

University of Southern Queensland  
Faculty of Engineering and Surveying

## **Mapping Greens at City Golf Course**

A dissertation submitted by

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**Courses ENG4111 and ENG4112 Research Project**

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## **ABSTRACT**

Golf clubs need to present information about their general golf course layout, distances, topography of greens, tee positions and hazards in a suitable format for all players, both professional and social. This dissertation will concentrate on mapping of the greens at Toowoomba City Golf Course to create a contour plan for each of the greens. This will update existing map information and add additional information to what is currently available through the Golf Club.

A combination of GPS, robotic total station and digital scanner were used to collect positional information on the greens. An accuracy assessment was performed on the information collected to determine the most accurate method of data collection to provide a contoured surface that represents the true contours of the actual surface. A number of maps were created using AutoCAD, Terramodel and Trimble Geomatics Office software packages. A wall mounted map of greens has been produced, to replace the existing map, showing location of greens and adjacent features. This map is designed to show golfers the location of the hole on each green for the day's play. The map hangs at the Golf Club beside the Pro Shop and is updated by greenkeepers as pin placements change. Individual green contour plans were also produced for the Golf Club to use in their marketing strategies when attracting new members and competitions. The plans are also to be used as an additional service to members and social golfers to assist in reading the roll of their ball when putting for improving their game.

Mapping Greens at City Golf Course

University of Southern Queensland

Faculty of Engineering and Surveying

**ENG4111 & ENG4112 *Research Project***

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Signature

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Date

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Wade Reynolds

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## **ABBREVIATIONS**

The following abbreviations have been used throughout the text and bibliography:-

USQ            University of Southern Queensland.

TCGC         Toowoomba City Golf Course

RTK            Real Time Kinematic

GPS            Global Positioning System

CAD            Computer Aided Drafting

TGO            Trimble Geomatics Office

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Golf has become a popular past time for a wide cross section of the community irrespective of background with everyone equal on the golf course. Both professional and social golfers are always looking for a competitive edge to improve their game, whether that is a personal challenge to reduce their own handicap, to better their playing partner or the chance for prizes in all levels of competition. Specific details on the slopes and distances of the greens can be valuable in deciding how best to approach the hole and play the green to reduce the number of strokes needed to sink the ball.

The Toowoomba City Golf Course (TCGC) is currently undergoing some major course and green redesign work to lower the course rating from a par 72 to a par 71. The 18 hole golf course is limited with what can be done in the redesign work as the course is bound by residential allotments and main collection roads on all sides. Due to this the course can not be lengthened, therefore the course needs to be made harder through adding more hazards and changing the greens to include more undulations.

By mapping the greens and providing contour plans of the greens the additional information can be used by all players to assist in improving their game. There is an existing plan of the greens located on the wall outside the Pro shop that is dated and also requires updating to include the new greens. The aim of this dissertation is to provide both an updated plan and the additional information of a contour plan of each of the greens.

## **1.2 Research Aim and Objectives**

The aim of the project is to map the shape and slope of the greens at Toowoomba City Golf Course (TCGC) and provide a contour plan of each green. This will be achieved through completing the following stages:

- Undertake a review of the accuracy of various mapping techniques appropriate for the mapping of the greens.
- Establish and verify control points to use during the mapping process.
- The measurement of the greens and the surrounding hazards, bunkers, trees and water.
- The 3D mapping of greens using a combination of methods, (GPS (Global Positioning System), robotic total stations and digital scanner).
- Create a hard copy map of greens and adjacent features and a digital contour plan of each green at the TCGC.
- Analyse and compare the accuracies achieved in the mapping and contouring using the different methods.

The dissertation has two main objectives that will be met. These objectives are as stated below:

- Determine the best technique to map a surface such as golf green or lawn bowl green.
- Create a contour plan of each of the playing greens at TCGC.

## **1.3 Justification**

Golf clubs are like any other business and are looking for a marketing edge to increase their membership and provide acceptable returns to all stakeholders. One way this can be done is by providing information to the playing members and social golfers that may assist in improving the handicap of players.

