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Probabilistic Estimation of CO_2 Surface Leakage from Abandoned Wells Using Analytic Models

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Integrated risk assessment for carbon sequestration projects is at an early stage. Protocols for risk assessment are an active area of research and are currently being developed by government research organizations and private organizations worldwide. Integrated risk is concerned with estimating the probability of health, safety and environmental (HSE), and financial consequences arising from leakage of CO_2 from an underground storage reservoir, primarily though not exclusively, to the surface. HSE risk end-points include humans, animals, biota, agriculture and groundwater. Financial risk end-points include security of capital investment, eligibility for carbon crediting and underwriting of long term liabilities.

Integrated risk assessments for the oil and gas, and chemical process industries are well established. They utilize cause-consequence analysis in which the probability of adverse consequences, such as a human exposed to thermal radiation from a pool fire, is estimated. In the case of a pipeline, the primary hazard event is a pipeline leak or rupture (spill). Historical data on pipeline spill distributions are readily available and date back over 30 years. In the case of carbon storage systems, historical surface leakage data do not exist. Therefore, surface leakage rates (the primary hazard event) must be estimated using probabilistic models.

This paper is concerned with the Wabamun Area Sequestration Project (WASP) which is a feasibility study for investigating the potential for 1GT of CO_2 storage in the Wabamun area, located southwest of Edmonton, Alberta (see the paper by Jensen and Eisinger at this conference for additional details on WASP). The target formation for a CO_2 reservoir is the Nisku formation located approximately 1800 m below the surface. The Wabamun area is an active oil and gas producing area and therefore there are many abandoned or active wells in proximity to potential storage sites. A total of 18 abandoned wells penetrate the Nisku formation in an area close to a possible injection site whereas over 100 abandoned wells penetrate the Banff formation in the same area, which is approximately 200 m above the Nisku and protected by two layers of cap rock. Although leakage from the Banff formation is expected to be lower because of its geologic isolation, nevertheless it is important to estimate the risk of leakage from this formation because of the large number of nearby penetrations. In this paper we estimate the leakage rate for two abandoned wells: one penetrating the Nisku and one penetrating the Banff formation to obtain a measure of the relative leakage risk. The importance of leakage through abandoned wells to the surface was established through a risk workshop involving WASP team members from both academia and industry.

Analytic Models

Analytic models have been developed for estimating surface leakage of gases through abandoned wells from an underground storage reservoir by Norbotten, Celia and Bachu (NCB) in a series of papers over the past 5 years. Applications of leakage estimation include both CO_2 sequestration and acid gas injection. The starting point for predicting surface leakage is first to estimate CO_2 pressure in the storage formation after the onset of injection at a specific radial distance from the injection site.

The case of one injection well penetrating the Nisku formation and two abandoned wells, penetrating the Nisku and Banff formation respectively is shown for the WASP situation in Figure 1. The NCB equations for this case can be easily solved in closed form for the 2 abandoned well leakage rates for WASP.

Probabilistic Modelling

Although we have obtained analytic expressions for abandoned well leakage rates using the NCB model approach, in practice this is insufficient for developing a predictive tool for risk assessment because many of the input parameters are uncertain and therefore cannot be represented deterministically. As per the methods of quantitative risk assessment, uncertain parameters can be represented as probability distributions. Sources of uncertainty are three-fold: first there is natural variability in such parameters as formation thickness and permeability at different points in the reservoir formation. In addition, there is so-called epistemic uncertainty arising from our lack of knowledge about input parameters to the model. Finally, there is modelling uncertainty arising from the simplifying assumptions made in the analytic model.

