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Good GIS functionality and practices in mine closure planning

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Abstract

The use of Geographic Information Systems (GIS) has emerged as a key tool in mine closure planning. GIS can be used to collate, analyse and display copious volumes of geospatial (mapping data and locations relative to the Earth's surface) and non-spatial data linked to closure risks, designs, costs and performance. It is common that the use of GIS in mine site rehabilitation and closure planning does not utilise the full extent of available site historic and operational data and information that can be useful for rehabilitation and closure planning.

Technical comprehension and training, and availability of user-friendly software (free and proprietary) for GIS were historical constraints to the use, improvement, review, and functionality of GIS on mine sites. With technological progress and the evolution of software, the use of GIS and the associated skillset required has become less onerous. This presents an opportunity to improve the functionality and practices around GIS use in mine rehabilitation and closure planning.

Companies, consultants, and contractors across the industry assign varying importance to GIS use with a move towards retaining enough information for processes and outcomes including closure cost estimation to be auditable and reproducible, and tracking strategies, changes, and decisions along the mine closure planning pathway.

GIS can be used to increase confidence levels in mine closure planning, track risk and performance, identify areas of concern, and track management of closure activities and execution e.g., information used in mine closure technical studies can be assessed for representativeness based on spatial coverage.

Mine closure planning GIS can be used alongside GIS-linked technology for mining operations including designating appropriate locations for dozer rehabilitation tasks, delineating drone imagery capture locations to support monitoring, and determining locations for automated closure water quality monitoring for performance compared to criteria.

This paper pinpoints some advantageous uses of GIS in mine closure planning functionality and practices as illustrated via recent case studies and provides suggestions for improving the benefits of GIS use. Improving GIS use in closure planning allows for more detailed records of mine rehabilitation and closure which can be invaluable in combating industry challenges such as staff turnover, moving goalposts of regulator and stakeholder expectations, confidence in adequate closure cost estimates and strategy decisions, and other key mine closure risks. Enlisting GIS as a key tool in mine closure supports developing technically defensible closure designs, cost estimates, and monitoring programs for successful closure planning, execution, and relinquishment.

Keywords: *geographic information systems, GIS, closure planning, closure costing, rehabilitation tracking*

1 Introduction

Geographic Information Systems (GIS) can be defined as comprehensive computer-based tools and frameworks that can be used to capture, store, query, analyse, manipulate, and display or visualise geographic and spatial data in various applications. GIS can be considered a modern extension of traditional cartography with both using a base map to which additional data can be added, but it also does not limit the data that can be added and can use analysis and statistics to present data in support of particular arguments.

The development of GIS is considered to have evolved from the 1960s as a new discipline with the first computer-based GIS launched in Ottawa, Canada (Dempsey 2015). Dr. Roger Tomlinson, a Canadian geographer, developed the first version of a computerised GIS called the Canada Geographic Information System (CGIS). GIS technologies were adopted by national agencies and exploited commercially followed by adoption by government agencies and mainstream media with online mapping. Advancement to today was supported by computer and GIS technology progress (along with reduced costs for access) and the world wide web with open-source software programs becoming available as an alternative to commercial and proprietary GIS software programs.

The application of GIS in mining is commonplace across the mining life cycle including exploration, design and permitting, operations, and progressive rehabilitation and closure. GIS from each of these stages often forms the project closure knowledge base through the integration and connectivity across technical disciplines and departments may depend on governance and other factors e.g., borehole information consideration in hydrogeology, geochemical and geotechnical studies.

GIS may be required by regulators in relation to compliance including assessment of land disturbance and rehabilitation areas, land tenure, infrastructure, mine openings and workings, final landform designs, exploration and geological datasets, financial assurance GIS datasets, and environmental monitoring. Some of this information may be provided to the public.

Mine closure requires an integrated approach to planning, design, risk assessment and mitigation, and impact predictions. GIS can provide one aspect of integration allowing for multi-faceted technical considerations and their interactions in a single domain, for example, as GIS technology allows different types of information to be overlaid based on location despite different sources or original formats.

The Integrated mine closure: good practice guide (ICMM 2019) published by the International Council on Mining and Metals (ICMM) illustrates key elements of mine closure and the pathway through them which can and should be supported by GIS; see Figure 1.