Professional golfers look for as much information as possible to provide that competitive edge to lower their score. The information that can prove useful

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includes distance and slope information when putting as this is a crucial part of the game. This is currently evident with caddies required to map courses prior to competition play to be able to provide the best possible information on the best line and direction when putting as well as distances along each fairway as approach shots are played. By having this information, the correct club selection for approach shots can be made to assist in a low scoring round greens are no different. By having an accurate map of each green, the roll of the ball can be predicted to assist in putting. Good putting can make the difference between a low scoring round and failing to make the cut.

### **1.4 Scope and Limitations**

This project is limited to the mapping of greens at TCGC and will not take into consideration any outside effects to a ball in play that may affect its the roll on the surface of a green. Contours will be created according to the green surface at time of mapping with the various methods.

Copies of the plans created will be provided to the Toowoomba City Golf Club to be used at their discretion, for the purpose of an information service to members, guests and social players of the course. The information is also available for their use as a marketing tool to promote the club and attract new members.

### **1.5 Conclusion**

The research will determine how best to create individual plans of each of the TCGC greens in a format that all professional and social golfers can access and use in determining how better to play the ball. This information can also be useful as a marketing tool by the TCGC to attract new members and additional competitions.



## Mapping Greens at City Golf Course

Any additional information available to professional and social golfers can be used as a tool to lower a golfer's score.

A review of literature will identify various appropriate mapping techniques used in the surveying industry to determine the accuracy and functionality of the techniques. The techniques established will be used for the design and capture of data for processing to obtain a user friendly green plan.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

Golf is a game played by all age groups from social games through to professional competitions with large sums of money involved. The game can be extremely competitive as players look to either improve their own personal best scores or that of their playing partners. Golfers today look for any information which may assist them in lowering their score such as contour maps of greens. This chapter will review literature required to establish the need for mapping of golf green surfaces.

Different mapping systems will be reviewed and evaluated in the process of creating a contour plan with the required accuracy. Various survey techniques and methods are also covered in this chapter as their concepts can be used to map golf greens at any course.

The review will be presented in several different categories. The first will look at how greens are currently analysed by players at all levels, during play and mapped prior to play. The legality to using tools to assist a player will also be clarified. The different survey methods to be used during the data capture will be looked at during the second section. This will cover laser scanning, global positioning systems and conventional surveying techniques. Section Three will look at what information is currently publicly provided by golf clubs.

## 2.2 Analysing Golf Greens

### 2.2.1 Determining Ball Roll on Golf Greens

Reading the roll of putting greens is a major challenge to all golfers both professional and social. Not only is this a challenge, it is an important part of the game that can significantly influence the difference between a good low score and failing to make the cut.

Players and their caddies take their time in determining the roll of the putt across the playing surface. By reading the undulations and the speed accurately a golfer can make any putt look easy. Practice and experience is the only way to read greens effectively. Golfers and their caddies currently use a variety of methods to assist in determining which direction the ball will break, such as:

- Using the putter as a plumb bob to determine the line of sight. Figure 2.1 demonstrates this action.
- Viewing the line from as close to the ground as possible to try and visualise the slope of the green. Figure 2.2 shows Tiger Woods preparing for his putt using this method.
- External equipment to assist determining the roll (prior to play).

External devices are only allowed to measure distances during play. Local rules need to be checked before using such equipment, as variations to their use may apply. The international rules of golf do not allow for the use of any device designed to measure other conditions during play that might affect play. In an amendment issued by the governing body for golf rules and regulations, The Royal and Ancient Golf Club of St Andrews (R&A), in December 2005 the following is stated

*“a player may obtain distance information by using a device that measures distance only. However, if, during a stipulated round, a player uses a distance measuring device that is designed to gauge or measure other conditions that might affect his play (eg, gradient, windspeed, temperature, etc), the player is in breach of Rule 14-3, for which the penalty is disqualification, regardless of whether any such additional functions are actually used.”*

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Golf Australia also states “The R&A further advises that any such Local Rule must prohibit the use of a distance measuring device that is capable of gauging or measuring other conditions that might affect play, even if such a function is not used.” Golf Australia also endorses these positions.



