Preston New Road: Technical Assessment of Hydrogeological Risk, Monitoring, and Governance Limits

A Non-Conclusive Technical Assessment Based on Planning, Regulatory, and Operational Evidence

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Executive Summary

This document presents a structured technical assessment of hydrogeological risk, monitoring adequacy, and governance limits associated with onshore shale gas development in faulted UK basin settings, with particular reference to Preston New Road. The assessment does not determine liability, assert causation, or claim environmental impact. Its purpose is to evaluate whether planning and regulatory decisions were supported by assumptions that were adequately bounded, tested, and governable under conditions of geological complexity and operational uncertainty.

The analysis applies an assumption–evidence–gap mapping framework anchored in a defined evidence hierarchy. Primary sources include planning decisions, regulatory documents, operator technical submissions, and government-commissioned scientific analyses. Secondary and tertiary sources are used only for corroborative pattern testing and not for causal inference. All findings are temporally anchored to avoid hindsight bias.

The assessment identifies that planning and regulatory confidence relied on conceptual models that treated subsurface domains as functionally separable and system behaviour as sufficiently predictable to be managed through model-confirmatory monitoring and threshold-based controls. Monitoring frameworks were primarily designed to validate predicted behaviour rather than to test alternative conceptual models in faulted and pressure-responsive geological settings.

Primary evidence shows that early site observations and operational data contradicted several baseline assumptions, including shallow hydrogeological behaviour and the boundedness of fault response. These observations were managed operationally within existing frameworks but did not consistently trigger conceptual reassessment, monitoring redesign, or planning-level review. Monitoring systems functioned largely as designed, but their spatial, temporal, and integrative structure limited their ability to detect or exclude certain classes of plausible system response.

The assessment concludes that, under faulted UK basin conditions, confidence in predictability and controllability depended on assumptions that were not fully testable within the monitoring and governance frameworks applied. The principal constraint identified is structural rather than procedural: monitoring and regulatory systems were aligned to confirm model expectations rather than to bound uncertainty through hypothesis testing and adaptive redesign.

These findings are planning-relevant because they concern foreseeability in category, the adequacy of monitoring design relative to geological complexity, and the presence or absence of governance mechanisms capable of responding when foundational assumptions are contradicted by observation. The conclusions do not assert that specific harms occurred or that non-compliance took place. They establish that system-level uncertainty was greater than the decision frameworks were structured to resolve.

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Section 1 — Purpose, Scope, and Methodological Approach

1.1 Purpose of This Document

This document sets out a technical position on the planning, regulatory, and evidential context surrounding onshore shale gas development in the Fylde Basin, with particular reference to operations at Preston New Road (PNR). Its purpose is not to determine liability, assert causation, or advocate for a particular policy outcome, but to document what was known, assumed, and not tested at the time key decisions were taken, and to assess whether subsequent outcomes were foreseeable within the bounds of that knowledge.

The document is intended to inform planners, regulators, inspectors, and community stakeholders by providing a structured assessment of system-level risk and decision-making under uncertainty, rather than a retrospective critique of individual actions.

1.2 Scope and Limits of the Assessment

The scope of this assessment is explicitly bounded.

It examines:

- The planning and regulatory framework applicable to PNR at the time of determination;
- The hydrogeological, geomechanical, and seismic assumptions underpinning that framework;
- The design and implementation of monitoring regimes intended to validate those assumptions;
- The extent to which emerging observations aligned with, challenged, or fell outside those assumptions.

It does not:

- Attribute intent or motive to any party;
- Assert causal links beyond those established in primary technical sources;
- Substitute local observation for regulatory or scientific determination;
- Predict outcomes for future developments.

Where reference is made to subsequent observations or outcomes, these are included only insofar as they relate directly to the assumptions and monitoring strategies originally relied upon, and are anchored temporally to avoid hindsight bias.

1.3 Evidence Hierarchy and Use of Sources

This document adopts a tiered evidence hierarchy, reflecting both the relative authority of sources and their appropriate analytical role.

Primary Evidence

Primary evidence comprises:

- Official planning documents and determinations;
- Environmental permits and regulatory decisions;
- Operator submissions and supporting technical reports;

- Seismic, geomechanical, and hydrogeological studies produced or relied upon by statutory bodies;
- Government policy statements and parliamentary records.

Primary evidence is used to establish what was formally stated, accepted, or relied upon at the time of decision-making.

Secondary Evidence

Secondary evidence includes:

- Satellite imagery time series;
- LiDAR datasets and elevation differencing analyses.

These sources are used only to corroborate spatial or temporal patterns that are consistent with mechanisms described in primary sources. They are not used to infer causation independently.

Tertiary Evidence

Tertiary evidence comprises:

- Local field observations;
- Citizen sampling and photographic records;
- Odour, vibration, and surface water reports.

These materials are treated as signals rather than conclusions. Their role is to test plausibility and coherence against established mechanisms, not to establish impact in isolation.

This hierarchy is applied consistently throughout the document to prevent evidential overreach.

1.4 Methodological Approach

The analytical approach adopted is assumption–evidence–gap mapping.

For each thematic area examined (e.g. hydrogeology, seismicity, flood risk, monitoring design), the analysis proceeds by:

Identifying the assumptions explicitly or implicitly relied upon at the time of planning and regulatory approval;

Describing how those assumptions were operationalised in modelling, design, or monitoring frameworks;

- Assessing whether those assumptions were adequately tested under site-specific conditions;
- Examining whether subsequent observations were consistent with mechanisms that had not been explicitly excluded.
- This approach avoids retrospective determinism and focuses instead on foreseeability under uncertainty.

1.5 Treatment of Uncertainty and Non-Linear Risk

A central premise of this document is that geological and hydrogeological systems exhibit non-linear behaviour, particularly where faulting, pressure diffusion, and stress redistribution are present. In such contexts, the absence of observed impact cannot be equated with the absence of risk unless monitoring systems are specifically designed to detect the relevant pathways and timescales.

Accordingly, this document distinguishes between:

The analysis does not assume that uncertainty implies harm, but it does examine whether uncertainty was appropriately bounded in light of available evidence.

1.6 Use of Temporal Framing

To avoid hindsight bias, all assessments are anchored explicitly in time.

Statements regarding knowledge, assumptions, or confidence are framed with reference to:

- The point of planning determination;
- The commencement of specific operational phases;
- The availability of particular datasets or analyses at those times.

Later outcomes are referenced only to evaluate whether earlier assumptions remained tenable, not to imply that outcomes were inevitable.

1.7 Relevance to Future Developments

While this document focuses on Preston New Road, its analytical framework is relevant to other proposed developments within the Fylde Basin and similar geological settings. Where reference is made to prospective sites (e.g. Burniston), this is done solely to identify structural similarities in uncertainty and planning logic, not to predict outcomes.

1.8 Section Synthesis: Framing the Analysis

In synthesis, this document proceeds on the basis that systemic under-monitoring and over-confidence can exist without any single regulatory breach, and that planning decisions may be vulnerable where assumptions are treated as validated by design rather than tested by observation.

The sections that follow apply this framework to specific domains, with the objective of clarifying which assumptions were relied upon, how they were bounded, and where evidential gaps remained at the time key judgements were made.

1.9 Disclosure of Analytical Tools and Assistance

Portions of the drafting, structuring, and citation management of this document were supported through the use of an artificial intelligence–based language tool.

The tool was used as an assistive aid to improve clarity, organisation, and consistency of presentation, and to support the identification and formatting of references. It was not used to generate primary evidence, interpret data independently, or determine analytical conclusions.

All factual assertions, interpretations, judgements, and conclusions contained in this document have been independently evaluated and are the responsibility of the author. The selection, weighting, and interpretation of evidence were undertaken by the author in accordance with the evidence hierarchy defined in Section 1.

Section 2 — Historic Misgivings and Prior Warnings Before Operations at Preston New Road

2.1 Purpose of This Section

This section documents material misgivings, warnings, and uncertainties that were articulated prior to the commencement of operations at Preston New Road. Its purpose is to establish the pre-existing knowledge environment within which planning and regulatory decisions were taken, and to clarify whether later outcomes occurred in a context of recognised uncertainty or in contradiction to contemporaneous expectations.

The section does not assess the adequacy of responses to these warnings, nor does it attribute responsibility for how they were treated. It confines itself to what was available, visible, or reasonably inferable at the time.

2.2 Evidence Base and Sources

This section draws primarily on **primary evidence**, including:

- Pre-operational scientific reviews and expert reports;
- Planning submissions and supporting technical documents;
- Governmental and regulatory publications relevant to shale gas development in the UK.

Secondary literature is referenced only where it was contemporaneous with planning decisions or widely cited in regulatory discourse at the time.

2.3 Early Recognition of Geological and Hydrogeological Uncertainty

Prior to the determination of planning applications for PNR, it was already well established in the scientific and regulatory literature that shale gas development in the UK would occur in geologically complex, faulted sedimentary basins, rather than the laterally extensive, relatively simple settings often cited from North American analogues.

National-level scientific reviews explicitly highlighted:

- The presence of extensive faulting within UK shale basins;
- The limited resolution of existing subsurface datasets at the scale relevant to individual well pads;
- The sensitivity of pressure-driven systems to small changes in stress and permeability.

These reviews did not predict specific outcomes at individual sites, but they did caution against over-confidence in subsurface predictability, particularly where faulted stratigraphy and shallow aquifer systems coexisted. (Royal Society and Royal Academy of Engineering, 2012; British Geological Survey, 2014; British Geological Survey, 2018)

2.4 Anticipated Challenges in Monitoring and Attribution

Pre-operational guidance and expert commentary also recognised that monitoring frameworks would play a decisive role in determining whether impacts could be detected, attributed, and managed.

Concerns articulated prior to operations included:

- The difficulty of detecting non-vertical migration pathways, particularly those controlled by faults or stratigraphic interfaces;
- The risk that monitoring systems designed to confirm predicted behaviour might be poorly suited to detecting unanticipated pathways;
- Temporal mismatches between operational events and reporting cycles, potentially obscuring slow or diffuse responses.

These issues were framed as design challenges, not as assertions of failure. (Royal Society and Royal Academy of Engineering, 2012; British Geological Survey, 2018)

2.5 Seismic Risk as a Known Uncertainty, Not a Novel Hazard

Induced seismicity was not an unforeseen issue in the context of UK shale gas exploration. Prior to PNR, it had already been acknowledged that:

- Fluid injection into stressed fault systems could induce seismic events;
- Magnitude and spatial extent were difficult to predict in advance;
- Monitoring thresholds would necessarily be reactive rather than preventative.

(Green, Styles and Baptie, 2012)

The introduction of traffic-light systems reflected an acceptance that seismic response would be observed and managed, rather than excluded entirely. This acceptance implicitly recognised that fault activation and pressure diffusion were plausible, even if expected to remain within defined bounds. (Department for Business, Energy & Industrial Strategy, 2019)

2.6 Treatment of Hydrogeology and Flood Risk in Planning Context

Planning and environmental documentation available prior to operations treated hydrogeological and flood risk considerations largely as static boundary conditions. Conceptual models generally assumed:

- Stable permeability structures;
- Predictable gradients;
- Limited interaction between deep operations and shallow groundwater systems.

While uncertainty was often acknowledged in principle, there is limited evidence in pre-operational documents that such uncertainty was framed as decision-relevant in the design of monitoring networks or reassessment triggers.

2.7 Independent and External Critiques

Alongside formal reviews, independent geoscientists and commentators raised concerns regarding:

- The density and orientation of faulting in the Fylde Basin;
- The limited capacity of sparse monitoring networks to resolve fault-controlled processes;
- The risk of interpreting absence of evidence as evidence of absence.

These critiques varied in tone and emphasis, but they shared a common focus on structural uncertainty, rather than on allegations of malpractice or inevitable harm. (Smythe, 2020)

2.8 Interpretation within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the materials described above establish that:

- Geological complexity and fault-controlled behaviour were recognised features of the regional setting;
- Monitoring limitations were understood as a general challenge;
- Uncertainty was acknowledged, but often treated as manageable within existing frameworks.

They do not establish that adverse outcomes were predicted, nor that impacts were expected to occur. They do, however, demonstrate that key assumptions regarding predictability, containment, and detectability were already known to be contestable.

2.9 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that planning and regulatory decisions for PNR were taken in a context where material uncertainties had already been identified, particularly in relation to faulted geology, pressure-driven processes, and monitoring sensitivity.

The critical assumption underpinning those decisions was that such uncertainties could be adequately bounded through model-based design and confirmatory monitoring, without the need for extensive hypothesis-testing or fault-focused observation prior to operations.

The sections that follow examine how this assumption was operationalised, and whether subsequent observations remained consistent with it.

Section 3 — Planning Assumptions and Design Logic

3.1 Purpose of This Section

This section examines how acknowledged uncertainties described in Section 2 were translated into planning assumptions, design choices, and regulatory conditions for the Preston New Road development. Its purpose is to document the logic by which uncertainty was operationalised, rather than to assess outcomes or compliance.

The focus is on what the planning framework assumed would be sufficient to manage geological, hydrogeological, and seismic risk at the site.

3.2 Evidence Base and Sources

This section draws primarily on **primary evidence**, including:

- Planning statements and environmental submissions provided by the operator;
- Flood Risk Assessments and supporting drainage documentation;
- Monitoring proposals submitted as part of the planning and permitting process;
- Regulatory responses and conditions attached to approvals.

Secondary sources are referenced only where they were incorporated explicitly into planning rationale or cited within primary documents. (Lancashire County Council, 2016; Environment Agency, 2015–2019; Cuadrilla Resources Ltd., 2018)

3.3 Conceptual Framing of the Subsurface

The planning and environmental documentation for Preston New Road relied on conceptual models that compartmentalised subsurface behaviour into discrete domains, typically treated as interacting weakly or indirectly.

In simplified terms, these domains included:

- Deep shale formations subject to hydraulic fracturing;
- Intermediate strata assumed to provide effective vertical separation;
- Shallow aquifer systems treated as hydraulically distinct from deep operations;
- Surface drainage and flood pathways addressed independently of subsurface processes.

While interconnections were acknowledged in principle, the planning logic generally treated these domains as functionally separable for the purposes of risk assessment and mitigation. (Lancashire County Council, 2016; Cuadrilla Resources Ltd., 2018)

3.4 Hydrogeological Assumptions Embedded in Design

Hydrogeological assessments submitted in support of planning approval generally assumed:

- Relatively stable permeability structures within shallow strata;
- Predictable hydraulic gradients under baseline conditions;
- Limited vertical connectivity outside wellbores and engineered pathways.
- These assumptions informed:
- The siting and depth of groundwater monitoring wells;
- The interpretation of baseline groundwater conditions;

The treatment of groundwater as a receptor rather than as a dynamic system responsive to stress redistribution.

While uncertainty was often acknowledged in narrative form, there is limited evidence that alternative hydrogeological conceptual models were explicitly tested prior to determination. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

3.5 Treatment of Faults Within Planning Logic

Faults were recognised within the geological setting of the site, particularly in the context of seismic risk. However, within planning documentation, faults were typically addressed as:

- Potential sources of seismic slip;
- Structural features to be avoided by well trajectories where practicable.

There is limited indication that faults were treated explicitly as potential hydraulic pathways within planning-stage hydrogeological or flood risk assessments. As a result, monitoring and modelling strategies were not generally oriented toward testing fault-controlled flow or pressure diffusion scenarios. (Cuadrilla Resources Ltd., 2018; Lancashire County Council, 2016; Green, Styles and Baptie, 2012)

3.6 Monitoring as a Confirmatory Tool

Monitoring frameworks proposed at the planning stage were largely designed to:

Establish baseline conditions;

- Detect deviations from predicted behaviour;
- Trigger predefined responses if thresholds were exceeded.

This reflects a confirmatory monitoring paradigm, in which monitoring is used to validate expected system behaviour rather than to test competing hypotheses about subsurface connectivity or response.

Key characteristics of this approach included:

- Monitoring locations selected based on predicted pathways;
- Limited spatial coverage outside the immediate operational footprint;
- Reporting intervals that prioritised regulatory compliance over high temporal resolution.

Such frameworks are effective where system behaviour is well constrained, but less well suited to environments characterised by structural complexity and uncertainty. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

3.7 Flood Risk Assessment as a Static Boundary Condition

Flood Risk Assessments supporting planning approval treated flood risk primarily as a surface-water and drainage management issue. Assumptions typically included:

- Stable infiltration characteristics;
- Fixed relationships between rainfall, runoff, and drainage capacity;
- Independence from deeper subsurface processes.
- There is limited evidence that flood risk was reassessed in light of potential:
- Stress redistribution within shallow strata;
- Changes in permeability associated with deformation;

- Altered groundwater–surface water interactions.

As a result, flood risk was largely framed as a design constraint, rather than as a variable potentially influenced by subsurface change. (Cuadrilla Resources Ltd., 2018; Lancashire County Council, 2016)

3.8 Regulatory Confidence and Decision Thresholds

Planning approval relied in part on assurances that:

- Regulatory oversight would detect adverse effects in a timely manner;
- Escalation mechanisms would be triggered if thresholds were exceeded;
- Data generated during operations would validate prior assumptions.

This logic presupposed that:

- Monitoring systems were appropriately located and sensitive;
- Relevant processes would manifest at detectable scales;
- Thresholds were aligned with meaningful system change.

The adequacy of these presuppositions was not itself a subject of explicit testing prior to operations. (Lancashire County Council, 2016; Environment Agency, 2015–2019; Department for Business, Energy & Industrial Strategy, 2019)

3.9 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the planning and design materials establish that:

- Uncertainty was acknowledged but operationalised through compartmentalisation;
- Monitoring was designed primarily to confirm predicted behaviour;
- Alternative conceptual models were not extensively explored at the planning stage.

These materials do not imply negligence or non-compliance. They do, however, demonstrate a systemic reliance on model-confirmatory approaches in a setting characterised by acknowledged geological complexity.

3.10 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that planning approval for Preston New Road relied on the assumption that complex subsurface behaviour could be adequately managed through predictive modelling and confirmatory monitoring, without the need for extensive hypothesis-testing or fault-focused observation prior to operations.

This assumption underpinned decisions regarding:

- Monitoring placement and density;
- The treatment of hydrogeology and flood risk as largely static;
- Confidence in regulatory thresholds as sufficient safeguards.

The sections that follow examine how this design logic interacted with site-specific conditions and emerging observations.

Section 4 — Hydrogeological Conditions Encountered at Site

4.1 Purpose of This Section

This section documents hydrogeological conditions encountered during early site works and drilling operations at Preston New Road, with particular focus on shallow groundwater behaviour. Its purpose is to establish what was directly observed, when it was observed, and how those observations relate to the assumptions described in Section 3.

The section does not seek to interpret causation or downstream effects. It confines itself to recording conditions encountered and responses taken, and to assessing whether those conditions were consistent with the conceptual models relied upon at the planning stage.

4.2 Evidence Base and Sources

This section draws primarily on **primary evidence**, including:

- Operator well construction records and addenda;
- Regulatory correspondence and reporting related to drilling activities;
- Supporting technical documentation describing drilling responses and mitigation measures.

Where reference is made to later analytical interpretations, these are clearly identified as such and not treated as contemporaneous knowledge. (Cuadrilla Resources Ltd., 2018; Lancashire County Council, 2016)

4.3 Encounter of Pressurised Groundwater During Early Works

During the installation of the conductor casing at Preston New Road, pressurised groundwater was encountered at shallow depth, reported at approximately 29 metres below ground level. This condition required unplanned intervention to stabilise the borehole, including the use of weighted drilling fluids to arrest artesian flow.

The encounter occurred prior to hydraulic fracturing operations, during an early phase of site development. As such, it represents a direct observation of pre-existing subsurface conditions, rather than a response to high-pressure injection. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

4.4 Characteristics of the Observed Condition

The reported artesian behaviour indicates that:

- Hydraulic head within the shallow subsurface exceeded surface elevation at the point of interception;
- Permeability and connectivity at that depth were sufficient to sustain upward flow;
- Existing conceptual models did not explicitly anticipate the magnitude of pressure encountered at that level.

The documentation does not indicate that this condition was associated with structural failure or loss of control. However, it does demonstrate that shallow groundwater behaviour was more dynamic than assumed in baseline descriptions.

4.5 Response and Treatment Within the Regulatory Framework

The immediate response to the artesian condition focused on operational control and borehole stability, rather than on re-evaluation of site-wide hydrogeological assumptions. Mitigation measures were implemented to allow drilling to proceed safely, and the condition was treated as a manageable engineering issue.

There is limited evidence that the encounter triggered:

- A revision of the shallow hydrogeological conceptual model;
- Reassessment of monitoring placement or density;
- Review of flood risk or surface–subsurface interaction assumptions.

