FINAL REPORT

O21: Dispersive and Slaking Soils Management – Year 1 (2020–21)

ARRB Project No.:	015720	
Project Managers:	TMR:	Louise Dutton
	ARRB:	Georgia O’Connor
Quality Manager:	Dr Tim Martin	
Author/s:	Zia Rice, Georgia O’Connor & Louise Dutton	
Prepared for:	Queensland Department of Transport and Main Roads	

November 2022

AN INITIATIVE BY:

Summary

Soils with slaking and dispersive properties are common across Queensland. While often undetected and unproblematic in the natural environment, soils with these properties cause problems for infrastructure as they are highly erodible in the presence of water. Slaking and dispersion are caused by different soil properties:

- Slaking refers to instability of soils when there is a lack of internal cohesive forces (commonly due to a lack of organic matter) to support the structure of the soils under certain environmental conditions, such as excess water infiltration.
- Dispersive soils (otherwise known as sodic soils) are soils with a chemical imbalance and/or excessive mechanical disturbance. A chemical imbalance can be related to the soil being sodic, or having high levels of exchangeable sodium, or can be caused by a lack of organic matter, similar to slaking.

The major concern with dispersive and slaking soils is erosion, which is caused when rainwater, freshwater, or low-level saline water comes into contact with dispersive and slaking soils. The high susceptibility to erosion poses a substantial risk to:

- Queensland Department of Transport and Main Roads' (TMR's) asset durability (due to subsidence of supporting land)
- the safety of the travelling public due to erosion of road shoulders (or beneath) the road
- legacy liabilities associated with degraded areas within the road corridor to be managed under Maintenance, Preservation and Operation's (MPO) Element 3 Degraded areas
- degradation of landscape biodiversity through loss of topsoil
- the financial and environmental costs incurred during construction associated with disposing of these materials and importing non-dispersive materials.

In addition to impacting infrastructure asset integrity and maintenance requirements, erosion resulting from disturbed dispersive soils is a major contributor of sediment loads to waterways from road corridors. This has an impact on local waterways as well as affecting the health of downstream areas including the Great Barrier Reef.

The aim of this project was to review scientific publications with a view to inform possible options to integrate effective management of dispersive and slaking soils into standard earthworks processes through TMR technical specifications. In order to achieve the project's aim the project:

- undertook a literature review of scientific publications to research and identify current industry best practice management options for dispersive and slaking soils through a literature review. Note that benchmarking to other state road agencies and Austroads publications was not included in the review
- undertook a gap analysis of existing TMR specifications and manuals against the literature findings about dispersive and slaking soils
- developed draft updates to technical specifications that integrate dispersive and slaking soil management measures, including testing and treatment
- workshopped the proposed updates with internal TMR stakeholders to confirm suitability of approach.

Generally, the project found that while there is sufficient information available within current TMR documentation to provide appropriate slaking and dispersive soils management guidance, the practices are not leading to effective management of dispersive and slaking soils. This is likely due to:

- insufficient identification of dispersive and slaking soils during pre-construction
- lack of understanding of dispersive and slaking soils within construction and earthworks contractors
- lack of treatment options for dispersive and slaking soils within the MRTS04 Technical Specification
- ad hoc application of the MRTS16 Landscaping and revegetation technical specification to contracts.

Furthermore, the project found that while dispersive and slaking soil management is mentioned in a number of manuals and specifications there is an absence of a single clear process for identifying, testing, managing and treating these high-risk soils, inadequate connections between the relevant resources, and poor clarity of roles and responsibilities which would otherwise guide the user through this process.

The project has sought to address these gaps through delivering:

- draft amendments to TMR MRTS04 technical specification suite that includes:
  - enhancement of the Emerson test with complementary physical and chemical tests to improve detection of risks of dispersive and slaking properties
  - new provisional work items for supply and installation of ameliorants
- a *Technical Note: Managing Dispersive and Slaking Soils on Infrastructure Projects*
- a revised test method based on Emerson test for laboratory analysis of dispersive and slaking properties
- improved procedures for identifying and evaluating risks for dispersive and slaking soils in pre-construction.

At a high level these amended technical publications provide clarity of process and roles, revised tests method to improve accuracy and provision of amelioration of dispersive soils as part of earthworks including new pay items within the schedule.

Contents

Tables

Figures

1. Introduction

This report presents the methodology, recommendations and outcomes of NACOE Project O21: *Dispersive and Slaking Soils Management*. The aim of this project was to provide recommendations for the improvement of guidance materials for the management of dispersive and slaking soils.

1.1 Background

Dispersive soils are highly erosive and vulnerable to sheet, tunnel, and gully erosion (Figure 1.1). Erosion of these soils results in dispersion of sediments when exposed to water. The repair of tunnel and gully erosion is often expensive, difficult, and prone to re-failure (Queensland Government 2014). These types of erosion can also cause extensive sub-surface damage before they are identified.

The issues associated with dispersive soils are not uncommon nor are they limited to certain areas across Queensland. Nearly half of all soils in Queensland are classed as either dispersive or slaking (Figure 1.2). One of the major causes of dispersive properties in soil is an imbalance in cations, specifically an excess of sodium. Soils with an exchangeable sodium percentage (ESP) above 6% are considered 'sodic'. These are the principal type of dispersive soils across Queensland (Figure 1.3).

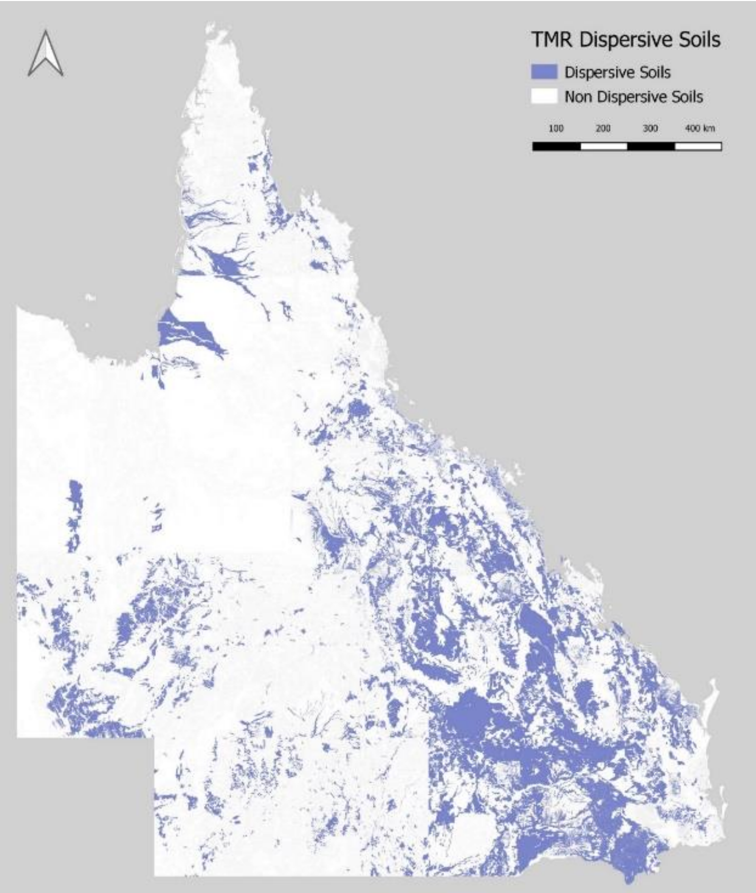
Slaking refers to the instability of soils when the aggregates are not strong enough to withstand internal stresses caused by rapid water update. As a consequence, slaking soils are of concern due to the increasing impact of erosion.

Slaking and dispersive soil properties are generally well understood and managed in agricultural applications. The identification and consideration of these soils are critical to effective land management and optimisation of crop production. However, the identification and management of these soil properties are not as well established in civil engineering contexts.

Figure 1.1: Examples of erosion due to dispersive soils

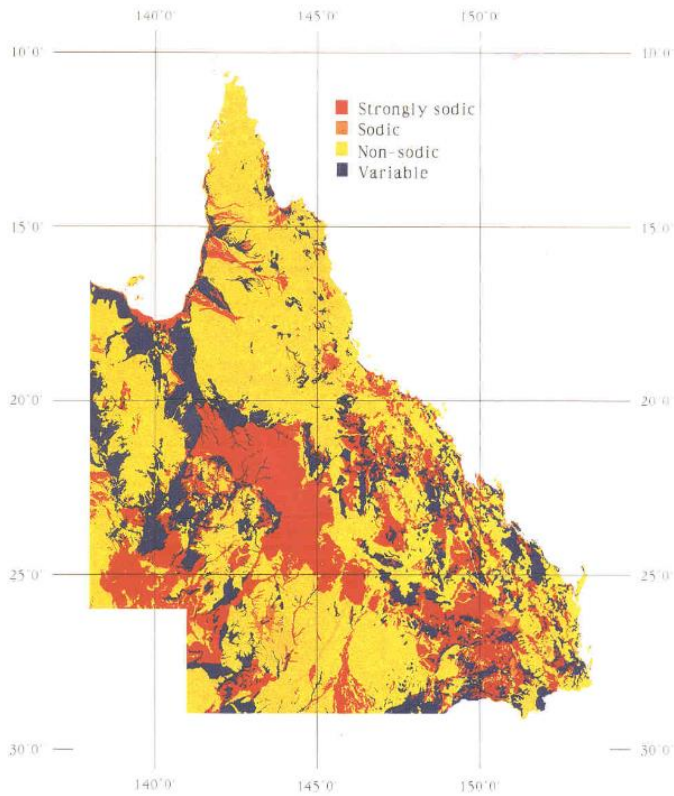
Source: Provided by TMR.

Figure 1.2: State-wide map of dispersive soils mapped across Queensland



Source: ARRB prepared and supplied.

Figure 1.3: Distribution of dispersive sodic soils in Queensland



Source: Raine and Loch (2003).

1.2 Project Objective and Context

Dispersive soils pose a substantial risk to:

- Queensland Department of Transport and Main Roads' (TMR's) asset durability
- the safety of the travelling public due to erosion of road shoulders or beneath the road
- legacy liabilities associated with degraded areas within the road corridor to be managed under Maintenance, Preservation and Operation's (MPO) Element 3 Degraded areas
- degradation of landscape biodiversity through loss of topsoil
- the financial and environmental costs incurred during construction associated with disposing of these materials and importing non-dispersive materials
- water quality in waterways, due to sedimentation.

TMR's technical specifications and manuals currently contain some guidance on management of dispersive and slaking soils. However, problems do still arise on projects and there are significant legacy issues across the network.

Therefore, the aim of this project was to investigate current industry best practice in managing dispersive and slaking soils, in order to make recommendations for the integration of appropriate management tools (including testing and treatment) into TMR's standard specification requirements.

The incorporation of the management of dispersive and slaking soils into TMR's infrastructure construction and maintenance practices will:

- improve the durability and performance of TMR's assets in dispersive soil areas
-
- reduce the capital costs and environmental impacts associated with disposing of dispersive soils and importing other material during construction
- improve water quality in waterways including the Great Barrier Reef catchment.

The goal of this NACOE project is to integrate improved dispersive and slaking soil management into standard earthworks practices such that it becomes 'business as usual' (BAU). The focus of the project has been specifically on earthworks operations and the MRTS04 Technical Specification.

