Ground movements in agricultural production

Public FINAL – prepared for Arrow Energy (March 2021)

DATA
FARMING

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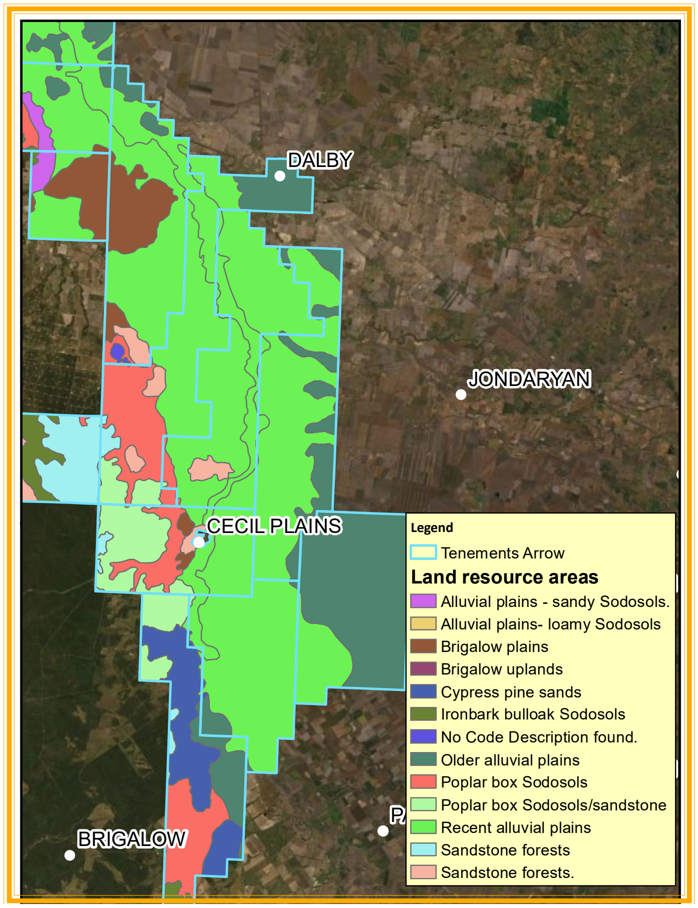
1. Introduction

Agricultural crop production on the Darling Downs region of Queensland is based on approximately 1,000,000 hectares of primarily ‘floodplain’ type landscapes. These landscapes are dominated by flat topographical relief, with intermittently flooding of the deposited ‘swell-shrink’ clay soils. Cropping is primarily dryland production of cereals, coarse grains, pulses, and cotton; with flood/furrow irrigation of (mainly) cotton also a prominent feature in the landscape. Irrigation water is drawn from the river systems, overland flow, and underground aquifers, and placed in earthen ring tanks for storage. Soils are generally deep and fertile, with high clay content. The dominant land types over the Arrow tenement are recent alluvial plains, with some sodosols, sandstone, and cypress pine sands as shown below.



Arrow Energy (Arrow) is seeking to identify how coal seam gas (CSG) induced ground movement can impact farm productivity. To do that Arrow has:

- estimated ground movement (via a geomechanical model) including absolute magnitude of subsidence and change in gradient based on:
    - actual rock strength properties,
    - observed ground movement in the vicinity of CSG operations,
    - actual groundwater drawdown and
    - independently forecast future groundwater drawdown.

- Undertaken satellite based Inferometric Synthetic Aperture Radar surveys (to quantify total ground movement) since 2006,
- Undertaken LiDAR capture and digital elevation mode construction for the majority of its Surat Basin tenure in 2012 and 2014, and
- Developed a framework (based on InSAR observations) for identifying when additional monitoring and remediation would be undertaken.

2. Scope and methodology

The scope of this work was to prepare a technical report which describes:

1. Representative slope on dryland or irrigated cultivation within Arrow's tenure,
2. Typical slope rectification techniques used within Arrow's tenure,
3. The accuracy with which the surface and slope on cultivated land can be measured and how that accuracy influences the possible range of actual slope on the same land,
4. The accuracy with which the surface and slope on cultivated land can be modified and how that accuracy influences the possible range of actual slope on the same land, and
5. Natural variations in ground surface including a description of the mechanisms causing this variation and magnitude in variations including the resulting changes to surface elevation that occur following rainfall.

3. Results and Discussion

3.1 Slope on Arrow's tenure and natural variations in the surface

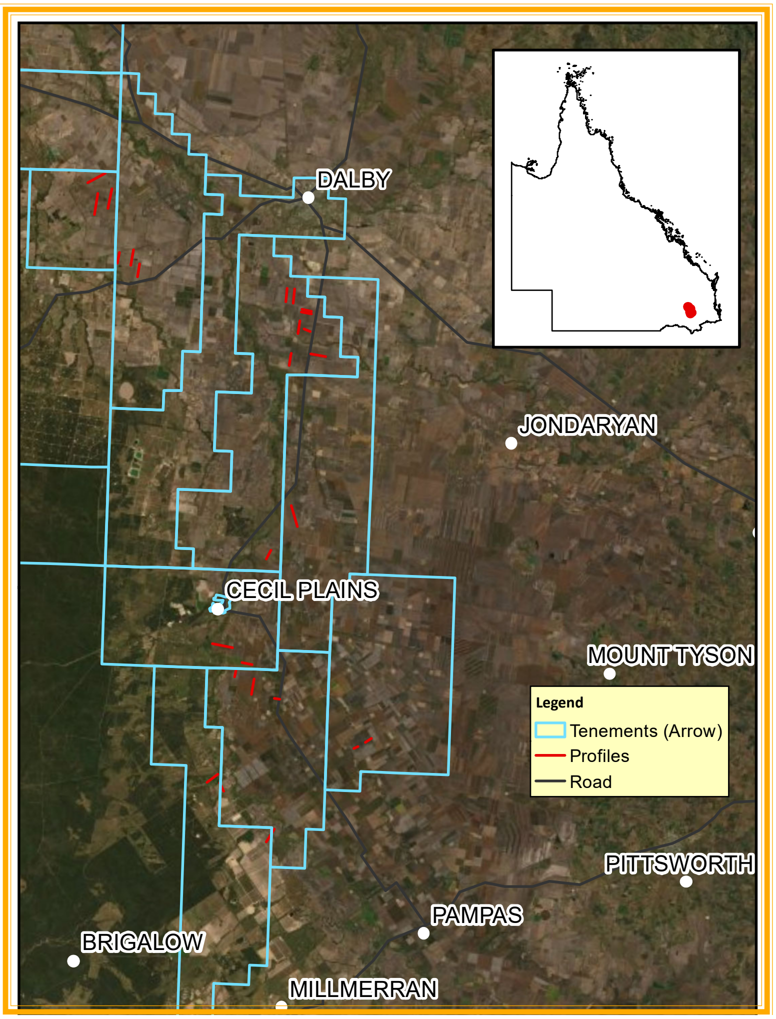
DataFarming conducted an analysis to determine land slope across 18 dryland and eight irrigated paddocks in the tenure area using airborne Lidar elevation date and GIS mapping software. These profiles were randomly selected over an area South of Dalby (Figure 1) to provide a snapshot of slopes on farming land. The average slope was determined from subtracting the height of the lower end of the field, with the height from the higher end of the field. All paddocks had areas where the minimum slope was effectively zero, where there were areas completely flat. The maximum vertical variation (in metres) was determined by examining the micro variations along the profile between close readings (over short distances); and the largest difference was extracted from each profile. It is important to note that farming direction in some paddocks was parallel to the slope (such as in irrigation), whilst others were perpendicular to the slope (such as strip cropping). It is fair to say that most paddocks have variable slopes and are often sloping in more than one direction. The results are below in the following table and the actual profiles are shown in Figure 2.

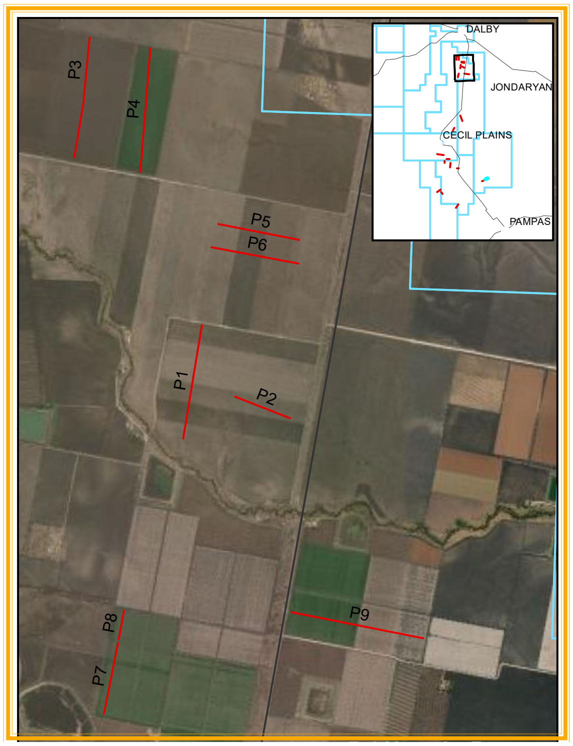
Profile #	Average slope (%)	Notes	Max. Variation (m)	Length of assess (m)
1 (dry)	0.08	Main slope direction, not paddock direction	0.20	1240
2 (dry)	0.15	Measurement was parallel to row direction	0.12	635
3 (dry)	0.10	Measurement was parallel to row direction	0.05	1300

4 (dry)	0.09	Measurement was parallel to row direction	0.12	1330
5 (dry)	0.08	Main slope direction, not paddock direction	0.15	880
6 (irrig)	0.10	Main slope direction, not paddock direction	0.06	1100
7 (irrig)	0.05	Measurement was parallel to row direction	0.10	770
8 (irrig)	0.06	Measurement was parallel to row direction	0.11	310
9 (irrig)	0.10	Measurement was parallel to row direction	0.05	1440
10a (irrig)	0.20	Crop rows perpendicular to main slope	0.06	400
10b (irrig)	0.01 (0.07/0.05)	Crop rows perpendicular to main slope	0.10	700
11 (dry)	0.05	Crop rows perpendicular to main slope	0.16	1425
12 (dry)	0.00 (0.1/0.05)	Measurement was parallel to row direction. Likely water flow direction perpendicular to paddock	0.10	800
13 (dry)	0.18	Measurement was parallel to row direction	0.06	1300
14 (dry)	0.03	Measurement was parallel to row direction	0.14	1500
15 (irrig)	0.07	Measurement was parallel to row direction	0.10	550
16 (irrig)	0.07	Measurement was parallel to row direction	0.10	590
17 (dry)	0.00	Crop rows perpendicular to main slope	0.10	850
18 (irrig)	0.07	Measurement was parallel to row direction	0.10	940
19 (dry)	0.20	Measurement was parallel to row direction	0.05	970
20 (dry)	0.06	Measurement was parallel to row direction	0.13	2000
K1 (dry)	0.06	Measurement was parallel to row direction	0.08	1160
K2 (dry)	0.06	Measurement was	0.10	1470

		parallel to row direction		
K3 (dry)	0.05	Measurement was parallel to row direction	0.15	1077
K4 (dry)	0.00 (0.05/0.06)	Measurement was parallel to row direction. Likely water flow direction perpendicular to paddock	0.10	1870
K5 (dry)	0.10	Measurement was parallel to row direction	0.10	1980
K6 (dry)	0.05	Measurement was parallel to row direction	0.05	1870

Figure 1: location of the test paddocks

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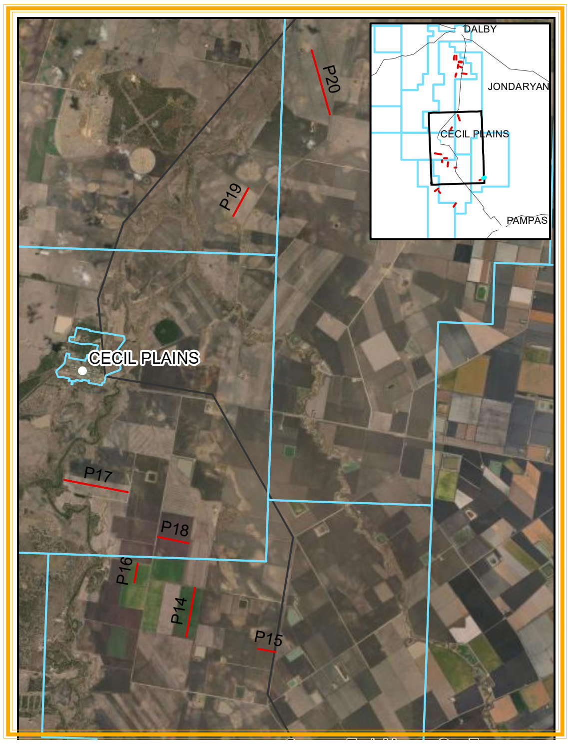
P5
P6
P1
P2
P8
P7
P9
DALBY
JONDARYAN
CECIL PLAINS
PAMPAS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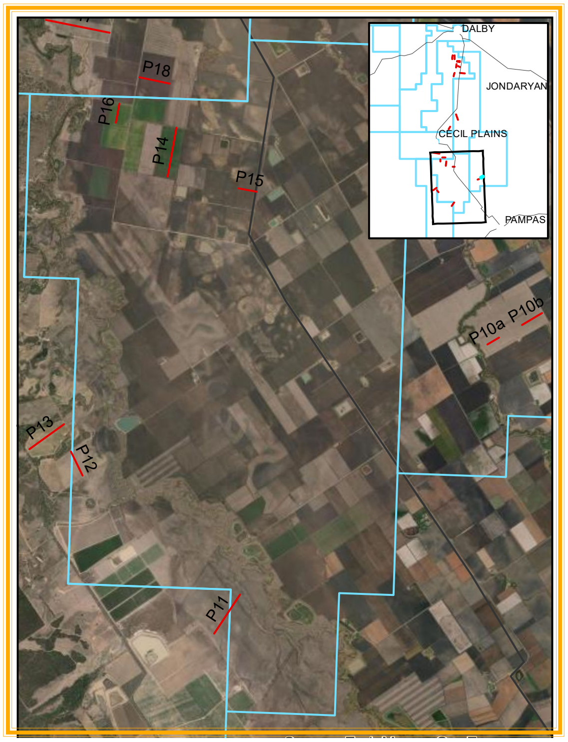
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P16
P14
P15
P10a
P10b
P13
P12
P11
DALBY
JONDARYAN
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PAMPAS

