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# Inside the Herd

Final Project Report

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Report to the Gas Industry Social and Environmental Research Alliance

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## Important disclaimer

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# Acknowledgments

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The *Inside the Herd* Project was funded by the Gas Industry Social and Environmental Research Alliance (GISERA). GISERA is a collaborative vehicle established to undertake publicly-reported independent research addressing the socio-economic and environmental impacts of Australia's natural gas industries. The governance structure for GISERA is designed to provide for and protect research independence and transparency of funded research. See www.gisera.org.au for more information about GISERA's governance structure, funded projects, and research findings.

# Executive summary

Much of the research to date within the Agricultural Land Management Portfolio of the Gas Industry Social and Environmental Research Alliance (GISERA) has targeted cropping systems and the soils, management and issues relevant to them. This project investigates the possible impacts of coal seam gas (CSG) development and production on the soils, pastures and livestock within grazing systems. Many of these impacts can be difficult to observe. Therefore, a range of traditional and modern digital and remote sensing technologies have been employed to describe the overall interaction between coexisting agricultural and resource development enterprises. These approaches include soil sampling and characterisation, three-dimensional mapping and water flow predictions to understand hydrology and erosion processes, mapping of pasture condition using ground-based assessments and long-term remote sensing, camera surveillance of farm and CSG traffic, and GPS monitoring of individual livestock and their interactions with CSG infrastructure. All work shown in this report was undertaken on "Victoria Park", an operating grazing property near Miles, Queensland, during the period from October 2017 to April 2018.

Analysis of the physical and chemical properties of representative soils across the property highlighted the fragile nature of many soils used for grazing within this region. The nature of these soils brings risks of tunnel erosion, subsidence, and difficulties in re-establishing pastures after disturbance. These predispose the soil to further damage from erosion processes. Ongoing damage to access tracks from surface water flows, as highlighted in previous GISERA research projects in the region, was evident across the site. Traffic volumes from CSG operations were highly variable across the study period. Whilst most of this traffic consisted of smaller, four-wheeled vehicles, a significant portion of the total traffic load consisted of much larger vehicles with more than twenty wheels. These larger vehicles may provide a disproportional contribution to road damage as compaction, disturbance and dust emission can be correlated with both the number of vehicles and wheels.

There was little evidence of livestock avoiding CSG infrastructure or decreased use of pastures along right-of-ways. In fact, time spent by livestock per hectare within CSG right-of-ways was 18% higher than similar open pasture areas. This extra pressure on areas undergoing rehabilitation may contribute to a greater risk for soils and re-establishing pastures. Grazing data also demonstrated low utilisation of some areas within the property such as riparian areas and areas of woody vegetation. As a result, the magnitude of the spatial footprint of CSG infrastructure may not accurately represent the production impacts of CSG on grazing. This variation in productive capacity across the property should be considered when planning CSG infrastructure and compensation arrangements.

Future research should investigate methods for improved installation of CSG infrastructure to avoid soil mixing, rehabilitation of pastures and soils on land grazed by livestock, and the location and design of access tracks to avoid ongoing damage from erosion processes.

# 1 Introduction

## 1.1 Background

Most of the existing research within the Agricultural Land Management Portfolio of the Gas Industry Social and Environmental Research Alliance (GISERA) has targeted cropping systems and the soils, management and issues relevant to them (e.g. Antille et al (2016), Huth et al (2018)). This includes studies of soil compaction and erosion, production and machinery impacts, and social and economic considerations. Recent landholder engagement activities as part of the "Telling the Story" project highlighted the remaining research gaps, particularly with respect to grazing systems. Grazing is an important agricultural land use across the Surat Basin. It is employed on more than 60% of the land on the Eastern Darling Downs and on more than 80% of the land in the west of the Surat Basin (Huth et al, 2018). Landholders raised issues of impacts on animal behaviour and pastures through factors such as dust or changed water flows. These included concerns about decreased pasture palatability for livestock due to dust, changes to pasture production with changed water flows or dust deposition, changed livestock behaviour due to CSG vehicles or infrastructure leading to changing use of watering points or shelter, or livestock damage of fragile soils after disturbance. Similar concerns were raised during workshops held as part of the "A Shared Space" project (Huth et al, 2018).

Studies of the grazing-related issues listed above can be difficult, especially when studies need to be conducted "on-farm". Recent technological advances now provide new opportunities for monitoring such things at remote locations. Furthermore, several initiatives within the CSIRO are evaluating new digital technologies for agricultural applications. Previous projects, such as the *Making Tracks, Treading Carefully* project which studied CSG impacts on surface hydrology using digital photogrammetry for 3D mapping and water flow modelling, have found modern spatial data approaches very useful for not only studying complex issues, but also for communicating them to various audiences. Direct community engagement has found that, in general, farmers understand landscapes and therefore read and understand maps well. These efforts have found that farmers can interpret complex hydrological data derived from aerial photography and can communicate lessons arising from maps.

For these reasons, this project will monitor CSG vehicles and infrastructure and their potential impacts on soils, pastures and cattle on an operational cattle property, and will undertake to use this information in community engagement activities.

## 1.2 Project Aims and Scope

This project will provide information for graziers through the detailed monitoring of grazing land including CSG infrastructure. Research will address questions about the impacts of CSG infrastructure, traffic and dust on animals and pastures. The research team will discuss these data with landholders at a relevant rural industry event using maps and animations worked into story pieces, using techniques developed as part of the GISERA *Telling the Story* Project (Huth et al 2016).

As stated above, most existing GISERA agricultural research has been undertaken in cropping lands. A research gap lies within the grazing landscapes, which are a large component of CSG development areas in both Queensland and New South Wales. Dust and impacts on livestock, surface water flows, and pastures have been raised as important issues by landholders in various landholder engagement forums (Huth et al 2018). Furthermore, landholders have also been outspoken about the need for science to be communicated in meaningful ways (Huth et al 2016). Those interacting with CSG companies regularly feel information overload and request information to be not "dumbed down" but communicated clearly to farmers (Huth et al 2018).

The outputs of this project include:

1. A detailed study of livestock behaviour, pastures, soil processes, and dust deposition for a real CSG property that is used to generate information that is suitable not only for scientific study of issues of importance for farmers, but also for communication to the general community.

2. A report and conference articles about the research and technologies employed.

3. A series of engagement activities designed for rural communities.

# 2 The Victoria Park Case Study

A case study was established to generate information for an operating grazing property that includes an established network of coal seam gas wells and related infrastructure. The case study property was chosen for several reasons. The design of gas infrastructure, soils and climate are representative of those found across the gas developments within south western Queensland.

## 2.1 Location

Victoria Park is a grazing property on the outskirts of the township of Miles in the western Darling Downs region in south western Queensland. The property lies within the Condabri coal seam gas tenement between Miles and the neighbouring township of Condamine. This region has a highly developed coal seam gas network as demonstrated in Figure 1.


**Figure 1 Location of the Victoria Park case study site within the state of Queensland (inset), and the western darling downs region. Figure also shows vegetation (green), state roadways (red) and coal seam gas wells and pipeline leases (orange), and the border of the property (black).**

## 2.2 Climate Conditions

### 2.2.1 Long term climate

The climate of the township of Miles (26.66 °S, 150.18 °E), 4km from the case study farm, is representative of sub-tropical inland continental climates with many hot summer days and cold winter nights. The township is situated at an elevation of 302 m. Daytime maximum temperatures can increase to over 40 °C, and night time minimum temperatures to below 0 °C for much of the year. The town has a mean annual rainfall of 647 mm.

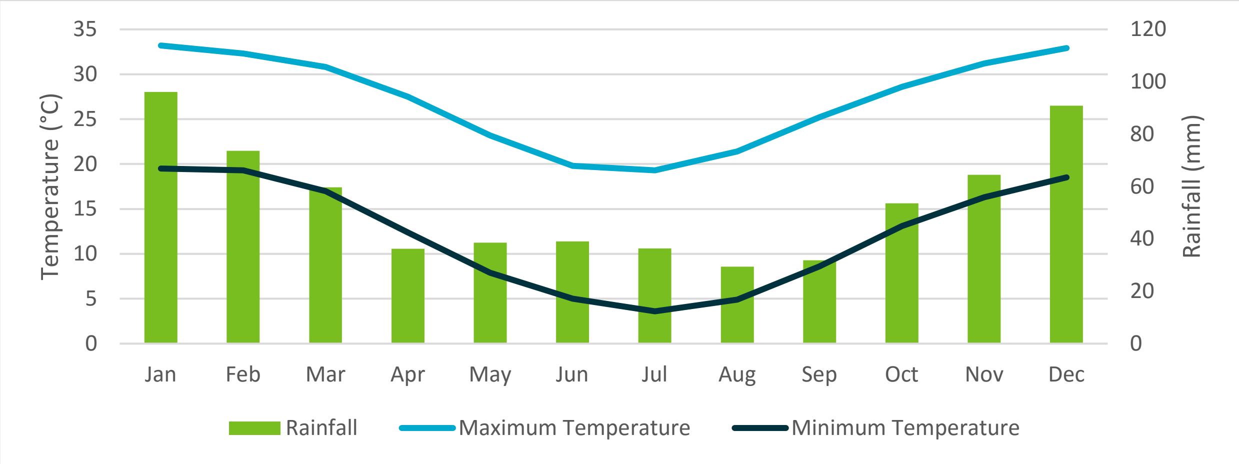



**Figure 2 Long term rainfall (1885 to 2017) and temperature (1908 to 2005) averages for Miles Post Office.**

### 2.2.2 Weather conditions during the case study

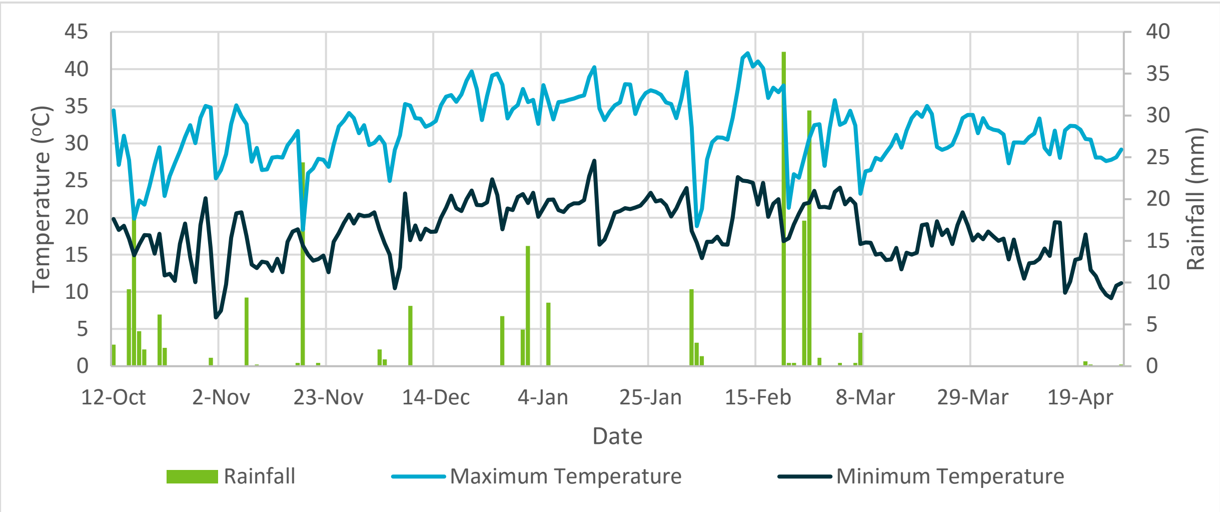
Weather conditions can play an important role in livestock behaviour and dust generation and dispersal. Furthermore, local microclimate in landscapes such as these can be strongly influenced by topography and vegetation. Therefore, three weather stations (Environdata WeatherMaster 3000) were installed onto the case study property to provide detailed records of temperature, humidity, rainfall and wind speed and direction. The three stations were sited at a range of positions across the property ranging from partially sheltered to open conditions.