The integration of key GIS information early and efficiently in closure planning can assist in key aspects for the life of asset designs and management for mine closure. Information about hydrogeology, geologic features (e.g., faults) and characteristics (e.g., geochemistry), physical stability, and catchments could be invaluable in determining landform designs for final voids, tailings, waste rock dumps, etc.

There are many opportunities where the use of historical and operational GIS in closure planning and rehabilitation has or could have assisted in optimising the design, management, and construction of sustainable final landforms and understanding the costs required to achieve this. Four (4) case studies based on Australasian operations are summarised to illustrate these opportunities and how GIS integration has been used for more efficient and successful closure planning across multiple aspects.

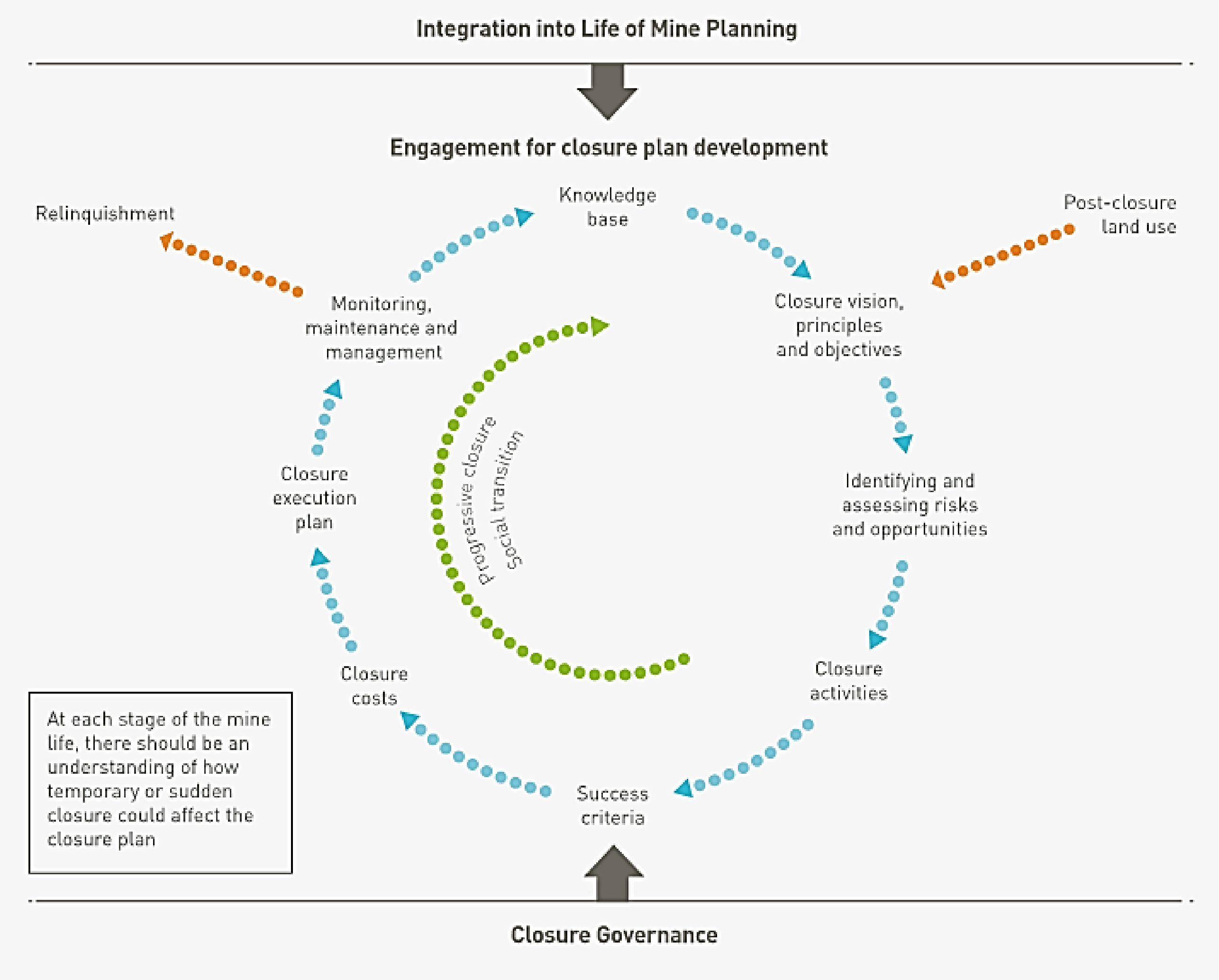

Figure 1 Elements of closure planning from Integrated mine closure: good practice guide (ICMM 2019)

2 GIS requirements for mine operations including closure

Common GIS to be provided or held for mine operations include approvals, submissions of plans, surveys, infrastructure designs, as-builts landforms, monitoring locations, mine planning designs and data (e.g., landforms, material movement – cut and fill and haulage, push lengths), mine optimisation data and exploration data.