2. Slaking and Dispersive Soils

Slaking and dispersive soils are common across Queensland.

Slaking refers to the instability of soils when there is rapid wetting. The internal forces between and within aggregates cannot withstand the pressure of water entering soil pores and this causes the aggregates to separate into smaller aggregates. Slaking soils often have a low amount of organic matter.

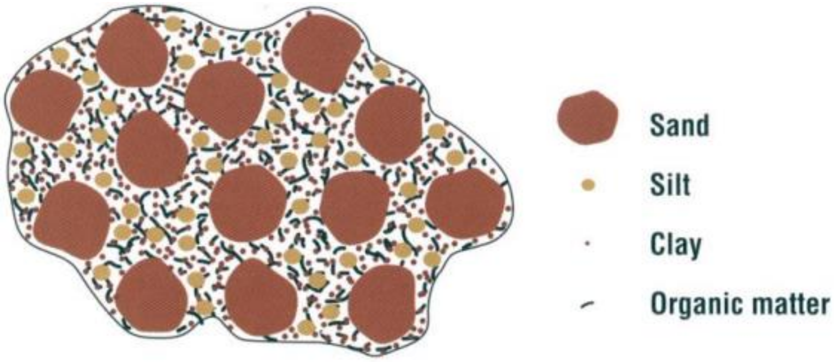
Dispersive soils are soils which have been disrupted by a chemical imbalance and/or excessive mechanical disturbance.

A chemical imbalance can be related to the soil being sodic (i.e. having high levels of exchangeable sodium) or can be caused by a lack of organic matter, similar to slaking (Dairy Australia 2021). These soil types are further explored in Section 2.2. While dispersion and slaking both cause issues due to structural instability resulting in erosion, the mechanisms that cause these reactions are different and the soil types that demonstrate these properties are different.

2.1 Background and Key Definitions

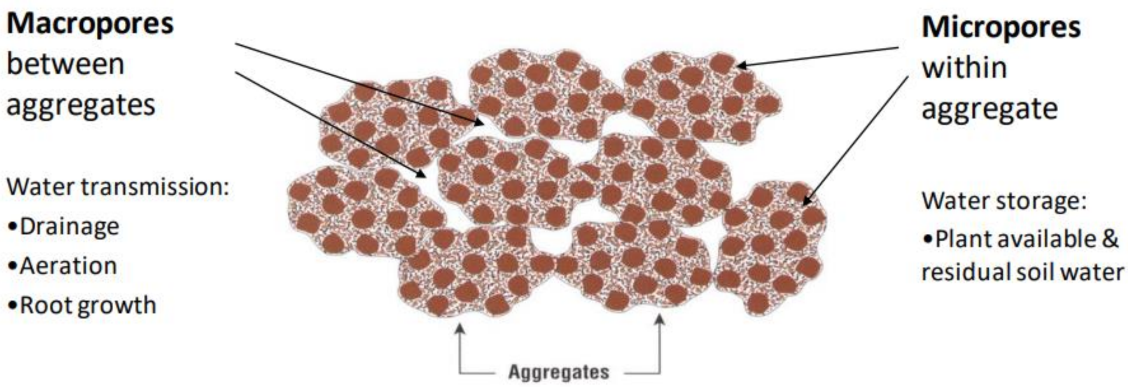
Soil particles (sand, silt, clay, organic matter) can be cemented together to form 'aggregates' as depicted in Figure 2.1. It is the electrical attraction properties found in clay and organic matter that cement all soil material together. A soil structure refers to the arrangement of soil aggregates and their size, shape, strength and stability. Within soil structure there are pores, or spaces. These pores allow air, water and root movement through the soil. Soil structure is depicted in Figure 2.2.

Figure 2.1: A depiction of a soil aggregate made up of different soil particles



Source: Agriculture Victoria (2020a).

Figure 2.2: Image of soil structure



Source: Agriculture Victoria (2020a).

Slaking refers to the rapid breakdown of soil aggregates into smaller aggregate fragments when the soil is exposed to moisture, or 'wetting'. This occurs when clay swells, causing the trapped air between soil particles to 'burst out' (Department of Primary Industries 1999).

Slaking can be advantageous in agricultural context as the slaking assists in breaking down surface crust and allowing water infiltration. In transport infrastructure context, slaking soils present in batters and drains can result in rapid erosion of soil surfaces in the presence of water.

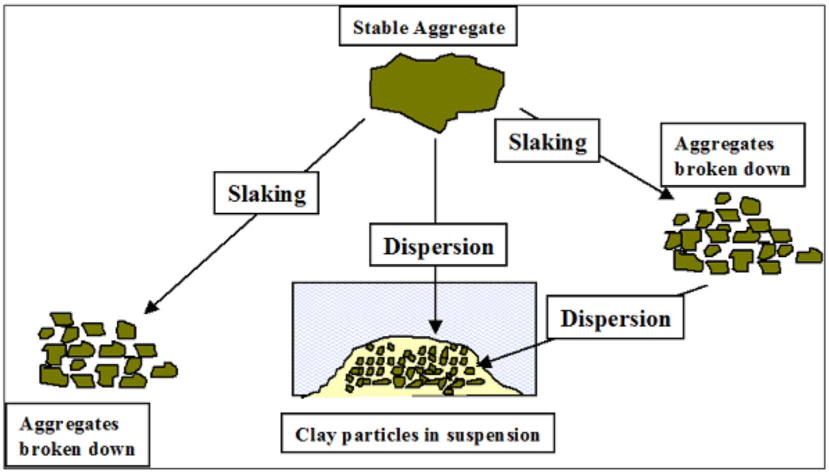
Dispersive soils are soils in which dispersion of particles occurs on wetting. Dispersion is the separation of soil into single particles. This is caused by soil texture, clay type, organic matter in the soil, the salinity of the soil (or sodicity) and the exchangeable cations. A soil which is dispersive has a very unstable structure when wet and can form a hard crust when dry (Department of Primary Industries 1999).

Key points of difference between slaking and dispersive soils are:

- slaking – rapidly breaks into smaller aggregates
- dispersive – the aggregate separates into individual particles rather than smaller aggregates.

This is depicted in Figure 2.3.

Figure 2.3: Slaking and dispersion

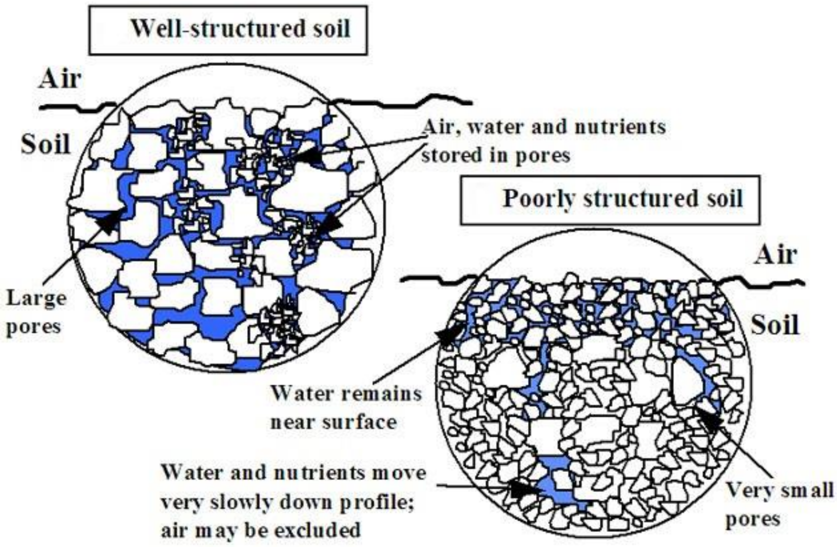


Source: Dairy Australia (2021).

Slaking and dispersion can occur together. Soils which slake may also be dispersive, but not all slaking soils are dispersive. Slaking and dispersion have a large impact on the behaviour and the management of soils (Department of Primary Industries 1999). Two major impacts are the aggregate stability of the soil, and the soil erosivity.

Aggregate stability refers to the stability of the structural units in the soil when it is immersed in water. A soil which has weak aggregate stability, caused by slaking or dispersion, is likely to collapse or be susceptible to tunnelling if used in earthworks (Hazelton & Murphy 2016). Well-structured and poorly structured soils are depicted in Figure 2.4.

Figure 2.4: Soil structure



Source: Quizlet (2021).

Dispersive and slaking soils are also highly susceptible to soil erosivity. Soil erosivity refers to the susceptibility of the soil particles to detachment and transport by water. The soils with the highest erodibility are those with weak bonds between the soil particles and an abundance of soil particles which are easily picked up by flowing water. If these properties are combined with properties such as low permeability, erosion levels can be very high (Hazelton & Murphy 2016).

2.2 Soil Mechanics of Dispersive and Slaking Soils

To investigate how to best manage these soils, it is necessary to understand the soil mechanics at their cause.

2.2.1 Slaking Soils

Slaking describes the process whereby a soil breaks down when exposed to water. Slaking generally occurs when the soil aggregates cannot withstand the internal physical stresses which can be caused by rapid water uptake. As a result of this water infiltration, swelling occurs in the clay particles which traps air in the soil pores. The trapped air is then forced out of the pores by pressure differential as capillary forces draw water into small pores between soil aggregates. This results in breakup of the aggregate into smaller aggregates due to the physical form of the air breaking out of the pores.

Where slaking occurs in exposed surfaces, the 'slaking' of the larger soil aggregates into smaller soil aggregates can result in the filling of the soils pores (or voids) with the smaller aggregates and particles. This reduces permeability of the material and can cause a crust or sealing of the surface to infiltration increasing runoff and erosion (TMR 2022).

The process of slaking is related to the process of self-mulching, something that commonly occurs in cracking clays. Self-mulching occurs when the soil produces a loose layer of granular aggregates. However, sometimes these aggregates can cause a thin fragile crust that caps the layer (Department of Primary Industries 1999).

Slaking is also common in extremely weathered rock formations and foundations. This is a large risk for the construction, maintenance and management of roads and transport infrastructure, as cutting and embankments can often be constructed from these materials. Figure 2.5 illustrates the phases of slaking.

Figure 2.5: Phases of soil slaking

a. Soil lump has collapsed around the edges but remains mainly intact

b. Soil lump has collapsed into angular pieces

c. Soil lump has collapsed into small (less than 2 mm diameter) rounded pieces, forming a cone

d. Soil lump has collapsed in single grains

Source: Department of Primary Industries (1999).

2.2.2 Dispersive Soils

Soils prone to break down due to slaking differ from soils which 'disperse' on wetting, as dispersion is based on the unstable structure of the soil, usually due to soil chemistry.