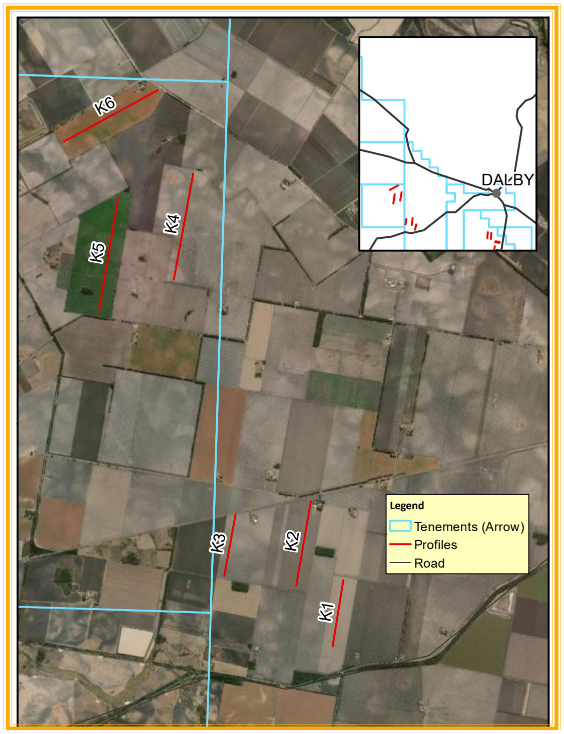
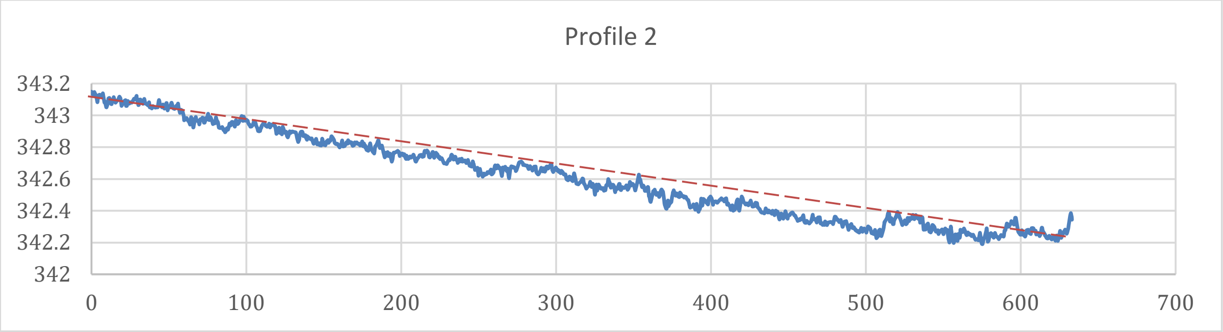
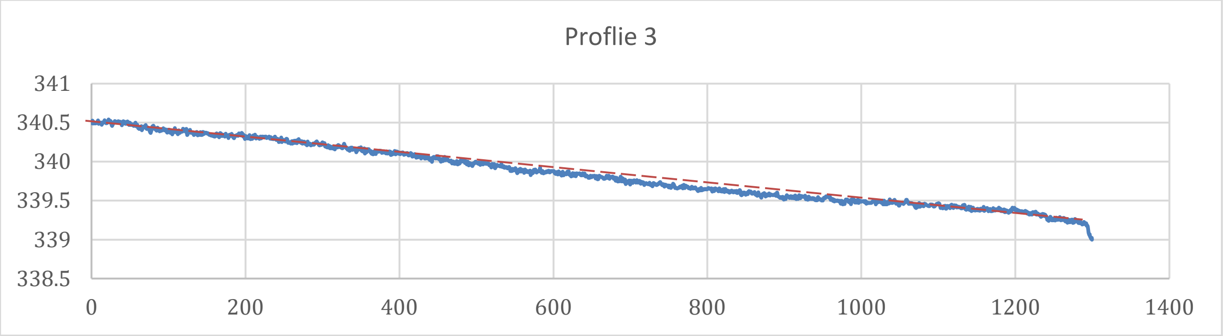
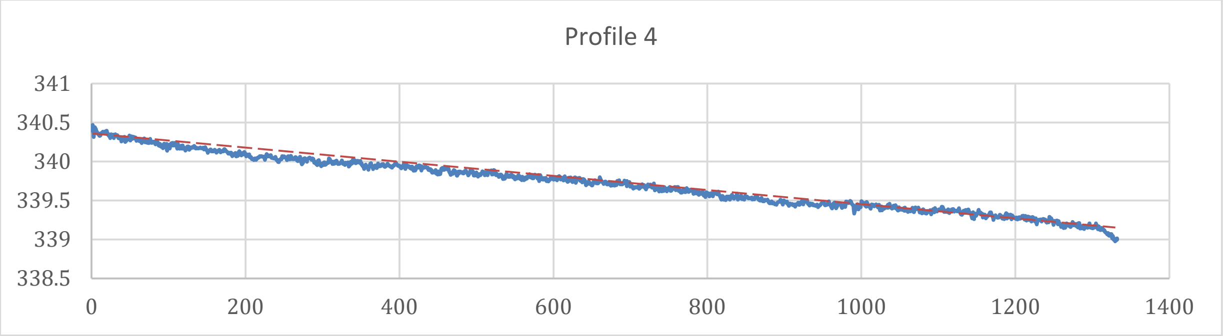
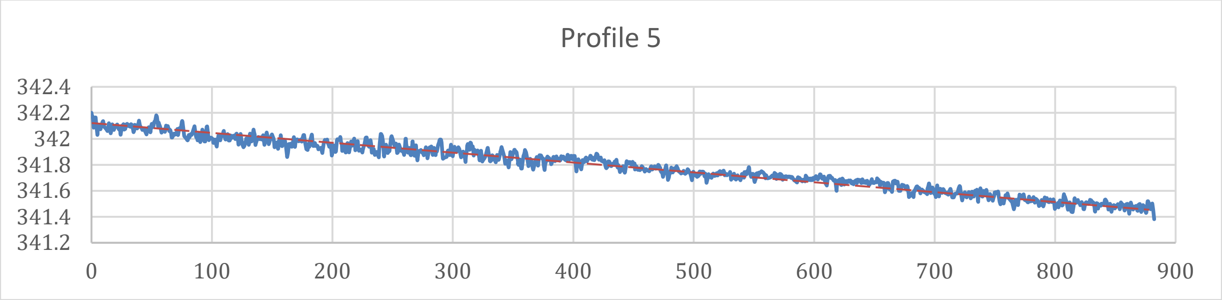

K6
K5
K4
K3
K2
K1
DALBY
Legend
Tenements (Arrow)
Profiles
Road

Figure 2: Twenty-six elevation profiles of randomly selected paddocks (X and Y Axis are all in metres – Y = vertical, X = distance from start point). The red dashed line represents average slope drawn across each field.