Figure 2.1 Phil Mickelson using his putter as a plumb bob to pick a line.

Source: [www.golf-live.at](http://www.golf-live.at)



Figure 2.2 Tiger Woods visualising the roll of his putt.

Source: [www.bizrate.com](http://www.bizrate.com)

### 2.2.2 External Device

The EyeLine Golf Green Reading Level as shown in Figure 2.3 is one external device that is used to enable golfers to roughly map the direction of fall on a green. This form of mapping provides limited information on a green and the accuracy of the information relates to the user's ability to draw a plan and collect information around the green. An example of a map drawn using this method is shown in figure 2.4.

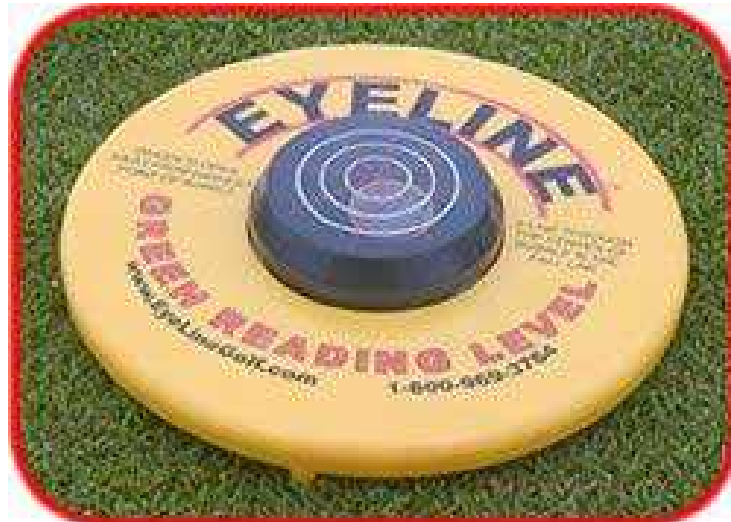


Figure 2.3 The EyeLine Golf Green Reading Level.

Source: <http://www.eyelinegolf.com/grl-tour.php>

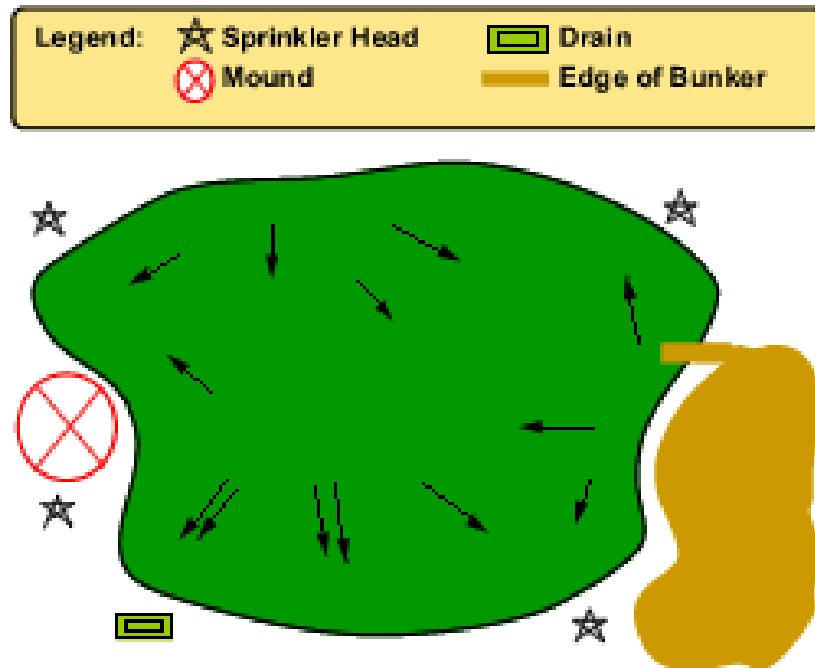


Figure 2.4 An example of a map created with the Green Reading Level.

