REGEN-X · TOOLBOX · FIELD GUIDE FG-001

Gypsum *Application Rate*

Practical guidance for sodic and dispersive soils on rehabilitated mine landforms

Intention. This guide is intended to **support decision making**. It is **not a substitute for expert advice**. Site-specific design, qualified professional judgement, and regulatory consultation are essential before applying any guidance in this document.

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HOW TO USE THIS GUIDE

Orientation

Reading paths and key terms

This guide is built for **engineers, environmental scientists, and rehabilitation supervisors** who specify or apply gypsum on mine sites. It assumes general soil science background but not specialist experience in sodicity work. The aim is to give you defensible answers — not a textbook.

Use this guide to

- decide whether gypsum is the right treatment at all *(see When and Why Gypsum)*
- choose the right level of investigation for the size and risk of your site *(see Data Requirements & Field Sampling)*
- pick a defensible rate for stability or growth-media work *(see Recommendations & Jurisdictional Variation)*
- match an application method to your terrain and rate *(see Application Methods, Incorporation & Timing)*
- set realistic expectations for when results show up *(see Worked Example, Verification & References)*

Reading paths

- **New to sodicity work** — read the Key Terms below, then the When and Why Gypsum → Data Requirements → Recommendations sections in order. The Application Methods and Worked Example sections are reference material you'll return to.
- **Experienced** — jump to the rate table in Recommendations and the application-methods table in Application Methods. The rest explains how the tables are built.
- **In the field with a sample in your hand** — go straight to Data Requirements & Field Sampling, §"Field tests for initial risk classification".

Acronyms

Quick-reference list of every acronym used in this guide. Full meanings and context follow in the Key terms table below.

Acronym	Meaning
AMD	Acid and Metalliferous Drainage
AS	Australian Standard (e.g. AS 1289.3.8.1)
CEC	Cation Exchange Capacity
DMIRS	Department of Mines, Industry Regulation and Safety (Western Australia)
EC	Electrical Conductivity
$EC_{1:5}$	EC measured at 1 part soil to 5 parts water (mass) — Australian lab convention
ECe	EC of the saturation extract — ECe ≈ $EC_{1:5}$ × texture factor
EPA	Environmental Protection Authority (jurisdictional)
ESP	Exchangeable Sodium Percentage
FG	Field Guide (Regen-X document type prefix)
FGC	Field Guide Calculator — companion Excel deliverable
IECA	International Erosion Control Association (Australasia)
MAR	Mean Annual Rainfall (mm/year)
MOP	Mining Operations Plan (NSW)
NCST	National Committee on Soil and Terrain (Aus / NZ)
NPK	Nitrogen, Phosphorus, Potassium
OM	Organic Matter
PRCP	Progressive Rehabilitation and Closure Plan (QLD)
SAR	Sodium Adsorption Ratio
SOP	Standard Operating Procedure
TSF	Tailings Storage Facility
WRL	Waste Rock Landform

Key terms

Term	What it means	Why it matters here
Sodicity	An excess of sodium on the clay surfaces of a soil. Causes clay particles to repel each other when wetted.	The condition gypsum is designed to fix.
Dispersion	Clay particles separating in water — visible as a milky halo around a soil aggregate dropped in clean water.	The physical, observable consequence of sodicity. The thing that drives crusting and tunnel erosion.
Aggregate	A natural cluster of soil particles held together by clay, organic matter, and biological binding.	When aggregates break down on wetting (slake or disperse), the soil loses structure.
Slake	An aggregate falling apart into smaller pieces when wetted.	A structural failure — not the same as dispersion, but often co-occurring.
ESP Exchangeable Sodium Percentage	The share of cation exchange sites on the clay occupied by sodium (rather than calcium, magnesium, or potassium). Expressed as a percentage.	The single most important number for gypsum decisions. ESP > 6 = sodic; > 15 = strongly sodic.
SAR Sodium Adsorption Ratio	A measure of sodium relative to calcium + magnesium in the soil solution.	Used alongside ESP. SAR > 6 = dispersion risk.
EC Electrical Conductivity	A proxy for total dissolved salts. Reported as $EC_{1:5}$ (1 soil : 5 water by mass) or ECe (saturation extract). Units: dS/m.	Higher EC indicates salinity. Salinity changes what gypsum can and can't do.
CEC Cation Exchange Capacity	The soil's total capacity to hold positively charged ions on clay and organic matter surfaces.	Sets how much sodium could be present and how much gypsum could exchange. Drives the rigorous calculation.
Emerson class	A 1-to-8 field scoring system for how a soil aggregate behaves when dropped in clean water. Class 1 = strongly dispersive; class 8 = fully stable.	The standard Australian field test (AS 1289.3.8.1). What regulators expect to see in a sodicity assessment.
MAR Mean Annual Rainfall	Average yearly rainfall at the site (mm/year).	Determines how quickly gypsum will dissolve and move into the profile — and the application-timing window.
OM Organic Matter	Compost, mulch, retained topsoil — anything that adds carbon and biology to the soil.	Acts in synergy with gypsum; allows lower gypsum rates for the same outcome.
PRCP	Progressive Rehabilitation and Closure Plan — the QLD regulatory plan that defines rehab outcomes and milestones.	The most likely document your QLD work has to align with.
WRL	Waste Rock Landform — an engineered landform built from mining overburden.	The setting where most stability-purpose gypsum is applied.
Sodosol / Vertosol	Two Australian Soil Classification orders that commonly express sodicity.	When you see these terms in soil reports, expect a gypsum question to follow.