LiDAR is a method of remote sensing using laser light to form 3D point clouds which can be used in a variety of geospatial analyses. Rasters such as LiDAR and topography as well as vectors are commonly used. Outputs from LiDAR, survey, and other key processes can be integrated into GIS for use to support operational as well as closure planning.

There are legal requirements for some GIS and associated mapping submissions. Regulatory bodies often require GIS information to be provided including for recent rehabilitation reforms in Queensland and New South Wales (NSW) requiring submission of GIS to the regulator to support progressive rehabilitation planning and assessment of financial assurance. A summary of some common mining GIS requirements in Australia is provided in Figure 2.

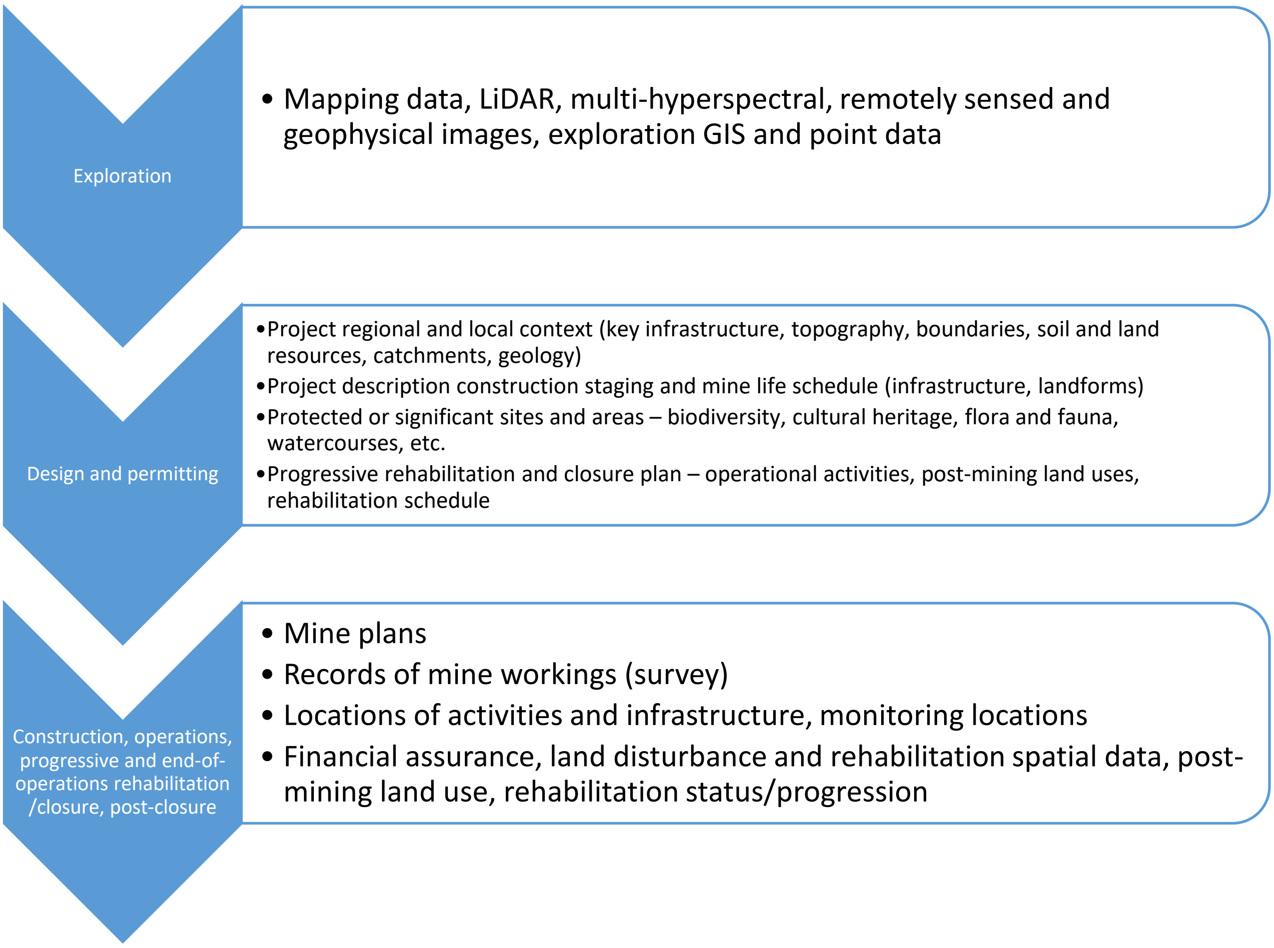

Figure 2 Examples of key GIS requirements for mining operations in Australia

Jurisdictions have varying requirements for GIS submissions associated with regulatory compliance, safety, and other key aspects related to mining. In Queensland, the level of detail required and available for consideration includes:

- GIS in relevant geometry types (lines, points, polygons) to support financial assurance
- Spatial Information Submission Guideline, data master schema, and various shapefile templates (Department of Environment and Science)
- Data and mapping available – historic aerial images, topography, data layers for industry, interactive mining and exploration data, geoscience datasets, etc. (Department of Resources).

Often for closure planning, site-wide knowledge has not been assimilated and the extent of information available and useful to closure may not be understood. Operationally, many times the responsibility for GIS management and submissions may belong to the environmental department due to requirements relating to approvals, compliance, and closure cost estimation. The management of GIS over time may change based on the skill, experience, and approach of personnel managing and editing the GIS considering GIS requirements and the company standards.

3 Key areas of mine closure planning and opportunities for using GIS

A summary of some areas where GIS is often very beneficial in closure planning is identified in Table 1.

Table 1 Key areas and opportunities for using GIS in elements of the mine closure planning process

Elements of the closure planning process (ICMM)	**Areas and opportunities for GIS use**
Integration into life-of-mine planning	• Planning for land access and disturbance • Tracking disturbance and rehabilitation • Integrating rehabilitation and key landform design features towards closure e.g., encapsulation of potentially acid-forming (PAF) materials, final landform slopes, spillway construction, etc. • Availability, sequence, and schedule for rehabilitation execution • Integrating rehabilitation material balance requirements into block modelling and scheduling e.g., rock meeting rip rap specifications • Holistic planning for closure e.g., sitewide drainage plans • Planning for the end of mine life e.g., demolition waste disposal, borrow areas • Identification of asset and infrastructure fates for management