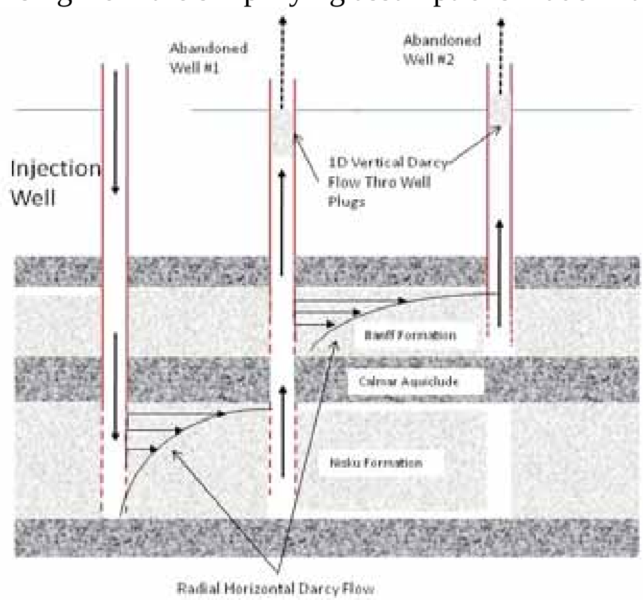

Figure 1. Schematic for WASP project showing 1 injection well and 2 abandoned wells

Because the input data associated with the analytic model for leakage are probabilistic, the leakage rates themselves become probabilistic and therefore are computed using Monte Carlo simulation. The NCB model forms the backbone of the Monte Carlo simulation and because it is algebraic, the 1,000's of Monte Carlo realizations needed to construct the probability distributions for wellbore leakage can be readily computed on a PC. Figure 2 shows a sample probabilistic annual leakage rate as a percentage of the injection rate for an abandoned well penetrating the Nisku formation for constant injection rate at a distance of 10 km from the injection site using the GoldSim dynamic simulation environment. Note that the NCB model predicts leakage rates to be in the form of a "smoothed" step function for constant injection rate.

Results to be presented at the conference will demonstrate that expected leakage from the Nisku storage formation to the surface via a single abandoned well is low compared with the injection rate. They will also show that expected leakage via two abandoned wells in series from the Nisku formation to the shallower Banff formation and thence to the surface is even less.

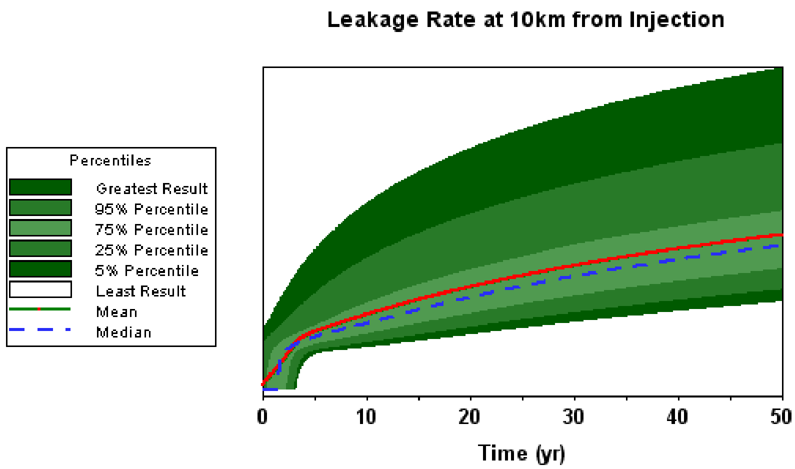

Figure 2 Percentiles of Leakage Rates for an Abandoned Well Penetrating the Nisku

In conclusion, analytic formulas were developed for the case of one injection well and two abandoned wells penetrating different geologic formations using the NCB method. The method can be extended to predicting leakage rates for many abandoned wells penetrating a few geologic formations using a numerical method to solve the NCB equations. NCB have extended their approach to account for two phase flow (CO_2 and brine). Further work may include extending the probabilistic modelling to include additional well penetrations and other leakage pathways such as faults, fractures and spill points. Such a comprehensive leakage model could form the basis for a fully quantitative and integrated risk assessment of geologic sequestration systems to address regulatory requirements, financial underwriting and engineering decision-making.

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