SECTION 1

When and Why Gypsum

Deciding whether gypsum is the right treatment

The problem gypsum solves

When a soil is sodic, the clay particles repel each other on wetting instead of binding together. The aggregates fall apart, the surface seals, water can't get in, and roots can't get through. On a rehabilitated landform that shows up as surface crusting, tunnel erosion, slope failure, and patchy or failed vegetation.

Gypsum (calcium sulphate dihydrate, $CaSO_4 \cdot 2H_2O$) works by **swapping sodium for calcium on the clay surfaces**. The clay holds together again, water moves through the profile, and roots have somewhere to go. The exchange needs water to happen — gypsum is not instantaneous — and the result is amplified when you co-apply organic matter (compost, mulch, or retained topsoil).

In one line: gypsum supplies calcium that replaces sodium on the clay; the soil stops slumping and starts behaving like a soil again.

Two distinct use cases — read this before selecting a rate

Gypsum gets used on mine rehab for two fundamentally different reasons. Confusing them is the single most common reason gypsum work disappoints. Decide which one you're doing **before** you pick a rate.

Use case	What you're treating	Objective	Rate	Incorporation	Timing
Subsoil / spoil — STABILITY	Bulk material that holds the landform together — constructed profiles, batter material, re-spread spoil.	Geotechnical. Stop the spoil dispersing, stop tunnel erosion, keep the cap or fill structurally sound for decades.	Higher	Deep (≥300 mm)	During landform construction
Topsoil / growth media — VEGETATION	Surface layer that plants have to establish in.	Biological. Keep the surface open to rain, stop it crusting, let roots get down.	Lower	Shallow (100–200 mm)	At capping / pre-seed

The two jobs are not interchangeable. **A growth-media rate applied to dispersive spoil will not stabilise the landform.** A stability rate applied to topsoil can suppress germination and waste money. The rate table in Recommendations splits these explicitly.

Use gypsum when...

- ESP > 6 (topsoil) or > 10 (subsoil / spoil) with confirmed dispersive behaviour
- Emerson aggregate class 1, 2, or 3(1) on the relevant horizon
- Surface crusting, tunnel erosion, or slumping observed on similar adjacent material
- SAR > 6 in conjunction with the above

Gypsum will NOT help if...

- The material is **saline** (ECe > 4 dS/m at the relevant horizon) and there's no plan to flush the salt out with extra water (a "leaching fraction"). Salt has to leave; gypsum alone can't make it leave.
- pH is below **5** — the soil is acid, not sodic. Apply lime first; consider gypsum afterward only if sodicity remains.
- The problem is **purely physical** — compaction, hardpan, machinery damage — with no sodicity driver. Mechanical loosening is the answer, not gypsum.
- The material is **coarse and non-dispersive** (sandy, very low clay content). Few clay surfaces means little for gypsum to do.
- There is an **ongoing source of sodium** (e.g. saline groundwater intrusion, marine fines). Gypsum will be undone faster than it can act — fix the source first.

Decision flow

1. **Set the investigation tier** — match **consequence and relinquishment risk** to Tier 1 / 2 / 3 (see Data Requirements). A small site with high-consequence factors (regulator-scrutinised, completion criteria attached, dam-adjacent, post-relinquishment liability, public-facing) belongs at Tier 3 regardless of area. Tier sets sampling density, lab spend, and rate-selection rigour.
2. **Sample** topsoil and subsoil / spoil separately, at the density required by the tier
3. **Test** — field tests L1–L5 first; lab analyses required from Tier 2 upward
4. **Classify** the horizon — sodic / non-sodic, dispersive / non-dispersive, saline / non-saline
5. **Decide use case** — stability (subsoil/spoil) vs growth media (topsoil) vs both
6. **Select rate** — lower band (Tier 1 Quick Estimate), typical pick adjusted for site conditions (Tier 2 Standard), Members Calculator layered profile + sensitivity (Tier 3 Detailed)
7. **Select method** appropriate to slope, access, and rate (see Application Methods)
8. **Apply, incorporate, verify** to the schedule set by the tier

SECTION 2

Data Requirements & Field Sampling

Scaling investigation to site risk

Scale the investigation to the site risk

Not every site warrants the same level of investigation. A 0.5 ha trial plot, an operational fix on an internal road, and a 200 ha final landform that will be relinquished to the State each demand a different intensity of data. Match the **investigation tier** to the **site value and consequence**, then apply the data requirements and sampling frequencies in that tier. The principle is consistent with NCST (2008) survey intensity guidance: more decisions, larger areas, and higher consequences require denser characterisation.

Preferred approach — two rounds of sampling. Wherever practical, run an **initial round of characterisation BEFORE reshaping**. The pre-reshape data drives two early decisions that are hard to revisit: (i) expected gypsum application rates by horizon (informs supply contracts, logistics, and cost estimates), and (ii) the **landform reshaping and layering strategy** — which spoil types to keep apart, which to cap, and where dispersive material should sit relative to the surface. A **second round AFTER the reshape** is then a confirmation step: it characterises the as-built profile (which is always partially mixed) and pins down the rate that will actually be applied. Skipping the pre-reshape round means rate decisions are locked in after the dispersive material is already at the surface, with fewer options remaining.

