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Groundwater contamination risks: Causal Pathways and modelling analysis

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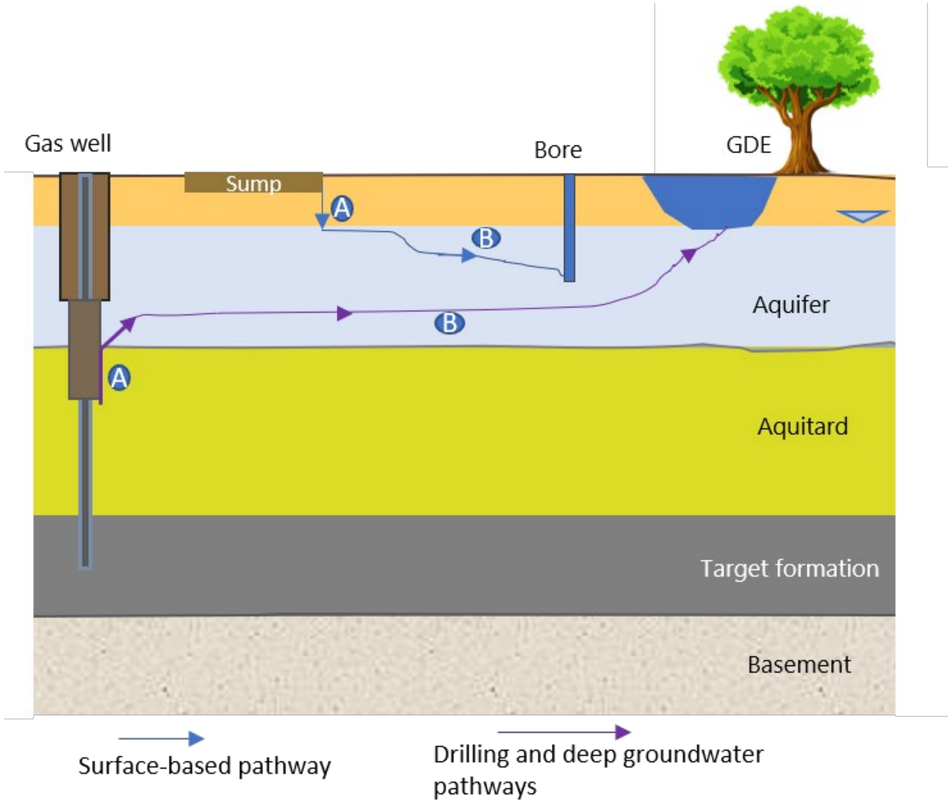
March 2020

Project objective

- Develop and apply a risk assessment approach that identifies potential causal pathways, undertake groundwater vulnerability, modelling and scenario analyses to provide realistic assessment of the likelihood of residual conventional gas-induced contamination risks



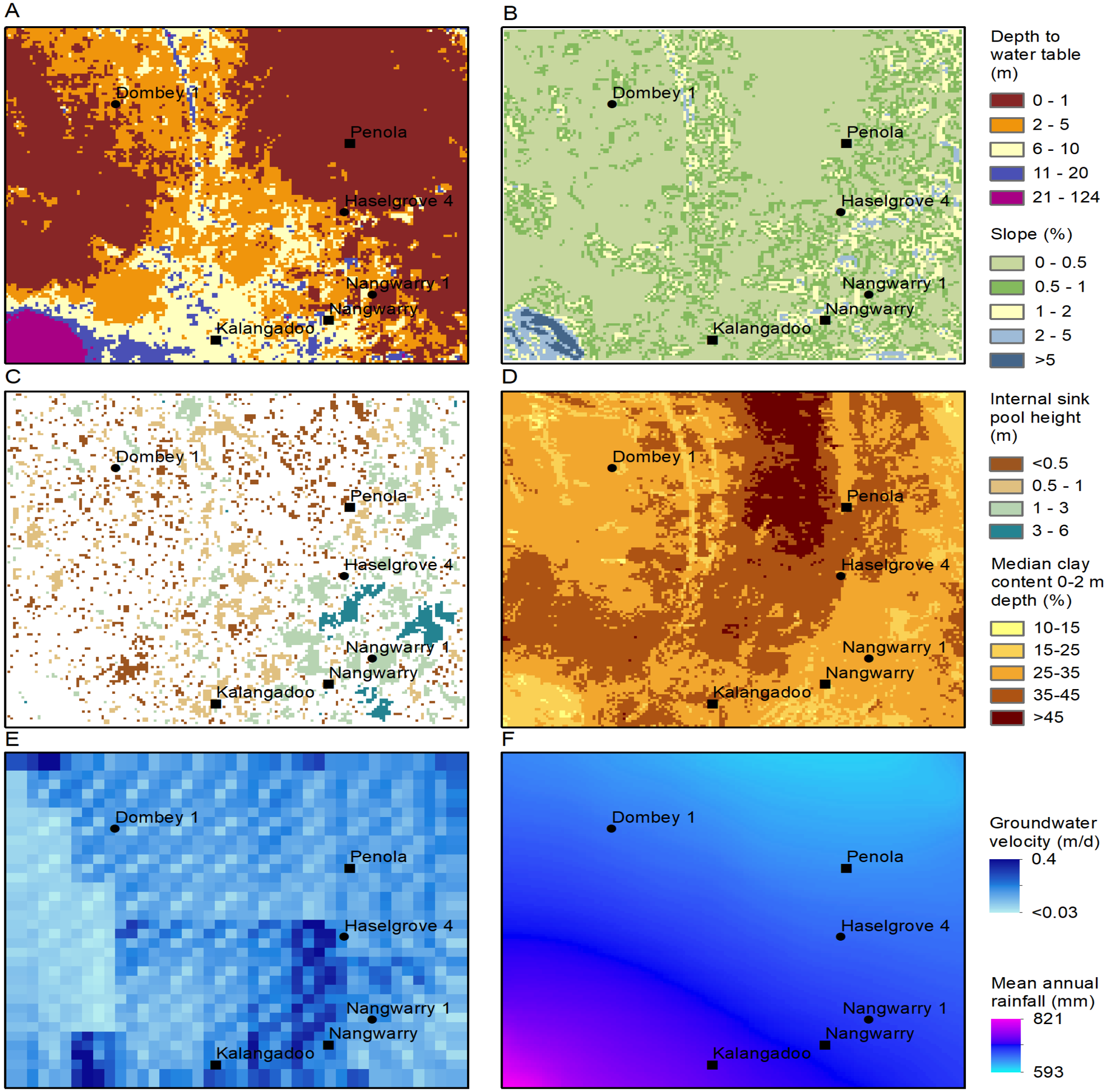
Key results

- Risks to water quality posed by the development of 3 gas wells are minimal for plausible scenarios of contamination events
- Extremely unlikely (≤ 5% chance) that maximal concentrations at any receptor locations intercepting the flow path would exceed 5% of the concentration at the source (e.g. the drilling sump) for conservative simulation considering no attenuation
- When also considering attenuation, concentrations are many orders lower e.g. a unit concentration of contaminant leaking from the drilling sump would dilute to ~10^{-7} before reaching the closest bore @165 m near the Dombey site, considering a half-life of 10 days
- Such very low concentrations indicate the contaminant substance disappearing (dilution and attenuation by decay, adsorption) before it reaches even the close by receptors. Receptors that are located farther have lower risks.