Source: <http://www.eyelinegolf.com/grl-tour.php>

## **2.3 Surveying Techniques**

Various surveying techniques and methods are used in the surveying industry today for numerous types of projects. For this project three methods of surveying have been used. The methods of data collection used were digital laser scanning, GPS and robotic total station.

The techniques for collecting the point data for the GPS and robotic total station were taken from Surveying Practice 1 through 4 run at USQ. The method of conducting a detail survey was to collect point data at the tops and toes of any slopes and a grid pattern over flat areas to fill in the required area. The points collected were to provide the most accurate representation of the surface. Through the areas with the greater undulations, more points were gathered to improve the accuracy of the final contours.

### 2.3.1 Digital Laser Scanning

The 3D Terrestrial Laser Scanner available for this project was the Riegl 3D-Laser Mirror Scanner LMS-Z210. This is a rugged and fully portable sensor designed for the rapid acquisition of high-quality three dimensional images. The *RIEGL* LMS-Z210 provides a wide field-of-view, high accuracy, and fast data acquisition. A laptop with I-Site software, enables the user to instantly acquire high-quality 3D data in the field.



Figure 2.5 Riegl 3D-Laser Mirror Scanner LMS-Z210

(Source: [http://www.riegl.com/terrestrial\\_scanners/lms-z210ii\\_/210ii\\_all.htm](http://www.riegl.com/terrestrial_scanners/lms-z210ii_/210ii_all.htm))

Laser scanning can be used in a wide variety of applications for the quick capture of large volumes of data. Applications range from the engineering, civil, architectural, 3D modelling and more. Scanning offers some advantages over traditional surveying, which include:

- Time and cost savings during data capture
- Complete 3D modelling of structures and surfaces
- Data can be collected remotely as no prisms are required
- Can be used under any lighting conditions, indoors or outdoors

The Riegl scanner operates on a time of flight measurement principle. This is where short laser pulses in the infrared wavelength region are emitted and the reflected signal is collected. The time difference between transmitted and received pulses is calculated to provide a distance (Riegl 2001). Further technical specifications are available in Appendix B.

### 2.3.2 Global Positioning System

Global Positioning Systems (GPS) are a method of acquiring positional information via a network of satellites orbiting the earth. There are different levels of accuracy available through GPS, depending on the method used. Generally GPS is divided into three main categories. These are listed below in table 2.1

Table 2.1 GPS Accuracies Obtainable

Type of GPS measurement	Precision Obtainable
Point positioning	+/- 100 Metre
Differential GPS	Sub Metre
Surveying GPS	Centimetre

Source: Trimble Navigation Limited (2003)

Differential GPS was the chosen method to capture the data for the initial green plan. This form of GPS measurement was chosen as the sub-metre accuracy obtainable was deemed to meet the requirements of a golfer for a green and hazard plan.

Surveying GPS or Real Time Kinematic (RTK) GPS was deemed to be the level of accuracy required in order to create an accurate contour plan.



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Figure 2.6 GPS base station setup.

The GPS data collection requires two receivers collecting data simultaneously from a minimum of four satellites. One of the receivers is fixed at known coordinates, this is known as a base station, and the second of the receivers is the rover used for collecting data at the required locations.

As with any survey technique, errors can occur through either human errors or instrument errors. Possible forms of human error include:

- Misreading antenna height measurement
- Incorrect data entry, transposing numbers, wrong datum's, using incorrect coordinates
- Rushing observations and shortening observation times
- Poor levelling and centring over points

GPS instrument errors include:

- Satellite geometry – Also known as Dilution of Precision (DOP) errors. These indicate the quality of a GPS position.

