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When 20 hectares costs a million dollars: why spatial integrity matters in mine rehabilitation reporting

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Abstract

Mine rehabilitation reporting underpins regulatory compliance, financial provisioning and long-term closure liability management. Across many jurisdictions, rehabilitation performance and financial assurance calculations rely heavily on spatial datasets used to quantify disturbed and rehabilitated areas. However, the integrity of the spatial data supporting these calculations is not always explicitly assessed, despite its influence on reported rehabilitation progress and closure cost estimates.

Small inconsistencies in spatial data management, including projection errors, topology issues, inconsistent digitising practices and misaligned datasets, can introduce discrepancies in calculated rehabilitation areas. In large mining operations, even relatively minor spatial inaccuracies may have material financial implications.

This paper examines the role of spatial data integrity in mine rehabilitation reporting through a case study of an operational mine in Queensland, Australia. It illustrates how common geographic information system (GIS) data management issues can propagate through reporting workflows and influence rehabilitation area calculations and associated liability cost estimates. This paper identifies typical sources of spatial error, explores how these issues arise within standard reporting processes, and considers the potential financial and compliance implications associated with inaccurate spatial reporting.

A practical framework for improving spatial integrity in rehabilitation reporting is also presented. This includes recommended GIS governance practices, quality assurance procedures and data management standards that can be implemented within existing mine reporting systems. Strengthening the spatial foundations of rehabilitation reporting has the potential to improve the reliability of closure metrics, reduce financial uncertainty and support greater confidence in regulatory reporting.

Keywords: *mine closure, rehabilitation reporting, spatial data integrity, closure cost estimation, environmental compliance*

1 Introduction

Mine disturbance and rehabilitation reporting is a critical component of environmental compliance, financial provisioning and long-term closure management (Laurence 2006). Across mining jurisdictions, these processes depend on spatial datasets to quantify disturbance extents, track rehabilitation progress and estimate closure liabilities. The accuracy and consistency of these datasets directly influence compliance outcomes, financial provisioning and business economic valuations where spatial quantities are used as model inputs.

In Queensland, Australia, this reliance is formalised under the *Environmental Protection Act 1994*, where spatial information is required to support multiple statutory processes (Department of Environment, Tourism, Science and Innovation [DETSI] 2026). These regulatory processes depend on spatial data for validation, assessment and analysis (DETSI 2026). Geographic information systems (GIS) underpin this

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framework, enabling the capture, management and analysis of spatial data across the mining life cycle, supporting verification that activities occur within approved areas.

Beyond regulatory compliance, disturbance and rehabilitation spatial datasets can support business-critical decisions including rehabilitation budgeting, financial assurance, closure liability estimation and capital allocation. Spatial data integrity should therefore be understood not only as a technical issue but also as a potential control point that may improve confidence in financial reporting inputs, auditability and closure-related business decisions.

The role of GIS in mine closure is well established, particularly in integrating spatial and non-spatial data to support decision-making, compliance and risk management (Poole 2023). Previous research highlights its importance in closure planning and cost estimation (Bloemhof & Bothma 2025; Kumari & Cooper 2019; Laurence 2006;), with spatially driven costing approaches demonstrating that closure liabilities are highly sensitive to spatial inputs, particularly where area and classification directly influence calculations (Kumari & Cooper 2019).

Despite this reliance, spatial integrity is often assumed rather than actively managed, allowing errors introduced during data creation or maintenance to propagate through reporting workflows (Hunter 2000). Common issues such as overlapping geometries, unit errors, incorrect classifications and non-compliant coordinate systems can lead to discrepancies in calculated disturbance and rehabilitation areas, with even minor inaccuracies translating into substantial financial risk (Bloemhof & Bothma 2025; Kumari & Cooper 2019).

Using a case study from an operational mine in Queensland, this paper illustrates how breakdowns in spatial data governance, process continuity, and compliance can degrade data integrity and increase financial and regulatory risk. It indicates how relatively small spatial discrepancies can translate into substantial differences in rehabilitation liability and reported outcomes.

This paper positions spatial integrity as a distinct and manageable source of error in rehabilitation reporting. Drawing on concepts from GIS uncertainty, data governance and mine closure literature, it proposes a practical framework centred on a unified spatial data model supported by governance, schema alignment and embedded quality assurance processes. By establishing spatial integrity as a key risk factor, this research provides a pathway to improve the reliability of rehabilitation reporting and reduce financial and compliance risk.

2 Spatial data integrity and uncertainty

Spatial data is commonly evaluated in terms of quality, accuracy and uncertainty, although these concepts are often treated as distinct within the literature. Spatial data quality refers to the fitness of a dataset for its intended use, accuracy describes how well spatial positions or attributes represent real world conditions, and uncertainty reflects the level of confidence in those representations (Hunter 2000). Consistency refers to the degree to which spatial data is uniform and aligned across datasets representing the same features or areas. While these concepts are well established, they are typically considered independently. In operational environments, however, spatial datasets are used across multiple systems and reporting processes, where errors can propagate and influence derived outputs (Hunter 2000).