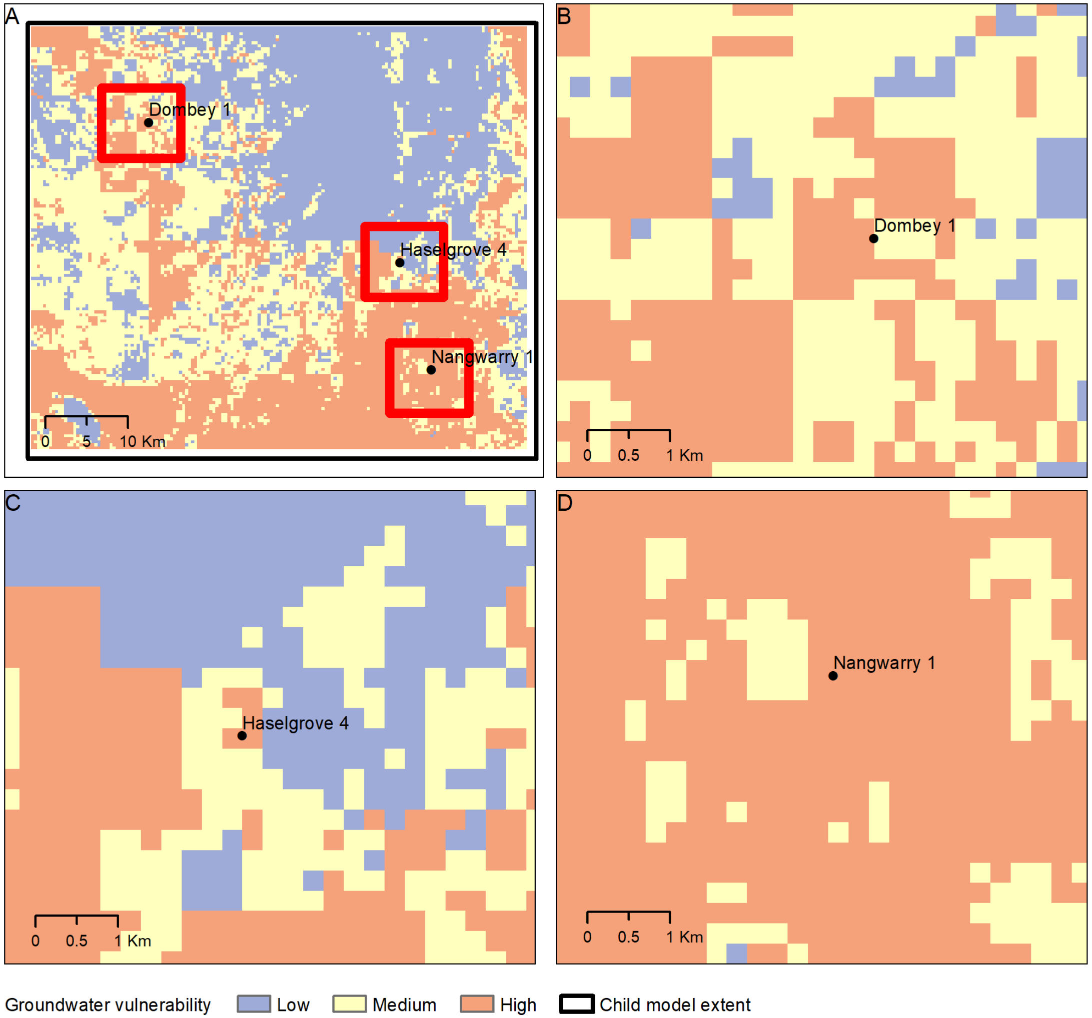
Physiography, proximity and vulnerability analysis

Upper Tertiary Limestone Aquifer

- Depth to water table
- Slope
- Internal sink pool height
- Clay content
- Groundwater velocity
- Rainfall



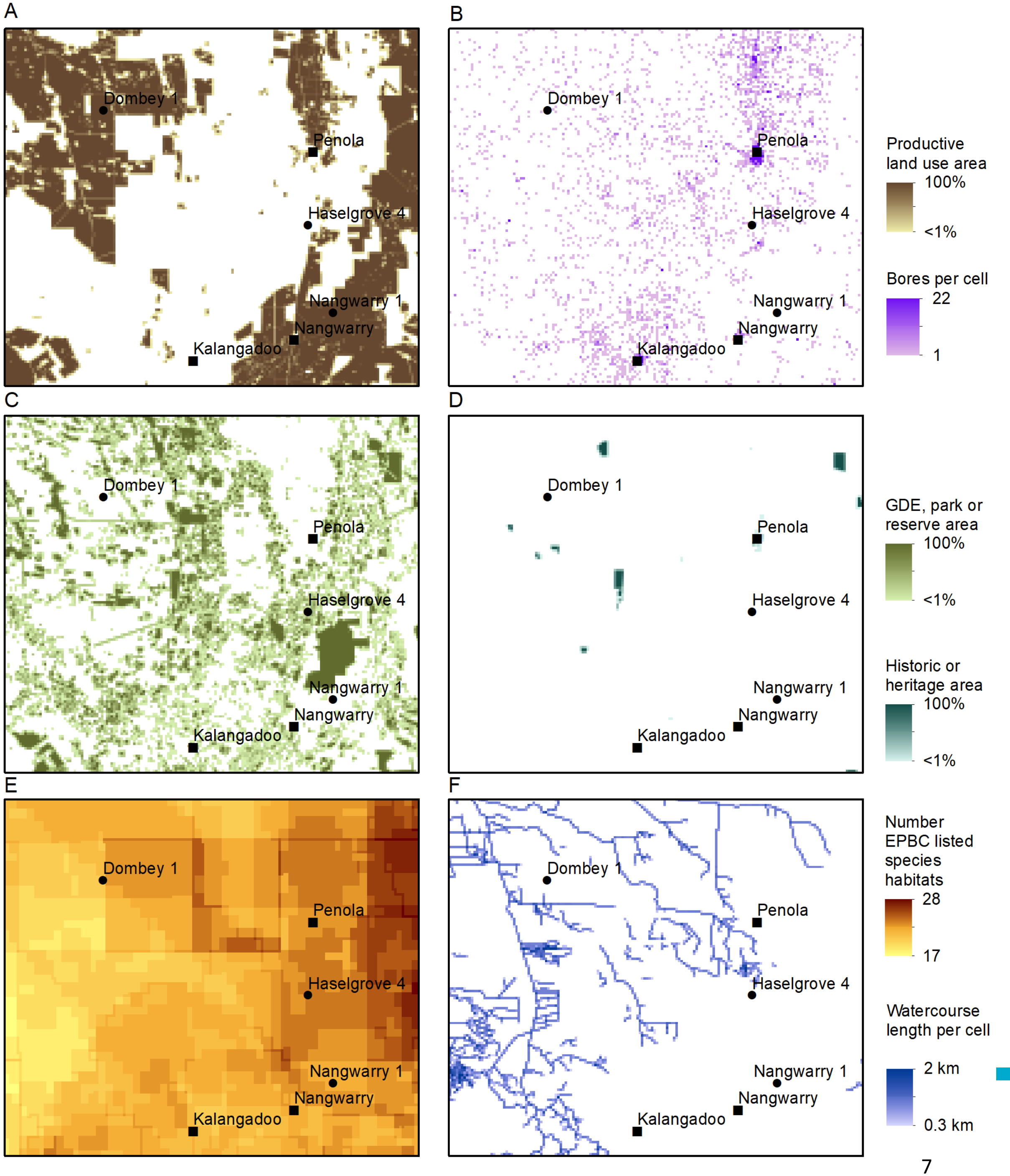
Vulnerability index



- Evenly weighted combination of normalised inputs
- Relatively vulnerable areas in the region warranted modelling analysis for risk assessment; higher at Nangwarry and Dombey wells compared to Haselgrove 4
- Patterns driven by topography, water table and clay content
- Slope, internal drainage, depth to water were most sensitive to perturbations in weights