Knowledge base	• As-built drawings of all mine facilities • Final landform design • Quantity inputs for closure cost estimates • Rehabilitation materials balance information e.g., volumes, locations for application, haul distance, schedule • Operational records and data e.g., tailings deposition and ore type, dump sequencing and geochemistry, subsidence locations, highwall failures, groundwater levels and recovery • Progressive rehabilitation and closure details e.g., sealing of boreholes, sealing of underground mine openings, rehabilitation areas • Key maps and information in GIS format retained as part of the closure planning process including from studies and reports
Closure vision, principles, and objectives	• Post-mining scenarios
Post-closure land use	• Land capability • Post-mining land uses analysis (e.g., constraints and opportunities) • Post-mining context (surrounding land uses, infrastructure, and features, etc.) • Post-mining plans

Elements of the closure planning process (ICMM)	Areas and opportunities for GIS use
Engagement for closure plan development	• Key figures presenting closure planning (e.g., post-mining scenario, post-mining land uses, final landforms, visual amenity assessment outcomes) • Infrastructure and opportunities for post-closure use • Analysis and mapping of closure engagement feedback in relation to the site including stakeholders' and regulators' expectations • Presentation of residual risk mapping and other key closure aspects
Identifying and assessing risks and opportunities	• Options assessments including stability assessments, stage storage curves, geochemistry assessments, etc. • Landform design impacts e.g., catchment, flow paths, potential for flooding • Landform sustainability e.g., modelled landform evolution assessments, placement of key features for preservation (such as abandonment bund location outside the zone of instability) • Groundwater modelling e.g., long-term predictions and hydrographs, connectivity across landforms, etc. • Analysis of landform features to identify where further or specific works and/or design are required (e.g., landform slope angles and material types, lowest points for spillway location, etc.) • Post-mining land use opportunities e.g., connectivity for biodiversity corridors
Closure activities	• Rehabilitation requirements by landform/area • Rehabilitation records – works completed, dates, amelioration, species applied, instrumentation, etc. • Rehabilitation QA/QC e.g., cover depth and application, landform features, construction to design (including using GPS technology-equipped machines) • Monitoring e.g., settlement, subsidence, vegetation progression, erosion, etc.