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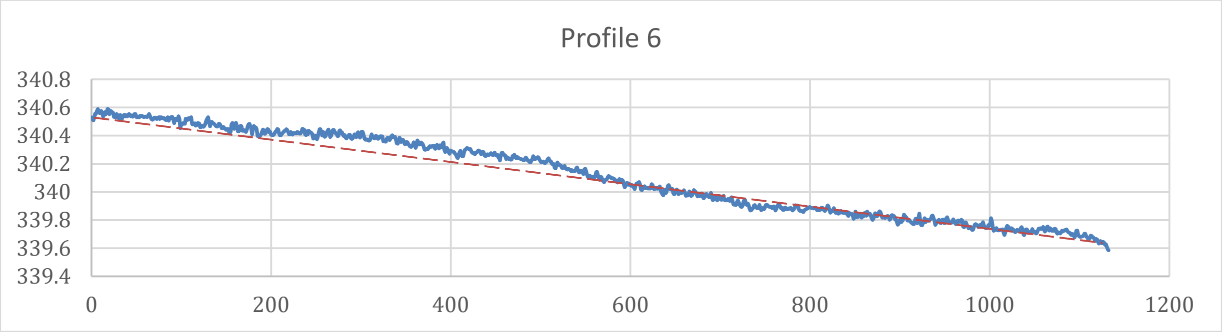
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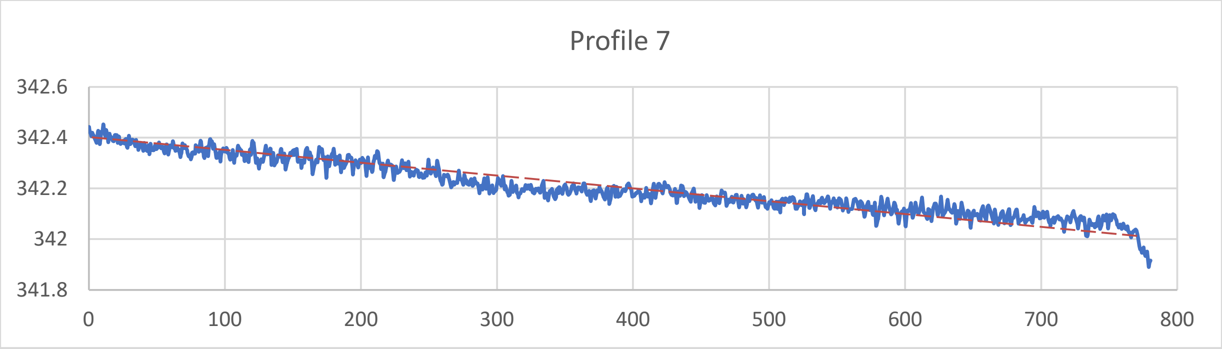
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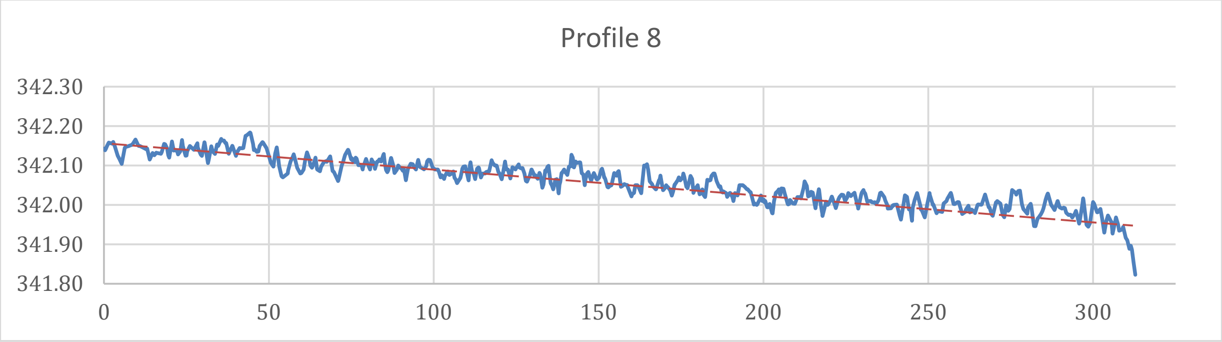
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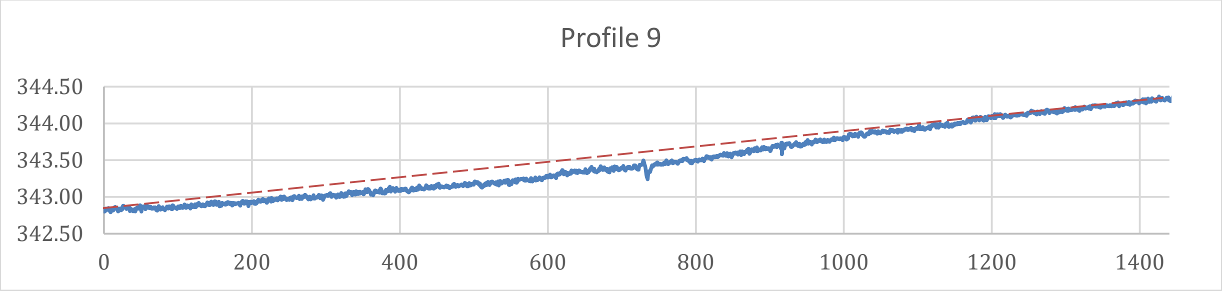
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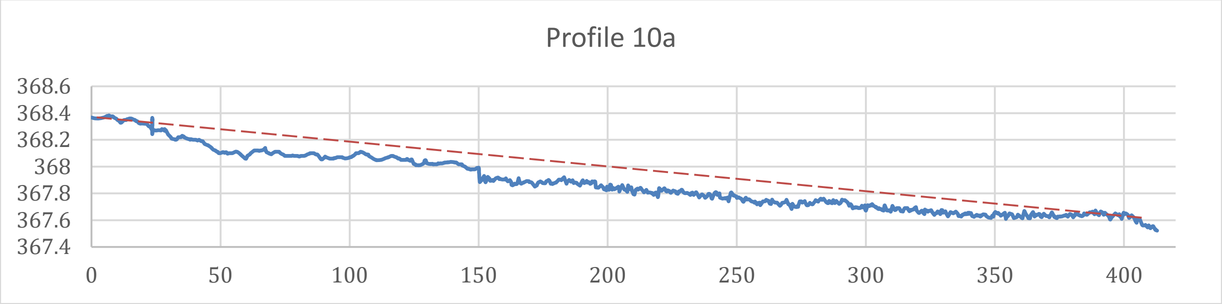
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367.8
367.6
367.4
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150
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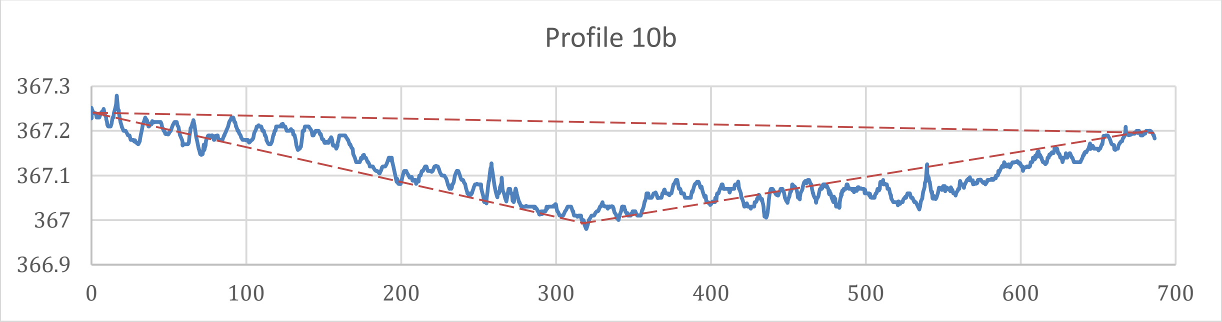
300
350
400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366.9
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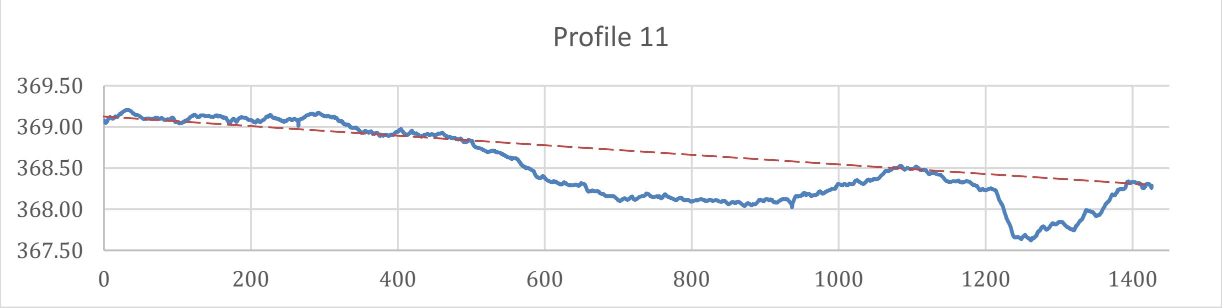
500
600
700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368.00
367.50
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600
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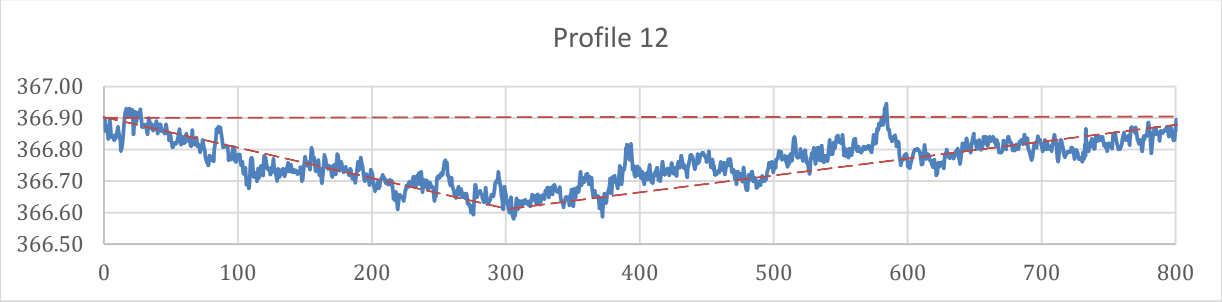
1000
1200
1400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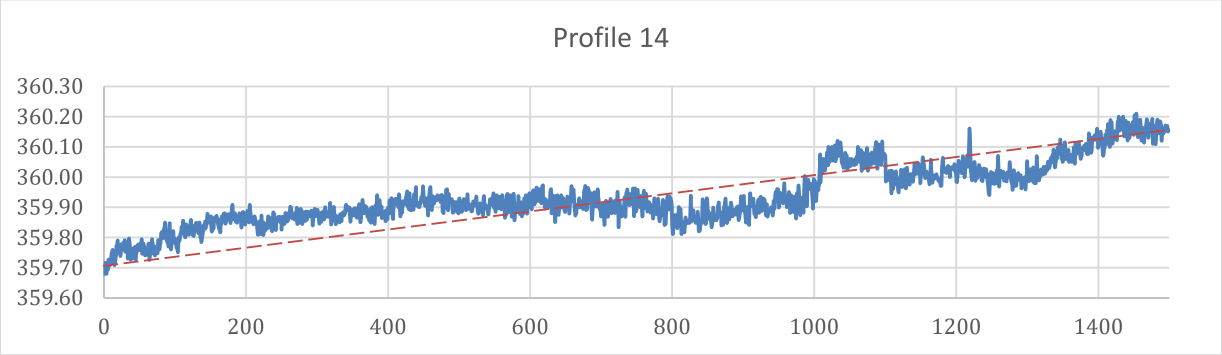
800


Profile 13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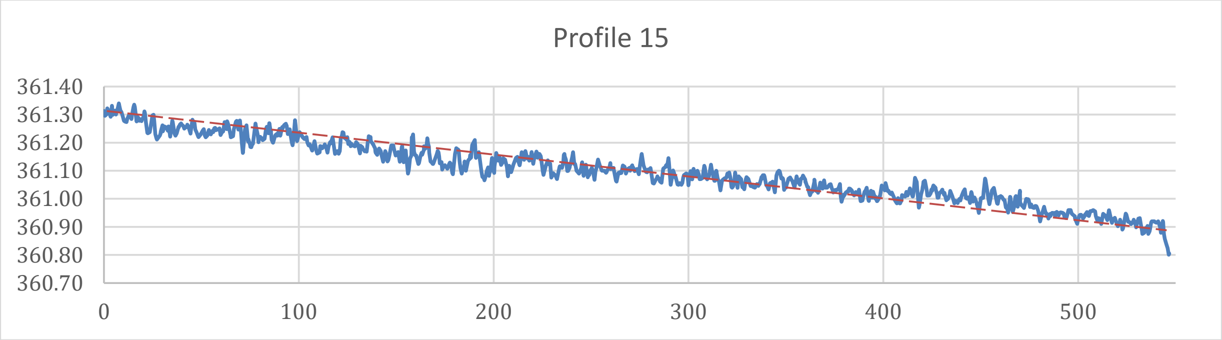
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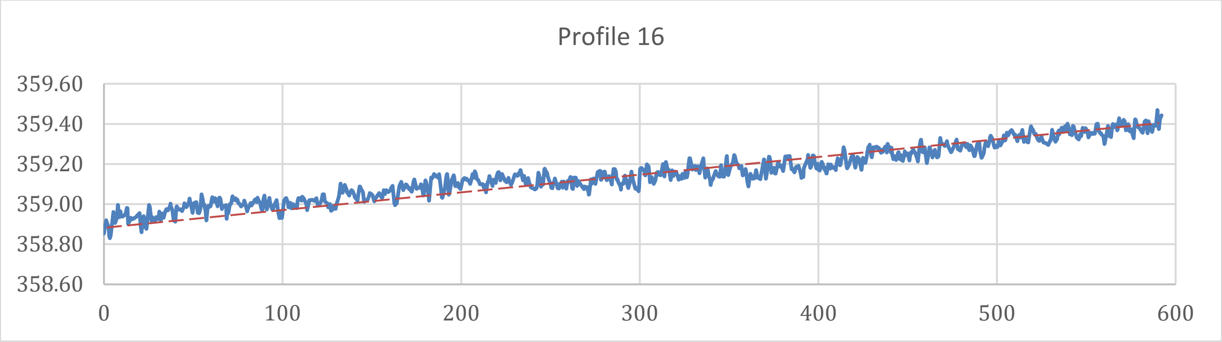
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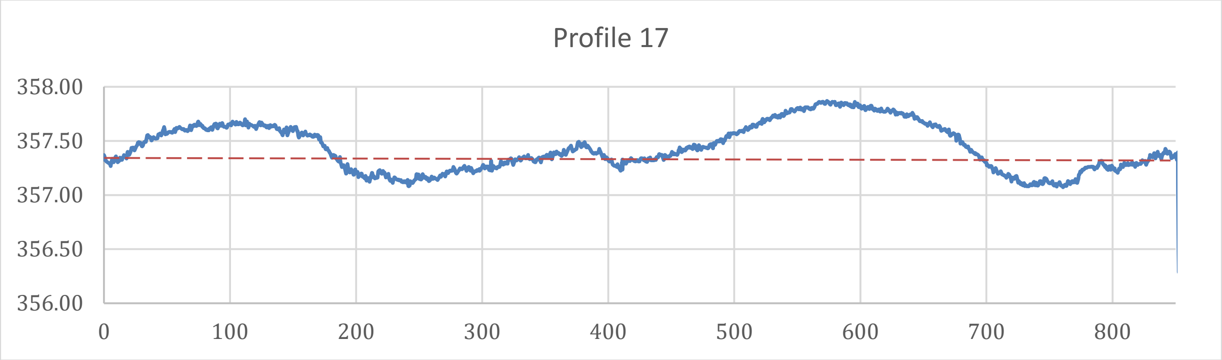
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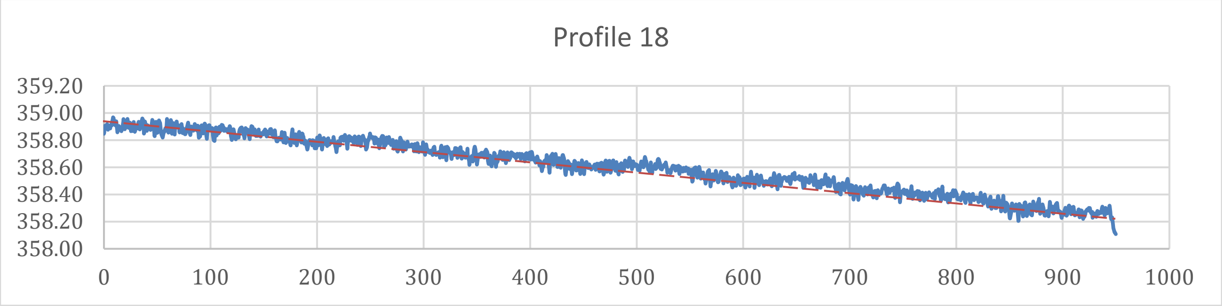
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700
800
900
1000