In mining contexts, spatial data represents both existing and proposed conditions. Existing disturbance data is constrained by measurable accuracy limits, whereas proposed disturbance and rehabilitation datasets are subject to greater uncertainty due to reliance on planning assumptions. When these datasets are used together, differences in accuracy and uncertainty may introduce inconsistencies in reported outcomes. These challenges are compounded where spatial data is managed across multiple datasets or systems. Data governance literature highlights the importance of ownership, standardisation and life cycle management in maintaining consistency (Khatri & Brown 2010; Otto 2011). In their absence, datasets may diverge over time.

Within this context, this paper adopts the term spatial integrity to describe the consistency, alignment and reliability of spatial data across interconnected reporting processes. In disturbance and rehabilitation reporting, spatial integrity is not determined solely by the accuracy of individual datasets but also by their ability to remain consistent across multiple processes over time. This definition extends conventional data quality concepts by emphasising cross-dataset consistency within operational workflows.

3 Regulatory frameworks and spatial dependencies

3.1 Regulatory context and spatial data requirements

Disturbance and rehabilitation reporting in Queensland operates within a structured regulatory framework in which spatial data underpins multiple statutory processes. These include estimated rehabilitation cost (ERC) applications, progressive rehabilitation and closure plan (PRCP) schedules and annual returns (AR), all of which are supported by spatial information submitted in accordance with the Department of Environment, Tourism, Science and Innovation (DETSI) Spatial Submission Guidelines (DETSI 2026).

To support regulatory use, spatial data submissions must adhere to defined schema requirements including geometry types, attribute structures, coordinate reference systems and metadata standards. The guideline further requires that spatial data accurately represent disturbance and rehabilitation areas and be provided in formats suitable for validation and analysis by the department (DETSI 2026). These regulatory dependencies may also intersect with corporate financial reporting. Under section 296 of the *Corporations Act 2001*, financial reports must comply with the Australian Accounting Standards (Commonwealth of Australia 2001). The Australian Accounting Standards require provisions to be recognised and measured using reliable estimates where a present obligation exists and an outflow of resources is probable (Australian Accounting Standards Board 2026). Where rehabilitation or closure provisions rely on cost models that use spatial inputs, errors in disturbance area, rehabilitation status or activity classification may affect the reliability of those estimates (Bloemhof & Bothma 2025; Kumari & Cooper 2019). Spatial data integrity may therefore support not only regulatory reporting but also the traceability and auditability of closure liability estimates.

3.2 Interdependent reporting processes

Each regulatory process uses spatial data for a distinct but interrelated purpose. ERC applications quantify the financial liability associated with rehabilitating disturbed land, requiring spatial datasets that represent disturbance extents and rehabilitation classifications used in cost calculations (DETSI 2024). PRCP schedules define intended rehabilitation outcomes over time, including spatially defined rehabilitation areas, post-mining land uses (PMLUs) and milestone-based commitments (DETSI 2023). ARs provide a temporal record of disturbance and rehabilitation progression, reporting actual site conditions on a yearly basis.

Despite these differing roles, the processes are functionally linked through their reliance on consistent representations of disturbance and rehabilitation extents. This interdependency is illustrated conceptually in Figure 1, where ERCs, PRCPs and ARs are all derived from the same underlying spatial surface, just at different stages.

Figure 1 Relationship between ERC, PRCP and AR submissions describing the same land surface

This linkage is explicitly reinforced within the ERC framework, which requires that rehabilitation cost calculations are consistent with an approved PRCP schedule, and that applications include a compliance statement confirming alignment with the PRCP where one exists (DETSI 2024). Furthermore, the PRCP framework requires that rehabilitation areas, PMLUs and progression milestones are spatially defined and aligned with submitted spatial datasets (DETSI 2023).

3.3 Spatial validation processes

As part of the submission framework, the department undertakes preliminary spatial file validation to ensure that datasets meet minimum structural and technical requirements prior to assessment (DETSI 2026). This validation includes checks on geometry and topology in accordance with ESRI geodatabase rules, with datasets containing invalid geometry returned for correction.

Typical issues addressed through this process include incorrect coordinate systems, invalid or self-intersecting geometries, schema mismatches, missing or incorrect metadata, and non-compliant file naming conventions. These common validation issues are illustrated in Figure 2.