Asset density

- Economic assets incl. bores, ‘productive land uses’ (connected to aquifer, mainly forestry, also fruit trees, nuts, grapes)
- GDEs mainly Eucalypt forest, wetlands
- Count per cell of overlapping distributions of listed species
- Sociocultural assets mainly historic buildings excluded (6 km^2), no hydrological connection
- No ILUA or NTD areas



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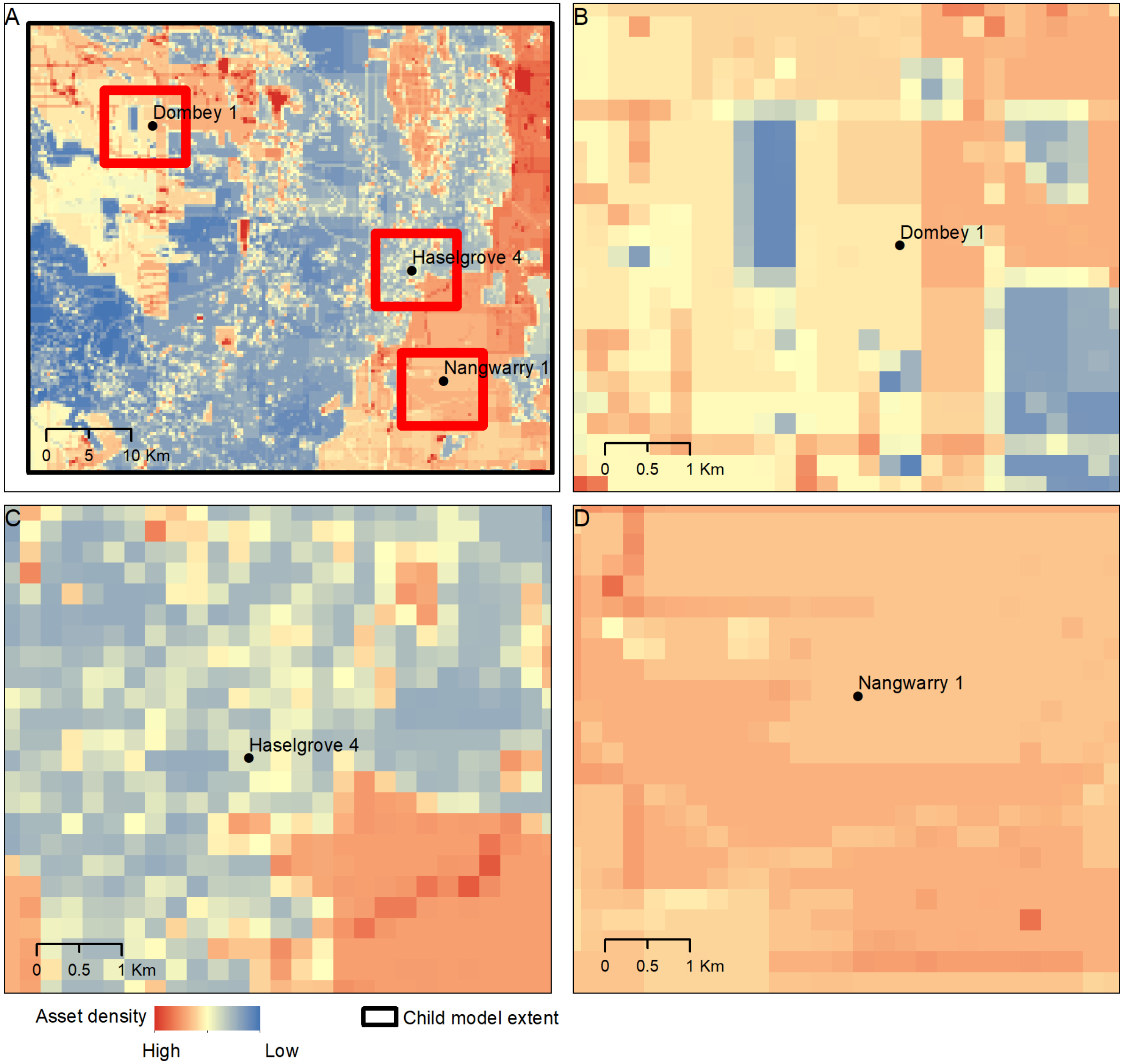
Combined asset density

- High density on eastern side, overlap of economic land use and habitat distributions
- Nangwarry 1 in area of relatively high asset density; Dombey 1 medium; Haselgrove 4 relatively low



Key insights from vulnerability analysis

- Gas wells located within areas of higher vulnerability and asset density across the assessment extent; higher at Nangwarry compared to Dombey and Haselgrove 4
- Vulnerability of confined aquifer from surface pathways (spills, leaks) will be limited due to presence of overlying soil, unconfined aquifer and aquitard layers, although the aquitard is probably leaky in some areas
- Contamination risk is informed by vulnerability together with contamination scenario (pathway), and transport characteristics
- The vulnerability is accounted in the contamination risk assessment by including the physiographic and groundwater characteristics in the modelling analysis