A total of 228 mm of rainfall fell on the property during the period from 12$^{th}$ of October 2017 to 27$^{th}$ of April 2018. This is well below the long term average rainfall of 474 mm for October to April. Daily temperatures were representative of the long-term average conditions for that time of year. The daily maximum temperature ranged from 18.4$^{o}$C to 42.1 $^{o}$C with an average of 31.9 $^{o}$C. Daily minimum temperature ranged from 6.6 $^{o}$C to 27.7 $^{o}$C with an average of 18.2 $^{o}$C.

a)

**Figure 3 a) One of the three weather stations installed onto the case study property, and b) Daily weather data recorded during the study period**

b)



## 2.3 CSG Infrastructure

The case study property covers an area of 955 ha and currently includes 20 Coal Seam Gas wells. The lease areas surrounding these wells covers an area of 19.8 ha. Servicing these wells is approximately 45.3 ha of Right-of-Way, including access tracks, gathering pipelines and easements for power transmissions lines. When combined, these features cover a total of 6.8 % of the area of the property.

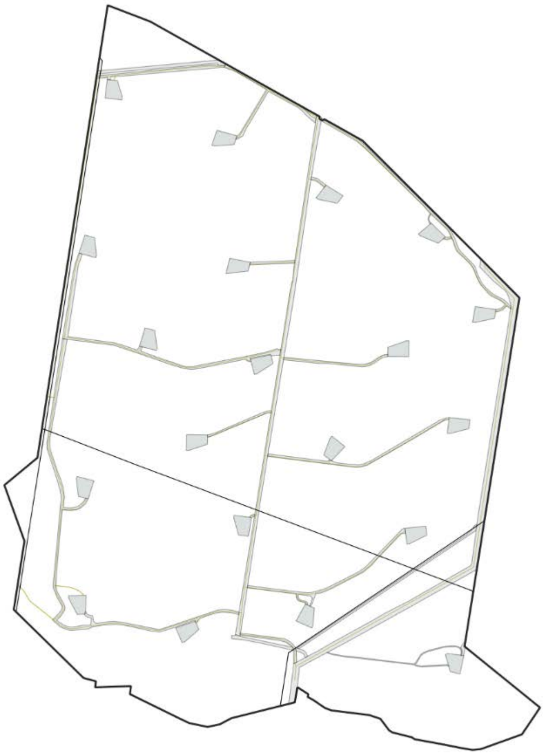


**Figure 4 Map of the case study property showing the location of well lease areas and Right-of-Ways (grey) and power transmission lines (black).**

The total infrastructure footprint is within the bounds demonstrated for another section of the Condabri Coal Seam Gas tenement (Marinoni and Navarro Garcia, 2016). This previous study found that 70% of the wells studied had a CSG spatial footprint of less than 8.8% for the area within 750 m of the well. That being the case, the amount of infrastructure within the current case study site is representative of most farms outside the highly developed areas neighbouring the gas processing plants. Areas close to major infrastructure may have much higher concentrations of gas infrastructure.

Examples of the types of infrastructure installed onto the property are shown in Figure 5.


**Figure 5 Infrastructure related to CSG developments including a) CSG well, b) pipeline after recent rehabilitation, c) access track and d) power lines.**

## 2.4 Soils

Victoria Park contains a range of soil types which are indicative of the soils of the region. The management issues for these soils are therefore also relevant to much of the CSG development within south western Queensland, especially for those used for grazing. The following is not an exhaustive description of the local soils and their management, but does demonstrate some of the likely issues for grazing lands undergoing CSG development or operation.

### 2.4.1 Soil Types

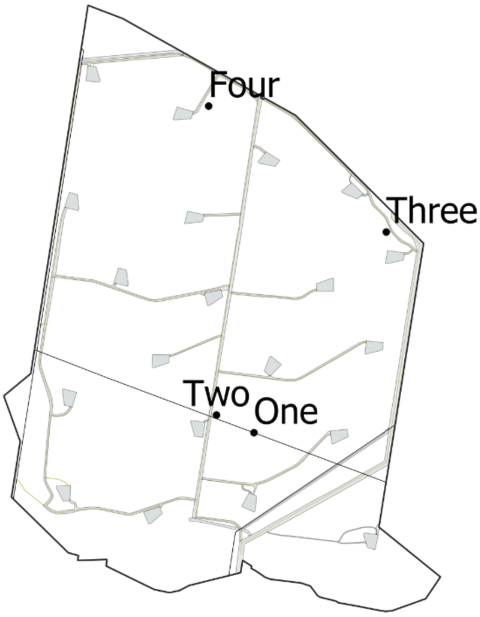



**Figure 6 Location of the four soil sampling sites for the case study property**

Four soil types were chosen from across the property based on texture and vegetation (Figure 6) and sampling was undertaken on 8th of January 2018. Soil samples were obtained to a depth of 150 cm using a steel sampling tube inserted using a vehicle-mounted hydraulic ram. Site three required manual sampling due to hard and dense soil at depth and, as a result, a sample depth of only 90 cm was possible. Four cores were obtained at each location and these were divided into consistent sampling intervals. All samples were dried and ground prior to chemical analysis. Samples were analysed for pH (1:5 in $H_2O$), organic carbon (%), chloride (ppm), electrical conductivity (dS/m), available phosphorus (ppm) and exchangeable cations (cmol/kg). Cation analysis included Aluminium (Al), Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na).

Each of the soil profiles have also been described according to the Australian Soil Classification (Isbell, 2002). Soil classification helps to indicate the nature of the soil, how it has formed, and the likely management issues encountered for that soil. The classification is explained in each case for ease of interpretation.

## Soil 1 – Red Kurosol

**Figure 7 Soil surface conditions for sampling area and example soil core for the Red Kurosol (Channing).**

**Table 1 Selected soil field and chemical properties for the Red Kurosol soil profile to a depth of 180 cm.**

| FIELD PROPERTIES | | CHEMICAL PROPERTIES | | | | | | EXCHANGEABLE CATIONS (cmol/kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil horizon | Field texture (depth cm) | Sample depth cm | OC % | pH (1:5) | P ppm | Cl ppm | EC dS/m | Al | Ca | Mg | K | Na | ECEC | ESP % |
| **A11** | Clay loam (0 - 15) | 0 – 15 | 1.33 | 4.7 | 36 | 39 | 0.13 | 1.5 | 1.5 | 2.9 | 0.3 | 0.8 | 7.0 | 11 |
| **B21** | Medium clay (15 - 35) | 15 – 30 | 0.71 | 4.7 | 27 | 102 | 0.20 | 3.3 | 0.9 | 5.1 | 0.1 | 2.1 | 11.6 | 18 |
| **B22** | Medium clay (35 - 90) | 30 – 60 | 0.44 | 4.6 | 24 | 514 | 0.44 | 2.3 | 0.5 | 6.6 | 0.1 | 4.6 | 14.1 | 33 |
| | | 60 – 90 | - | 4.6 | 24 | 719 | 0.54 | 1.8 | 0.4 | 6.4 | 0.2 | 5.3 | 14.1 | 38 |
| **B23** | Clay loam (90 - 150) | 90 – 120 | - | 4.5 | 24 | 841 | 0.61 | 1.6 | 0.3 | 6.0 | 0.1 | 5.7 | 13.7 | 41 |
| | | 120 – 150 | - | 4.5 | 23 | 998 | 0.67 | 1.7 | 0.3 | 5.7 | 0.2 | 6.0 | 13.9 | 43 |

### Soil Classification Explained

This soil can be classified as a *Sodic, Magnesic–Natric, Red Kurosol*.

*Kurosols* - Soils with strong texture contrast between A horizons and strongly acid (pH<5.5) B horizons. They may have some unusual subsoil chemical features such as high magnesium, sodium and aluminium.

*Sodic* – Exchangeable Sodium Percentage (ESP) of the fine earth material is 6 or greater.

*Magnesic-Natric* - Exchangeable Ca/Mg ratio of less than 0.1 in the major part of the B2 horizon.

The acidity of this soil is likely to affect nutrient availability, particularly phosphorus, calcium, and magnesium for pastures. Low pH also has the potential to lead to aluminium toxicity causing reduced microbial and plant activity. The exchangeable sodium percentage (ESP) is high enough (> 6%) to affect soil structural stability primarily through dispersion of clays; which clogs soil pores, reduces water infiltration and air movement, creates dense subsoils, promotes surface erosion and the loss of soil nutrients. If the soil (particularly subsoil) is stripped of surface organic matter and plant cover, it will be highly susceptible to erosion when exposed to moving water (i.e. rainfall and runoff). A low Ca/Mg ratio indicates the potential for Mg induced Ca deficiency in some plant species. High exchangeable Mg may also cause K deficiency and cause soil dispersion.

It is recommended that disturbed layers of the soil are incorporated with lime and organic matter and seeded with a fast growing grass species. The lime is used to neutralise acidity, balance nutrient availability and provide Ca to prevent clay dispersion. Organic matter and grass species reduce runoff velocity compared to bare soil. Organic matter also helps to improve water holding capacity of the soil to sustain plant life. Addition nitrogen fertiliser and irrigation may be required to boost plant growth. Non-disturbed areas may require surface application of lime and organic matter as an erosion prevention method. An NPK fertiliser may also be applied to encourage plant growth in improved pastures.