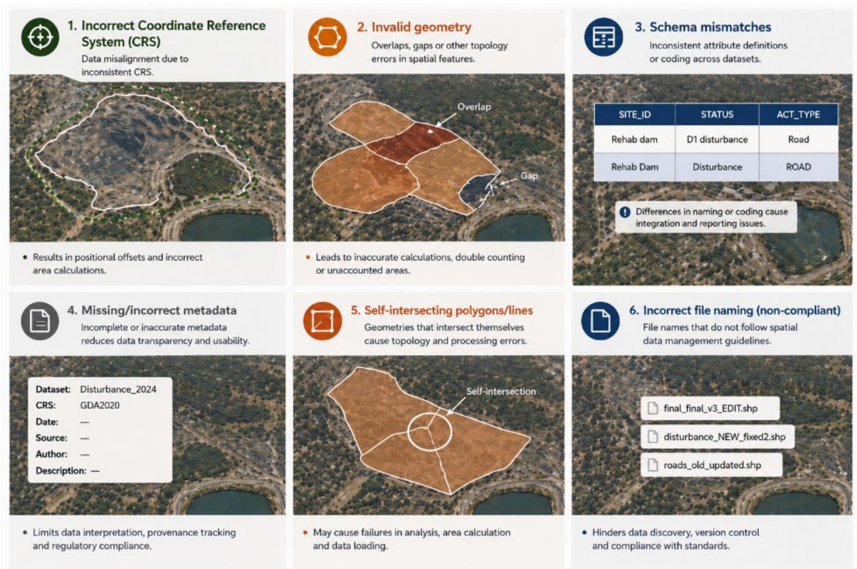

Figure 2 Examples of common spatial data errors identified during submission validation

These checks ensure that submitted datasets are technically valid, interpretable and compatible with departmental systems. If spatial data fails to meet these requirements it may be returned for resubmission (DETSI 2026).

3.4 Limitations of dataset level validation

While spatial validation aims to ensure that datasets meet required formatting and technical standards, it is limited to the assessment of individual datasets and is separate from the broader evaluation of the associated application (DETSI 2026). As a result, validation operates at the level of individual submissions rather than across the full set of interdependent reporting processes. There is no explicitly defined requirement within the spatial submission or validation framework to assess consistency between datasets submitted for ERC, PRCP and AR processes for the same site. This may create a structural limitation. Spatial datasets representing disturbance and rehabilitation extents may be independently valid across submissions yet differ in extent, classification or spatial alignment.

This limitation is particularly significant given the regulatory dependency between these processes. ERC calculations must reflect rehabilitation obligations defined within PRCP schedules, and PRCP schedules are themselves developed using spatial representations of disturbance, rehabilitation areas and final land use outcomes (DETSI 2023, 2024).

3.5 Assessment processes and information requests

Despite this interdependency there is no clearly defined mechanism within the spatial validation processes to ensure that the datasets supporting these reporting frameworks are consistent. This may result in a disconnect between regulatory intent and technical validation whereby spatial datasets are required to be aligned across processes but are not systematically validated as such.

While spatial validation processes do not explicitly assess cross-dataset consistency, inconsistencies may still be identified during application assessment. The ERC framework includes an information request stage, allowing the department to request additional information where submitted data is unclear or insufficient (DETSI 2024). However, this process is reactive and occurs during the review of submitted applications rather than forming part of a systematic validation of spatial consistency across submissions.

4 Data issues in disturbance and rehabilitation reporting

Building on the concept of spatial integrity, data issues in disturbance and rehabilitation reporting are most clearly observed at the level of spatial dataset construction and management. These issues are not necessarily the result of regulatory framework design and may arise from how spatial data is created, edited and maintained within operational environments.

4.1 Common geographic information system errors in disturbance and rehabilitation datasets

Spatial errors within disturbance and rehabilitation datasets can be broadly categorised into geometry, attribute, spatial reference, unit and source data issues. These issues are commonly observed in mining spatial data and associated workflows, where GIS is used to integrate, analyse and display spatial data for closure planning and cost tracking (Poole 2023). These errors are observable, measurable and can influence calculated disturbance extents, particularly where surface area measurements are used as inputs to closure cost models (Kumari & Cooper 2019). Geometry errors include overlapping polygons, slivers and self-intersections, which are well-documented issues in GIS datasets used in mining environments (Poole 2023). These affect area calculations and can result in double counting or omission of disturbance and rehabilitation extents. As spatial analysis outputs are dependent on the quality of input data, such errors reduce the reliability of derived results (Hunter 2000).

Attribute errors occur where disturbance or rehabilitation classifications are incorrectly assigned. For example, areas that have been rehabilitated may remain classified as active disturbance, or incorrect activity types may be applied. Attribute errors may also occur where an area has been treated, seeded or otherwise rehabilitated but has not yet met the closure completion criteria required under PRCP guidance (DETSI 2024). If these areas are recorded as completed rehabilitation and removed from liability calculations, remaining rework, monitoring or maintenance costs could be omitted from area-based closure cost calculations (Kumari & Cooper 2019). As cost calculations are dependent on classification, these errors may influence financial outputs through the application of incorrect unit rates or the exclusion of areas that still require further rehabilitation work.

Spatial reference issues, including projection mismatches or misaligned datasets, can result in positional inaccuracies when datasets are combined or compared. These errors may introduce gaps, overlaps or incorrect attribution, particularly where multiple datasets are used within reporting workflows. These issues are not isolated anomalies but reflect common challenges in spatial data management within mining environments, particularly where multiple data sources and workflows are involved (Poole 2023).

Unit and measurement errors may also affect disturbance and rehabilitation calculations as spatial data uncertainty can arise from measurement, representation and analysis processes (Li et al. 2018). In mine closure datasets, these errors can occur where spatial datasets, derived area fields or exported values are created using inconsistent units, measurement assumptions or coordinate reference systems (Poole 2023). Where rehabilitation liability calculations are area based, unit or measurement errors can scale calculated quantities substantially and may not be apparent from map visualisation alone (Kumari & Cooper 2019).