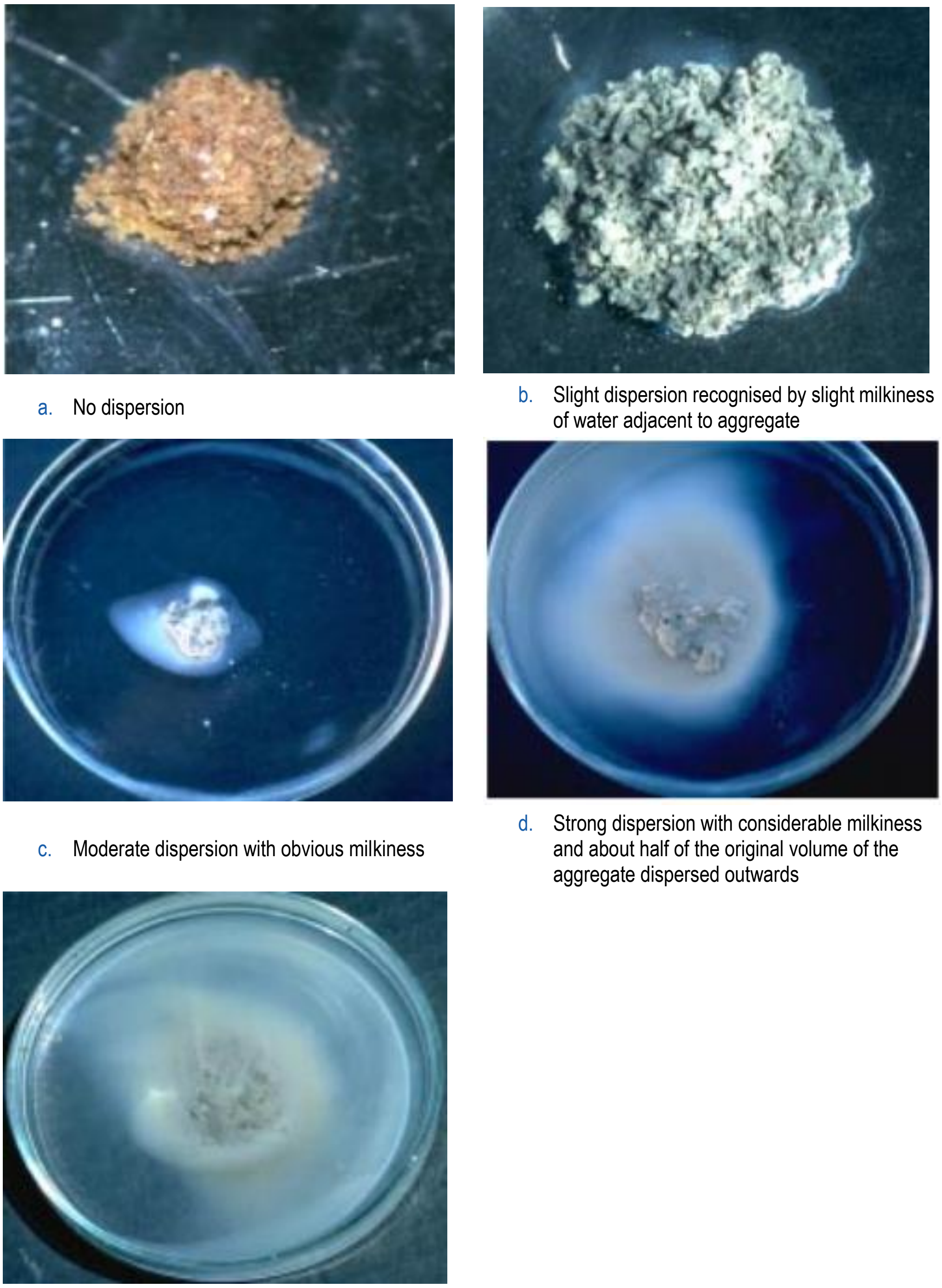
The dispersion of soils, as shown in Figure 2.6, arises from the presence of exchangeable sodium ions between clay platelets. This results in the swelling of the clay platelets and the collapse of clay aggregates. Dispersion is further explained by Agriculture Victoria (2020b) as:

> Clays particles are small in size (less than 0.002 mm) but have a very large surface area. The surface area of all clays is negatively charged. This is because of the complex arrangement of elements (e.g. aluminium, oxygen, silicon) that make up the clay structure. Positive ions (cations such as calcium, Ca^{2+}) present in the soil are electrostatically attracted to the negative clay surface and neutralise the charge in the clay. As all the negative charges on the clay are neutralised, a layer of positive charge surrounds the clay particle. This layer of positive charge is also known as a 'shell'.
>
> The width of the shell depends on whether the cations are single (sodium, Na^{+}), double (calcium, Ca^{2+}) or triple (aluminium, Al^{3+}) charged. That is, one Na^{+} will neutralise one negative charge on the clay, whereas one Al^{3+} will neutralise three negative charges on the clay.
>
> Cations floating around in the soil solution as salts, also affect the width of the shell. Cations 'attached' to the clay particle diffuse away from the surface of the clay until the concentration of cations is equal to the concentration of cations in the soil solution. Thus, the saltier the soil solution, the thinner the layer of positive charge surrounding the clay particle.
>
> Like charges repel one another, however, this can be overcome by close distance nuclear attraction, called Van der Waal's forces. If the shell is thick, the clay particles are going to have trouble coming close enough together for the Van der Waals' forces to act and for the particles to flocculate. They will tend to remain as separate (colloidal) entities – and the clay will be dispersed.

The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion.

Similar to slaking processes, dispersion can lead to rapid erosion and cause a surface crust on drying. The soils below the surface, known as subsoils, become blocked by dispersed soil particles, leading to an increased risk of swelling on wetting as there is no room for the water to infiltrate through the soil (Department of Primary Industries 1999). This can cause adverse impacts in the context of infrastructure. Figure 2.6 illustrates the process of dispersion on wetting.

Figure 2.6: The process of soil dispersion on wetting



a. No dispersion

b. Slight dispersion recognised by slight milkiness of water adjacent to aggregate

c. Moderate dispersion with obvious milkiness

d. Strong dispersion with considerable milkiness and about half of the original volume of the aggregate dispersed outwards

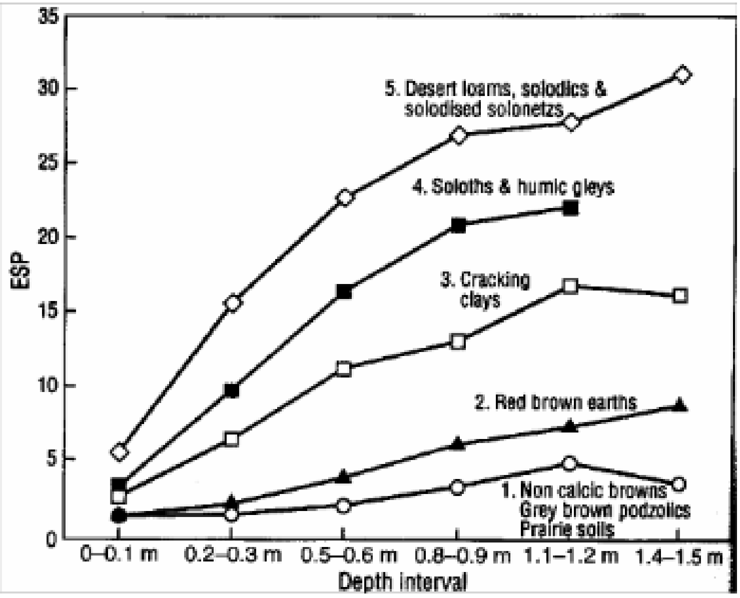
e. Complete dispersion leaving only sand grains in a cloud of clay

Source: Department of Primary Industries (1999).

A major type of dispersive soil is known as sodic soils. Approximately 25% of all soils across Queensland are classified as being strongly sodic and another 20% as variably sodic. These soils are primarily formed from the weathering of sedimentary parent materials of marine origin.

Dispersive soils can be found throughout the soil profile. The exchangeable sodium percentage (ESP) of sodic soils has been found to increase with depth, as older sediments are more likely to accumulate higher proportions of sodium (Raine & Loch 2003). This is depicted in Figure 2.7 and Figure 2.8.

Figure 2.7: Mean ESP values with increasing depth of Queensland



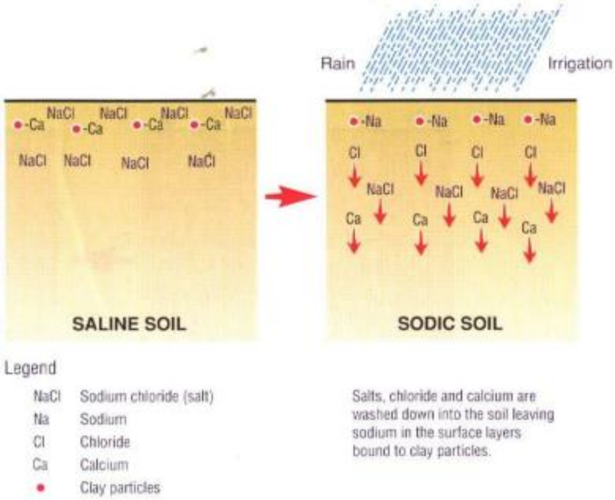
Source: Powell et al. (1995; cited in Raine & Loch 2003).

Figure 2.8: Image of dispersive sub soils exposed on a cut batter showing the stable topsoils overlaying the dispersive subsoils

Source: Lake Macquarie City Council Fact Sheet 8H – Dispersive Soils.

Lastly, the level of sodicity of topsoil can be impacted by increasing intensity and frequency of rainfall or irrigation infiltration (Raine & Loch 2003). High rainfall causes salts, principally chlorides, to be 'leached' out of the soil profile through water infiltration and movement through the soil. When the chlorides have been leached out of the soils, the sodium component of salts remains and is left in higher concentrations, thereby effectively increasing the ESP of the topsoil (Figure 2.9).

Figure 2.9: Saline soil being leached to form sodic topsoil



Source: Cooperative Research Centre for Soil and Land Management (1994).

2.3 Why Management of Dispersive Soils is Needed

A major concern with dispersive soils is erosion. This is caused when rainwater, freshwater, or low-level saline water come into contact with dispersive subsoils. Erosion, or soil erodibility, describes the susceptibility of soils to detachment and transport by flowing water.

The erodibility of soils is influenced by the soil texture and the strength of the bonds between the soil particles. Soils which have a low permeability will be affected by accelerated erosion due to higher run-off rates. Therefore, dispersive and slaking soils are much more prone to erosion than well-structured soils (Hazelton & Murphy 2016).

The increased rate of erosion in dispersive and slaking soils means that erosion which would typically occur over a period of several years can occur in a single rain event.

Figure 2.10 provides an example of erosion of dispersive materials and resultant deposition of sediment in culverts. In addition, Figure 2.11 provides example photos of dispersive soils in the field.

Figure 2.10: Example specification of erosion of dispersive materials and resultant deposition of sediment in culverts

Source: Provided by TMR.

Figure 2.11: Example photos of dispersive soils

Source: Provided by TMR.

2.3.1 Erosion and Sedimentation

Soils which have detached and been transported by flowing water, can end up depositing or suspending in waterways. This process is known as ‘erosion and sedimentation’. As dispersive and slaking soils erode rapidly and generally involve movement of fine clay particles, erosion and sedimentation is exacerbated. Weathering and erosion of assets that may normally take years can occur in the space of a couple of storms. Sedimentation within the waterway can lead to changes to waterway morphology or choking of the system, as well as smothering of riparian vegetation.

Sedimentation also has a major impact on drainage assets, resulting in more frequent maintenance. Erosion from cut and fill batters increases the risk of undermining of roads and structures, which impacts on the integrity of assets, resulting in very expensive maintenance regimes and reduced asset life.

In addition to sedimentation, the erosion of fine clay particles impacts on water quality and the aquatic ecosystem (TMR 2020a). Fine clay particles have relatively strongly electrostatic forces and do not tend to deposit out of solution readily. As such, the clay particles stay as suspended sediment for longer and can be transported large distances within a waterway.