## Mapping Greens at City Golf Course

- Selective availability – Is a degradation of the GPS satellite signal. The US Department of Defence purposely introduced an artificial distortion of the satellites location and time. This was turned off on 1 May 2000 and can be turned on if required.
- Atmospheric effects – The troposphere and ionosphere can cause a delay in the GPS signal and can be eliminated by using short base lines.
- Multipath – Occurs when the GPS signal is reflected of a surface taking a longer path to reach the receiver and the receiver receives the signal from multiple paths. Surfaces that can cause multipath include trees, powerlines, buildings and the surface of the ground.

### **2.3.3 Robotic Total Station**

The Trimble S6 is a Robotic Total Station that offers fully robotic operation enabling the user to work independently of the instrument as long as a line of sight is obtainable.

The 360 degree prism can be used in conjunction with the Trimble GPS receiver. The levelling bubble located on top of the prism is easily removed to allow the GPS receiver to attach to the same pole for simultaneous use. This is shown in Figure 2.7.



Figure 2.7 GPS and S6 prism attached to same pole

Source: Trimble

## **2.4 Golf Course Information Provided**

### **2.4.1 Hope Island Golf Course**

Hope Island is one course that provides green information on their web page. The detail provided is limited to distances from the front of each green to points on the green where undulations are and the distance through to the rear of the green. Figure 2.8 shows the first hole at Hope Island Golf Club and the information provided.

## Mapping Greens at City Golf Course

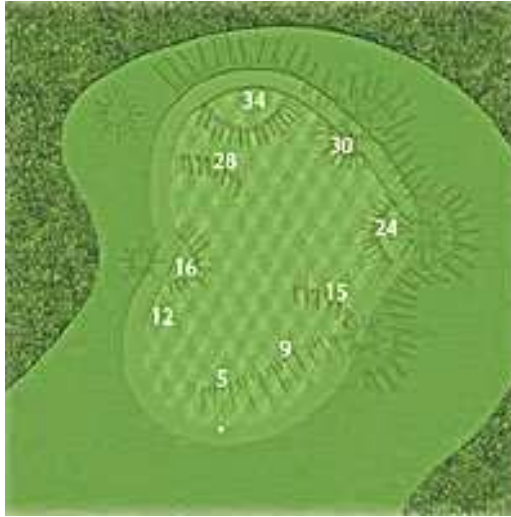


Figure 2.8 The first green layout at Hope Island Golf Club

Source: <http://www.hir.com.au/golf/holebyhole/hole1.asp>

The symbols used to indicate slope can be confusing to those using the information as there is no indication as to the direction of slope or the high/low points, generally this can be determined once reaching the green. However subtle slopes and grades are not obvious or shown on the green plans. This plan does not show if the green, as a whole has any major slope such as front to back or left to right which could play a major role in the final resting place of an approach shot or affect a long putt across the direction of fall.

### 2.4.1 Club Pelican Golf Course

Club Pelican also provides green information on their web page. The Club Pelican format uses arrows and shading to indicate the direction and grade of the fall.

As with the symbols used on the Hope Island web page the information is limited and there is no real indication as to the level of fall. Once again the plan does not show if the green as a whole has any major slope such as front to back or left to right. Figure 2.9 shows a green layout provided at Club Pelican.

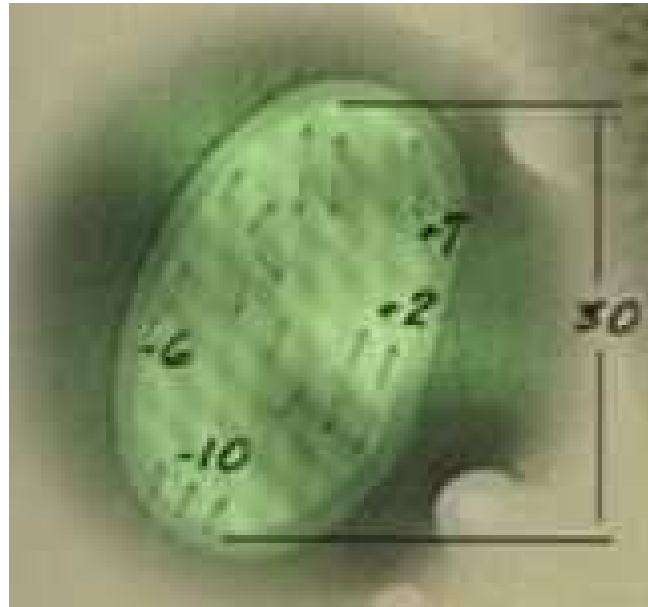


Figure 2.9 The first green layout at Club Pelican

Source: <http://www.pelicanwatersgc.com.au/golf-course-layout.php#>

## 2.5 Conclusion

Other factors that can influence the roll of a golf ball on a green include;