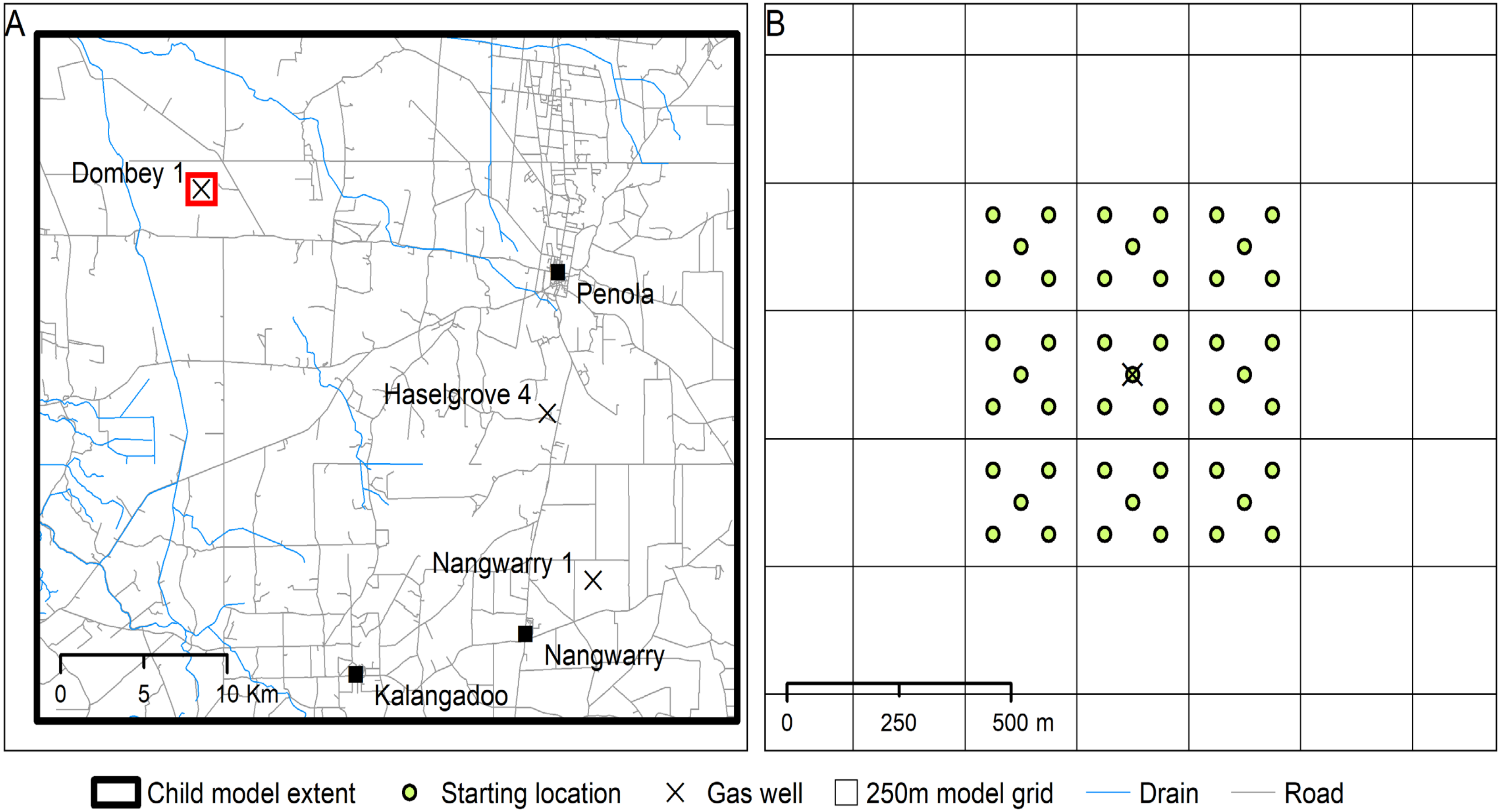
Modelling and scenario analysis

Probabilisitic flow and transport modelling analysis to quantify likelihood of water quality changes at risk receptors

Scenarios

Scenario modelled	Pathway	Risk	Modelling approach
Scenario 1: Slow leaking drilling sump,	Leakage from surface storage facility due to breach of lining and gravity flow to shallow groundwater	Contamination of soil and shallow groundwater, SW bodies	Transport modelling for the vadose and saturated zones
Scenario 2: Loss of well integrity, leaky bores, faults **2a – Unconfined aquifer** **2b – Confined aquifer**	Leakage through micro annulus directly in to the aquifer	Contamination of deeper parts of aquifers and transport to bores	Transport modelling for the saturated zones
Scenario 3: Spill **3a – Surface spill (short duration)** **3b – Flow line leak (sub-surface, undetected, longer duration)**	Accidental spill of contaminant and migration through surface soil into shallow groundwater Pipeline from well to the facility leak under ground resulting in condensate reaching soil column	Contamination of shallow aquifer and bores Contamination of soil and shallow groundwater	Transport modelling for the vadose and saturated zones Transport modelling for the vadose and saturated zones

Particle tracking



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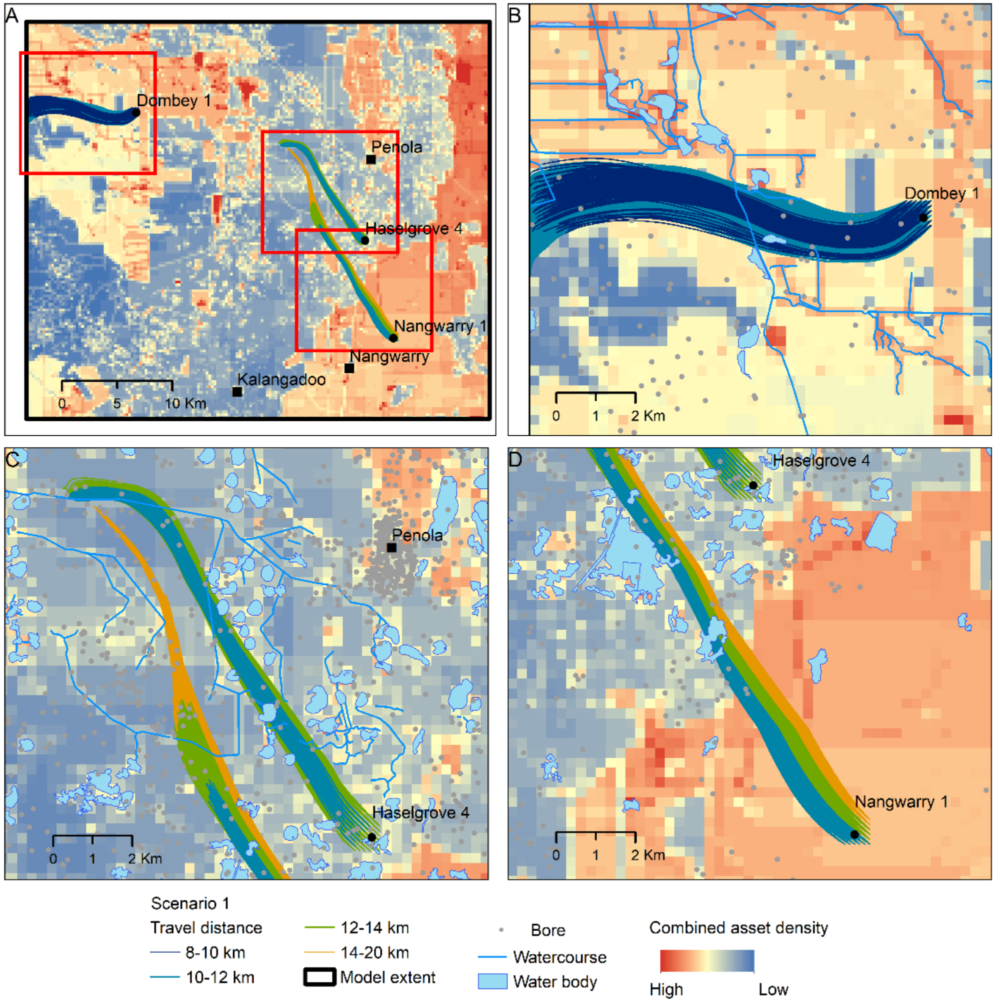
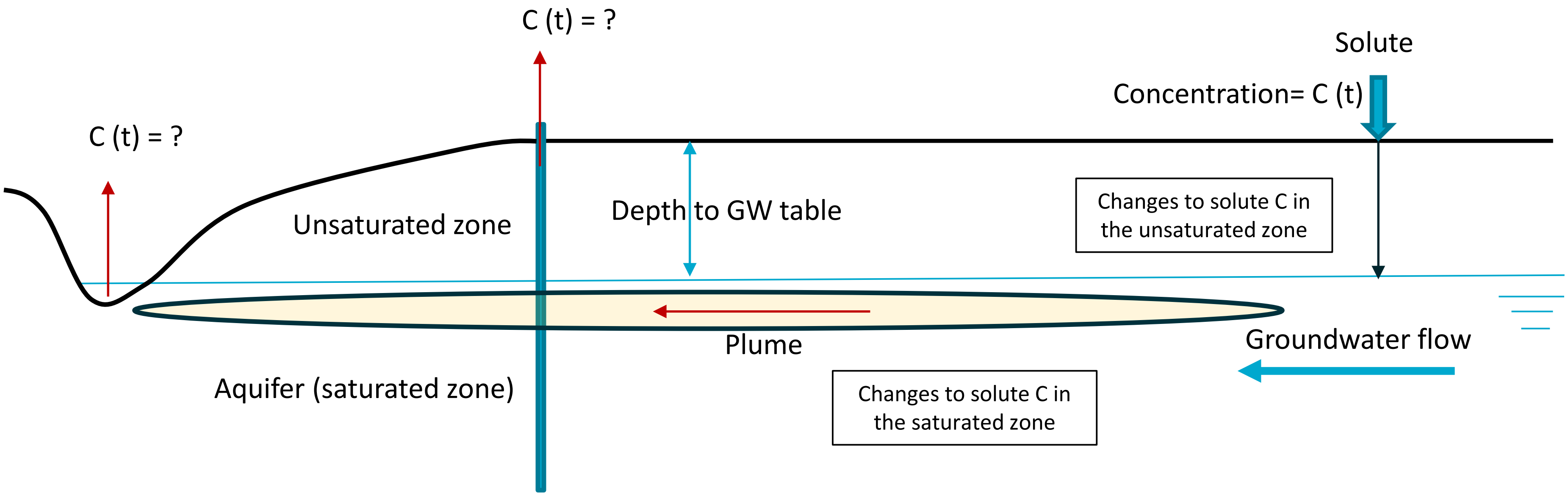
Particle tracking...

