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A Practical Workflow of Stochastic Simulations For Fast-Track CCS Development

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Agenda

- Introduction
- Overall workflow for the uncertainty study
- Stochastic simulation results
  - Probabilistic S-curves
  - Probabilistic CO2 plume map
  - Probabilistic CO2 plume migration
- Summary

Introduction

Project	The Bonaparte CCS project
Permit	G-7-AP
Award Year	2022
Area	~ 27,550 km^2
CO_2 Sequestration	Saline Aquifer
Joint Venture	Inpex Corporation (Operator): 53% TotalEnergies: 26% Woodside Energy: 21%

- **The purpose of this paper is to demonstrate how subsurface risk and uncertainties are captured and managed prior to obtaining data from a planned appraisal program.**

Source:
Inpex, Bonaparte Carbon Capture and Storage.pdf, < https://www.inpex.com.au/projects/ccs-activities> [6 January 2025].

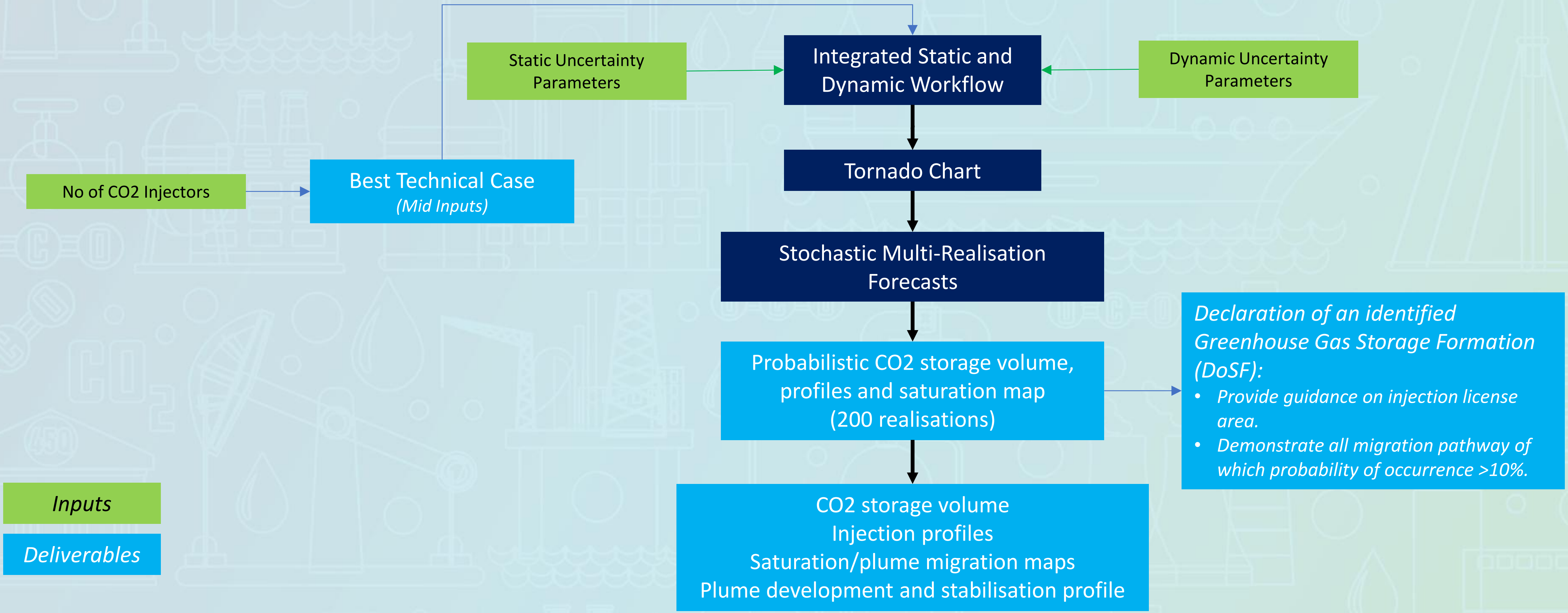
Uncertainty Study Workflow

- **Static and dynamic workflows are combined to ultimately create unique realisations that capture a broad range of technically credible reservoir/subsurface scenarios.**
  - Static workflow integrates seismic interpretation, various geological concepts and uncertainties in petrophysical parameters.
  - Dynamic workflow is created to capture facility, wellbore and fluid uncertainties.