Tier	Site profile (CONSEQUENCE-driven)	Investigation level	Decision confidence	Typical effort
Tier 1 Quick Estimate	**LOW CONSEQUENCE** work. Early planning, trial plots, internal triage, single-batter repair. Failure is easily redoable.	Field tests L1–L5 only; one representative composite per landform unit; no lab unless triage indicates	Directional — use **lower-band rate** from the Recommendations rate table as conservative pick	Hours; single site visit
Tier 2 Standard	**MODERATE CONSEQUENCE** work. Operational rehab, production sites, internal landforms, non-relinquishment.	Field tests + lab confirmation; 1 composite per 2 ha; minimum 3 per landform unit	Defensible for operational decisions — use **typical-pick rate** from the Recommendations rate table, site-adjusted	Days; one round of lab analysis
Tier 3 Detailed	**HIGH CONSEQUENCE** work — regardless of site size. Regulator-scrutinised, completion-criteria attached, public-facing, dam-adjacent, drainage to receiving environment, post-relinquishment liability, or community-sensitive. A small site with any of these factors belongs HERE. Very large sites (>200 ha) attract additional density and paired trial-plot rigour within this tier.	Tier 2 + stratified sampling by spoil / soil domain + spatial mapping + Members Calculator layered calculation + adjustment-factor sensitivity check + paired controls + temporal verification series	Defensible to regulator; site-specific rate with documented assumptions and uncertainty bounds	Weeks to months; multi-round sampling, design iteration, trigger-based contingency

Tier is driven by CONSEQUENCE — use the highest applicable tier

- **Consequence of failure** — cosmetic / operational / regulatory / public safety / relinquishment liability (the primary driver)
- **Visibility** — public-facing, community-sensitive, monitored by stakeholders
- **Relinquishment pathway** — landforms intended for sign-off attract higher scrutiny and longer audit horizons
- **Cost of re-treatment** if the rate is wrong (mobilisation, schedule disruption, regulator re-engagement)
- **Material variability** — heterogeneous spoil benches step up one tier
- **Area of treatment unit** — informs sampling density within a tier, but a small high-consequence site is still Tier 3

Default rule: when in doubt, step up one tier. The marginal cost of additional sampling is small compared to the cost of re-treatment, a failed completion audit, or a relinquishment refusal.

Minimum dataset per landform unit

Parameter	Topsoil (0–100 mm)	Subsoil / spoil (>100 mm)	Used for
ESP	✓	✓	Rate selection (primary driver)
$EC_{1:5}$ or ECe	✓	✓	Salinity screening — rules gypsum in / out
pH (1:5 water and $CaCl_2$)	✓	✓	Rules out alternative treatments (lime)
Emerson aggregate class	✓	✓	Confirms dispersion in practice
Exchangeable cations (Ca, Mg, Na, K)	✓	✓	Calculates ESP and Ca:Mg ratio
CEC	✓	✓	Mass-balance for Members Calculator
Bulk density	—	✓	Converts rate from g/kg to t/ha
Texture / particle size	✓	✓	Adjustment factor (clay content)
Treatment depth	✓	✓	Determines mass to be amended
Rainfall context (MAR, seasonality)	—	—	Leaching potential, timing window

Reshaped landforms — Tertiary vs Permian spoil mixing. In Australian coal regions the spoil placed during construction is typically a mix of Tertiary (younger, often more dispersive) and Permian (older, often more competent) material. A reshaped landform is rarely homogeneous — patches of each type sit side by side, and the surface mapping should reflect this. **Mapping rule:** map material distribution across the reshape; if patches are small (≤ 0.5 ha) or interleaved, sample BOTH and specify the treatment for the worse-case material across the unit. Larger discrete patches can be treated as separate landform units within the same tier.

Topsoil — sample separately, and think beyond gypsum. Topsoil (the growth-media horizon) is ALWAYS sampled separately from subsoil / spoil — same analyses but a separate composite. While sampling for sodicity, also assess the growth-media improvement requirements at the same time: organic matter, available P and K, micronutrients, pH, and infiltration. Gypsum addresses one constraint (dispersion); the cap may need others (fertiliser, compost, mulch, biology). Note that **topsoil can often be MORE dispersive than the subsoil beneath it** — stripping and stockpiling exposes fines, breaks aggregates, and removes the protective organic matter that stabilised the surface. Don't assume the topsoil is the easier horizon. Topsoil is also **typically ripped to integrate amendments** (disc, tine, or shallow ripper to 100–200 mm), so incorporation depth is part of the rate decision — see Section 4 for the depth-method matrix.

Sampling depths

- **Topsoil:** composite 0–100 mm
- **Shallow subsurface:** 100–300 mm
- **Subsoil / spoil:** 300–600 mm, and any deeper horizons exhibiting visible change
- **Spoil (constructed):** sample by spoil type, not by uniform depth — variability is lateral as well as vertical

Sampling frequency by investigation tier

Phase	Tier 1	Tier 2	Tier 3
Characterisation / design	1 representative composite per unit	1 per 2 ha; min 3 per landform unit	1 per 1 ha; stratified by spoil/soil domain. **Dam-adjacent or post-relinquishment sites: 1 per 0.5 ha + paired trial plots**
Verification post-application	Not required (lower-band rate is the safety margin)	1 per 5 ha + paired control where practical	1 per 2 ha + paired controls + temporal series (12 / 24 / 36 mo). **Very large or post-relinquishment sites: extend monitoring ≥ 5 years**
Spoil characterisation	One per accessible material type	Per material type, not by area — define by geology / weathering / sulphide content	Per material type + variability bounding (n ≥ 5 per type; **n ≥ 10 for dam-adjacent / >200 ha sites**)

Field tests for initial risk classification — ranked by diagnostic value

Before lab data returns, a coordinated suite of field observations and tests will get a competent assessor 70% of the way to a defensible early classification. The five tests below are ranked from **highest diagnostic value for sodicity / dispersion** to **lowest**, with the Australian standards or respected guidelines that govern each. Together they take 20–30 minutes per site.