- Provided travel times, paths and flow velocities in the aquifer
- Particle tracks were simulated for 100 years with starting points around the three well locations

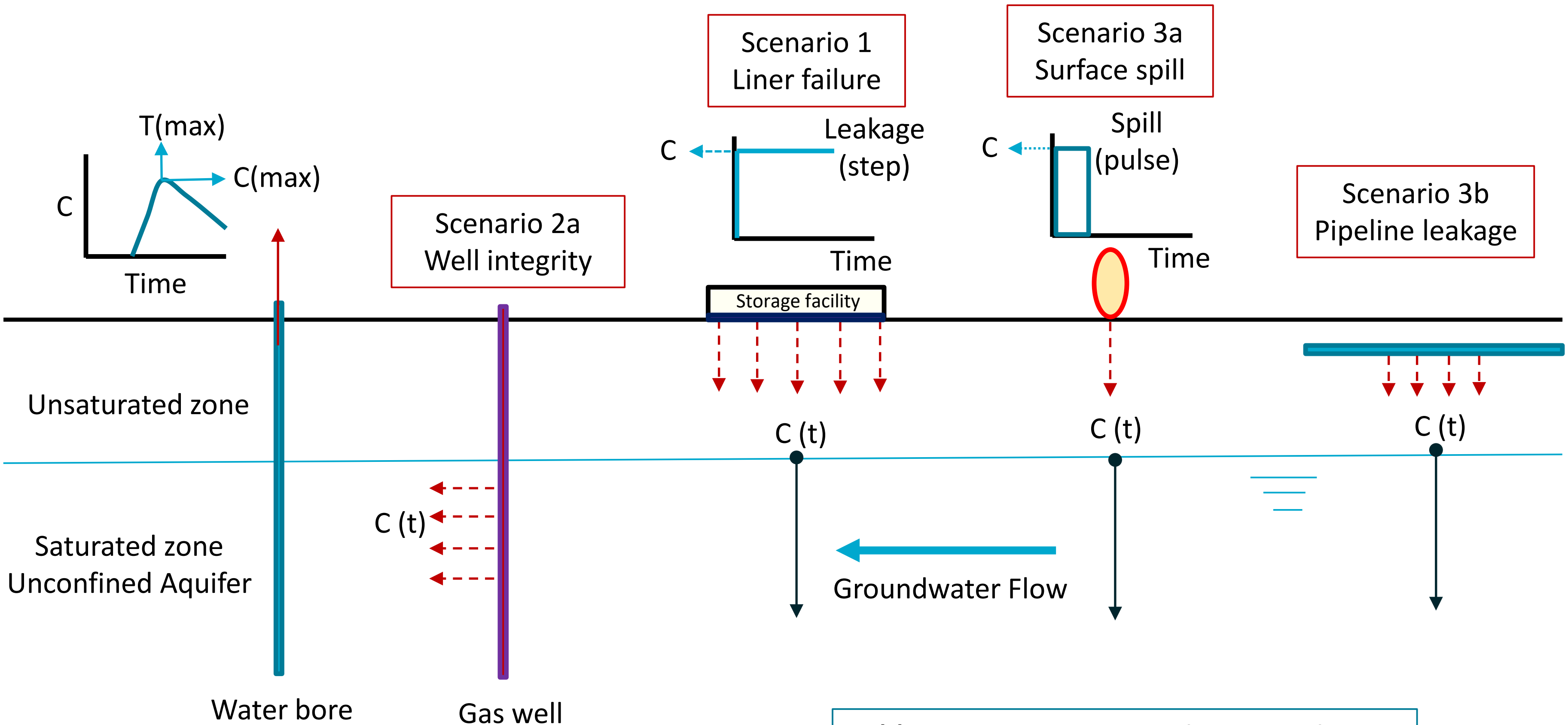


Conceptual representation for solute transport pathways



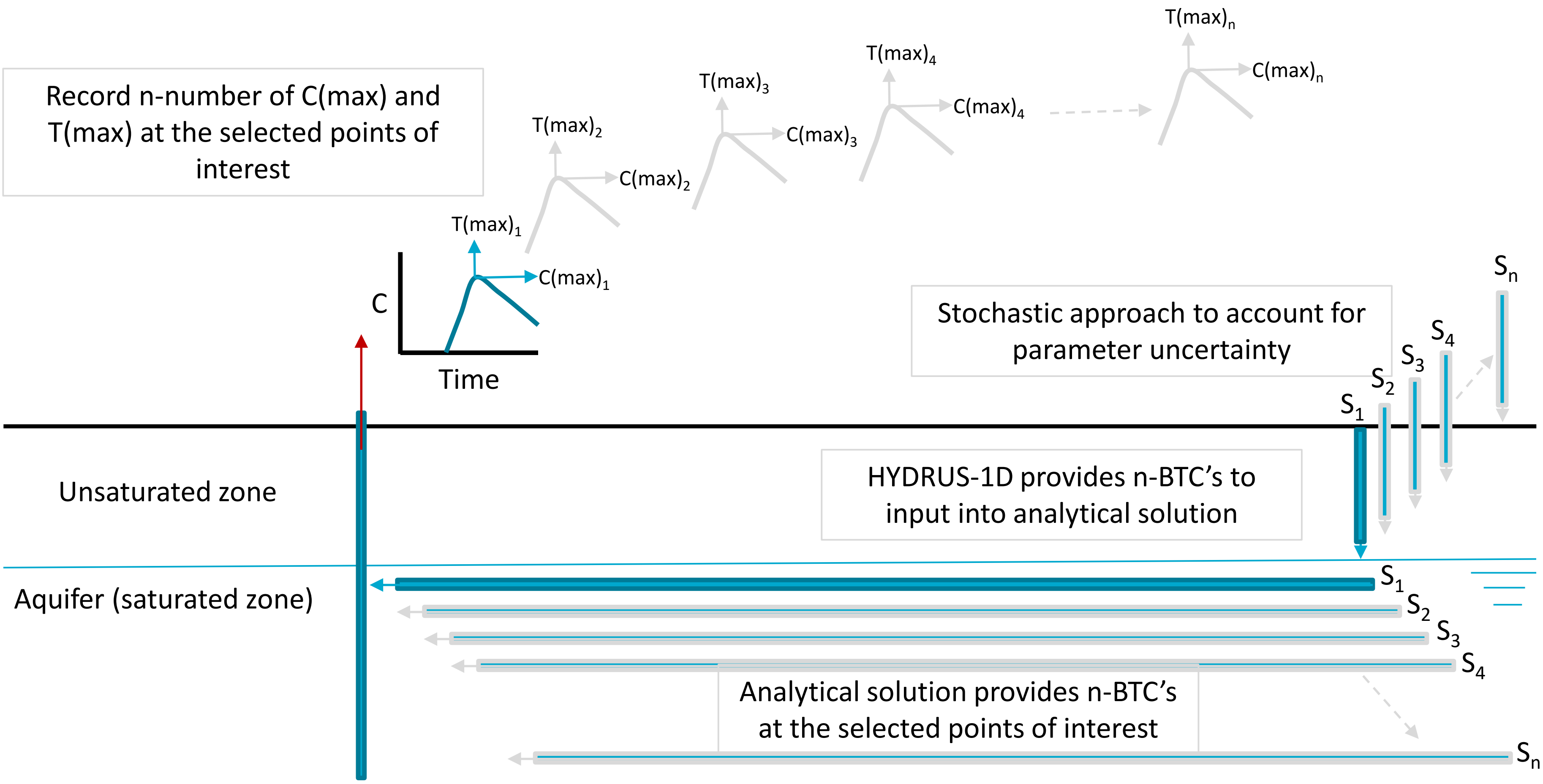
Changes to solute concentration due to dispersion, Sorption, and decay

