# Potential consequences of CSG-induced subsidence for farming operations on the Condamine alluvial floodplain

## Final Report

July 2023

## DISCLAIMER

# Executive Summary

Over recent years coal seam gas (CSG) induced subsidence has emerged as a significant concern for landholders in areas of dryland and irrigated farming located on the Condamine River flood plain near Dalby in southern Queensland.

Farming systems on the flood plain are highly developed. There is concern that as these farming systems rely on highly specialised farming techniques and very low slope, even minor subsidence could have consequential impact on farming operations and productivity.

Landholders and agricultural peak bodies have also raised concerns about the adequacy of the regulatory framework to protect landholders from the potential impacts of CSG- induced subsidence on farming operations.

In response the Commission has undertaken two bodies of work: (a) a review of the regulatory framework; and (b) a project to assess the consequence of CSG-induced subsidence on farming enterprises. This report is in relation to the second body of work.

This project seeks to better understand the risks of CSG-induced subsidence impact to various types of irrigated and dryland farming enterprises and to identify the matters that are required to be considered when a farm assessment is carried. It is intended outcomes from this project will be key inputs to the development of regulatory guidelines for the carrying out farm assessments under a future regulatory framework.

The approach taken has been to identify those types of farming operations most susceptible to CSG-induced subsidence within focus areas and engage with landholders with these types of operations. Through engagement with those landholders about their concerns, the matters that will need to be considered during a farm assessment were identified.

The criteria used to identify focus areas included: proximity to CSG development; maturity of nearby CSG development; low existing land slope; maximum predicted subsidence and rate of subsidence; and dryland as well as irrigated farm land.

Landholder advice together with expert advice is that effective drainage is the most important factor of production. The report explores interaction between drainage and potential CSG-induced subsidence impact for different farming systems including: furrow irrigation; bankless irrigation; overhead irrigation and dryland farming.

In summary the key conclusions are:

1. **Drainage is the key issue.**
   The farmland of the Condamine plains is highly productive and carefully managed. The potential for impairment of farm drainage is the key concern for landholders. If effective drainage is impaired through landform change resulting from CSG-induced subsidence there will be some (potentially high) reduction of productivity.

2. **CSG-induced subsidence must be considered in the context of other variations.**
   Any variation in landform due to CSG-induced subsidence will be superimposed on landform variations due to other causes. Any CSG-induced subsidence will be a permanent change superimposed on any background landform changes. Modern precision farming technologies have the potential to assist in identifying contributing causes of landform change.

3. **Each farm is different.**
   Each farm is different in terms of susceptibility to the impact of subsidence on farming operations. Under the planned regulatory framework regional scale assessment will identify areas where farms are at higher risk of impacts from CSG-induced subsidence. Within those areas each farm would need to be assessed for impact on farm operations. The planned regulatory framework provides for such farm scale assessments.

4. **Further farm scale predictive modelling is critical.**
   OGIA maintains that while the regional modelling indicates an overall subsidence pattern, it is not designed for direct farm scale assessment. Ongoing work from OGIA suggest that the difference in magnitude of subsidence along any direction across a farm field will vary over time, however, at any given point in time the difference is likely to be only a small fraction of the maximum subsidence of the farm field as a whole. CSG-induced subsidence is also expected to be progressive with generally a period of relatively faster subsidence at early stages.

5. **It is expected that rectification work may be required on some farmland because of CSG-induced subsidence.**
   Given the previously summarised current understanding of the characteristics of CSG- induced subsidence, interventions to manage the impact on farming operations is likely to be needed in some situations.

The following recommendations are outlined in the report

1. **Re-evaluate consequences of subsidence on individual farms when farm scale subsidence modelling is complete -** conclusions about the expected impact of CSG- induced subsidence are currently based on regional modelling and should be reviewed by OGIA (with appropriate technical experts) when farm scale modelling is complete.

2. **Provide landholders with farm field scale data -** because each farm is different, landholders need be able to assess data relevant to their individual farms. Airborne LiDAR can identify topographic profiles at a fine scale and should be made accessible to landholders.

3. **Develop ways of representing changes to drainage of natural landforms –** further work developing techniques for dryland and overhead irrigated farm fields that focus on representing any changes to effective drainage along natural flow paths is required.

4. **Assess farm field landform irregularities -** to assist in development of systematic methods and guidelines associated with the regulatory framework, pilot assessments of farm field landform irregularities currently claimed to be caused by CSG-induced subsidence should be carried out and results shared with landholders in potentially affected areas to provide clarity.

5. **Assess potential for landscape scale impacts to the overland flow -** the focus of the project is on the potential consequences of landform change at the farm field scale on farming operations. The potential impact of landform changes at the broad landscape scale to significantly alter overland flow patterns needs to be assessed.

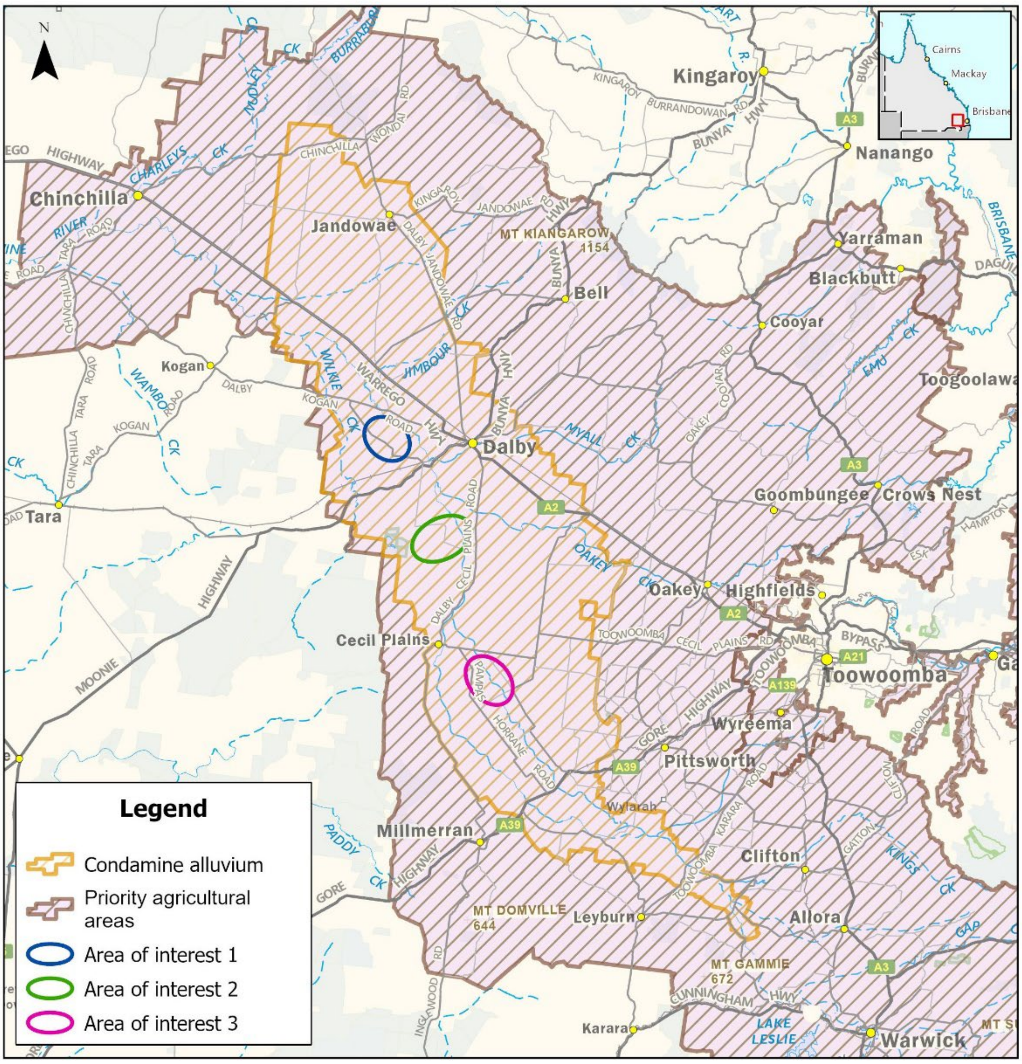
## Contents

# Introduction

## Context

Over recent years coal seam gas (CSG) induced subsidence has emerged as a significant concern for landholders in areas of dryland and irrigated farming located on the Condamine River flood plain near Dalby (**Map 1**).