Profile 19
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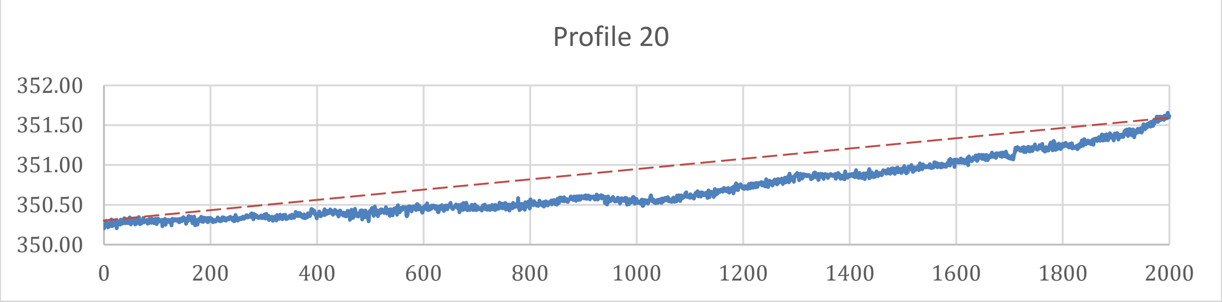
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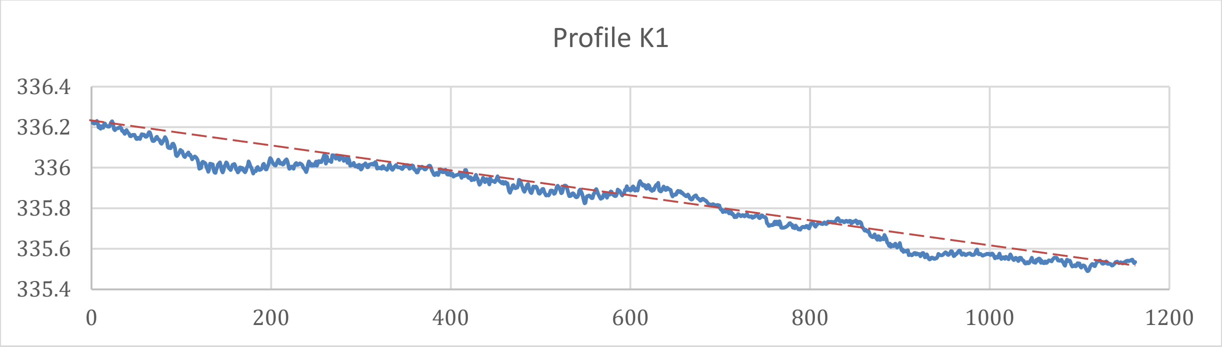
2000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335.8
335.6
335.4
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400
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800
1000
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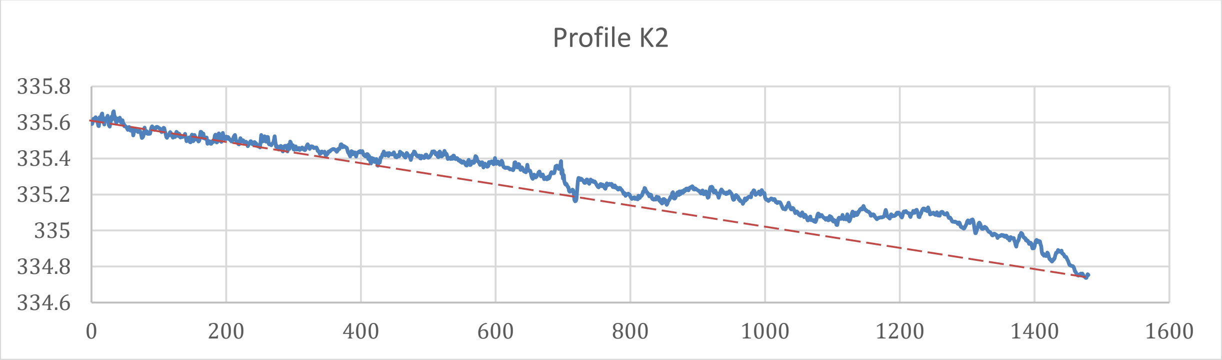
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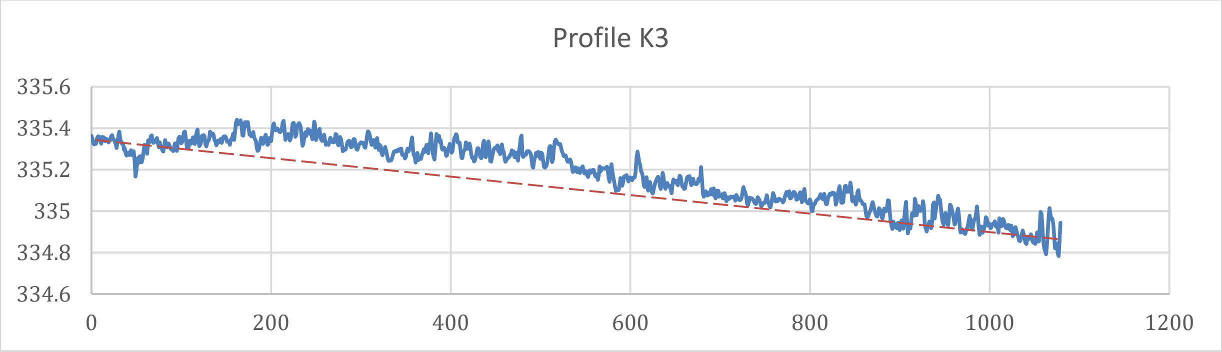
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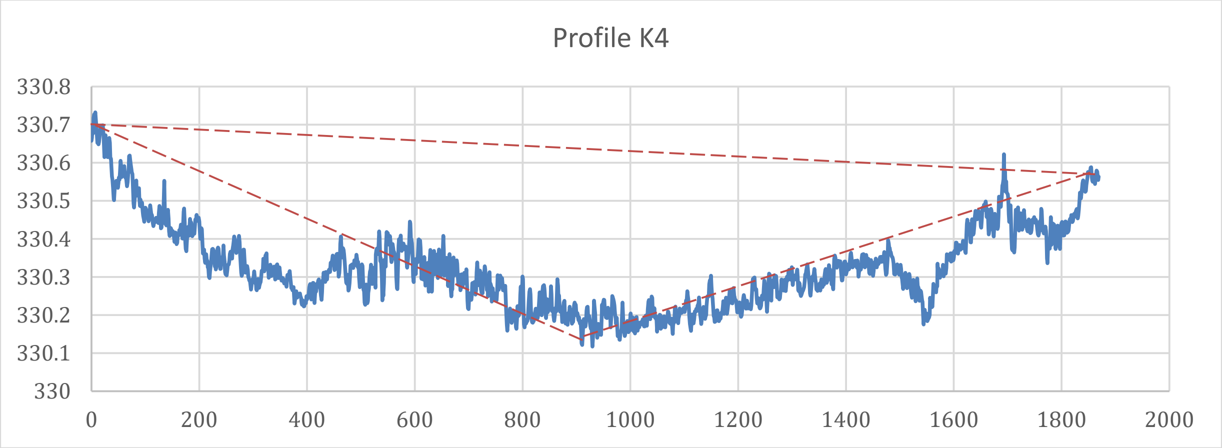
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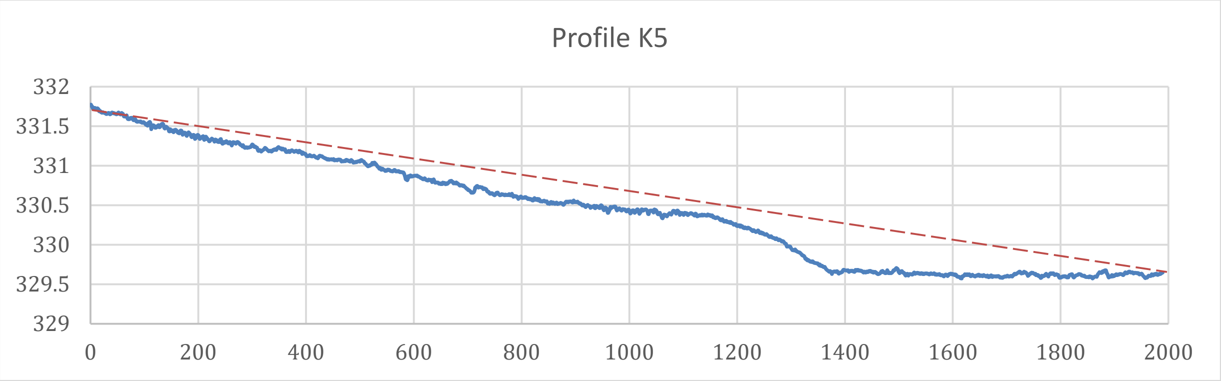

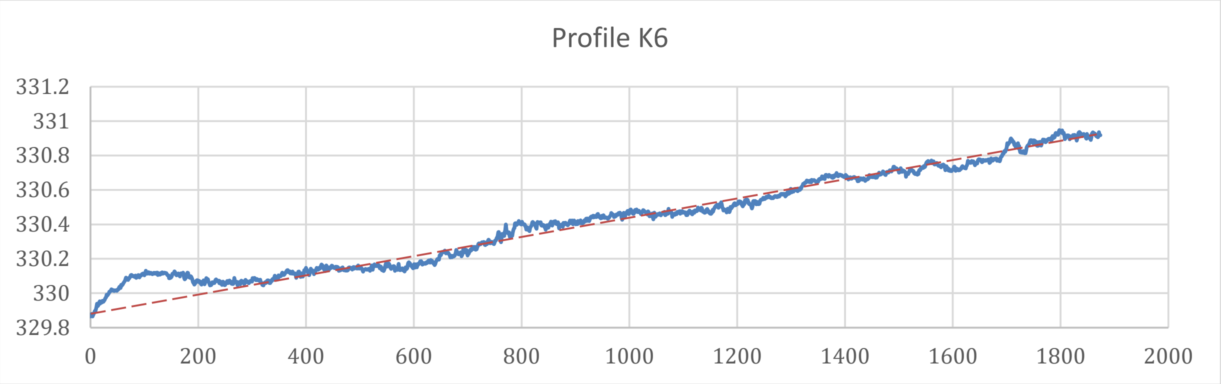

Arrow also looked more broadly at the slope classes across the whole tenement (across all land uses) using GIS mapping techniques. The slope increments/classes were selected to focus on the very flat slopes in the landscape that are intensively farmed. This is based on a pixel-by-pixel analysis, not across paddocks or farms. The results of the area and percentage of each slope class across the whole Arrow tenement are shown below; with the dominant slope class being greater than 0.5% (0.5m in 100m).

Slope classes	Area (ha)	Area (%)
< 0.01%	465	0.07%
0.01 - 0.03%	3650	0.52%
0.03 - 0.06%	11766	1.68%
0.06 - 0.12%	39420	5.62%
0.12 - 0.5%	190452	27.15%
> 0.5%	455790	64.97%

When confined only to dryland and irrigated cropping lands, the following table shows the results of analysis of the slope classes against the area in hectares and percentage. The dominant slope class is 0.12 to 0.5%.

	Dryland		Irrigated		Total	
Slope Class	**Area (ha’s)**	**Area (%)**	**Area (ha’s)**	**Area (%)**	**Area (ha’s)**	**Area (%)**
<0.01%	227	0.22%	130	0.26%	357	0.2%
0.01-0.03%	1,771	1.7%	1,037	2.0%	2,808	1.8%

0.03-0.06%	5,418	5.2%	3,425	6.7%	8,483	5.7%
0.06-0.12%	15,753	15%	10,843	21%	26,596	17.1%
0.12-0.5%	50,171	48%	26,711	52%	76,882	49.6%
>0.5%	31,097	30%	8,529	16%	39,526	25.5%
TOTAL	104,437	100%	50,675	100%	155,112	100%

DataFarming also looked at the natural variations in the surface due to the swell shrink nature of the Vertisol clays present on the Darlings Downs. Anecdotal evidence from soil experts suggest that vertical movement is up to 200mm[1] between wet and dry. Some research from the 1960's suggests up to 150mm vertical heave in heavy clay soils, depending on surface conditions[2]. Other research has been conducted in Queensland by Ted Gardner in the 1970's and 1980's however the journal articles could not be found online.

Vertical movement is difficult to measure but one method tested for this project compares adjacent strips in a strip cropping layout; a typical floodplain management practice. Strips of crop/fallow/crop are established perpendicular to the main flood flow direction varying in width from tens of metres to hundreds of metres. An example image of strip cropping is shown below in Figure 3.

Figure 3: example of strip cropping layouts on the Darling Downs, perpendicular to the flood flow

Strip cropping provides an insight into the likely vertical movement due to differences in soil water content as typically one strip profile will be dry (due to crop extraction) and the other will be wet (due to fallow soil water accumulation). Several sites we identified from Lidar imagery sourced from the Queensland Government (2014 data). Figures 4, 5, 6, and 7 below shows the lidar elevation and cross-section profile results.

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[1] Sharp, G (2020) Soil scientist pers comm.

[2] Rao, Subba K.S. (2000) Indian Geotechnical Journal 30 (1)

Figure 4: Elevation data showing the vertical impact of strip cropping; and also the profile (black) lines where data was extracted from. The vertical difference represented in the colours (red to green) is approximately 4 metres. Red dot on inset map indicates location of profiles.