Mechanisms for delivery of solutes



C (t) is concentration as a function of time, termed 'Breakthrough Curve, BTC'

Stochastic modelling of solute transport

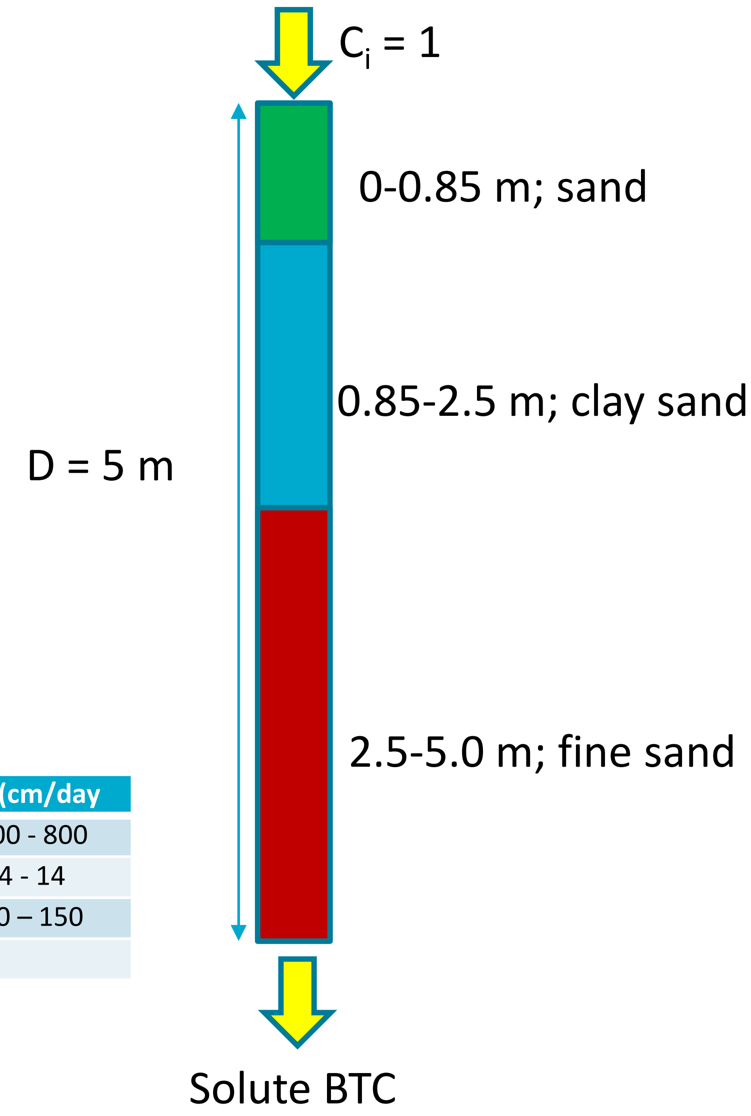


Scenario 1; 30 day liner failure

- This Scenario assumes a 'Liner Failure', that persists for 30 days, during which the soil surface is subjected to a head of 2 m
- A unit input concentration is assumed
- After the 30-day period, the profile continues to freely drain and recharge the aquifer; no rainfall recharge as area is covered

Flow and solute transport in the unsaturated zone

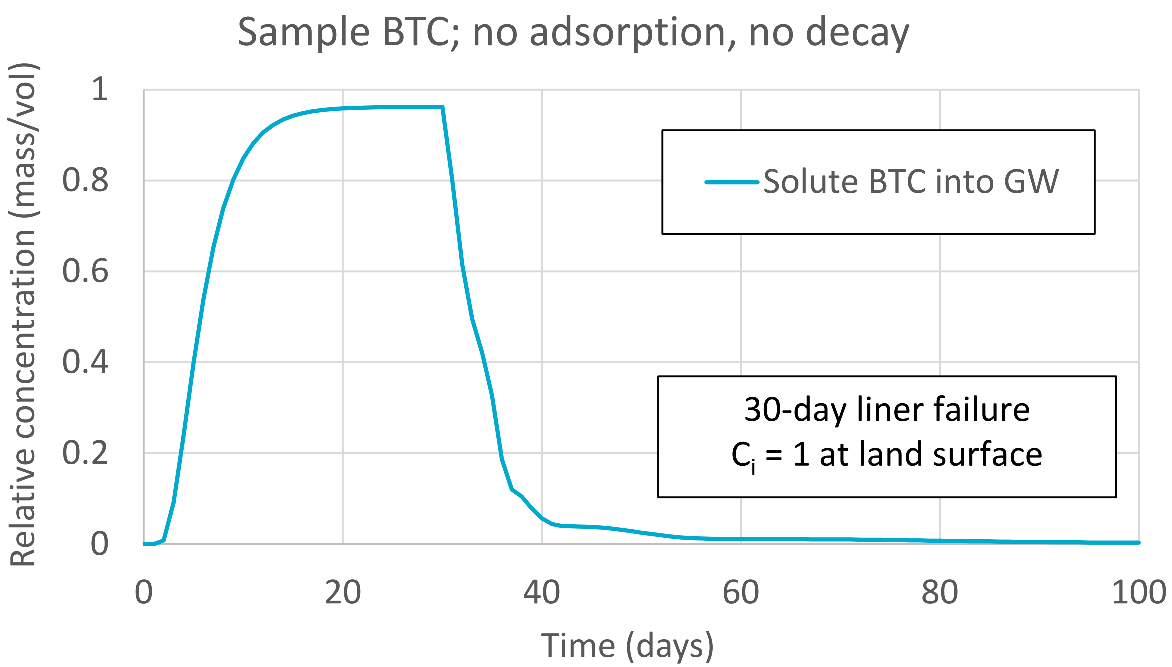
- We use HYDRUS-1D to model water flow and solute transport in the unsaturated zone.
- HYDRUS-1D models many solute processes including dispersion, adsorption and decay.
- Profile discretization and hydraulic parameters for the 'Dombey' site are shown here.