The flood plain is prime agricultural land, supporting a major agricultural industry that produces a range broadacre crops including cotton, grains, and legumes as well a feedlots and grazing. The region is a significant contributor to the Queensland agricultural production value, with commodities destined for the domestic and export markets. The agricultural sector in the region supports the broader economy, contributing by direct spending and providing jobs in local towns such as Dalby and Toowoomba. It is understood that due to the quality of the soils and access to water, the region can produce both winter and summer crops, maximizing seasonal productivity.




**Map 1 – Area of Interest.** The Condamine alluvium overlays the Priority Agricultural Areas

Farming systems on the flood plain are highly developed. There is concern that as these farming systems rely on highly specialised farming techniques and very low slope, even minor subsidence could have consequential impact on farming operations and productivity. Some landholders feel that CSG subsidence will impact farming operations significantly and could cause farming of some lands to become impracticable.

Landholders and agricultural peak bodies have also raised concerns about the adequacy of the regulatory framework to protect landholders from the potential impacts of CSG- induced subsidence on farming operations.

In response to these concerns the GasFields Commission Queensland (the Commission) has undertaken two bodies of work:

- A review of the regulatory framework to identify potential regulatory enhancements; and
- A project to assess the consequence of CSG-induced subsidence on farming enterprises.

This report is in relation to the second body of work.

Movement of the surface of the ground (ground movement) can be caused by a range of factors such as swelling and shrinkage of soil in response to wetting and drying. CSG extraction will cause the land surface to subside in and adjacent to CSG well fields. This is referred to as CSG-induced subsidence (Underground Water Impact Report (UWIR) 2021[1]). While ground movement due to factors such as wetting and drying are temporary and manageable, CSG-induced subsidence is permanent.

The Office of Groundwater Impact Assessment (OGIA) undertook a regional assessment of CSG-induced subsidence for the purpose of determining impacts on environmental values in the 2021 UWIR1. OGIA noted (p103) existing ground movement of about 100mm has been observed within established wellfields as CSG-induced subsidence. The 2022 Annual Report on Surat CMA noted (p20) that subsidence in the area had increased to about 120mm broadly in line with model predictions based on current monitoring data.

Based on the regional modelling undertaken as part of the UWIR assessment, OGIA predicted that, in most areas across the Condamine alluvium, subsidence is likely to be 100mm but may be around 175mm around more heavily developed CSG fields (2021 UWIR-p108). More relevant to farming operations is any change in land slope caused by CSG-induced subsidence. In that regard, the UWIR predicted subsidence would cause a change of land slope of <10 mm/km (0.001%) over most areas, up to 40 mm/km (0.004%) over some areas, and a high probably of more than 50 mm/km (0.005%) in a localised area north of Cecil Plains.

The 2021 UWIR details a strategy for monitoring of subsidence including tools and techniques, baseline monitoring and trend monitoring. It describes two technologies used for monitoring ground movement, InSAR (interferometric Synthetic Aperture Radar) and LiDAR (Light Detection and Ranging). InSAR is a satellite-based technology that gives information about the change in the height of ground surface at suitable points each time the satellite passes overhead. InSAR is good at showing long-term trends in CSG-induced subsidence in an area.

LiDAR data is collected by aircraft or drone surveys. OGIA tested various methods for baseline and concluded that the airborne LiDAR is an effective method for establishing baseline landform – including the slope of a farm field and any variations within a farm field.

[1] OGIA, 2021. Underground Water Impact Report 2021 for the Surat Cumulative Management Area. OGIA, Brisbane. https://www.rdmw.qld.gov.au/data/assets/pdf_file/0008/1584728/uwir-2021-report.pdf

The UWIR strategy for monitoring primarily relies on InSAR for trend monitoring and LiDAR for establishing baseline landforms.

## Planned regulatory framework

Under the existing statutory arrangements, if CSG induced subsidence affects farming operations, the CSG company has an obligation to compensate the landholder. However, the burden of proof rests with the landholder and the Commission is of the view that procedural systems are generally unsuitable for managing the issue.

To address this issue, in May 2023 the Government accepted the recommendations of the Commission to develop a new regulatory framework specifically designed to manage the impact of CSG induced subsidence on farming operations, with support of OGIA.

The framework, once implemented, will provide a statutory process to ensure that landholders will be compensated for impacts directly attributable to CSG-induced subsidence, including the cost of management needed to correct any impacts of CSG induced subsidence, as well as for any associated loss of farm productivity. The legislative framework will also provide mechanisms that avoid individual landholders needing to prove that CSG induced subsidence has or is expected to affect their farming operations.

The elements of the planned regulatory framework relevant to this report are as follows:

1. The *regional predictive modelling* carried out by OGIA be utilised to identify areas where farming operations are at higher risk of being disrupted by CSG-induced subsidence.
2. *Farm scale predictive modelling tools* be developed by OGIA to assess future potential CSG-induced subsidence at the farm field scale.
3. *Farm assessments* be carried out for higher risk farms to identify the consequence of predicted subsidence on farming operations, thereby providing a basis for planning and an agreement between a landholder and the CSG operator if remedial works are needed. The assessments are proposed to be carried out in consultation with the relevant landholder and CSG operator using tools developed by OGIA, with expert support where necessary and with a dispute resolution process available.
4. An independent *farm investigation* available to landholders who believe that subsidence impacts have occurred that were not identified through a farm assessment.

## Objective and scope

This project seeks to better understand the risks of CSG-induced subsidence impact to various types of farming enterprises and to identify the matters that landholders require to be considered when a farm assessment is carried out under the planned regulatory framework.

It is intended outcomes from this project will be key inputs to the development of regulatory guidelines for the carrying out farm assessments under a future regulatory framework.

The project deals with the direct impact of CSG induced subsidence on farming operations. Broader potential landscape impacts on overland flow of water which may in turn impact individual farms and or potential impacts on engineered structures (such as farm dams) are beyond the scope of the project.

## Project methodology

The approach taken has been to identify those types of farming operations most susceptible to CSG-induced subsidence and engage with landholders with these types of operations. The approach has also seen the project engage with landholders that are likely to eventually experience CSG-induced subsidence to some degree. To focus this engagement a number of pilot sites were adopted. Through engagement with those landholders about their concerns, the matters that will need to be considered during a farm assessment were identified.

### Pilot sites

Pilot sites were selected to collectively cover a range of situational criteria relevant to CSG-induced subsidence. The criteria used are as follows:

- dryland and irrigated farm systems;
- proximity to CSG development;
- density, time sequencing and configuration of planned CSG wells;
- maturity of nearby CSG development;
- low existing land slope; and
- maximum predicted subsidence and rate of subsidence.

These criteria and current regional model were used to identify 10 pilot sites. Each site is a farm containing 4 to 15 individual farm fields. Individual farm fields could be irrigation or dryland and several of the pilot sites contained both types.