The response was therefore **procedural and localised**, rather than analytical and systemic. (Environment Agency, 2015–2019; Cuadrilla Resources Ltd., 2018)

4.6 Relationship to Planning-Stage Assumptions

The encounter of pressurised groundwater at shallow depth is relevant to several assumptions identified in Section 3, including:

- The expectation of stable hydraulic gradients in shallow strata;
- The treatment of shallow aquifers as passive receptors rather than pressure-responsive systems;
- The implicit separation between drilling operations and wider hydrogeological behaviour.

While the planning documentation acknowledged uncertainty in general terms, the observed condition demonstrates that **site-**specific behaviour departed from baseline expectations at an early stage.

4.7 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the artesian condition constitutes **primary factual evidence** of shallow subsurface behaviour at the site. It does not, in itself:

- Establish hydraulic connectivity to deeper formations;
- Imply off-site migration pathways;
- Indicate adverse impact.

It does, however, narrow the range of plausible conceptual models by demonstrating that upward hydraulic gradients and transmissive pathways existed within the shallow subsurface prior to fracturing.

4.8 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that material hydrogeological conditions were encountered at an early stage that were not fully anticipated in planning-stage conceptual models. The critical assumption exposed by this observation is that shallow groundwater behaviour could be treated as predictable and weakly pressurised under baseline conditions.

Although the condition was managed operationally, there is limited evidence that it prompted a reassessment of:

- Hydrogeological uncertainty bounds;
- Monitoring design relative to faulting or pressure pathways;

- The interaction between shallow groundwater, surface drainage, and later operational phases.

The sections that follow examine how this early divergence between assumption and observation interacted with subsequent operational and monitoring frameworks.

Section 5 — Induced Seismicity and Fault Activation

5.1 Purpose of This Section

This section documents the occurrence, characteristics, and regulatory treatment of induced seismicity associated with shale gas operations at Preston New Road. Its purpose is to establish what was observed, how it related to pre-existing assumptions, and how it was managed within the regulatory framework, without asserting broader impacts or causal chains beyond those supported by primary evidence.

5.2 Evidence Base and Sources

This section draws primarily on **primary evidence**, including:

- Seismic monitoring data reported by statutory bodies;
- Operator reporting submitted under regulatory requirements;
- Post-event analyses and reviews produced or commissioned by government agencies and expert panels.

Secondary interpretations are referenced only where they were formally adopted or cited by regulatory authorities. (Green, Styles and Baptie, 2012; Department for Business, Energy & Industrial Strategy, 2019)

5.3 Occurrence of Induced Seismicity During Operations

During hydraulic fracturing operations at Preston New Road in 2018–2019, a sequence of **induced seismic events** was recorded, including a maximum local magnitude event of ML 2.9. This exceeded the operational threshold established under the Traffic Light System (TLS), resulting in the suspension of fracturing activities.

The seismicity exhibited characteristics that included:

- Spatial clustering consistent with fault-controlled behaviour;
- Temporal association with injection activity;
- Continued seismic response following cessation of injection.

These observations were documented contemporaneously and are not contested. (British Geological Survey, 2019)

5.4 Relationship to Pre-Operational Expectations

Prior to operations, induced seismicity was recognised as a **plausible risk**, and the TLS was explicitly designed to manage such events. The planning and regulatory framework therefore did not assume seismicity would be absent, but that it would:

- Remain within predefined magnitude limits;
- Be responsive to operational controls;
- Cease promptly following injection shutdown.

The observed seismic sequence challenged aspects of these expectations, particularly with respect to:

- Event magnitude relative to thresholds;

- Persistence of seismic response after operational pause;
- Spatial migration of events along fault structures.

(British Geological Survey, 2019; Kettlety et al., 2020)

5.5 Fault Activation as a Known but Poorly Bounded Process

Post-event analyses identified that the seismicity was associated with **reactivation of pre-existing faults** within the subsurface. This aligns with established geomechanical understanding that fluid pressure changes can reduce effective stress on critically stressed faults.

What remained less well constrained prior to operations was:

- The degree of hydraulic connectivity between injection zones and fault structures;
- The spatial extent over which pressure diffusion could occur;
- The sensitivity of faults to relatively small pressure perturbations.

These parameters were acknowledged as uncertain but were not tightly bounded in advance.

(Kettlety et al., 2020; British Geological Survey, 2019; Verdon et al., 2019)

5.6 Implications for Conceptual Models and Monitoring

The seismic response at Preston New Road has implications for how subsurface behaviour was conceptualised at the planning stage. Specifically, it demonstrates that:

- Faults acted as active mechanical elements rather than passive structural features;
- Pressure diffusion occurred over distances greater than those assumed in simplified models;
- Monitoring frameworks were effective at detecting seismic response, but were not designed to prevent it.

This distinction is important: the monitoring system functioned as designed, but it was **inherently reactive**.

(Department for Business, Energy & Industrial Strategy, 2019; British Geological Survey, 2019)

5.7 Regulatory Interpretation and Response

Regulatory responses to the seismicity included:

- Immediate suspension of hydraulic fracturing activities;
- Review of seismic data and fault interpretations;
- Commissioning of further expert analysis.

Subsequently, government concluded that it could not be confident in the ability to manage induced seismicity within acceptable bounds under the existing framework, contributing to the decision to introduce a moratorium on hydraulic fracturing.

This decision implicitly acknowledged limits to predictive confidence, rather than attributing failure to implementation or compliance.

5.8 Interpretation within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the induced seismicity at Preston New Road constitutes primary evidence of fault activation and pressure-driven response to injection.

It does not, in itself:

- Establish pathways for fluid migration beyond those directly observed;
- Imply damage to other environmental receptors;
- Demonstrate systemic failure across all regulatory domains.

It does, however, confirm that fault behaviour and pressure diffusion were more dynamic and less predictable than planning-stage assumptions had implied.

5.9 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that induced seismicity at Preston New Road fell within a category of risk that was acknowledged in advance but insufficiently bounded in practice. The critical assumption exposed by the seismic sequence was that fault response could be reliably constrained through operational thresholds and reactive controls, despite limited prior testing of fault sensitivity and connectivity.

The significance of this finding lies not in the occurrence of seismicity per se, but in what it reveals about the limits of model-confirmatory approaches in faulted geological settings.

The sections that follow examine how this confirmed fault activity intersects with hydrogeological assumptions, monitoring blind spots, and surface–subsurface interactions.

Section 6 — Monitoring Frameworks and Structural Blind Spots

6.1 Purpose of This Section

This section examines the design, scope, and functional limits of monitoring frameworks implemented at Preston New Road. Its purpose is to assess whether the monitoring systems in place were capable, by design, of detecting the full range of plausible and decision-relevant subsurface and surface responses identified in preceding sections.

The analysis does not evaluate compliance or performance against regulatory requirements. Instead, it focuses on what the monitoring frameworks were structured to observe, and, by implication, what they were not structured to detect.

6.2 Evidence Base and Sources

This section draws primarily on **primary evidence**, including:

- Monitoring proposals submitted as part of planning and permitting applications;
- Regulatory conditions and reporting requirements;
- Published descriptions of monitoring network design and objectives.

Secondary commentary is referenced only where it reflects contemporaneous regulatory understanding. (Environment Agency, 2015–2019; Cuadrilla Resources Ltd., 2018; British Geological Survey, 2019)

6.3 Monitoring Objectives as Defined at the Planning Stage

Monitoring systems at Preston New Road were designed to meet several stated objectives, including:

- Establishment of baseline conditions;
- Detection of deviations from predicted behaviour;
- Verification of compliance with regulatory thresholds;
- Provision of data to support operational decision-making.

These objectives reflect a **confirmatory monitoring paradigm**, in which monitoring is intended to validate the performance of predictive models and risk assessments, rather than to explore alternative or unexpected system behaviours. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

6.4 Spatial Configuration and Pathway Assumptions

The spatial distribution of monitoring infrastructure was informed by anticipated pathways and receptors, as defined in planning-stage conceptual models. As a result:

- Monitoring wells and sensors were preferentially located along predicted gradients and near operational infrastructure;
- Limited monitoring was directed toward fault-intersecting zones or structural interfaces not identified as primary pathways;
- Off-site and down-gradient coverage was comparatively sparse.

This configuration was consistent with the assumption that dominant pathways were already well characterised. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

6.5 Temporal Resolution and Reporting Lag

Monitoring data were typically reported on **periodic cycles**, aligned with regulatory reporting requirements rather than with the temporal dynamics of subsurface processes.

This introduces several structural constraints:

- Slow or diffuse responses may be averaged out or masked;
- Transient signals may fall between reporting intervals;
- Attribution becomes more difficult where responses lag operational triggers.

Such limitations are inherent to periodic reporting frameworks and do not imply deficiency in implementation. (Environment Agency, 2015–2019)

6.6 Threshold-Based Escalation and Reactive Logic

Monitoring frameworks incorporated predefined thresholds intended to trigger escalation or intervention. This approach assumes that:

- Meaningful system change will manifest as threshold exceedance;
- Thresholds are aligned with early indicators of undesired behaviour;
- Processes of concern are sufficiently energetic to cross detection limits.

"In faulted and pressure-responsive systems, however, redistribution of stress or flow may occur without immediate threshold exceedance, particularly where effects are spatially distributed or temporally delayed. (Environment Agency, 2015–2019; Department for Business, Energy & Industrial Strategy, 2019)

6.7 Interface Between Seismic and Hydrogeological Monitoring

Seismic monitoring at Preston New Road successfully detected fault activation, demonstrating that faults were mechanically responsive to injection-induced pressure changes. However, seismic and hydrogeological monitoring were largely treated as parallel but distinct domains, with limited integration at the conceptual level.

As a result:

- Confirmation of fault activity did not automatically trigger reassessment of hydrogeological connectivity assumptions;
- Monitoring systems were not reoriented to test fault-controlled fluid pathways;
- Data streams were interpreted within their original disciplinary silos.

6.8 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the monitoring frameworks at Preston New Road constitute primary evidence of design intent, rather than of environmental outcome.

They demonstrate that:

- Monitoring was effective at detecting anticipated signals (e.g. seismic events);
- Monitoring was less well suited to detecting unanticipated or diffuse processes;
- Absence of detected impact cannot be equated with absence of process where detection capability is limited by design.

This interpretation does not rely on tertiary observations and does not assert that undetected impacts occurred.

6.9 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that monitoring at Preston New Road was structurally aligned with a model-confirmatory approach, in which predicted behaviours were monitored for compliance, rather than alternative behaviours tested for exclusion.

The critical assumption exposed by this analysis is that processes of concern would necessarily manifest in ways detectable by the monitoring systems in place, within the spatial and temporal bounds of those systems.

Where that assumption does not hold — particularly in faulted, pressure-responsive environments — monitoring may produce false negatives without any breach of procedure or oversight.

The sections that follow consider how this structural limitation intersects with surface observations and secondary evidence, and how such evidence should be interpreted within a disciplined analytical framework.

Section 7 — Corroborative Secondary Evidence: LiDAR and Satellite Observations

7.1 Purpose of This Section

This section summarises secondary evidence derived from remote sensing, including LiDAR elevation datasets and satellite imagery time series, in order to assess whether observed surface patterns are spatially and temporally consistent with mechanisms already identified in primary evidence.

The purpose of this section is explicitly corroborative. These data are not used to infer causation, nor to establish environmental impact independently. They are included to test coherence between documented subsurface behaviour and surface-level patterns, within the evidence hierarchy defined in Section 1.

7.2 Evidence Base and Analytical Constraints

The secondary evidence considered comprises:

- Repeat LiDAR elevation datasets covering the Fylde area (2018–2022);
- Publicly available satellite imagery, including Google Earth time series.

These datasets are subject to known limitations, including:

- Vertical and horizontal resolution constraints;
- Artefacts introduced by vegetation, land management, and interpolation;
- Uncertainty in attribution of surface change to specific subsurface processes.

Accordingly, the analysis focuses on relative spatial patterns and persistence, rather than on absolute magnitudes or precise deformation values. (Environment Agency, 2018–2022; Google Earth Pro, 2009–2024)

7.3 LiDAR-Derived Elevation Change Patterns

LiDAR differencing indicates localised areas of uplift and subsidence within the wider Fylde landscape. These patterns are:

- Spatially heterogeneous rather than uniform;
- Persistent across multiple survey intervals;
- Not readily explained by regional-scale processes alone, at the resolution of the available data.

In proximity to Preston New Road, LiDAR analyses identify small-magnitude but spatially coherent elevation changes, which align more closely with structural or deformation-controlled zones than with diffuse settlement or compaction expected from agricultural activity.

(Environment Agency, 2018–2022; British Geological Survey, 2018)

No attempt is made here to attribute these patterns to specific operational causes.

7.4 Satellite Time Series: Surface Hydrology and Vegetation Signals

Satellite imagery time series show changes in surface hydrology and vegetation condition in areas down-gradient or downstream of the site, including:

- Episodic water pooling in low-lying areas;
- Persistent changes in vegetation vigour or colouration;
- Temporal persistence beyond single weather events.

Such signals are non-specific and can arise from multiple drivers, including land use change, drainage modification, or climatic variability. However, their spatial distribution is not random, and in several instances aligns with:

- Topographic lows;
- Drainage pathways;
- Zones plausibly influenced by shallow groundwater behaviour.

(Google Earth Pro, 2000–2024; British Geological Survey, 2018)

7.5 Relationship to Primary Evidence

When considered alongside primary evidence presented in earlier sections, the secondary observations described above are consistent with:

- The presence of shallow pressurised groundwater (Section 4);
- Fault-controlled deformation and stress redistribution (Section 5);
- Monitoring frameworks not optimised for detecting diffuse or delayed responses (Section 6).

Importantly, secondary evidence is not used to assert that these mechanisms occurred, but to demonstrate that surface patterns do not contradict them. (Cuadrilla Resources Ltd., 2018; British Geological Survey, 2019; Department for Business, Energy & Industrial Strategy, 2019)

7.6 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document:

- LiDAR and satellite observations serve as pattern corroborators;
- They do not establish new mechanisms;
- They do not substitute for direct measurement or regulatory determination.

Their value lies in showing that surface behaviour remained within the envelope of plausibility defined by primary evidence, rather than providing independent confirmation of impact.

7.7 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that secondary remote sensing evidence does not undermine the plausibility of mechanisms identified through primary sources, and in several respects is spatially and temporally coherent with them.

The critical planning-relevant implication is not that surface change has been proven, but that the absence of detected impact within primary monitoring frameworks cannot be assumed to imply the absence of process, particularly where secondary evidence indicates structured, non-random surface behaviour.

This reinforces the importance of aligning monitoring design with the full range of plausible system responses identified *or acknowledged* at the planning stage.

Section 8 — Implications for Burniston and Comparable Sites

8.1 Purpose of This Section

This section considers the relevance of the preceding analysis to prospective shale gas developments in the Fylde Basin and comparable geological settings, with particular reference to the proposed Burniston site. Its purpose is not to predict outcomes, but to identify whether the same categories of uncertainty, planning assumptions, and monitoring dependencies observed at Preston New Road may reasonably recur if similar approaches are adopted.

The section is explicitly prospective and analytical. It does not assert that outcomes at Preston New Road will be replicated elsewhere.

8.2 Evidence Base and Scope

This section draws on:

- Regional geological and hydrogeological characterisation of the Fylde Basin;
- Planning-stage information publicly available for proposed sites;
- The analytical framework established in Sections 1–7 of this document.

No site-specific operational data are assumed for Burniston, and no tertiary observational material is relied upon.

8.3 Geological and Hydrogeological Context

The Burniston area lies within a structurally complex sedimentary basin, characterised by:

- Faulted stratigraphy;
- Interactions between deep formations and shallow groundwater systems;
- Spatial variability in permeability and hydraulic connectivity.

These characteristics are not identical to those at Preston New Road, but they fall within the same broad class of geological environment in which:

- Fault behaviour cannot be treated as purely mechanical;
- Hydraulic connectivity may be anisotropic and poorly resolved at planning scale;
- Site-specific conditions may depart from regional averages.

(Environment Agency, 2015–2019; Lancashire County Council, 2016; Applicant planning documents, Burniston)

8.4 Foreseeable Planning-Stage Challenges

Based on the analysis presented in earlier sections, several foreseeable challenges arise for sites such as Burniston if planning frameworks rely on similar logic to that applied at Preston New Road.

These include:

- Reliance on conceptual models that compartmentalise deep operations, shallow groundwater, and surface processes;

- Monitoring designs optimised to confirm predicted behaviour rather than to test alternative pathways;
- Treatment of uncertainty as acceptable risk rather than as a trigger for hypothesis-testing or adaptive monitoring design.

These challenges are not specific to any one site, but to the interaction between complex geology and model-confirmatory planning approaches.

8.5 Monitoring Design and the Risk of Structural Blind Spots

As demonstrated in Sections 5 and 6, confirmation of fault activity does not automatically translate into reassessment of hydrogeological assumptions unless monitoring systems are explicitly integrated.

For future sites, including Burniston, a key implication is that:

- Seismic confirmation of fault responsiveness should be treated as decision-relevant information beyond seismic risk alone;
- Monitoring frameworks that do not incorporate fault-intersecting or boundary-focused observation may be unable to exclude certain classes of response;
- Absence of detected impact cannot be assumed to indicate absence of process where detection capability is limited by design.

8.6 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document, the relevance of Preston New Road to Burniston is structural rather than evidential.

That is:

- No direct inference is made from outcomes at one site to expected outcomes at another;
- The relevance lies in the planning logic, treatment of uncertainty, and monitoring philosophy, not in site-specific results.

This distinction is essential to avoid inappropriate extrapolation.

8.7 Section Synthesis: Implications for Planning Judgement

In synthesis, this section indicates that future shale gas developments in faulted basin settings may reasonably be expected to encounter comparable categories of uncertainty observed at Preston New Road, even if the specific manifestations differ.

The critical planning-relevant assumption exposed by this comparison is that existing planning and monitoring frameworks are sufficient to bound uncertainty without substantial adaptation to site-specific structural complexity.

Where that assumption is relied upon, the risk is not that impacts are inevitable, but that decision-making confidence may again exceed observational capability.

To illustrate how the structural uncertainties identified above may manifest at other prospective sites, Appendix A provides a first-principles, satellite-based assessment of baseline hydrogeological sensitivity at Burniston. This assessment does not assert impact or prediction, but demonstrates that off-site receptors, preferential pathways, and boundary-controlled discharge zones exist prior to development and must therefore be treated as design constraints for monitoring and assessment.

Section 9 — Hydrogeological System Failure

9.1 Purpose of This Section

This section demonstrates how hydrogeological risk at Preston New Road was systematically under-characterised, under-tested, and subsequently managed in a manner that prioritised operational continuity over conceptual reassessment.

Unlike earlier sections, which establish context and assumptions, this section draws together documented contradictions between planning-stage hydrogeological models and site-observed conditions, and examines how those contradictions were treated within the regulatory framework.

The purpose is not to assert environmental impact, but to demonstrate a failure mode in system understanding and governance.

9.2 Evidence Base and Scope

This section draws on **primary evidence**, including:

- Planning-stage hydrogeological assessments and Flood Risk Assessments;
- Drilling records and well construction addenda;
- Regulatory correspondence relating to groundwater encounters;
- Published post hoc technical analyses relied upon by regulators.

Secondary and tertiary evidence is referenced only where it illustrates what the primary framework failed to detect or test, not to establish impact.

9.3 Planning-Stage Hydrogeological Model: Assumptions and Limits

At the time of planning determination, hydrogeological characterisation at Preston New Road was based on a conceptual model that treated shallow groundwater systems as stable, weakly pressurised, and hydraulically separable from deeper operations.

Key assumptions included:

- Predictable hydraulic gradients governed primarily by topography;
- Absence of significant upward hydraulic head at shallow depth;
- Limited vertical connectivity outside engineered well paths;
- Hydrogeology treated as a receptor framework rather than a stress-responsive system.

While uncertainty was acknowledged in qualitative terms, the model did not incorporate explicit tests of alternative conceptualisations, such as fault- or fracture-controlled pressure connectivity within shallow strata. (Cuadrilla Resources Ltd., 2018; Lancashire County Council, 2016)

9.4 Encountered Artesian Conditions as a Model-Invalidating Observation

As documented in Section 4, pressurised groundwater was encountered at approximately 29 metres below ground level during conductor installation, necessitating unplanned weighting of drilling fluids to arrest artesian flow.

This observation is significant because:

- It occurred prior to hydraulic fracturing, excluding injection-induced pressurisation as a cause;
- It demonstrates upward hydraulic gradients inconsistent with baseline assumptions;
- It indicates transmissive pathways capable of sustaining flow at shallow depth.