Errors may also be introduced through differences in source data technology. Disturbance and rehabilitation layers are often compiled from mine planning exports, satellite imagery, remote sensing, drone imagery, survey data and legacy GIS datasets. Each source may have different spatial resolution, positional accuracy, capture date, processing assumptions and attribute completeness. Without documented lineage, source metadata and integration checks, these differences can introduce misalignment, omissions or inconsistent rehabilitation status across reporting datasets (Poole 2023).

4.2 Process and workflow drivers of spatial error

Spatial issues are commonly introduced through operational processes rather than regulatory requirements, often arising from data integration, editing workflows and inconsistent data management practices (Poole 2023). Contributing factors include inconsistent digitising practices, use of multiple data sources, varying levels of GIS expertise and limited quality assurance processes.

Where spatial datasets are updated over time without consistent workflows or validation, errors may persist or compound. This aligns with established understanding that spatial uncertainty can propagate through GIS-based processes and influence downstream outputs (Hunter 2000).

4.3 Implications for reporting and cost calculations

Closure cost estimation is subject to substantial uncertainty, particularly where estimates are affected by long time frames, evolving closure criteria, regulatory change, incomplete data and changing technical assumptions (Bloemhof & Bothma 2025). Inadequate forecasting may result in under provisioning, while overestimation may unnecessarily tie up capital (Bloemhof & Bothma 2025).

This uncertainty has broader financial implications as rehabilitation and closure obligations may be recognised as asset retirement obligations or closure provisions. Moody's Ratings (2024) reported that mining reclamation obligations are increasing globally, while the Ranger uranium mine in Australia provides an example of rehabilitation cost estimates increasing materially as scope, technical risks and execution requirements became clearer (Fitzgerald 2022).

Disturbance and rehabilitation datasets form a key input into reporting processes, including financial assurance calculations and closure liability accounting provisioning. As these calculations are directly dependent on spatial inputs such as area and classification, errors in spatial data may propagate into derived outputs.

Previous studies have demonstrated that closure cost estimates are sensitive to spatial inputs, particularly where area and classification influence liability calculations (Kumari & Cooper 2019). As a result, even relatively small discrepancies in spatial data can be associated with measurable variations in reported disturbance extents and associated cost estimates.

5 Case study of a Queensland coal mine: spatial data integrity in practice

The following case study provides a practical example of how these spatial data issues manifest in an operational context and demonstrates the potential impact this can have on disturbance reporting and financial assurance calculations.

A spatial audit was undertaken on disturbance and rehabilitation datasets from an operational Queensland coal mine to assess data integrity and its impact on regulatory reporting processes. These datasets underpin key submissions including ERC, PRCP schedules, and AR, all of which rely on spatial representations of disturbance extent, rehabilitation status and activity classification.

The ERC framework is highly dependent on spatial inputs, where rehabilitation liability is calculated based on the area of disturbance, assigned activity type and corresponding unit rate (DETSI 2024). This process relies on spatial data being accurate and representative of site conditions despite evidence that uncertainty and error propagate through GIS-based analytical workflows and influence derived outputs (Hunter 2000; Li et al. 2018).

5.1 Identified spatial data issues

The audit identified several common GIS data issues consistent with those documented in mining spatial data workflows (Poole 2023), as well as additional errors that may result in submission data being rejected by the department (DETSI 2026). These issues include:

- geometry errors – overlapping polygons and slivers resulting in duplicated disturbance areas
- attribute errors – misclassification of disturbance types and incorrect rehabilitation status
- spatial reference issues – inconsistent coordinate systems and misaligned datasets
- metadata deficiencies – incomplete or missing documentation of dataset structure and assumptions.

These issues align with known challenges in spatial data management, where inconsistencies in data integration, editing workflows and governance practices reduce the reliability and auditability of datasets (Poole 2023).

5.2 Quantified impacts on estimated rehabilitation cost calculations

The identified spatial errors were not isolated technical issues but were shown to influence ERC calculations through their effect on area and classification inputs.

As shown in Figure 3, overlapping polygons may result in double counting of disturbance extents, inflating total disturbance area and associated rehabilitation liability. Misclassification of activity types may lead to the application of incorrect unit rates, further distorting cost estimates.