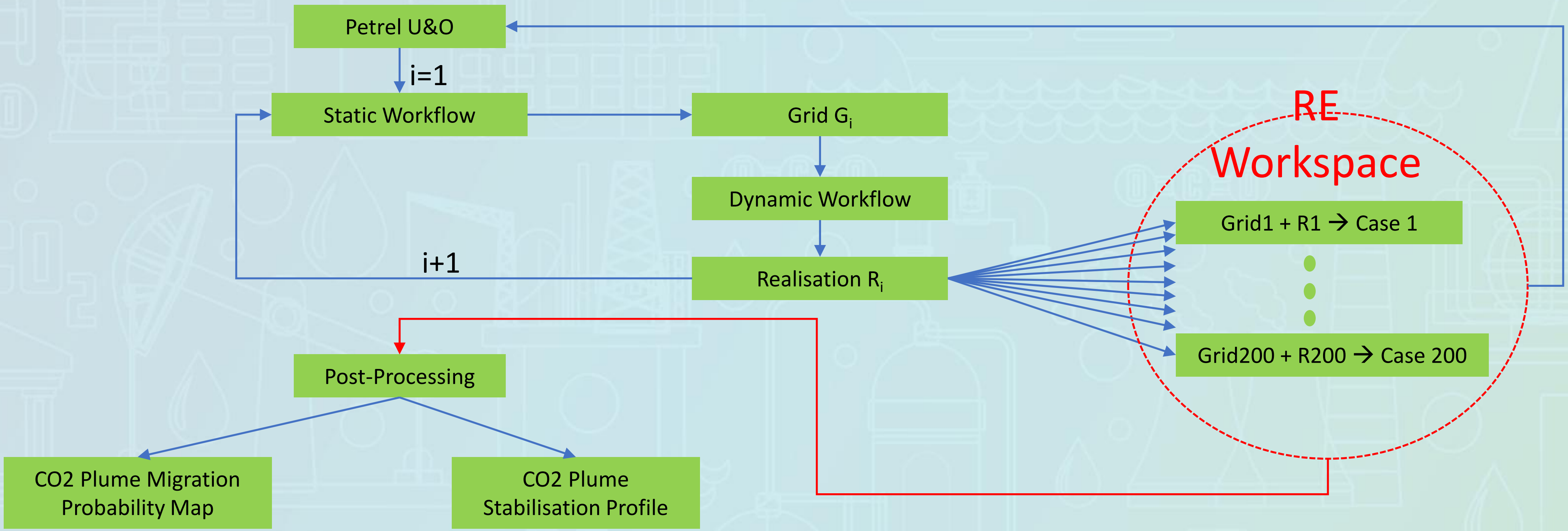
- **167 static and dynamic parameters are captured in the uncertainty study.**

- **Latin hypercube stochastic method was used to create 200 realisations for the two sets of uncertainty study ensembles.**
  - All runs are conducted in parallel within the cloud virtual environment.
  - Each realisation consist of a unique grid and a different set of rock-fluid properties.
  - The first ensemble is based on 1 injector to understand CO2 plume migration behaviour with time due to various unique combinations of subsurface parameters.
  - The second ensemble is based on the notional development plan containing notional injectors and planned injection profile.