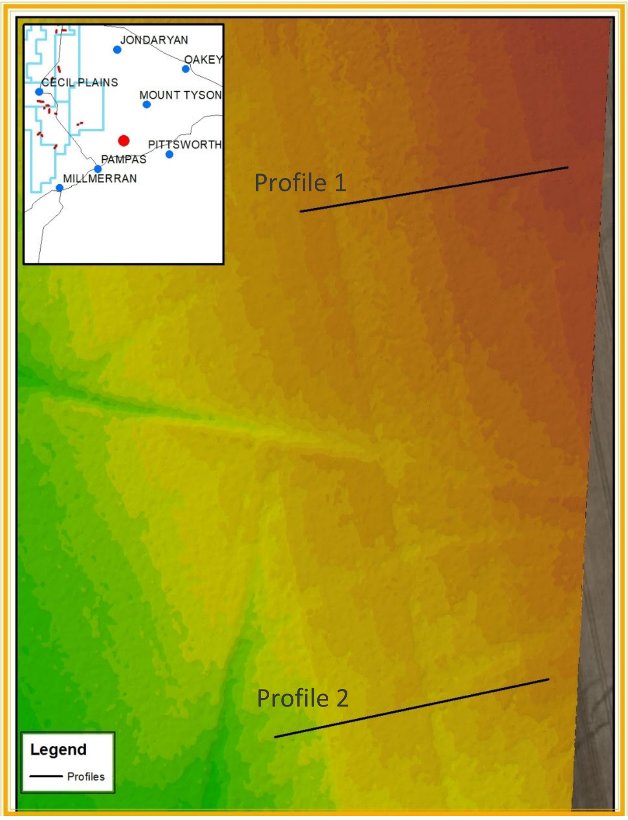
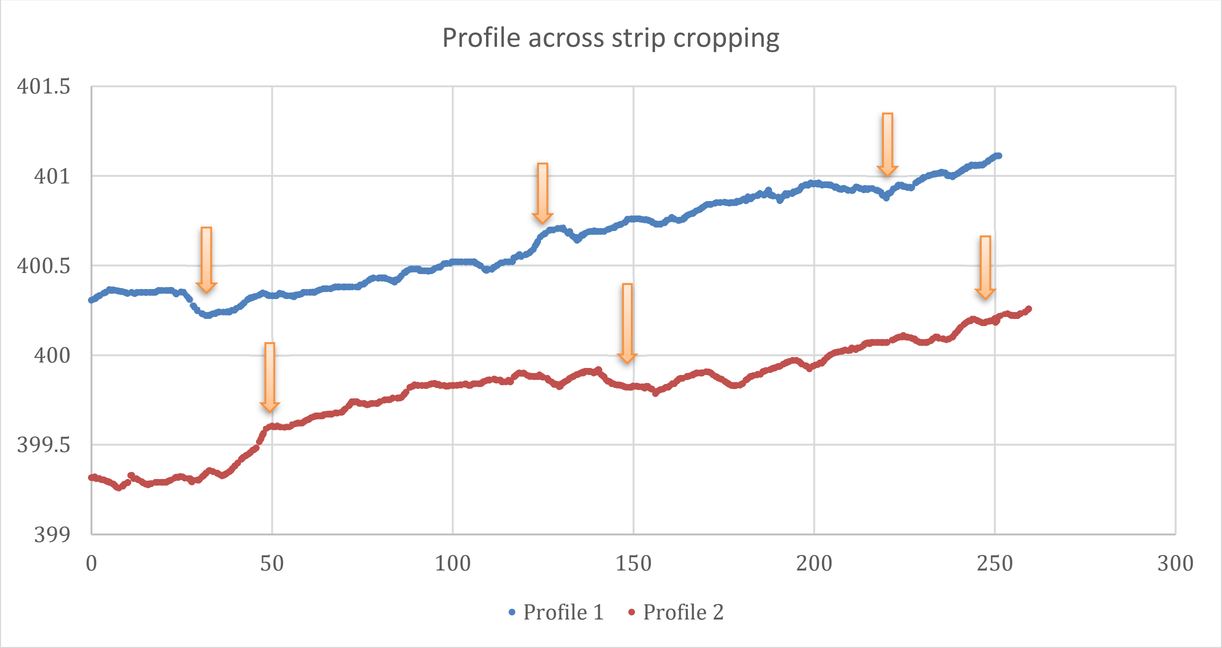


Figure 5: cross-sectional profiles perpendicual to the strip crop layout (arrows indicate strip join)



If the two cross section profiles are separated, and the vertical difference is determined, we can see that some of these strips differ by between 75mm and 200 mm (see figures 6 and 7). Some of this impact could be due to sedimentation, but this is less likely as you would expect to see higher elevations on the uphill side of the strip; however, this is not evident in these profiles. Other profiles we tested from across the Downs showed varying levels of vertical difference (due to different moistures and potential sedimentation), and the example shown here was where the differences were most evident.

Figure 6: profile 1 with wet/dry lines imposed – arrows indicate strip change (~75mm vertical difference)

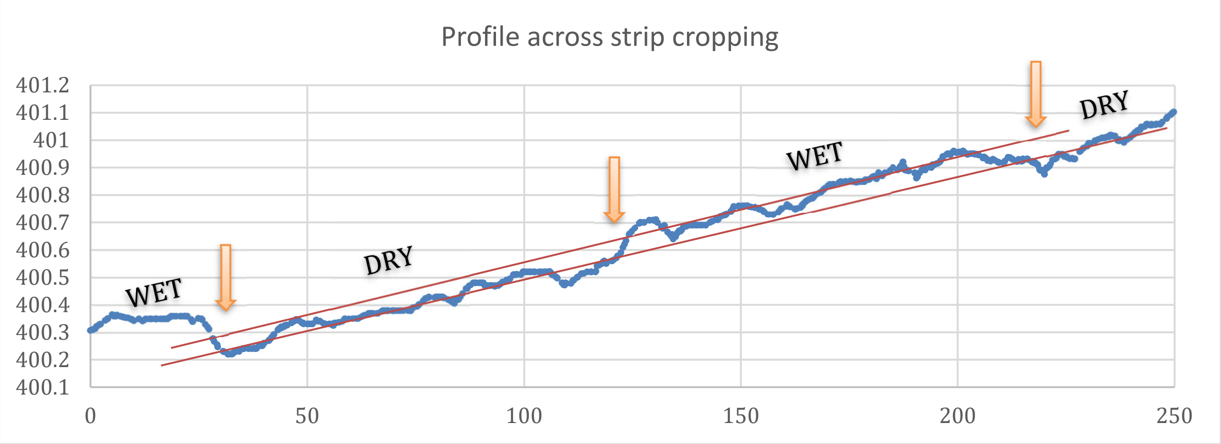
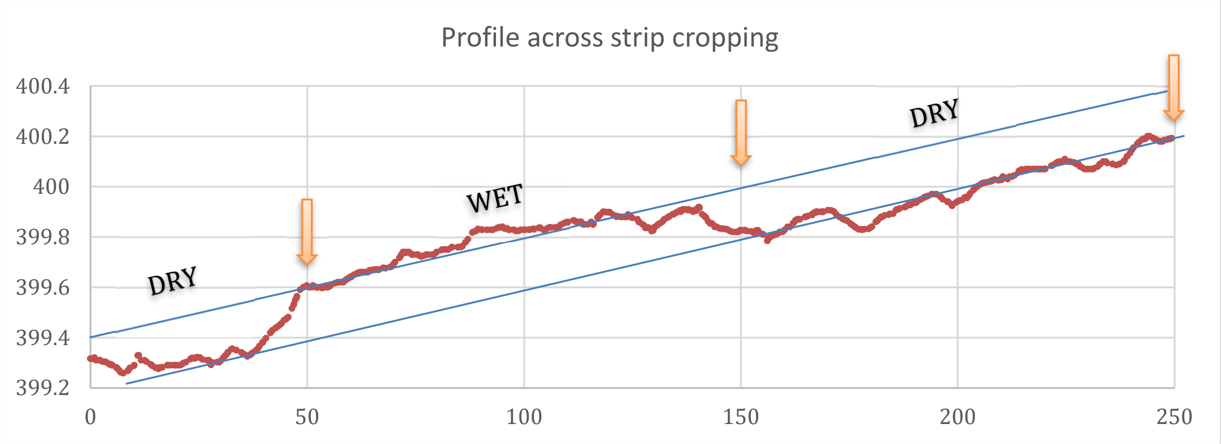


Figure 7: profile 2 with wet/dry lines imposed – arrows indicate strip change (~200mm vertical difference)



3.2 Typical land forming techniques used on the Darling Downs

Land forming (land levelling) is a range of techniques using agricultural machines to achieve either:

- A single (or multiple) flat plane(s) at a consistent grade (slope) primarily for flood/surface irrigation. Surface irrigation using formed furrows works most effectively where there is consistent grade to ensure even wetting of the soil profile. In the past this approach has primarily been implemented by using what's termed as a 'laser bucket'.
- Removal of water pondage areas in dryland and irrigated paddocks by levelling the ground to ensure all areas of the field are within a set slope range, and water freely drains from the field. This is a newer technique using GNSS (GPS) technology. The same earth moving bucket is used, however

control is now conducted by satellite positioning.

- Smoothing of 'melon holes' (gilgai's) using land planing with no external vertical control. This is an old technique using a large blade towed by a tractor to smooth out the landscape by essentially removing the high points and grading them into the low areas.
- Repair after flooding events where overland flow has shifted large volumes of soil, and/or damaged irrigation infrastructure.
- To re-level melon hole country where the gilgai's start to re-form, which is normally after several decades. This is triggered by signs of waterlogging re-appearing in crops.

3.2.1 Laser (controlled) bucket

'Laser bucket' land forming is a technique that combines a land forming 'bucket' towed by a large tractor, with the grade (slope) controlled by a laser light. A tower is set up in the paddock with the laser attached, and the tractor has a receiver. Grade is set by the operator using an interface in the tractor cab, and the height is automatically controlled using hydraulic control valves and controller. Buckets (that cut and release soil via hydraulic control) and blades (that drag soil and hold within the blade) can be controlled with lasers.

The main situations where laser bucket work has been conducted in the past has been in surface/flood irrigation systems, where furrows are formed to carry water evenly down the field. This is the primary irrigation technique employed across the Arrow tenure. The figure 8 below shows a land formed field with furrow irrigation. Finished slope is typically between 1:500 (0.2%) to 1:1500 (0.066%), and common furrow lengths are 300 to 1000 metres (Waterpak, 2012[3]). Most effective field length for furrow irrigated fields is between 600m and 700m. **Water will not drain adequately below slopes of 1:1650 (0.06% or 6cm/100m fall).**

Figure 8: Furrow/surface/flood irrigation in practice. (source link.springer.com)

The key points to note about laser systems are that:

- There is no position information (relative to the earth's surface);
- They are really only suited to flood/surface irrigation systems that require a uniform slope, and have a greater return per hectare to afford the costs of laser levelling;
- They have limited range between the transmitter and receiver (the laser light quality deteriorates

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[3] Waterpak – a guide for irrigation management in cotton and grain farming systems (https://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf)

with distance, dust, and mirage conditions);

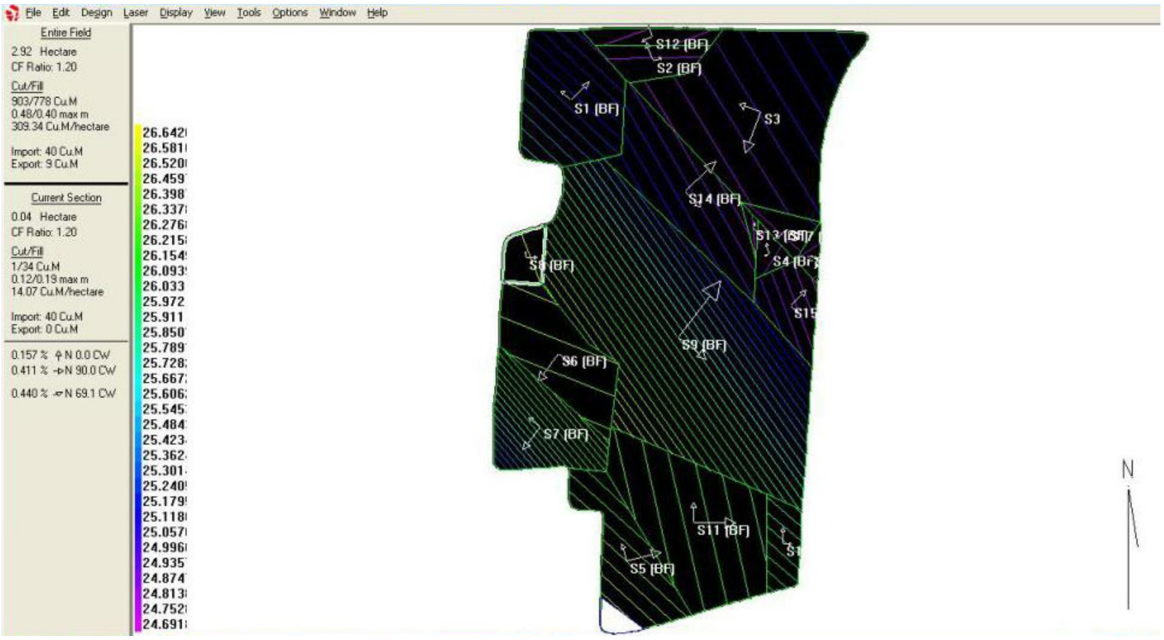
- They are limited to forming flat planes, and not able to work with the natural topography which often results in high volumes of soil moved;
- The equipment is relatively cheap to purchase, and easy to install and operate; and
- They do not factor in the curvature of the earths surface or the AHD (Australian Height Datum).

A typical flat land forming scenario using a laser bucket may shift in excess of 300-1000m^3 per hectare, depending of course on the topography. Pictures of the main components is shown below in Figure 9.

Figure 9: Laser bucket operating in the field with the laser receiver circled (source Justheavyequipment.com.au)

Designs are either conducted directly in the field, or pre-planned using software such as Multiplane[4]. As the name suggests the software breaks the field into a number of flat planes to optimise soil movement. An example of a multiplane design is shown below in Figure 10.