### Expert advisors

To assist in understanding the issues of concern for landholders, expert advisors in irrigation design and agronomy were engaged. The individuals have extensive practical and professional experience and operate commercially in the geographic area of the pilot sites. They understand the challenges of irrigation and dryland farming and the potential consequences of changes in landform for farming practice. The expert advisors were proposed by one or more of the pilot site landholders.

The expert advisors initially worked directly with the project team improving understanding of the potential consequences of subsidence. Subsequently the expert advisors were part of the landholder workshops, where they engaged in discussions with landholders, and in a subsequent landholder briefing.

## Workshops and briefings

Two rounds of engagement workshops were held with pilot site landholders. At the request of the landholders', interested neighbours and community members were invited to participate in the workshops. To improve efficiency, pilot site landholders were grouped into three groups which were small enough to facilitate active engagement. The groups met at either a pilot site or a local urban centre.

### First round of workshop 1 – June 2022

The focus of the first round of workshops was to introduce the project and to seek an initial understanding of the concerns of landholders as they relate to potential consequence of CSG-induced subsidence on farming operations.

Assessment of the farm scale consequences of predicted subsidence under a possible future regulatory framework depend on the availability of farm scale predictions of subsidence rather than the regional predictions currently carried out as part of the UWIR process. At the workshop, OGIA discussed the future development of farm scale modelling and OGIA's current understanding, from its own work and that of other researchers, of the potential characteristics of CSG-induced subsidence at the farm scale.

The Commission then introduced the consequence project. The Commission explained that it was in the progress of engaging expert advisors that had been suggested by pilot site landholders and that they would attend the next workshop.

Workshop participants then summarised the types of concerns they had in relation to subsidence.

The Commission provided an update on progress with the regulatory review. Landholders expressed the view that improvements to regulatory system to remove the burden of proof of CSG- induced subsidence from the landholder is essential.

### Second round of workshops – August 2022

The second round of workshops focused specifically on the consequence project and detailed discussions around farming systems, farm management practices and potential issues that could arise from slope or landform change. The expert advisors were introduced to those landholders who did not already know them from previous professional involvement.

The original intention when the project was in the planning stage was that farm scale predictions of CSG subsidence for the pilot sites would be the basis for discussion with pilot sites landholders about the consequence of the predicted changes on farming operations on their individual farm fields. However, while OGIA supported the project with a range of useful technical information such as the InSAR, LiDAR, some preliminary local scale modelling and scientific understanding of the subsidence process, detailed farm scale model predictions were not available in the timeframe of the project because that task continued to be outside the statutory mandate of OGIA. Therefore, the approach adopted was to identify though discussion with landholders the important vulnerabilities to farming operations from potential landform change.

Accordingly, information about each of the farm fields on a pilot site was made available to the workshop groups to stimulate discussion and provide a reference point for landholders to highlight particular aspects of farm management that could be impacted by subsidence.

The information provided to stimulate that discussion comprised aerial imagery of pilot sites, gradients along irrigation furrows derived from LiDAR data, and topographic maps of farms also derived from LiDAR data. In practice, discussion tended to centre around a small number of pilot sites which provided an adequate basis for landholders as a group to discuss the issues of concern to them.

### Subsequent briefings

In September 2022 and March 2023 briefings were held at Dalby. Those briefings covered the consequence project, progress with the proposal for a new regulatory framework and tools being developed by OGIA relevant to the project.

### Range of concerns raised

The primary concern of landholders was about any potential impact on drainage systems that could cause damage to crops through waterlogging, There were also concerns about impact on drainage systems causing disruptions to access to farm fields, the timing of the movement of farm machinery and disruptions to weed and disease control programs.

While supporting the focus of the project on direct on-farm impacts, landholders considered that the effect of CSG-induced subsidence on regional overland flow of water was of equal concern and should be an important focus.

There are a number of claims that have been made by landholders about landform irregularities such as localised depressions causing ponding on farm fields that are being attributed to CSG-induced subsidence. These irregulates are not consistent with the currently understood expected pattern of CSG- induced subsidence, however this has not been tested through thorough investigation. While the cause of existing landform irregularities is outside the scope of the project it is a concern for landholders and should be further investigated.

Some landholders continue to have concerns about the adequacy of LiDAR for establishing baseline trends in landform changes. LiDAR is reflected by ponded water and crops on the land surface, preventing the identification of the soil surface. However, OGIA considers that as data continues to be collected from multiple runs at different points of time a sound baseline is being established. There were also concerns raised with InSAR data due to the identified limited penetration of datapoints in cultivated areas. This is another area of focus for OGIA in terms of its monitoring of CSG-induced subsidence.

Landholders were also concerned that perceptions about potential impacts on the economic viability of farming operations, potential flow on impacts to finance and other obligations. Whilst these matters are out of scope for this report, examples of these concerns are relate to the potential for:

- reduction in yield and increased costs affect the profitability of farming operations and therefore the ability to service debt;
- diminution of farm value due to the impacts of CSG-induced subsidence;
- production impacts as a result of the impacts of CSG-induced subsidence may restrict farming operations to meet forward (contracted) sales commitments; and
- impact on Environment, Social and Governance obligations for agricultural enterprises.

Landholders also noted concern around stress and mental health issues relating to uncertainty around CSG-induced subsidence impacts and protections.

## Drainage is the central concern

Crop yield of a farm field varies over small distances depending on many factors such as drainage, soil type, salinity, nutrient content and disease. Modern precision agriculture data shows that variations in these factors can lead to 50% variations in yields over very small distances within a farm field. Precision agriculture involves understanding the differences and changing agronomic practices over small (20m -30m) grid spacings to optimise productivity. Appendix A is an example that gives some understanding of the complexity of the variability.

Landholder advice provided through project engagement together with expert advice is that within this complex background of variability, effective drainage is the most important factor of production. This is consistent with OGIA's conclusions reported in the UWIR 2021 which also guided their approach to establishing baseline slope and drainage, and reporting of subsidence predictions.

If drainage is impaired to the extent that crops remain inundated with water for long periods (which maybe a matter of days), then crop yield will be reduced. There is some difference in the sensitivity of different crops to prolonged inundation. For example, corn and cotton are typically more tolerant of inundation than legumes such as chickpeas. However, corn and cotton also suffer large yield penalties after relatively short inundation times. In addition to reducing crop growth, prolonged inundation can also result in disease which further reduces crop yield. Prolonged inundation can cause loss of soil structure. Significant inundation also causes the bogging of machinery preventing access to fields

Farms on low slope lands in the area are highly productive. However, low slope farm fields have drainage challenges during wet periods and are therefore more susceptible to any additional issues arising from CSG-induced subsidence. Also, some farming systems by their inherent design are more susceptible to any additional drainage issues resulting from CSG-induced subsidence, as discussed in a later section.

However, irrespective of the drainage susceptibility of a farm to CSG-induced subsidence, there are other changes to landform that may affect drainage. Any CSG-induced subsidence impact on drainage will be superimposed over these changes as discussed below.

### Background drainage changes

Most farms on which modern irrigation is practiced will have had some degree of levelling carried out to establish optimal and uniform gradients. When a farm field is initially developed soil is often moved from higher positions to lower positions such as natural drainage lines to establish uniform gradients. Levelling may also be carried out as a part of the reconfiguring a farm, for example to join adjacent fields to create a single field. After any of these operations the 'fill' areas tend to subsequently compact and settle disrupting the levelled surface (**Figure 1**). If those disruptions become sufficiently significant, further minor levelling or 'brushing' will be needed.

Some degree of leveling may be necessary to repair erosion. During wet periods water can break out of a drainage feature and run across a field. Once a flow path is established, flow concentrates along the path causing erosion. Settlement of fill introduced to repair erosion may continue with landholders carrying out brushing to the affected parts of the farm field to return the affected area to full productivity as soon as possible (**Figure 2**).

