The Chilean approach to addressing uncertainty in environmental impact assessment related to groundwater

Patricio Walker Huyghe
patricio.walker@sma.gob.cl

Superintendencia del Medio Ambiente, Gobierno de Chile

Abstract

Environmental Impact Assessment (EIA) is a tool based on future predictions. These predictions are accompanied by an intrinsic uncertainty that cannot be ignored and needs to be explicitly incorporated into the assessment to manage the associated risks.

While this uncertainty is shared by different environmental components, some are more critical than others. This is the case of water, which is becoming scarcer while supporting several activities (mining, tourism, agriculture by native peoples, human consumption) that are constantly competing for its use. In particular, the predictions about the behavior of groundwater present a significant challenge since it involves complex mathematical modeling and furthermore must guarantee the protection of this important source of drinking water for the population. Meanwhile, its availability is also subject to events that can hardly be predicted accurately (such as Climate Change).

In Chile, while this uncertainty is not explicitly recognized, the law has provided a way to generally address it. Moreover, a specific strategy has been developed in practice that is widely used and accepted in Chile. This work presents the “Chilean approach” to address uncertainty in EIA related to groundwater. This may be an interesting case study to other countries.

1. Introduction

Chilean Law states that EIA should be conducted prior to the execution of the works involved in projects or activities. For the component "water", the Regulation states that (i) water quality should be assessed according to the current standards and that (ii) the availability (quantity) should be assessed regarding water table level fluctuations[1].

To carry out those predictions, modeling -which is considered worldwide as the best tool available for quantifying and predicting the behavior of groundwater- is used. However, groundwater modeling is a complex task and relies on complex meteorological, hydrological and geological environmental conditions influenced by human activities. In many cases data is scarce and many assumptions have to be made to put together all the information to create a conceptual model. This model is furthermore represented mathematically by a set of simplified equations that reproduces only a set of important processes and boundary conditions. Moreover, model predictions are supposed to match future groundwater behavior that is strongly affected by future

[1] Article 6 letter d and g, D.S. N°40/2013 Ministry of the Environment

scenarios that are likely to be different from past scenarios used in model calibration. Uncertainty in groundwater simulation is thus inevitable. As a matter of fact, "*all models contain uncertainty, no matter how much effort and expense has been brought to bear to have it be otherwise*" (Barnett et al, 2012).

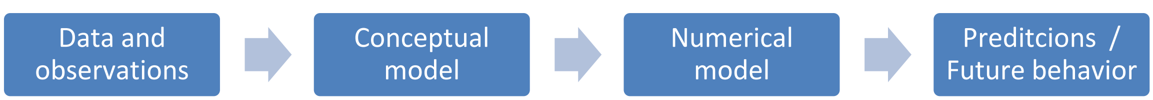
Nonetheless, without modeling, it is not possible to predict the behavior of groundwater systems, which is an essential input for decision making. And central to any decision making process is an assessment of risk. Such an assessment is impossible without some assessment of predictive uncertainty (Doherty et al, 2010).

In technical literature the uncertainty related to different parts of the modeling process and the various tools available to assess it has been extensively discussed (Wu and Zeng, 2013). Unfortunately this is a very complex and time consuming task when facing regional and/or complex systems. As the same authors point out, "*the uncertainty analysis of groundwater numerical simulation has received extensive research and attention, and produced a series of valuable achievements. Nevertheless, most research rests on theory analysis or simplified artificial cases, which are not enough powerful and reliable for practical application, such as the risk assessment of a contaminant site's remediation, water resources management of a watershed under global climate change, etc*".

2. Main sources of uncertainty in the process of groundwater modeling

The sources of uncertainty when modeling are several, and can be set according to different criteria depending on the author. We will use the main groundwater modeling steps (Hesch and Chmakov, 2011) (Figure 1) to broadly discuss how they are affected by uncertainty.

Figure N°1: Main groundwater modeling steps.



<u>Data and observations</u>: Usually, available data is limited both spatially and temporally. This can lead to errors when interpolating, extrapolating, defining and quantifying relevant system variables. There are also parameters that cannot be measured directly and are estimated, and others which are subject to scale effects.

<u>Conceptual model</u>: The conceptual model is a simplification of reality, and as such relies on a significant number of assumptions that allow a simpler interpretation of complex phenomena, keeping only its main elements.

<u>Numerical model</u>: The numerical model is a mathematical formulation of the elements set out in the conceptual model in order to establish a more accurate quantitative estimate of the state variables. In this step, calibration and definition of the model parameters is carried out, which represent an important source of uncertainty.

Future behavior: To evaluate the predictive performance of the model, the forecasted values have to be compared with the observed. This implies that success depends largely on the future behavior of the environmental variables, which is unknown and cannot be controlled.

There are many tools and scientific methodologies available to assess and reduce the uncertainty related to the first three steps. This is discussed in detail by Barnett et al (2012). The same authors even point out that "*given the many possible methods to estimate uncertainty, the best approach to estimate model uncertainty is itself uncertain*".

The uncertainty related to the fourth step is, by definition, impossible to evaluate. This needs to be tackled differently from the other three (for example, by adaptive management).

However, model uncertainty cannot be assessed by parts as each compartment is dependent on the rest. For example, the uncertainty introduced by the lack of data affects the way the system is understood and thus the resulting conceptual model, and then the predictions made by the subsequent numerical model. In each stage the uncertainty may be amplified. This is of particular importance in cases where the simulation period is much longer than the period of calibration, so relatively small errors in modeling can be highly magnified in the predictive simulations.

3. The Chilean approach

This section presents the practical approach used by many EIA practitioners in Chile to take into account the uncertainty and to mitigate risk.

