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Prototype Near-Field/GIS Model for Sequestered-CO2 Risk Characterization and Management

K. T. Bogen, S. G. Homann, F. J. Gouveia, L. A. Neher

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PROTOTYPE NEAR-FIELD/GIS MODEL FOR SEQUESTERED-CO_2 RISK CHARACTERIZATION AND MANAGEMENT

Kenneth T. Bogen, Steven G. Homann, Frank J. Gouveia, and Lee A. Neher

University of California, Lawrence Livermore National Laboratory
Energy and Environment Directorate (Bogen L-396)
Livermore, CA 94550-9900 USA
e-mail: bogen@LLNL.gov

INTRODUCTION

Detecting unmapped abandoned wells thus remains a major carbon sequestration (CS) technology gap. Many ($>10^5$) abandoned wells are thought to lie in potential sequestration sites. For such wells, risk analysis to date has focused on aggregate long-term future impacts of seepage at rates < or << ~1 g m^2 d^{-1} on storage goals as sequestered plumes encroach upon wells with assumed distributions of seal ineffectiveness (Oldenburg and Unger, 2003; Saripali *et al.* 2003; Celia, 2005). However, unmapped abandoned wells include an unknown number without any effective seal at all, venting through which may dominate CO_2-loss scenarios. A model of such a well is Crystal Geyser (CG), a prospective oil well abandoned in the 1930s with no barrier installed after it encountered a natural CO_2 reservoir rather than oil (Baer and Rigby, 1978; Rinehart, 1980). CG demonstrates how an unimpeded conduit to the surface now regularly vents from 10^3 to $>10^4$ kg of CO_2 gas to the terrestrial surface (Figure 1). Unique field data recently gathered from Crystal Geyser (CG) in Utah (Gouveia *et al*. 2005) confirm that, although resulting surface CO_2 concentrations resulting from CG-like eruptions would likely be safe in general, they could accumulate to pose lethal hazards under relatively rare meteorological and topographic (MT) conditions. This source of foreseeable risk needs to be managed if carbon sequestration is to be publicly accepted. To address this concern, we used CG field data to estimate the source term for a prototype model that identifies zones at relatively highly elevated risk for sequestered-CO_2 casualties. Such a model could be applied both to design and comply with future regulatory requirements to survey high-risk zones in each proposed sequestration site for improperly sealed wells.

DISPERSION MODEL

Basin topographies seriously limit turbulent mixing because they shelter the basin atmosphere from external winds, and because they enhance stable stratification through drainage flows and cold pool formation (Whiteman *et al*., 2004). Basin and valley atmospheres are very poorly understood, partly because of deficiencies in model parameterizations, in particular for representing turbulence under stable stratification. Analysis of CG data disproved prior claims that eruptions were ≤12 h apart based on local anecdotal accounts (Shipton *et al.*, 2005), and instead indicates that after a CO_2 plume reaches an unimpeded well, an eruption of up to 40,000 kg CO_2 over a 2-h period could occur every 24-48 h. Accurate frequency monitoring EPIcode® Version 7.0 (a U.S. Department of Energy approved "Tool-box" Gaussian dispersion code, Homann Associates, Inc., www.epicode.com) was thus adapted to model this size CO_2 release, using realistic assumptions for a dense gas at wind speed (and wind direction variation) values ranging from 0.1 m/s ($\sigma_\theta = 25°$) to 5 m/s ($\sigma_\theta = 15°$), to assess the impact of basic terrain constraints on predicted downwind distance of potentially lethal ambient 5-min CO_2 concentrations (≥5% at a 1-m height). Results obtained indicate that potentially lethal hazards may arise for nearby prone individuals under low-wind conditions (e.g., campers sleeping at night), particularly if wellhead occlusion were to eliminate most or all vertical gas momentum and if the local terrain were to have basin-like features (Figure 2).

***Figure 1.** Crystal Geyser erupting.*

GIS TERRAIN-SPECIFIC RISK MODEL

An ArcGIS® 9.0 software (ESRI, Redlands, CA) program was developed to identify nearly flat basin-like terrain areas likely to present the greatest potential likelihood of serious hazard in the event of CO_2 release (Figure 3). Potentially hazardous areas