L# = diagnostic-value Level. L1 has the highest diagnostic value for sodicity / dispersion (a positive result is near-conclusive on its own); L5 is supporting evidence only and cannot rule sodicity in or out by itself. Use L# rank when prioritising tests given limited time. The Tier 1 / 2 / 3 ranking (see Data Requirements) is a separate dimension — investigation depth driven by site consequence, not field-test diagnostic value.

Note on order: rank order (below) is by diagnostic value. Field workflow order is the reverse — do visual inspection first (5 min while approaching the site), then hand texture and slake on grab samples, then field pH/EC, finally jam jar with the cleanest aggregates.

Rank	Test	What it diagnoses	Diagnostic value	Reference standard / guideline
L1	Jam Jar (Emerson aggregate test)	Direct evidence of dispersion behaviour; Emerson class 1–8	**Highest** — regulator-accepted, repeatable, definitive for dispersion in the absence of lab ESP	**AS 1289.3.8.1** — Methods of testing soils for engineering purposes — Emerson dispersion test; McDonald et al. (2009) §2.5
L2	Field pH and EC	Salinity vs sodicity discrimination; rules alternative treatments (lime, leaching) in or out	**High** — quantitative, fast; determines whether gypsum is even the right treatment	**Rayment & Lyons (2011)** — *Soil Chemical Methods (Australasia)* methods 4A1 (pH) and 3A1 (EC); McDonald et al. (2009) §3.4–3.6
L3	Hand texture / ribbon	Clay content estimate; informs magnitude of gypsum demand	**Moderate** — qualitative but standardised in Aus; foundational for any soil description	**McDonald et al. (2009)** *Australian Soil and Land Survey Field Handbook* (NCST / CSIRO), §3.2 Field Texture Grade
L4	Slake test / aggregate stability	Structural integrity on wetting; fast precursor to jam jar	**Moderate** — structural rather than chemical; can miss true dispersion that requires longer observation	**McDonald et al. (2009)** §3.5 Soil Structure; **Isbell (2021)** *Australian Soil Classification* — pedal stability
L5	Visual landscape / morphological inspection	Site-scale targeting of sodic / saline patches; sampling priority	**Supporting** — directional rather than diagnostic; cannot rule sodicity in or out alone	**McDonald et al. (2009)** §2 Site Description; **Isbell (2021)** sodosol / vertosol indicators

L2 — Field pH and EC

- Calibrated portable pH meter, or indicator strips for triage only, on a **1:5 soil:water slurry** (5 g air-dried < 2 mm soil + 25 mL distilled water, shake for 1 min, allow 15 min, read).
- Portable EC meter on the same slurry. Convert $EC_{1:5}$ to approximate ECe via texture factor: sand ×14, sandy loam ×12, loam ×10, clay loam ×8, clay ×6.

Interpretation:

- pH 7.5–9.0, $EC_{1:5}$ < 0.4 dS/m → **probable sodicity, low salinity** → gypsum strong candidate
- pH > 8.5, $EC_{1:5}$ > 0.4 dS/m → **saline-sodic** → leaching strategy + gypsum
- pH < 5 → **acid soil** → lime first, gypsum secondary or unnecessary

Method references: Rayment & Lyons (2011) methods 3A1 ($EC_{1:5}$) and 4A1 (pH water 1:5).

L3 — Hand texture / ribbon test

- Moisten ~10 g soil to a plastic ball; work between thumb and forefinger to extrude a ribbon.
- Score against the **Australian field texture grades** in McDonald et al. (2009) §3.2 — sand (S), sandy loam (SL), loam (L), clay loam (CL), light clay (LC), medium clay (MC), heavy clay (HC).
- <25 mm, gritty, no plasticity → S–SL, <15% clay → low gypsum demand
- 25–40 mm, some plasticity → L–CL, 15–35% clay → moderate gypsum demand
- >50 mm, smooth, sticky → MC–HC, >35% clay → high gypsum demand *if sodic*

L4 — Slake test / aggregate stability

- Drop a single **air-dry aggregate** (pea-sized, undisturbed) into a beaker of distilled or rainwater. Do not stir.
- Observe at 10 seconds and 60 seconds.
- Aggregate intact at 60 sec → **stable** → unlikely to be strongly sodic; proceed only if other indicators suggest otherwise.
- Aggregate slumps / disintegrates within 10 sec → **unstable** → proceed to jam jar.

Reference: McDonald et al. (2009) §3.5 — field assessment of soil structure and pedal stability. Limitation: a slaked but non-dispersive aggregate can still show structural failure here; the jam jar (L1) is required to confirm true dispersion.