From a hydrogeological perspective, this constitutes an observation inconsistent with baseline model assumptions, and one that would ordinarily warrant reassessment of the conceptual framework. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

9.5 Regulatory Treatment: Engineering Control Without Conceptual Reassessment

The response to the artesian condition focused on engineering mitigation, enabling drilling to proceed safely. This approach addressed immediate operational risk but did not trigger:

- Revision of the hydrogeological conceptual model;
- Expansion or relocation of groundwater monitoring;
- Reassessment of Flood Risk or surface–subsurface interaction assumptions;
- Consideration of whether the permitted risk envelope remained valid.

The artesian encounter was therefore treated as a localised construction issue, rather than as evidence of systemic hydrogeological mischaracterisation. (Environment Agency, 2015–2019; Cuadrilla Resources Ltd., 2018)

9.6 Implications for Flood Risk and Surface–Subsurface Coupling

Flood Risk Assessments for Preston New Road treated infiltration capacity, groundwater levels, and drainage behaviour as static boundary conditions.

The documented presence of shallow pressurised groundwater directly challenges this framing, because:

- Elevated groundwater head reduces infiltration capacity;
- Shallow pressure systems can alter surface drainage behaviour;
- Stress redistribution and deformation (later confirmed seismically) can modify permeability.

Despite this, there is limited evidence that Flood Risk assumptions were revisited in light of the artesian encounter or subsequent subsurface behaviour. (Cuadrilla Resources Ltd., 2018; Lancashire County Council, 2016; British Geological Survey, 2019)

9.7 Structural Blind Spot: Hydrogeology Treated as Passive

The handling of hydrogeological information at Preston New Road reveals a structural blind spot: hydrogeology was treated as passive and observational, not as an active system capable of non-linear response.

This is evident in:

- Monitoring designs that assumed stable baseline behaviour;
- Absence of trigger conditions tied to unexpected groundwater head or flow;
- Lack of integration between hydrogeological and geomechanical findings.

As a result, early warning signals that should have prompted conceptual revision were instead absorbed into routine operational management. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

9.8 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document:

- The artesian groundwater encounter constitutes primary evidence of a departure from assumed baseline conditions;
- The absence of regulatory reassessment constitutes primary evidence of governance response, not inference;
- Secondary and tertiary observations merely illustrate the consequences of this blind spot.

9.9 Section Synthesis: Hydrogeological Failure Mode Identified

In synthesis, this section demonstrates that the hydrogeological system failure at Preston New Road did not arise from an unforeseen phenomenon, but from the failure to treat contradictory observations as decision-relevant.

The critical failure mode is identified as follows:

Planning and regulatory confidence rested on a hydrogeological model that was contradicted by early site observations, yet was not revised, re-tested, or re-bounded before operations continued.

This failure mode is systemic, reproducible, and independent of intent or compliance.

Section 10 — Monitoring System Failure

10.1 Purpose of This Section

This section demonstrates that the monitoring framework implemented at Preston New Road was structurally incapable of detecting or excluding several classes of plausible system response, despite functioning largely as designed.

The purpose is not to assess compliance, data quality, or diligence, but to identify a design-level failure mode in which monitoring was optimised to confirm expected behaviour rather than to test alternative hypotheses arising from geological complexity and early site observations. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

10.2 Evidence Base and Scope

This section draws on **primary evidence**, including:

- Planning and permitting documentation specifying monitoring objectives and layouts;
- Regulatory guidance defining monitoring requirements and reporting frequency;
- Publicly available descriptions of the monitoring systems in operation;
- Regulatory responses to emerging observations during operations.

Secondary material is referenced only where it demonstrates the limitations of confirmatory monitoring approaches in faulted and pressure-responsive systems.

10.3 Monitoring Philosophy: Confirmation Rather Than Hypothesis Testing

Monitoring at Preston New Road was designed around a model-confirmatory philosophy, whereby:

- Baseline conditions were established;
- Operational data were compared against predicted envelopes;
- Threshold exceedance triggered predefined responses.

This approach presupposes that:

- The dominant pathways and receptors are correctly identified at the planning stage;
- System response will manifest within those pathways;
- Deviations of concern will cross predefined detection thresholds.

Such a philosophy is appropriate where system behaviour is well constrained, but it is structurally unsuited to environments where alternative pathways are plausible but untested. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

10.4 Spatial Blind Spots in Monitoring Design

Monitoring infrastructure was spatially configured according to anticipated pathways, as defined by planning-stage conceptual models. As a consequence:

- Monitoring wells and sensors were concentrated near the well pad and predicted gradients;
- Fault-intersecting zones were not deliberately targeted unless already assumed to be relevant;

- Off-site and boundary locations were under-represented.

This created a structural blind spot whereby processes occurring outside predicted pathways could proceed without detection, not because monitoring failed, but because it was never designed to observe them. (Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

10.5 Temporal Blind Spots and Reporting Lag

Monitoring data were collected and reported at intervals aligned with regulatory requirements rather than with the temporal dynamics of subsurface systems.

This introduces several known limitations:

- Slow pressure diffusion may not produce abrupt threshold exceedance;
- Transient or episodic responses may be missed between sampling intervals;
- Delayed responses may be misattributed or rendered ambiguous.

In pressure-responsive and fault-controlled systems, these limitations materially reduce the ability of monitoring to function as an early-warning mechanism. (Environment Agency, 2015–2019)

10.6 Threshold-Based Escalation as a Reactive Control

Escalation mechanisms at Preston New Road relied on **threshold-based triggers**, under the assumption that:

- System change of concern would manifest as discrete exceedance events;
- Thresholds corresponded to early indicators of unacceptable behaviour;
- Absence of exceedance implied acceptable system performance.

However, significant redistribution of pressure or flow can occur without breaching thresholds, particularly where effects are spatially distributed, cumulative, or delayed.

This creates a condition in which false negatives are structurally possible, even under full procedural compliance. (Environment Agency, 2015–2019; Department for Business, Energy & Industrial Strategy, 2019)

10.7 Failure to Integrate Seismic and Hydrogeological Signals

As demonstrated in Section 5, seismic monitoring confirmed fault activation and pressure diffusion during operations. However, this information was **not operationally integrated** into hydrogeological monitoring strategy.

Specifically:

- Confirmation of fault responsiveness did not trigger reassessment of hydraulic connectivity assumptions;
- Monitoring networks were not reoriented to test fault-controlled fluid pathways;
- Seismic and hydrogeological datasets were interpreted in parallel rather than as components of a coupled system.

This siloed interpretation represents a system-level integration failure, not a data failure. (British Geological Survey, 2019; Cuadrilla Resources Ltd., 2018; Environment Agency, 2015–2019)

10.8 Absence of Re-Opener Triggers Linked to Monitoring Limitations

- Planning and permitting conditions did not include automatic re-opener mechanisms tied to:
- Unexpected hydrogeological conditions (e.g. artesian head);
- Confirmation of fault activation beyond assumed bounds;
- Inability of monitoring to test alternative conceptual models.

As a result, monitoring outputs were interpreted within the original assumption set, even when those assumptions were contradicted by observed behaviour. (Environment Agency, 2015–2019; Lancashire County Council, 2016)

10.9 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document:

- The monitoring framework constitutes primary evidence of design intent;
- Its limitations are demonstrable without reliance on outcome-based inference;
- Absence of detected impact cannot be interpreted as absence of process where monitoring is structurally incomplete.

This conclusion does not depend on tertiary observations or post hoc attribution.

10.10 Section Synthesis: Monitoring Failure Mode Identified

In synthesis, this section identifies the monitoring system failure at Preston New Road as follows:

Monitoring was designed to confirm predicted behaviour within a constrained conceptual model, and therefore lacked the spatial, temporal, and integrative capacity to detect or exclude alternative system responses in a faulted, pressure-responsive geological setting.

This failure mode is systemic, reproducible, and independent of procedural compliance. It explains how contradictory observations could emerge without triggering formal reassessment or loss of regulatory confidence.

Section 11 — Seismic Governance Failure

11.1 Purpose of This Section

This section demonstrates that, even where monitoring systems successfully detected a significant subsurface response — namely induced seismicity — the governance framework governing seismic risk at Preston New Road failed to translate detection into effective planning control.

The failure identified here is not one of monitoring capability, but of institutional framing: seismicity was treated as an operational hazard to be managed, rather than as a planning-relevant signal of assumption breach requiring reassessment of development acceptability. (Department for Business, Energy & Industrial Strategy, 2019; British Geological Survey, 2019)

11.2 Evidence Base and Scope

This section draws on primary evidence, including:

- Seismic monitoring data and official reporting;
- Regulatory documentation describing the Traffic Light System (TLS);
- Government-commissioned reviews and post-event analyses;
- Policy statements and regulatory responses issued during and after operations.

Secondary commentary is referenced only where it reflects the contemporaneous understanding adopted by regulators.

11.3 Seismicity as a Known but Bounded Risk at Planning Stage

At the planning stage, induced seismicity was acknowledged as a plausible consequence of shale gas operations. The accepted mitigation strategy was the Traffic Light System, which was explicitly designed to:

- Detect seismic events in near real time;
- Trigger operational pauses or shutdowns when magnitude thresholds were exceeded;
- Allow operations to resume once conditions stabilised.

This framework implicitly framed seismicity as a manageable operational risk, rather than as a planning constraint tied to site acceptability. (Green, Styles and Baptie, 2012; Department for Business, Energy & Industrial Strategy, 2019)

11.4 Observed Seismic Behaviour and Its Significance

As documented in Section 5, seismic activity at Preston New Road exceeded pre-defined thresholds, culminating in a maximum local magnitude event of ML 2.9, followed by continued seismic response after injection ceased.

From a governance perspective, the critical features of this behaviour were:

- Confirmation of fault activation;
- Evidence of pressure diffusion beyond immediate injection intervals;
- Demonstration that operational controls did not result in immediate system stabilisation.

These characteristics directly challenged the assumption that seismic response would be both bounded and promptly controllable. (British Geological Survey, 2019; Kettlety et al., 2020)

11.5 TLS as an Operational Control, Not a Planning Safeguard

The Traffic Light System functioned as designed in detecting seismic events and triggering operational pauses. However, it is structurally limited in several respects:

- It is reactive, responding only after seismic events occur;
- It does not prevent fault activation, only manage its progression;
- It does not assess whether the occurrence of seismicity itself invalidates planning assumptions.

As such, the TLS cannot answer the planning-relevant question of whether continued development remains acceptable once fault responsiveness is confirmed. (Department for Business, Energy & Industrial Strategy, 2019)

11.6 Absence of Planning-Level Reassessment Triggers

Despite the confirmation of fault activation and pressure diffusion, there is limited evidence that seismic exceedances triggered:

- Formal reassessment of planning consent assumptions;
- Review of hydrogeological or flood risk models;
- Consideration of whether the development remained within its permitted risk envelope.

Instead, seismicity was treated as an operational compliance issue, addressed within the regulatory domain, rather than as a signal necessitating planning reconsideration.

This separation created a governance gap between detection and decision. (Lancashire County Council, 2016; Environment Agency, 2015–2019)

11.7 Misclassification of Seismicity as Isolated Hazard

A critical governance failure arises from the treatment of seismicity as a stand-alone hazard, disconnected from other system components.

In reality:

- Seismicity confirms mechanical connectivity along faults;
- Fault activation implies pathways relevant to fluid and pressure migration;
- Pressure diffusion observed seismically has implications beyond ground motion alone.

By failing to integrate seismic findings into wider system understanding, governance structures effectively ring-fenced seismicity, preventing it from informing broader risk assessment. (British Geological Survey, 2019; Department for Business, Energy & Industrial Strategy, 2019)

11.8 Government Response as Implicit Acknowledgement of Governance Limits

Subsequent government decisions to suspend and ultimately impose a moratorium on hydraulic fracturing were justified on the basis that confidence in the ability to manage induced seismicity was insufficient.

This response implicitly acknowledges that:

- Predictive control was not achievable within existing frameworks;
- Operational management alone was inadequate;
- The planning and regulatory system lacked tools to bound uncertainty acceptably.

However, this acknowledgement occurred after seismic outcomes had already materialised, rather than being triggered by earlier signals. (Department for Business, Energy & Industrial Strategy, 2019)

11.9 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document:

- Seismic monitoring data constitute primary evidence of subsurface response;
- The TLS constitutes primary evidence of governance design;
- The failure identified arises from the relationship between detection and decision-making, not from inference or outcome-based reasoning.

11.10 Section Synthesis: Seismic Governance Failure Mode Identified

In synthesis, this section identifies the seismic governance failure at Preston New Road as follows:

Seismicity was successfully detected but institutionally misclassified as an operational hazard rather than a planning-relevant signal of assumption breach, resulting in continued reliance on a consent framework whose foundational premises had been contradicted.

This failure mode explains how confirmation of fault activation did not trigger reassessment of development acceptability, despite its implications for hydrogeology, monitoring adequacy, and system control.

Section 12 — Planning and Regulatory Circularity

12.1 Purpose of This Section

This section demonstrates that the failures identified in Sections 9–11 were not isolated or accidental, but were enabled and sustained by a circular allocation of responsibility between planning authorities, regulators, and operators.

The purpose is to show how system-level risk was never substantively owned, because each institutional actor relied on another to assess, manage, or intervene — even as core assumptions were contradicted by evidence. (Lancashire County Council, 2016; Environment Agency, 2015–2019; Department for Business, Energy & Industrial Strategy, 2019)

12.2 Evidence Base and Scope

This section draws on **primary evidence**, including:

- Planning decision notices and committee materials;
- Regulatory remit statements and statutory guidance;
- Correspondence and public statements by regulatory bodies;
- Government policy framing regarding shale gas regulation.

It does not rely on outcome-based inference or retrospective judgement, but on the documented division of responsibilities as they existed at the time.

12.3 Role of the Planning Authority: Conditional Deference

Planning authorities considering development at Preston New Road operated within a framework that explicitly deferred technical risk assessment and control to specialist regulators.

In practice, this meant that:

- Geological, hydrogeological, and seismic risks were treated as matters "to be controlled by the appropriate regulator";
- Planning acceptability was assessed on the assumption that regulatory controls would be sufficient;
- Planning conditions focused on process compliance rather than system performance.

This approach is consistent with established planning doctrine, but it presupposes that regulators are both willing and able to reassess acceptability when assumptions fail. (Lancashire County Council, 2016)

12.4 Role of Regulators: Compliance Within Approved Envelopes

Regulators operated within defined statutory remits focused on:

- Permit compliance;
- Threshold-based operational control;
- Enforcement against specific breaches.

Crucially, regulators did not hold responsibility for determining whether planning assumptions remained valid once operations were underway. Their function was to regulate activity within the permitted envelope, not to question the envelope itself.

As a result:

- Regulatory action was framed around manageability rather than acceptability;
- Emerging contradictions were addressed procedurally rather than structurally;
- No regulator had a clear mandate to trigger planning reconsideration absent explicit non-compliance.

(Environment Agency, 2015–2019)

12.5 Role of the Operator: Model Ownership Without System Accountability

Operators were responsible for:

- Developing the conceptual and numerical models underpinning applications;
- Proposing monitoring frameworks aligned with those models;
- Reporting data generated during operations.

However, operators were not required to:

- Test alternative conceptual models beyond those supporting development;
- Redesign monitoring proactively in response to emerging contradictions;
- Suspend operations on the basis of uncertainty alone.

This created a condition in which model ownership did not equate to system accountability. (Cuadrilla Resources Ltd., 2018)

12.6 Circular Assurance and the Absence of a Failsafe

The interaction of these roles produced a circular assurance loop:

- Planners relied on regulators to manage technical risk;
- Regulators relied on operator models and monitoring to demonstrate compliance;
- Operators relied on planning consent and regulatory approval to proceed.

At no point in this loop was there an actor tasked with answering the question:

"Do these observations invalidate the assumptions that made the development acceptable in the first place?"

This question fell between institutional remits. (Lancashire County Council, 2016; Environment Agency, 2015–2019; Cuadrilla Resources Ltd., 2018)

12.7 Consequences for Escalation and Intervention

The practical consequence of this circularity was that:

- Early contradictory observations were absorbed without triggering reassessment;
- Monitoring data were interpreted within original assumptions;
- Seismic exceedances triggered operational pauses, not planning review;
- Confidence was maintained until outcomes forced policy-level intervention.

Escalation occurred **only after outcomes**, not at the point where **assumption breach became evident**. (British Geological Survey, 2019; Department for Business, Energy & Industrial Strategy, 2019)

12.8 Systemic Nature of the Failure

The failure identified here is **systemic**, not attributable to negligence, misconduct, or bad faith.

It arises from:

- Fragmented responsibility;
- Over-reliance on predictive assurance;
- Lack of re-opener mechanisms tied to assumption validity;
- Absence of an institutional owner for emergent risk.

This structure can function adequately in stable, well-characterised systems. It is poorly suited to faulted, pressure-responsive geological environments, where uncertainty must be actively managed rather than procedurally acknowledged. (Department for Business, Energy & Industrial Strategy, 2019)

12.9 Interpretation Within the Evidence Hierarchy

Within the evidence hierarchy adopted in this document:

- Planning decisions constitute primary evidence of deference structure;
- Regulatory frameworks constitute primary evidence of remit limitation;
- The circularity identified arises from documented role separation, not inference.

No tertiary evidence is required to establish this failure mode.

12.10 Section Synthesis: Governance Failure Mode Identified

In synthesis, this section identifies the planning and regulatory failure at Preston New Road as follows:

Responsibility for system-level risk was distributed in such a way that no authority was mandated to reassess development acceptability when foundational assumptions were contradicted by evidence, resulting in a governance loop that sustained confidence beyond its evidential basis.

This circularity explains why:

- Hydrogeological contradictions did not halt progression;
- Monitoring limitations were tolerated;
- Seismic confirmation of fault activation did not trigger planning review;
- Intervention occurred only at the level of national policy, rather than site governance.

Note on Human Rights Relevance

(Scope Delimited)

This document is confined to a technical assessment of planning, regulatory, and governance frameworks associated with unconventional hydrocarbon development, with specific reference to Preston New Road and comparable geological settings. It does not make findings of legal liability, nor does it assess compliance with human rights law.

However, the analysis presented herein establishes several conditions that are recognised in human rights jurisprudence as potentially relevant contextual factors for the engagement of state duties, including:

- documented foreseeability of risk in category, though not in specific manifestation;
- confirmation of non-linear system behaviour and fault responsiveness;
- evidence that early contradictory observations did not trigger reassessment of development acceptability;
- structural limitations in monitoring and governance that constrained detection and corrective response.

These conditions are relevant to the procedural and substantive duties of public authorities under instruments including, but not limited to, the European Convention on Human Rights and the Aarhus Convention, particularly where environmental risk intersects with the protection of private life, home, and effective participation in decision-making.

No assessment is made in this document as to whether any such duties were breached. Matters relating to proportionality, adequacy of safeguards, access to information, availability of effective remedies, or the conduct of law enforcement bodies are explicitly out of scope.

A separate, dedicated analysis addressing human rights and governance obligations, grounded in the technical findings of this document and supplemented by additional evidence, is intended to be produced independently.

13 - Conclusions — Technical Viability, Foreseeability, and Governance Limits

13.1 Foreseeability Revisited: Category, Not Detail

The analysis demonstrates that outcomes at Preston New Road were foreseeable in category, though not in specific manifestation.

In particular, the following were foreseeable prior to operations:

- non-linear subsurface response in a faulted basin;
- pressure diffusion and fault activation beyond well-centric models;
- limitations of confirmatory monitoring frameworks;
- the possibility that early contradictory observations would not trigger reassessment.

What could not be predicted with precision were the timing, magnitude, or spatial expression of those responses. Foreseeability here therefore does not imply inevitability; it reflects the fact that the assumptions underpinning planning confidence were already known to be contestable. (Royal Society and Royal Academy of Engineering, 2012; British Geological Survey, 2018; Department for Business, Energy & Industrial Strategy, 2019)

13.2 Technical Viability Under UK Geological Conditions

On the basis of the evidence presented, this document reaches the following technical conclusion:

Under faulted UK basin conditions, the technical preconditions required to render unconventional hydrocarbon extraction both predictable and governable are not demonstrably achievable within existing planning and regulatory frameworks.

- This conclusion does not rest on any single event or outcome. It arises from the demonstrated interaction of:
- structurally complex geology with pressure-sensitive behaviour;
- hydrogeological systems capable of upward and lateral response;
- monitoring architectures unable to exclude plausible alternative pathways;
- governance mechanisms that respond after confirmation rather than prior to assumption breach.