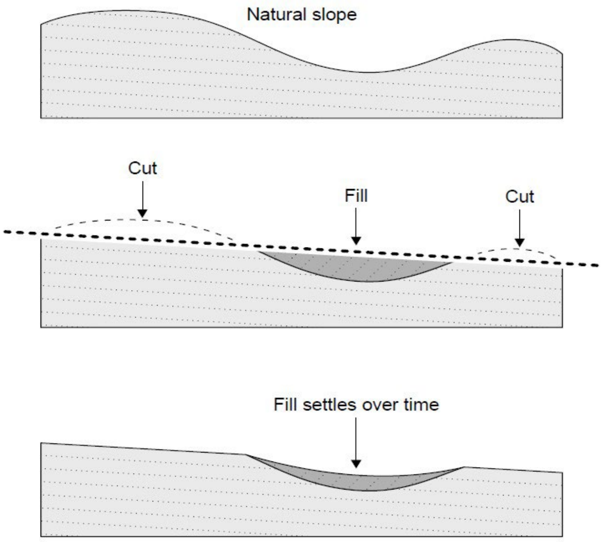



**Figure 1 – Drainage issues after levelling**. When land is levelled by moving soil from high areas to fill low areas, the fill settles over time causing drainage difficulties. Further leveling may be needed to restore drainage efficiency.

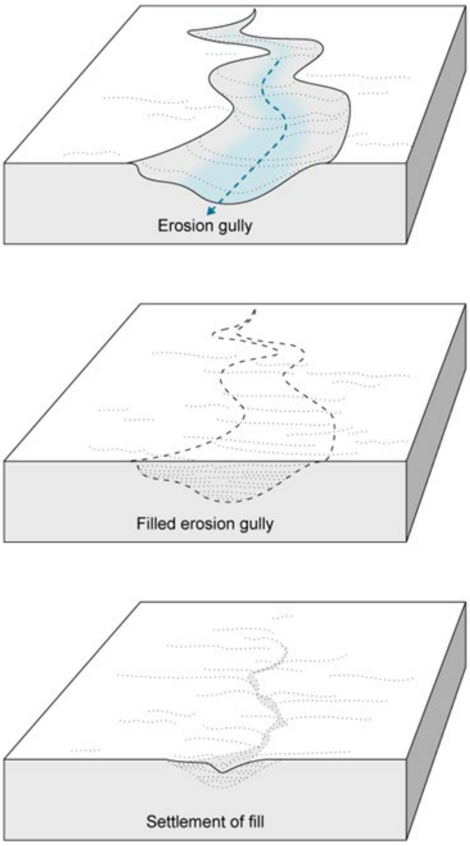



**Figure 2 – Drainage issues after erosion**. The movement of flood water over farmland can leave erosion gullies. Fill material introduced to repair the erosion may settle over time causing drainage difficulties.

All farming operations are different and need to be considered on a case-by-case basis. While some farm fields rarely need brushing, more typically it is carried out every 10 plus years. Some farm operations would like to do it more often, but the practice of levelling is an expensive operation and the benefits achieved need to exceed the cost and loss of production. As more detailed data on yield reductions in low areas within a farm field becomes available through precision agriculture techniques, farmers are more able to identify where the financial benefits of brushing outweigh the costs.

# Drainage vulnerabilities for different types of farming

If CSG-induced subsidence changes the landform of a farm field sufficiently to impair effective drainage then levelling, brushing or the regrading drain works may be needed. The vulnerabilities of drainage to CSG-induced subsidence depends on the method of farming carried out. For very flat land, relevelling may be needed. For tail drains and tail water return systems with low grades, regrading and desilting may be needed. A later section discusses the difficulties associated with levelling. The vulnerabilities of different methods that would need to be considered during a farm assessment are discussed in the following sections.

## Furrow irrigation

Furrow irrigation is the most common irrigation technique in the area. Water may be taken under water entitlement from a water bore, watercourse or as overland flow and may be held in a farm dam storage. Water is supplied directly from a water bore or released from the storage into a supply channel that carries it to the farm fields. Water is diverted from the channel into the head ditch of each farm field.

To commence irrigation siphons are set to move water out of the head ditch into the furrows. After gravitating along the furrows excess water drains into a tail drain. A tailwater return system collects water from the tail drains for return and lifting back into the dam. The basic arrangement of these components is set out in **Figure 3**.

### Furrow slope

The generally preferred furrow slope for conventional flood irrigation is 0.1% (or 1:1000 or 1m/km). If furrow slopes of this order are relatively uniform along the furrow, the maximum predicted slope change from regional modelling of 0.005%[2] may not cause drainage difficulties. However, slopes do vary along a furrow and the low slope sections will be more prone to drainage difficulties.

Although it is generally recognised that furrow slopes as low as 0.05% can be successfully flood irrigated, some fields with even lower slopes are successfully irrigated in the area, although with difficulty during wet periods. For furrow slopes <0.05% any reduction in slope caused by CSG-induced subsidence, or local disruption of slope at any point along a furrow, could increase drainage difficulties and levelling may be needed to correct the impacts.

### Tail drain slope

The slope of tail drains is critical for successful irrigation. Head ditches and tail drains are generally orientated across the furrow slope and will therefore have lower slopes than the furrows. Even on farm fields with high furrow slopes, the tail drain and head ditch slopes are low. Tail drain slopes can be as low as 0.02%. If water does not flow readily from a tail drain it will tend to backup into the bottom section of the furrows causing water to remain on the land for an extended period.

If CSG-induced subsidence impaired the efficiency of a tail drain, then regrading of the drain would be needed. Grading of tail drains is carried out when necessary, particularly to remove siltation after flooding or at the end of an irrigation season. A change of slope caused by CSG subsidence could result in the need for additional redesign and regrading.

## Head ditch slope

Head ditches are constructed at between 0.005% and 0.01% to enable water to fill the head ditch along its whole length. If the head ditch slope is too high it will tend to overflow at the lower end as well as cause uneven siphon flow due to the differences in water height between the water in the ditch and the furrow. High furrow slopes are managed with options such as channel check structures to limit falls to between 100mm to 150mm in any section of head ditch.

The size of the siphon from a head ditch is the primary control on the rate of movement of water along a furrow. However, the height of water in the head ditch is sometimes used as a further regulator of flow rate. If CSG-induced subsidence disturbed the efficiency of a head ditch in delivering water to the furrows then regrading of the drain would be necessary.

## Tailwater return

Tail water return systems move water upgradient from tail drains back toward farm storages at higher levels. Tail water return upgradient is achieved under gravity by increasing the depth of a return channel from the tail drain back to a collection point.

Tail water return systems can be several kilometres long traversing alongside several farm fields. They often have the most critical slopes of any infrastructure on an irrigation farm. The part of the system may have slopes as low as 0.01% and therefore have little tolerance for change in the slope of land. If CSG-induced subsidence impaired the efficiency of a tail water return system, then the system would need to be regraded or potentially redesigned.