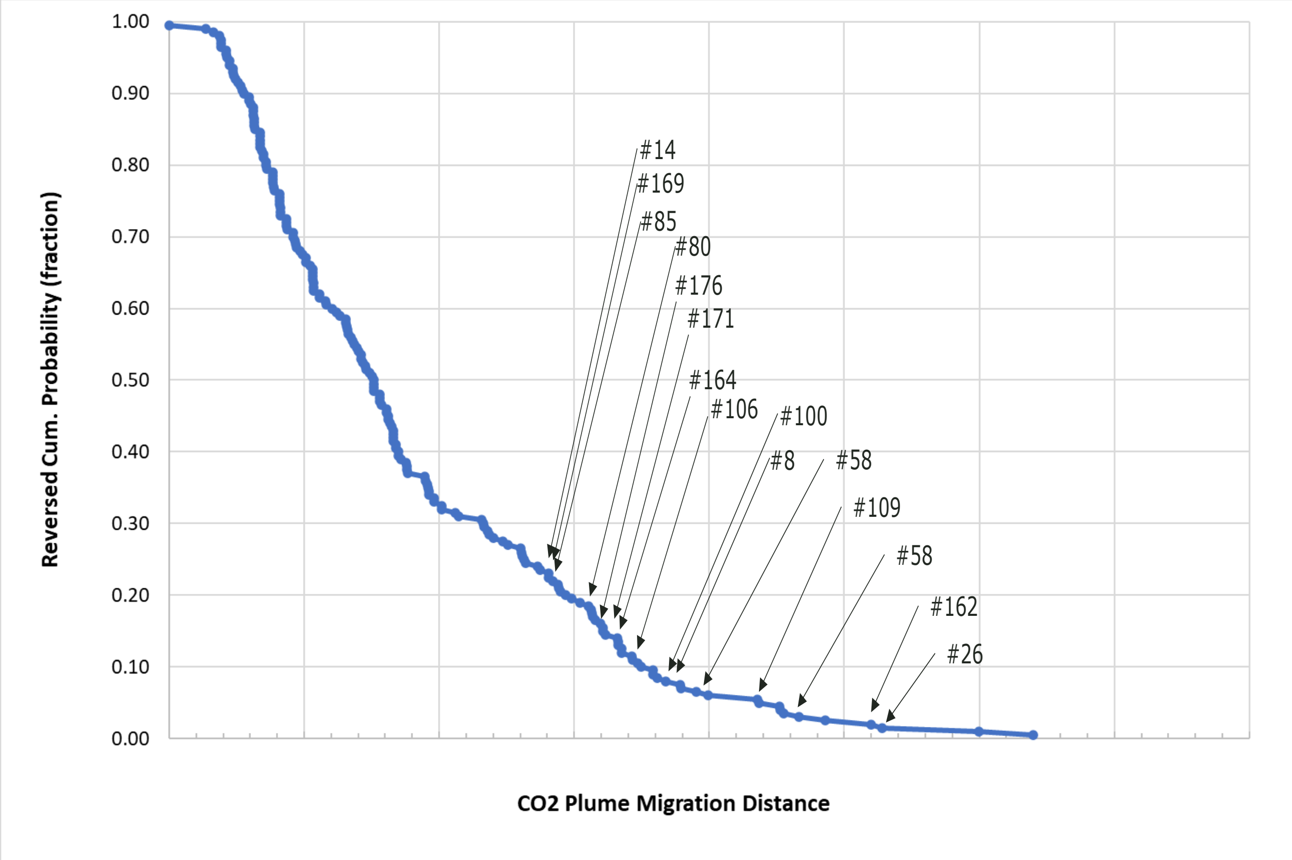
Overall Uncertainty Study Workflow



Uncertainty Study Workflow (Stochastic Multi-Realisation Forecast)