The issue is not whether impacts will occur in every case, but whether confidence in controllability can be justified in advance. The evidence presented indicates that such confidence cannot be robustly established. (British Geological Survey, 2019; Department for Business, Energy & Industrial Strategy, 2019)

13.3 The Nature of the Failure: Systemic, Not Accidental

The failure modes identified at Preston New Road are systemic rather than incidental. They do not depend on error, misconduct, or non-compliance by any single actor.

- Instead, they arise from a governance structure in which:
- predictive models are treated as sufficient surrogates for observation;
- monitoring is designed to confirm expected behaviour rather than test alternatives;
- detected hazards are managed operationally without reassessing acceptability;
- responsibility for emergent risk is institutionally diffuse.

In such a system, corrective capacity is lost even when individual components function as intended.

13.4 Limits of Regulatory Assurance

Regulatory assurance at Preston New Road was consistently framed in terms of **manageability**, not **acceptability**.

The analysis demonstrates that:

- operational control mechanisms (including the Traffic Light System) are inherently reactive;
- monitoring sufficiency cannot be assumed where system behaviour is underdetermined;
- absence of detected impact is not equivalent to absence of process under structural blind spots.

Where regulatory frameworks lack mechanisms to reassess planning assumptions in real time, confidence becomes self-referential rather than evidential. (Department for Business, Energy & Industrial Strategy, 2019; Environment Agency, 2015–2019)

13.5 Implications for Future Decision-Making

The relevance of this analysis extends beyond Preston New Road.

For future proposals in comparable geological settings, including other parts of the Fylde Basin, the evidence demonstrates that:

- static conceptual models are insufficient;
- confirmatory monitoring cannot render developments precautionary;
- fault responsiveness must be treated as a system-wide constraint;
- planning permissions that lack automatic re-opener mechanisms are structurally vulnerable.

Absent substantive redesign of both monitoring philosophy and governance responsibility, the same failure architecture can reasonably be expected to recur, even if specific outcomes differ. (British Geological Survey, 2018; Royal Society and Royal Academy of Engineering, 2012)

13.6 Final Statement

This document has not argued that harm was inevitable, nor that impacts have been conclusively demonstrated. It has shown something more fundamental:

That the planning and regulatory system lacked the structural capacity to test, bound, and respond to uncertainty once its foundational assumptions were contradicted by evidence.

In faulted, pressure-responsive geological environments, that limitation is decisive. Where uncertainty cannot be actively governed, confidence in technical viability is not a scientific conclusion but an institutional assumption.

That assumption has now been examined against the record.

Appendix A — Baseline Hydrogeological and Geomorphological Sensitivity of the Burniston Site (Planning-Relevant Context)

(Satellite-based first-principles assessment)

A.1 Site setting and boundary conditions

Review of multi-temporal satellite imagery indicates that the proposed Burniston site lies immediately inland of an actively interacting coastal cliff system. Coastal cliffs represent combined hydraulic, geomorphological, and stress-release boundaries, where groundwater discharge, slope processes, and erosion operate in close coupling. Such boundaries are inherently sensitive to changes in groundwater head and pore pressure, even where absolute changes are small.

The proximity of the site to the cliff edge therefore constitutes a first-order constraint on development, as groundwater pathways originating inland may terminate at, or interact with, the cliff face with limited buffering distance.

A.2 Persistent wet ground and shallow groundwater expression

Across multiple years and seasonal conditions, imagery shows a recurring wet area to the south-east of the proposed site, located between the site and existing water treatment infrastructure. The persistence of this feature across differing crop regimes and climatic conditions indicates a structurally controlled shallow groundwater or seepage zone, rather than transient surface ponding or agricultural artefact.

Such features are characteristic of perched groundwater, preferential subsurface pathways, or zones of impeded drainage associated with lithological contrasts. The repeated manifestation of this wet ground identifies it as an existing off-site receptor area consistent with shallow groundwater conditions described in planning-stage documents.

A.3 Preferential flow pathways and landform control

Linear and curvilinear tonal and vegetation features are visible extending northwards from a scarp-like landform toward the coastal cliff edge. These features are consistent with laterally directed subsurface flow, guided by topography, bedding, or fracture-controlled permeability, rather than vertical percolation alone.

Importantly, these pathways are not radially oriented around the proposed site, but instead reflect landscape-scale controls. This indicates that groundwater movement in the area is anisotropic and structurally governed.

A.4 Episodic fines mobilisation and deposition

Several fields in the vicinity exhibit recurring patches of lighter-toned material consistent with fines deposition. The spatial recurrence of these patches suggests episodic low-energy water movement—such as sheet flow or shallow subsurface exfiltration—rather than uniform drainage.

This behaviour indicates fluctuating near-surface saturation and variable effective stress conditions, increasing sensitivity to any changes in groundwater head or flow regime.

A.5 Development of semi-permanent ponding and springs

Imagery to the east–south-east of the village shows the emergence of a pond in later years, with subsequent establishment of a tree. The development of woody vegetation implies sustained water availability over multiple seasons, demonstrating hydrologic persistence rather than ephemeral pooling.

In adjacent fields, a spring feature is visible and appears aligned with a landform to the north, indicating a connected shallow groundwater system responding to structural or stratigraphic controls.

A.6 Planning-relevant interpretation

Taken together, these observations indicate that the Burniston site is located within an active, laterally connected shallow groundwater system, with multiple off-site discharge and receptor zones and a coastal cliff acting as a terminal boundary. These conditions pre-date any proposed development and represent baseline sensitivity rather than impact.

As such, pad-centric or static hydrogeological assessments are insufficient to characterise risk. The observed features necessitate enhanced off-site, multi-directional monitoring and integration of groundwater behaviour with slope stability considerations. These features are consistent with shallow groundwater conditions described in planning-stage hydrogeological assessments, but highlight the need for spatially extended verification.

Figure 1 - Location of the proposed Burniston site relative to settlement, infrastructure, and the adjacent coastal cliff system. The figure provides spatial context for subsequent satellite-based observations and illustrates the proximity of the site to coastal and off-site boundary conditions relevant to groundwater discharge and geomorphological sensitivity. (Google Earth December 2001)

Figure 2 - Comparison of satellite imagery from December 2001 (left) and July 2009 (right), shown at identical scale and extent. The 2001 image provides a pre-development baseline, while the 2009 image illustrates the emergence and persistence of laterally aligned surface features and wet-ground expression. The comparison is used to assess relative spatial coherence and persistence, not to infer causation.

Figure 3 - Satellite imagery from March 2023 illustrating enhanced surface expression of shallow groundwater and seepage features under contrasting climatic and seasonal conditions. The figure demonstrates the capacity of the landscape to express subsurface hydrological processes when stressed, supporting interpretation of baseline sensitivity rather than episodic surface ponding.

Figure 4 - Satellite imagery from 2025 showing the present-day configuration of surface features previously identified in earlier imagery. The figure is included to confirm persistence into the current period and to demonstrate that observed patterns are not confined to a single year or land-use phase.

Appendix B — Monitoring Scope and Community Reporting Framework

Purpose and Status of Appendix B

This appendix sets out a structured framework of planning-relevant hold points and reassessment triggers derived directly from the failure modes demonstrated at Preston New Road. It is not a prescriptive operational manual, nor a substitute for regulatory control. Its purpose is to illustrate how planning permissions can be conditioned so that assumption breach, emergent risk, or monitoring limitation triggers **automatic pause and reassessment**, rather than discretionary or post-hoc response.

The framework is intended to support planning authorities in retaining control over development acceptability where uncertainty, structural complexity, or non-linear system behaviour is present.

B1–B3: Pre-Determination Hold Points (Before Permission Is Granted)

B1. Reliance on Static Flood Risk or Drainage Models

Trigger:
The application relies on a Flood Risk Assessment (FRA) or drainage model that assumes fixed infiltration rates, permeability, or groundwater gradients, and does not include an explicit re-opener linked to subsurface change.

Required response:
The application must be paused until the applicant provides a dynamic reassessment framework, identifying:

what data or observations would invalidate the FRA assumptions; and

what procedural response would follow such invalidation.

Rationale:
Evidence from Preston New Road demonstrates that subsurface stress and pressure behaviour can change materially during development, rendering static assumptions unreliable.

B2. Model-Confirmatory Monitoring Design

Trigger:
The proposed monitoring network is designed solely to confirm predicted pathways or impacts, with monitoring points placed only where effects are expected.

Required response:
Monitoring design must be revised to deliberately test alternative hypotheses, including:

- fault-intersecting locations;
- boundary and off-site receptors;
- down-gradient and laterally connected zones.

Rationale:
Evidence from Preston New Road demonstrates that model-confirmatory monitoring can produce false negatives where actual system behaviour departs from predicted pathways.

B3. Insufficient Reporting Frequency

Trigger:
Monitoring proposals rely on quarterly reporting, delayed publication, or do not provide high-frequency or near-real-time data for key parameters.

Required response:
Planning conditions must require:

- high-frequency monitoring (daily or weekly, as appropriate);
- rapid public data publication within defined time limits.

Rationale:
Time-lag in reporting constitutes a structural blind spot in pressure-responsive and faulted systems.

B4–B6: Construction and Drilling Hold Points

B4. Unexpected Groundwater Head or Artesian Behaviour

Trigger:
Unplanned weighting of drilling fluids, circulation changes, or sustained groundwater flow at shallow depth inconsistent with baseline assumptions.

Required response:
Automatic suspension pending:

- an updated hydrogeological conceptual model;
- revised risk assessment;
- expansion or relocation of monitoring.

Rationale:
This represents real-time evidence that shallow hydrogeology has been underestimated.

B5. Unpredicted Water Ingress or Dewatering Requirements

Trigger:
Pumping or dewatering volumes exceed predicted envelopes or persist longer than planned.

Required response:
Reassessment of:

- hydraulic connectivity;
- drainage and Flood Risk assumptions;
- potential off-site impacts (springs, streams, wetlands).

Rationale:
Such behaviour indicates permeability or pathways not accounted for at planning stage.

B6. Material Ground Instability or Abnormal Settlement

Trigger:
Settlement, heave, repeated repairs beyond construction tolerances, or cracking patterns indicating differential movement.

Required response:
Automatic pause pending independent geotechnical review and update of land stability and subsidence assessments.

Rationale:
Land stability is a planning matter and an early indicator of model failure.

B7–B10: Stimulation, Testing, or Flowback Hold Points

B7. Seismicity Above a Planning-Defined Limit

Trigger:
Seismic events exceed a conservative, planning-set threshold (distinct from the Traffic Light System), or show migration toward mapped structures or sensitive receptors.

Required response:
Suspension pending independent review and planning reassessment of whether the permitted envelope remains valid.

Rationale:
The TLS is an operational tool; planning requires a safeguard tied to acceptability, not manageability alone.

B8. Pressure Diffusion Inconsistent With Model Predictions

Trigger:
Delayed, migrating, or sustained pressure response beyond predicted temporal or spatial bounds.

Required response:
Updated geomechanical and hydrogeological modelling and re-validation of containment assumptions.

Rationale:
Trailing pressure behaviour was a demonstrated failure mode at Preston New Road.

B9. Flowback or Produced Water Chemistry Outside Predicted Bounds

Trigger:
Water chemistry deviates from baseline envelopes, including salinity, metals, hydrocarbons, sulphide indicators, radioactivity screening, or unexpected solids load.

Required response:
Suspension pending reassessment of waste handling, containment, and potential pathways, and evaluation of whether EIA assumptions are breached.

Rationale:
This provides a direct, data-driven test of assumption validity.

B10. Well Integrity Anomalies

Trigger:
Casing or cement bond anomalies, sustained annulus pressure, deformation, or integrity test failure.

Required response:
Suspension until independently verified integrity is restored and pathway risk reassessed.

Rationale:
Integrity failure is a single-point failure with system-wide consequences.

B11–B12: Surface Water and Ecological Hold Points

B11. Hydrological Signals Beyond Seasonal Baseline

Trigger:
Changes in stream baseflow, spring emergence, persistent wet ground expansion, or drainage reversal exceeding established seasonal variance.

Required response:
Investigation as a potential connectivity signal, expansion of monitoring, and reassessment of Flood Risk and water environment models.

Rationale:
Surface expressions are often the earliest detectable indicators in shallow coupled systems.

B12. Pollution Indicators, Even if Classified as "Minor"

Trigger:
Iron ochre, sheens, foam, odour events, fish stress, or repeated discolouration, even where "no impact observed on inspection day".

Required response:
Targeted sampling and time-series follow-up, treating the signal as hypothesis-testing input rather than dismissible anomaly.

Rationale:
"Not present during inspection" is a documented failure mode.

B13–B15: Governance and Planning Control Hold Points

B13. Deviation From Approved Development Envelope

Trigger:
Changes to well numbers, depths, volumes, pressures, chemicals, duration, traffic, hours, lighting, or waste storage.

Required response:
Classification as a notifiable change requiring fresh planning approval, not solely regulatory sign-off.

Rationale:
Prevents scope creep via non-material amendments.

B14. Regulatory Changes That Imply Assessment Failure

Trigger:
Regulators require revised controls due to unanticipated conditions.

Required response:
Planning authority review of whether the development remains acceptable under original assumptions.

Rationale:
Prevents responsibility deferral between planning and regulation.

B15. Inability to Implement Approved Monitoring

Trigger:
Land access issues, equipment failure, data gaps, or failure to publish monitoring data on schedule.

Required response:
Automatic suspension until monitoring compliance is restored.

Rationale:
A development operating without monitoring operates without visibility.

Implementation Note: Hold Point Conditions

In planning terms, effective implementation requires:

- re-opener clauses tied to defined triggers (not discretion);
- automatic suspension upon trigger activation;
- independent verification at each hold point;
- time-limited public data publication requirements.

Independent reviewers should be empowered to recommend monitoring escalation, targeted investigation, or referral where emerging patterns indicate potential assumption breach.

Appendix C — Monitoring Scope Required to Render the Development Assessable

Purpose and Status of Appendix C

This appendix defines the minimum monitoring scope necessary to render a proposed onshore hydrocarbon development *assessable* within a planning framework, where geological complexity, faulting, and pressure-responsive behaviour are present.

It does not assert that impacts will occur, nor does it prescribe operational outcomes. Its purpose is to demonstrate that, without continuous, off-site, and integrated monitoring across relevant environmental domains, planning authorities cannot reliably test or bound the assumptions upon which development acceptability rests.

C1. Rationale for Continuous, Off-Site Monitoring

Evidence from onshore shale operations demonstrates that subsurface responses to drilling, stimulation, and testing are not necessarily spatially coincident with the well pad, nor temporally synchronous with operational activity. In faulted and stress-sensitive settings, pressure redistribution and seepage may be delayed, intermittent, and displaced along structural pathways (Clarke et al., 2014; Clarke et al., 2019).

Monitoring frameworks that are episodic, pad-centric, or limited to predicted pathways are therefore structurally incapable of detecting early system change. To be planning-relevant, monitoring must be capable of identifying off-site signals at sufficient temporal resolution to distinguish operational effects from natural variability (British Geological Survey, 2018).

C2. Continuous Off-Site Air Monitoring

C2.1 Determinands and Instrumentation

Fixed, off-site air-monitoring stations shall measure, at minimum:

• methane (CH_4)
• carbon dioxide (CO_2)
• radon (Rn)
• meteorological parameters (wind speed, wind direction, atmospheric pressure, temperature, humidity)

Radon monitoring is relevant both as a public-health baseline parameter and as a contextual tracer of subsurface gas behaviour and ventilation conditions (BGS, 2018; Public Health England, 2016).

Monitoring locations should be selected at multiple distances and compass points so that dispersion and migration hypotheses can be evaluated if anomalies arise.

C2.2 Frequency and Duration

Air monitoring shall be continuous throughout baseline, construction, drilling, testing, and post-operational phases.

Discrete or grab sampling is insufficient, as gas emissions are episodic and strongly modulated by meteorological conditions, with short-duration events often dominating cumulative flux (Allen et al., 2013).

C2.3 Planning Relevance

Without continuous off-site air monitoring, absence of detected emissions cannot be interpreted as absence of seepage. Continuous monitoring is therefore a prerequisite for evidentially defensible planning conclusions.

C3. Continuous Off-Site Water Monitoring

C3.1 Monitoring Architecture

Off-site groundwater monitoring shall include:

• fixed piezometers or boreholes equipped with continuous loggers for
– hydraulic head
– temperature
– electrical conductivity

• periodic chemical sampling for
– major ions
– metals
– dissolved methane
– isotopic or tracer parameters where feasible

Surface-water receptors (springs, baseflow-dominated stream reaches, drainage features) shall be included where hydrologically connected systems exist.

C3.2 Frequency and Baseline Requirements

Hydraulic parameters shall be logged continuously. Chemical sampling shall be undertaken at least monthly during baseline and at increased frequency during drilling and testing phases.

Short-term head responses and subtle changes in groundwater behaviour frequently precede detectable chemical change and are commonly missed by quarterly or event-only regimes (Environment Agency & Mott MacDonald, 1997; BGS, 2018).

C3.3 Justification

Unexpected shallow artesian conditions encountered during drilling at Preston New Road demonstrate that baseline hydrogeological conditions may be materially underestimated. Continuous off-site monitoring is therefore required to detect early departure from assumed conditions (Clarke et al., 2014).

C4. Integration of Air and Water Monitoring

Fault-controlled migration does not respect environmental media boundaries. Gas may migrate in free phase, remain dissolved in groundwater, or transition between phases depending on pressure and temperature (Faulkner et al., 2010).

Monitoring programmes that consider air and water in isolation are therefore incapable of reliably testing or excluding fault-mediated migration. Integrated interpretation across datasets is required to evaluate alternative hypotheses rather than merely confirm predicted pathways.

C5. Mud Degasser Sampling at Source

Gas sampling shall be undertaken at the mud degasser or equivalent point of return, with sufficient temporal resolution to preserve depth attribution.

Parameters shall include methane, higher hydrocarbons, carbon dioxide, and hydrogen sulphide where relevant.

Sampling downstream of treatment or storage removes depth attribution and eliminates diagnostic value. Without at-source sampling, off-site anomalies cannot be confidently attributed or falsified.

C6. Landscape-Scale Surface Deformation Monitoring

C6.1 Methods and Frequency

Surface deformation monitoring shall comprise:

• satellite InSAR analysis at regular intervals
• repeat LiDAR surveys at six-month intervals
• continuous GNSS stations where appropriate

A six-month LiDAR interval captures seasonal extremes while identifying cumulative or progressive deformation.

C6.2 Justification

Stress redistribution may produce spatially distributed deformation not centred on the pad. Repeat datasets are required to distinguish natural variability from induced change (BGS, 2018).

C7. Live Meteorological Monitoring

On-site and off-site weather stations shall provide live, publicly accessible data on wind speed, wind direction, temperature, and atmospheric pressure.

Meteorological data are essential for:

• interpretation of air-quality and gas data
• corroboration of odour and nuisance reports
• transparent scrutiny by regulators, planners, and the public

Air-quality interpretation without concurrent meteorological data is inherently ambiguous and has been repeatedly identified as a regulatory failure mode (DEFRA, 2016).

C8. Independent Professional Scrutiny and Audit

Continuous monitoring alone is insufficient without independent interpretation.

Monitoring frameworks shall therefore include:

• scheduled independent review of datasets (e.g. quarterly), regardless of threshold exceedance
• event-driven review triggered automatically by anomalies or reports
• access to raw and processed data with metadata
• publication of interpretive summaries suitable for planners and the public

Independent reviewers must be demonstrably free of operational or commercial conflict and possess appropriate expertise in hydrogeology, geomechanics, atmospheric science, or environmental monitoring.

C9. Community Reporting as a Monitoring Component

C9.1 Rationale

Local observations frequently identify early surface indicators—odour events, intermittent seepage, subtle deformation—that occur outside scheduled inspections and away from fixed instruments (Clarke et al., 2014; BGS, 2018).

Where live monitoring data are publicly available, structured community reporting functions as a distributed sensing network, extending both spatial and temporal coverage.

C9.2 Structured Reporting Requirements

A formal reporting mechanism shall ensure observations are:

• time-stamped and geolocated
• assessed against live monitoring and operational data
• investigated within predefined timeframes

Reports are not required to demonstrate causation; their purpose is signal identification.

C9.3 Integration and Escalation

Reported observations shall be cross-referenced with:

• air and water monitoring data
• meteorological conditions
• seismic and operational activity

Where correlations or patterns emerge, relevant Mandatory Pause / Re-Assess Triggers shall be activated.

C10. Planning Relevance

Without continuous, off-site, integrated monitoring—supplemented by structured community reporting—the development cannot be meaningfully assessed against its stated assumptions.