L5 — Visual landscape / morphological inspection

Standardised against McDonald et al. (2009) site description protocol. Record:

- **Surface condition** — crusting, polygonal cracking, milky films after rain, surface seal
- **Erosion features** — tunnel collapse, piping, "blown out" gullies, circular sub-surface failures
- **Salt indicators** — white efflorescence (a powdery white salt deposit at the surface) and salt crystallisation (points to salinity, not sodicity alone)
- **Vegetation** — patchy bare clumps among healthy cover on uniform slope/aspect (strong indicator of localised sodicity)
- **Indicator species** — bare scalds = sodic surface sealing; saltbush / samphire = salinity in arid zones; *limited diagnostic specificity, use directionally*

Triage logic from field tests alone

- Visual signs of dispersion + slake failure + Emerson class 1–2 + pH 7.5–9 + low EC → **strong gypsum candidate**; proceed to lab confirmation
- Same as above but **high $EC_{1:5}$** → **saline-sodic** — leaching strategy required alongside gypsum
- pH < 5 → **acid soil** — lime first
- Stable aggregates, Emerson 4–8, short ribbon → **non-dispersive material** — gypsum unlikely to be useful

L1 detailed — Jam Jar (Emerson) Dispersion Test SOP

The jam jar field method follows the principle of **AS 1289.3.8.1** (Emerson dispersion). A field execution sufficient for screening and characterisation; the standard test under laboratory conditions remains the defensible record for completion criteria.

9. Collect ~5 g of air-dried soil aggregates (pea-sized, undisturbed where possible)
10. Half-fill a clear jar with distilled or rainwater (not site water — salts will mask dispersion)
11. Drop 3–5 aggregates gently into the water — do not stir
12. Observe at **10 minutes**, **2 hours**, and **24 hours**
13. Score against the Emerson classes (see table below)
14. Photograph each reading for the record — append site, sample ID, time, water source

Reading at 10 min	Reading at 2 hr	Emerson class	Action
Complete dispersion (milky halo, no aggregate)	n/a	**1**	Strongly dispersive — treat
Some dispersion (cloudy halo)	Halo persists / expands	**2**	Dispersive — treat
No dispersion, slaking visible	Slaked, no milky halo	**3(1)** if disperses after remoulding	Marginal — lab confirm
No dispersion, intact aggregate	Intact	**4–8**	Not dispersive — gypsum not indicated for dispersion control

Lab analyses to request (Australian context)

Request as a package — most commercial soil labs (CSBP, APAL, EAL, ALS) offer a "sodicity / structure" suite:

- Exchangeable cations (Ca, Mg, Na, K) by ammonium chloride or barium chloride
- Cation exchange capacity (CEC)
- Electrical conductivity (1:5 water) — convert to ECe via texture factor where required
- pH (1:5 water and $CaCl_2$)
- Particle size (laser or pipette)
- Emerson aggregate class (some labs)
- Bulk density — measure in the field, do not request from lab

SECTION 3

Recommendations & Jurisdictional Variation

Rate selection, adjustments, and state-by-state variation

General guidance — gypsum application rates by ESP and use case

The table below gives **indicative ranges and a typical pick** for general planning. The Members Calculator delivers a site-specific rate accounting for layer thickness, bulk density, target ESP reduction, gypsum purity, and exchange efficiency. **This table is not a substitute for layered calculation on detailed design.**

ESP band	Dispersion	Use case: TOPSOIL / growth media	Use case: SUBSOIL / spoil — stability
6 - 10	Weakly sodic	2 – 8 t/ha *(typical 5)*	5 – 15 t/ha *(typical 10)*
10 - 15	Moderately sodic	5 – 15 t/ha *(typical 10)*	15 – 30 t/ha *(typical 20)*
15 - 20	Strongly sodic	10 – 20 t/ha *(typical 15)*	30 – 45 t/ha *(typical 35, aligns with TMR / Bennett 2022)*
> 20	Severely sodic (mine spoil)	15 – 25 t/ha *(typical 20)*	50 – 75 t/ha *(typical 60, per Spain et al. 2023 / Emmerton & Doyle 2016)*

Practical upper limit on rate — broadacre rule of thumb. In broadacre application contexts, field experience indicates that rates above ~30 t/ha begin to approach the point where the application is more gypsum than soil — physically harder to integrate, more expensive per unit of ESP exchange, and at risk of compromising the substrate as a growth medium. **If your calculated rate is ≥ 30 t/ha, do not just apply more gypsum — step back and consider:** (a) **rock-mulch capping** or surface armouring to remove the stability requirement from the spoil itself; (b) **placement of a stable spoil layer** (less-sodic material) over the dispersive material; (c) **dilution by re-handling** with a less-sodic spoil type; or (d) **co-amendment with organic matter** to reduce the gypsum requirement to a practical rate. Discuss with the closure team before committing.

Adjustment factors

Factor	Effect on rate	Notes
Deep incorporation (>300 mm)	**+** retain upper-band rate	Critical — see Emmerton & Doyle (2016)
High clay content (>35%)	**+** upper band	More exchange sites, more sodium to displace
Rock content / coarse fragments	**+** scale rate inversely with fines fraction	Gypsum only acts on the <2 mm fines. Rule of thumb: at 30% rock by volume, increase nominal rate by ~40% to maintain the same fines-basis dose. At >50% rock, total-mass rate becomes misleading — calculate on fines-only basis. Quantify rock content during sampling.
High rainfall / leaching context	**−** lower band	Sodium will leach with adequate Ca; revisit at 24 months
Co-amendment with OM / compost / topsoil cap	**−** lower band, **+** outcome	Synergistic — per Spain et al. (2023)
Ongoing Na source (saline groundwater, marine clay)	**No adjustment — gypsum will not arrest re-sodification**	Treat the cause first
Gypsum purity < 80% $CaSO_4 \cdot 2H_2O$	**+** scale rate inversely with purity	Specify product analysis on supply
Cold / dry climate, low MAR (<400 mm)	**+** upper band; expect slower onset	Dissolution rate-limited by moisture — see the timeline in Worked Example, Verification & References

Jurisdictional variation — Australia

The fundamental science is the same in every jurisdiction. The regulatory framing, default rates, and what regulators expect to see in a closure plan differ. This is a summary of where the variation actually shows up.

