	Indicates the impact area

Appendix 2 - Adobe Illustrator

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Actor

Attribute	Description
ID_Actor	Primary Key
Name_Actor	Text

Action

Attribute	Description
ID_Action	Primary Key
Name_Action	Text

Activity

Attribute	Description
ID_Activity	Primary Key
Category_CUBF	Text
Code_CUBF	Numerical
Name_Activity	Text

Impact

Attribute	Description
ID_Impact	Primary Key
Type_Impact	Text
Name_Impact	Text

Contaminant

Attribute	Description
ID_Contaminant	Primary Key
Name_Contaminant	Text
Max_Concentr_Accept	Text
Aesthetic_Obj	Text
Molecular_Form	Text
Seuil_Naturel	Text

Tool

Attribute	Description
ID_Tool	Primary Key
Name_Tool	Text

Reference

Attribute	Description
ID_Reference	Primary Key
Type_Document	Text
Name_Document	Text
Name_Author	Text
Date_Document	Date

Toxicity

Attribute	Description
ID_Toxicity	Primary Key
Ponderation_PACES	Numerical
Tox_1st_Product	Multiple Choice List
Tox_2nd_Product	Multiple Choice List
Tox_3rd_Product	Multiple Choice List

Quantity

Attribute	Description
ID_Quantity	Primary Key
Ponderation_PACES	Numerical
Quantity_Product	Text
Concentration	Multiple Choice List

Zone

Attribute	Description
ID_Impact_Zone	Primary Key
Name_Impact_Zone	Text

Recurrence

Attribute	Description
ID_Frequency	Primary Key
Frequency_Name	Text

Risk

Attribute	Description
ID_Risk	Primary Key
Codification_Risk	Text
Color_Risk	Text

Action name
Effective management of septic tank sludge
Encourage a sustainable land-use development
Ensure compliance with rules for storage of fertilizer / toxic products
Ensure compliance with various wastewater disposal regulations for isolated / unconnected residences
Ensure proper drainage of septic systems
Establish preservation areas to protect the most vulnerable areas and wetlands
Geolocation of individual septic systems
Identify strategic locations for snow deposits
Implement sustainable forest management
Integrate new developments within the municipal sewer system
Manage agricultural waste
Monitor lake water quality
Raise awareness about how to store, use and dispose of hazardous household waste
Raise awareness of good practices in the use of fertilizers
Raise public awareness of good practices in septic tank maintenance
Reduce fertilizer input in lakes and streams
Reduce the spread of de-icing salt
Reduce the spread of fertilizer
Reduce the spread of pesticides
Rehabilitate contaminated soils
Require raw material industries to periodically conduct soil quality surveys within harvested areas
Restoration of contaminated lakes and streams (mechanical, physical, chemical, biological)
Restore natural sites that have undergone a modification following an industrial activity
Set up flood barrier to retain and filter contaminated water

Actor name
Citizens
Commission de la Protection du Territoire Agricole du Québec (CPTAQ) [Commission for the Protection of Agricultural Land in Quebec]
Conseil régional de l'environnement (CRE) [Regional environmental council]
Eco-centers
Farmer
Ministère des Forêts, de la Faune et des Parcs (MFFP) [Ministry of Forests, Wildlife and Parks]
Ministère des transports du Québec (MTQ) [Quebec Ministry of Transportation]
Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC) [Quebec Environment Ministry]
Municipalités régionales de comté (MRC) [Regional county municipalities]
Municipalities
Non-profit organizations
Organismes de Bassins versant (OBV) [Watershed organizations]
Private organizations
Promoters
Public administrations
Resident associations