Monitoring designed solely to confirm predicted behaviour does not constitute precautionary assessment. To be planning-relevant, monitoring must be capable of detecting unexpected system responses and triggering reassessment mechanisms before outcomes force intervention.

Appendix D — Remote Sensing and Spatial Corroboration

D.1 Study Area Definition and Analytical Framework

D.1.1 Study Area Definition

The study area assessed in this appendix is defined as the polygon shown in Figure A.1, encompassing a corridor extending from the south-west to the north-east of the Preston New Road (PNR) site. The area includes agricultural land, drainage features, surface water bodies, infrastructure corridors, and coastal margins that lie spatially coincident with mapped and inferred subsurface structures identified in seismic and geomechanical assessments.

Figure 5 – Aerial imagery showing the site area and surrounding land parcels with geometric boundary overlays used for spatial reference in this assessment. The outlined shapes indicate analysis sectors and observation envelopes only. They do not represent subsurface structures, inferred pathways, or impact zones. Base imagery source: Google Earth. Scale approximate

The selected extent deliberately captures surface expressions both proximal and distal to the well pad, including areas not directly instrumented during operations, but which fall within plausible zones of stress redistribution, fault-controlled fluid migration, and secondary surface response.

D.1.2 Rationale for Spatial Extent

The study area was expanded beyond the immediate vicinity of the PNR pad to include identifiable geomorphological and hydrological features that exhibit continuity across multiple datasets. These include linear depressions, persistent wet zones, drainage convergence points, and areas of repeated sediment mobilisation observed in time-series imagery.

Limiting analysis to a narrow pad-centric buffer would risk replicating the same spatial assumptions that constrained the original monitoring framework. The chosen polygon therefore reflects a precautionary, system-level approach consistent with fault-bounded basin behaviour, rather than a containment-based operational footprint.

D.1.3 Relationship to Subsurface Interpretation and Monitoring Data

The defined study area intersects the surface projection of subsurface features identified in seismic interpretation, including fault corridors associated with induced seismicity during hydraulic fracturing operations. While this appendix does not reinterpret seismic datasets, it situates surface observations within the spatial context established by those analyses.

LiDAR differencing (2018–2022), satellite imagery, and aerial photography are used to examine whether surface change patterns exhibit spatial coherence with these subsurface interpretations. This linkage provides contextual corroboration between independent datasets without asserting direct causation.

D.1.4 Evidential Scope and Analytical Limits

The datasets presented in this appendix are used strictly as secondary, corroborative evidence, in accordance with the evidence hierarchy established in the main body of this document. LiDAR elevation data are used to identify relative patterns of surface elevation change, while satellite and aerial imagery are employed to assess the persistence, recurrence, and spatial organisation of surface features over time.

These datasets do not replace regulatory monitoring, nor are they used to infer subsurface processes in isolation or to attribute causation. Their analytical role is confined to evaluating whether observed surface patterns are spatially and temporally consistent with, or contradictory to, the assumptions embedded in planning-stage and regulatory assessments. In particular, they are used to test the robustness of assessments that rely on static, compartmentalised, or pad-centric conceptual models in settings characterised by structural complexity and heterogeneous groundwater behaviour.

D.1.5 Relevance to Monitoring Design and Re-assessment Triggers

The spatial and temporal patterns documented within this study area have direct relevance to the design and adequacy of environmental monitoring frameworks. Observed surface changes occurring beyond instrumented zones highlight the limitations of monitoring strategies that are narrowly focused on predicted pathways.

This appendix therefore supports the argument that effective monitoring must be spatially distributed, hypothesis-testing rather than model-confirmatory, and capable of triggering reassessment where unanticipated surface responses are detected. The findings presented here inform the monitoring principles and pause-and-review triggers set out in the main document.

Appendix D.2 - Subsurface Context

D.2.1 Mapped Structural Features and Fault Corridor

The study area defined in Section D.1 overlies a zone of known structural complexity within the Fylde Basin. Published seismic interpretations and geomechanical analyses identify a series of faults and fracture zones with a broadly south-west to north-east orientation that intersect the Preston New Road (PNR) area and extend beyond the immediate well pad footprint.

These structural features are not confined to discrete, vertically isolated compartments but form part of a wider faulted system capable of transmitting stress and pressure changes laterally. The surface projection of this fault corridor intersects the study area polygon shown in Figure 5, providing a spatial framework within which surface observations may be considered.

The surface projection of the fault corridor shown in Figure 5 is reproduced from previously published work by David K Smythe, and is included here for spatial reference only. No new interpretation or validation of this projection is undertaken in this appendix.

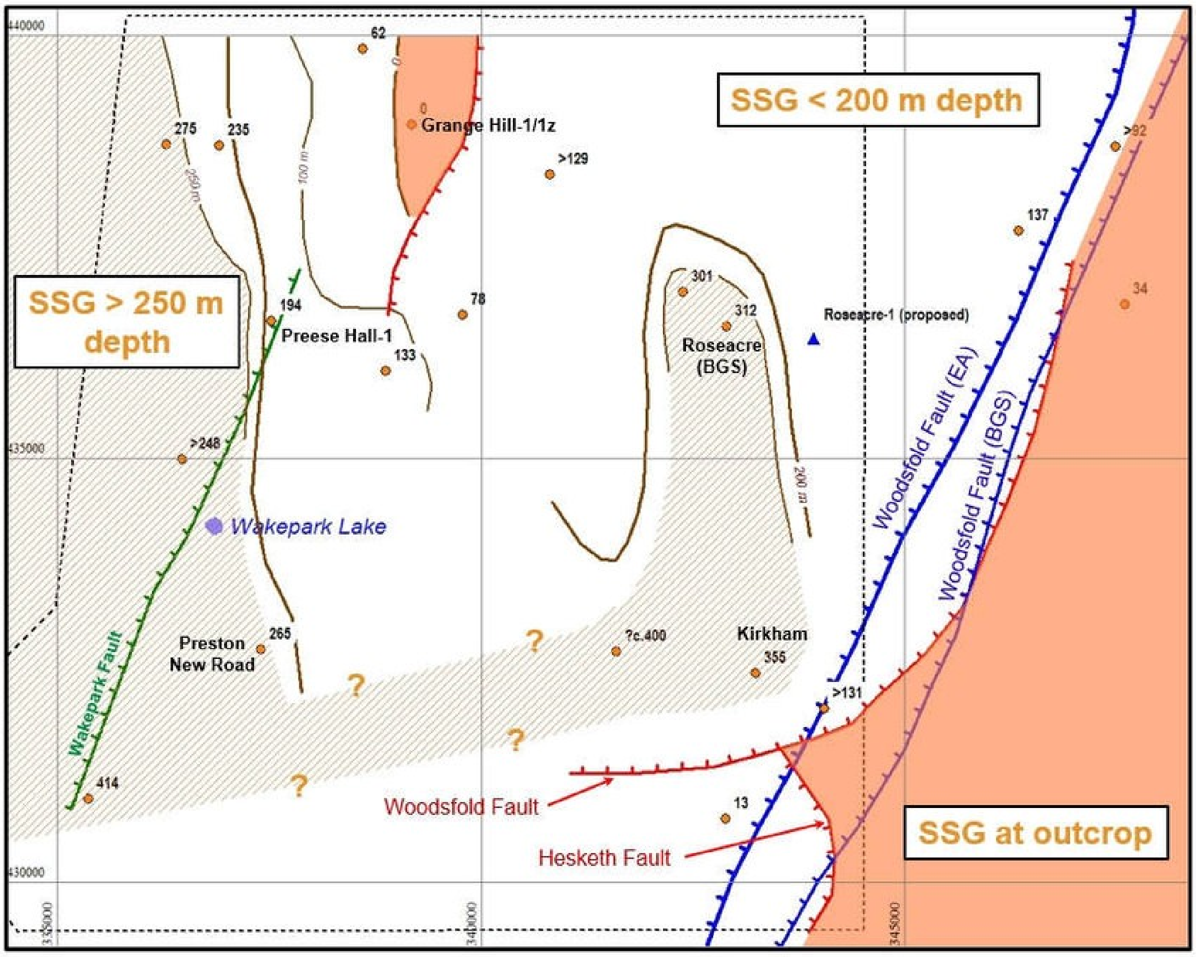


Figure 6 - Surface projection of a fault in the Wakepark area, reproduced from Smythe (2020). The figure is included for spatial reference only in relation to the Appendix D study area. No new interpretation or validation of the fault geometry is undertaken in this appendix.

This appendix does not seek to reinterpret fault geometry or extent, but relies on subsurface characterisation already established and referenced in the main body of the paper.

D.2.2 Pressure Diffusion and Fault Responsiveness (Established Evidence)

Operational data and subsequent analyses associated with hydraulic fracturing at PNR demonstrated that injected pressures were sufficient to activate pre-existing faults, resulting in induced seismicity that exceeded pre-operational model expectations. The occurrence of seismic events following injection cessation further indicated pressure diffusion and delayed fault response inconsistent with simplistic containment assumptions.

These behaviours are documented in primary sources, including regulatory reports and peer-reviewed studies, and underpin the conclusion that fault systems in the area are mechanically responsive and hydraulically connected over distances greater than those assumed during planning.

This section does not advance new interpretations of these processes, but acknowledges them as established context relevant to the spatial framing of surface observations.

D.2.3 Relevance of Subsurface Context to Surface Analysis

The inclusion of subsurface context within this appendix serves solely to situate surface-based analyses within an already-documented geological framework. It does not imply direct coupling between observed surface changes and specific subsurface processes, nor does it seek to attribute causation.

Rather, the presence of a mapped fault corridor and demonstrated fault responsiveness provides a rational basis for examining whether surface patterns identified through LiDAR differencing and satellite time-series analysis exhibit spatial coherence along that corridor.

The surface analyses that follow are therefore exploratory and corroborative in nature, intended to test the plausibility of planning and monitoring assumptions rather than to establish new subsurface conclusions.

D.2.4 Spatial correlation between subsurface operations and surface deformation

Figure D.X presents an overlay of interpreted subsurface operational geometries (including stimulation stage locations and pressure “plumbs”) with differential LiDAR elevation change between 2018 and 2022. The LiDAR data are presented independently and are not processed to enhance or suppress specific features.

The purpose of this figure is not to infer causation, but to demonstrate spatial coincidence between zones of documented subsurface intervention and areas exhibiting non-uniform surface elevation change. Such spatial correspondence provides context for subsequent surface observations discussed in Appendix D.3 and informs the selection of locations examined in greater detail.

Importantly, the observed elevation changes are not continuous or uniform across the study area, but are instead spatially clustered. This non-random distribution warrants consideration of subsurface–surface coupling mechanisms, particularly in faulted and hydraulically heterogeneous settings.

D.2.5 Relevance of seepage erosion and sapping mechanisms

Laboratory and theoretical studies have demonstrated that seepage-driven erosion and surface instability can arise where subsurface hydraulic gradients intersect near-surface granular or weakly consolidated materials. Berhanu et al. (2012) describe how groundwater flow emerging at the surface can produce channel initiation, headward erosion, bank collapse, and surface deformation in the absence of overland flow, with morphology strongly dependent on the spatial distribution of subsurface flux. (Berhanu, 2012)

While the experimental conditions described by Berhanu et al. (2012) differ in scale and material properties from the Fylde setting, the governing processes—namely pressure-driven seepage, emergence at preferential locations, and mechanically induced collapse are scale independent in principle. As such, this work provides a mechanistic framework within which observed LiDAR deformation patterns and subsequent surface expressions may be interpreted, without asserting direct equivalence or causation.

While the experimental conditions described by Berhanu et al. (2012) differ in scale and material properties from the Fylde setting, the governing processes—namely pressure-driven seepage, emergence at preferential locations, and mechanically induced collapse—are scale-independent in principle. As such, this work provides a mechanistic framework within which observed LiDAR deformation patterns and subsequent surface expressions may be interpreted, without asserting direct equivalence or causation.

D.2.6 Spatial correlation between subsurface operations and surface deformation

To provide spatial context for the analyses that follow, Figure 8 presents the LiDAR-derived elevation change dataset for the wider Preston New Road study area. The dataset represents differential elevation patterns derived from repeat LiDAR surveys and is used here solely to examine the spatial distribution and coherence of surface change, not to quantify magnitude or infer causation.

The Preston New Road well pad is indicated for reference (red box). The figure is intended to situate the site within the broader landscape-scale pattern of non-uniform surface behaviour, against which subsequent overlays and comparisons are presented. Methodology, resolution limits, and evidential role of the LiDAR data are described earlier in this document and are not repeated here.

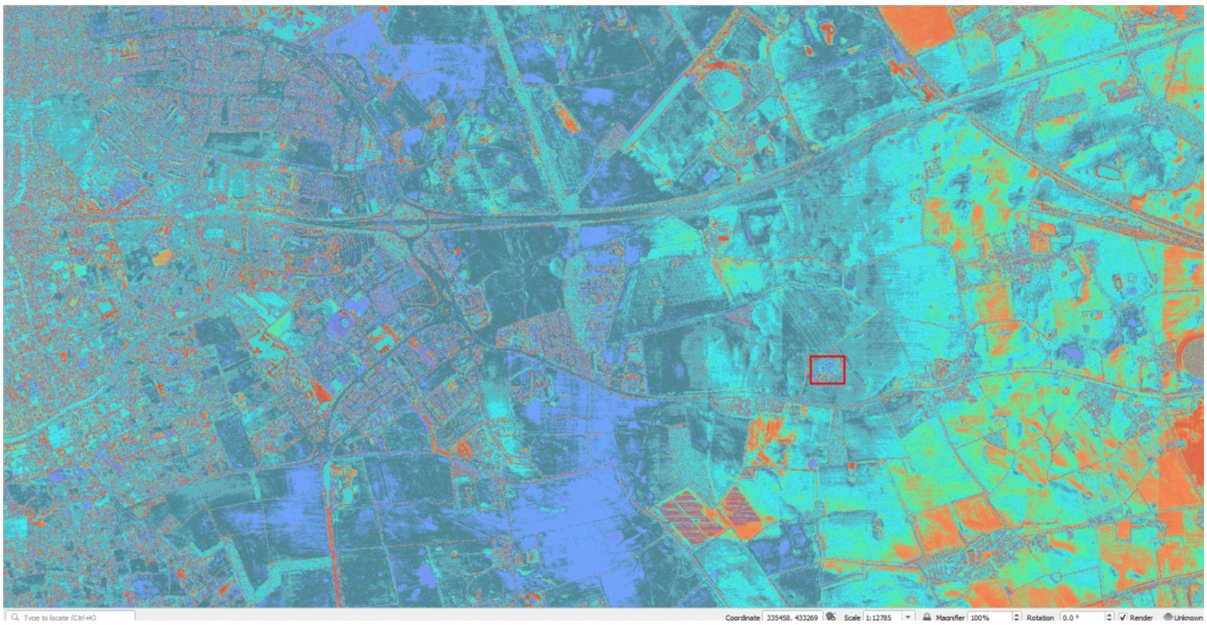


Figure 7 - Figure X presents an expanded LiDAR-derived elevation-change surface with reinstated contouring, shown at a wider spatial extent to provide geomorphological context for the localised feature discussed below. The contours represent the same differenced LiDAR dataset introduced earlier in this section; no changes have been made to source data, processing steps, or contour interval. High- and low-value contours that were previously suppressed for performance reasons were re-enabled for interpretive clarity.

Within the expanded view, a coherent, nested contour pattern is visible within an otherwise comparatively uniform agricultural surface. The morphology is spatially discrete, internally consistent, and not aligned with field boundaries, drainage infrastructure, or known surface works. The location was selected for further examination because it lies directly above a recorded low-magnitude seismic event (ML 0.1), providing an analytically relevant point of comparison between shallow surface expression and independently observed subsurface response.

The contour geometry bears qualitative similarity to deformation patterns described in the literature for pressure-driven response in structurally controlled settings. This comparison is limited to geometric form and spatial organisation only; no equivalence of mechanism, scale, or causation is asserted. The purpose of the figure is to demonstrate spatial coherence and plausibility within the bounds established by primary evidence, rather than to infer impact.

Figure 8 reproduces plumb-line deformation data collected during hydraulic fracturing operations at Preston New Road between late 2018 and August 2019. These measurements provide near-real-time indicators of localised ground tilt during active injection and immediately prior to the ML 2.9 seismic event of 26 August 2019. While spatially discrete, the plumb-line data offer important temporal context linking subsurface stress changes to subsequent surface deformation observed in later LiDAR datasets.

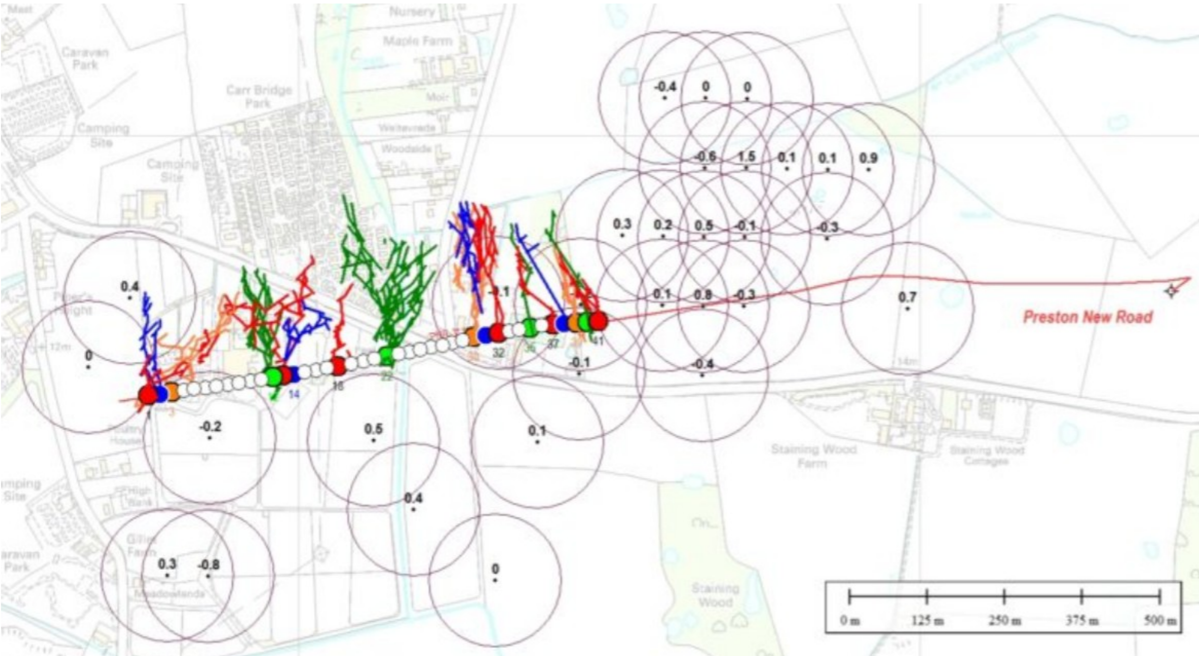
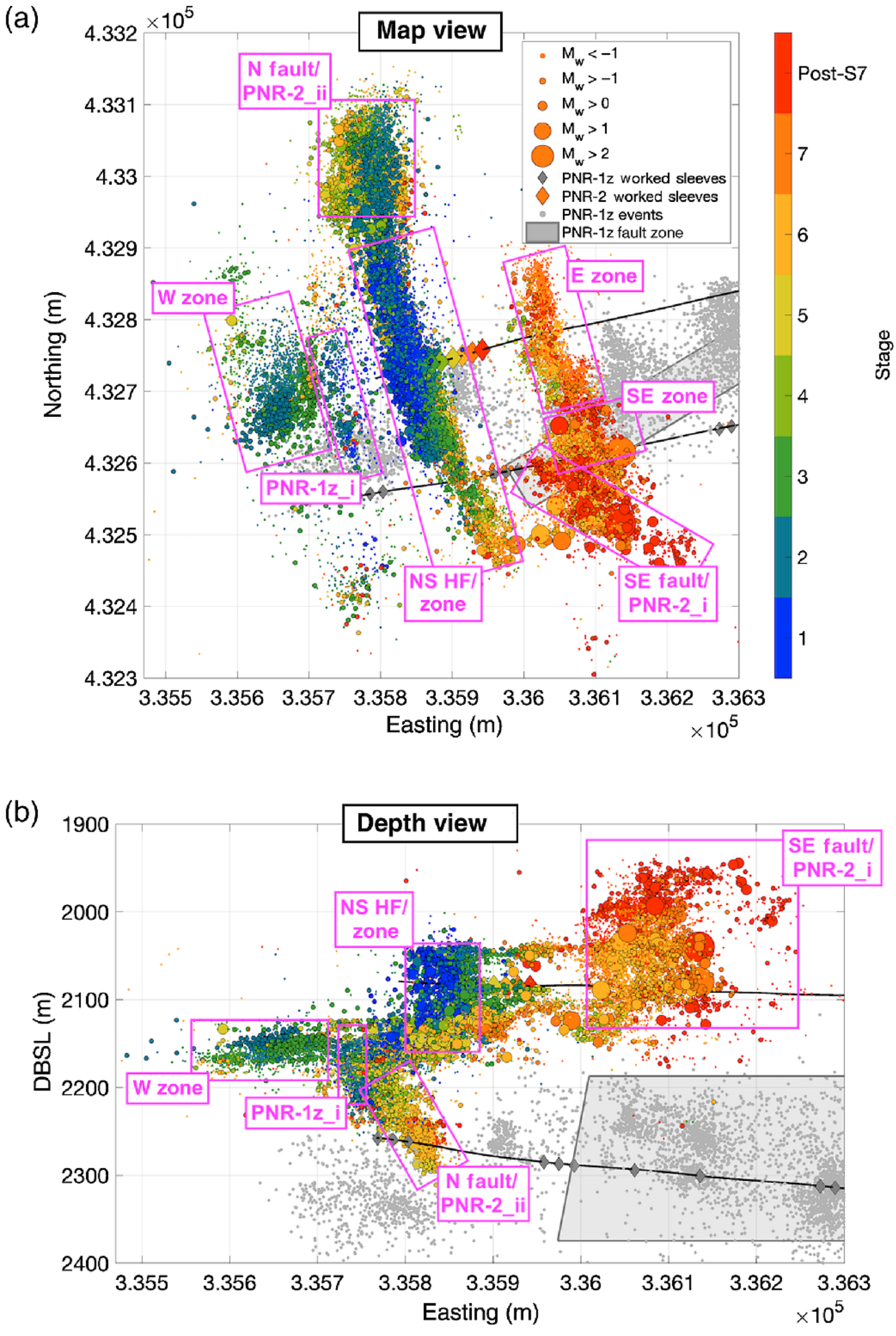


Figure 8 - Geological interpretation of faulting and Millstone Grit absence at Preston New Road, reproduced from Smythe (2019). Figure shown for illustrative purposes to demonstrate an alternative structural interpretation discussed contemporaneously with operations; not presented as primary observational data.