Queensland (DRMP / EHP guidance, *Land Use Planning Guideline 17* and *Mine Rehabilitation Commissioner* expectations)

- Closure plans and Progressive Rehabilitation and Closure Plans (PRCPs) require explicit sodicity characterisation by landform domain.
- Bowen Basin coal spoil typically reports ESP 15–25 — rates in the 30–60 t/ha range are common and expected.
- Emerson aggregate testing is a routine field record; jam jar evidence is acceptable for characterisation but not for final rate justification.
- Verification sampling is increasingly requested at 24 months post-application.

New South Wales (Resources Regulator, *ESG3 Mining Operations Plan Guideline*)

- Similar expectations to QLD on sodicity characterisation and rehabilitation completion criteria.
- Hunter Valley spoil typically ESP 10–20; Western Coalfields lower.
- Greater emphasis in completion criteria on demonstrated vegetation establishment rather than purely chemical outcomes — implies a growth-media pathway must be evidenced.

Western Australia (DMIRS *Mine Closure Plan Guideline 2020*, complementary EPA Pilbara guidance)

- Pilbara iron-ore waste rock often ESP < 6 but with very high sodium-adsorption potential and dispersive fines in the matrix — Emerson testing is critical because ESP alone underestimates risk.
- Goldfields spoil and SW WA bauxite residue / mineral-sands tailings: ESP regularly 15–25, requiring high rates.
- DMIRS expects explicit linkage between soil chemistry and proposed landform performance — i.e. rates must be defended against the failure mode (stability vs growth media).

South Australia (*Mining Regulations 2020*, *Mining Rehabilitation Compliance Reports*)

- Olympic Dam and Cu / U operations: highly variable spoil, often saline-sodic — confirm ECe is within range before specifying gypsum.
- Limited dedicated state guidance on rates — defer to industry standards.

Northern Territory (Mining Management Plan, NT EPA)

- Wet-dry tropical climate accelerates both leaching of beneficial Ca and re-sodification from saline groundwater in coastal sites.
- Wet-season timing constraints are a critical scheduling input — application windows are narrower than southern jurisdictions.

> **Common across jurisdictions:** regulators expect (i) sampling that distinguishes topsoil from subsoil, (ii) rate justification linked to a target outcome (stability or vegetation), and (iii) post-application verification.

SECTION 4

Application Methods, Incorporation & Timing

Matching delivery to terrain, rate, and use case

The single biggest determinant of gypsum outcome on a rehabilitated landform is **whether the product is incorporated, and to what depth** — not the headline rate. A 60 t/ha surface application without incorporation will underperform 30 t/ha deep-ripped on the same material.

Application methods — capabilities and limits

Method	Practical rate per pass	Max total rate	Suitable terrain	Use case	Opportunities	Limitations
Truck spreader (dry, agricultural)	Up to 20 t/ha	50+ t/ha (multi-pass)	<15% slope, low rock	Subsoil/spoil stability + topsoil growth media	High rate capability; cheap per tonne; well-understood	No access to steep batters or rock-armoured slopes; needs follow-up incorporation
Tracked / articulated spreader (purpose-built)	Up to 15 t/ha	50+ t/ha (multi-pass)	Up to 25–30% slope	Subsoil/spoil stability on engineered batters	Reaches steeper / softer terrain than ag truck	Cost / availability limited; still rock-constrained
Bulldozer / loader spread (mine fleet)	30+ t/ha (single placement)	75 t/ha	Any active earthworks surface	Subsoil/spoil stability during landform construction	Integrates with construction sequence; no separate plant mobilisation	Coarse coverage; relies on incorporation by subsequent ripping or cap placement
Liquid / slurry application (hydroseeder, tanker)	1 – 3 t/ha	~5 t/ha total	Steep slopes (>30%), rock armouring	Topsoil / growth media surface conditioning, dust suppression	Accesses terrain other methods cannot; combines with seed slurry; uniform distribution	Low total mass — **cannot deliver stability rates.** Gypsum is only sparingly soluble (~2.4 g/L), so a tanker can carry only a small fraction of its volume as gypsum; multiple passes needed for any meaningful rate.
Aerial — fixed-wing crop duster / helicopter	1 – 5 t/ha per pass	10 – 15 t/ha (multi-pass, cost-limited)	Remote, inaccessible, steep, rocky	Topsoil / growth media top-ups; emergency response on isolated sites	Only viable option for inaccessible terrain; rapid coverage of large areas	Surface-applied only — no incorporation possible; expensive; weather-dependent; payload-limited; drift risk; **not a stability solution**

In-situ rock often limits ripping depth. Mine spoil frequently contains boulders or coarse rock fragments within the upper 200–400 mm — exactly the depth ripping needs to reach for stability-purpose gypsum. Where rip depth is constrained to < 200 mm by sub-surface rock, deep ripping is not a usable incorporation method; gypsum then sits in the active root zone only, not the dispersive subsoil that needs treating. **Pre-assess ripping feasibility on a representative trial pit before specifying a stability-purpose rate.** If achievable rip depth is < 300 mm, treat the work as a growth-media application (Section 1 framing) rather than spoil stability — and look at the alternatives in the 30 t/ha callout above.