This characteristic has manifested in large plumes of sediment being washed into the Great Barrier Reef Region. Once transported out to the reef, these fine sediments combine with other organic debris to form a gluey mass, known as a floc, which then deposit on coral. Once the floc has covered the coral it prevents the coral and the surrounding aquatic ecosystem from accessing natural light. Access to natural light is a key factor in the success of these ecosystems (Queensland Government 2017).

2.3.2 Tunnel Erosion

Tunnel erosion occurs due to the dispersion of clay subsoil under a cap of stable topsoil. Tunnel erosion differs from typical erosion processes in that the erosion occurs from soils underneath the surface. Tunnel erosion can occur from overland flow, or concentrated flow, finding a path into subsoils or can be initiated from top-down infiltration creating dispersion in soils beneath the surface.

Tunnel erosion is dependent on whether the soil matrix has sufficient permeability to enable the movement of the dispersed soil through cracks and pores in the soil structure. This movement of the dispersed soils leaves behind small cavities in the soil structure. Additional rainfall or water infiltration will cause more dispersion and results in expansion of the cavities. Once these cavities link up, a continuous tunnel can be formed.

As water flows through the tunnel system it further erodes and scours the walls of tunnel. This eventually results in slumping, and tunnel enlargement. This will eventually undermine the overall structure above the tunnel leading to a complete collapse. This can be a sporadic process that can occur across a long period of time (Hardie et al. 2009).

Tunnel erosion within the road embankment or within backfill of structures can cause safety issues as it is often difficult to detect until the tunnel manifests at the surface. Tunnels can therefore go undetected until ‘collapse’, causing sudden failure in embankments, pavements and structures. Figure 2.12 demonstrates examples of tunnel erosion within road infrastructure that has been detected once it has broken through the surface.

Figure 2.12: Tunnel erosion along the verge of rod pavements on the Cunningham Highway

Source: Provided by TMR.

2.3.3 Poor Bearing Capacity and Failure

Construction of roads on dispersive soils can be difficult due to the low bearing capacity of these materials when wet.

For culverts and drains constructed on dispersive soils, if water is concentrated in these roadside structures, it can lead to erosion and collapse of the roadside embankments.

An example of this in a table drain is shown in Figure 2.13. The rainfall, which was concentrated in this table drain, created erosion, resulted in slumping and caused undercutting of the road and the adjacent batter slopes (Hardie et al. 2009).

Figure 2.13: Example of table drain constructed in dispersive soils

Source: Hardie et al. (2009).

2.4 Triggers for Dispersive and Slaking Impacts

Soils with dispersive and slaking characteristics are very common across Queensland and in a lot of instances are not actively dispersing or causing impacts. The main activities related to construction of transport infrastructure which can trigger dispersion and slaking to initiate include:

- removal of topsoil
- cut and fill activities
- road and culvert construction.

2.4.1 Removal of Topsoil

Topsoil is a key factor is preventing erosion in dispersive subsoils. Topsoil provides both a physical and chemical barrier to water which could infiltrate into the dispersive subsoils, either through rainfall or irrigation. Removing this topsoil, even if it is only for short periods of time, will likely expose the dispersive subsoils to moisture. The wetting of dispersive soils will result in mechanical and chemical changes, causing the initiation of the tunnel erosion process.

2.4.2 Cut and Fill Activities

‘Cut-and-fill’ refers to earthworks where material is ‘cut’ from one location and ‘filled’ in another location to level the ground. A ‘cut’ is made when earth is excavated from above the desired ground height and a ‘fill’ is when earth is used to build up/raise the existing ground to a desired level (Hardie et al. 2009).

Cut and fill activities can create risks to roads from dispersive soils in 2 locations:

1. Cut batters – in the construction of cuttings, soils previously not impacted by erosion are exposed to rainfall or overland flows. If the constructed cut batter is comprised of dispersive materials, there is a high risk that these soils will experience rilling (< 30 cm deep) and if left to progress, rills can grow to form gullies (> 30 cm deep).
   Rill and gully erosion of batters has the potential to create failures in batters, as well as sedimentation in drainage lines. It can also impact on the stability of structures and undermine pavements.
   Rill erosion can be difficult to repair if not treated at the time of construction.
2. Embankment – where the dispersive material is used for the construction of road embankment, risks of rill, gully and tunnel erosion can occur. This is particularly detrimental to asset integrity as failures in the embankment can directly impact on the strength of the pavement. Figure 2.11 provides an example of fill embankment erosion.

Tunnel erosion can also develop in the footings of structures when these are constructed in dispersive soils. This generally occurs as a result of rainfall ponding on dispersive fill material. Figure 2.14 and Figure 2.15 shows an example of this process, where tunnel erosion has occurred on a flat area, without a slope generating the water movement (Hardie et al. 2009).

Figure 2.16 demonstrates the impact to structures and asset integrity where structures are undermined by dispersion of the embankments and cuttings.

Figure 2.14: Example of rill erosion

Source: Hardie et al. (2009).

Figure 2.15: Example of tunnel erosion in footings

Source: Hardie et al. (2009).

Figure 2.16: Undermining of fence footings by erosion of dispersive material

Source: Supplied TMR, Darling Downs District.

2.4.3 Construction of Roads and Culverts

Road drainage and structures are particularly susceptible to impact from unmanaged dispersive and slaking soils. Due to the concentration of water in these structures, exposure to water and infiltration is highly likely. Failure in and around road drainage and structures can be very expensive, create significant safety risks to road users and are difficult to prevent and repair. Figure 2.17 and Figure 2.18 depict drainage structures which have been damaged when dispersive soils have subsided due to erosion.

Figure 2.17: Damaged drainage structure from dispersive soils

Source: Quizlet (2022).

Figure 2.18: Collapsed pipe culvert on the Mt Lindsay Highway (Queensland) caused by tunnel erosion around the outside of the culvert

Source: Supplied by TMR.

3. Identification and Testing

Identification of dispersive and slaking soils is commonly undertaken through:

1. desktop assessment of existing geospatial information datasets (mapping)
2. field observations
3. material testing.

3.1 Desktop Assessment

There are several published soil datasets available for Queensland. The level of accuracy and scale differs across the various datasets.

TMR have access to a range of mapping systems which can be used to identify risk areas. It is important to note that these maps are typically only indicative of surface soil characteristics and therefore it is important to understand the underlying geology to assess the risk of disturbing slaking and dispersive soils through cut to fill operations or borrow (gravel) operations particularly in Western and Far North Queensland.

Undertaking sufficient desktop assessment during project planning can help reduce the risk of dispersive soils. In most cases it will not be possible to avoid dispersive soils entirely. Identification of potential dispersive soils through mapping informs projects of the presence of a risk that needs to be investigated and scoped for management as part of the project.

TMR has developed a state-wide soils dataset named ‘TMR soil group classification’ which is available on the Departmental IMaps portal. The TMR soil group classification dataset combines published soil and geology datasets into a single, ‘ground-truthed’ dataset for TMR.

The mapping labels soils as low, medium and high risk. Soils with dispersive and slaking characteristics are incorporated within the high-risk category, thereby informing Project Managers that further investigation should be undertaken to scope the associated risk.

Figure 3.1 provides a screenshot of the TMR soil group classification map. In particular, it depicts the high-risk soils around the Toowoomba region in regional Queensland. In addition, Figure 3.2 provides a screenshot of TMR’s ECHO soil group mapping system, which is provided as a mobile application.

Figure 3.1: Screenshot of TMR soil group classification showing high risk soils around Toowoomba

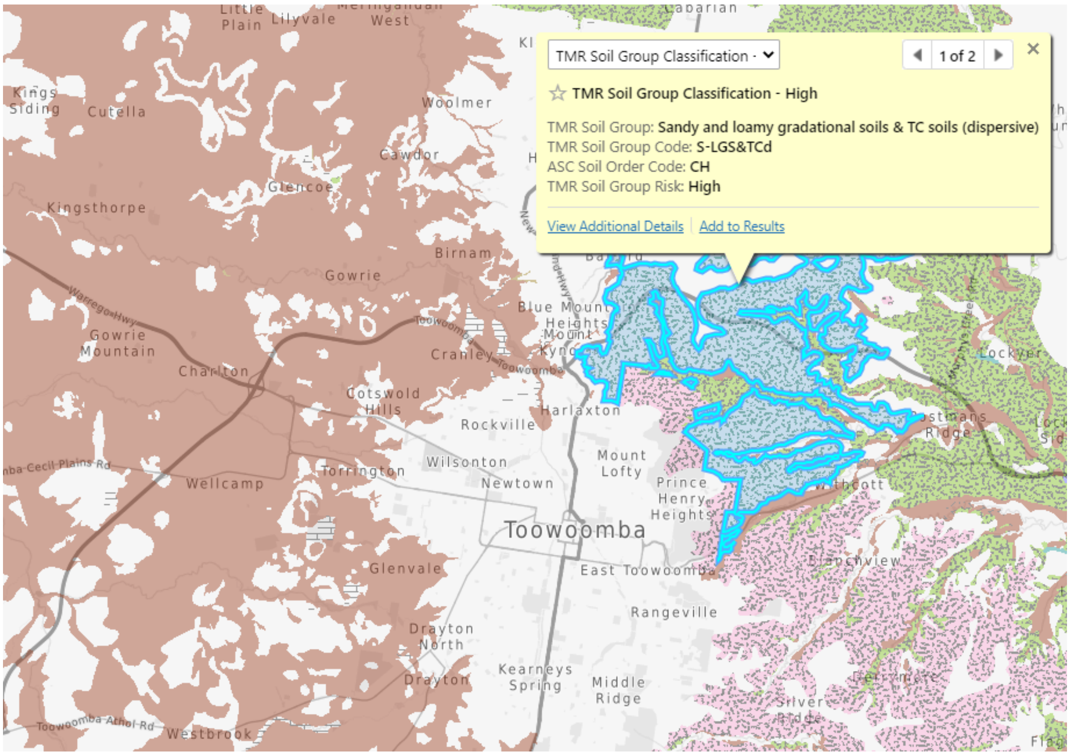
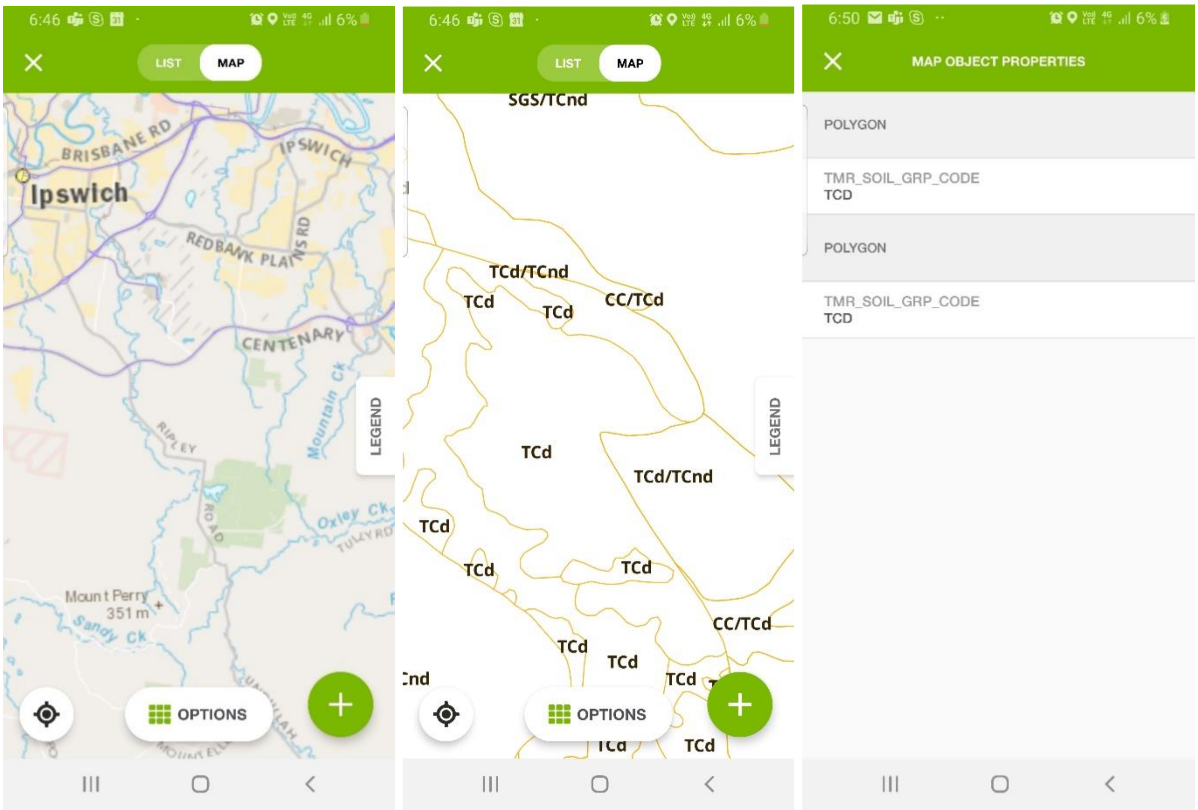