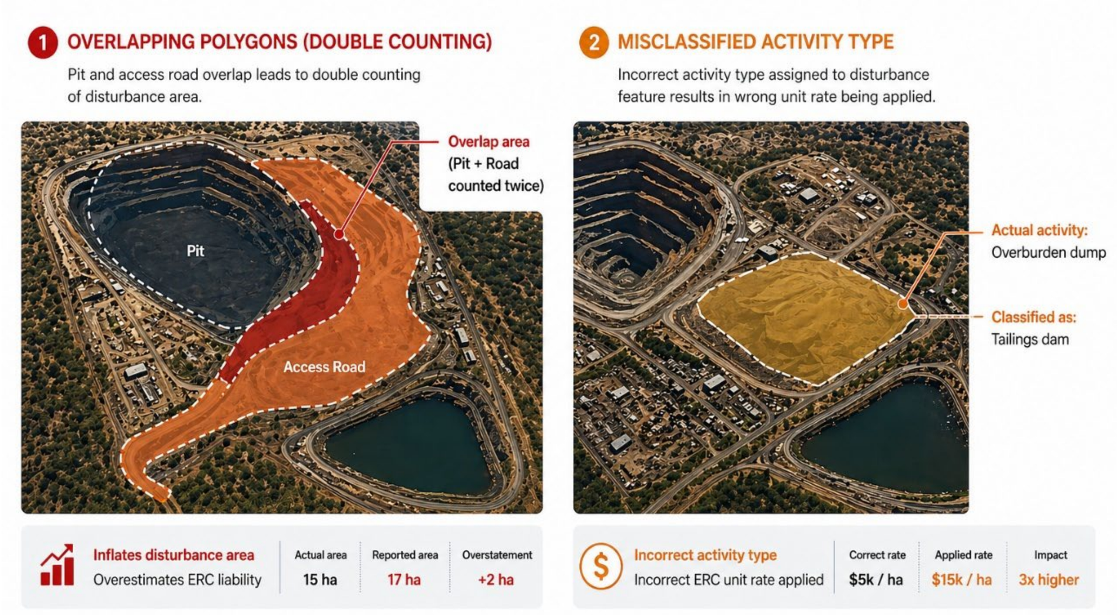

Figure 3 Conceptual model showing how spatial data errors propagate into estimated rehabilitation cost (ERC) calculations

This sensitivity is demonstrated quantitatively in Figure 4, where default rehabilitation unit rates vary measurably depending on activity classification. For example:

- light earthworks at ~AUD 200,000 (20 ha)
- high-risk tailings up to ~AUD 3.9 million (20 ha)

This illustrates that even small classification errors can result in potentially substantial cost variation.

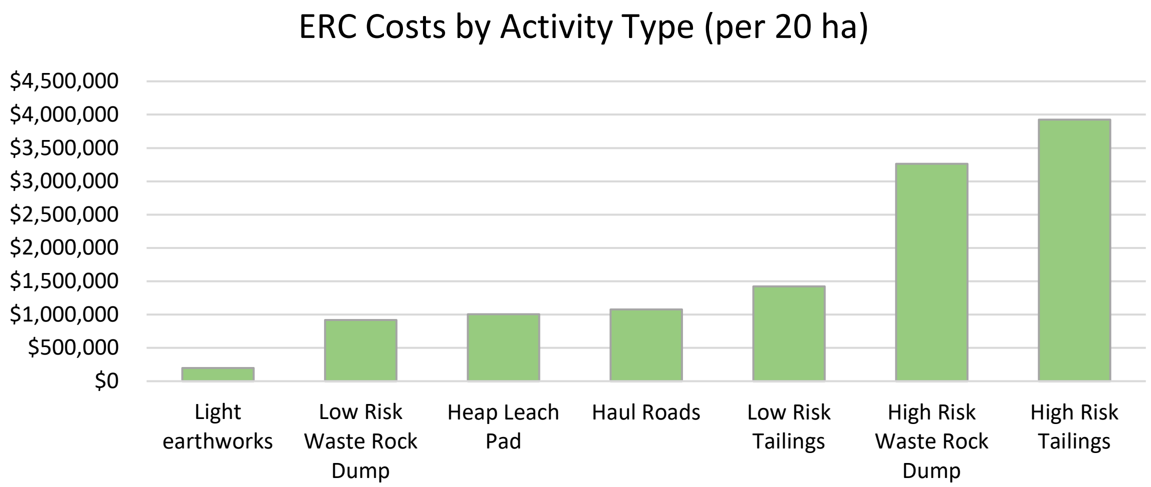

Figure 4 Graph representing the table of values derived from the Queensland Government estimated rehabilitation cost (ERC) calculator (Department of Environment, Tourism, Science and Innovation 2024)

Further, Figure 5 presents a conceptual representation based on a subset of overlapping polygons (~7 ha) identified in the case study data, illustrating the impact of classification and costing approach on ERC calculations. As shown, the same overlapping area can produce substantial variation in cost outcomes depending on classification, with estimated values ranging from approximately AUD 38,000 to AUD 65,000.

The actual reported cost of approximately AUD 103,000 reflects the compounding effect that occurs when overlapping areas are counted across multiple disturbance classifications.

These values are derived from standardised unit rates within the ERC calculator and are used to estimate rehabilitation liability based on disturbance area and activity classification. In this example, a spatial overlap of approximately 7 ha resulted in a disproportionate variation in reported costs. If similar overlaps, duplications or misclassifications occurred across larger disturbance areas, or within higher cost rehabilitation domains such as tailings storage facilities or waste rock dumps, the resulting financial impact could scale from tens of thousands of dollars to millions.

Figure 5 Impact of overlapping polygons on estimated rehabilitation cost calculations, showing variation in cost outcomes based on classification and compounding effects where overlaps are counted across multiple disturbance types

These findings reinforce that spatial data errors may propagate into financial outputs and operational budgets for rehabilitation, with closure cost models highly sensitive to both area and classification inputs (Kumari & Cooper 2019).