High-resolution spatial analysis of the induced seismicity associated with the August 2019 ML 2.9 event further illustrates the degree of structural organisation present within the subsurface response at Preston New Road. As shown in Figure 9, seismic events cluster into discrete, spatially coherent zones aligned with mapped fault structures, both in plan view and with depth. The distribution is not radially symmetric around the wellbore, nor temporally confined to injection periods, but instead reflects fault-controlled behaviour and progressive activation across multiple zones. This level of spatial organisation reinforces the interpretation that faults functioned as responsive system elements rather than passive boundaries.



(a)
Map view
N fault/
PNR-2_ii
W zone
E zone
SE zone
PNR-1z_i
NS HF/
zone
SE fault/
PNR-2_i
M_w < −1
M_w > −1
M_w > 0
M_w > 1
M_w > 2
PNR-1z worked sleeves
PNR-2 worked sleeves
PNR-1z events
PNR-1z fault zone
Northing (m)
Easting (m)
×10^5
4.332
4.331
4.33
4.329
4.328
4.327
4.326
4.325
4.324
4.323
3.355
3.356
3.357
3.358
3.359
3.36
3.361
3.362
3.363
Stage
Post-S7
7
6
5
4
3
2
1
(b)
Depth view
SE fault/
PNR-2_i
NS HF/
zone
W zone
PNR-1z_i
N fault/
PNR-2_ii
DBSL (m)
1900
2000
2100
2200
2300
2400
Easting (m)

Figure 9 - Three-dimensional seismic relocation of the ML 2.9 August 2019 event sequence, showing the spatial relationship between recorded seismicity and mapped fault structures. The figure demonstrates fault activation and subsurface structural complexity confirmed by monitoring, providing contextual evidence relevant to planning and monitoring assumptions. No surface attribution is implied.

Figure 10 presents an overlay of interpreted subsurface operational geometries (including stimulation stage locations and pressure “plumbs”) with differential LiDAR elevation change between 2018 and 2022. The LiDAR data are presented independently and are not processed to enhance or suppress specific features.

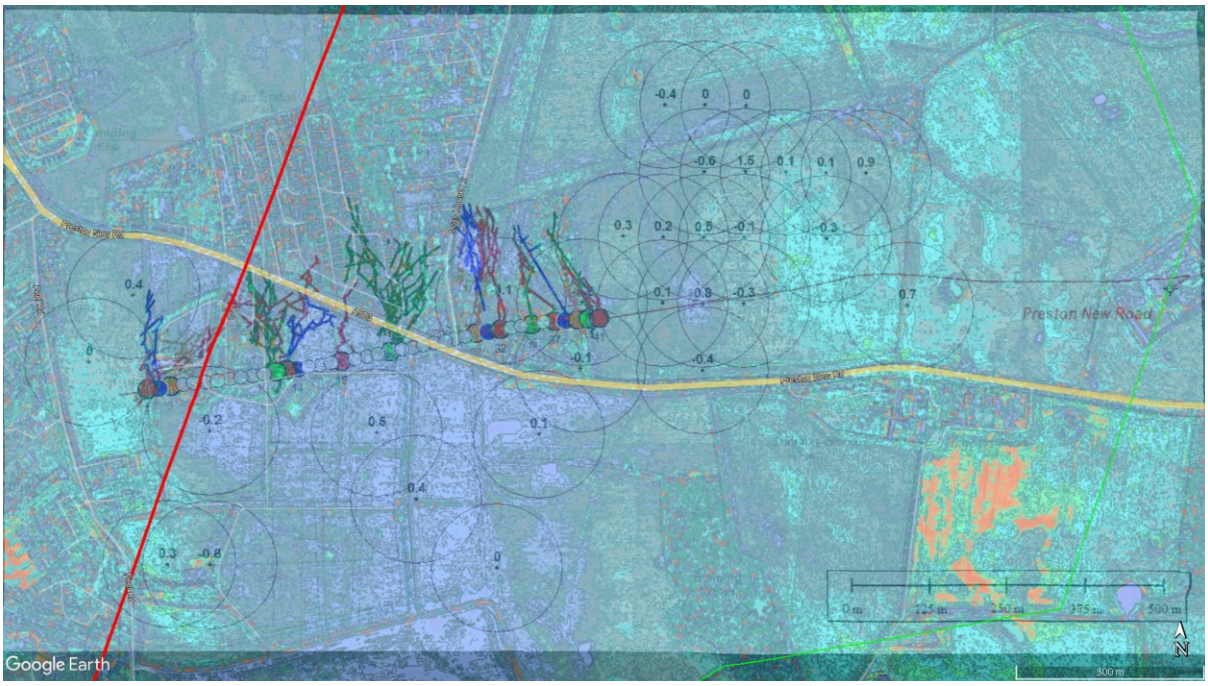


Figure 10 - Overlay showing interpreted subsurface operational geometries (including stimulation stage locations and plumb-line deformation indicators) in relation to differential LiDAR-derived surface elevation change between 2018 and 2022.

The LiDAR data are presented without enhancement or thresholding and are used solely to examine spatial coincidence and clustering, not to infer causation or absolute magnitude of deformation.

The figure provides contextual corroboration between documented subsurface intervention zones and non-uniform surface elevation patterns within the defined study area, consistent with the secondary evidential role assigned to LiDAR datasets in this document.

Figure 11 provides spatial context for the location-based analyses that follow. The purpose of this figure is not to infer causation, but to demonstrate spatial coincidence between zones of documented subsurface intervention and areas exhibiting non-uniform surface elevation change. Such spatial correspondence provides context for subsequent surface observations discussed in Appendix D.3 and informs the selection of locations examined in greater detail.

Importantly, the observed elevation changes are not continuous or uniform across the study area, but are instead spatially clustered. This non-random distribution warrants consideration of subsurface–surface coupling mechanisms, particularly in faulted and hydraulically heterogeneous settings.

In the following sections we will look at 3 areas chosen for their relevance

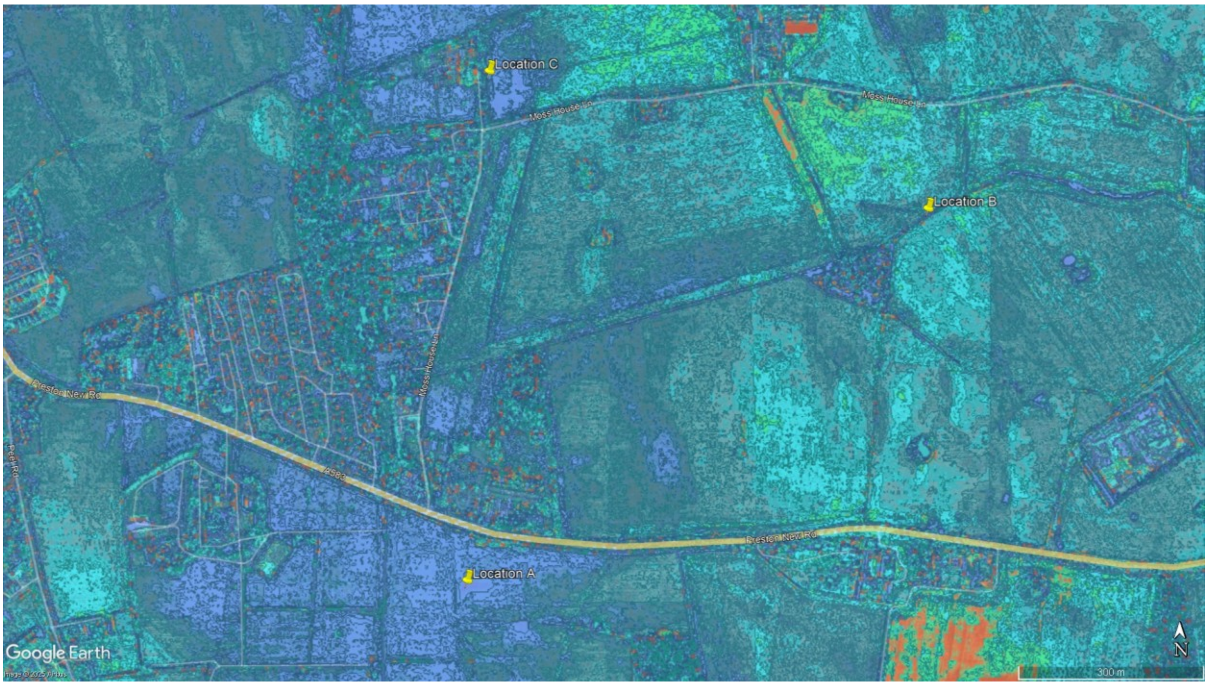


Figure 11 - LiDAR-derived elevation differencing across the study area, illustrating spatially discrete and internally coherent zones of non-uniform surface elevation change. The figure provides contextual grounding for the selection of Locations A–C examined in Sections D.2.7–D.2.9.

D 2.7 Location A

Location A was selected due to the presence of a nested contour geometry in the LiDAR elevation differencing dataset. This pattern is situated directly above the epicentral location of a recorded ML 0.1 seismic event and persists across multiple survey intervals.

The location is included to illustrate spatial coincidence between shallow surface expression and independently documented subsurface response. No inference is made regarding causal linkage, directionality, or mechanism.

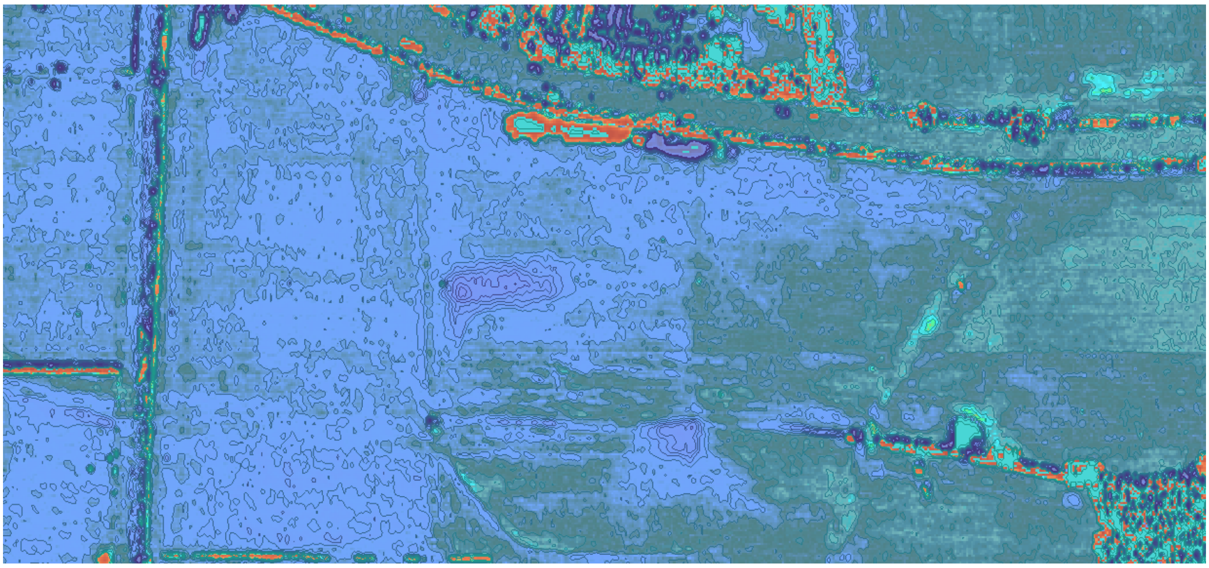


Figure 12 - LiDAR-derived elevation differencing at Location A, showing a nested contour pattern situated above the epicentral location of a recorded ML 0.1 seismic event. The figure is included to illustrate spatial coincidence between shallow surface expression and independently documented subsurface response. No causation is inferred.

For contextual comparison, Figure 13 reproduces experimental seepage-driven contour geometries described by Berhanu et al. (2012). The comparison is qualitative and limited to geometric form.

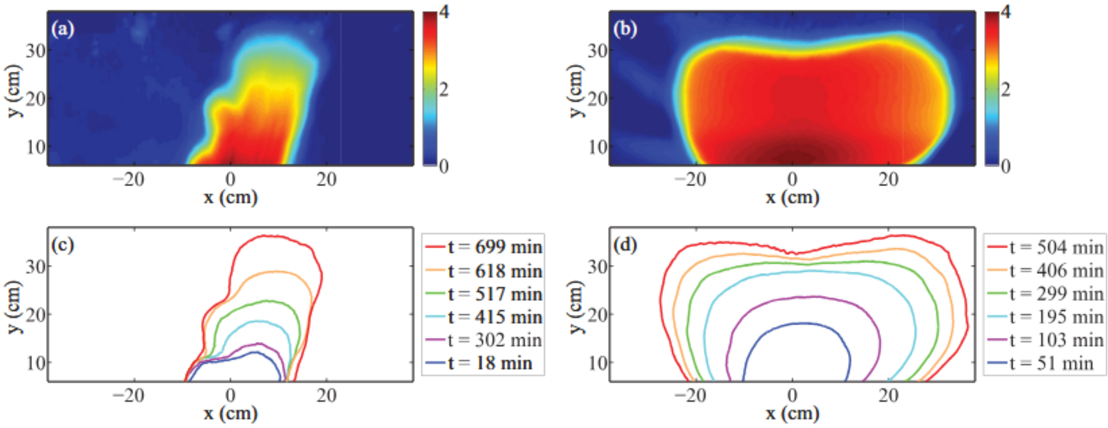


FIG. 5. (Color online) Comparison of channels in a shallow channel regime where the capillary rise is of order of the channel depth. (a) Depth map of the channel observed after $t = 677$ min with $\delta_H = 5$ cm, $P = 0$, and $d_{outlet} = 4$ cm. Depth is indicated with a scale in centimeters measured from the initial flat bed. (b) Depth map of channel observed after $t = 300$ min with $P_l \sim 1.04 \times 10^{-4}$ m s^{-1}, $\delta_H = 0.9$ cm, and $d_{outlet} = 4$ cm. (c,d) The corresponding channel shape evolution for the depth $d(x, y) = 1$ cm contour increase in length with time.

Figure 13 - Experimental contour geometry associated with seepage-driven erosion reproduced from Berhanu et al. (2012). The figure is included for qualitative comparison of geometric form only.

D2.8 Location B

Location B was selected on the basis of internally coherent surface deformation patterns observed in the LiDAR elevation differencing dataset. These patterns are not aligned with field boundaries, surface drainage infrastructure, or recent land management features, and persist across multiple LiDAR survey intervals.

The location lies adjacent to Carr Bridge Brook and exhibits surface morphology that is spatially structured rather than diffuse. The LiDAR-derived features are therefore considered suitable for comparison with experimental seepage-driven deformation forms, strictly in terms of geometric organisation and spatial coherence.

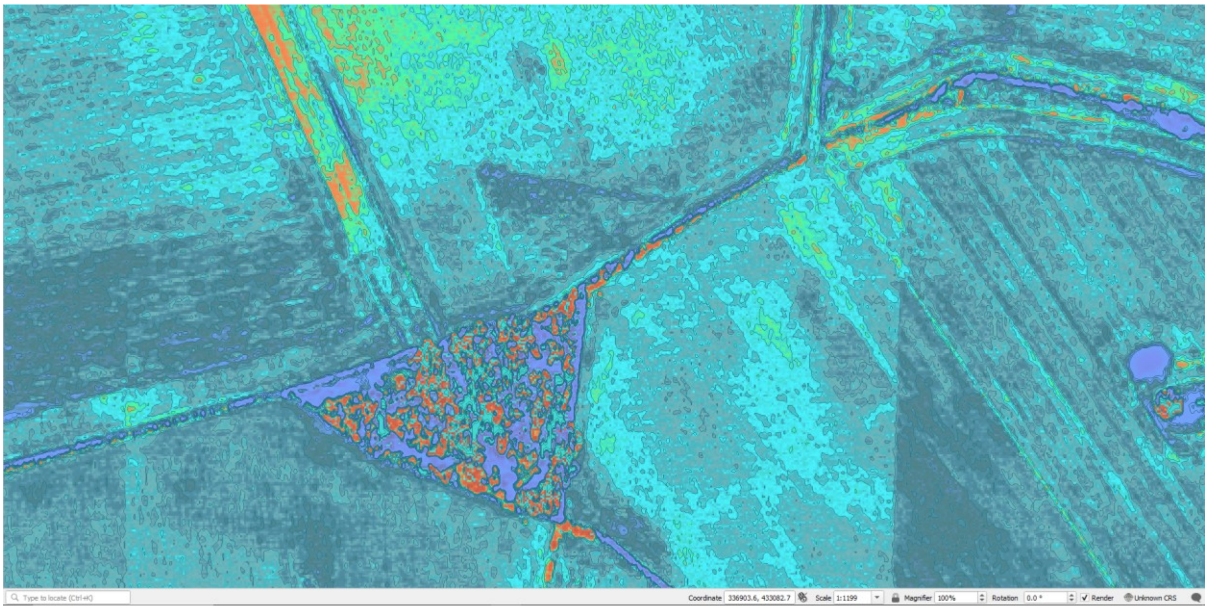


Figure 14 - LiDAR-derived elevation differencing at Location B, showing internally coherent surface deformation patterns not aligned with field boundaries or drainage infrastructure.

To provide additional surface context, aerial imagery of the adjacent brook bank is included. This imagery illustrates low-energy surface forms that are qualitatively comparable to seepage-related morphologies described in controlled experimental settings.

Figure 15 - Aerial imagery (28 January 2026) of the bank of Carr Bridge Brook, illustrating surface morphology qualitatively similar to seepage-related forms described in experimental studies.

For reference, Figure 16 reproduces experimental seepage morphology from Berhanu et al. (2012). This figure is included solely to support qualitative comparison of form and organisation and does not imply equivalence of process or scale.