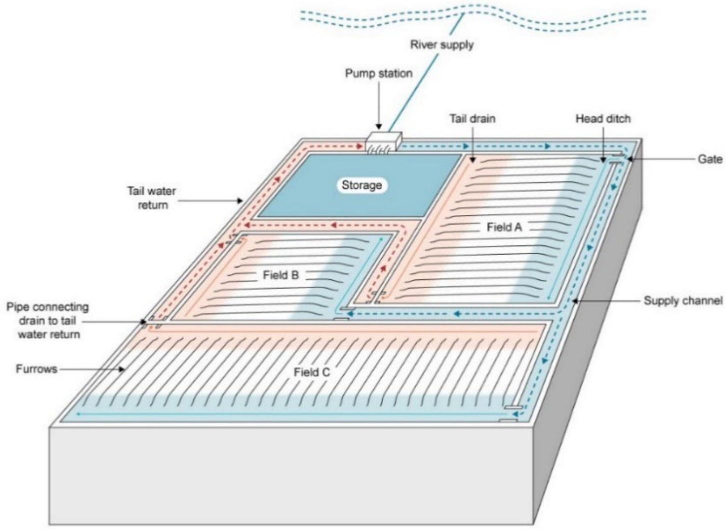



**Figure 3 – Furrow irrigation**. Irrigation water gravitates through a farm from the top of the supply channel to the bottom of the tailwater return system. On very low slope farmland the gradients of the component parts are necessarily small. If the efficiency of drainage is impaired water will remain for too long at the bottom of the furrows which causing crop damage.

## Bankless irrigation

Bankless irrigation is an emerging irrigation technique (**Figure 4**). It involves flooding then draining small areas or cells of land in sequence. Water is released from a water supply channel into a distribution gallery which then floods down the furrows of a cell. Tail water from a flooded cell may be released into the next cell at the time that the head ditch for the cell is flooded, wetting the furrows from both ends.

There is very little bankless irrigation currently carried out on the Condamine floodplain, however it is an emerging technique. It eliminates the labour-intensive process in conventional flood irrigation of setting a siphon for each furrow to transfer water out of the head ditch into the furrow. It saves water because watering is faster resulting in less water loss to deep drainage. It saves energy because the improved irrigation efficiency results in there being less water to pump back from the tail water system into the farm dam. However, bankless irrigation necessarily involves very low furrow slopes, within small cells. The general slope of the land may be relatively high, but the cells step down the land surface and the designed furrow slopes within the cells are typically as low as 0.045%.

Although bankless irrigation is an emerging technique, it is not suitable in all situations. Water needs to be applied quickly and therefore a farm dam for bulk water storage is needed. Therefore, farms supplied directly from water bores are unsuitable. Also, while there are many configurations of bankless irrigation, generally a significant natural land slope is needed to enable the stepping of cells. Further, because of the high moisture holding capacity of much of the soil on the Condamine flood plain, the technique does not bring as much improved irrigation efficiency as in areas with lighter, more freely draining soils.

Establishing the system typically involves land levelling to create precise low slopes. Because the slopes are so low, brushing is likely to be carried out more frequently than on other farmland. For bankless irrigation, as for low slope furrow irrigation and dryland fields, any reduction of slope caused by CSG- induced subsidence could increase drainage difficulties. Although only a few bankless operations exist at the present time on the Condamine floodplain, it is an emerging technique, and therefore the impact of predicted subsidence on any planned conversion to a bankless system should be considered during a farm assessment.

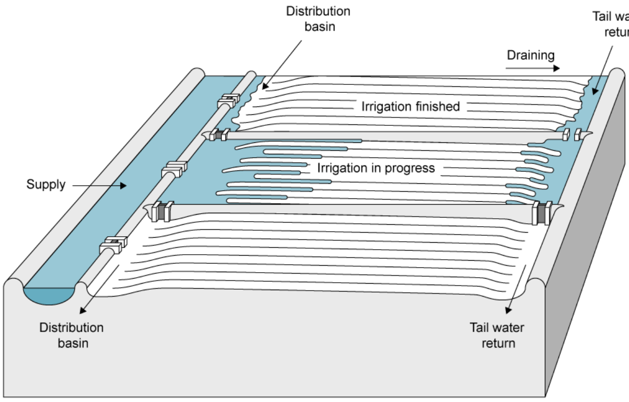



**Figure 4 – Bankless irrigation**. Water is released from the supply channel into the distribution basin from which it floods down the furrows, avoiding the labour-intensive process of setting siphons that is necessary on furrow irrigation farms. Tail water from the previously irrigated cell is released to wet the bottom of the furrow in the next cell, speeding up the irrigation process. The furrows are designed with very low gradients.

## Dryland

Dryland farm fields have different drainage characteristics to irrigation fields. They tend to have not been levelled to any significant extent although there may have been limited levelling to link natural drainage lines to achieve more effective overall drainage. Cultivation of the land would modify the natural drainage patterns to some extent.

Unlevelled land will have an undulating surface (**Figure 5**) rather than the regular drainage lines of land levelled for irrigation. As a result, low slope dryland fields are likely to have pockets where the last of runoff water is unable to drain freely from the field. During wetter periods any pockets of restricted drainage will tend to become areas of pondage. Therefore, for a low slope dryland cultivation field, any reduction in slope caused by CSG induced subsidence is likely to cause some increase in pondage related difficulties that affect low slope irrigated land. Dryland farms rely on overland flow as well as direct rainfall and are particularly vulnerable to any change in landscape scale changes in runoff patterns.

For dryland cultivation fields, a farm assessment should include predicted change to drainage maps, any change in the location of the points of drainage discharge and any predicted increase in the area of pondage. Also farm assessments should be carried out having regard to predicted changes in overland flow of water.

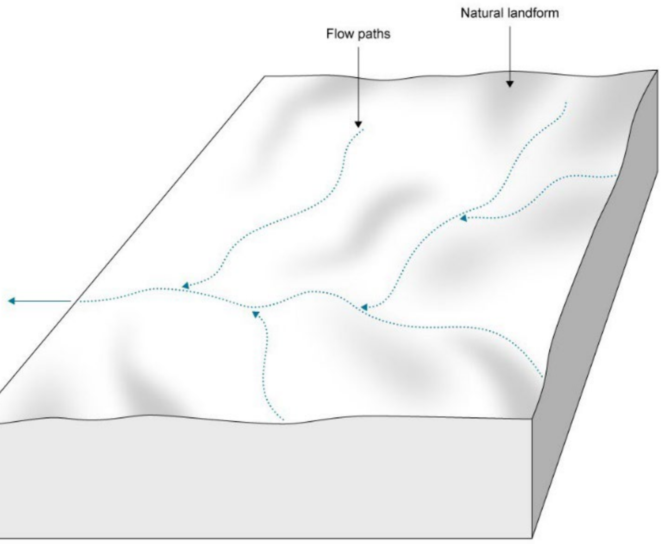



**Figure 5 – Natural drainage paths on dryland farms**. Leveling is less common on dryland farm fields than irrigated land and therefore tend to reflect natural drainage paths

## Overhead irrigation

Overhead irrigation is the application of irrigation water through a lateral move (**Figure 6**) or centre pivot system. Fields irrigated in this way tend to share the drainage characteristics of dryland in that they reflect natural drainage patterns with low slope areas being prone to pondage. However, unlike dryland there is likely to have been some land levelling to improve drainage away from the line of application of irrigation. For a lateral move or centre pivot system, an additional important concern is that any drainage issue along the wheel tracks or the guidance road can lead to bogging of the machine.

Overhead irrigation also differs from dryland farming in that there is greater financial investment with a view to generating higher financial returns. As a result, should CSG-induced subsidence cause a drainage issue the financial cost is likely to be higher.

Notwithstanding these differences the primary concern is as for dryland cultivation. Therefore, for overhead irrigation fields, a farm assessment should include predicted change to drainage maps, any change in the location of the points of drainage discharge and any predicted increase in the area of pondage.