Figure 3.2: Screenshots of TMR ECHO soil group mapping system



3.2 Field Observation Techniques

Dispersive soils can be identified through a variety of field observation techniques. Key indicators can be observed around existing infrastructure, adjacent properties or around other land use that cause disturbance to the topsoil and exposure of subsoils.

Existing rill, gully or tunnel erosion within soil groups onsite is a strong indication of dispersive soils, where that erosion has occurred over a short period of time.

Hardie et al. (2009) suggested that dispersive soils can be identified through distinctive 'dribble' patterns that will form in the soil following exposure to rain or run-off. The presence of this pattern is generally an indicator of a moderately to highly dispersive soil. This pattern can be observed on the walls of the majority of tunnel erosion cavities (Section 2.3.2). This pattern can be seen in Figure 3.3.

Figure 3.3: Example of dribble pattern on an exposed subsoil

Source: Hardie et al. (2009).

Another field identifier is where topsoil has been removed by erosion or excavation, and ‘pitting’ or ‘pocketing’ can be seen in the subsoils where these soils have been exposed to rainfall (Hardie et al. 2009). This is shown in Figure 3.4.

Figure 3.4: Example of pitting and pocketing of subsoil

Source: Hardie et al. (2009).

Lastly, early signs of tunnel erosion (Section 2.3.2) can be identified through the presence of ‘sediment fans’ or ‘spew holes’. This phenomenon is the result of the ejection of fine sediments or dispersed clays from the downslope end of the tunnel. Once a ‘spew hole’ has developed, it means that considerable sub-surface erosion has occurred (Hardie et al. 2009). This is shown in Figure 3.5.

Figure 3.5: Example of spew holes or sediment fans

Source: Hardie et al. (2009).

3.3 Testing

The dispersion potential of subsoil can be assessed by the determination of several soil properties/parameters including exchangeable sodium percentage (ESP), calcium (Ca): magnesium (Mg) ratios, salinity, pH, particle size, Emerson class numbers and clay mineralogy. There are, therefore, several methods for determining the dispersion and slaking characteristics of soils.

While there is general agreement that these chemical and physical tests of materials can identify dispersive and slaking characteristics and causes within the soils there is considerable dispute amongst agronomists, soil scientists and erosion and sediment control professionals as to the exact suite of tests required and interpretation of results (Davies & Lacey 2009; Zund 2017).

Adding to the confusion, there have been several variations of the commonly applied ‘Emerson class’ test for dispersion. Various methodologies have been developed based on the Emerson class test and apply different class number schemes or completely different scoring methods.

Generally testing for dispersive and slaking characteristics tends to fall into 2 categories:

1. physical test
2. chemical test.

3.3.1 Physical Testing

The most common methods for testing and characterising dispersive and slaking soils are presented in the following section. A summary and comparison of these tests, including the advantages and disadvantages, is provided in Table 3.1.

Table 3.1: Summary of testing and identification methods for dispersive and slaking soils

Test	Summary	Advantages	Disadvantages
Emerson test – (Emerson 1967)	• Original test method involving submersion of soil aggregates in petri dish of water • Observation of clouding and slaking in petri dish • 8 classes	• Simple test can be done by material laboratory	• Observations at 2 hrs and 20 hrs makes field use difficult and hard to schedule for laboratories • Qualitative assessment of results
Emerson Method – AS 1289.3.8.1:2017	• Applies general process of original Emerson test. Utilises the same 8 classes as original Emerson test • The AS Test method is applied in MRTS04 General Earthworks • Requires the 5 g soil to be screened on 4.75 mm and 2.36 mm sieves. Only aggregates that are not retained on the 2.36 mm sieve are to be used in the test	• Australian Standard, therefore, consistently known and understood • Provides a class for the soil so differences can be easily discerned • Does involve remoulding of sample to assess dispersion	• Involves sieving the bulk sample. This 'disturbs' the soil aggregates prior to testing. Particles may be too small to effectively observe dispersion • The test method involves use of very small aggregates • Aggregates may not disperse when they should if they have not been sufficiently dried • Qualitative assessment of results
TMR Test Method Q161 Field Dispersion Indicator Test of Soil: Slaking	• The test method applied through MRTS16 Landscaping and Revegetation works for assigning a slaking class to characterise a slaking soil in Queensland • This test method is similar to the Emerson Aggregate Test, outlined in AS 1289.3.8.1:2017	• Developed by TMR's Landscape Architects, aligns with TMR landscaping practices • Similar to Australian Standard, therefore, consistent • Involves larger aggregate samples of 5–10 mm • Does not include sieving of bulk sample • Observations at 5 mins and 2 hours	• Qualitative assessment of results • Does not include remoulding of the soil • Slaking classes are inconsistent with AS 1289.3.8.1:2017
TMR Test Method Q162 Field Dispersion Indicator Test of Soil: Clouding	• Current test method applied in MRTS16 for assigning a clouding class for characterising dispersive soils in Queensland • This test method is similar to the Emerson Aggregate Test, outlined in AS 1289.3.8.1:2017	• Developed by TMR, and therefore, aligns with other TMR practices • Similar to Australian Standard • Involves larger aggregate samples of 5–10 mm • Does not include sieving of bulk sample • Observations at 5 mins and 2 hrs	• Qualitative assessment of results • Does not include remoulding of the soil • Clouding classes are inconsistent with AS 1289.3.8.1:2017 • Dispersion and slaking are separate tests
NSW Department of Primary Industries (1999) 'Slaking Score' and 'Dispersion Index' (SOILpak method)	• Similar to TMR Q161 and Q162, however, it is a slightly more detailed method	• More detailed than TMR test methods	• Cannot be completed in field as it requires drying time for the soils

Test	Summary	Advantages	Disadvantages
NSW Department of Sustainable Natural Resources (n.d.) – Soil Survey Standard Test Method: Emerson Aggregate Test		• Observations at 10 mins and 2 hours • Combines slaking and dispersion into a single method	• Index is a unique scoring system unrelated to Emerson Class • Small samples 3–5 mm aggregates
ASWAT (Aggregate stability in water) Field et al. (1997)	• Based on Emersons • Uses similar subdivisions but shorter time period • Uses scoring system	• 10 mins and 2 hours • Similar to Loveday-Pyle method • Includes remoulding • Does not include sieving	• Small aggregates 3–5 mm • Different scoring method referred to as the ASWAT score
Loveday-Pyle (Loveday & Pyle 1973)		• 2 hrs and 20 hours • Does not include sieving • Semi-quantitative	• Sample 3–5 mm • Utilises 'dispersion index'
Pinhole Dispersion test AS 1289.3.8.3:2014	• Water is directed through a small hole drilled through the compacted specimen Observation of effluent cloudiness and final size of the pinhole qualitatively classifies soil discursiveness	• Can be used to test ameliorated soil • Demonstrates behaviour of soil under flow of water conditions	• Requires different equipment although not expensive • Qualitative assessment

As demonstrated by the variety and derivations in the table above, there is considerable inconsistency of method and scoring of dispersive characteristics within physical testing of soils.

Discussion of the soil testing methods with Queensland Government Soil Scientists from Department of Natural Resources and Water and the Department of Environment and Science identifies some key considerations when nominating the physical testing of dispersion and slaking:

1. Sieving of samples prior to testing as prescribed in the AS 1289.3.8.1 method disturbs the soil structure within the sample. This may artificially impact the results from the test.
2. The timing of observations has been shown to be relatively minor in influencing the outcomes of the test. Therefore, for ease of implementation a test method that includes observations at 10 minutes and 2 hours would be the most practicable and still provide reliable results.
3. Sample size does affect the results of the test as the test is reliant on human observations. The smaller the sample size the more difficult to detect dispersion (clouding) or slaking. It is therefore recommended that test samples be 5–10 mm diameter aggregates of soil.
4. Where TMR is attempting to understand the soil behaviour in the context of earth embankments, it would be advantageous to test the soil in a similar condition. That is, create an 'embankment' like sample by wetting a larger sample to near optimum moisture content and compacting to near 100% compaction. This basically recreates field conditions. Then take sub-samples (5–10 mm) of this compacted sample and apply the petri dish test.
5. The current variety of classifications and scoring approaches applied across the different test methods is confusing for non-soil scientists. It is essential to ensure clarity of classification approach with the test method to remove uncertainty.

Physical tests provide an indication of the behaviour of the soil in the field situation. Physical tests are not able to provide conclusive information on the chemical and physical parameters causing the behaviour of the soil.

Consequently, determination of amelioration treatments needs to be determined based on either complementary chemical test results or application of experience and background knowledge of soil science.

3.3.2 Chemical Testing

Assessing the Emerson class or slaking and clouding class in conjunction with chemical testing, or soil characterisation parameters, allows for a more accurate determination of erodibility risks. It can also aid in specifying appropriate amelioration agents and rates of application.

Important characterisation parameters include exchangeable sodium percentage (ESP), exchangeable calcium to exchangeable magnesium (Ca:Mg), electrical conductivity (EC), pH, soil texture, particle size analysis (PSA), effective cation exchange capacity (ECEC), and ECEC to clay % (CCR).

No single test has been found to be effective in identifying either dispersive or slaking soils. Rather a combination of tests, and consideration of the results of each, can aid in identification of the characteristics of the soils. These tests are outlined below.