Figure 10: multiplane design showing breaklines and slope direction



Entire Field
2.92 Hectare
CF Ratio: 1.20
Cut/Fill
903/778 Cu.M
0.48/0.40 max m
309.34 Cu.M/hectare

Import: 40 Cu.M
Export: 9 Cu.M

Current Section
0.04 Hectare
CF Ratio: 1.20
Cut/Fill
1/34 Cu.M
0.12/0.19 max m
14.07 Cu.M/hectare

Import: 40 Cu.M
Export: 0 Cu.M

0.157 % N 0.0 CW
0.411 % N 90.0 CW
0.440 % N 69.1 CW

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[4] Multiplane is a brand owned by Trimble

3.2.2 GNSS control of land levelling equipment

Instead of using laser to control the height of the levelling equipment, almost all current land forming is conducted using GNSS (Global Navigational Satellite Systems). This method provides added advantages over laser including:

- Having position information relative to the earth's surface means location specific land forming can occur, which can dramatically reduce the amount of soil needed to be moved;
- Working with the natural topography of the land, instead of having to make a flat plane;
- GNSS levelling considers the Australian height datum and curvature of the earth surface;
- It can be operated in dusty conditions, and 24/7 operation (depending on satellite availability);
- It has much longer base lines (distance between the transmitter and receiver), although limits do apply;
- Are suited to a wide range of applications from surface and sprinkler/pivot irrigation, and dryland farming situations;
- Multiple machines can operate in the same field, off the same design, simultaneously; and
- Considers the cut:fill ratio to allow for compaction and settlement (typically a factor of 1.2).

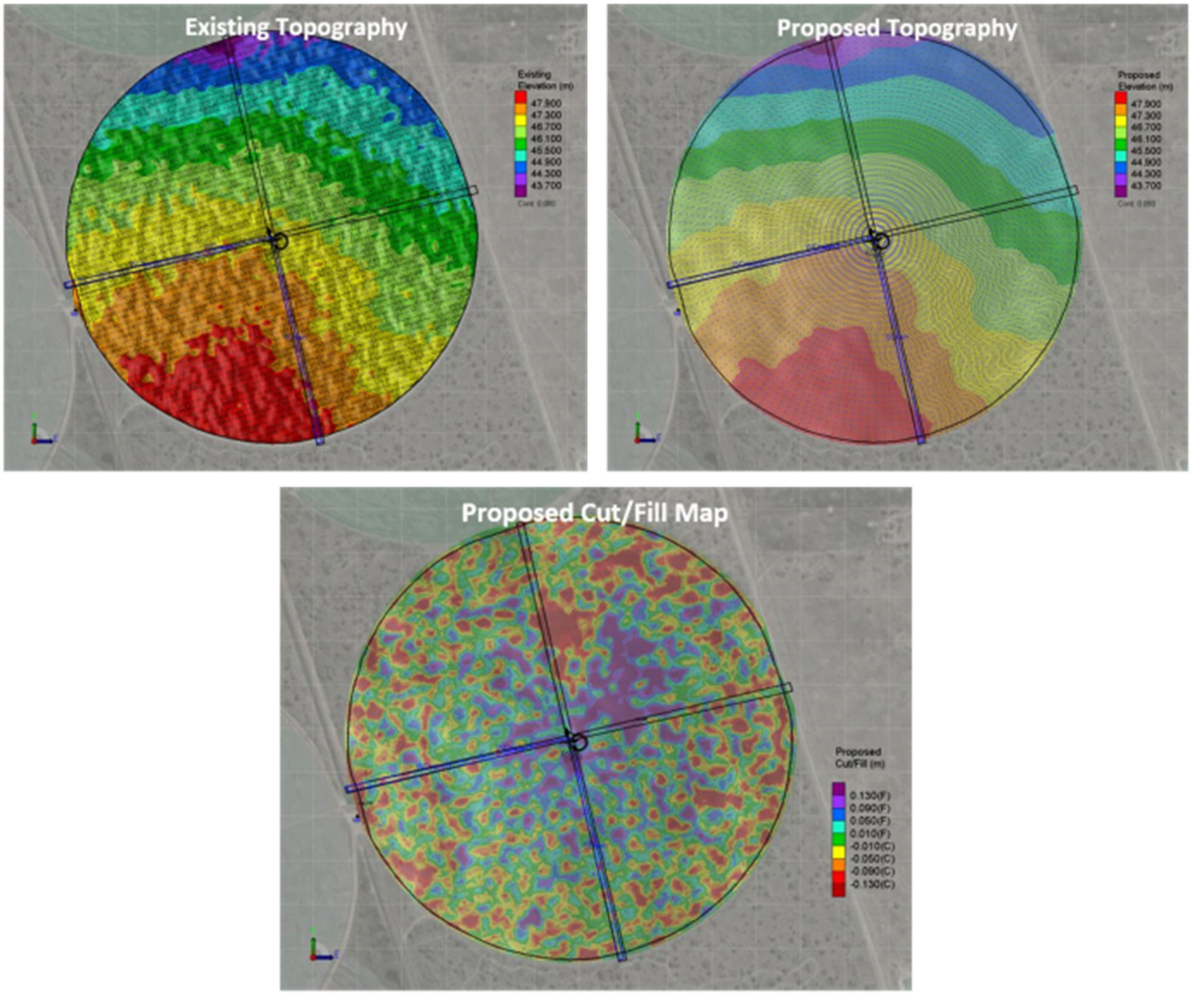
Depending on topography, typical GNSS controlled land forming shifts 80-300m^3 of soil per hectare. Buckets (that cut, hold, and release soil via hydraulic control) and blades (that drag soil and hold within the blade) can be controlled with GNSS. Photos of the main components are shown below in Figure 11 and Figure 12.

Figure 11: Single receiver GNSS land levelling components (source Tim Neale), and dual antennae options below (Source BMS lasersat)

Figure 12: levelling blade and Pulldozer style levelling options (source Optisurface top, and Pulldozer bottom – source Bridgeview manufacturing)

There are several software options for land forming using GNSS technology. It is not the aim of this report to go into detail of the available software, more the concept of land forming using the latest technology. The examples below using OptiSurface™ are for demonstration purposes only. Figure 13 shows: the data collection step, (where the existing topography is collected through a GNSS survey), the proposed topography (from the software design phase), and the resultant cut:fill map (where there needs to be soil cut or soil filled and the depth of these). You can clearly see that the proposed topography takes into consideration the existing topography to ensure the absolute minimal amount of soil is shifted and still obtain adequate drainage (at least 0.05%, or 5cm/100m, slope).

Figure 13: example of the design process for GNSS land forming. (source Author)[5]



The process of land forming using GNSS technology is as follows:

1. The first step starts back in crop selection. Paddocks with high levels of stubble remaining before land preparation will take extra work to reduce this. Heavy stubbles such as sorghum tend to inhibit the land levelling blade. It is best to level either after a low cover crop such as chickpea, or cotton where pupae busting (cultivation) is required.
2. The next step in the levelling process is to prepare the land with heavy cultivation. This achieves several outcomes. Firstly, it removes more stubble allowing earthmoving buckets to work most effectively, secondly it provides deep tilth helping the operator cut the soil, and thirdly it levels any old wheel tracks which cause problems with the survey.
3. Conduct the RTK GPS/GNSS survey once the cultivation is completed, as near as practical to the land levelling operation. A light vehicle or tractor can complete this operation. This may not always be the case with the erratic rainfall patterns of Australia. LiDAR data if available could be used. Swath widths of the survey need to be varied depending on the nature of the topography.

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[5] https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/07/reducing-yield-losses-from-waterlogging-by-improving-drainage-in-melon-hole-country

4. The survey data is loaded into the computer software and the operator enters required information, such as minimum and maximum grades, as well as the cut:fill ratios and flow paths. Several decisions will need to be made at this step with regards to how the field is planned to be farmed into the future; which includes factors such as the wheel track/run line direction, length of run, location of field drains, public infrastructure, irrigation method (if applicable), neighbouring properties water coordination, and the location of roads/tracks for the removal of grain/cotton.
5. The cut:fill file is then loaded into the machine to begin the levelling process. The operator should refer to the benchmarks regularly through the survey, as vertical drift (inaccuracies) can occur due to the nature of GNSS systems. New technology such as Trimble's Vertical Point RTK technology has greatly improved vertical accuracies and reduced the period when vertical accuracies are outside tolerance limits.

The final result of this type of land forming is shown below in Figure 14, in this case heavy 'melon hole' gilgai country.

Figure 14: The resultant lack of ponding on land formed areas of the landscape compared to no treated areas[6]

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[6] Source: OptiSurface

3.2.3 Land planes

This is an older technique rarely used any more on the Darling Downs but was used extensively in the early days of land development to smooth out the landscape to prevent ponding, mainly from 'melon holes' or gilgai's. An image of a land plane is shown below in Figure 15 – note there is no external height control.

Figure 15: Land plane (source: http://www.tgschmeiser.com/)

3.3 The accuracy with which the surface and slope can be measured

To determine the potential impact of deformation on the land surface, it is important to be able to measure this impact over the longer term. There are a number of ways of measuring the elevation, topography, and slope of the ground surface. Methods of elevation measurement that are most relevant for this project include:

- Lidar from airborne platforms;
- Airborne photogrammetry from aeroplanes or UAV's (unmanned aerial vehicles or drones); and
- RTK GNSS/GPS ground survey or from farm machinery.

The results are summarised in the following table and explained in detail in the following sections.

Method	Specific sources	Vertical accuracy	Key limitations
Lidar from airborne platforms	Airborne laser scanner	+/- 5 to 10cm (to 50cm for legacy platforms)	Quality of ground control points, and accuracy of instrument, will determine accuracy
Airborne/UAV photogrammetry	UAV photogrammetry	+/- 5cm	Limited to line of sight (~500m) operation unless authorised; will not penetrate through vegetation
	Airborne photogrammetry	+/- 5cm to 50cm	Will not penetrate through surface vegetation to obtain terrain
RTK GNSS ground survey from farm	Trimble AG542 base station (static)	+/- 1.5cm + 1ppm	For every 1km from the base station vertical accuracy will

machinery			degrade by 1mm (10km = +/-1cm)
	Trimble AG372 rover (static)	+/- 3.7cm + 2ppm	For every 1km from the base station vertical accuracy will degrade by 2mm (10km = +/- 2cm)
	Trimble NetR9 receiver	+/-1.5cm+ 0.5ppm	With Ag25 or compatible receiver, within 30km of the base station.
	John Deere 6000 series receivers (pass to pass)	+/- 4.2cm + ppm	Recommended to be within 2km of a base station

3.3.1 Lidar from airborne platforms

Lidar (light detection and ranging) is a technique, typically collected from an aeroplane (and more recently from UAV/drones) which emits and measures laser light, and has been used in Australia since the late 1990's. Each laser strike return comprises information about the intensity of the 'strike' along with the vertical and horizontal height of that strike. In some cases, there may be up to several hundred Lidar strikes over each square metre of ground, providing high-definition data, and detailed understanding on the surface characteristics.

LiDAR height data is calibrated by positioning technologies such as GNSS ground control to ensure a high-quality product. An example Lidar map of terrain is shown below in Figure 16, with the resultant surface model of tree cover. The nature of Lidar means the ground can easily be separate from the vegetation. There are typically two types of outputs from a Lidar survey:

1. A digital elevation model (DEM) – the lowest values where the laser strikes the ground
2. A digital surface model (DSM) – the values where the laser strikes the tree/vegetation/structure

If we look at a cropping situation on the Darling Downs, Figure 17 shows the results of a single, Lidar generated, contour line. The blue lines are all at the **same height** and show the incredible detail that Lidar can provide due to the large number of strikes per square metre. In a relative sense these are very accurate, and if you compare to a GNSS survey that may be on a 12m x 5m point grid spacing that needs to be interpolated, Lidar provides highly detailed information at a much finer scale and has complete ground coverage.

'Actual' vertical accuracies of Lidar surveys in the past have been between 10cm and 50cm[7], depending on survey quality and ground control, with most modern surveys now being 5 to 10cm. The surveys commissioned by Arrow Energy are 5cm (pers comm). Keeping in mind that these accuracies are across the survey and relate to **actual heights** (vertical datums), and the **relative** accuracies are much better than this. Relative accuracies are what are used to determine drainage across the paddock. Figure 17 below demonstrates this clearly – the small micro variations of the same height (blue contour lines are exactly the same elevation) are detected every square metre, however the accuracy of the elevation in real terms is +/- 5cm.

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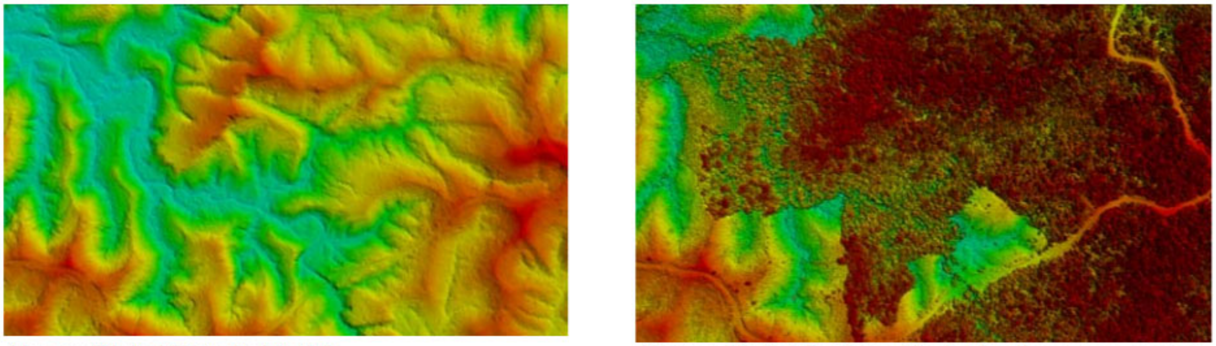
[7] https://www.aamgroup.com/_literature_111669/3D_Terrain_Image_Data

UAV mounted Lidar is starting to become commercially available. Due to current CASA (Civil Aviation Safety Authority) regulations the require line of sight flight operations, the area of coverage will still be quite limited. This is likely to change but will not be in the reach of most landholders as there will be significant licencing and aircraft restrictions/requirements.