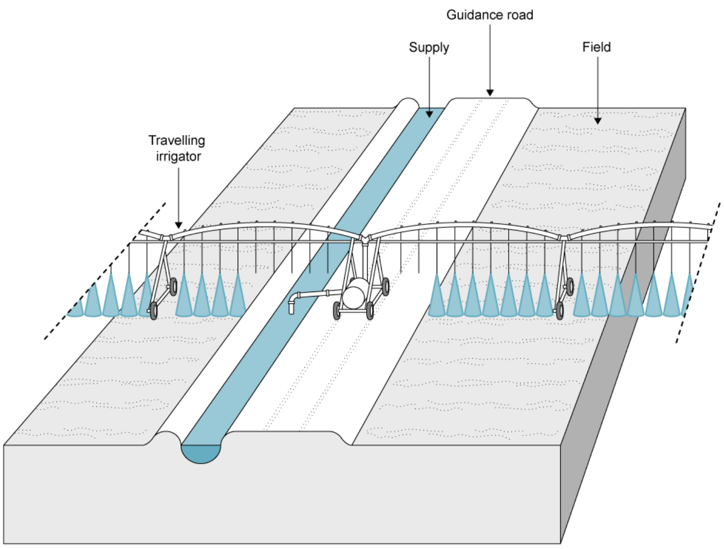



**Figure 6 – Travelling Irrigator**. Disturbance to the guidance road could cause bogging of the machine.

## Levelling to correct slope changes

Effective drainage is the most important factor of production. If CSG induced subsidence impairs effective drainage on low slope irrigation or dryland farms, then as previously noted there will be a loss of productivity. The loss will depend on the extent of the impairment. There will be a reduction in yield to some extent but extensive impairment could cause disruption to machine access to a farm field and a long period of inundation could damage the soil. In these instances, it is likely that levelling will be required to correct slope changes impact productivity.

Importantly there are complexities that need to be considered in carrying out levelling or brushing to correct slope changes. The leveling process itself reduces productivity. The weight of the levelling machinery causes compaction of the soil which then reduces plant access to oxygen. The removal of soil from cut areas to fill areas leads to loss of nutrients and organic matter from the cut areas. Wetting and drying cycles together with cultivation restore soil structure and health over time.

On irrigated farmland restoration may be achieved within one to two years, however in some instances this restoration period may be longer. On dryland restoration is more problematic because wetting drying conditions are completely subject to weather conditions. The stubble cover is removed in the process of levelling, disrupting farming practice and soil moisture retention, which ultimately affects farm productivity.

Levelling is difficult to schedule. Some landholders carry out brushing of farm fields but all other brushing and or leveling is carried out by a small number of heavily committed contractors. Scheduling of leveling is also subject to weather conditions. For example, apart from major weather events, if soil moisture is too high levelling may need to be delayed to minimise compaction during the levelling process.

Levelling disrupts site specific farming. With detailed information available through precision agriculture techniques farming inputs such as specific nutrients are applied on a site-specific basis typically 20m to 30m grid cells. The ability to apply the inputs optimally depends on a detailed understanding of the variability within the farm field built up over several years. After leveling the knowledge base would need to be rebuilt to return to optimal productivity.

Yield mapping data such as that shown in Appendix A is increasingly collected by landholders and would provide useful input to assessing productivity loss after a levelling event.

## Indirect operational impacts

If CSG-induced subsidence occurs without rectification, then there may be indirect impacts on farm operations associated with the subsidence. Examples are as follows:

- Crop rotations are planned for a range of purposes including disease and weed management. For example, cotton is susceptible to diseases which can be reduced by fallowing the field for one or more years to allow the disease to attenuate. If reduction in drainage efficiency led to changes in crop rotations, the overall disease or weed management program could be impacted.
- Plans for the movement of machinery between farm fields and the individual properties that comprise a single farming enterprise is based on scheduled cropping. If a reduction in drainage efficiency disrupts operations on one farm field, the efficiency of the farming enterprise as a whole could be impacted.

## Opportunity costs

While a farm assessment may deal with the impacts of predicted subsidence on a farm field as it is currently farmed, the trends in farming should be taken into account.

For example, there is a trend to shift from flood irrigation using siphons and or overhead irrigation to bankless irrigation. A property assessment should consider not only the impact of predicted subsidence on existing irrigation practice, but also the impact that would occur on planned changes to the farming enterprise.

## Farm assessment in higher risk areas

Farm assessments will be complex because of the range of vulnerabilities to subsidence of different farming systems on different farmlands. Because each farm is different in detail, farms that are at risk of experiencing consequential impacts of CSG-induced subsidence will need to be assessed individually, addressing the range of considerations noted in this report.

OGIA's regional scale modelling reported in the UWIR identified areas where CSG-induced subsidence is predicted to occur and its magnitude. As part of the regulatory framework it is proposed that the identification of higher risk farms for which subsequent individual farm assessments may be necessary will involve multiple criteria including regional scale modelling, land use and other factors.

OGIA maintains that while the regional modelling presented in the UWIR indicates an overall subsidence pattern, it is not designed nor appropriate for direct farm scale assessment. Ongoing work from OGIA and other researchers suggest that the difference in magnitude of subsidence along any direction across a farm field will vary over time depending upon the sequencing of CSG well production in the immediate area. However, at any given point in time the difference is likely to be only a small fraction of the maximum subsidence of the farm field as a whole.

Subsidence is also expected to be progressive, generally with a period of relatively faster subsidence at early stages of CSG development. While the expectation is that subsidence will affect farm fields as a whole, claims of local landform irregularities being caused by CSG-induced subsidence should be investigated.

With the predicted maximum change of slope likely to be small, levelling to restore slopes because of CSG-induced subsidence may be necessary on low slope irrigated farm fields (<500 mm/km). If CSG-induced subsidence reduced the slope of very low gradient tail water return systems, then engineering work to re-establish gradients may be necessary.

On low slope dryland farm fields, some levelling may be required to correct any increase in pondage.

Although there are only a few bankless irrigation systems in the area there is a trend towards implementing these systems. Bankless irrigation systems use very low gradients and are therefore more vulnerable to landform change.

# Conclusions and recommendations

## Conclusions

1. **Drainage is the key issue.**
   The farmland of the Condamine alluvial floodplain is highly productive and carefully managed. The potential for impairment of farm drainage is the key concern for landholders. Small changes in slope can result in significant impacts. If effective drainage is impaired through landform change resulting from CSG-induced subsidence there will be some (potentially high) reduction of productivity.

2. **CSG-induced subsidence must be considered in the context of other variations.**
   Any variation in landform due to CSG-induced subsidence will be superimposed on any landform variations due to other causes. Many farm fields once established are rarely releveled to any significant extent. Parts of other farm fields are levelled from time to time to correct settlement of fill resulting from previous levelling or introduced to repair erosion (noting that the introduction of fill is typically soil from within the farming field as externally sourced soil represents a biosecurity risk and increased cost). Any CSG-induced subsidence will be a permanent change superimposed on any such background landform changes. Modern precision farming technologies have the potential to assist in identifying the contributing causes of landform change.

3. **Each farm is different.**
   Each farm is different in terms of susceptibility to the impact of subsidence on farming operations. Under the planned regulatory framework regional scale assessment will identify areas where farms are at higher risk of impacts from CSG-induced subsidence. Within those areas each farm would need to be assessed for impact on farm operations. The planned regulatory framework provides for such farm scale assessments.

4. **Further farm scale predictive modelling is critical.**
   There is a preliminary understanding of the characteristics of subsidence at the farm scale. OGIA maintains that while the regional modelling presented in the UWIR indicates an overall subsidence pattern, it is not designed for direct farm scale assessment. Ongoing work from OGIA and other researchers suggest that the difference in magnitude of subsidence along any direction across a farm field will vary over time depending upon the sequencing of CSG well production in the immediate area. However, at any given point in time the difference is likely to be only a small fraction of the maximum subsidence of the farm field as a whole. CSG-induced subsidence is also expected to be progressive with generally a period of relatively faster subsidence at early stages.