Incorporation — depth matters more than rate

Method	Achievable depth	Suits	Notes
Deep ripping (winged tine)	400–600 mm	Subsoil / spoil stability	Best result on most mine rehab applications. Emmerton & Doyle (2016) — essential for effectiveness.
Disc ploughing	100–250 mm	Topsoil incorporation	Standard agricultural method; rapid; risks bringing subsoil up if cap is thin
Tine cultivation	100–200 mm	Topsoil / cap surface	Lighter touch; appropriate where cap is shallow
Hydraulic incorporation (rainfall, infiltration)	<50 mm effective	Surface treatment only	Slow, partial; appropriate only for top-up applications or where no equipment can access
No incorporation	Surface only	Aerial application, steep rock-armoured slopes	Expect significantly reduced performance; budget for re-application

Rule of thumb: match incorporation depth to treatment depth. If you need to amend the upper 400 mm of spoil, gypsum that sits in the top 100 mm has not done the job.

Timing

Window	Application phase	Rationale
During landform construction	Subsoil / spoil — stability	Incorporate as bulk material is placed; no separate equipment mobilisation; deepest effective incorporation
At capping / pre-seed	Topsoil — growth media	Incorporate with topsoil cap; sets up the surface for revegetation
Pre-wet season (Apr–Oct in QLD/WA; pre-monsoon NT)	Either	Soil moisture is required for dissolution; aim to have product in the profile ahead of the first significant rainfall
Avoid: dry-dry application	—	Gypsum needs moisture to dissolve — broadcast on bone-dry surface ahead of zero forecast rain is wasted
Avoid: saturated / wet application	—	Compaction risk during incorporation, runoff loss, equipment damage

SECTION 5

Worked Example, Verification & References

Putting it all together

Worked example — Sodic spoil on a QLD coal site (Tier 3)

Setting. A central QLD open-cut. Final landform: 12 m high WRL with 3H:1V batter, 35 ha treatment area, capped with 500 mm of spoil-derived growth medium overlying re-handled spoil. Public-visible from a regional road; covered by approved PRCP with formal completion criteria. → **Tier 3 — Detailed** (regulator-scrutinised, completion criteria attached, public visibility, formal PRCP — these consequence factors place the work at Tier 3 regardless of area; the 35 ha then sets sampling density within the tier).

Inputs (per landform unit, characterisation phase)

Horizon	Depth	ESP	$EC_{1:5}$	Emerson	Bulk density	Rock content (>2 mm)
Topsoil cap (growth medium)	0–500 mm	9	0.4 dS/m	3(1)	1.4 t/m³	<5%
Re-handled spoil (subsoil)	500–1500 mm	18	0.8 dS/m	1	1.5 t/m³	30%

Use-case split

- **Topsoil:** growth media — ESP 9, weakly sodic, marginal Emerson. Target rate from table: 5 t/ha (typical pick).
- **Subsoil/spoil:** stability — ESP 18, severely dispersive, strongly sodic. Target rate from table: 35 t/ha (typical pick).

Adjustments

- Deep incorporation planned to 400 mm in the spoil — retain upper band (no adjustment).
- **Rock content 30% in spoil — apply +40% rock adjustment to maintain fines-basis dose: 35 × 1.4 = 49 t/ha.**
- High rainfall (>700 mm MAR) — could justify lower band, but Emerson 1 + slope failure consequence argues against reduction.
- Co-application with composted bagasse mulch on the cap — could reduce topsoil rate to 3 t/ha (lower band).

Final selection

- **Topsoil:** 3 t/ha gypsum, co-applied with composted mulch, disc-incorporated to 200 mm at cap placement.
- **Spoil:** 49 t/ha gypsum (35 t/ha typical + 40% rock-content correction), applied by truck spreader during spoil placement, deep-ripped (winged tine) to 400 mm prior to capping.
- **Method choice rationale:** Spoil rate cannot be delivered by liquid or aerial — both are physically incapable of 49 t/ha. Truck spreader is viable here because the landform is still under construction and access is unrestricted.
- **Effectiveness expectation:** based on the timeline curve below, design ESP reduction at the spoil treatment depth (300–500 mm) is expected to reach ~30–50% by 12 months and 50–70% by 24 months. Verification sampling timed accordingly.

Verification schedule for this site

- **12 months:** surface erosion inspection, photo points, vegetation cover scoring
- **24 months:** paired sampling (treated + control), ESP and Emerson re-test at 0–100 mm and 300–500 mm
- **36 months:** completion-criteria audit if relevant

Trigger for re-treatment: ESP at 300–500 mm has reduced by < 30% of the target reduction, or visible tunnel erosion / surface dispersion on treated areas.

Expected timeline to effectiveness

Gypsum is not instantaneous. Dissolution is rate-limited by soil moisture, contact surface area, and incorporation depth. Set verification expectations and re-treatment triggers against the curve below — **not** against an assumption of complete exchange within 12 months.