As stated before, there are many available tools to assess and reduce the controllable sources of uncertainty. But this is a time consuming and complex task and may not be reliable enough for some practical applications. However, if predictive uncertainty is already taken into account through implementation of representative engineering safety factors, then use of a simpler approach may suffice (Doherty et al, 2010). This reveals a tradeoff between efforts made to assess uncertainty and the use of engineering safety factors (or other actions aimed to reduce risk).

The "Chilean approach" considers the use uncertainty assessment combined with safety factors and adaptive management. The objective is to keep the complex task of uncertainty assessment as simple as possible through the use of other simple and well known strategies to reduce risk. This rests on four elements which are applied in the following order:

I. Cost-effectively reduce the controllable sources of uncertainty
II. Make realistic predictions and consider a safety factor
III. Set corrective works and/or actions to keep the system within the range of predictions
IV. Modify the given permit to avoid or mitigate additional impacts

Unfortunately the Law and the EIA regulations in Chile do not describe the complete process for handling uncertainty. Some of the listed items are contained in different documents and others are not addressed by regulation but have been adopted in practice. More details of each one are presented in the following sections.

4. Uncertainty reduction

In general it can be accepted that a rigorous model built following the commonly accepted best practices is more likely to succeed. For this there is a Guide for the best practices as applied to the Chilean case (Servicio de Evaluación Ambiental, 2012). The Chilean Environmental Agency expects that the use of this document can contribute to generate more robust models and therefore less uncertainty in comparison to other models built with unknown standards and criteria.

The most challenging issue in Chile is the lack of baseline data. The northern regions of Chile have a dry climate and encompass the driest desert in the world. Water is extremely scarce and is present mainly as groundwater. The north is a very large and unpopulated area where much of the recent mining activity is concentrated, which needs large amounts of water for its processes. However, the lack of both space and time data in this area should not impede economic activity. To deal with this issue, modelers are required to use the best available data (if there is any) and also collect a minimum but sufficient amount of data to build a reasonable model[2].

The uncertainty related to the lack of data is usually compensated for in two ways. Firstly, by performing sensitivity analyses of relevant variables so that a range for the expected behavior of each one can be taken into account on the predictions. Secondly, by establishing a monitoring plan to obtain further information during the construction and execution of the project. The aim of the later is to generate new and valuable information to (i) verify the performance of the predictions made at the beginning and (ii) periodically update the model and its predictions, thus increasing the reliability of new predictions over time.

5. Realistic predictions and safety factor

The Regulation states that "*Where appropriate, the prediction and assessment of environmental impacts shall consider the state of the elements of the environment and the project or activity in its worst condition*"[3]. As permits are based on the results of modeling predictions, this allows keeping a safety factor. This can be seen in practice as a way to deal with some deviations from predictions without generating risks (they would be considered in the given permit).

6. Corrective works and/or actions

These actions are part of an instrument called the "Early Warning Plan"[4] which is not included in the Chilean Law nor in other regulations. It was in fact adopted by practitioners within the EIA. Because of its success it has been recently reviewed by regulators (Dirección General de Aguas, 2012) and incorporated into a Guide for best practices (Servicio de Evaluación Ambiental, 2012). This is the heart of the strategy to manage the risk.

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[2] The space and time extent of data depends on the characteristics of each project and location. Generally it is assumed that one year of data is the absolute minimum (Servicio de Evaluación Ambiental, 2012).
[3] Article 18 letter f, D.S. N°40/2013 Ministry of the Environment
[4] In Spanish “Plan de Alerta Temprana”

An "Early Warning Plan" includes the timely setup of works and/or actions aimed to prevent environmental impacts bigger than those predicted and accepted in the EIA. By these means the response of the system can be “corrected” if the real behavior is different from predictions. The basic elements of an "Early Warning Plan" are:

Key state variables: relevant parameters (eg. water level) in specific control points located between the stressor (eg. pumping wells) and the protected environmental object. Its monitoring is used to anticipate as much as possible the expected (and unexpected) impacts.

Decision criteria: a value of the key state variables that represents the limit of the predicted behavior for the system. If the value is exceeded it means that actual impacts are bigger than predicted. It is used to trigger the following corrective works and/or actions.

Corrective works and/or actions: These are often defined by the following three sequential steps: (i) strengthen monitoring and investigate the causes of the deviation, (ii) reduce the intensity of the activity that produces the impact (eg. reduce pumping.), (iii) take corrective actions to prevent the spread of the impact (eg. build a hydraulic barrier). The purpose is to avoid worse environmental impacts than those predicted and accepted in the EIA.

7. Modification of the given permit

Despite all the previous preventive and corrective mechanisms it is still possible that unpredicted effects can occur. This would mean that predictions failed significantly, which may be due to various causes. For these circumstances, the Chilean Law recognizes that predictions can always fail and provides a way to modify the given permit[5]. The purpose of the modifications is explicitly defined and aims to take all necessary actions to avoid (if still possible) or mitigate environmental impacts beyond former predictions.

Conclusions

In Chile, a specific strategy to deal with uncertainty in EIA related to groundwater has been developed in practice. This strategy is widely used and accepted, and relies on a practice-oriented way to assess uncertainty combined with other simple and well known strategies to reduce risk. The key recommendations that arise from this approach are the following:

- Models should be built following the commonly accepted best practices, or at least be based on known standards and criteria.
- Keeping reasonable safety factors is a valuable and simple way to reduce risk.
- When lacking data, good monitoring is essential to update the model and increase the reliability of new predictions over time.
- Use adaptive management with early action triggers to correct deviations and minimize risk.

This approach may be an interesting case study to other countries.

[5] Article 25 quinquies, Law N°19.300

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