## Soil 2 – Red Vertosol

**Figure 8. Soil surface conditions for sampling area and example profile for the Red Vertosol (Arden).**

**Table 2. Selected soil properties for the Red Vertosol soil profile to a depth of 150 cm.**

| FIELD PROPERTIES | | CHEMICAL PROPERTIES | | | | | | EXCHANGEABLE CATIONS (cmol/kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil horizon | Field texture | Depth cm | OC % | pH | P ppm | Cl ppm | EC dS/m | Al | Ca | Mg | K | Na | ECEC | ESP % |
| **A11** | Medium clay (0 - 6 cm) | 0 – 15 | 1.05 | 5.6 | 30 | 759 | 0.8 | 0.1 | 5.4 | 10.1 | 0.3 | 3.9 | 19.6 | 19 |
| **B21** | Medium heavy clay (6 - 30 cm) | 15 – 30 | 0.82 | 5.0 | 30 | 1450 | 0.9 | 0.2 | 4.4 | 9.4 | 0.2 | 6.1 | 20.2 | 30 |
| **B22** | Medium heavy clay (30 - 80 cm) | 30 – 60 | 0.75 | 4.7 | 28 | 3050 | 1.6 | 0.5 | 3.4 | 9.8 | 0.2 | 8.7 | 22.5 | 38 |
| | | 60 – 90 | - | 4.4 | 30 | 3900 | 1.9 | 0.6 | 2.7 | 9.8 | 0.2 | 9.5 | 22.9 | 42 |
| **B23** | Medium heavy clay (80 - 150 cm) | 90 – 120 | - | 4.8 | 32 | 4150 | 2.0 | 0.7 | 2.3 | 9.9 | 0.3 | 14 | 27.1 | 52 |
| | | 120 – 150 | - | 4.4 | 35 | 4200 | 2.1 | 0.7 | 1.9 | 9.9 | 0.3 | 11 | 23.4 | 46 |

### Soil Classification Explained

This soil can be classified as an *Episodic–Endoacidic, Crusty, Red Vertosol*.

*Vertosols* - Clay soils with shrink-swell properties that exhibit strong cracking when dry and at depth have slickensides and/or lenticular structural aggregates.

*Episodic–Endoacidic* – Soils in which the upper 0.1 m is sodic (ESP > 6) and the major part of the upper 0.5 m is calcareous (Carbonate segregations).

*Crusty* - Soils with a weakly structured surface crusty horizon less than 0.03 m thick, often of lighter texture (lower clay content) than the underlying clay which is not self-mulching.

High chloride deeper in the soil profile is characteristic of Vertosols in SE Queensland. Chloride is dissolved within the soil water. Its negative charge means that it is highly mobile and will leach or rise with water movement (i.e. drainage or evaporation). Values of over 1000 ppm may hinder plant growth.

Vertic (shrink-swell) properties of the soil are beneficial for soil water holding capacity and nutrient cycling, but also means they are more sensitive to sodium induced soil dispersion, surface crusting and soil compaction. If the surface is left bare, further structural problems such as crab holes or tunnel erosion may develop.

This soil profile has high chloride, particularly at depth, which is likely to restrict plant access to water and cause toxicity problems. The combination of chloride and other dissolved cations in the soil (Mg, Na, K, Ca) reflect the high measures of EC in the soil.

The acidic subsoil may also restrict root growth and cause nutritional problems in deeper rooted salt tolerant plants - particularly during dry periods. Exchangeable Mg is particularly high and may cause Mg induced Ca deficiencies in plants.

Soils should be maintained with lime to maintain surface structural integrity and increase soil pH. The only way to address the salinity issue is to leach the soil with good quality water (low salt content), however, this is probably not cost effective or required unless salt sensitive species are going to be planted in this soil. It is recommended that a cover with a salt-tolerant grass species is maintained. This may require an addition of NPK fertiliser to encourage plant establishment.

## Soil 3 – Grey Sodosol

**Figure 9. Soil surface conditions for sampling area and example profile for the Grey Sodosol (Cypress).**

**Table 3. Selected soil properties for the Grey Sodosol profile to a depth of 90 cm.**

| FIELD PROPERTIES | | CHEMICAL PROPERTIES | | | | | | EXCHANGEABLE CATIONS (cmol/kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil horizon | Field texture (Depth cm) | Depth cm | OC % | pH | P ppm | Cl ppm | EC dS/m | Al | Ca | Mg | K | Na | ECEC | ESP % |
| **A11** | Loam (0 - 5) | 0 – 15 | 0.59 | 5.6 | 25 | 39 | 0.1 | 0.2 | 2.1 | 2.3 | 0.1 | 0.9 | 5.6 | 16 |
| **A12** | Sandy loam (5 - 25) | 15 – 30 | 0.44 | 7.2 | 24 | 131 | 0.2 | 0.0 | 4.2 | 5.7 | 0.1 | 2.6 | 12.6 | 20 |
| **B21** | Medium clay, fine sandy (25 - 55) | 30 – 60 | 0.16 | 8.4 | 21 | 488 | 0.4 | 0.0 | 4.2 | 7.2 | 0.2 | 4.3 | 15.8 | 27 |
| **B22**<br>**B23** | Medium clay, fine sandy (55 - 75)<br>Medium clay, fine sandy (75 - 90) | 60 – 90 | - | 8.1 | 22 | 606 | 0.5 | 0.0 | 4.6 | 7.6 | 0.2 | 5.2 | 17.6 | 30 |

### Soil Classification Explained

This soil can be classified as a *Eutrophic, Hypernatric, Grey Sodosol*.

*Sodosol* - Soils with strong texture contrast between A and B horizons, the major part of the B horizon is sodic (ESP >6) and not strongly acid (pH >5.5). They may have some unusual subsoil chemical features such as high magnesium, sodium and aluminium.

*Eutrophic* - Soils in which the major part of the B2 horizon has high ECEC (> 15 cmol/kg) but the B and BC horizons have no carbonate segregations.

*Hypernatric* - soils in which the major part of the upper B2 horizon has an ESP greater than 25.

Sodosols are generally highly susceptible to erosion once the surface organic matter and topsoil layers are lost. This Sodosol is typical in nature with high ESP percentages (< 6%), low EC, clay subsoil and a slightly elevated pH in the subsoil which may cause some minor micronutrient deficiencies, but this is not expected to impact pastures unless production rates are high. High Mg in the subsoil may cause Ca deficiency. Dense subsoils in sodosols may restrict infiltration of water, as well as air and root movement, making it difficult for plant roots to access nutrients and water below.

It is critical to ensure vegetation/grass cover remains to prevent exposure of the soil surface to moving water. For restoration, it is suggested that gypsum rather than lime is used to supply Ca (due to higher pH of this soil), organic matter (mulch) and NPK fertiliser are applied to the soil and seeded with a hardy grass / and or legume combination.

## Soil 4 - Black Kurosol

**Figure 10. Soil surface conditions for sampling area for the Black Kurosol (Eucalyptus).**

**Table 4. Selected soil properties for the Black Kurosol profile to a depth of 150 cm.**

| FIELD PROPERTIES | | CHECMICAL PROPERTIES | | | | | | EXCHANGEABLE CATIONS (cmol/kg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil horizon | Field texture (Depth cm) | Depth cm | OC % | pH | P ppm | Cl ppm | EC dS/m | Al | Ca | Mg | K | Na | ECEC | ESP % |
| **A1** **A2(e)** | Clay loam (0 - 5) Clay loam (5 - 7) | 0 – 15 | 0.82 | 4.8 | 30 | 164 | 0.2 | 1.3 | 1.5 | 3.8 | 0.2 | 1.4 | 8.2 | 17 |
| **B211** | Medium heavy clay (7 - 35) | 15 – 30 | 0.56 | 4.5 | 27 | 571 | 0.4 | 3.2 | 0.5 | 6.9 | 0.2 | 4.0 | 14.8 | 27 |
| **B22** | Medium heavy clay (35 - 75) | 30 – 60 | 0.50 | 4.4 | 26 | 1200 | 0.8 | 2.4 | 0.3 | 8.1 | 0.2 | 6.7 | 17.6 | 38 |
| **B23** | Medium clay, fine sandy (75 - 130) | 60 – 90 | - | 4.4 | 23 | 943 | 0.7 | 1.4 | 0.3 | 6.3 | 0.2 | 5.5 | 13.8 | 40 |
| | | 90 – 120 | - | 4.6 | 24 | 836 | 0.6 | 1.0 | 0.3 | 5.5 | 0.2 | 5.0 | 12.0 | 42 |
| **B211** | Medium clay, fine sandy (130 - 150) | 120 – 150 | - | 4.7 | 25 | 819 | 0.6 | 1.0 | 0.3 | 5.0 | 0.2 | 4.8 | 11.2 | 43 |

### Soil Classification Explained

This soil can be classified as a *Bleached-Vertic, Magnesic-Natric, Black Kurosol*.

*Kurosols* - Soils with strong texture contrast between A horizons and strongly acid (pH<5.5) B horizons. They may have some unusual subsoil chemical features such as high magnesium, sodium and aluminium.

*Magnesic-Natric* - Exchangeable Ca/Mg ratio of less than 0.1 in the major part of the B2 horizon.

*Bleached-Vertic* - Soils with a bleached A2 horizon and a B horizon with a clayey field texture which cracks strongly when dry.

This Black Kurosol is of low fertility status (low pH, Ca and available P), high ESP (> 6%) and is likely to be susceptible to erosion if the existing vegetation and topsoil are removed. The soil has a high clay content and salt bulge at 60 cm, which is symptomatic of vegetation holding salts in the soil. It is likely that root growth will be restricted at this depth due to osmotic effects and Cl toxicity. Plants may develop a Mg induced Ca deficiency due to the high exchangeable Mg.

The vertic (shrink-swell) properties provide good soil water holding capacity and nutrient cycling, but also makes the soil more sensitive to sodium induced soil dispersion, surface crusting and soil compaction. If the surface is left bare, further structural problems such as crab holes or tunnel erosion may develop.

It is recommended that the topsoil is maintained with lime to increase pH and supply calcium to maintain surface stability. Grazing should be managed to maintain grass cover and the soil fertility could be improved with NPK fertiliser.

### 2.4.2 Management Issues

Soils will most likely be impacted during the installation of coal seam gas infrastructure by surface disturbance, compaction, or soil blending and layer inversion and these changes can result in different soil physical, chemical and biological characteristics (Vacher et al 2014). As shown in the previous section, many of the soils of this region have chemical or structural constraints that are difficult to manage after significant soil disturbance; such as the installation of coal seam gas infrastructure.

If disturbed and not rehabilitated, it is possible that a runaway feedback system of perpetual erosion could develop, particularly after excavation and mixing causing loss of topsoil.

This is frequently the case for soils in grazing systems which are explicitly used for non-arable farming because of their fragile nature. Other grazing lands may be farmed in this way because the land slope is excessive for cultivation. All these factors highlight the need for careful consideration of soil management. Some of these are demonstrated in more detail here.

Industry and pipeline manufacturing guidelines exist for best practice for effective pipeline installation, soil management, and re-compaction during backfilling. However, it is not uncommon for pipeline subsidence, surface and tunnel erosion to occur on soils such as those described above. This can occur if the soils are not compacted correctly, or if natural processes of sodic soils leave voids for water entry. The depression zone caused by subsidence or tunnel erosion (see Figure 11) increases the interception of water flows and exacerbates subsequent erosion processes (Vacher et al 2016).

Industry practices include the use of installing a mound above pipelines to account for settlement or subsidence. Whilst there may be some concern that mounds may divert water flows and add to soil loss, research has shown that such approaches do not necessarily generate greater erosion rates than undisturbed field areas whereas unmanaged settlement or subsidence has the greater potential to generate higher erosion rates (Vacher et al 2016).

a) b)

**Figure 11 a) Subsidence of soils overlying a pipeline on the eastern boundary of the case study farm. b) Sodic subsoils can be difficult to rehabilitate and restore to productive pasture after pipeline installation.**

Sodic subsoils (ESP > 6%) are extremely susceptible to water and wind erosion and can cause problems with rehabilitation and restoration of pastures if soil mixing occurs during pipeline installation. Topsoils need to be retained separately in heaps and replaced after pipeline installation. High grade gypsum (for high pH soils) or lime (for low pH soils) may be required, but efforts should ensure that the material is very fine and pure (i.e. low levels of magnesium).