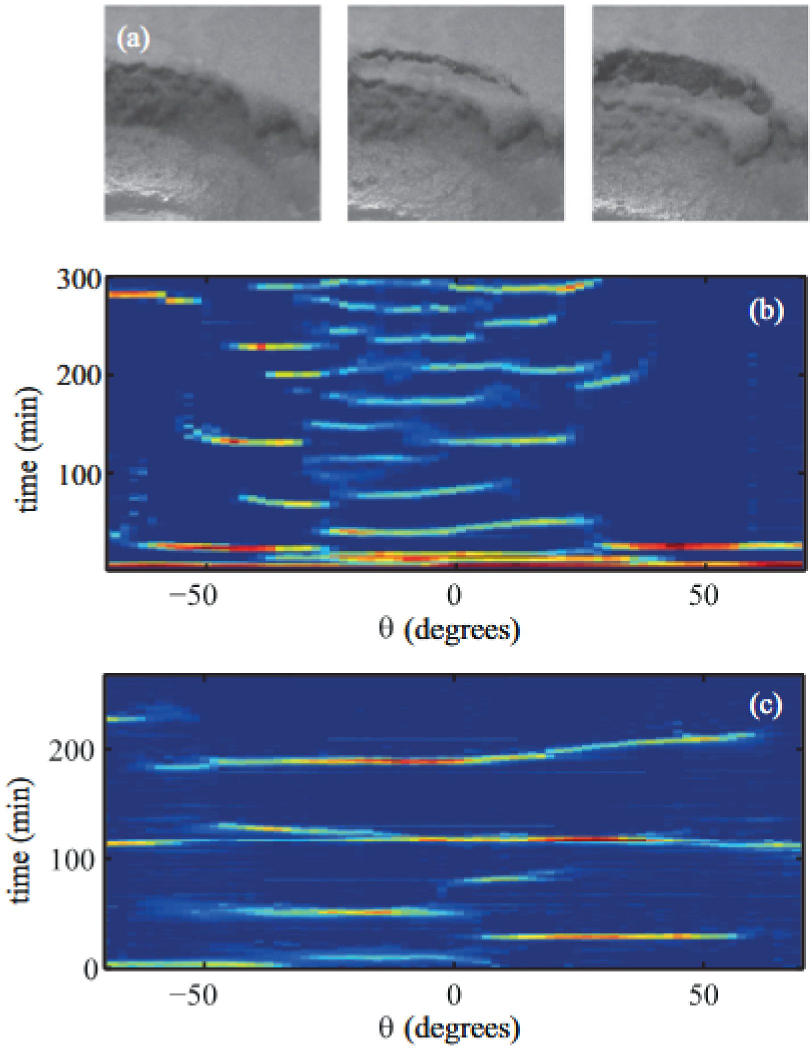


FIG. 9. (Color online) (a) Sequence of images illustrate a channel bank collapse. A crack initially appears and breaks a block, which falls inside the channel over the time scale of a minute. (b) The spatiotemporal development of avalanches as a function of the angle θ and time (b) in case of flow from reservoir and (c) in case with local rain (the experimental parameters are the same as in Fig. 7). The color scale is in arbitrary units and corresponds to the temporal derivative of the distance from the contour at $d(x,y) = 1$ cm and origin.

Figure 16 - Experimental seepage morphology reproduced from Berhanu et al. (2012), included for geometric comparison only.

D 2.9 – Location C

Location C was selected due to the persistence of surface deformation features across multiple LiDAR survey intervals and the availability of earlier satellite imagery showing surface expression prior to LiDAR-detected elevation change.

The combination of time-staggered satellite imagery, LiDAR differencing, and ground-level photography allows temporal sequencing of surface change to be illustrated without reliance on inference regarding causation.

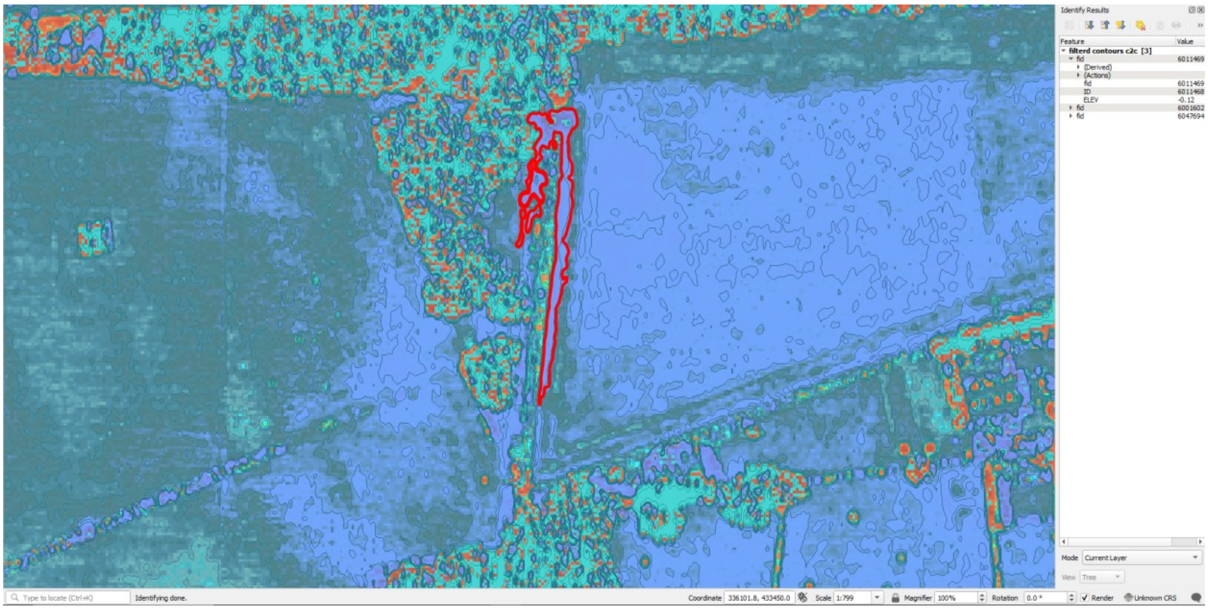


Figure 17 - LiDAR-derived elevation differencing at Location C (2018–2022), showing persistent surface deformation features across multiple survey intervals.

Figure 18 - 27/9/17 - Satellite imagery (27 September 2017) of Location C, showing early surface expression prior to later LiDAR-detected deformation.

Figure 19 - Ground-level photograph of Location C showing advanced surface change consistent with progressive deformation under low-energy hydrological conditions.

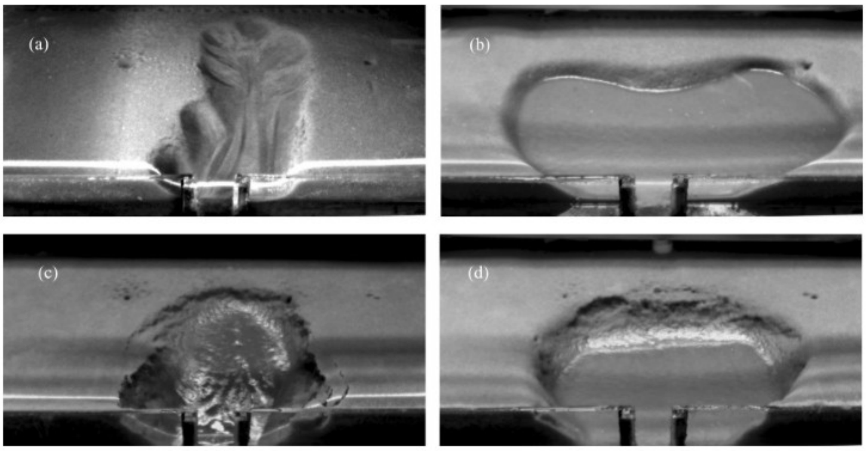


FIG. 4. Images of the four kinds of channels observed in the experiments. (a) An elongated channel fed by a flow from a reservoir at the back of the bed after $t = 916$ min with $d_{outlet} = 4$ cm, $\delta_H = 5$ cm, and no rainfall ($P = 0$). (b) A wider bifurcated channel fed by rain ($P_1 \sim 1.04 \times 10^{-4}$ m s^{-1}) is observed with $d_{outlet} = 4$ cm ($\delta_H = 5$ cm, $t = 595$ min). (c) An elongated deeper channel with steeper banks is observed with $d_{outlet} = 8.0$ cm ($P = 0$, $\delta_H = 6.8$ cm, $t = 311$ min). (d) The channel is deeper with $d_{outlet} = 8.0$ cm and wider with rain ($P = P_1$, $\delta_H = 2$ cm, $t = 240$ min).

Figure 20 - Experimental seepage-driven surface evolution reproduced from Berhanu et al. (2012), included for qualitative comparison of form and organisation.

D.2.10 Interpretation of location-based analysis

The three locations examined above were selected because they exhibit recurring geometric and morphological features that are internally coherent within LiDAR-derived elevation differencing and are qualitatively consistent with seepage-driven surface deformation mechanisms described in controlled experimental settings. The selection does not imply that these features share a common cause, nor that they result from subsurface operations. Rather, they are used to demonstrate that the observed surface expressions fall within a class of behaviour that is physically plausible under pressure-driven, fault-influenced groundwater conditions.

Across all three locations, several common characteristics are evident:

• deformation patterns are spatially discrete rather than diffuse
• features are not aligned with field boundaries, drainage infrastructure, or surface works
• contour geometry is nested and internally structured rather than random
• surface expression persists across multiple observation periods

These characteristics distinguish the identified features from artefacts associated with agricultural activity, ploughing, or routine drainage maintenance, and justify their consideration as analytically relevant surface signals within a corroborative framework.

D.2.11 Relationship to Berhanu et al. (2012)

The experimental work of Berhanu et al. (2012) demonstrates that seepage-driven erosion and surface deformation can arise where groundwater flow intersects the surface under low-energy conditions, producing characteristic planform and contour geometries. While the Fylde setting differs substantially in scale, material properties, and boundary conditions, the governing processes of pressure-driven emergence and mechanically induced surface adjustment are scale-independent in principle.

The comparison made in this appendix is therefore limited to qualitative geometric similarity and spatial organisation. No equivalence of mechanism, magnitude, or timescale is asserted. The Berhanu figures are used solely to establish that the observed LiDAR patterns fall within a recognised class of seepage-related surface response, and not to claim direct process correspondence.

D.2.12 Evidential role within the document

Within the evidence hierarchy adopted in this document, the location-based analyses presented in Appendix D serve a secondary corroborative role. They do not establish causation, nor do they override primary monitoring or regulatory findings. Their function is to test the plausibility of assumptions made at the planning stage, particularly where those assumptions relied on static or compartmentalised hydrogeological models.

The presence of structured, non-random surface deformation patterns beyond instrumented zones reinforces the conclusion that pad-centric monitoring frameworks were not sufficient to exclude all plausible system responses. This finding supports, but does not extend beyond, the governance and monitoring limitations identified in Sections 6, 9, and 10 of the main document.

D.2.13 Scope limitation and future work

The spatial scope of Appendix D was constrained by time and data-processing considerations. The locations presented here are illustrative rather than exhaustive. Additional sites exhibiting similar characteristics may be identified through extended analysis of the LiDAR and satellite datasets, and future work may expand this appendix accordingly.

The reduction in spatial extent does not alter the analytical conclusion: that surface expressions consistent with pressure-responsive behaviour exist beyond the immediate operational footprint, and that such expressions fall within the class of behaviour that planning-stage assessments and monitoring frameworks were not designed to test or exclude.

Appendix E — Persistent Ponding and Shallow Surface Water Behaviour (Tertiary Corroborative Evidence)

E.1 Nature and provenance of the material

This appendix documents a persistent surface-water feature ("Moss Lane pond") observed and recorded over time through a structured local monitoring diary. The material comprises dated observations, photographs, and descriptive notes compiled contemporaneously by local observers, documenting the appearance, persistence, and evolution of a ponded water body in an agricultural setting.

The diary does not constitute a regulatory assessment and does not claim attribution or causation. It is included as tertiary observational material, consistent with the evidence hierarchy defined in Section 1, and is treated as a signal requiring contextual interpretation rather than as proof of impact.

E.2 What the observations represent

The diary records repeated ponding at a consistent location over extended periods, including conditions outside of obvious short-term rainfall events. The persistence of standing water, seasonal recurrence, and apparent independence from acute flooding episodes indicate that the feature is not readily explained by transient surface runoff alone.

From a hydrogeological perspective, such behaviour is consistent with:

- shallow groundwater emergence or perched saturation,
- impeded drainage associated with subsurface heterogeneity,
- or pressure-responsive near-surface conditions interacting with local topography.

No single mechanism is asserted. The observations are relevant because they describe surface expressions that are hydrologically persistent**,** spatially fixed, and temporally structured.

E.3 Relationship to the main analysis

The significance of this material lies not in demonstrating harm, but in illustrating the type of surface expression that would be expected to occur first in a shallow, laterally connected, pressure-responsive system — precisely the class of behaviour discussed in Sections 4, 6, and 9 of the main document.

In particular, the observations are coherent with:

- the documented presence of shallow pressurised groundwater at PNR (Section 4);
- the demonstrated limits of pad-centric monitoring (Section 6);
- the treatment of hydrogeology and flood risk as static boundary conditions (Sections 3 and 9).

The pond diary therefore functions as a **corroborative signal** that surface hydrological behaviour can be persistent, spatially localised, and detectable outside formal monitoring networks.

E.4 Relevance to monitoring design and reassessment triggers

The Moss Lane observations directly support the monitoring principles articulated in Appendix B and Appendix C, particularly:

- the need for off-site surface-water observation points;
- the inclusion of persistent wet ground and ponding as explicit reassessment triggers;
- the requirement for monitoring systems capable of detecting slow, diffuse, or delayed responses.

The diary illustrates how such signals may be visible to local observers long before they are captured by periodic inspection regimes or threshold-based monitoring. As such, it demonstrates why surface-water changes should be treated as **hypothesis-testing inputs**, not dismissed as isolated anomalies.

E.5 Evidential limits

This appendix does not:

- assert causation,
- substitute for regulatory determination,
- or claim linkage to specific subsurface operations.

Its role is limited to demonstrating **plausibility, persistence, and detectability** of surface-water signals that fall within the range of mechanisms already established by primary evidence elsewhere in the document.

Appendix F — Community Environmental Observations Within the Preston New Road Area (Structured Tertiary Evidence)

F.1 Nature and provenance of the material

This appendix summarises a collection of environmental observations reported by residents living within approximately a two-mile radius of the Preston New Road site. The material comprises dated written accounts describing observed changes in air quality, odours, ground conditions, surface water behaviour, noise, and vibration.

The reports were compiled independently by residents and are presented here as **structured** tertiary evidence, consistent with the evidence hierarchy set out in Section 1. They are not treated as proof of impact, but as observational data points requiring contextual evaluation.

F.2 What the reports represent

The resident reports describe:

- transient or recurring odour events,
- unusual or persistent wet ground and seepage,
- changes in surface water appearance or behaviour,
- low-frequency noise or vibration occurring outside visible surface activity,
- spatially distributed phenomena occurring away from the well pad.

Individually, such observations are non-specific and may have multiple explanations. Collectively, however, they represent **distributed, time-resolved environmental sensing** across locations and periods not covered by fixed monitoring infrastructure.

F.3 Relationship to the main analysis

The relevance of these reports lies in their alignment with known monitoring blind spots identified in the main document:

- episodic events occurring between inspection visits (Section 6);
- off-site signals beyond instrumented zones (Sections 6 and 10);
- delayed or diffuse responses inconsistent with threshold-based escalation (Sections 9 and 10).

Importantly, the reports do not introduce new mechanisms. They describe surface-level phenomena that are not inconsistent with mechanisms already documented through primary evidence, including fault responsiveness, pressure diffusion, and shallow hydrogeological variability.

F.4 Why these reports matter in planning terms

From a planning perspective, the key issue is not whether individual reports are "correct," but whether the monitoring system in place was capable of detecting, contextualising, and responding to the class of signals being described.

- The material demonstrates that:
- potential early-warning signals may manifest first as local observations;

- such signals are spatially and temporally distributed;
- dismissal on the basis of "no impact observed during inspection" risks systematic false negatives.

This directly supports the argument in Appendices B and C that community reporting must be treated as an integral component of monitoring**,** not as a consultation or complaints process.

F.5 Integration with reassessment mechanisms

The observations documented here illustrate the necessity of:

- formal logging, time-stamping, and geolocation of reports;
- cross-referencing with live environmental and operational data;
- predefined escalation pathways where patterns emerge.

Absent such integration, planning authorities cannot reasonably claim that potential off-site effects would be identified in a timely or systematic manner.

F.6 Evidential limits

This appendix does not:

- assert causal links,
- override regulatory findings,
- or elevate anecdotal observation above primary data.

Its function is to demonstrate what information was available at the surface, how such information could have functioned as an early signal, and why its systematic exclusion represents a structural monitoring limitation rather than a lack of public concern.

Appendix G — Assumptions Register and Assumption Breach Log

(Planning-Critical Analytical Tool)

G.1 Purpose and status of this appendix

This appendix makes explicit the planning and regulatory assumptions that underpin the Preston New Road development and documents how those assumptions were operationalised, tested, and—where applicable—contradicted by subsequent evidence.

The register does **not** attribute fault, negligence, or non-compliance. Its purpose is to render visible the *assumption structure* on which planning confidence relied, and to record whether contradictory evidence triggered formal reassessment.

This appendix is analytical, not adjudicative. It converts narrative findings from the main body (Sections 2–12) into an auditable planning tool, consistent with the evidence hierarchy adopted in this document.

G.2 How to read the register

Each entry identifies:

- an assumption stated or implied at planning or permitting stage,
- the document(s) in which it appears,
- how it was operationalised in design, monitoring, or regulation,
- the evidence that tested or contradicted it,
- and whether a formal reassessment of acceptability occurred.

The register demonstrates foreseeability in category, not prediction of outcome. Where no breach is identified, this is recorded explicitly.

G.3 Assumptions Register and Breach Log

Assumption (as stated or implied)	Source document(s)	Domain	How the assumption was operationalised	Evidence that tested or contradicted the assumption	Formal reassessment triggered?	Planning relevance
Shallow groundwater systems are weakly pressurised and stable under baseline conditions	Planning hydrogeology assessments; FRA submissions	Hydrogeology	Groundwater treated as a passive receptor; monitoring wells sited to confirm baseline levels	Artesian groundwater encountered at ~29 m during conductor installation	No	Demonstrates baseline hydrogeological conditions were underestimated
Hydraulic gradients are predictable and governed primarily by topography	Hydrogeological conceptual models	Hydrogeology	Models assumed downward or lateral flow consistent with surface gradients	Upward hydraulic head sufficient to sustain artesian flow	No	Challenges suitability of static groundwater models
Shallow groundwater is hydraulically separable from deeper operations	Planning submissions; EA permitting documents	Hydrogeology	Vertical separation assumed outside engineered well paths	Pressurised shallow groundwater prior to fracturing narrowed plausible separation models	No	Narrows acceptable conceptual models at planning stage
Faults are relevant primarily as seismic hazards, not hydraulic pathways	Geological risk assessments; seismic sections	Seismic / Hydrogeology	Faults mapped for seismic avoidance but not targeted for hydraulic monitoring	Seismicity confirmed fault activation and pressure diffusion	No	Indicates faults should have been treated as coupled mechanical–hydraulic features
Induced seismicity will remain within bounded, controllable limits	TLS framework; planning rationale	Seismic	Traffic Light System used as primary control mechanism	ML 2.9 event and post-injection seismicity	No (policy response only)	Shows operational controls did not bound response as assumed
Seismic response will stabilise promptly following injection cessation	Seismic risk assessments	Seismic	Assumed temporal containment of response	Continued seismicity after injection stopped	No	Indicates delayed system response not accounted for
Monitoring can detect adverse effects in time to intervene	Planning conditions; monitoring plans	Monitoring	Monitoring designed to confirm predicted pathways	Structural blind spots identified; false negatives possible	No	Undermines reliance on absence of detected impact
Monitoring networks capture dominant pathways	Operator monitoring proposals	Monitoring	Wells placed near pad and predicted gradients	Off-site, fault-guided pathways not directly monitored	No	Monitoring design insufficient to exclude alternative responses

Threshold exceedance will capture meaningful system change	Regulatory escalation logic	Monitoring / Governance	Threshold-based triggers for intervention	Distributed, cumulative, or delayed responses may not breach thresholds	No	Shows reactive controls insufficient for precautionary planning
Flood risk can be treated as a static boundary condition	Flood Risk Assessment	Flood risk / Hydrogeology	Fixed infiltration and drainage assumptions	Elevated groundwater head challenges infiltration capacity assumptions	No	Flood risk models not robust to subsurface change
Regulatory oversight can manage emerging technical risk	Planning decision rationale	Governance	Planners deferred to regulators for technical control	Regulators operated within permitted envelope	No	Demonstrates governance circularity
Planning acceptability remains valid unless non-compliance occurs	Planning consent structure	Governance	No automatic re-opener mechanisms	Assumption breach did not trigger planning review	No	Core planning failure mode
Operator models are sufficient basis for risk management	Planning submissions	Governance / Modelling	Predictive models treated as decision anchors	Contradicted by site observations	No	Model confirmation substituted for hypothesis testing
Absence of detected impact implies acceptable performance	Regulatory interpretation	Governance	Monitoring results interpreted within original assumptions	Monitoring limitations documented	No	Absence of evidence misused as evidence of absence

G.4 What the register demonstrates

Taken together, the entries show that:

- key assumptions were explicitly or implicitly relied upon in planning determination;
- several were tested by early or mid-operation evidence;
- contradictory observations were managed procedurally, not analytically;
- no assumption breach triggered a formal reassessment of planning acceptability.