5. **It is expected that rectification work may be required on some farmland because of CSG-induced subsidence.**
   Given the previously summarised current understanding of the characteristics of CSG-induced subsidence, interventions to manage the impact on farming operations is likely to be needed in some situations. Those situations and interventions are likely to be as follows:

   - Regrading of some very flat slopes (typically < 500mm /km) within farm fields - these fields are likely to already experience drainage issues under wet seasonal conditions. Any changes to landform that impairs already poor drainage would need to be corrected by regrading or redesign of field layout.

   - Correction to the gradient of tail water systems - these systems comprise tail water drains at the end of furrows and tailwater return channels that collect tail water from multiple farm fields and gravitate it back to a water storage. Modifications to such works may be needed to maintain efficiency.

   - Some degree of regrading of 'bankless' flood irrigation systems – there are very few bankless systems in existence in the area at present, but because of their efficiency, in the future there may be trend to convert to these systems where suitable circumstances exist. Bankless systems are designed with very low gradients and are therefore vulnerable to changes of landform caused by CSG induced subsidence. However, they tend to need minor dressed levelling more frequently than other systems to maintain critical gradients, at least in the early years after the major levelling associated with establishment of the system. This activity may correct any minor landform change due to CSG-induced subsidence occurring at the time.

   - Some degree of levelling of low slope dryland farm fields - low slope dryland farm fields will tend to have areas of pondage that are subject to drainage difficulties during wet periods. Any increase in these areas would need to be corrected by establishing drainage lines.

   - Levelling is not a simple matter - it would cause productivity loss until the soil recovered from impacts such as compaction caused by levelling machinery which could be take several years for dryland farms, and on farms carrying out precision agriculture until any necessary changes to site specific application of inputs such as fertilisers are understood. The regrading would be subject to the scheduling challenges associated with weather and the availability of contractors. The planning of regrading and all its implications would be a matter for consideration during a farm assessment, along with loss of productivity resulting from levelling.

## Recommendations

1. **Re-evaluate consequences of subsidence on individual farms when farm scale subsidence modelling is complete.**
   Conclusions about the expected impact of CSG- induced subsidence on farming operations are currently based on regional modelling and conceptual understanding of subsidence including around individual CSG wells. The conclusions should be reviewed by OGIA (with appropriate agronomic and irrigation expert input) when farm scale modelling is complete.

2. **Provide landholders with farm field scale data.**
   Because each farm is different, landholders need be able to assess data relevant to their individual farms. Airborne LiDAR can identify topographic profiles at a fine scale and is being made accessible to landholders by OGIA through tools it has developed. This can complement the data being collected by progressive landholders using precision agriculture techniques. When farm scale modelling has been completed, model output should also be made accessible to landholders in a similar way to the LiDAR data. This will assist landholders to ensure that critical gradients on their farm fields are considered during farm assessments.

3. **Develop ways of representing changes to drainage of natural landforms.**
   Assessing the susceptibility of CSG-induced subsidence on flood irrigated paddocks can be carried out by reference to the slope of linear transects and predicted changes or disruptions to those slopes. However, dryland farm fields and overhead irrigation farm fields usually reflect natural ground slopes and therefore irregular drainage patterns. For those situations the transect based approach is difficult to apply. Techniques are needed that focus on representing any changes to effective drainage along natural flow paths. OGIA is developing tools and techniques to support this kind of assessment.

4. **Assess farm field landform irregularities.**
   When the planned regulatory system is implemented, there will be opportunity for a landholder who believes that a farm field landform has been impacted by CSG-induced subsidence in a way not predicted by modelling, to seek for the situation to be investigated independently of the CSG operator. To assist in development of systematic methods and guidelines, some pilot assessments of farm field landform irregularities currently claimed to be caused by CSG-induced subsidence, should be carried out and results shared with landholders in potentially affected areas to provide clarity.

5. **Assess potential for landscape scale impacts to the overland flow.**
   The focus of the consequence project is on the potential consequences of landform change at the farm field scale on farming operations. The potential impact of landform changes at the broad landscape scale to significantly alter the overland water flow patterns need to be assessed. OGIA is developing tools and techniques which may support this kind of assessment.

# Appendix A – Variability within a farm field

Agriculture has become a precision industry for progressive farmers as they seek to adjust farming operations to maximise crop yields. Precision agriculture involves understanding the differences and changing agronomic practices over small (20m-30m) grid spacings to optimise productivity.

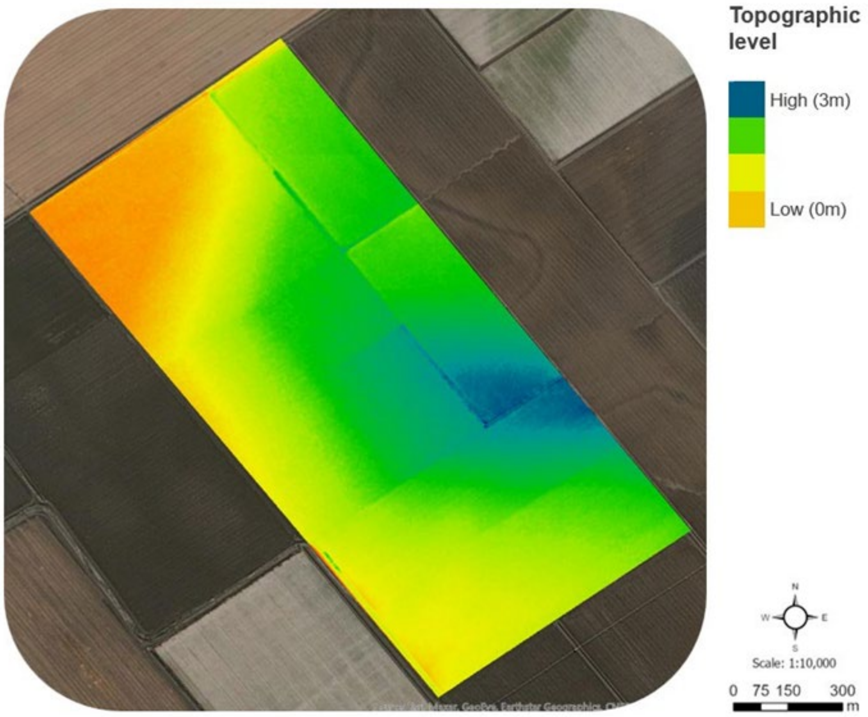
Some of the tools available to farmers are as follows:

- Electromagnetic surveys can be carried out to better understand soil characteristics for farm planning purposes.
- Ground positioning sensors (GPS/RTK) attached to farm machinery map the level of the ground.
- Sensors on harvesting machinery can show variations in crop yield over small distances within a farm field.
- Also, data is increasingly available from airborne and satellite remote sensing that provides additional information about ground movement and crop performance.

Farmers use the precision agriculture data to better understand and improve farm productivity. Crop yield maps show that yield can vary enormously over small distances within a farm field. By using yield maps together with other data, a farmer can infer the reasons for variations in productivity and plan farm management accordingly. If a drainage issue developed in part of a farm field due to any cause, it is likely that that the impact of the impaired drainage along with other factors affecting production, would be reflected in the crop yield map. The longer the period for which records are held the more possible it is to understand the contribution of the various factors impacting on crop yield.