Rehabilitation of soils showing signs of tunnel erosion, subsidence or soil mixing is common because of the nature of the soils and the difficult in avoiding mixing of soil during disturbance. This can be seen in the photo of the case study property (Figure 12) where evidence of sequential intervention is apparent. Any efforts such as these will need to consider increased risks of soil damage by machinery or soil losses by hydrological processes after further disturbance. Both these risks can be minimised by accounting for future weather conditions and current soil moisture levels. Monitoring of cattle movements within this case study has demonstrated that cattle residence times can be higher on right-of-way areas (e.g. pipelines) than in neighbouring pastures as livestock regularly use roadways for ease of passage across the property. Any new pasture established as part of rehabilitation is at risk of preferential grazing, and newly exposed topsoil is at risk of further pugging and disturbance by livestock hooves. Management of rehabilitated soils during active livestock grazing should be considered carefully.

**Figure 12 Sequential rehabilitation of a pipeline including seeding of pasture species at case study property.**

## 2.5 Water Flow Mapping

Surface water flows are important in sub-tropical grazing systems for many soil and plant processes. The impact of CSG development and operation on such flows have been raised by landholders as an important issue. Furthermore, research in catchments from around the globe have shown that unsealed rural roads provide a disproportionate contribution to sediment flows into local waterways. This research has also shown that much of this sediment comes from a small proportion of the overall road network, so-called “hot spots”. Previous research within CSG tenements has evaluated the use of digital aerial photogrammetry to provide detailed maps of soil surface relief and predicted surface water flows within these catchments. Such maps have proven highly effective in communicating issues resulting from changes in surface hydrology and in locating areas of possible erosion risk.

### 2.5.1 Use of photogrammetry

Digital aerial photogrammetry is one approach used to create 3-dimensional models of landscapes. Previous studies into the impacts of access tracks on soil erosion have performed aerial surveys of 1300 $km^2$ between Chinchilla, Miles and Condamine in 2013 and 2015. These surveys have been used to create a 3D model of the soil surface with a spatial resolution of 20 cm. These ground surface models have been tested against corresponding ground surface elevation measurements using standard surveying techniques. Water flow models have been applied to these surfaces to create high resolution water flow maps, which have also been compared to observed water flow paths in both farmland and native forests. Further detail about the methods used here can be found in Huth et al (2015a) or from the GISERA web site (https://gisera.csiro.au/project/making-tracks-treading-carefully/).

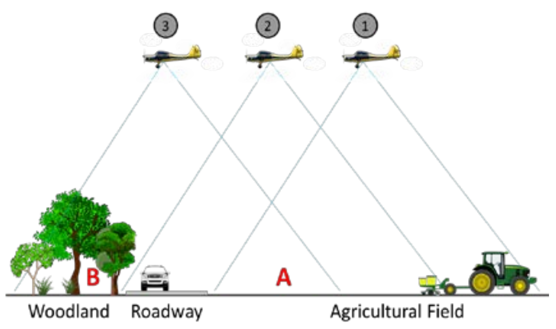


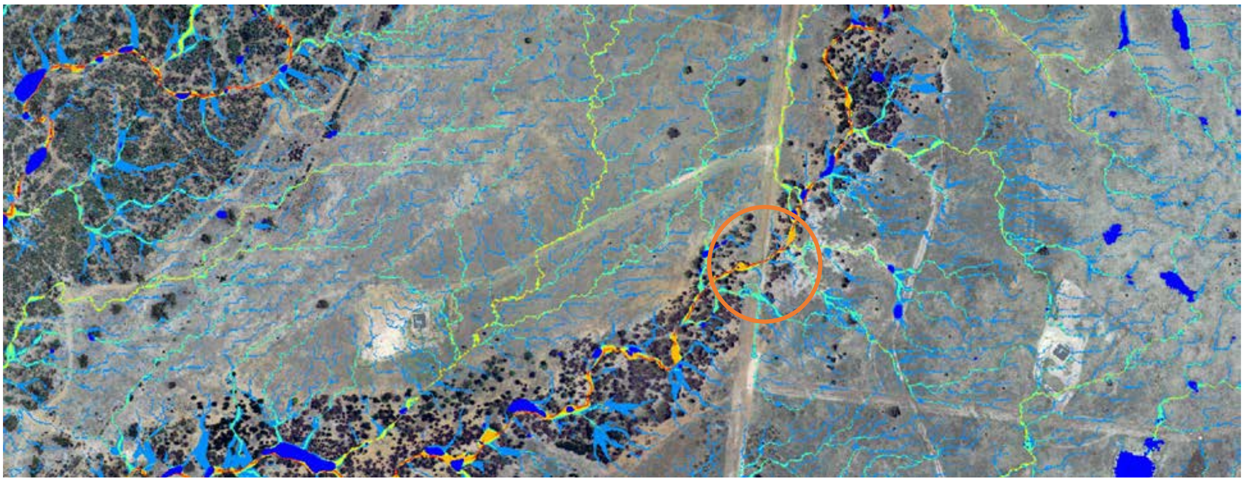

**Figure 13 A point “A” in an agricultural field is identified in three overlapping aerial images. If the position of the aircraft is known for locations 1,2 and 3, the position of point A can be calculated. Ground surface points within wooded areas (e.g. Point B) may need to be inferred from other nearby visible points if the view is obscured by foliage.**

This approach can be used to identify the position of areas of high erosion risk arising from water flow paths from large catchment areas crossing unsealed sections of roadway or coal seam gas access track. For example, Figure 14 shows a section of roadway intersecting a natural water flow path. The road surface has been fortified using imported rocky material to minimise ongoing erosion of the roadway.

a)

**Figure 14 An example of the road maintenance issues (a) arising from the intersection of CSG access tracks with local water flows. The position of this water flow is indicated below (orange circle) (b) to demonstrate the utility of water flow mapping to highlight the location of possible erosion risks. Note that changing colours used in mapping water flows show a sequential 10-fold increase in catchment area from 0.1 ha to 1000 ha.**

b)



An example of a recurring erosion problem on a section of road within the case study property is demonstrated in Figure 15. The road base at this location had been sampled for studying possible dust emissions (see Section 2.8.1) as it represented a site that had been repaired using imported gravel material, possibly in response to an earlier erosion event. Figure 15a shows the road in good condition on 9th of January 2018 with a smooth and firm road surface with coarse gravel held together by an effective interstitial matrix of fine material. Figure 12b shows the same location on 26th of April 2018 with significant loss of fine material from the road base and the formation of large erosion rills. Sections of the roadway nearby had lost all imported gravel and deposition of material had occurred across a nearby intersection with an adjoining access track and in the pastures downslope. The cause of this damage is illustrated in Figure 15c. The water flows predicted using data from an aerial survey in 2015 show clearly that water flows from a large catchment area are intercepted by the access track with water then flowing along the roadway toward the intersection with the adjoining access track. The deposition of material at the intersection and the pasture below this is predicted by the previous modelling. It is possible that such damage will continue to occur unless alternate methods are used to manage the intersection of water flows and roadways.

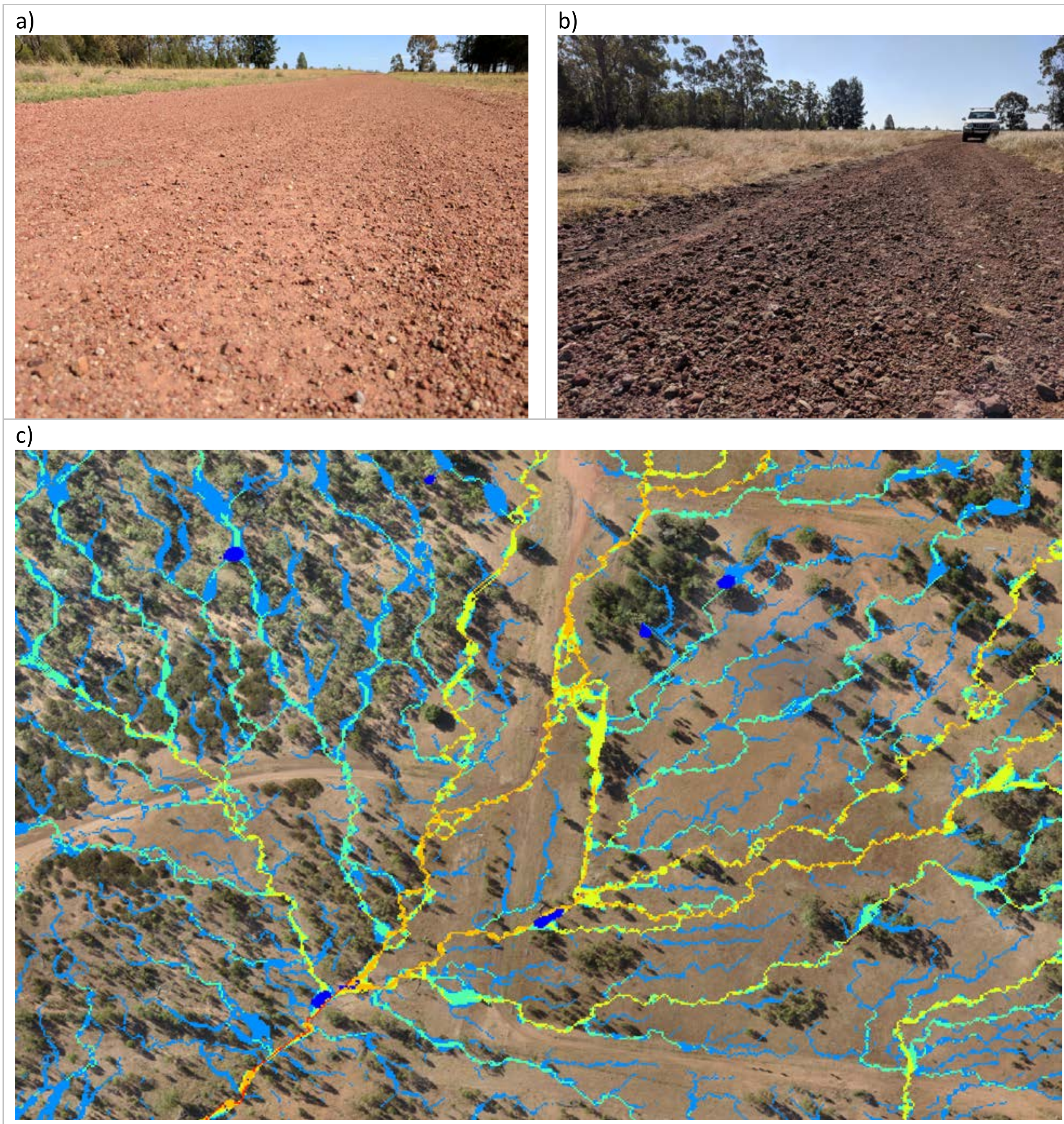


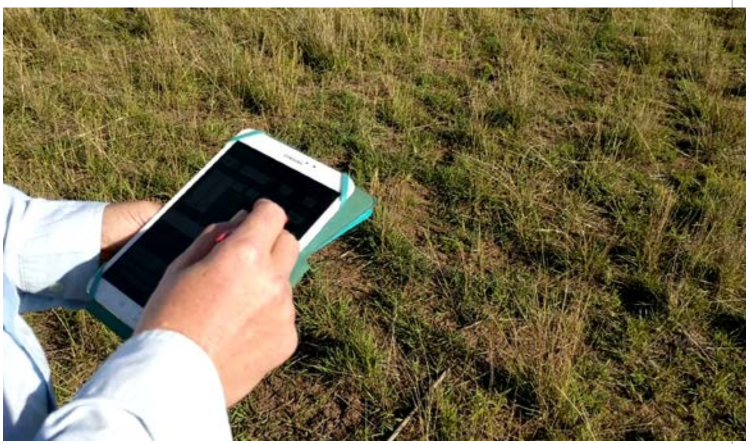

**Figure 15 An example of reoccurring road damage from surface water flows. a) Roadway after resurfacing with gravel, b) roadway after large rainfall event showing loss of fine particles and formation of erosion rill, and c) predicted water flows across roadway indicating the cause of these problems.**

## 2.6 Pasture Monitoring

Pasture condition is important in any grazing system. Pastures not only provide the feed-base for the grazing livestock, but are also key to protecting soils from processes such as erosion.