GIS should be verified as part of closure planning. In the closure planning process, ground-truthing and site investigations can be used to support closure design and planning to confirm that proposed approaches and assumptions are realistic and the likelihood that closure objectives can be achieved.

In some instances, operational planning forms part of mine closure planning including the implementation of good industry practices for example waste segregation as part of acid rock drainage (ARD) prevention and management. Based on closure risk, key controls should be integrated into mine closure planning and would include GIS considerations.

To realise mine closure planning opportunities using GIS, good industry practice for geospatial data management is key. This should include guidance on securing data and version control, data integration, and data management. For key datasets, the frequency of updates and uses should be identified. Some proposed methods for mitigation of outlined challenges are summarised in Table 2.

4 Key challenges for GIS use

Some themes for GIS challenges were observed by the author in mine closure planning projects and operations. Three key themes are outlined in the following sections.

4.1 Data formats and integration

Varied sources and types of data may be used in closure planning. Mine planning and other operational software outputs such as planned disturbance may need to be used within GIS software e.g., Vulcan, Surpac, survey data. Data transfers and integration into GIS software may not readily translate all the applicable data and attributes from the other software in exports. This may lead to issues with data loss and inaccuracies with coordinate system projections. Additionally, there may be uncertainty in integrating GIS and remote sensing related to issues such as scale incompatibility and measurement disparities.

Data integration may be required manually, via shared interface(s), via integration application, etc. (Al-Yadumi et al 2021). Once data is to be integrated into an existing database or dataset, the method would require this data to be cleaned and standardised (e.g., time stamps, measurements, etc.) to be completed. Repairs to geometry should be undertaken to address errors in the dataset. File processing may delay file size and processing times but is helpful to confirm data is appropriate.

Data availability/cost and appropriate technological infrastructure are relevant to the integration process. Some datasets may be available via differing sourcing including Government in a range of jurisdictions; however, these may not be available in all countries with mining, or especially for more remote operations.

Retention of a master file such as an ESRI geodatabase is key to maintaining relevant integrated data in preferred formats, projections, and georeferenced data with key attributes such as area names and domains. Beneficial considerations to combat the challenges relating to data formatting and integration include documenting responsibility and procedures for data integration such as cleaning data to be integrated, exporting in formats that allow for inclusion of key attribute data, additions and deletions to the dataset including naming and version control, adding unique identifiers for attributes, and removing overlaps and gaps from the dataset once integration has occurred. Key checks for duplicate values of unique identifiers and other unique information etc. should be included as part of quality analysis and control.

An example of big data integration steps is shown in Figure 3 with integration methods in mining commonly used. Proposed methods for mitigation of outlined challenges are summarised in Table 2.