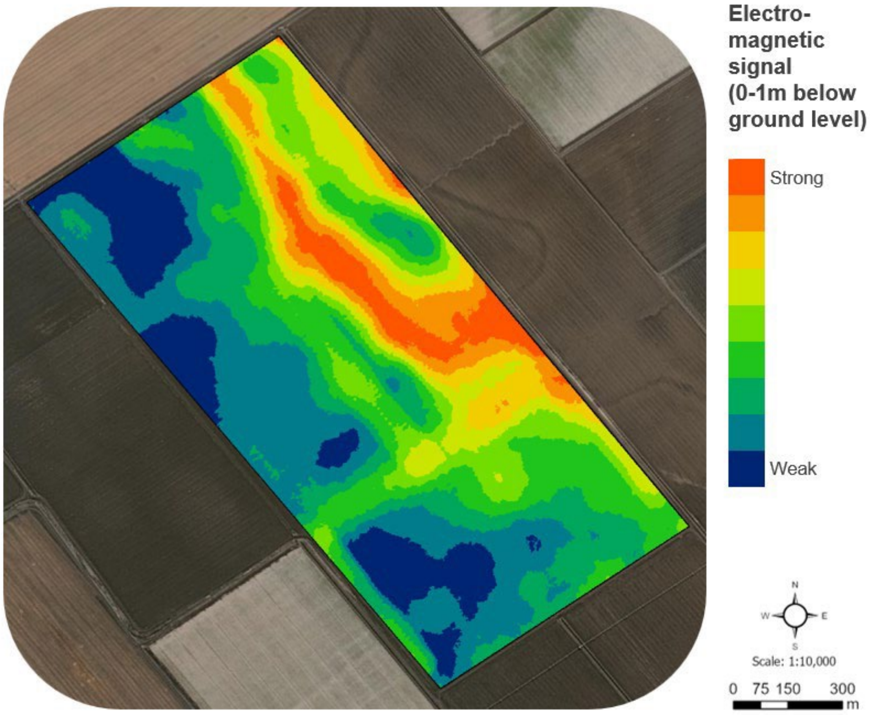
The images below are for a farm in the area. It is larger than the typical farm field and has been formed by the combining of several fields. The images are provided to convey a sense of the extreme variability that may exist naturally within a farm field. While each farm field will be unique, as more data is collected through precision agriculture, it is apparent that high variability is common across farm fields.

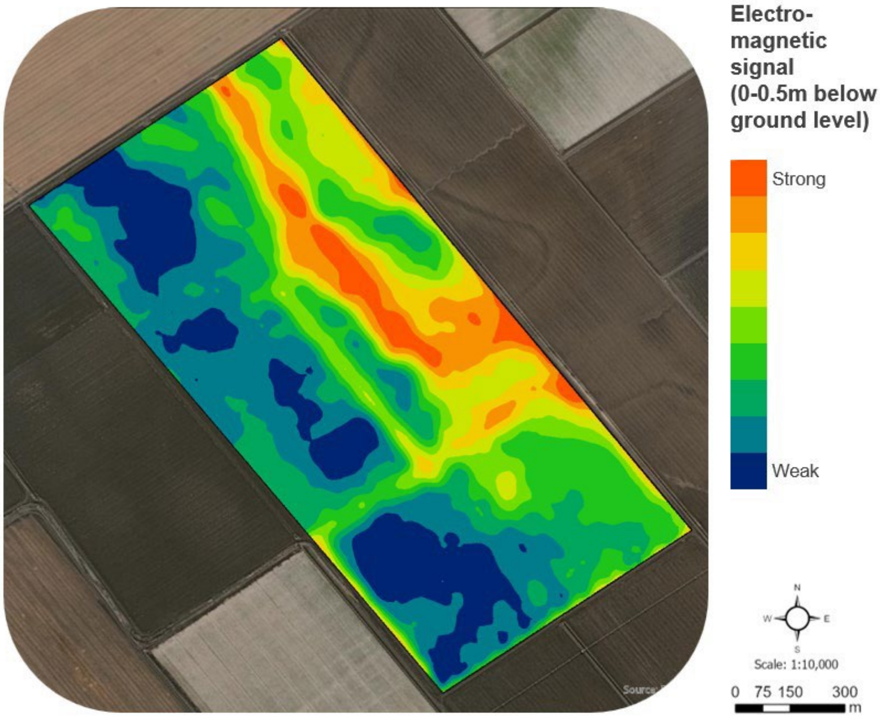
## Variation in Topography




The colours on this image show the topography of a large farm field irrigated with a travelling irrigator, traversing between the NW boundary to the SE boundary. Regular data collection will show changes in topography over time. This field has been formed by combining four flood irrigated farm fields, the old boundaries of which are still apparent on the image.

## Variation in Electromagnetic (EM) signal



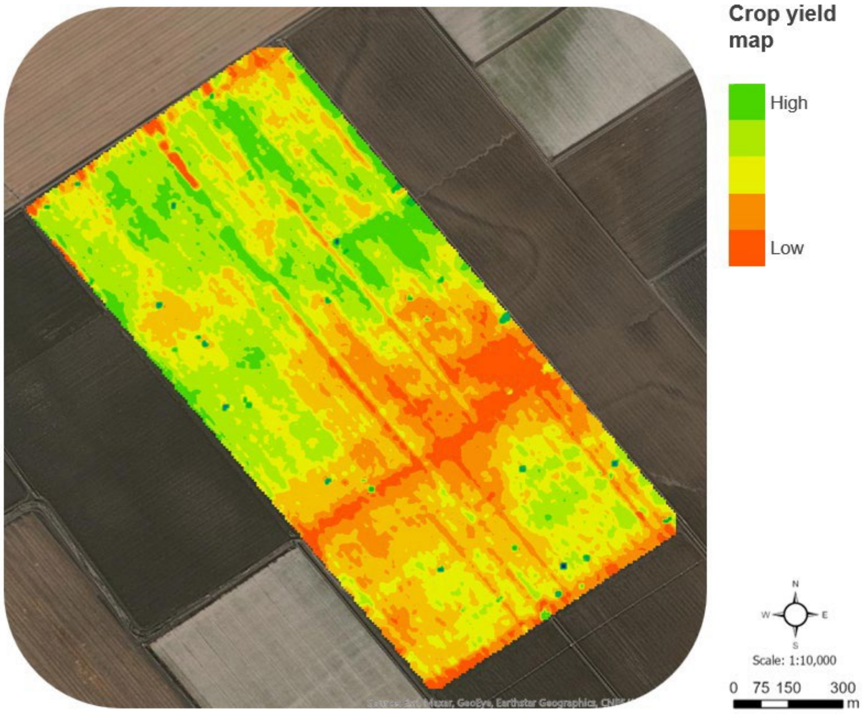




These two images are the result of an electromagnetic (EM) survey. Such surveys typically involve multiple traverses of a farm field with a quad runner on which array of EM sensors (and perhaps other sensors) are mounted. The signal (commonly referred to as 'apparent conductivity') is the combined effect of several variables including sand content, clay mineralogy, soil moisture and organic material content. Because of their complexity, these survey results need to be interpreted by a professional. Differences in the signal is likely to primarily reflect the relative amount of sand in the soil.

The sensors can be adjusted so that the readings give the average signal for different depth ranges. The first image shows the signal for the soil material in the depth range zero to 1m below ground level. The second image shows the signal for the depth range zero to 0.5m below ground level.

From each of the images it can be seen that there is significant variation in soil characteristics over small horizontal distances. By comparing the two images it can be seen that there is also variation vertically. The differences in soil, as well as affecting yield, will also affect the way the ground moves in response to wetting and drying cycles.

## Variation in crop yield




The variations in colour on this image show the spatial variation in crop yields over the farm field. The most obvious feature of the image is the variability of the yield. Although the factors affecting yield are different in each farm field, it is common for the yields to vary significantly. In any farm field it is not unusual for the yield to drop by 50-100% over short distances.

The cause of variability of yield in both space and time is complex. Variations in prolonged inundation with water is one of these factors, the impact of which can be exacerbated by interactions with climate, soil compaction, disease, nutrition, and other factors. Crop yield maps collected over time enable continuous improvement in understanding the cause of variations in yield and the way those changes affect farm productivity.

GasFields Commission Queensland

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