- Moisture
- Grass type and cut
- Direction and height of cut
- Wind speed and direction
- Plug marks

These are outside the scope of the project. This project focuses on the contouring of the existing surface by a number of methods to determine the most effective and efficient method for providing the service.

Many golf courses do not provide information as to the slopes of greens and the directions they roll, this is left up to the player to determine for themselves. By providing contour plans, the golfer could plan his/her approach shot a little better to improve his/her position for easier putting while aiming to improve their score.

## Mapping Greens at City Golf Course

A lack of information was available on the specifics of mapping golf greens and other similar surfaces such as that of bowling greens. Some of the businesses that provide a green mapping service are reluctant to provide information as to their procedures for producing contour plans for golf greens other than to say it is a detail survey and no different from a large scale detail survey.

Some golf courses currently provide limited but freely available information as to the slope of the greens, with many providing only an outline if any information is provided at all.

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Introduction**

Providing 3D data to golfers will assist in improving their game through a better understanding of slope, distance, putting direction etc. The information needs to be in an easily accessible and readable format. To determine the best accuracy and most reliable mapping method, green maps will be created and compared using three survey techniques.

The aim of this chapter is to discuss the components used in providing a contour plan of the greens at TCGC. This will be achieved by discussing how the data was collected and processed through to how the plans were presented and created.

3D digital scanning, RTK GPS and conventional surveying methods will be used for this dissertation to provide a contour plan for each of the greens at TCGC. The information collected from each of the methods will provide a series of points which will be contoured using a computer aided drafting package or CAD program. The data from each method will be compared for levels of accuracy to provide an accurate final plan of each green. By providing this information to the TCGC, they will then be able to pass this information on to members and visitors. The information can also be used as a design tool for any further course redesign or rebuilding the greens in future upgrades.

## 3.2 Data Capture

### 3.2.1 Global Positioning Systems

Differential GPS or mapping grade GPS was used initially to obtain an outline plan of each new green and surrounding hazards, bunkers, trees and water. This was used to update the existing green plan located outside the Pro shop at TCGC. The edges of the greens and any hazards in the immediate vicinity were mapped using Trimble's Pro XR GPS receiver. From the data gathered the updated green plan was produced for display. The data collected was logged on a time interval basis, where a point was recorded every second as the receiver was walked around each feature to be mapped. By using the Pro XR along with a receiver in backpack allowed for real time corrections to be calculated reducing the processing required for the data.

For RTK GPS, a rover GPS unit was required along with a base station. The base station was a rover set up over a known mark with a radio emitting positional information as shown in figure 2.6.

In order to set up a base station a fast static survey was conducted using PSM 40382 which is known to have good coordinates, easting, northing and height, and Ananga, the base station located on top of Z Block at The University of Southern Queensland, Toowoomba campus. The third mark, the base station was a star picket placed at the TCGC in a clear area out of play between the 17<sup>th</sup> green and the 13<sup>th</sup> and 14<sup>th</sup> fairways. Two setups are required to provide redundant base lines and prevent any closed loops during processing. Trimble data controllers, TSCes were used to collect and store the data. Once a job had been created in the controller the fast static survey style option was used to measure points and log the collected data. For each setup, data was logged simultaneously at each position to provide a minimum of ten minutes of overlapping data at each station. Once the first block of data had been collected each of the receivers was reset over the same mark and the process repeated for the second setup. The processing of the information will be discussed later in this chapter.