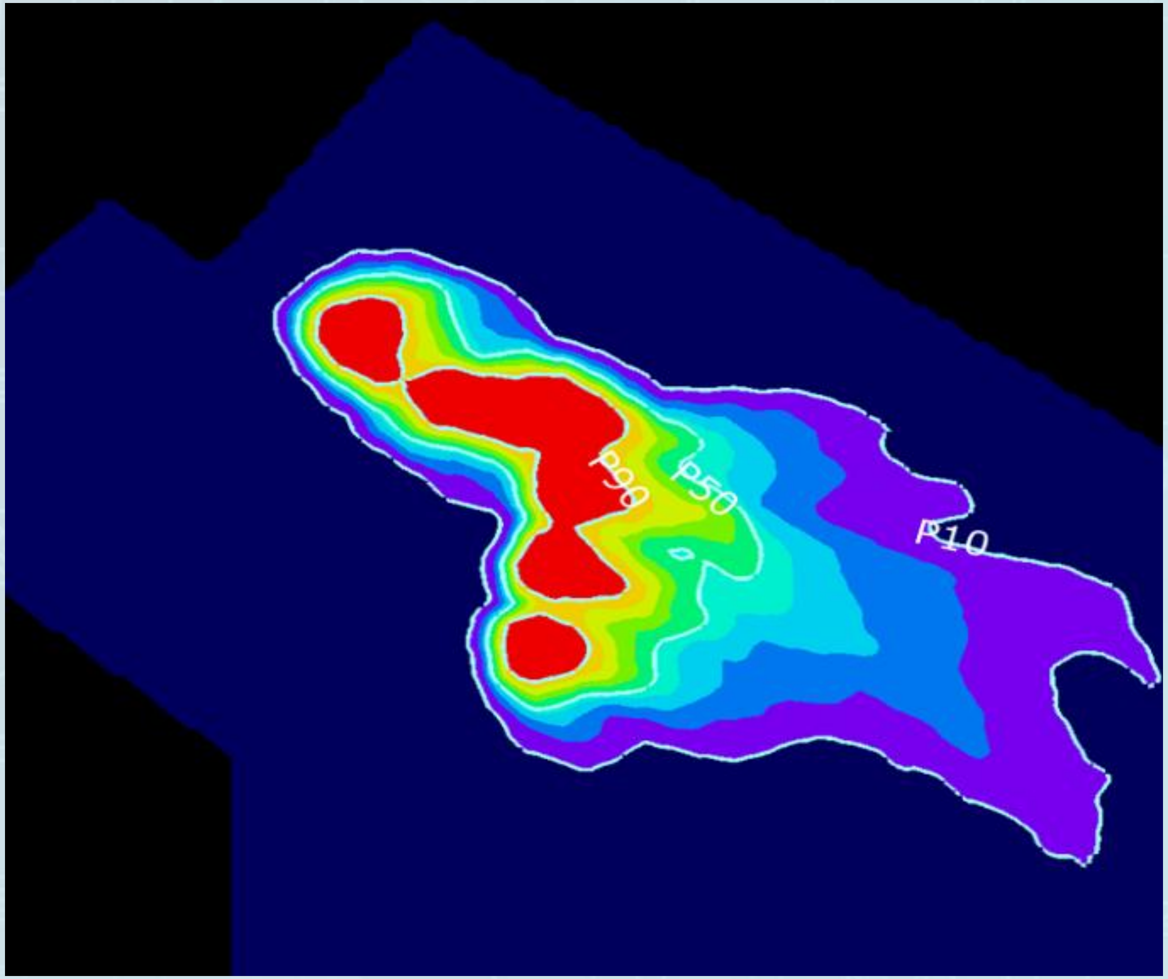


S-Curve from First Ensemble With 1 Injector



- **The initial result is a construction of the probabilistic S-curve to measure CO2 plume migration extent from a single injection perspective.**
- **Based on plume lateral migration length, the 200 cases are ranked to generate the probabilistic S-curve.**
  - Plume length is measured from Well I1 to outer most edge of the plume at the last time step.
  - Top 10 parameters from previously generated Tornado are extracted from each ranked realisation to deduce how these key parameters impact CO2 migration behaviour.
- **Each realisation unique combination of static and dynamic parameters and grids are then retained to repeat the ensemble run for the full field development plan.**
  - The purpose of this probabilistic CO2 plume migration map is to capture all possible CO2 migration footprints as a function of injection well count, injection distribution, injection profile and reservoir properties.

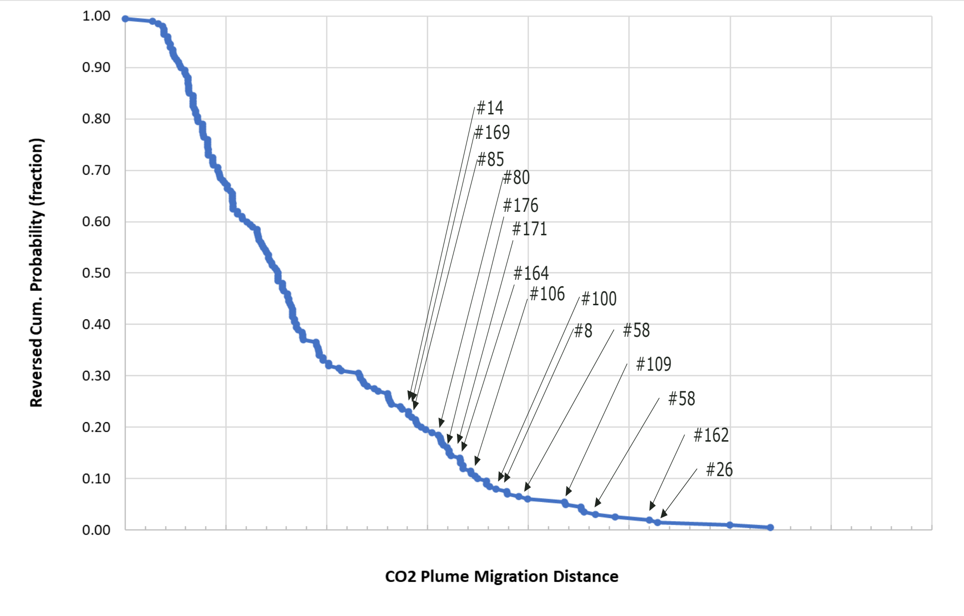
CO_2 Plume Probability Map



- **The CO_2 plume probabilistic map is constructed by combining all 200 realisations gas saturation net map.**
- **This probabilistic map demonstrates the level of confidence of CO_2 migration and stabilisation over time for the notional FDP.**
  - In this case, the P50 and the conservative P10 contours provide a high degree of confidence that the injected CO_2 will remain within the potential storage complex.
  - The Best Technical Case is highly comparable to P50 contour confirming minimal biasness in its input assumptions.
- **The map also indicates that the initial injection spacing assumption is sufficient to provide displacement distance between injectors to minimize different CO_2 plume fronts from merging and thus, resulting in longer CO_2 plume lateral extents.**