Time post-application	% of design ESP reduction achieved	Conditions assumed	Observable indicators
0 – 3 months	5 – 15%	First significant wetting event	Aggregate slaking reduced; surface crusting persists
3 – 6 months	15 – 30%	One wet-season cycle	Improved infiltration test; first vegetation cover gains
12 months	30 – 50%	Full annual moisture cycle, adequate incorporation	Visible vegetation establishment; reduced erosion features
24 months	50 – 70%	Two annual cycles	Measurable ESP reduction at treatment depth; cover criteria approach attainable
36 months	65 – 85%	Three annual cycles, no re-sodification source	Closure / completion criteria typically defendable on lab evidence
60 months +	75 – 90%+ asymptote	Long-term steady state	Maintenance / monitoring phase

Conditions that delay the curve

- MAR < 400 mm — dissolution slow
- High rock content (incomplete fines treatment)
- Poor incorporation (gypsum concentrated in upper 100 mm of a 400 mm target depth)
- Compacted profile (poor water movement)
- Ongoing Na source (groundwater intrusion, marine fines, saline irrigation)

Conditions that accelerate the curve

- Deep incorporation with winged tine
- High-rainfall context with adequate drainage
- Co-amendment with organic matter / compost
- Higher gypsum purity and finer particle size (faster dissolution surface)

Verification sampling — what to test, when

Time post-application	Top priority parameters	Reason
12 months	Visual erosion, vegetation cover, surface infiltration test	Performance proxy; cheap; rapid. Do not yet expect strong ESP signal.
24 months	ESP and Emerson class at treatment depth; paired with untreated control	First defensible chemical evidence of exchange — expect 50–70% of design reduction
36 months	Full sodicity suite + bulk density	Closure / completion criteria evidence — expect 65–85% of design reduction
Re-treatment trigger	Achieved ESP reduction at treatment depth < 30% of design target by 24 months	Indicates dilution by rock, poor incorporation, or ongoing Na source — diagnose before re-applying

References

Australian standards and field methods

- **Standards Australia — AS 1289.3.8.1.** *Methods of testing soils for engineering purposes — Soil classification tests — Determination of dispersion characteristics — Emerson class number of a soil.* The defensible SOP for Emerson dispersion testing.
- **McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J., and Hopkins, M.S. (2009).** *Australian Soil and Land Survey Field Handbook* (3rd edn). National Committee on Soil and Terrain / CSIRO Publishing. The "Yellow Book" — site description, hand texture, structure, and morphological assessment.

- **Rayment, G.E. and Lyons, D.J. (2011).** *Soil Chemical Methods — Australasia.* CSIRO Publishing. Reference SOPs for soil pH (4A1), EC (3A1), exchangeable cations, CEC, ESP.
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- **National Committee on Soil and Terrain (NCST, 2008).** *Guidelines for Surveying Soil and Land Resources* (2nd edn). Methodology for soil survey, sampling, and characterisation.

Gypsum on mine spoil — applied research

- **Bennett, J. McL., Cattle, S.R., Singh, B., and others (2022).** *Soil sodicity and dispersion: refinements to the Oster & Jayawardane gypsum requirement methodology.* — Updated total recommended rate 31.7 t/ha for the worst-case Emerson scenario examined.
- **Brautigan, D. (2010).** *Behaviour of calcium and aluminium in alkaline soils.* PhD thesis. — Gypsum at 2–10 g/kg (≈3–14 t/ha at BD 1.5) reduced two alkaline soils from pH 10 / 9.7 by 0.9–1.4 pH units.
- **Emmerton, B.J. and Doyle, R.B. (2016).** Field trials at Moura and Blackwater. — 40–75 t/ha reduced crusting and improved root penetration in sodic spoil; deep incorporation essential.
- **Oster, J.D. and Jayawardane, N.S. (1998).** Original gypsum requirement methodology — the basis of most subsequent Australian guidance.
- **Shainberg, I. and Letey, J. (1984).** *Response of soils to sodic and saline conditions.* — 25–100 t/ha on sodic soils in California's Central Valley; improved infiltration, ESP reduction, sodium leaching.
- **Spain, A.V., Emmerton, B.J., and Hinz, D. (2023).** — 50–70 t/ha on mine spoil at ESP > 20%, combined with organic matter and topsoil, improved soil stability and vegetation cover.

Jurisdictional guidance

- **DMIRS (WA, 2020).** *Mine Closure Plan Guideline.*
- **Queensland DES / Mine Rehabilitation Commissioner.** PRCP guidance and *Land Use Planning Guideline 17.*
- **NSW Resources Regulator.** ESG3 — *Mining Operations Plan Guideline.*

For layered calculation — Members Toolbox

For a site-specific, layered calculation accounting for layer thickness, bulk density, target ESP reduction, gypsum purity, and exchange efficiency, see the **Regen-X Gypsum Requirement Calculator** in the Members Toolbox at **regen-x.com.au/toolbox**.

Disclaimer

This field guide is intended to **support decision making** by engineers, environmental scientists, and rehabilitation supervisors working on mine rehabilitation projects. It is general guidance only.

There is no substitute for expert advice. This document does not constitute, and is not a substitute for, qualified professional engineering, environmental, or regulatory advice. Site-specific design, expert professional judgement, and regulatory consultation are required before applying any of the guidance contained here.

Rates, methods, incorporation depths, and timing must be verified for the specific material, landform, climate, and jurisdictional context of the work - and reviewed by an appropriately experienced practitioner. Application of any guidance in this document is at the user's own risk.

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