Lidar is the tool of choice by governments and the commercial sector for gathering elevation data as it is repeatable, it can produce DEM's and DSM's, is cost effective, can cover large areas, and has a complete coverage of the land surface.

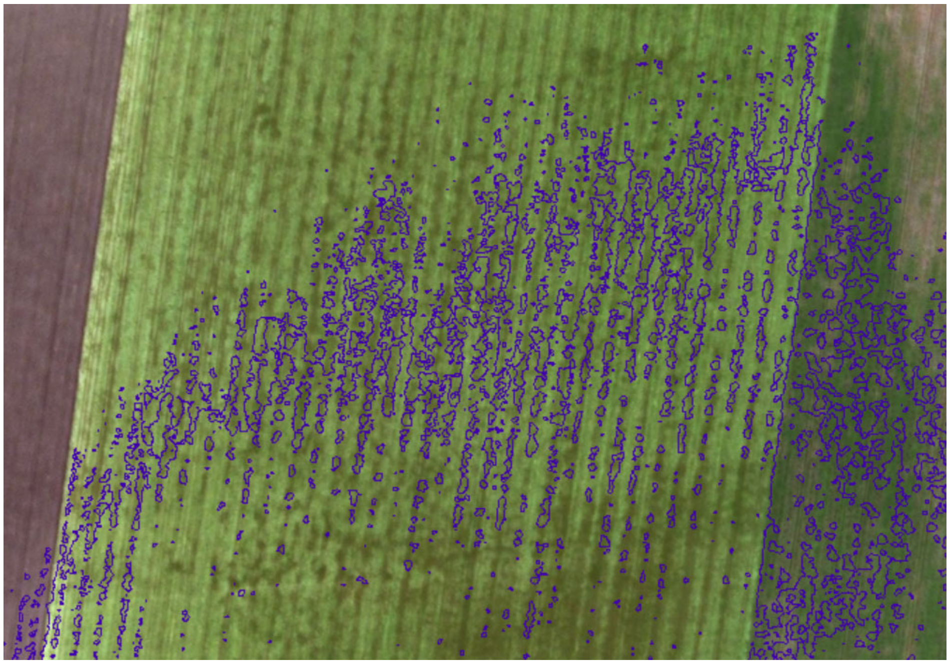
Figure 16: Airborne Lidar showing terrain (left) and surface model showing tree cover (source AAM group)



Above: Digital Terrain Model

Above: Digital Surface Model for the same area to the immediate left!

Figure 17: Lidar data generated (blue) contour line over a cropping paddock (DataFarming)



3.3.2 Airborne/UAV derived photogrammetry

Photogrammetry is the process of generating maps, models and measurements from standard photographic imagery, that has a large amount of overlap between the images to provide the method to determine the terrain. This process started in WW1 where rectifying aerial images and viewing them as 'stereo pairs' was a way to take accurate measurements from them. The advent of computing meant that this process could be improve considerably to a point where even UAV's (Unmanned Aerial Vehicles) or drones can now fly over the land capturing a large number of photographs, and once stitched together, can create 3D point clouds of elevation data. Vertical accuracies for UAV derived data can be around +/-5cm, however greater accuracies can be achieved with better ground control and image overlap[8]. Airborne derived photogrammetry vertical accuracies are typically in the range of 5-50cm, depending on flying altitude and ground conditions[9].

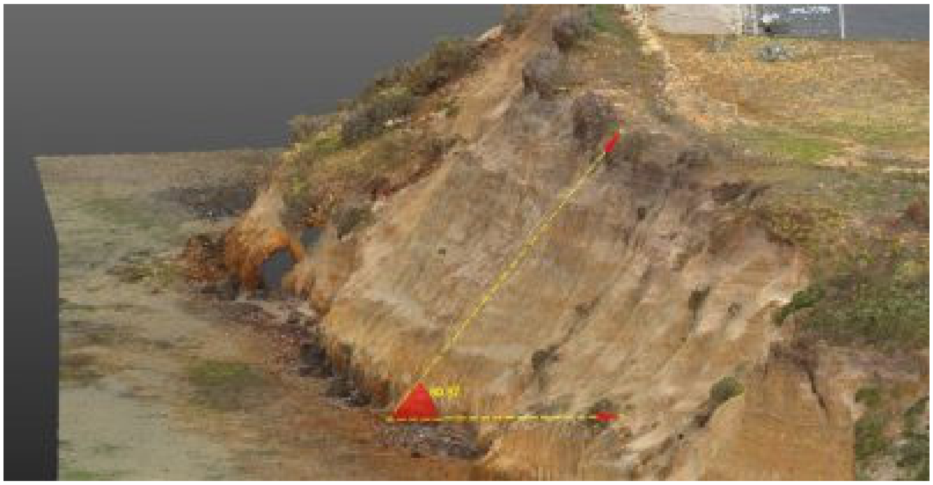
An important requirement to obtain highly accurate elevations and 3D terrain models using photogrammetry is well spaced and regular ground control points, which are typically captured by RTK GNSS. GNSS also have vertical accuracy constraints as explained in other sections. It is unlikely that UAV derived terrain models will ever be at the scale required by a farmer to monitor changes in elevation (unless technology changes significantly). This is due to several factors including:

- the limitation on the effective coverage area due to line-of-sight flight restrictions;
- the large number of ground control points needed to obtain high accuracies, which much be RTK GNSS referenced;
- it cannot penetrate surface vegetation;
- requires specialist software to process; and
- data volumes are very large and often require processing in the 'cloud' which is challenging in rural areas with limited broadband.

UAV mounted Lidar is just entering the market now and will be a better option compared to photogrammetry in the future.

Examples are shown below of 3D models created by UAV and airborne photogrammetry (Figures 18 and 19).

Figure 18: UAV photographs draped over a 3D terrain model (source auav.com.au)



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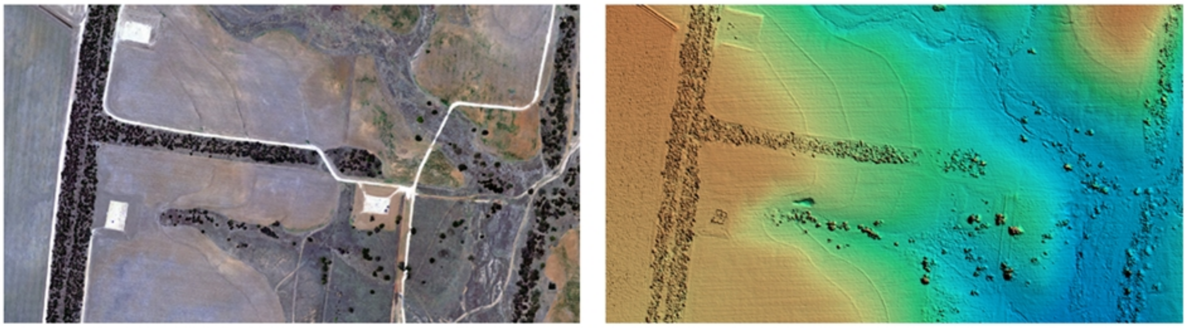
[8] Source auav.com.au

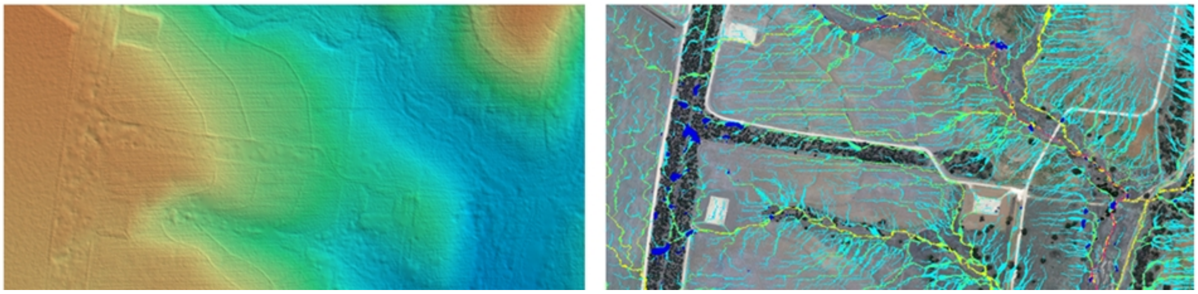
[9] https://www.aamgroup.com/_literature_111669/3D_Terrain_Image_Data

Figure 19: Airborne digital photography and determining terrain and water flows (source GRDC[10])



Step 1 - Visual Image from aerial survey

Step 2 - Digital surface model including trees and buildings



Step 3 - Ground elevation model (trees and buildings removed)

Step 4 – Soil surface water flow model derived from Step 3.

The main limitation with photogrammetry however is that if there is a large amount of material covering the ground surface, then it will provide a digital **surface** model (the surface of the material) instead of a digital **terrain** model (the actual ground terrain). Whist some can be removed with some sophisticated processing as shown in the example above, this is where Lidar provides a better result. Another limitation is that UAV's will only be able to capture a small amount of the landscape, whereas airborne photogrammetry can cover vast areas.

The preference would always be to use Lidar over airborne photogrammetry as it can penetrate the vegetation canopy and obtain more accurate ground measurements.

3.3.3 RTK GNSS ground survey or from farm machinery

Most new agricultural machines now include high accuracy GNSS (Global Navigational Satellite System) units who primary purpose is to provide hands free autosteering. There is a receiver on the roof of the machine, a base station on the property (to provide correction signal), a steering control valve, and a screen. There are a range of accuracy options available, but most farmers are now opting for RTK (real-time kinematic) corrections which provide approximately +/- 2.5cm repeatable static horizontal accuracies. Whilst this is rarely achieved at the machine in a dynamic field environment, it provides a very reliable method of farm operation. The resultant straight crop rows are impressive. Other forms of GNSS (such as free to air, or corrected) are not covered in this report, as their accuracies are considerably less than RTK and hence are not suitable for monitoring vertical movements.

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[10] https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/07/aerial-photogrammetry-to-assist-farm-layout-planning-and-management

It is important to note that the accuracies quoted by each manufacturer are **relative static** accuracies. When observed in a **dynamic** state, i.e., moving and on a machine, then this introduces a range of other errors into the measurement of the x, y, and z (latitude, longitude, altitude). Some early studies show a tripling in the in-accuracy, however more up-to-date studies could not be found and improvements in technology are likely to have been made.

Most farm operated base stations are not surveyed in, which means they are only 'relatively' accurate. Any data in relation to horizontal and vertical measurements are only as good at the accuracy of the base station coordinates. Agricultural base stations are typically averaged for between 60 seconds and 24hours – which means they could be several metres horizontally and vertically from the 'actual' location on the earth surface (in relation to the horizontal and vertical datum's). This needs to be considered when comparing farm GNSS data to other sources of data such as Lidar.

If RTK GNSS on farm machinery is being used for measuring height changes over time, then obvious additional errors can come from:

- Wheeltracks and changes over time (see below in Figure 20);
- Differences between the machines collecting the data (for example tractor vs harvester where there might be slight differences in measured antennae height above the ground);
- The type of machine (for example, as a spray rig empties its load, the height of the machine increases, and similarly as a harvester accumulates grain, the height of the machine decreases);
- Implements attached to the machine; and
- The setup and operating speed of the machine will impact its ability to accurately collect height data.

Figure 20: Wheeltracks in a paddock caused by wet soils and heavy farm machinery (source: Author)

The most prevalent brands of RTK GNSS is agriculture are John Deere and Trimble and would represent more than 90% of the agricultural market today.

John Deere's latest generation of receivers, the 6000 series (shown below in Figure 21), has a pass to pass (15-minute interval at 95% confidence) **vertical** accuracy of +/-4.2cm.