5.3 Governance and process breakdown

Beyond technical errors, the audit identified a breakdown in spatial data governance and process continuity as a key contributing factor. An initial spatial data management framework had been established at the site, including defined data structures and workflows for regulatory reporting. However, following personnel changes, these processes were not consistently maintained. Subsequent dataset updates were undertaken without adherence to established standards, resulting in divergence from the original data model.

This reflects broader data governance challenges where the absence of clearly defined decision rights, ownership and data standards leads to inconsistent data management practices (Khatri & Brown 2010). Without governance controls, spatial datasets become fragmented, reducing their reliability and usability across reporting processes. As a result, datasets supporting government reporting submissions became misaligned, requiring substantial effort to reconstruct a consistent representation of disturbance and rehabilitation extents.

The case study also highlights a potential assurance gap between financial audit processes and spatial data governance. Financial statement audits may review closure provisions and supporting cost models, as auditors are required to report on whether the annual financial report is in accordance with the *Corporations*

Act 2001 (Commonwealth of Australia 2001). However, where closure estimates rely on spatially derived quantities, GIS-specific issues such as topology errors, coordinate reference inconsistencies, unit conversion errors, incomplete metadata or undocumented spatial lineage may not be identified unless specialist geospatial quality assurance and control is included (Hunter 2000; Kumari & Cooper 2019; Poole 2023). Documented geospatial validation could therefore improve the traceability and auditability of the spatial inputs supporting closure liability estimates (Poole 2023).

5.4 Business and compliance impacts

The implications of these spatial data issues extend beyond technical inaccuracies and have direct business and regulatory consequences. From a financial perspective, inflated disturbance areas and misclassification of activities may result in overstated ERC values, leading to excess financial assurance being held. This ties up capital that could otherwise be allocated within the business. Conversely, understated disturbance areas, omitted incomplete rehabilitation or misclassified high-cost domains could result in insufficient operational rehabilitation budgets, understated closure provisions or future budget shocks when discrepancies are later identified. Where spatially derived quantities support closure liability models, these errors may also reduce confidence in the underlying inputs and could contribute to audit queries or management adjustments (Australian Accounting Standards Board 2026; Bloemhof & Bothma 2025).

From a compliance perspective, inconsistencies between submissions increase the likelihood of regulator queries, requests for further information and potential audit scrutiny. While spatial validation processes focus on format and schema compliance, incomplete or inconsistent submissions may still require resubmission or additional supporting information (DETSI 2026).

Fragmented datasets result in inefficiencies, with increased time required to validate, reconcile and prepare submissions. Rework becomes a recurring requirement, particularly where discrepancies are identified during regulatory review. A further critical risk is the loss of institutional knowledge. In the absence of documented workflows and governed datasets, personnel turnover can considerably disrupt reporting capability. As noted in industry practice, inadequate GIS management and loss of historical data context reduce confidence in datasets and compromise their auditability (Poole 2023).

In this case, substantial effort was required to reconstruct datasets, identify sources of error and re-establish alignment across reporting processes. This highlights that spatial data integrity is not solely a technical issue but also a critical factor in ensuring reliable, auditable and defensible mine rehabilitation reporting.

6 Proposed framework for spatial data integrity

The findings of this study demonstrate that spatial data issues in disturbance and rehabilitation reporting are not solely technical but also arise from a combination of fragmented datasets, inconsistent workflows and limited governance. Addressing these challenges requires a structured framework to ensure that spatial data is consistent, reliable and fit for use across multiple reporting processes.

6.1 Master spatial dataset: a unified spatial model

A key component of improving spatial data integrity is the establishment of a unified master spatial dataset that serves as a single authoritative dataset for disturbance and rehabilitation data. Rather than maintaining separate datasets for ERC, PRCP and AR submissions, a single authoritative dataset should be developed and maintained, with attributes structured to support multiple reporting outputs. This concept is illustrated in Figure 6, where a unified master dataset supports multiple reporting views through shared core spatial attributes, reducing duplication and supporting the derivation of reporting processes from a consistent spatial representation of site conditions.

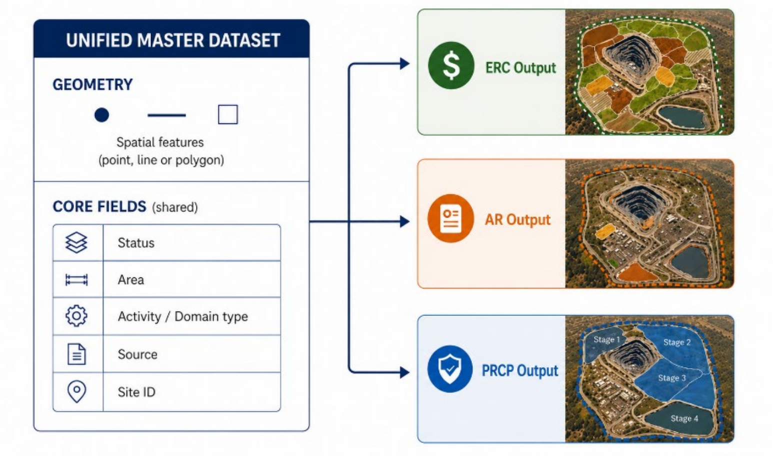

Figure 6 Conceptual model of a unified master spatial dataset supporting estimated rehabilitation cost (ERC), progressive rehabilitation and closure plan (PRCP) and annual return (AR) reporting through shared core attributes