	Qr	Qs	Alpha (1/cm)	n	Ks (cm/day
Layer 1	0.045	0.43	0.145	2.68	300 - 800
Layer 2	0.1	0.38	0.027	1.23	4 - 14
Layer 3	0.045	0.43	0.145	2.68	80 – 150
Dispersivity	5 – 500 cm (0.1L ± 1 order of magnitude)				

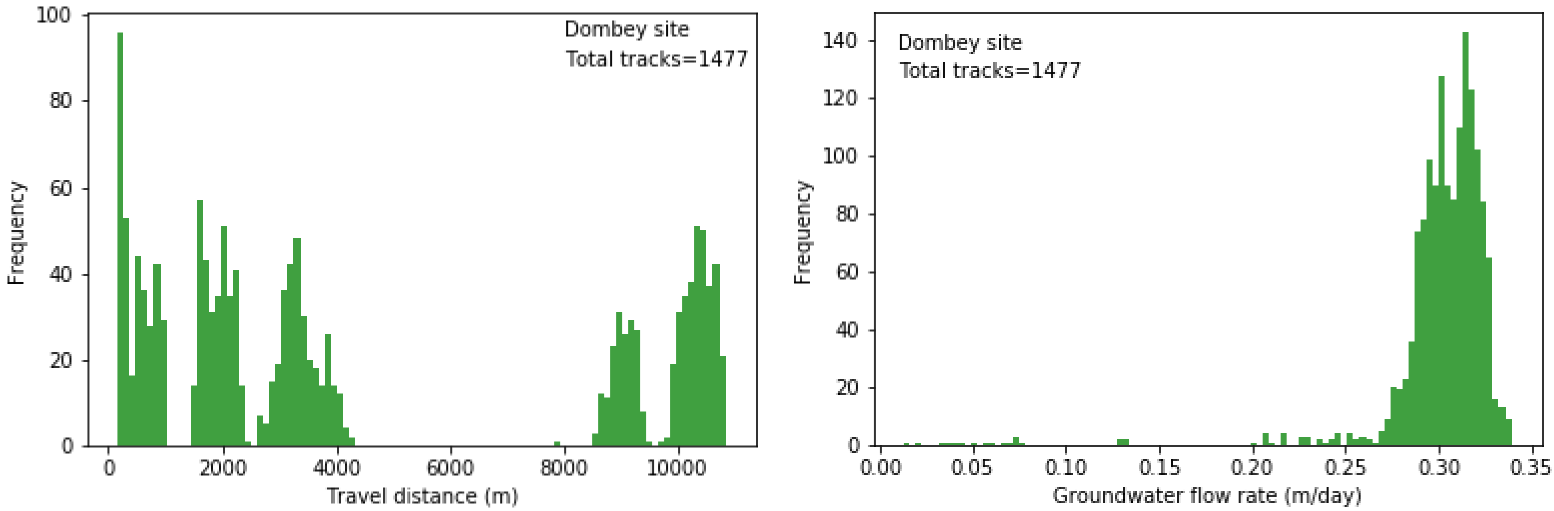
Flow and solute transport in the unsaturated zone; Scenario 1 for Dombey Site

- Sample BTC for Scenario 2 'Liner Failure'; output from HYDRUS modelling
- Case represents a worst-case scenario (no adsorption, no decay)
- This BTC is used as an input to the analytical solution of the ADE to evaluate solute BTC for each of the potential pathways identified by the 'Particle Tracking Analysis'



Flow and solute transport in the saturated zone; Scenario 1 for Dombey Site

- Particle tracking analysis identified all potential pathways (marked as tracks in the figure below) that may intercept an asset (e.g., water bore)
- The length and flow rate for each unique track are recorded
- Figures below show the statistical distribution of track lengths and flow rates for the 'Dombey' site.



Flow and solute transport in the saturated zone; Scenario 1 for Dombey Site

- 45 particles were released during each of the 179 stochastic simulations thus totalling to 8055
- Only 1477 (tracks) intercepted the 16 bores that happened to be within the particles path lines
- That is, only 18.34% of the particles intercepted water bores

Groundwater bore receptors

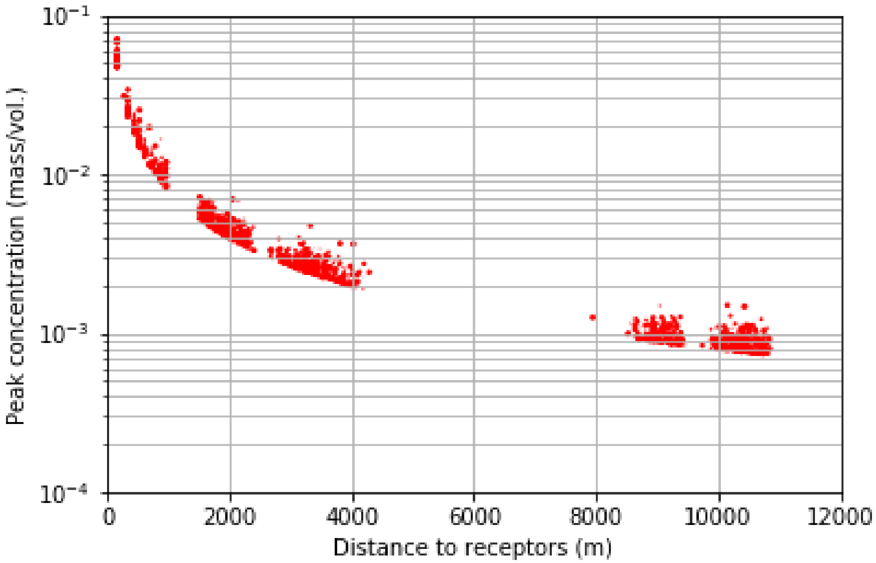
Distance to receptor (m)	No. of interceptions	Acual no. of bores	% Prob. of interception
0 - 2000	545	3	6.77
2000 - 4000	413	6	5.13
4000 - 6000	20	2	0.25
6000 - 8000	1	1	0.01
8000 - 10000	196	3	2.43
10000 - 12000	302	1	3.75
Total	1477	16	18.34

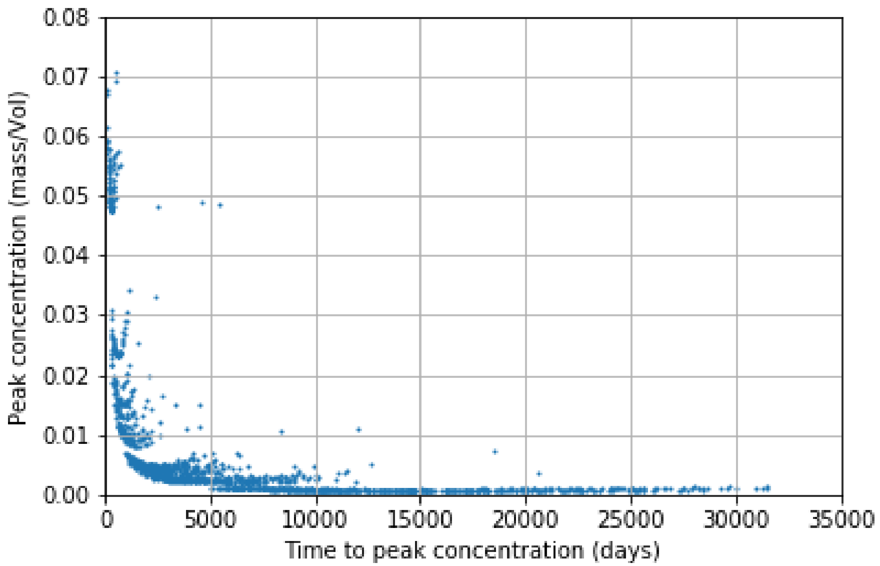
Water courses

well	**watercourse/drain**	**waterbody name/auswetnr**	**Distance from well**
Dombey	drain off Bakers Range Main Drain		2800
Dombey	drain off Bakers Range Main Drain		3100
Dombey		S0110176	3500
Dombey	Bakers Range Main Drain		4300
Dombey		S0110185	4300
Dombey	Un-named minor watercourse		9300