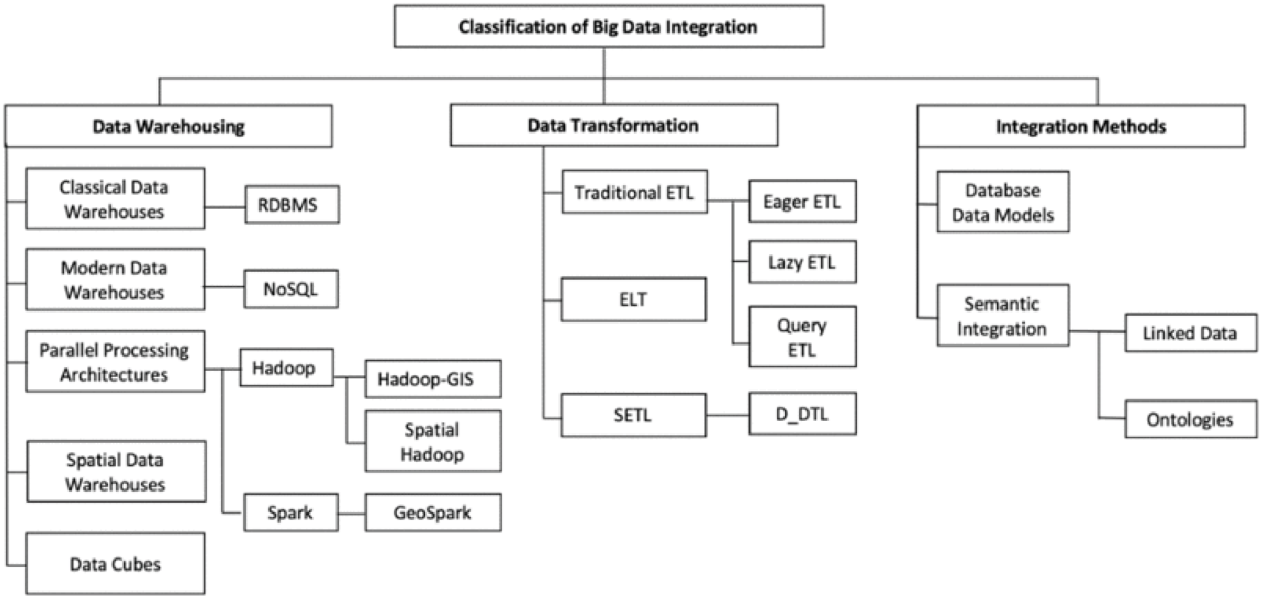

Figure 3 Example of methodology for the classification of big data integration (Al-Yadumi et al 2021)

4.2 GIS understanding, training, and management

Understanding and training in the use of GIS varies across companies and departments. Reliance upon GIS and maturity in this field can be driven by multiple factors including technical background and focus, experience, corporate requirements, and management standards. Where there is a demand or expectation for repeatable/auditable data capture and processes and management risks are identified as material, there may be documented requirements for GIS.

Personnel experience with GIS may range from nil to very experienced with sources of knowledge ranging from academic studies, and software-specific training to on-the-job training. Oftentimes personnel with responsibility for GIS management on-site or in environmental departments have multiple roles and are not only responsible for GIS. Even where there are specifically designated resources for GIS, familiarity and experience with software, comprehension of and experience with mine closure planning, understanding of the use and objective of information, GIS and closure planning management procedures or lack thereof, workloads and other aspects may impact on quality of GIS outputs and identification of opportunities for efficiency and integration for closure planning.

Bridging the skills gap for using GIS may be difficult due to limited talent pools, industry staff turnover, and unique skillset requirements. However, alongside proprietary software, the progression of GIS technology has resulted in user-friendly free software that can be used to develop and edit GIS datasets e.g., QGIS.

Key potential issues with GIS use due to challenges with understanding, training, and management include:

- Topological errors (spatial relationships between adjacent features) such as gaps, slivers, and overlaps – these errors may occur during editing and may be present in mine datasets which may be the product of years of edits.
- Representativeness – whether data extents are accurate and representative of disturbance. This may include whether disturbance type/domain is correct, boundaries are accurate/representative, rehabilitation status is correct, all mine-related disturbance is captured, if non-mine related disturbance is captured, etc.
- Inadequate information capture – not enough information is captured within datasets for personnel with less experience, site history, and familiarity to use the data or undertake analysis and understand relevance. Key assumptions to support GIS processes are not documented.
- Update of data – inadequate systematic management of data including version control, retaining raw incoming data, and master dataset management (accidental deletions).
- Projection issues – different projections used resulting in misrepresented spatial locations for data e.g., Mine grid conversions, combining datasets from differing projections
- Attributes – extensive information can be included for tracking against areas but compliance reporting may require only specific schema and templates or attributes to be reported
- Personnel turnover – limited institutional knowledge and understanding of site GIS management procedures without documented procedures, difference in GIS skill capabilities, loss of site-specific closure knowledge (e.g., appropriate data is only held for a snapshot in time rather than a time series which is more reliable)

Table 2 provides some proposed mitigations to these challenges by utilising available GIS tools.