## Mapping Greens at City Golf Course

Once the base file had been reduced and the coordinates determined the collection of green information could commence through a RTK survey. The first of the RTK surveys was to establish control marks at each of the greens. The control marks used were sprinkler heads, hundred metre markers, signs located on the tee boxes and other fixed marks found around a green. Each of the points was collected as a control point requiring twenty epochs of data before the point could be stored. This file was then later used when importing the control points into the S6 to be used for setting up a station at each green.

Second of the RTK surveys was in conjunction with the S6 when the green information was collected. Both the S6 and RTK points were collected at the same point and time to allow for an effective comparison between the two surfaces.

### **3.2.2 3D Digital Laser Scanning**

The scanner used for the data capture was the Riegl LMS-Z210. Due to the size and the weight of the scanner a golf cart was loaned from the TCGC to transport the scanner and all other required equipment around the course. The scanner was setup over a coordinated position, a sprinkler head, with two coordinated targets placed around each green to provide orientation of each scan onto the Map Grid Australia (MGA) coordinate system. In doing this, it enabled for a direct comparison between each method to be conducted. The marks were coordinated using an RTK GPS survey.

The Riegl scanner works on the principle of time of flight measurement of laser pulses in the infrared wavelength. Time of flight refers to the time interval between transmitting the infrared light pulse and receiving the pulse. Technical data for the Riegl LMS-Z210 can be found in Appendix B

The golf greens scanned were selected to cover a range of slopes and sizes. In all, six greens were scanned due to the limited availability of the scanner and access to golf course.

## Mapping Greens at City Golf Course

In the scanning process, all the greens scanned were able to be captured with just the one set up. For each set up, the scanner was linked, via cable to a laptop running the I-SITE Studio software to operate the scanner and store the data. This can be seen in Figure 3.1, a target used is also shown in the background.



Figure 3.1 Scanner setup at the 1<sup>st</sup> green

Two scans were completed at each of the six greens scanned. To collect the data on each scan it is possible to set and limit the field of view for each scan. This can be done for both the horizontal and vertical angles. When performing the scans the angle of scan was set to cover the entire green. This angle varied depending on the location of the scanner. On the smaller greens where the scanner was set up to one corner, as at the 10<sup>th</sup> green, the angle was limited to 90 degrees. On the larger greens such as the 2<sup>nd</sup> and 8<sup>th</sup> where the scanner was positioned to the middle of the green, the angle of scan was set to 180 degrees.

## Mapping Greens at City Golf Course

As well as limiting the angle of scan the minimum and maximum distances of scan were set to reduce the number of points collected. Due to the positioning of the scanner on each occasion, the minimum distance was set to the limit of instrument at two meters and the maximum was set to cover the length of the green plus an additional 5 to 10 meters to include the targets. This particular function of the scanner was not operational at time of use, causing a large volume of additional data to be collected. As a result the scanned images needed to be cropped to the limits of the green during processing.

To collect a scan the I-Site program provides a number of preset options as to the intensity of scan required. For the purpose of this project, the fine scan option was used as, at this intensity, the fringe of the green could be clearly seen in the scan. This allowed a boundary to be set as to the limits of the green. The other options from course through to ultra fine were determined to provide excessive data or not enough to show the fringe line. Figure 3.2 shows a screen capture of a scan at the second green where the fringe can be clearly seen.