Maximal solute concentrations; Scenario 1 for Dombey Site

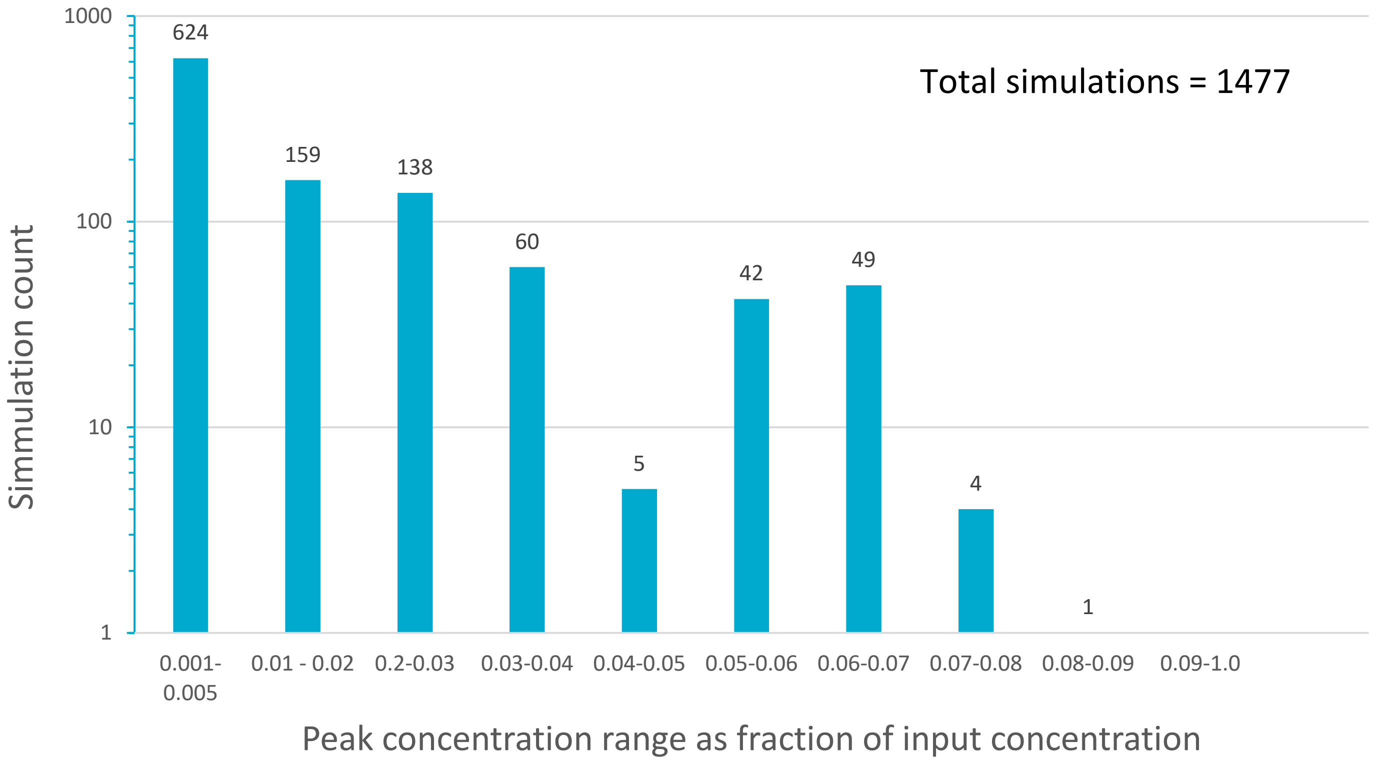
- Figures below show maximal concentration and time at which they occurred for the 1477 tracks that intercepted receptors (water bores)
- The further the receptor, the lower is the maximal concentration due to higher dispersion and transformations
- The spread for any particular distance is due to the stochastic nature of the analysis during which parameters are being varied





Statistics of maximal solute concentrations; Scenario 1 for Dombey Site

- Analysis shows very low concentrations for all potential flow pathways with 99% having a maximal concentration < 7% of the source input concentration



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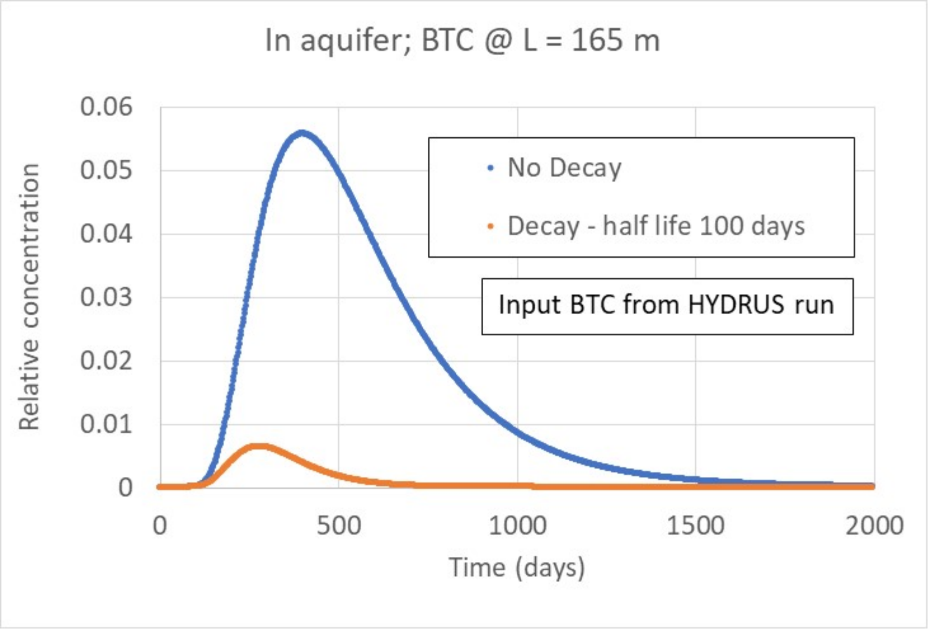
No decay and decay simulations

- Modelling considered 'no decay' and other probable rates of decay of contaminants
- Concentrations reduce to very low values even in the 'no decay' simulations
- Experiments in the companion GISERA project using samples from the field demonstrated that all the chemicals disappear within 34 days in the aquifer media



Breakthrough curve for receptor located @ 165 m due to input shown in Figure 1; for half life = 10 days, C ≈ 3 x 10^{-7}

Conclusions; solute transport modelling

- The impact of four potential contamination scenarios were assessed:
  - Scenario 1: slow leaking drilling sump (Presented today)
  - Scenario 2: Well integrity
    - 2a – Unconfined aquifer
    - 2b – confined aquifer
  - Scenario 3: Spill
    - 3a – Spill at the surface (quickly contained)
    - 3b – Spill from sub-surface pipeline (longer duration)

- Only a small number of receptor bores are located within 2 km that are intersected by particle tracks from the gas well (Dombey-11, Haselgrove-21 and Nangwarry-32). Transport calculations has shown that concentration decreases quickly with distance and time before reaching the receptors along those tracks.

- Extremely unlikely (≤ 5% chance) that maximal concentrations at any receptor locations intercepting the flow path would exceed 5% of the concentration at the source (e.g. the drilling sump) for conservative simulation considering no attenuation

- When decay is considered, contaminants disappear (very low concentrations in simulations) before reaching even the closest receptors. For the realistic scenarios and incidents considered in this study, risk of contamination to bores and other water dependent receptors are very unlikely

Limitations

- This study provides a screening analysis for quantifying contamination risks from onshore gas development for assets and receptors in a gas development area
- Assumptions were made (eg, 1D transport without lateral dispersion) to do a conservative quantification of risk
- The study is not intended for to do predictive assessment of contaminant concentrations at any specific risk receptor for any actual contamination event.
- Nor is the study intended to do fate analysis of individual chemicals used as part of gas development activities
- Such predictive assessments would require detailed modelling at finer spatio-temporal resolutions of the transport processes for individual species

Thank you

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