Exchangeable sodium percentage (ESP) and cation exchange capacity (CEC)

The ESP is a measure the amount of exchangeable sodium (Na^+) in the soil and is an indicator of soil sodicity. The ESP is generally expressed as a percentage of the exchangeable Na^+ in proportion to the soil's cation exchange capacity (CEC) expressed as centimole per kilogram ($cmol_c/kg$) on an oven-dry basis (Rayment & Lyons 2011), see Equation 1.

$$ESP = \frac{(100 * exchangable\ Na^+)}{CEC} \qquad 1$$

where

ESP	=	exchangeable sodium percentage
CEC	=	cation exchange capacity

The higher the ESP score, the higher the sodium ratio to available cation exchange sites. This represents an imbalance in the soil, where there are a large number positively charged sodium atoms that do not have corresponding negatively charged cation exchange sites and therefore they are 'loose' within the soil matrix.

This creates electrostatic forcing pushing against each other contributing to dispersion.

Typically, the following ranges for ESP provide a guide to the chemical dispersion potential of a soil:

- ESP < 6% non-sodic
- ESP 6–15% sodic
- ESP > 15% strong sodic (Rayment & Lyons 2011).

The CEC is best calculated using the ECEC as it sums all exchangeable cations in alkaline and acid soil conditions. The cations measured are Ca, Mg, Na, phosphorus (K) in alkaline soils and H, Al are added in acid soils (pH < 5.5). The ratings of ECEC and the parameters requirements are detailed in Table 3.2 (TMR 2020c). The table demonstrates that the acceptable range of ECEC for a soil is dependent on the type of soil and thus, a 'one size fits all' range is not feasible.

The CEC of a soil can also provide an indication of the type of clay present in the soil and the amount of organic matter (Table 3.3).

Table 3.2: ECEC – meq/100 g – ratings and parameter requirements

ECEC ratings		Acceptable parameter requirements		
< 6	Very low	Site topsoil and subsoil	> 5	Loamy sand – clayey sand
6–12	Low		> 10	Sandy loam – silty clay loam
12–25	Moderate		> 10	Light clay – heavy clay
25–40	High	Imported topsoil	> 10	Imported standard topsoil
> 40	Very high		> 15 – < 25	Imported premium topsoil

Source: TMR (2020c).

Table 3.3: CEC of typical soil components

Soil component	CEC (cmol(+)/kg)
Coarse sand	Negligible
Fine sand	Negligible
Kaolinite clay	3–20

Soil component	CEC (cmol(+)/kg)
Illite clays	10–40
Smectite clays (includes montmorillonite)	80–150
Organic matter	150–500

Source: Hazelton and Murphy (2016).

An alternative method for the calculation of the ESP can be undertaken using the sodium adsorption ratio (SAR) for soils.

The SAR is a common measure of the 'activity' of the sodium ions within a soil, relative to the calcium and magnesium ions. This is an important consideration because soils with a high activity of sodium relative to calcium and magnesium, will have a high ESP, and therefore, be defined as sodic. The SAR is calculated using Equation 2.

$$\mathrm{SAR}=\frac{\mathrm{Na}}{\sqrt{\frac{(\mathrm{Ca}+\mathrm{Mg})}{2}}} \qquad 2$$

where

Na = concentration of sodium cations (mEq/L)
Ca = concentration of calcium cations (mEq/L)
Mg = concentration of magnesium cations (mEq/L)

Where Na, Ca and Mg are the concentrations of the cations in mEq/L in the soil and water solution and are determined using *Method 15B3* when pH ≤ 7.3 or *Method 15C1* when pH > 7.3 (MRTS16:2017, Rayment & Lyons 2011).

The ESP can be calculated from the SAR using Equation 3.

$$\mathrm{ESP}=1.95*\mathrm{SAR}+1.8 \qquad 3$$

where

ESP = exchangeable sodium percentage
SAR = sodium adsorption ratio

The ESP or the SAR can be used, in conjunction with the total cation concentration (TCC) which is the total cation available in the soil or the electrical conductivity (EC) of the soil and water solution which is related to the total cations and anions of a soil, to predict the soil dispersion. The TCC is calculated as follows in Equation 4.

$$TCC = 9.62 * EC(1:5) + 0.14 \qquad 4$$

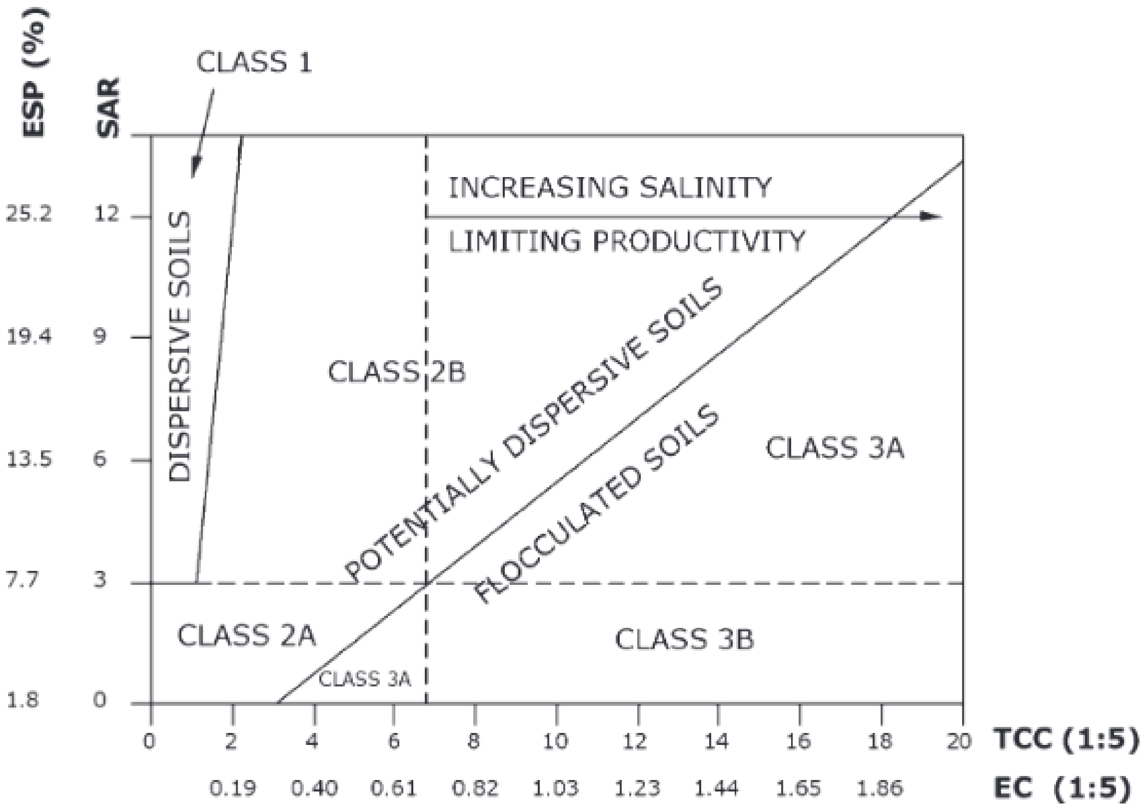
where

TCC = total cation concentration
EC(1:5) = electrical conductivity in a 1:5 soil: water solution

Figure 3.6 provides a summary of the prediction of soil dispersion, based on the exchangeable sodium percentage and electrical conductivity of the soil (Hazelton & Murphy 2016).

Note the influence of EC in Figure 3.6 below. As EC (salinity) increase the dispersion is reduced due to the increased electrostatic bonds within the soil. If EC is reduced the influence of the sodium cations increases and soils are more susceptible to dispersion.

Figure 3.6: Predicting soil dispersion



Source: Hazelton and Murphy (2016).

Ratio of exchangeable calcium (Ca) to exchangeable magnesium (Mg)

Another method used to support the assessment of soil dispersion is the ratio of exchangeable calcium (Ca) to exchangeable magnesium (Mg) (Equation 5). This is due to the hydrated radius of the Mg ion being approximately 50% greater than that of Ca ion. Soil surfaces where exchangeable Mg is present will tend to absorb less water than where exchangeable Ca is present. This differential weakens the forces that keep soil particles together and in turn increases the risk of dispersion.

This means the higher the Ca in the ratio the lower the dispersion and the higher the Mg in the ratio the higher the dispersion (Ogbonna et al. 2013).

$$\frac{Ca^{2+}}{Mg^{2+}} = \frac{exchangable\ Ca^{2+}}{exchangable\ Mg^{2+}} \qquad 5$$

where

Ca^{2+} = exchangeable Mg^{2+} ($cmol_c$/kg)

Mg^{2+} = exchangeable Ca^{2+} ($cmol_c$/kg)

Where both exchangeable Ca^{2+} and Mg^{2+} are from the same method and expressed as $cmol_c$/kg soil on the same soil moisture basis (Rayment & Lyons 2011).

Electrical conductivity

Electrical conductivity (EC) gives an indication of the concentration of electrically charged water soluble salts in the soil which consist predominantly of the cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} (Rayment & Lyons 2011).

When the ratio of sodium to other ions is high, clay particles are less tightly bound to each other. This is due to the positive electrostatic charge of the ions repelling and pushing particles apart. This causes the soil aggregates to easily disperse when the soil becomes wet (Davies & Lacey 2009).

Understanding the salinity of the soil by the measure of electrical conductivity provides important information in relation to dispersive nature of soils. High salinity can 'mask' potential dispersion. Salts can be 'leached' out of the soil profile over time by infiltration and water moving through the soil profile. As salts are leached, the sodium is left behind creating high sodium levels and potentially creating dispersive properties.

pH

The pH value of a soil is a numerical expression of the intensity of acidity (or alkalinity) (Rayment & Lyons 2011) and can provide insight into the application rate of ameliorants and their expected effectiveness against dispersion and sodicity.

While the pH does not provide any indication of dispersive or slaking characteristics, the pH is important in determining the appropriate ameliorant for a dispersive/slaking soil. Without identifying pH, adverse impacts may occur by applying an ameliorant that negatively impacts pH.

Particle size analysis & clay fraction ratio

Particle size analysis (PSA) of a soil describes the amounts and sizes of the particles which make up the soil matrix. These particles are often termed gravel, sand, silts and clays depending on their size (Table 3.4).

Table 3.4: Particle size of different soil components

Soil component type	Particle size range (mm)
Clay	< 0.002
Silt	0.002–0.02
Sand (fine to course)	0.02–2.0
Fine gravel	2–6
Coarse gravel	> 6–60

Source: Hazelton and Murphy (2016); TMR (2020c).

The PSA parameter can be used to calculate the ECEC to clay fraction ratio (CCR) to determine the clay mineralogy (shrink-swell tendency) of a soil.