The dataset should include disturbance and rehabilitation status, activity and domain classification aligned with ERC requirements, and temporal attributes to support annual reporting and rehabilitation tracking. These attributes reflect a shared set of core spatial fields required across ERC, PRCP and AR submissions, reinforcing the feasibility of maintaining a single dataset to support multiple reporting requirements. This is consistent with established industry practice, where the retention of a master dataset is critical for maintaining consistency, auditability and reproducibility of spatial data (Poole 2023).

6.2 Data governance and ownership

The effectiveness of a master spatial dataset is dependent on strong data governance. Clear ownership, defined roles and standardised processes are required to ensure that spatial data is maintained consistently over time.

Key governance elements include defined data ownership and responsibility, controlled editing and version management, standardised schemas aligned with regulatory requirements, and comprehensive metadata documenting data sources and assumptions. Together, these controls support the consistent, traceable and auditable management of spatial data.

Without such governance, datasets are likely to diverge over time, particularly in environments involving multiple contributors or personnel changes (Khatri & Brown 2010; Otto 2011). This increases the risk of inconsistencies developing across reporting datasets and reduces confidence in their reliability. Establishing formal governance frameworks therefore provides accountability and supports the long-term integrity of spatial data used in regulatory reporting.

6.3 Quality assurance and validation

Quality assurance and quality control processes should be embedded within spatial data workflows to prevent the introduction and propagation of errors. These processes include automated geometry validation such as overlaps, gaps and topology rules, attribute validation to ensure correct classification and status assignment, coordinate system and projection checks, and validate against regulatory schema requirements. Together, these processes help ensure that spatial data is consistent prior to submission.

To support consistency and repeatability, these processes should be implemented through structured and standardised workflows. Tools such as ESRI Task workflows can be used to guide users through defined validation and data preparation steps. A structured implementation workflow is presented in Figure 7, outlining the progression from spatial audit through to sustained data integrity.

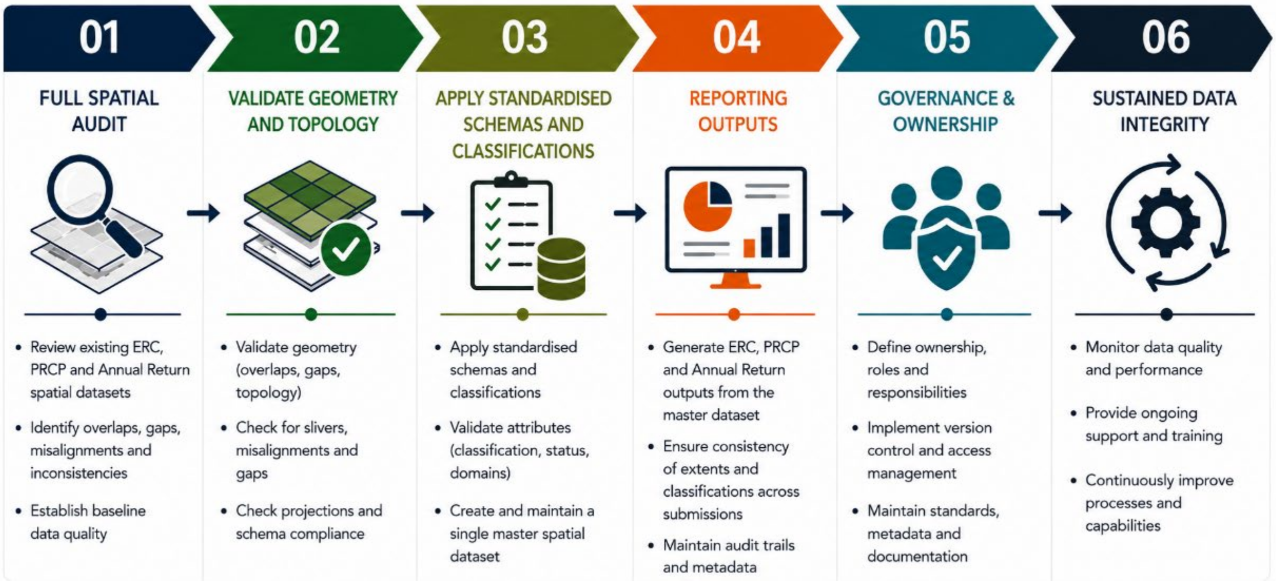

Figure 7 Structured workflow for spatial data validation, standardisation and integration into rehabilitation reporting processes for estimated rehabilitation costs (ERC), progressive rehabilitation closure plans (PRCP) and annual returns (AR)

While existing validation processes focus on submission compliance, internal quality assurance and control processes ensure that spatial datasets are consistent and reliable before they are used in reporting. This reduces the likelihood of errors propagating into downstream outputs and supports the requirement for spatial data to be accurate and suitable for analysis (DETSI 2026). These processes also directly address the spatial data issues identified in Section 4, including overlaps, misclassification and alignment inconsistencies. In doing so, these processes also support improved identification and management of spatial uncertainty, increasing confidence in derived outputs (Hunter 2000).