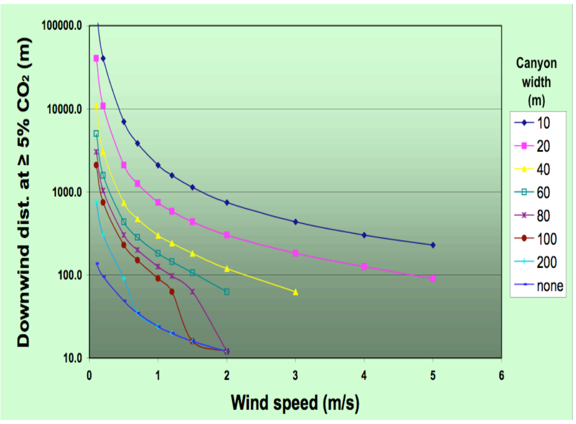

Figure 2. *Downwind distance predicted to incur potentially lethal CO_2 concentrations after a 40,000-kg release over 2 hours.*

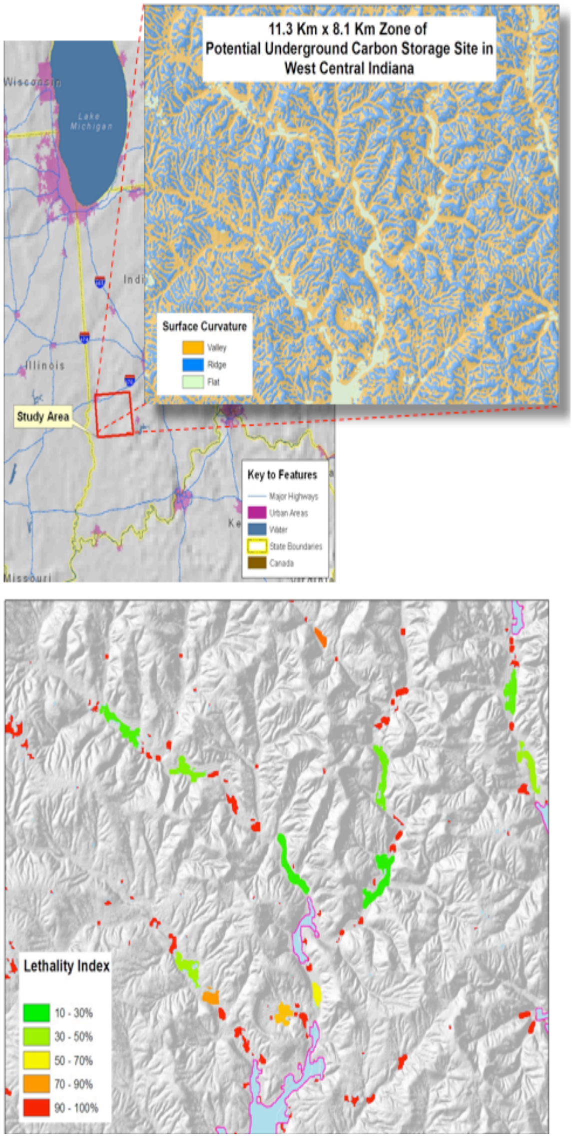

Figure 3. *In a study area in a proposed west-central Indiana CS site (top), our GIS algorithm was used first to define surface curvature (top), identify corresponding potential CO_2 hazard areas (bottom, all colored zones), and finally classify these areas by lethality potential (bottom, key colors). E.g., red areas would be 100% lethal at height ≤1 m if the modeled source term were contained. A subset of the study area is shown above.*

identified by the GIS algorithm can then be ranked by relative lethality risk using, wind-speed and terrain-specific lethal-range information like that summarized in Figure 2. The GIS/MT risk-indexing algorithm was applied to characterize CO_2 risk using local topographic data for a 63-by-55 km study area (Figure 3, top) in a proposed west-central Indiana CS site where Mt. Simon Sandstone is 1700 m deep, is 350 m thick, and is covered by 260-m thick caprock (Gupta *et al*., 2004). For the sake of this illustration, 1-m/s cañon-parallel winds were assumed. In this Indiana CS-site application of our protype GIS/MT algorithm, the area of concern (defined by >50% lethality likelihood) was reduced from 3,469 km^2 (100%) to just 119 km^2 (3.1%), implying an approximate 30-fold gain in the cost-effectiveness of surveying the site for seriously compromised or unsealed wells. Hazard predictivity attained by this method can readily be enhanced by incorporating more detailed MT data addressing local variation in slope, wind direction and forestation.

CONCLUSIONS

The prototype GIS/MT risk-indexing approach developed demonstrates a method to identify subzones within much larger (≥100-km^2) regions considered for potential CO_2 sequestration that are at relatively high risk, conditional on both CO_2 efflux and simultaneous incidental occupation. This approach will greatly enhance the efficiency of detailed surveys for ineffectively sealed wells, by allowing the greatest survey resources to be focused on those subzones identified as harboring the greatest potential risk, analogous to a system previously developed to assess the potential air quality and visibility degradation caused by wildfires (Ferguson *et al*., 2003), which could take into account local wind speed, forestation and topographic data.

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