Pasture condition was mapped at ten locations across the property on 23rd of November 2017. Three transects of 200 m length were sampled at each location with individual distinct patches of pasture condition classified in terms of plant, soil and litter condition using the CSIRO Patchkey software (Abbott & Corfield, 2012). Pasture functional types were identified in each patch, and pasture mass was recorded after visual estimation. Visual estimates of each observer were corrected using measured pasture mass on a range of sampling areas on the day of the survey.

**Figure 16. Location of 30 pasture sampling transects (red) across the case study property (left) recorded using CSIRO Patchkey software (below)**



Pasture and vegetation composition along the study transects was classified into the following groups:

**Palatable, perennial and productive (3P) grasses** - Native decreaser tussock grasses - *eg Heteropogon sp*, Native *Bothriochloa sp*, *Dichanthium sp* and *Themeda sp.*
**Increaser perennial grasses (INPG)** - *eg Aristida sp, Eragrostis sp, Eriachne sp*
**Exotic perennial tussock grasses (EXPGT)** - *eg Cenchris sp (Buffel), Urochloa sp*
**Exotic perennial stoloniferous grasses (EXPGS)** - *eg. Bothriochloa pertusa*
**Annual grasses and legumes (ANNG)** – Various species
**Bare surface areas (BARE)** – No ground layer vegetation
**Low woody vegetation (SHRUBS)** – *e.g. Acacia sp*, woody vegetation usually below 2m.


**Figure 17. Summary data from 30 transects across 10 locations including a) pasture composition (see text for definitions), b) pasture mass, and c) litter cover. In each figure, the proportion of sampled area within each classification is shown.**

Pasture composition was dominated mostly by increaser perennial grasses such as *Aristida* and *Eragrostis* species. Pasture mass and litter cover were mostly low, reflecting the productivity of the soil, grazing pressure and nature of the growing season with below average rainfall. Pasture production within cattle exclusion cages installed onto the property showed approximately 4000 kg/ha of pasture growth for the period from 24$^{th}$ October to 27$^{th}$ April. Standing pasture levels across the property were much lower as a result of continuous grazing over this period. Low grass and litter cover can contribute to increased risk of soil loss from erosion processes.

## 2.7 Vehicle Monitoring

Increased vehicle movements on grazing properties have been raised by farmers as an important factor for the impacts of CSG development on farms (Huth et al, 2018). Possible impacts arise from light and noise effects on livestock and farm households, dust impacts on pasture production and palatability, and damage to farm roads and subsequent erosion. Difficulties in maintaining gates, and thus effectively managing livestock movements, are also related to the increased traffic on farms during CSG construction and operations. However, to date, little information has been published on traffic volumes on farms containing CSG infrastructure.

A series of digital surveillance cameras were installed on the case study property to record the number of vehicle transits at various locations. The photographs were then manually processed to provide information on the type (e.g. 4WD, Bus, Car, Truck, and Machinery) and the number of wheels for each vehicle. Vehicles relating to farm operations, and the research team, were also identified and labelled as such.

### 2.7.1 Traffic volumes over time

The daily number of vehicles entering the property varied greatly over the survey period from mid-October 2017 to mid-January 2018. (Figure 18). The highest traffic volumes were observed during short periods of intense CSG maintenance tasks such as work-over activities for wells or maintenance of CSG access tracks. The traffic during these periods included higher levels of heavy machinery. There were also periods of low traffic volume, including 26 days with no traffic during this 91 day period.

Many of the concerns raised by landholders in previous studies had been recorded in studies during the main construction period of the CSG industry (Huth et al, 2018). Traffic volumes during construction would likely reach levels similar to the peak periods recorded here.

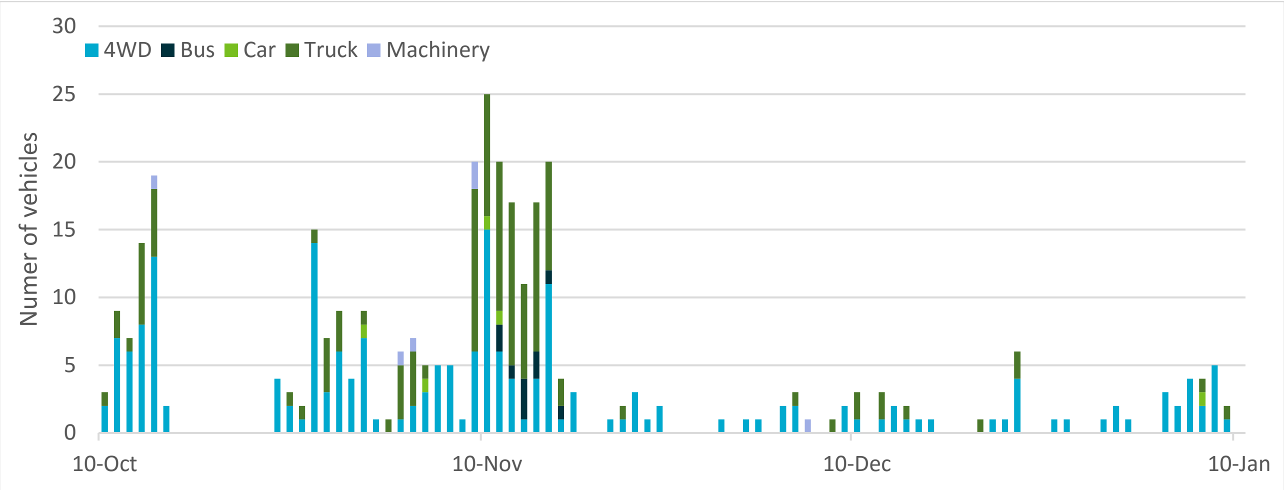



**Figure 18 Number and type of vehicles entering the case study farm from mid-October to mid-January.**

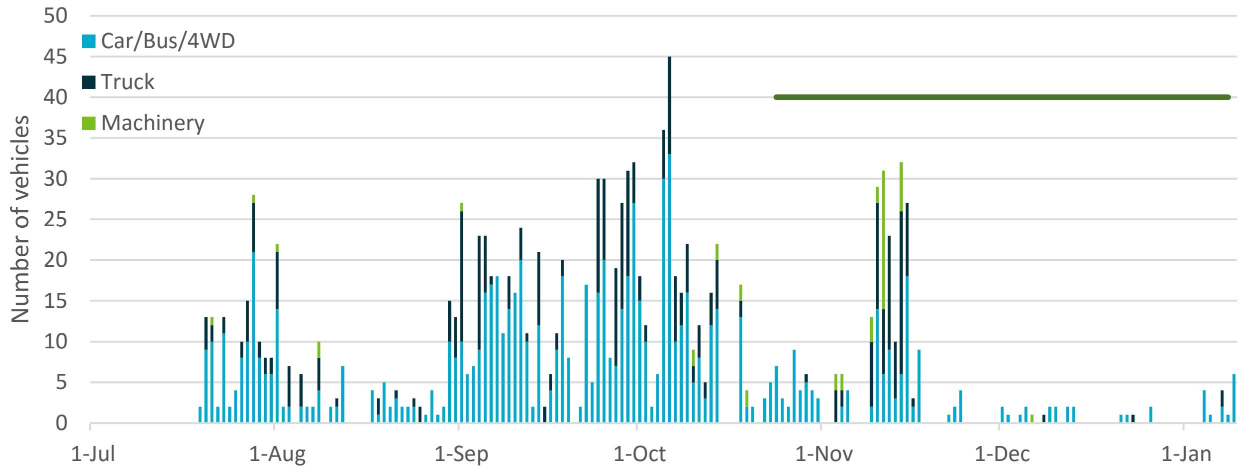



**Figure 19 Number of vehicle passes (both directions) for an internal roadway over a six-month period. The horizontal line indicates the period shown in the previous figure for traffic entering the property.**

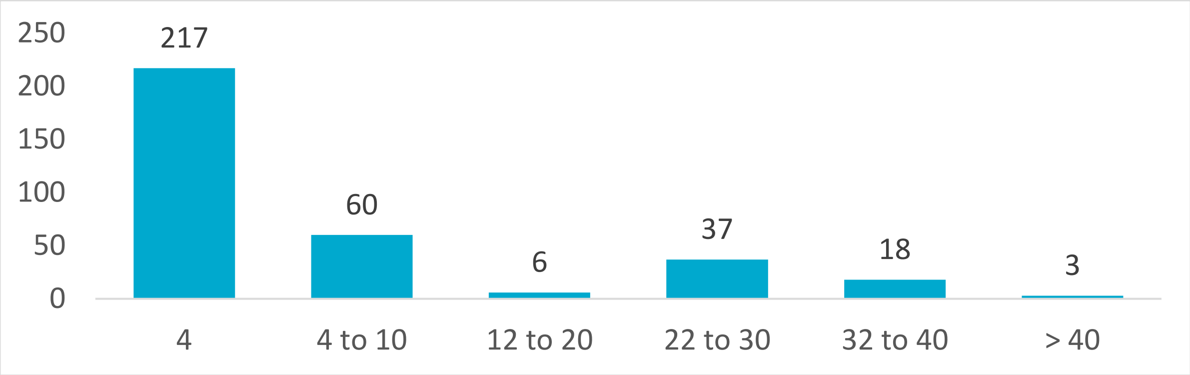
A longer survey period was available for a camera location near the centre of the property. The patterns of vehicle numbers are similar to that entering the property for the period October to January. However, these data indicate much higher volumes earlier in the year. Machinery, such as earth moving equipment represented a lower proportion of the traffic during this time. Some of this earlier traffic was involved in pipeline maintenance on the southern boundary of the property.