6.4 Integration with reporting processes

Spatial datasets underpin multiple reporting processes, including financial reporting, ERC calculations, PRCP schedules and AR. While these processes serve different purposes, they rely on consistent representations of disturbance and rehabilitation extents.

The proposed framework integrates spatial data management across these processes through the use of a single dataset to generate reporting outputs, supporting consistency in classification and spatial extents. This approach also supports alignment between existing disturbance, proposed rehabilitation and reported annual changes over time.

Importantly, this approach does not require datasets to be identical across submissions. Instead, it promotes consistency by deriving them from a shared underlying spatial representation. This supports regulatory requirements for alignment between rehabilitation planning and cost estimation processes and reduces the risk of discrepancies between submissions. Collectively, this framework positions spatial data integrity as a managed and controlled component of rehabilitation reporting rather than an outcome of individual GIS processes.

7 Discussion

The findings of this study indicate that spatial data issues in disturbance and rehabilitation reporting are not isolated technical anomalies but are indicative of broader challenges in how spatial data is managed, maintained and applied across reporting processes.

The case study identified common GIS errors, including overlapping polygons, misclassification and spatial misalignment, which influenced calculated disturbance extents and associated ERC values. While these errors are well recognised in spatial data management (Poole 2023), their implications within regulatory reporting contexts are less frequently examined. In this case, relatively small spatial discrepancies were associated with measurable variation in cost estimates, reinforcing the sensitivity of financial assurance models to spatial inputs (Kumari & Cooper 2019).

These findings align with established understanding that uncertainty in spatial data can propagate through analytical workflows and influence derived outputs (Hunter 2000). However, this study extends that concept by demonstrating how such uncertainty manifests within regulatory reporting systems where spatial datasets support multiple processes with differing purposes, reinforcing the need for a unified and consistently managed data model.

A key insight from this research is that spatial data issues are not solely driven by regulatory frameworks but also by the operational management of spatial data. While ERC, PRCP and AR submissions are designed to serve distinct functions, they rely on consistent representations of disturbance and rehabilitation extents. In practice, however, these datasets are often developed and maintained independently, increasing the risk of inconsistencies.

The results also highlight the role of governance in maintaining spatial integrity. The breakdown in data management processes observed in the case study suggests that the absence of clearly defined ownership, standardised workflows, and quality assurance and control processes can lead to dataset divergence over time. This supports broader data governance literature which emphasises the importance of structure, accountability and life cycle management in maintaining data consistency (Khatri & Brown 2010; Otto 2011).

Importantly, this study does not suggest that regulatory datasets must be identical across submissions. Rather, it highlights the need for consistency in the underlying spatial representation from which these datasets are derived. The concept of a unified master spatial dataset, supported by governance and quality assurance processes, provides a practical approach to achieving this consistency while accommodating the differing requirements of each reporting process.

By positioning spatial integrity as a system level issue, this research contributes to a more integrated understanding of spatial data management in mining. Rather than viewing data quality as a characteristic of individual datasets, spatial integrity is framed as the ability of datasets to remain consistent, aligned and reliable when used across interconnected workflows.

8 Conclusion

This study indicates that spatial data integrity is an important factor in disturbance and rehabilitation reporting, with direct implications for regulatory compliance and financial assurance outcomes. Through a case study of a Queensland coal mine, common geographic information systems data issues including overlapping polygons, misclassification and coordinate reference system inconsistencies were shown to influence calculated disturbance extents and estimated rehabilitation cost (ERC) values. The findings highlight that even relatively small spatial discrepancies can result in measurable variation in cost estimates, reflecting the sensitivity of closure cost calculations to spatial inputs.

Importantly, these issues were not driven by regulatory frameworks but how spatial data is managed in practice. Fragmented datasets, inconsistent workflows and limited governance contribute to the introduction and persistence of spatial errors, increasing the risk of inconsistencies across reporting processes.

To address these challenges, this paper proposes a structured framework centred on a unified master spatial dataset supported by data governance, quality assurance processes and integrated workflows. This approach supports consistent, reliable and fit-for-purpose spatial data across multiple reporting requirements while accommodating the differing purposes of ERC, progressive rehabilitation and closure plan and annual return submissions.

Collectively, this research highlights that spatial data integrity should be actively managed as a core component of rehabilitation reporting, not assumed. Strengthening spatial data management practices has the potential to improve the reliability, transparency and efficiency of regulatory submissions while reducing uncertainty in mine rehabilitation cost estimation and supporting more traceable, auditable and defensible closure-related decisions.

Use of artificial intelligence disclosure statement

In the preparation of this work, the authors used Chat GPT to create conceptual images and diagrams. The authors have reviewed the content and edited it where required and take full responsibility for said content.

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