4.3 GIS progression

The different terrestrial reference systems and frames (e.g., WGS84) have varying accuracy, stability, and realisations (coordinate differentiation). Differences in accuracy can be linked to corrections of field distances by meteorological factors and angles by meridian convergence among other factors considering reductions to ellipsoids based on the earth's shape, consideration of plate tectonics, etc. (Baselga 2021) Increasing demands and capabilities of modern technologies and technical advances have resulted in improved accuracy in GIS projections to millimetres compared to years past. This is especially relevant to historical datasets.

The availability of more user-friendly software (free and proprietary) for GIS has occurred with technological advances. GIS technology progress has resulted in more functionality including easy linkages to jurisdictional databases, ease of import (different sources, file types, and projections can be assimilated), and functional tools for measurements, creating and updating datasets, etc.

Additionally, there is increased availability of more data, more consistently collected data, and more easily available data on online platforms. Accuracy can be improved using ground-truthing and QA/QC as indicated by suggestions for mitigations related to this theme provided in Table 2.

4.4 Responses to key challenges to GIS use in mine closure planning

Advantageous uses of GIS that improve the functionality in mine closure planning may result in positive impacts such as improved closure knowledge base and information management, and wider risk-based basis of design for final landforms including operational limits. Table 2 summarises some beneficial strategies for GIS management and use that can be used to address challenges identified in sections 4.1 to 4.3.

Table 2 Some responses to key challenges for GIS use in mine closure planning

Key aspects	Good, functional GIS practices for mitigation	Examples of key inputs	Examples of key outputs
GIS management	Development of work instruction or procedure for GIS management identifying responsibilities, management, QA/QC, key inputs and outputs as well as scheduling, confirming capability of software in use for integration and requirements for attribute, file cleaning, and processing	Mine planning disturbance, survey information, progressive rehabilitation polygons,	GIS management documentation, work instruction for other departments re: providing GIS inputs (including projections, attributes required), relevant assumptions for financial assurance, etc.
Master dataset	Include a full list of attributes warranted for disturbance and rehabilitation including domain type, feature name, amelioration, species mix, rehabilitation status, financial assurance description, unique identifier, etc.	Financial assurance classifications, historic rehabilitation information, site-specific features, and attribute information	Master dataset, other datasets for compliance submissions extracted from the master dataset
	Ground truthing of identified disturbance and rehabilitation information.	Site-specific observations from inspection and records	(As above.)
GIS skills and experience	Undertake private licenced software-specific training or utilise user-friendly free GIS software based on staffing, experience, continuity, etc.	GIS software and/or training for required GIS management	Maps, updated GIS and datasets

Key aspects	Good, functional GIS practices for mitigation	Examples of key inputs	Examples of key outputs
Closure knowledge base	Identify key site-specific GIS information available for use based on closure risk and technical studies likely required e.g., underground workings, mine entries, geotechnical faults, groundwater levels, final landform designs, etc.	Locations for key data, LiDAR, survey, etc.	Analyses, maps
Closure and rehabilitation execution	Monitoring locations, rehabilitation records, closure actions and activities required, representativeness checks	Monitoring locations	Rehabilitation records, updated GIS to reflect closure actions

5 Case studies/examples – GIS in mine closure planning

The author has managed mine closure planning in site-based and consulting roles for more than 16 years internationally and within Australia. Some case studies where GIS management for closure planning required innovation or improvement are in Table 3. Due to the sensitivity around maturity, compliance, and other such information, names of companies or sites have not been included.