### 2.7.2 Vehicle Types

A total of 341 vehicles were recorded entering the property over the given survey period. The number of vehicles within a range of size categories is shown in Figure **20**. In this study, the number of wheels is used as an indicator of size given the relationship between the number of wheels and vehicle carrying capacity and possible dust emission (see Section 2.8.2). Smaller vehicles contributed the most to overall traffic volumes. Vehicles with four wheels (e.g. 4WD, buses and cars) accounted for nearly two-thirds of all vehicles entering the property. The next most common category of vehicle included trucks, or four-wheeled vehicles pulling trailers, with six to ten wheels. However, there were still a significant number of large vehicles entering the property. Vehicles with greater than 22 wheels accounted for 17% of all traffic.

The total number of wheels may provide an indication of the overall risk of damage by the various traffic categories as each wheel is a potential source of compaction or dust. Combining the number of vehicles with the number of wheels per vehicle indicates that overall risk may arise from the larger vehicles. For example, whereas vehicles with four wheels accounted for 64% of all traffic entering the property, they only accounted for 29% of all wheels. Vehicles with greater than 22 wheels accounted for 53% of all wheels.

**a) Number of vehicles**




**b) Number of wheels**

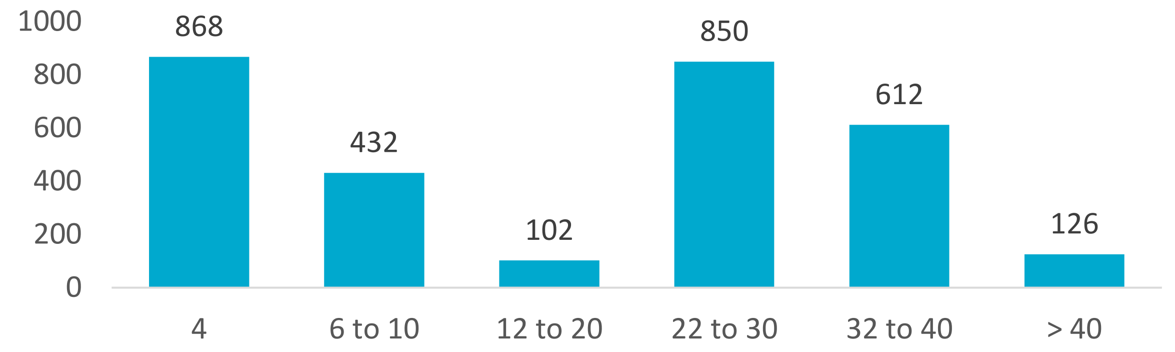



Figure **20** a) Total number of vehicles and b) total number of wheels on vehicles entering the case study farm during the monitoring period. Data are distributed according to vehicle size (ie number of wheels per vehicle).

## 2.8 Dust Emissions

Studies of dust emissions by the United States Environmental Protection Agency (US EPA) have explored the contribution of road and vehicle conditions to dust emissions from unsealed roads. These data have been used by the US EPA in the development of into a simple model of dust emissions that can be used with the data obtained within this study to explore the likely contributions of various factors to dust emissions (US EPA, 2006).

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt (particles smaller than 75 micrometres [µm] in diameter) in the road surface materials. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method.

At industrial sites, where large trucks and other heavy equipment are common, emissions are highly correlated with vehicle weight. The following empirical relationships have been developed expressions may be used to estimate the quantity of size-specific particle emissions per vehicle kilometre travelled (VKT) on an unpaved road.

For vehicles traveling on unpaved surfaces at industrial sites, emissions are estimated from the following equation (US EPA 2006):

$$E = k\left(\frac{s}{12}\right)^{0.9}\left(\frac{W}{3}\right)^{0.45}$$

Where E is a size-specific dust emission (g/km), s is the road surface material silt content (%), W is the mean vehicle mass (t) and k is an empirical constant. The second and third terms in this simple equation can be used to estimate the likely impact of road surface material and vehicle size on relative dust emissions to better understand the impacts of these two variables on farms including CSG infrastructure and operations. In many applications, this simple estimate is further modified according to the number of “dry days”, that is, days with rainfall below a given critical value.

### 2.8.1 Road Conditions

Six sampling points were chosen from across the property to cover the range of road surface materials used as part of the coal seam gas access track network (Figure 21). These road surfaces varied in terms of particle size (Table 5) and road condition (Figure 22). The locations also included roads graded into four native surface soil types and two types of imported gravel. At each location, loose surface material from four transects of 30cm width was collected using a broom and combined for particle size analysis. Samples were thoroughly mixed in the laboratory before being subsampled and passed through eight sieves of varying size to provide information on the distribution of particle size.


**Figure 21 Location of the six road surface sampling points across the case study property.**

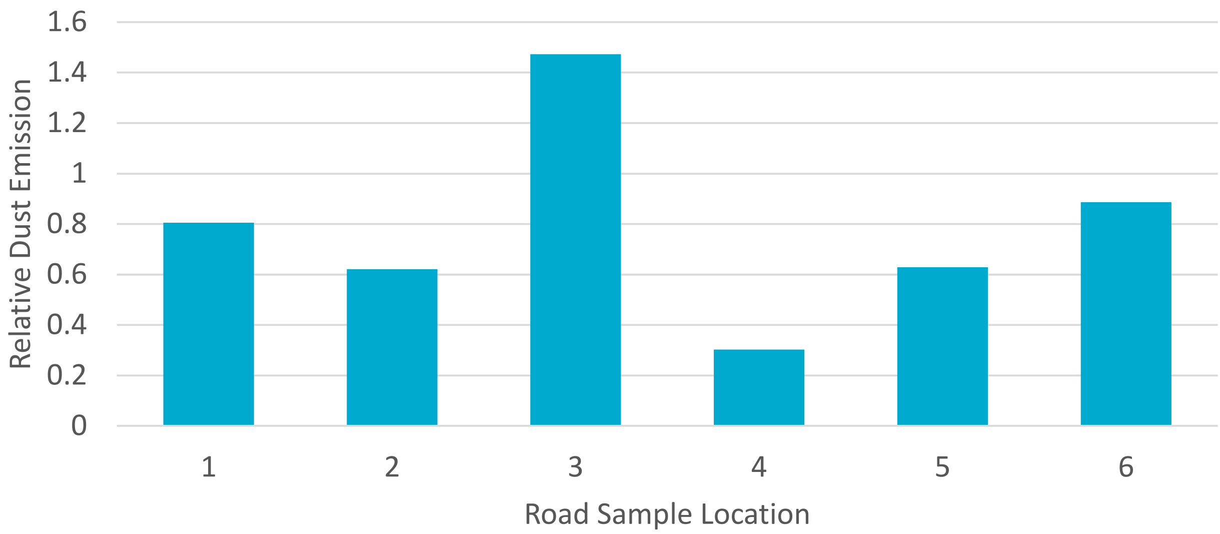
**Table 5 Particle size distributions for loose road surface material from six sampling locations across the case study property. The statistical model used in this study uses the smallest size fraction (<75 µm, highlighted) to estimate the effect of road material on emissions.**

| Site | Description | Proportion by mass (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | >5600 µm | >4000 µm | >2000 µm | >1000 µm | >530 µm | >125 µm | >75 µm | <75 µm | Organic Matter |
| **1** | Native grey sandy soil | 1.4 | 1.5 | 4.6 | 5.8 | 10.0 | 55.3 | 11.4 | **9.4** | 0.4 |
| **2** | Imported red gravel | 15.3 | 8.7 | 17.1 | 10.2 | 7.7 | 28.1 | 5.5 | **7.1** | 0.0 |
| **3** | Native sandy soil | 0.1 | 0.2 | 2.3 | 4.0 | 8.1 | 52.0 | 13.8 | **18.5** | 1.1 |
| **4** | Imported white gravel | 2.1 | 2.9 | 9.8 | 7.8 | 8.6 | 58.9 | 5.0 | **3.2** | 0.2 |
| **5** | Native grey clay soil | 0.3 | 0.1 | 3.4 | 2.2 | 8.7 | 66.9 | 9.8 | **7.2** | 1.3 |
| **6** | Native grey sandy loam soil | 0.1 | 0.1 | 0.7 | 1.8 | 6.8 | 69.7 | 9.3 | **10.5** | 0.1 |


**Figure 22 Photographs of the road surfaces for the six (a-f) sampling sites.**

The results of the analysis are shown in Table 5. Road bases differed greatly in terms of fine and coarse particle composition. The imported red gravel had higher levels of larger particles and the imported white gravel had higher levels of medium sized particles. The proportion of particles < 75µm is used US EPA dust emission model to capture the effect of road base on likely dust emissions. The highest proportion of particles of this size was found in some of the roadways formed from native soils. This is not surprising, given the well-known 'bull dust' phenomena in rural areas of Australia. Unsealed rural roads of inland Australia are well known for the levels of dust created by vehicles. The statistical model suggests that the dust emissions from roads formed from native soil would be up to 4.8 times higher than those from imported gravel roads on the case study property (Table 6). This indicates the likely importance of road base on dust emissions from CSG operations within Queensland.

**Figure 23 Relative dust emission for the size road sampling locations as estimated from the particle size distribution of the road base alone.**




### 2.8.2 Vehicle Conditions

The large variation in vehicle numbers and size over time will cause similarly large variation in the levels of dust emission. Furthermore, monitoring of traffic across the property suggests that traffic levels vary spatially according to the number of wells on any individual track. The size of vehicles is expected to impact dust emissions according to the relationship described the in US EPA Dust Emission Model. The following figure shows relative dust emission for variation in mean number of wheels per vehicle. Vehicle mass was unknown in this study. Therefore, vehicle mass has been estimated from the National Heavy Vehicle Regulator General Mass Limits (www.nhvr.gov.au). Note that masses of vehicles will vary greatly, especially as trucks are loaded and unloaded on site. These results serve only to illustrate the role of vehicle size on possible dust emission.