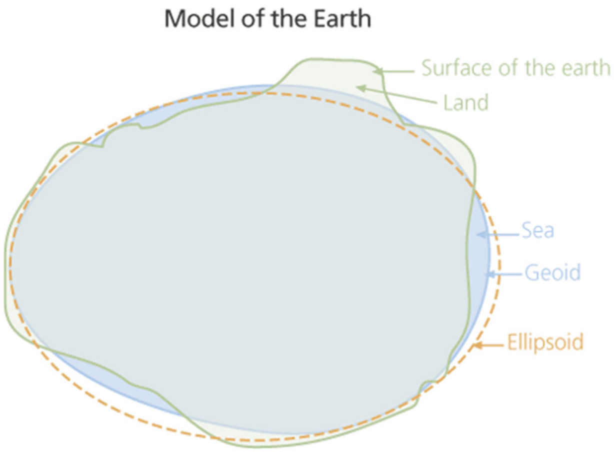
Figure 21: John Deere 6000 series receivers (left) on a tractor and bucket (right), source John Deere

Trimble's AG542 receiver quotes accuracies of 15mm vertically + 1ppm (1mm/km away from the base station). Technically this vertical accuracy is +/-15mm. An AG372 receivers' vertical accuracy is +/-37mm + 2 ppm (mm/km). These units are shown below in Figure 22

Figure 22: Trimble roof array (left) and base station (source Trimble)

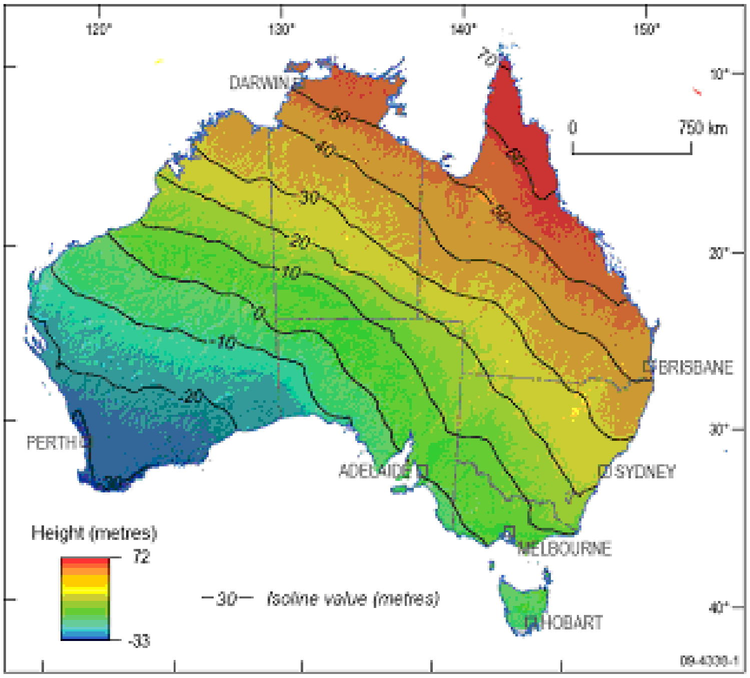
Without getting into a lot of detail in this report, most GNSS systems integrate a factor to account for the differences between the height which GNSS uses (ellipsoid height) and the geoidal height (which simulates sea level). This is called the geoidal separation. A diagram to explain the difference is below in Figure 23.

Figure 23: Model of the earth showing the geoid, ellipsoid, and the land surface



Geoidal separation is not consistent across Australia (see below in Figure 24); therefore, a factor is implemented into modern GNSS receivers. Typically, this factor is on a grid basis, and between 1 minute (~1.5km[11]) and 5km[12] depending on the receiver. If we look at the difference within the 1km grid then the 'error' between the GNSS (ellipsoid) height and geoidal height could be around 2.8cm/km in a NE/SW direction, which is in addition to the GNSS atmospheric errors reported above. This will potentially impact water flows and land levelling, but more importantly it adds another 'error' into the system when trying to measure the true height of the ground surface.

Figure 24: Geoidal separation across Australia (source Geoscience Australia).



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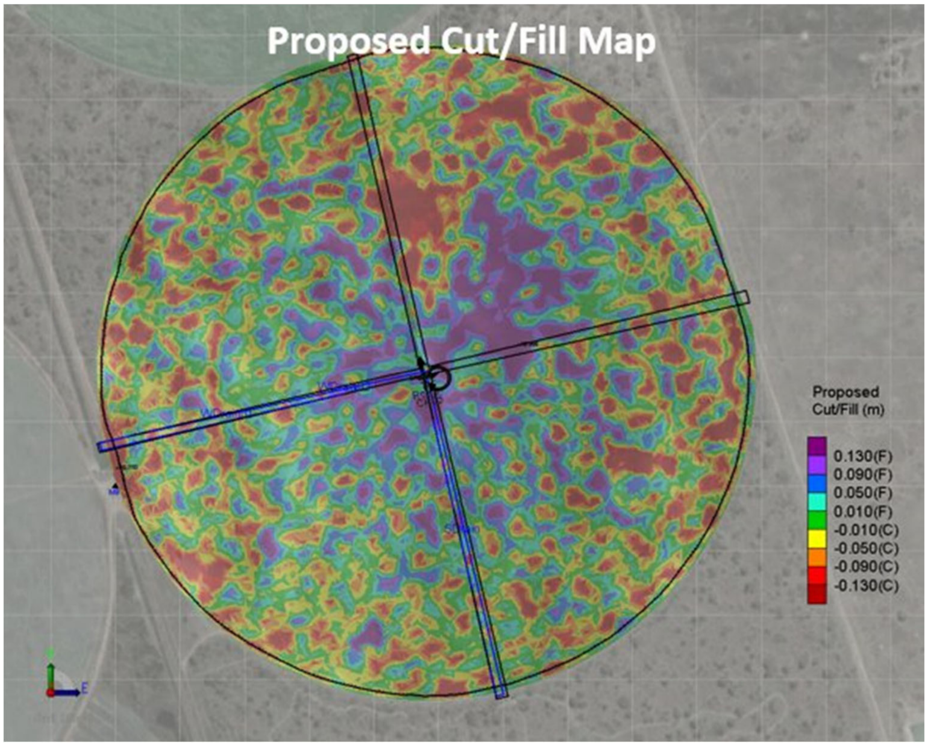
[11] http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/ahdgm/ausgeoid2020

[12] From Author's recollection

3.4 The accuracy with which the surface can be modified using land forming

Once the land surface has been surveyed for land levelling (this can be from Lidar or GNSS survey), there are a number of software solutions available to design highly targeted soil movement. Software such as Optisurface and Terra Design offer the ability to precisely determine the cut and fill required to achieve drainage of surface water from agricultural land. Parameters such as minimum and maximum slopes, drainage direction, and compaction are all taken into consideration when developing the drainage design. After the computer has processed the data, a map and associated file is produced which shows where soil needs to be cut, and where it is to be filled across the paddock; and the total soil volume to be moved is displayed. The computer software balances out the cut:fill volumes (whilst taking into account soil compaction) to ensure no additional soil is left over at the end of the job. An example of a cut:fill map is shown below in Figure 25. As you can see there are areas for cut (C) and fill (F); and in this example due to the nature of the terrain, there are a lot of very fine cut's and fill's planned. The software is anticipating a relatively large area to have less than 5cm (vertically) of soil being shifted, which is fantastic in reducing the cost of earthworks.

Figure 25: Example Cut(C):Fill(F) map



Once the user is satisfied with the output, the file is fed into the machine to complete the work. Whilst very slight cuts and fills are requested by the software, those less than 2-3cm aren't practically achievable in the final surface due to some of the following factors:

- GNSS drift in the receiver, which requires continual 'benching' to re-align the bucket to the survey;
- Longer baselines than recommended (the distance between the base station and the tractor);
- Lower accuracy receivers, such as the John Deere 6000 with a vertical accuracy of +/-4.2cm;
- Intensity of the survey and the data feeding into the model (for example using a 40m swath width

instead of a 10m swath at the time of the GNSS survey);

- The speed and precision of the hydraulic system on the machines;
- Crop stubble on the ground surface causing dragging and deeper cuts;
- Blocky and compacted soil structure, which are common in heavy clay soils (soil clods with high clay content might be 5-10cm in diameter – see Figure 26);
- Rainfall or changes in soil condition between survey and land levelling;
- Settlement of the soil in fill areas, and potential swelling of the soil in cut areas after treatment; and
- Large buckets and whether they have dual antennas installed to control the blade more accurately.

Figure 26 : Sub 2-3cm accuracies are unlikely to be achieved in situations like these due to cloddy or soft nature of soil (source: top – dryhireonline, bottom - Collier and Miller)

There have been considerable improvements in the GNSS technology over recent years. Vertical accuracies have improved considerably with the advent of new generation receivers, increased satellite availability, and advances is firmware and software. Atmospheric errors still continue to cause vertical drift in the receiver and reduce the ability of GNSS to provide a highly accurate land levelling solution. There are however a couple of new tools available, including the Toomey ECS system, and Trimble's vertical point.

Toomey ECS system [13]where the base station is fitted with an actuator which raises and lowers the base to account for vertical 'drift' in the GNSS system. Vertical accuracies can be improved to around 6mm, but ideally less than 10mm[14]. This only represents the accuracy of the GNSS equipment, not the actual final ground surface as a result of the levelling operation. An image of the Toomey system is shown below in Figure 27.

Figure 27: The Toomey linear actuator fitted to a GNSS base station (Source Toomey)

Trimble vertical point RTK system improves the accuracy like the Toomey system above; by adding additional static rovers to account for GNSS 'drift' as shown below in Figure 28.

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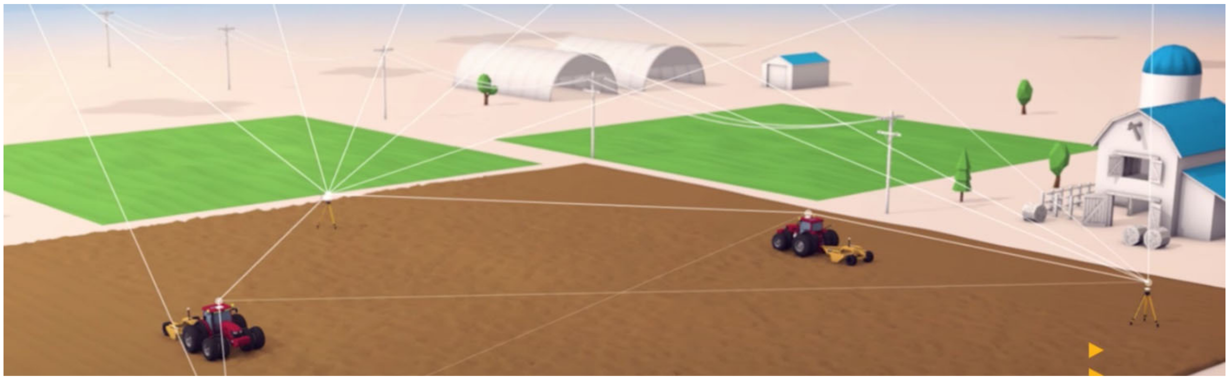
[13] https://www.toomeyearthmovers.com/ecsfeatures

[14] Toomey ECS

Figure 28: Trimble's vertical point RTK system noting 2 base stations (Source https://agriculture.trimble.com/product/verticalpoint-rtk-grade-control)



Both of these solutions however are usually limited to temporary use during earthmoving operations, not long-term measurements. However, that said, they significantly improve the ability to obtain greater accuracy in land levelling operations.

4. Summary

According to the analysis of slopes over the Arrow tenement, most cropping paddocks of the Darling Downs have slopes ranging from 0.12% to 0.5%, which equates to 1.8m to 7.5m vertical drop over a typical 1500m long paddock. In the 'technically' flattest of furrow irrigation paddocks at a slope of 0.06%, the average vertical difference from top to bottom is 0.42m for a 700m long field. Seven percent (7%) of dryland and nine percent (9%) of all irrigated land has slopes of less than 0.06%, which is considered too flat to drain effectively. Areas of dryland cropping lands that are farmed at less than 0.06% will suffer waterlogging losses in heavy rainfall years, keeping in mind that during drought years with limited rainfall, the ponded areas may in fact lead to the highest yields due to soil water accumulation in these areas. Roadside table drains, farm drains, and irrigation tail drains also form a critical role in farm drainage. Over the past 30 or 40 years, natural resource groups and state government departments have spent considerable effort in coordinating water flows across the floodplains with strip cropping, removal/levelling of old fence lines, better farming practices, designated drainage systems, and inter-property water coordination through Property Management Planning (PMP); all in an effort to minimise the damage from flooding and soil erosion.

A study of vertical movement, using strip cropping as an indicator of swelling and shrinking, showed that in some cases there is potentially a 0.2m difference due to soil moisture changes. Changes of 0.05m to 0.2m are often seen over a short distance in cropping paddocks due to surface micro-relief, due mostly to wheeltracks, soil erosion, furrows, or planter lines.

Considering a range of factors such as accuracy, repeatability, cost, access and timing, Lidar remains the best method to measure the elevation and terrain of the landscape over large areas. Even though RTK GNSS can potentially provide greater vertical accuracies at a point in time, the complicating factors of wheeltracks, machine setup and spacing between measurements means that it is not practical over a larger scale. Vertical accuracies of the measurement of the actual ground surface, whilst they may improve over time, are likely be +/-0.1m for the foreseeable future; keeping in mind that Lidar provides incredible relative detail.

When it comes to modifying cropping lands to improve drainage, then clearly RTK GNSS is the technology of choice due to the recent advances in hardware and software. Soil movement using GNSS controlled buckets is greater than 80m^3 per hectare in most cases, and it is unlikely that vertical cuts and fills of less the 3-5cm are practically achievable given all the factors of earth moving. The combined errors of measuring what elevation the land surface actually is, the location of where the levelling equipment is at any given time (baseline), the drift in GNSS, plus the variability of tyre pressure, size of equipment, soil compaction, soil clods, etc means that the likely achievable accuracy for levelling is greater than +/-2-3cm at any one point and at least +/- 5cm across a 1500m paddock.

5. Glossary of terms

- DEM – Digital Elevation Model (the actual ground surface)
- DSM – Digital Surface Model (the surface above the ground which could include buildings, vegetation, infrastructure)
- Ellipsoidal height – what GNSS uses for its horizontal and vertical datums, and is a simulation of the earth as a flattened sphere
- Geoidal height – simulates mean sea level
- GNSS – Global navigational satellite systems. Comprises of not only the GPS (USA) constellation of positioning satellites, but also those developed by other countries such as Russia (GLONASS), China (Beidou), Europe (Galileo)
- RTK – Real time kinematic which is the highest accuracy GNSS system available. A base station or network is used to provide real time updates on atmospheric correction
- Swath width – distance between run lines when GNSS surveying