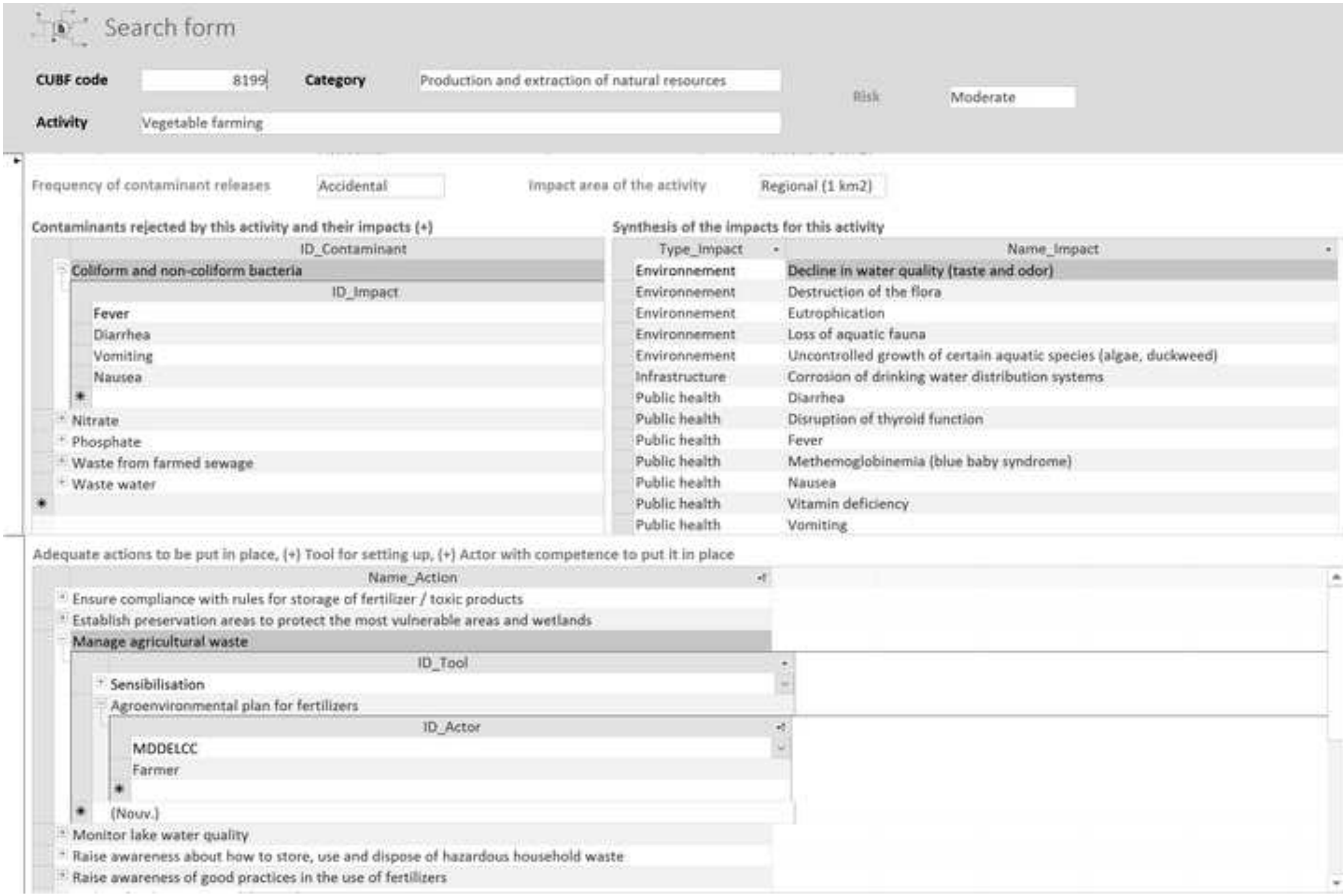
Contaminant name	
Anti-agglomeration additives (de-icing salts)	Sodium (de-icing salts)
Anticorrosive Additives	Sodium ferrocyanide (de-icing salts)
Bore	Soluble potash
Calcium chloride (de-icing salts)	Solvents
Chromium, chromate (de-icing salts)	Waste from farmed sewage
Coliform and non-coliform bacteria	Waste from households and businesses
Copper	Waste water
Ferric ferrocyanide (de-icing salts)	Zinc
Fertilizer	
Food oils	
Herbicides	
Highly corrosive acids	
Iron	
Lixiviate	
Manganese	
Metals	
Mineral and metal sulphides	
Mineralized Waters	
Molybdenum	
Nitrate	
Nitrogen	
Oils	
Organic and inorganic chemical contaminants	
Pesticides (especially against mosquitoes, ticks, ants) and other pesticides	
Phosphate	