Identifying Extreme Cases

- **For the notional FDP, extreme cases contributing to the P1 contour are also investigated to understand the circumstances whereby the CO_2 plume migration may have extreme lateral migration relative to the injectors and boundary permit.**
- **Key objectives of the investigation are to (1). Quantify the extreme extent of CO_2 migration and (2). Capture the circumstances these extreme cases may occur.**
- **The identification of key <u>combination</u> of static and dynamic parameters provides guidance on the objectives of the appraisal program in terms of location of appraisal wells and their coring, logging and well test objectives.**

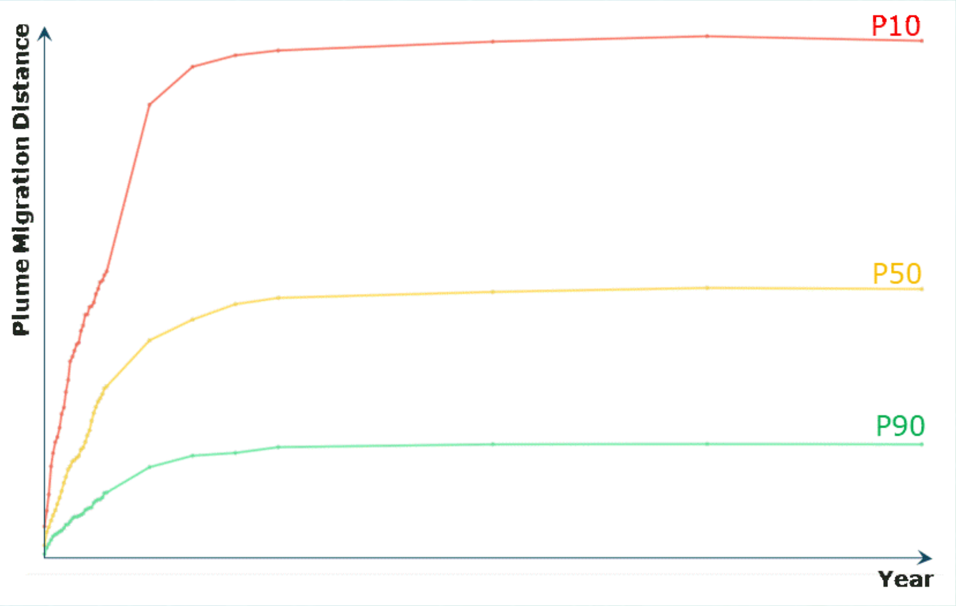


Constraint Boundary	Static Parameters	Dynamic Parameters
Criteria 1	• High reservoir properties of formations above with lowest shale content. There is also permeability contrast between channels and Inter-distributary bay and delta plain)	• Mid-High Kv/Kh • High CO_2 relperm. • Low-Mid reservoir temperature • Conservative CO_2 solubility.
Criteria 2	• Seismically interpreted ridges, (present in all current realisations). • Conceptual modelling of high quality distributary channels within top formation.	• High CO_2 relperm. • Conservative CO_2 solubility.

Essential reservoir and fluid data are being evaluated to narrow the initial estimated ranges and distribution function applied to key parameters.

Probabilistic Plume Migration and Stabilisation

- **The CO_2 plume lateral extent at each simulation time-step was also extracted from each realisation. It provides:**
  - An insight how the plume lateral extent changes with time.
  - The time required for CO_2 plume to stabilise.
- **The MMV plan under evaluation will be designed to appropriately monitor CO_2 containment through targeted, fit-for-purpose monitoring and management strategies.**
- **The monitoring system will incorporate an iterative update process of refining the stochastic simulations based on surveillance data. This approach enhances the accuracy of CO_2 movement forecasts and enables dynamic adjustment of operational parameters as needed.**



Summary

- **The stochastic workflow enables capturing range of potential CO2 plume migration due to elements of subsurface parameters and project design.**
- **As key reservoir and fluid parameters are identified through the uncertainty study, the appraisal program and subsequent studies can be tailored accordingly.**
  - Results obtained from the appraisal program will allow uncertainty ranges to be calibrated and, in some cases narrowed. Thus, providing the basis of adjusting initial assumptions used in the uncertainty study.
  - A proportion of the extreme cases will also likely be removed which is key to derisking the project uncertainties.
- **The MMV plan under evaluation will be designed to appropriately monitor CO2 containment through targeted, fit-for-purpose monitoring and management strategies.**
  - Monitoring technologies will be deployed to track the development and actual migration of the CO2 plume.
  - The monitoring system will incorporate an iterative update process of refining the stochastic simulations based on surveillance data.
  - The integration of monitoring data with predictive models enables adaptive management throughout the storage operation.

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