This pattern supports the conclusion in Sections 9–12 that the failure mode at Preston New Road was systemic and structural, not accidental.

G.5 Planning relevance

From a planning perspective, the critical issue is not whether assumptions were reasonable at the time they were made, but whether the governance framework included mechanisms to:

- identify when assumptions were no longer valid, and
- reassess acceptability when that occurred.

The register demonstrates that such mechanisms were absent or inoperative.

G.6 Evidential limits

This appendix:

- does not assert environmental harm,
- does not determine causation,
- does not substitute for regulatory or judicial findings.

Its sole function is to document assumption reliance versus evidence availability, in a form suitable for inspection, scrutiny, and comparison with future proposals.

Appendix H — Regulatory Dependency and Responsibility Map

(Governance Structure and Decision Gaps)

H.1 Purpose of this appendix

This appendix provides a structured representation of how responsibility for risk assessment, monitoring, and intervention was allocated between planning authorities, regulators, and the operator at Preston New Road.

Its purpose is not to assign fault or to critique individual decisions, but to make explicit the governance architecture within which those decisions occurred, and to identify where responsibility for system-level reassessment was absent or undefined.

This appendix supports the analysis in Section 12 by presenting the same findings in schematic form.

H.2 Overview of the governance structure

At Preston New Road, responsibility for assessing, managing, and responding to risk was distributed across three principal institutional actors:

- the Planning Authority,
- statutory Regulators (Environment Agency, HSE, OGA / successor bodies), and
- the Operator.

Each actor operated within a defined remit. The interaction of those remits created a system in which confidence was maintained through mutual reliance**,** rather than through ownership of emergent risk.

H.3 Institutional roles and limits

H.3.1 Planning Authority

Primary role

- Determine whether the development was acceptable in principle.
- Impose planning conditions governing scope, process, and mitigation.

Operational dependency

- Relied on specialist regulators to manage technical and environmental risk.
- Accepted assurances that risks would be "controlled by the appropriate regulator."

Structural limit

Did not retain an explicit mechanism to reassess acceptability once operations commenced, absent formal non-compliance.

H.3.2 Regulators (EA / HSE / OGA)

Primary role

- Regulate activities within statutory remits.
- Enforce permit conditions, thresholds, and safety requirements.

Operational dependency

- Relied on operator-submitted models, monitoring data, and reporting.
- Acted within the envelope established by planning consent.

Structural limit

- No mandate to revisit or invalidate planning assumptions.
- Escalation framed around *manageability* rather than *acceptability*.

H.3.3 Operator

Primary role

- Develop conceptual and numerical models underpinning applications.
- Implement monitoring and report data.
- Operate within consented and permitted parameters.

Operational dependency

- Relied on planning permission and regulatory approvals to proceed.
- Required to demonstrate compliance, not to test alternative system behaviours.

Structural limit

- No obligation to suspend operations on the basis of uncertainty alone.
- Model ownership did not equate to responsibility for reassessing development acceptability.

H.4 Circular dependency structure

The interaction of these roles produced a **circular assurance loop**, summarised as follows:

- **Planning Authority**
  → defers technical risk control to **Regulators**
- **Regulators**
  → regulate activity within the **permitted envelope**, relying on **operator data**
- **Operator**
  → operates within **consented scope**, relying on planning approval and regulatory sign-off

At no point in this loop was an actor explicitly tasked with answering the question:

"Do emerging observations invalidate the assumptions that made the development acceptable in the first place?"

This question fell between institutional remits.

H.5 Identified decision gaps

The following governance gaps are demonstrated by the evidence reviewed in this document:

- No authority owned responsibility for reassessing planning acceptability following:
    - unexpected artesian groundwater conditions,

    - confirmation of fault activation,
    - evidence of pressure diffusion beyond predicted behaviour,
    - recognition of monitoring blind spots.

- Seismic exceedances triggered operational pauses, not planning review.
- Monitoring limitations were tolerated so long as procedural compliance was maintained.
- Escalation occurred only after outcomes forced policy-level intervention.

H.6 Why this does not imply individual fault

The circularity identified here does not imply negligence, misconduct, or bad faith by any actor.

Each institution acted broadly within its defined remit. The failure mode arises from the absence of a system-level owner for emergent risk**,** not from the failure of individual components.

This structure can function adequately where system behaviour is predictable and well constrained. It is poorly suited to faulted, pressure-responsive geological environments.

H.7 Planning relevance

From a planning perspective, the significance of this appendix is that it demonstrates why:

- early contradictory evidence did not trigger reassessment,
- monitoring insufficiency did not halt progression,
- confidence persisted beyond its evidential basis.

The governance structure itself constrained the system's ability to self-correct.

H.8 Relationship to other appendices

This appendix should be read alongside:

- **Appendix G** (Assumptions Register), which identifies what was relied upon; and
- **Appendix I** (What Monitoring Could Not Detect), which explains why absence of detection could not resolve uncertainty.

Together, these appendices demonstrate how assumption reliance, monitoring limits, and governance structure interacted to produce a systemic failure mode.

Appendix I — What the Monitoring Could Not Detect

(Structural Limits of Detection and False-Negative Risk)

I.1 Purpose of this appendix

This appendix identifies categories of system behaviour that the monitoring frameworks implemented at Preston New Road were structurally incapable of detecting or excluding**,** even if those frameworks operated exactly as designed.

Its purpose is not to criticise monitoring implementation, data quality, or regulatory diligence. Instead, it documents the negative capability of the monitoring system: what it could not reasonably observe, resolve, or falsify given its spatial configuration, temporal resolution, and conceptual assumptions.

This appendix supports the interpretation in Sections 6, 9, 10, and 11, and provides explicit context for why absence of detected impact cannot be equated with absence of process.

I.2 Framing principle: detection versus exclusion

Monitoring systems can only exclude processes that they are explicitly designed to test.

Where:

- pathways are assumed rather than interrogated,
- responses are distributed rather than point-based,
- or signals are delayed, intermittent, or low-magnitude,
- the absence of detection may reflect design limitation rather than system stability**.**

This appendix documents those limitations by domain.

I.3 Hydrogeological processes not reliably detectable

I.3.1 Slow pressure diffusion in shallow groundwater systems

Why detection is unlikely

- Monitoring focused on discrete wells and predicted gradients.
- Periodic sampling averages out gradual head changes.
- No triggers tied to subtle but sustained deviation from baseline.

What may be missed

- Progressive elevation of groundwater head.
- Redistribution of pressure along faults or stratigraphic interfaces.
- Early-stage seepage that does not breach thresholds.

Planning relevance
Slow pressure diffusion can materially affect infiltration capacity, surface drainage, and receptor sensitivity without producing abrupt or localised exceedance events.

I.3.2 Fault-guided lateral groundwater migration

Why detection is unlikely

- Fault-intersecting monitoring points were not deliberately installed.
- Monitoring networks were pad-centric and pathway-confirmatory.
- Off-site boundary zones were sparsely instrumented.

What may be missed

- Lateral migration emerging away from the well pad.
- Discharge at distal springs, wet ground, or low-energy seepage zones.
- Spatially displaced responses misattributed to background variability.

Planning relevance
Such behaviour directly challenges assumptions of vertical isolation and pad-centric impact.

I.4 Seismic and geomechanical processes not reliably detectable

I.4.1 Aseismic slip and stress redistribution

Why detection is unlikely

- Seismic monitoring detects only events above defined magnitude thresholds.
- Stress transfer and deformation can occur without felt or recorded seismicity.

What may be missed

- Gradual fault creep.
- Redistribution of stress altering permeability or connectivity.
- Deformation that manifests hydrologically rather than seismically.

Planning relevance
Absence of seismic events does not exclude fault-mediated system response.

I.5 Atmospheric and gas-related processes not reliably detectable

I.5.1 Episodic or short-duration gas releases

Why detection is unlikely

- Reliance on periodic monitoring and inspections.
- Strong dependence on meteorological conditions.
- Short-lived events may dominate cumulative flux but evade detection.

What may be missed

- Nocturnal or calm-condition releases.
- Low-concentration chronic seepage.
- Events occurring outside inspection windows.

Planning relevance
Absence of detected emissions does not exclude episodic or spatially displaced releases.

I.6 Surface water and shallow surface processes not reliably detectable

I.6.1 Delayed or intermittent surface-water response

Why detection is unlikely

- Monitoring focused on predefined receptors.
- Seasonal variability masks gradual change.
- Inspections capture conditions at single time points.

What may be missed

- Altered baseflow persistence.
- Intermittent seepage or wet ground expansion.
- Cumulative effects emerging over multiple seasons.

Planning relevance
Surface expressions are often the first visible indicators of shallow system response, but may not coincide with monitoring schedules.

I.7 Monitoring integration limits

Across domains, the monitoring system was not designed to:

- integrate seismic confirmation of fault activity with hydrogeological reassessment,
- reinterpret air or water data in light of emerging structural behaviour,
- test alternative conceptual models once contradictions emerged.

As a result, datasets that appeared benign in isolation may still have been consistent with broader system change when considered collectively.

I.8 Interpretation within the evidence hierarchy

Within the evidence hierarchy adopted in this document:

- The limitations described above are inferred from monitoring design and scope, not from outcome-based reasoning.
- No tertiary or anecdotal evidence is required to demonstrate these limits.
- This appendix does not assert that undetected processes occurred.

It demonstrates only that monitoring was not capable of excluding them.

I.9 Planning relevance and evidential caution

From a planning perspective, the significance of this appendix is that it establishes why:

- monitoring compliance cannot be equated with system stability,
- absence of detected impact cannot be relied upon as evidence of non-occurrence,
- confidence in acceptability cannot be maintained solely through confirmatory monitoring.

Where monitoring cannot exclude plausible system responses, continued reliance on original assumptions becomes evidentially fragile.

I.10 Relationship to other appendices

This appendix should be read in conjunction with:

- **Appendix G** — identifying which assumptions required exclusion, and
- **Appendix H** — explaining why no authority was positioned to act when exclusion was not possible.

Together, these appendices demonstrate how structural monitoring limits contributed to the loss of corrective capacity identified in the main body.

Appendix J — Timeline of Decision Points vs Knowledge Availability (Contemporaneity and Foreseeability Context)

J.1 Purpose of this appendix

This appendix sets out a structured timeline comparing key planning and regulatory decision points with the state of knowledge available at the time those decisions were taken.

Its purpose is to demonstrate that the analysis presented in this document does not rely on retrospective interpretation or later-acquired evidence. Instead, it shows that:

• categories of uncertainty were already recognised,
• assumptions underpinning consent were contestable at the time, and
• subsequent observations contradicted those assumptions without triggering reassessment.

This appendix is intended to guard explicitly against hindsight bias by distinguishing between:

• what was known,
• what was not yet known, and
• what decisions were nevertheless taken.

J.2 Structure and method

The timeline is organised chronologically and records, for each phase:

• the decision or action taken,
• the knowledge available at that time,
• the assumptions relied upon, and
• whether mechanisms existed to revisit those assumptions if contradicted.

No later evidence is used to critique earlier decisions except to identify whether and when assumption breach became observable.

J.3 Timeline of decision points and knowledge availability

Pre-determination phase (prior to planning approval)

Knowledge available

• UK shale gas development was recognised as occurring in faulted, structurally complex basins, unlike many North American analogues.
• National scientific reviews identified:
– uncertainty in fault connectivity,
– limited resolution of subsurface datasets at site scale,
– sensitivity of pressure-driven systems to small perturbations.
• Induced seismicity was acknowledged as a plausible risk, with mitigation proposed via the Traffic Light System.
• Hydrogeological uncertainty was acknowledged qualitatively but treated as manageable within existing models.

Assumptions relied upon

• Shallow groundwater systems were assumed to be stable, weakly pressurised, and hydraulically separable from deep operations.
• Faults were treated primarily as seismic hazards, not as hydraulic pathways.
• Monitoring was assumed to be capable of detecting adverse effects in sufficient time to intervene.
• Flood risk and drainage behaviour were treated as static boundary conditions.

Decisions taken

• Planning consent was granted on the basis that:
– technical risks would be controlled by regulators,
– monitoring would validate predicted behaviour, and
– uncertainty was acceptable within the proposed framework.

What was not yet known

• Site-specific hydrogeological behaviour during drilling.
• Degree of fault responsiveness to pressure perturbation.
• Whether monitoring design would be capable of detecting non-predicted pathways.

Early construction and drilling phase

Knowledge available

• Pressurised groundwater was encountered at shallow depth during conductor installation.
• Unplanned engineering measures were required to control artesian flow.

Assumptions tested

• The assumption of weakly pressurised shallow groundwater.
• The assumption of predictable hydraulic gradients under baseline conditions.

Decisions taken

• The artesian condition was treated as a localised engineering issue.
• Drilling was allowed to proceed following operational mitigation.

What was not done

• No formal reassessment of the hydrogeological conceptual model.
• No expansion or reorientation of monitoring.
• No review of flood risk or surface–subsurface interaction assumptions.

Hydraulic fracturing and testing phase

Knowledge available

• Induced seismicity was detected in near real time.
• Seismic events exceeded pre-defined operational thresholds.
• Continued seismic response was observed after injection ceased.

Assumptions tested

• The assumption that seismic response would be bounded in magnitude, promptly controllable, and confined temporally to injection periods.
• The assumption that fault activation was manageable within operational controls.

Decisions taken

• Operations were paused and resumed in accordance with the Traffic Light System.
• Seismicity was treated as an operational compliance issue.

What was not done

• No planning-level reassessment of development acceptability.
• No integration of seismic findings into hydrogeological risk models.
• No reconsideration of monitoring adequacy in light of confirmed fault activation.

Post-event and policy response phase

Knowledge available

• Government-commissioned reviews concluded that confidence in managing induced seismicity was insufficient.
• It was recognised that predictive control of fault response was not achievable within existing frameworks.

Decisions taken

• A moratorium on hydraulic fracturing was introduced at national level.

Significance

• Intervention occurred only after outcomes had materialised.
• No earlier mechanism existed to translate emerging knowledge into planning reconsideration at site level.

J.4 Interpretation and planning relevance

This timeline demonstrates that:

• uncertainty was recognised prior to consent,
• contradictory evidence emerged during early operations, and
• confirmation of assumption breach occurred during fracturing.

At no point prior to national policy intervention was there a mandated mechanism requiring reassessment of planning acceptability when foundational assumptions were contradicted.

The critique advanced in this document is therefore contemporaneous rather than retrospective. It arises from the documented interaction between decision-making and knowledge availability as events unfolded.

J.5 Summary

The relevance of Preston New Road does not lie in the benefit of hindsight, but in the absence of institutional capacity to respond when foresight proved incomplete.

This appendix establishes that:

- categories of risk were foreseeable,
- assumptions were contestable at the time they were relied upon, and
- decision-making frameworks lacked re-opener mechanisms tied to emerging evidence.

As such, the failures identified in the main body of this document arise from governance structure, not from retrospective reinterpretation of events.

Appendix K — Climate Context and Acceptability of Risk (Policy and Decision-Relevance Addendum)

K.1 Purpose and scope of this appendix

This appendix addresses the acceptability of the proposed development in a climate-policy context, independent of the technical system failures demonstrated elsewhere in this document.

It does not introduce new empirical findings, nor does it seek to quantify greenhouse gas emissions or climate impacts. Instead, it situates the development within the United Kingdom's stated climate commitments and examines whether long-term uncertainty and risk associated with unconventional hydrocarbon extraction can be reconciled with those commitments.

This appendix is normative in nature and is explicitly framed as a matter of planning judgement and public interest, not technical proof.

K.2 Separation from the technical analysis

The preceding sections of this document demonstrate that, under faulted and pressure-responsive geological conditions, the planning and regulatory system lacked the structural capacity to:

- reliably predict subsurface behaviour,
- detect all plausible system responses, or
- correct course once foundational assumptions were contradicted.

Those conclusions are independent of climate considerations.

This appendix proceeds on the basis that even if the technical uncertainties identified elsewhere were considered acceptable, a separate question remains:

Is it reasonable to accept long-term, potentially irreversible environmental risk in support of new fossil fuel development under current climate commitments?

K.3 Climate commitments and planning relevance

The United Kingdom has committed, in statute and policy, to:

- achieving net-zero greenhouse gas emissions by 2050,
- reducing reliance on fossil fuel extraction over time,
- applying precaution where long-term environmental harm may arise.

While planning authorities are not required to adjudicate global climate outcomes, they are required to consider whether developments are compatible with national policy objectives and the public interest, particularly where:

- benefits are time-limited, and
- risks extend beyond the operational life of the project.

Unconventional hydrocarbon developments are distinctive in this regard because their risk horizon extends far beyond their productive phase, particularly where subsurface uncertainty cannot be actively governed.

K.4 Long-term risk under climate constraint

The analysis in this document establishes that:

• subsurface responses may be delayed, distributed, or non-linear,
• monitoring and governance mechanisms may not detect or respond to change in a timely manner,
• corrective capacity may be lost even under regulatory compliance.

In a climate context, these characteristics are particularly problematic because:

• remediation of subsurface impacts may be infeasible or carbon-intensive,
• responsibility for long-term effects may persist beyond the operational entity,
• future generations inherit both the environmental burden and the governance gap.

Where climate policy demands risk reduction rather than risk transfer, developments with uncertain long-term subsurface behaviour present a structural incompatibility.

K.5 Risk acceptability versus technical possibility

This document has not argued that impacts are inevitable, nor that harm has been conclusively demonstrated. It has shown that:

• uncertainty cannot be eliminated,
• monitoring cannot exclude all plausible adverse responses, and
• governance mechanisms cannot guarantee timely intervention.

In a climate-constrained policy environment, the relevant planning question is therefore not:

Can this development be managed if things go wrong?

but rather:

Should this category of risk be accepted at all in pursuit of new fossil fuel extraction?

Where uncertainty is systemic and long-lived, acceptability becomes a policy judgement rather than a technical one.

K.6 Planning relevance and precaution

From a planning perspective, precaution does not require proof of harm. It requires recognition that:

• long-term environmental risks cannot be fully bounded,
• governance mechanisms may be insufficient to respond once harm manifests, and
• alternative energy pathways exist that do not carry equivalent subsurface legacy risk.

In this context, refusal of consent does not represent failure of regulation, but application of precaution in line with climate objectives.

K.7 Final statement

Taken together with the technical findings of this document, the climate context reinforces a clear conclusion:

Even if the development could be rendered technically compliant, the acceptance of long-term, poorly governable subsurface risk in support of new fossil fuel extraction is incompatible with a precautionary planning approach under current climate commitments.

This conclusion does not rely on prediction of specific outcomes. It rests on the recognition that where uncertainty cannot be actively governed, proceeding becomes a choice to externalise risk into the future.

Assessment Limitations

This assessment is intentionally bounded in scope and method. It evaluates planning, regulatory, monitoring, and governance frameworks using documented evidence and a structured analytical approach. It does not constitute a legal, enforcement, or impact determination.

The following limitations apply.

The assessment relies on publicly available and formally submitted primary materials, including planning documents, regulatory publications, operator technical reports, and government-commissioned scientific analyses. It does not incorporate proprietary operator datasets, internal regulatory deliberations, or non-public monitoring records.

No independent field measurements, subsurface investigations, or site access activities were conducted for the purposes of this document. The analysis does not introduce new empirical data and does not attempt to replicate or replace regulatory measurement programs.

Secondary evidence, including LiDAR and satellite observations, is used only to test spatial and temporal coherence with mechanisms identified in primary sources. Such material is not used to establish causation or to demonstrate impact.

Tertiary materials, including community observations and local reports, are treated strictly as plausibility signals and are not used as proof of mechanism or outcome. No conclusion in this document depends solely on tertiary evidence.

The assessment does not determine legal liability, regulatory breach, or policy non-compliance. It does not evaluate intent, motive, or conduct of any organisation or individual. All findings are framed at system and framework level.

No predictive claims are made regarding future site performance or outcomes at other developments. References to comparable sites are structural and analytical, not predictive.

Technical interpretations are bounded by the resolution and scope of the cited sources. Where uncertainty exists, it is identified explicitly rather than resolved through inference.

Portions of drafting and structural organisation were assisted by an AI language tool. All analytical judgements, interpretations, and conclusions were selected and validated by the author.

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