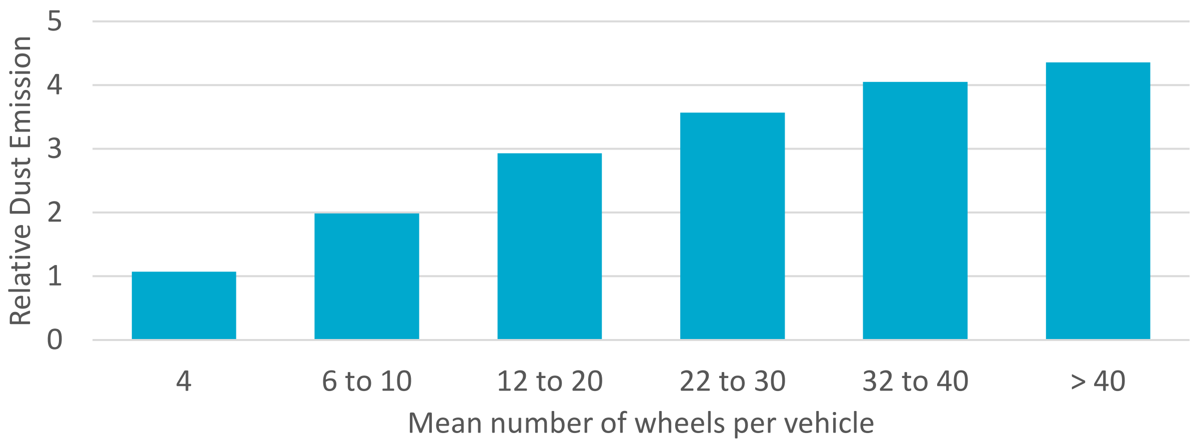



**Figure 24 Variation in relative dust emission for changes in mean number of wheels per vehicle. Results are estimated using US EPA model and show emission relative to that of a 3 tonne vehicle.**

### 2.8.3 Weather Conditions

Simple methods for estimating dust emissions from vehicles, such as the method described above, often account for the effect of dry weather conditions on road surfaces using road surface moisture content or the number of rainfall events within a given study period. The following figure (Figure 24) shows the average number of rainfall events of given amounts for each month for the long term weather record for the township of Miles. This figure shows that there is an average of 3 to 6 days of rainfall of 1 to 5 mm per month across the year, with higher values during the summer and lower values during the winter. This number will, of course, be much lower during drought periods. For much of any year, there are likely to be large numbers of days for which road surface conditions are dry enough to allow dust emission. The long term weather record shows an average of 75 days per year with rainfall greater than 1mm. However, the number of rainfall events also varies greatly between years (Figure 25). The lowest number of rain days (>1mm) in a calendar year occurred in 2002 (43 days) and the highest fell in 1950 (115 days). The above rainfall statistics demonstrate how road moisture conditions are likely to be conducive to dust generation, but also the high variability in this driver of possible dust generation.

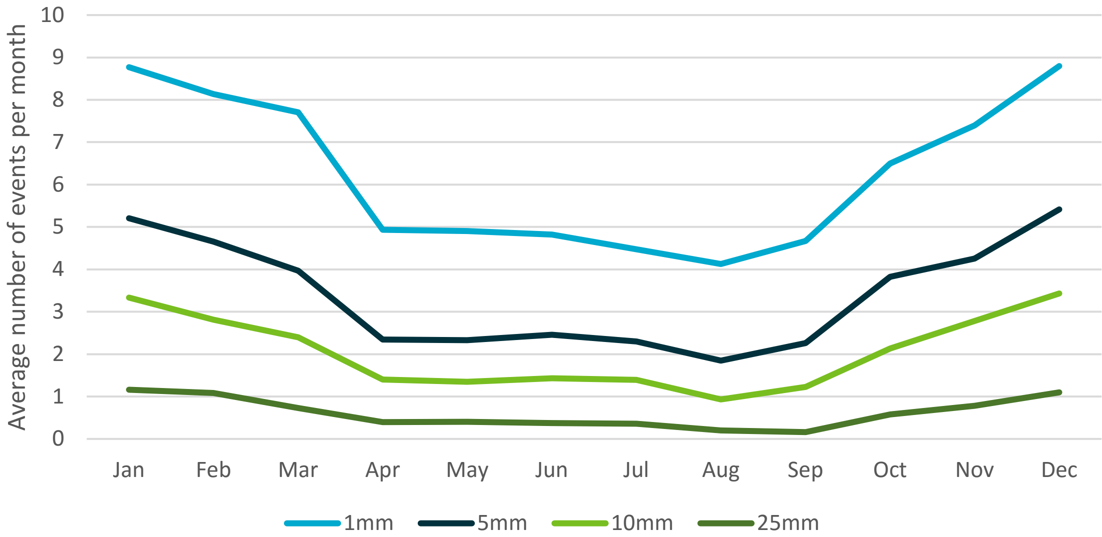



**Figure 25. Average number of rainfall events of various amount per month for the long term weather record for the township of Miles, Qld.**

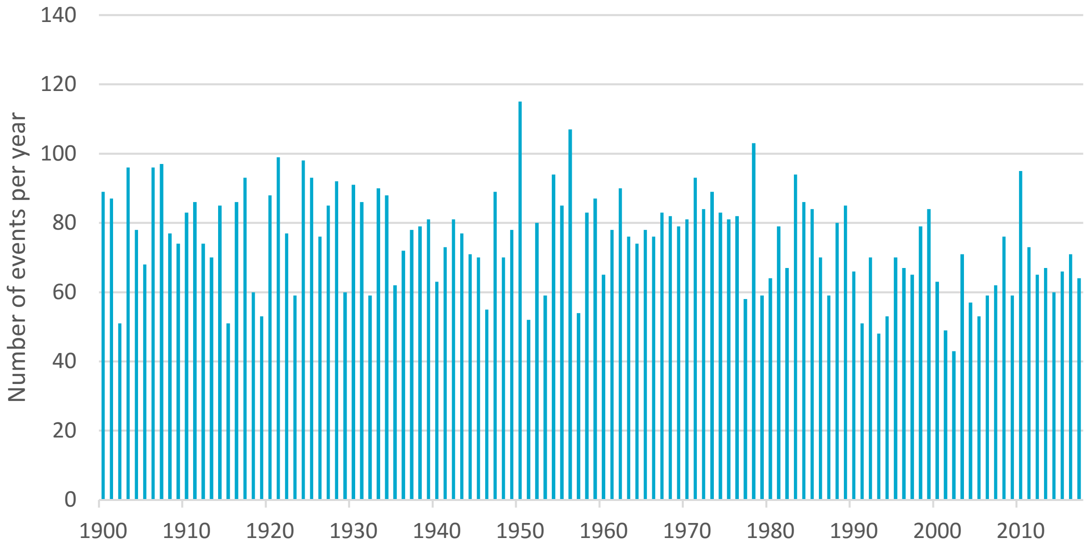



**Figure 26. Number of rainfall events of 1mm or greater per year for the long term weather record for the township of Miles, Qld.**

The rainfall data also give some insight into the likelihood of higher road surface moisture condition. During such periods dust emission is likely to be lower. Furthermore, traffic levels may also be lower as care is used to avoid vehicular damage to roads by road users. For example, high traffic volumes are unlikely for the days following larger rainfall events. Figure 13 shows an average of approximately 1 event of 25mm or greater over summer months. Traffic volumes are likely to be lower for several days after such events leading to lower dust emission for an extended period.

## 2.9 Livestock Monitoring

Studies of livestock behaviour have traditionally been difficult, especially for complex interactions as may be expected for grazing properties with resource infrastructure. However, modern spatial data approaches have proven very useful for not only studying complex issues, but also for communicating them. For these reasons, a range of these approaches have been used here to understand any possible interactions between livestock and CSG infrastructure and vehicles, whilst also understanding other major drivers of livestock behaviour which may influence them.

### 2.9.1 Livestock GPS Monitoring

The location of 16 cattle was recorded using GPS monitoring collars (Figure 26). Collars were installed as part of normal mustering and handling undertaken by the farm manager on 24th of October 2017. Livestock were monitored prior to release to observe behaviour and ensure acceptance of the collar by each animal. Animals were monitored regularly by the farm manager until they were removed. Procedures for safe handling and ethical treatment of all animals were approved by CSIRO Queensland Animal Ethics Committee (Ethics Approval Number: 2017-29, Date of Approval: 18.08.2017). Data was downloaded from the collars after removal on 8th of January 2018 and processed to provide information on animal behaviours in space and time. Behaviour was interpreted from the spatial data with periods of grazing, camping and travelling inferred from locational data. The possible impact of infrastructure or vehicles on livestock was studied by spatial analysis of livestock GPS data with information on the infrastructure footprint, timing of traffic volumes, high resolution vegetation maps, and 3D modelling of the farm topography.

a)

b)

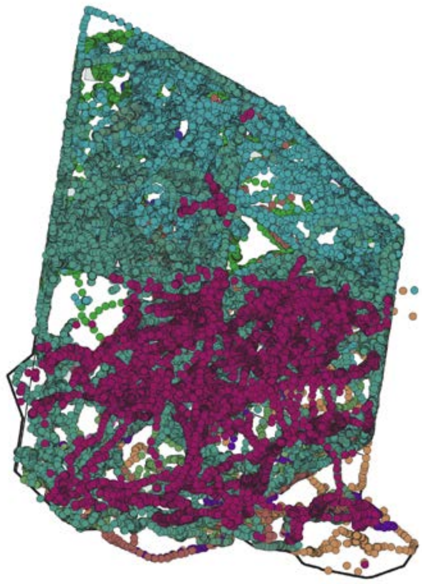


**Figure 27. a) Cow wearing GPS collar used for monitoring livestock during the case study, and b) example location data from GPS collars with different colours representing different animals.**

### 2.9.2 Interactions with vehicles

Whilst the data gathered as part of this project is not able to look at individual interactions between livestock and vehicles, there are several trends and observations that can inform us on the likelihood and nature of interactions between livestock and vehicles.

Figure 27 illustrates the differing patterns of livestock activity and traffic volumes throughout the day. The data within Figure 27 show the total number of vehicles entering or leaving the property for any given hour of the day for 10th October to 9th of January. Traffic volumes follow a diurnal pattern, starting soon after sunrise (note: these data are for a summer period) and ending around sunset, with peak volumes occurring during the middle of the day. Traffic volumes are slightly higher for probable morning tea and lunch periods.

The same figure also shows average animal speed for 16 monitored cattle for each hour of the day. The daily pattern of cattle activity is more complex. Cattle activity increases with sunrise and peaks mid-morning before decreasing through the middle of the day as cattle camp under shelter through the heat of the day. Activity increases again with the afternoon and only declines after sunset. For this reason, cattle can be considered "crepuscular" animals (active during twilight) rather than "diurnal" (active during daylight) or "nocturnal" (active during night). The cattle in this study showed the least activity just prior to sunrise (3 to 4 am), and in the evening after sunset (9 to 10 pm). A slight increase in activity is demonstrated around midnight, with the highest midnight activity observed on the evening of the full moon (4th November 2017).