Table 3 Case studies of key challenges to GIS in mine closure planning

Site closure context and situation	Challenges and issues	Treatments applied
An open cut and underground coal operation wanted to review the GIS due to dataset issues, improve GIS management and analyse multiple mine planning options to understand the maximum liability for the proposed period	Master dataset – inaccuracy of site GIS and inadequate documentation of assumptions for ease of calculations	Update the master dataset including detail on attributes key to the cost estimation process, ground-truthing, and verification of disturbance types
	GIS management – inadequate procedures for GIS tracking of disturbance and rehabilitation	Develop GIS procedures/documentation including responsibilities, QA/QC, GIS update, and output exports process
	Ease of assessment of financial assurance estimation of multiple mine planning options to support selection	Utilise GIS software integration programming automated data outputs and cost model inputs for comparative estimates
	Closure activities – execution of rehabilitation required to design	Use GPS dozers for landforms, survey completed works to verify depths
An open-cut metalliferous mine was looking to confirm rehabilitation strategies for progressive disturbance and develop a cost model	Integration into life-of-mine planning – with a large footprint and potential for ARD generation, rehabilitation strategies and design required progressively to minimise costs	Use mine planning and area layout designs, landforms, groundwater level details, etc. to identify operational and progressive rehabilitation mitigations to minimise closure costs
	Identifying and assessing closure risks and opportunities – closure risks and opportunities not well understood in site-specific areas	Assessment of multiple GIS inputs to understand risks and opportunities including geochemistry, groundwater, surface water, sensitive receptors, wet season, etc.
	Closure activities – determine the risk profile of footprint and prioritise activities and schedule based on rehabilitation and closure risks	Sequencing and scheduling of rehabilitation activities based on risk profiles. Closure design features included in disturbance approvals and reviewed as part of progressive works.

Site closure context and situation	Challenges and issues	Treatments applied
A historic underground and open-cut coal mine in care and maintenance required detailed closure planning toward relinquishment	Closure knowledge base – limited closure knowledge for the historic site Master dataset – none existed for the site	Request information and collate a GIS closure knowledge base for the site Data review and integration to develop a master dataset for the site to support all technical works required Ground-truthing of key historic data not well known (mine openings)
	Identifying and assessing closure risks and opportunities – closure risks and opportunities not well understood	Use GIS data and information to inform closure risks and opportunities assessments, technical studies and assessments, and development of rehabilitation strategies to mitigate risks Landform evolution assessment considered for water management, cover depth, etc. on landforms Groundwater modelling to understand the risk related to workings, landforms, and aquifers and predict recovery levels
	Closure knowledge base and closure activities – rehabilitation materials balance and material take-offs	Use of rehabilitation strategies and extents based on GIS master datasets to determine quantities of rehabilitation materials and material take-offs and associated costs assigned to site areas
	Closure vision and post-closure land use, engagement for closure plan development	Use information including land zoning and landforms to analyse potential post-mining land uses Engagement with stakeholders and regulators on asset fates, post-mining land uses using maps
Underground coal and metalliferous pits (separate sites)	Identifying and assessing closure risks and opportunities – final operational limitations and closure design dependent on final pit landform in order to protect groundwater (backfill of pits with tailings and other geochemical materials may be required below groundwater aquifers, etc.)	Use mine planning and area layout designs, landforms, groundwater level details, etc. to identify operational and progressive rehabilitation limits for backfill and/or in-pit deposition considering closure risks.

6 Conclusion

There is a wide range of practical applications of good GIS practices in mine closure planning which improve functionality across mine closure aspects. Good industry practices around GIS management including delineation of responsibilities, processes and procedures, streamlining data sourcing and import, ground-truthing, and including QA/QC can easily be applied prior to and during operations to benefit both operational and closure planning and outcomes.

GIS should be collated to confirm the closure knowledge base and identify and assess risks and closure activities among other focus areas. GIS can be from various sources and will consider aspects from mine planning, groundwater, vegetation, geochemistry, surface water flows, mine opening, etc. GIS practices identified here address all key elements of the mine closure planning process (ICMM 2019).

Key challenges identified included data formats and integration, GIS understanding, training and management, and GIS progression. Responses to key challenges were noted to include improvements and documentation on GIS management, developing a master dataset, and increasing the closure knowledge base relative to GIS. Case studies were presented showing how key challenges to GIS in mine closure planning were addressed including GIS management improvements, integration in the LOM, etc.

These GIS challenges occur across the mining life cycle and treatments have included a risk-based approach to increase closure confidence, and progress closure planning and rehabilitation while looking to minimise costs. Future developments and progress in computers and GIS technologies will likely increase the ease and functionality of dataset integration and data analysis as well as opportunities to retain and access operational GIS records for future use and analysis and integrate GIS benefits in the mining life cycle including closure planning.

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Many thanks to past and present clients who have provided the challenges and opportunities and utilised some of these strategies herein to improve the closure planning process. Hopefully, our approaches have assisted in improving your own processes supported by improvements in auditable and reproducible information for comparison year upon year.

Thanks to God as ever for putting me in a position to learn, assimilate and document these things while having fun doing it.

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