Impact type	Impact name
Environment	Animal Infertility
Public health	Articulation pain and deformity
Public health	Cancer (all types)
Infrastructure	Corrosion of drinking water distribution systems
Infrastructure	Corrosion of road infrastructure
Material goods	Corrosion of vehicles
Environment	Decline in water quality (taste and odor)
Environment	Destruction of the flora
Public health	Diarrhea
Public health	Disruption of thyroid function
Public health	Effect on reproduction (testicular atrophy and spermatogenesis)
Environment	Eutrophication
Public health	Fever
Public health	Increased risk of cancer
Public health	Liver dysfunction
Environment	Loss of aquatic fauna
Public health	Methemoglobinemia (blue baby syndrome)
Public health	Nausea
Public health	Neurological complications
Infrastructure	Obstruction of drinking water distribution systems
Public health	Respiratory complications
Public health	Skin irritation
Environment	Uncontrolled growth of certain aquatic species (algae, duckweed)
Public health	Vitamin deficiency
Public health	Vomiting

Tool name
Agro environmental plan for fertilizers
Pesticide management code
Advice and expertise
Sustainable forest management Act
Protection of agricultural land and agricultural activities Act
Land-use development plan (Plan d'aménagement d'ensemble)
Implementation and architectural integration plan (Plan d'implantation et d'intégration architecturale)
Master plan (Plan d'urbanisme)
Environmental management plan for road salts (Plan de gestion environnementale des sels de voirie)
Special urban planning (Plan particulier d'urbanisme)
Soil Protection and Contaminated Land Reclamation Policy
City policy
Special projects for the construction, alteration or occupancy of a building
Regulation respecting municipal agreements
Zoning regulations
Sewage disposal and wastewater treatment regulations
Regulation respecting quarries and sand pits with respect to soil restoration
Snow removal site regulations
Municipal pesticide regulation
Voluntary lakes surveillance network
Land-use planning and development plan
Awareness raising

Appendix 4 - Microsoft Access

Click here to download Supplementary Material Appendix4.tif



Search form

CUBF code 8199 **Category** Production and extraction of natural resources

Risk Moderate

Activity Vegetable farming

Frequency of contaminant releases: Accidental

Impact area of the activity: Regional (1 km2)

Contaminants rejected by this activity and their impacts (+)

ID_Contaminant
Coliform and non-coliform bacteria
ID_Impact: Fever
ID_Impact: Diarrhea
ID_Impact: Vomiting
ID_Impact: Nausea
Nitrate
Phosphate
Waste from farmed sewage
Waste water

Synthesis of the impacts for this activity

Type_Impact	Name_Impact
Environnement	Decline in water quality (taste and odor)
Environnement	Destruction of the flora
Environnement	Eutrophication
Environnement	Loss of aquatic fauna
Environnement	Uncontrolled growth of certain aquatic species (algae, duckweed)
Infrastructure	Corrosion of drinking water distribution systems
Public health	Diarrhea
Public health	Disruption of thyroid function
Public health	Fever
Public health	Methemoglobinemia (blue baby syndrome)
Public health	Nausea
Public health	Vitamin deficiency
Public health	Vomiting

Adequate actions to be put in place, (+) Tool for setting up, (+) Actor with competence to put it in place

Name_Action
Ensure compliance with rules for storage of fertilizer / toxic products
Establish preservation areas to protect the most vulnerable areas and wetlands
Manage agricultural waste
ID_Tool: Sensibilisation
ID_Tool: Agroenvironmental plan for fertilizers
ID_Actor: MDDELCC
ID_Actor: Farmer
ID_Tool: (Nouv.)
Monitor lake water quality
Raise awareness about how to store, use and dispose of hazardous household waste
Raise awareness of good practices in the use of fertilizers