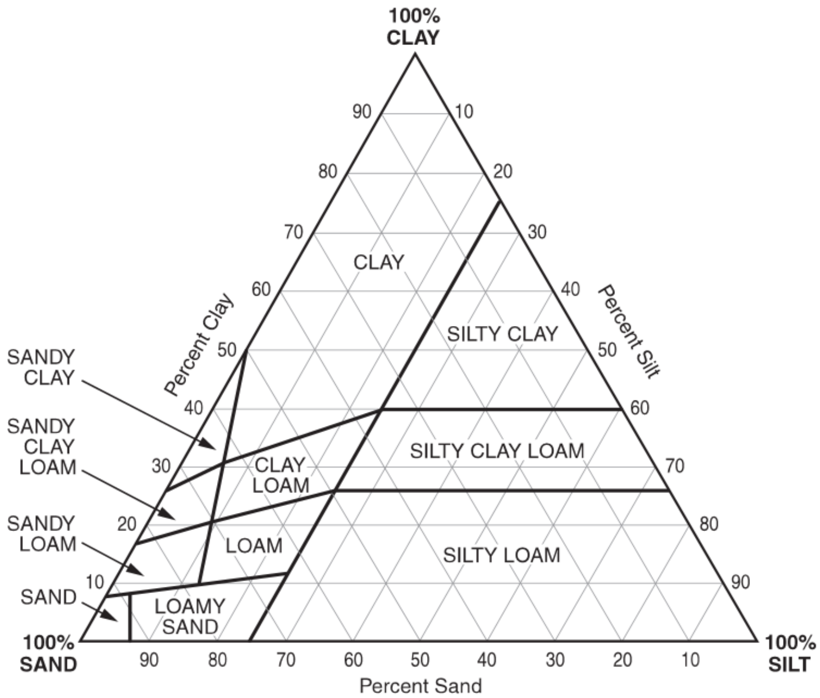
In addition, the PSA can generally confirm the soil texture class test result, particularly when site observations and field texturing indicate a different texture class (TMR 2020c).

Soil texture

Soil texture or field texture provides an assessment of the relative proportions of particles in a soil and as well as the dominant particle sizes (Hazelton & Murphy 2016). It is determined using the results of the PSA in conjunction with a texture diagram (Figure 3.7). It should be noted that the percentage of sand on the bottom axis of the diagram refers to the total percentage of fine and coarse sand particles in the sample.

Soil texture affects the capacity of the soil to store water and nutrients and therefore knowing soil texture is vital to assess the severity of salinity within a soil (Davies & Lacey 2010). For example, a given amount of salt in sandy soils will be more concentrated than an equivalent amount in clay soils because the sandy soils hold less water to dilute the salts than clay soils (NSW Agriculture 2002).

Figure 3.7: Texture diagram



Source: CSRIO (2019).

3.3.3 Discussion of Testing Methodology

As identified above, there are a variety of both physical and chemical tests that are often applied to identify dispersive and slaking soils. Within both, there is also a variety of methods that are currently being applied across agriculture and civil engineering.

In summary, the physical test methods are qualitative, some relying primarily on the judgement of the observer. The variety and inconsistency across very similar test methods has introduced uncertainty and unreliability. However, the benefits of the physical test methods are that they:

- can be done by construction material laboratories with very basic equipment thus making application easier within civil engineering context
- can be undertaken without the need for specialised soil scientist interpretation
- can demonstrate the behaviour of the soils in the field but not the soil conditions causing the behaviour
- require complementary testing in order to determine appropriate amelioration.

Chemical testing approaches are quantitative reducing the inaccuracies introduced by observer judgement. However, while chemical testing results are quantitative, the results are complex. The complexity of results, interrelationship between parameters and different thresholds dependent on soil types essentially means that use of chemical testing for dispersive and slaking properties requires the engagement of a suitably qualified person (generally a soil scientist) to interpret results.

The validity of using the chemical test ESP has also been questioned in recent years based on research from the University of Southern Queensland and Grains Research and Development Corporation (GRDC). This is due to ESP focusing on sodic soils; however, in reality not all sodic soils are dispersive (GRDC 2021).

The current material testing laboratories that undertake construction material testing are not typically accredited or equipped to undertake the chemical testing methods for dispersive soils. Samples would need to be sent to separate, accredited laboratories to undertake these tests. While this is possible, it would make integration of the chemical testing as 'business as usual' difficult within current construction material testing. Specifically, if sampling and testing is to integrate into the existing MRTS04 General Earthworks Appendix A1 Table of sampling frequency, this would require a constant stream of samples to be couriered to the chemical laboratory during the earthworks stage of a project. Each batch of test results would then need to be interpreted by a soil scientist before the contractor can proceed with incorporation into the embankment. This could be a difficult and costly for smaller scale projects in regional areas.

Alternative approaches could make chemical testing more feasible such as:

- reduced frequency of testing such that dispersive and slaking properties were not tested on a strict lot basis could reduce this requirement on projects
- applying full chemical testing to high-risk projects only could make this more feasible.

The application of the full suite of chemical tests requiring soil scientist interpretation would be challenging all projects as business as usual.

4. Management and Treatment Options

There are several ways of treating dispersive and slaking soils, and managing the outcomes that can occur, such as erosion. The standard management hierarchy applies avoid, minimise and mitigate.

4.1 Avoid

Avoidance is difficult as dispersive and slaking soil properties are common in a number of soil types across Queensland. The existing Queensland state-controlled road network already intersects these soils in a number of locations and TMR is currently managing the related issues.

New road alignments may be able to avoid issues related to dispersive and slaking soils through:

- alignment selection
- building on top of the existing ground level rather than cutting into the ground surface and exposing the sub-soils. The ability to avoid cutting and excavation is dependent on topography, road geometry requirements and economic feasibility. Building up would mean that the road embankment is above the natural ground level and drainage is via sheet-flow off the road verge and does not incorporate table drains cut into the natural surface.

The ability to minimise impacts is reliant on the presence of dispersive and slaking soils being identified in planning and being a consideration for alignment and project options. This requires early detection through use of desktop assessment of spatial GIS soil datasets (mapping) potentially supported by complementary field testing.

The simplest way of avoiding these outcomes is to identify and then avoid dispersive soils where possible (Hardie et al. 2009). However, this is often unable to be achieved due to a variety of other considerations for locating road alignments. Therefore, management of the soils is necessary as part of the planning, design, construction and maintenance of roads and other transport infrastructure.

4.2 Minimise

While total avoidance of dispersive and slaking soils is difficult and generally not feasible, there are a number of design considerations that can be applied to minimise the exposure of dispersive and slaking soils and thereby minimise the risk. The ability to minimise impacts is reliant on the presence of dispersive and slaking soils being identified in preconstruction and being a consideration for design. Design techniques in dispersive and slaking soils generally apply the principles of:

- Reduce exposure of dispersive and slaking sub-soils in the final design surface, which may be achieved by raising the vertical alignment to reduce cut requirement.
- Utilise ‘capping’ to prevent water infiltration into dispersive and slaking soils. Capping may be in the form of topsoil and revegetation, a layer of non-dispersive or slaking material or hard armouring.
- Cut batters may be steeper than normal to prevent water infiltration on the surface of the batter.
- Fill batters may be flattened to allow a surface treatment of topsoil and revegetation to be effectively installed.
- Drainage design
  - Reduce drainage lines cut into dispersive or slaking soils or, if they are required, design protection of those soils to minimise water ingress.
  - Select appropriate drainage types based on the subsoil and runoff characteristics including armouring drainage channels in areas of dispersive or slaking soil.
  - Consider the use of suitable hard treatments within drainage channels where flow velocities are high.
  - Consider appropriately designed basins.
  - Ensure drains are accessible for cleanout and maintenance activities and design drainage sides to allow for vegetation establishment.

4.3 Mitigate

The main method of management is through mitigation to reduce the severity of the dispersive and slaking properties. Mitigation can be through:

- addition of an ameliorant to the soils
- moisture and compaction to minimise water infiltration to the soils.

4.3.1 Ameliorating

Soil amelioration of dispersive soils describes the improvement of soil properties through the use of additives or amendments to the subsoils, in conjunction with or alternative to deep tilling (GRDC 2020). In order to protect newly ameliorated soils, it is important to maintain adequate topsoil cover and drain any surface water which may cause waterlogging of the soils (Davies & Lacey 2010).

The practice of soil amelioration is long established in agricultural applications. Soil amelioration within a civil engineering context tends to be limited to revegetation applications and not integrated within earthworks procedures.

Evidence in Western Australian studies is showing that the benefits of soil amelioration can be long lasting, especially when used in conjunction with deep soil mixing approaches. These approaches have shown benefits for 5 or more years. However, research is still ongoing for the long-term benefits of these practices, including practices such as deep ripping (GRDC 2017).

Chemical additives

In this context, ameliorating soils describes the practice of applying a chemical material such as agricultural lime or gypsum to the soil surface (Davies & Lacey 2010). The initiation of the process of tunnel erosion is predominately a chemical process; therefore, it is logical to use a chemical process to prevent or reverse these impacts (Hardie et al. 2009).

The calcium ions present in both lime and gypsum interact with, and in principle displace, some of the sodium ions in the soil surface, allowing for these sodium ions to leach out. When lime is added to clay soil, the tiny clay particles group themselves around the lime particles and together form larger particles. The process is called flocculation.

Flocculation creates more air spaces, so the soil drains better. From an agricultural perspective, the soil becomes easier to cultivate and for roots to grow in. If organic matter is present, it binds the larger particles into aggregates and produces a good soil structure and improves soil stability.

For acidic soils, agricultural lime is recommended to assist with both dispersion and correcting the pH of the soil. However, in alkaline soils the effectiveness is reduced due to its low solubility and the formation of calcium carbonate. Therefore, gypsum (a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO\ 4{\cdot}2H_2O$) is recommended. Further, if a soil has a high magnesium content, dolomite can be used as ameliorate to correct this (TMR 2020b).

TMR has utilised these ameliorants for treatment of dispersive and slaking soils with good effect in landscaping applications and limited earthwork applications.

Other chemical ameliorant options include aluminium sulphate, and long chain polyacrylamides. However, studies have concluded these types of ameliorants are not suitable due to the limited data available on application rates, acidity of these elements, and a lack of understanding of how these elements will interact with varying chemical and physical properties across soil types (Hardie et al. 2009).

TMR technical specification *MRTS16 Landscaping and Revegetation* outlines the approved list of soil ameliorant agents which includes agricultural lime, agricultural dolomite and agricultural gypsum.

Organic matter

In agricultural applications another additive which has been researched is the use of organic matter, where stubble retention (retaining the basal part of plants within the soil after harvest or removal), green and brown manuring or other methods of adding organic matter can improve and consolidate the soil structure. The organic matter binds to the soil to assist with the resistance of physical breakdown of the soil aggregates from one another. However, organic matter is most effective when applied in conjunction with gypsum or lime (Davies & Lacey 2010). Amelioration with organic matter in the context of revegetation or agriculture can provide co-benefits with the increase of organic matter availability for plant growth. However, the application of organic matter to general earthworks is not generally recommended and may not be the most economical mitigation method.

4.3.2 Deep Soil Mixing and Inversion

Another common mitigation method in agricultural applications is deep soil mixing and inversion. This is a practice used to mix nutrients, organic matter and soil ameliorants into the subsoil.

There are 2 types of strategic deep ploughing for mixing, these are:

1. deep soil mixing, typically with rotary spaders or large offset disc ploughs
2. soil inversion using mouldboard, square or modified one-way disc ploughs.

Working depths can be anywhere from 30 to 70 cm based on the soil type, the implement used and the practice in place. In agricultural contexts, research has shown that the use of this technique can provide soil improvements for up to 10 years (GRDC 2017).

While deep soil mixing and inversion assists in breaking up the impervious ‘crust’ commonly created in dispersive and slaking soils, the effects of this treatment are typically short term. Deep soil mixing and inversion needs to be accompanied with a soil additive such as ameliorant to effect long-term change of the soil structure.