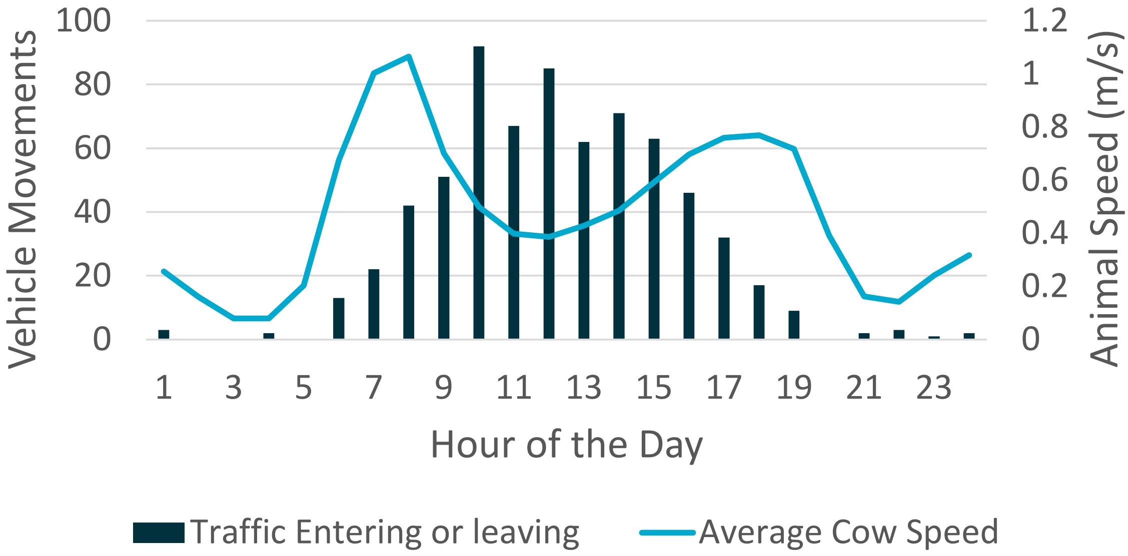



**Figure 28 Comparison of the timing of vehicle movements on or off the case study property and livestock activity.**

### 2.9.3 Interactions with infrastructure

Interactions with CSG infrastructure were evaluated in terms of the time spent at various distances from CSG right-of-ways, and time spent within right-of-ways versus the time spent for equivalent areas of open pasture grass.

Data from the GPS collars on the cattle did not suggest that livestock were avoiding CSG infrastructure. For example, Figure 28 shows very little variation in total time spent by cattle (ie grazing, walking, resting) at various distances from CSG right-of-ways. In fact, when active (ie grazing and walking), cattle spent 18% more time per hectare within right-of-ways than for equivalent areas of open pasture grass nearby.

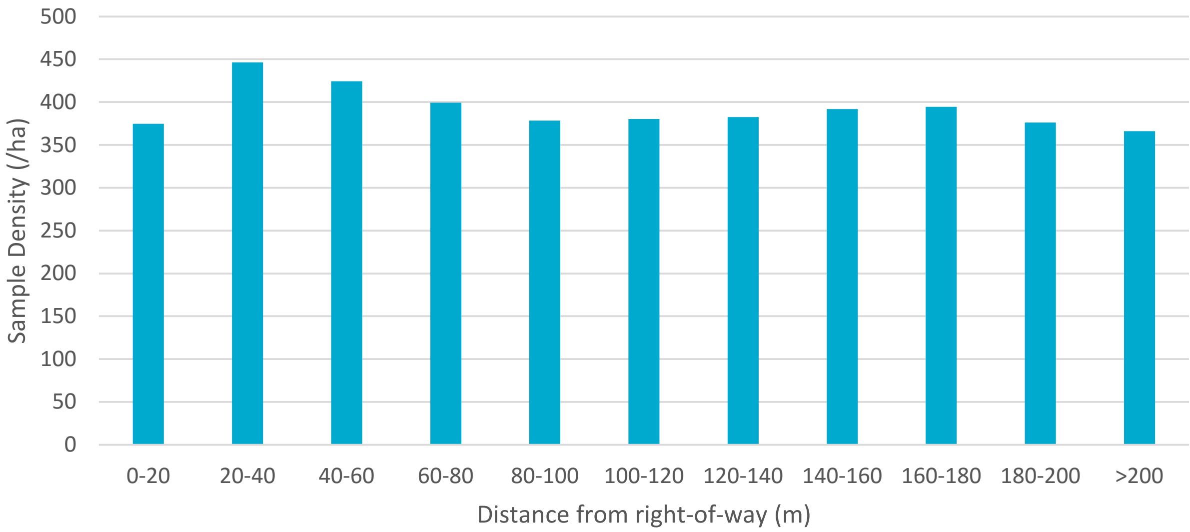



**Figure 29. Variation in the density of cattle GPS observations at various distances from CSG right-of-ways.**

**Figure 30 Damage to CSG access track due to livestock movement following periods of wet weather.**

The apparent preference for elements of the CSG footprint is probably due to several reasons. First, CSG right-of-ways provide ease of thoroughfare across the property. Access tracks and pipelines provide direct routes which are free from obstacles and therefore may be preferentially used by cattle rather than traversing woody areas. Second, many of the pipeline areas have undergone rehabilitation with palatable grass species. These grasses may be preferentially grazed relative to less palatable species found on the property.

The increased use of right-of-ways may suggest an increased risk to soils and pastures undergoing rehabilitation after the installation of CSG infrastructure. As mentioned in earlier sections, soils are often fragile, and minimisation of compaction, mixing and overgrazing is important for effective rehabilitation. The preferential use of right-of-way areas may be a product of the dry seasonal conditions with low pasture biomass across the property. However, this issue of grazing pressure on rehabilitation should be considered by landholders.

Finally, the variation in grazing pressure across the entire property is evident in Figure 30. As expected, grazing is heaviest in areas of open pasture. Pasture availability will be lower in heavily wooded areas due to competition with trees. As a result, larger portions of Victoria Park were not heavily grazed. Installation of CSG infrastructure has also avoided vegetated riparian areas and sections of remnant vegetation. In cases like this, it is possible that CSG infrastructure may be installed into the more productive areas of a grazing property. As a result, the magnitude of the spatial footprint of CSG infrastructure may not accurately represent the production impacts of CSG on grazing. This is similar to findings in cropping systems where the location of CSG infrastructure resulted in differing costs to farmers through impacts on machinery operations (Huth et al, 2015b). This variation in productive capacity across the property should be considered in the planning for CSG infrastructure and compensation arrangements.

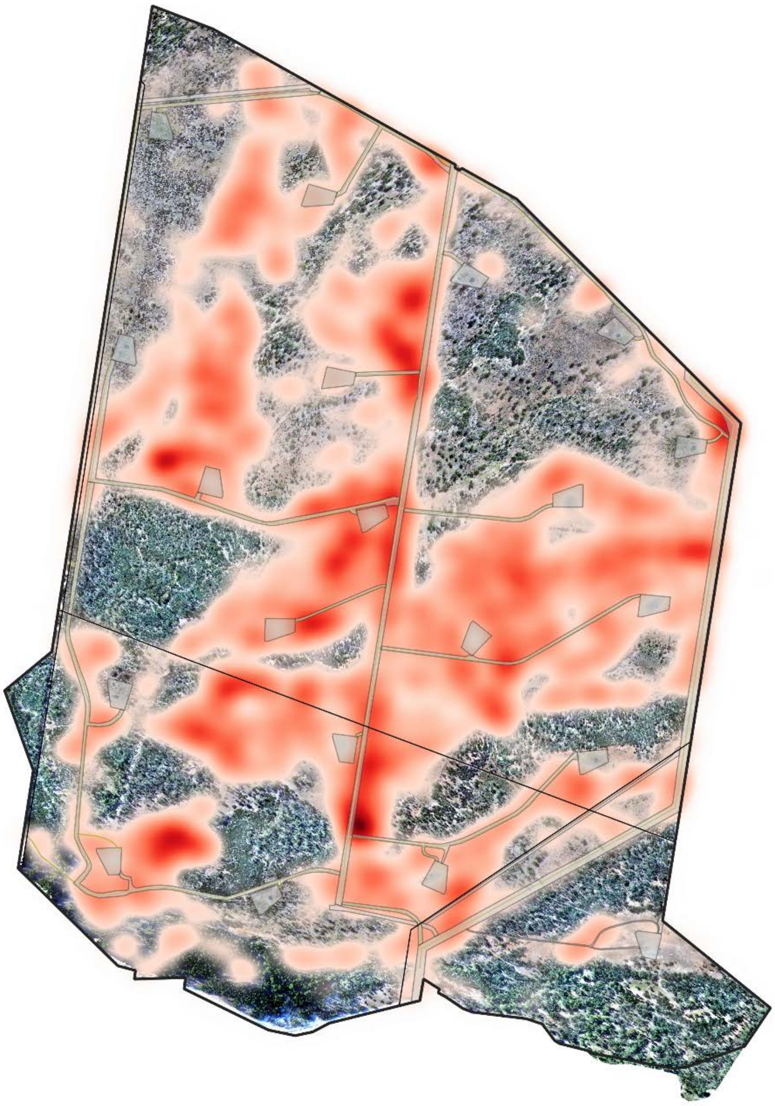


**Figure 31 Heat map showing relative grazing intensity across the case study property. Grazing density varies from very low/nil (transparent), low (pink) to high (dark red).**

# 3 Key Messages

This project addresses a research gap through the investigation of possible CSG impacts on grazing systems whilst echoing some of the same messages arising from the previous research on cropping systems. Some of the key messages are summarised below.

**Soils found in grazing systems are often fragile and need to be carefully managed.** Many of the more resilient soils are used for more intensive, arable agriculture. Installation of CSG infrastructure would need to be undertaken with care, and rehabilitation would need to be tailored to the nature of these soils.

**Damage to roads by erosion processes can be a common and ongoing occurrence.** Care should be used in the location of roadways to minimise interception of water flow paths. More effective road designs or interventions for water management may be required for roads with ongoing damage. Long term risks need to be considered if access tracks are to be retained after decommissioning of CSG wells.

**Traffic volumes on properties with active CSG infrastructure are highly variable in space and time.** The number and type of vehicles varies greatly from day to day, and the possible impact of vehicles on farm operations will further depend on the location of CSG activity within the property. For these reasons, whilst individual interactions between farm operations or livestock and CSG traffic may be observed (e.g. animals disturbed by passing vehicles), identification of any persistent impact may be difficult.

**Traffic on properties involves a wide range of vehicle types and sizes.** Whilst a 4WD is the most common vehicle type, much of the CSG-related traffic involves much larger vehicles. These larger vehicles may present a disproportionate contribution to issues of compaction, road damage and dust generation.

**Dust emissions from vehicles is also likely to be highly variable.** These emissions are highly related to road surface conditions and these can change with ongoing repair to roadways. As stated above, traffic volumes are also highly variable. Furthermore, variation in rainfall is likely to impact on both dust generation and dust accumulation on pasture grasses. Again, whist observations of dust emission and accumulation on pastures is possible, the likely impact of dust on grazing operations will be difficult to detect.

**This project found no evidence of livestock avoiding CSG infrastructure.** Conversely, the data suggested higher occupancy within CSG right-of-ways relative to neighbouring grassy areas. However, the behaviour identified within the study may only be representative for the pasture and climate conditions of the study period.

**Use of the CSG footprint by livestock may present a problem for rehabilitation of soils and pastures.** It is possible that increased soil compaction and grazing by livestock may adversely impact on areas undergoing rehabilitation after CSG installation. Methods for effectively rehabilitating soils and pastures on operating grazing properties need to be considered in a wholistic approach to managing coexistence of CSG and farming.

**The variation in productive capacity across the property should be considered when planning CSG infrastructure and compensation arrangements.** The magnitude of the spatial footprint of CSG infrastructure may not accurately represent the production impacts of CSG on grazing. Livestock do not utilise all sections of a grazing properties equally.  As a result, it is possible that CSG infrastructure could be positioned onto the more productive areas within a property.  This should be considered in the design of infrastructure on farms.

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