Other treatments

In addition to amelioration, there are other alternative techniques which can be used to manage dispersive and slaking soils. These are:

- compaction and moisture
- ensuring topsoil cover
- erosion prevention treatments.

4.3.3 Compaction and Moisture

Another commonly used method is compaction. A high degree of compaction will reduce the permeability of the soil, restricting the movement of water, and therefore the severity of dispersion. However, dispersive soils can be difficult to compact as these types of soils lose strength rapidly at or above optimum moisture content. Therefore, these soils will require a greater compaction effort than other soils (Hardie et al. 2009).

Research has shown that dispersive clays must be compacted at a moisture content of 1.5–2% higher than the optimum moisture content in order to achieve a sufficient density (Bell & Bryun 1997 cited in Hardie et al. 2009). It is recommended that a sheepsfoot roller be used for this process, as it has an appropriate weight for the requirements to compact dispersive soils (Sorensen 1995 cited in Hardie et al. 2009).

This method may provide short-term benefits, although it is unlikely to provide long-term stability on the exposed surface of the material. As natural weathering occurs, water is likely to eventually enter the soils triggering the inherent dispersion behaviour.

4.3.4 Topsoil or Capping Cover

As outlined in Section 2.4.1, topsoil is pivotal in minimising erosion, as topsoil minimises the interaction between water and dispersive soils by providing both a physical and chemical barrier. Topsoil cover also reduces soil desiccation and the development of surface cracks. The burial of exposed dispersive soils through the use of topsoil or another capping material minimises erosion and the likelihood of tunnel erosion by (Hardie et al. 2009):

- providing a source of salt to increase the electrolyte concentration in the water

- promoting even infiltration
- providing a protective cover for rain drop impact.

Topsoil cover is also important as a way of protecting newly ameliorated soils, and it is important to maintain adequate topsoil cover to protect against rain and any surface water which may cause waterlogging of the soils (Davies & Lacey 2010).

Topsoil or capping of dispersive materials is generally applied in combination with amelioration. Each treatment will likely have limited success if used in isolation however as a combination can improve long-term stability outcomes.

4.3.5 Erosion Prevention Treatments

As discussed in Section 2.3, dispersive and slaking soils are much more prone to erosion (Hazelton & Murphy 2016). Techniques for the prevention of erosion will depend on the applications but typically fall into the following categories (Witheridge 2012, TMR 2020c, IECA 2008):

- Minimise disturbance
  - effective pre-works planning
  - rapid and effective rehabilitation
- Implementation of controls
  - effective water/drainage management
  - effective soil management (including treatment of soils where applicable)
- Vegetation or other forms of impact protection (groundcover)
  - planting suitable vegetation to help soil stability and prevent exposure of high-risk soils to direct rainfall impact and flows. Plants are chosen based on the soil chemical properties such as pH to ensure ongoing effectiveness
  - other forms of protection or cover which can minimise the effect of direct raindrop impact include mulching, hydro-mulching, compost blankets, and proprietary soil binders and dust palliatives
- Ongoing inspections and maintenance.

5. Summary

The aim of this project was to investigate current industry best practice management measures for dispersive and slaking soils and to develop and integrate management measures, including testing and treatment, into TMR's specification requirements.

The review process undertaken as part of this project determined that while physical testing alone can be unreliable due to its qualitative nature, it can provide useful insight into soil behaviour. Chemical testing can be applied to better understand the soil chemistry and thus interpolate likely soil behaviour; however, results are complex and require an expert to interpret.

The ability to integrate processes as 'business as usual' are reliant on processes being efficient and effective for those applying them. As such, the application of comprehensive chemical testing is difficult due to the complexity of results. Through engagement with soil scientists from DES and DNRM, an enhanced testing suite can be created, that combines basic chemistry tests with physical tests to identify likely behaviour of soil in the field and the most appropriate amelioration method. This inclusion within MRTS04 will improve identification and provide a clear pathway for use of these materials through amelioration.

The recommended specification updates have mainly focused on new content and clauses within MRTS04, MRTS04.1 and MRS04 based on some applicable clauses from MRTS16 and associated documents. The aim of the specification updates is to ensure effective management of slaking and dispersive soils enhanced testing requirements and the inclusion of amelioration requirements throughout a project.

The development of a new TMR Technical Note *Investigating and Managing Dispersive and Slaking Soils as Part of Transport Infrastructure Projects* aims provide clear and concise best practice advice for managing slaking and/or dispersive soils. The intended audience of this technical note includes project planners, designers, preconstruction project managers, delivery contract administrators and construction contractors.

References

Agriculture Victoria 2020, *What is soil*, Victoria State Government, accessed 24 November 2022, <https://agriculture.vic.gov.au/farm-management/soil/what-is-soil>.

Agriculture Victoria 2020b, *Dispersion*, Victoria State Government, accessed 25 November 2022, <https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_soil_structure_dispersion>.

Cooperative Research Centre for Soil and Land Management 1994, *Technical Note 1 – Introduction to soil sodicity,* accessed 28 November 2022 <https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/0d08cd6930912d1e4a2567d2002579cb/813c7894348b29d4ca256ea8000327c6/$FILE/crc%20intro%20soil%20sodicity.pdf>

CSIRO 2019, *Mineral soils field texture grade*, webpage, CSIRO Linked Data Registry, Canberra, ACT, accessed 02 October 2020, <http://registry.it.csiro.au/def/soil/au/asls/soil-prof/field-texture-mineral>.

Dairy Australia 2021, *Dairy soils and fertiliser manual: chapter 7.2: slaking and dispersion*, Dairy Australia, Melbourne, Vic, accessed 7 October 2020, <https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert$mart-chapter-7---managing-limiting-soil-factors#.Y4BPYxRByUk>.

Davies, S & Lacey, A 2009, *Farm note 386: Identifying dispersive soils*, Department of Agriculture and Food, Perth, WA.

Davies, S & Lacey, A 2010, *Farm note 387: managing dispersive soils*, Department of Agriculture and Food, Perth, WA.

Department of Primary Industries 1999, *Southern irrigators SOILpak: part C: diagnosis of soil: chapter 7: slaking and dispersion,* DPI, Sydney, NSW accessed 17 October 2022 https://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0005/167459/soil-pak-sis-Part-C.pdf.

Department of Sustainable Natural Resources n.d., *Soil survey standard test method: Emerson aggregate* test, DSNR, Sydney, NSW.

Emerson, W 1967, 'A classification of soil aggregates based on their coherence in water', *Australian Journal of Soil Research*, vol.5, no.1, pp.47–57.

Field, DJ, McKenzie, DC, and Koppi, AJ 1997, 'Development of an improved Vertisol stability test for SOILpak', *Australian Journal of Soil Research*, vol.35, no.4, pp.843–852.

Grains Research and Development Corporation 2017, *Soil amelioration in Western Australia*, webpage, GRDC, Bentley, WA, accessed 17 October 2022, <https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/soil-amelioration-in-western-australia>.

Grains Research and Development Corporation 2020, *Dealing with dispersive soils – Fact Sheet*, GRDC, Bentley, WA.

Grains Research and Development Corporation 2021, *Identifying dispersive (sodic) soils*, webpage, GRDC, Bentley, WA, accessed 25 November 2022, <https://www.agric.wa.gov.au/dispersive-and-sodic-soils/identifying-dispersive-sodic-soils>.

Hardie, M, Doyle, R, Cotching, B, Duckett, T & Zund, P 2009, *Dispersive soils and their management: technical reference manual*, Department of Primary Industries and Water, Hobart, Tas.

Hazelton, P & Murphy, B 2016, *Interpreting soil test results: what do all the numbers mean?*, CSIRO Publishing, Clayton South, Vic.

International Erosion Control Australasia 2008, *Best practice erosion & sediment control*, IECA, Picton, NSW.

Lake Macquarie City Council 2015, *Fact Sheet 8H – Dispersive Soils,* Lake Macquarie, NSW.

Loveday, J & Pyle, J 1973, *The Emerson dispersion test and its relationship to hydraulic conductivity*, technical paper no. 15, Division of Soils, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, Vic.

NSW Agriculture 2002, *Interpreting soil tests for calcium, magnesium and Ca:Mg ratios*, leaflet no. 7, NSW Agriculture.

Ogbonna, CS, Igwe, CA, and Ogbonna, PE 2013, 'Effects of exchangeable Ca:Mg ratio on the dispersion of soils some southern Nigeria Soils', *Journal of Tropical Agriculture, Food, Environment and Extension*, vol.12, no.2, pp.10–19.

Queensland Department of Transport and Main Roads 2020a, *Erosion and sediment control*, webpage, TMR, Brisbane, Qld, accessed 6 October 2020, <https://www.tmr.qld.gov.au/Community-and-environment/Environmental-management/Land/Erosion-and-sediment-control.aspx>.

Queensland Department of Transport and Main Roads 2020b, *Geotechnical design standard: minimum requirements*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020c, 'Soil management manual', internal, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2022, *Materials testing manual*, edn 5, amendment 7, TMR, Brisbane, Qld.

Queensland Government 2014, *Soil sodicity,* webpage, Queensland Government, Brisbane, Qld, accessed 17 October 2022, <https://www.qld.gov.au/environment/land/management/soil/soil-properties/sodicity>.

Queensland Government 2017, *Reducing sediment run-off: reducing sediment run-off to protect the Great Barrier Reef,* webpage, Queensland Government, Brisbane, Qld, accessed 17 October 2022, <https://www.qld.gov.au/environment/coasts-waterways/reef/preserve-the-wonder/sediment-runoff>.

Quizlet 2021, *Soil Assignment #1,* webpage, accessed 28 November 2022 <https://quizlet.com/203553041/soil-assignment-1-flash-cards/>.

Quizlet 2022, *Dealing with dispersive soils,* webpage, accessed 25 November 2022 <https://quizlet.com/162946396/dealing-with-dispersive-soils-flash-cards/>.

Raine, S & Loch, R 2003, 'What is a sodic soil? Identification and management options for construction sites and disturbed lands', *Workshop on soils in rural Queensland, 2003, Toowoomba, Queensland,* Queensland Department of Transport and Main Roads, Brisbane, Qld, 14 pp.

Rayment, G & Lyons, D 2011, *Soil chemical methods – Australasia*, CSIRO, Melbourne, Vic.

Witheridge 2012, *Principles of Construction Site Erosion and Sediment Control.* Catchments & Creeks Pty Ltd., Brisbane, Queensland.

Zund, PR 2017, *Soil erodibility- user guide*, Queensland Department of Science, Information Technology and Innovation, Brisbane Qld.

Transport and Main Roads Technical Specifications

MRTS04.1:2020, *General earthworks: annexure*.

MRTS04:2020, *General earthworks: technical specification*.

MRTS16:2017, *Landscaping and revegetation: technical specification*.

Transport and Main Roads Test Methods

Q161:2022, *Field dispersion indicator test of soil: slaking*.

Q162:2022, *Field dispersion indicator test of soil: clouding*.

Standard Australia Test Methods

AS 1289.3.8.1:2017, *Methods of testing soils for engineering purposes: soil classification tests: dispersion: determination of Emerson class number of a soil*.

AS 1289.3.8.3:2014, *Methods of testing soils for engineering purposes: soil classification tests: dispersion: determination of pinhole dispersion classification of a soil.*