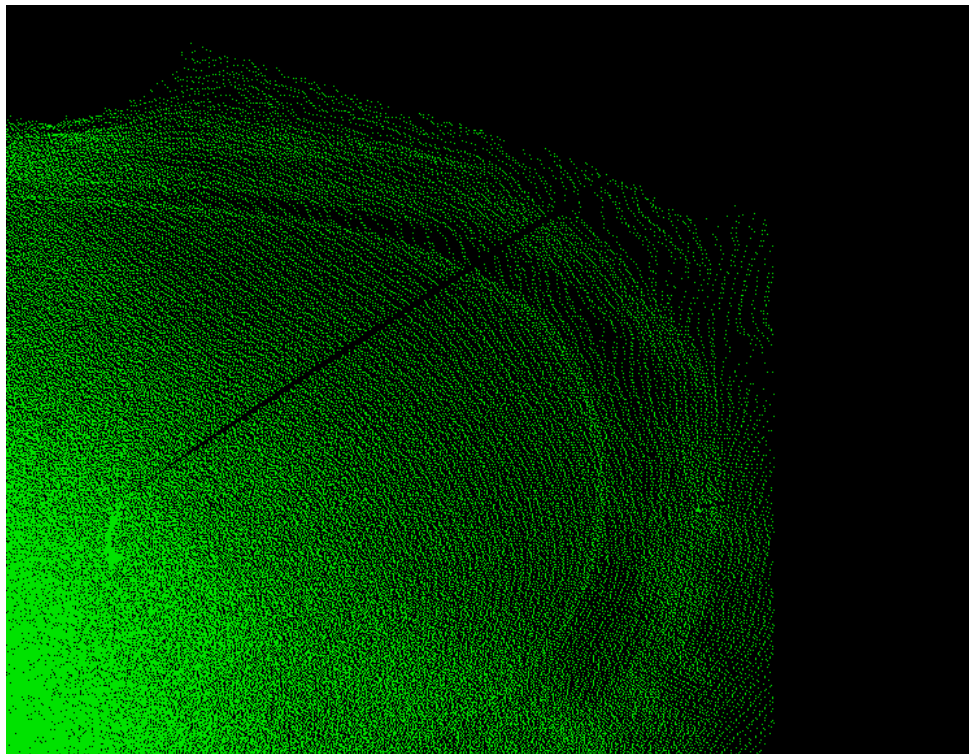


Figure 3.2 Scan of second green

## Mapping Greens at City Golf Course

After the data has been acquired, the information needs to be processed to filter out unnecessary points and align the scan onto the required coordinate system, MGA. Processing of the data will be discussed later in this chapter.

### 3.2.3 Robotic Total Station

To prevent additional marks being placed around each green, sprinkler heads were used to set up over with the one hundred metre markers used as a backsight. If a one hundred metre marker was not available, such as on the short par three holes, a sign located at the tee box was used for this purpose. These marks were coordinated using the RTK control survey.

The number of observations required for each green varied due to the size, shape and level of undulations over the green. To provide for accurate contours, between two hundred and four hundred points were collected at each of the greens.

The Trimble S6 was the instrument selected of this project, as the S6 has the capacity to be operated by a single person and was provided through the USQ. A topo plate was made to attach to the base of the range pole to replace the usual spike. The purpose of the plate was to prevent damage to the green and allow the measurement to give a true indication of the surface. By using a ball joint to attach the topo plate to the pole, it allowed the pole to be levelled no matter what the slope of the green.

The S6 was set up at each green in tracking mode with a 360° prism. A string of points were collected around the edge of each green as a boundary to the area to be contoured. This was followed by points covering the surface of the green. The points were collected along the tops and toes of any obvious grade changes as well as collecting other points to allow the CAD program to accurately contour the surface.

The density of points over each green varied, based on the detail required to accurately represent the surface. Over large open flat sections, the spacing of points increased, while they decreased over heavily sloped areas to provide a true indication of the slope.

### **3.2.4 Check Observations**

In order to provide a check of the accuracy of each of the survey methods used, a series of independent random points were collected over the 8<sup>th</sup> green using the S6 for horizontal positions and each point was levelled using a digital level. Twenty three points in all were collected independent of other data collection and imported into the 8<sup>th</sup> green file where the points were used to interpolate a height at each position onto each of the three surfaces. The results of the height differences are shown in Chapter 4.

## **3.3 Data Processing**

### **3.3.1 Data Reduction for Differential GPS**

Differential GPS or mapping grade GPS was used initially to obtain an out line of each green and any hazards in the immediate area. This data was downloaded into Trimble Geomatics Office (TGO) where the point data was checked to ensure it was on the correct coordinate system and datum. This data was then exported for use in AutoCAD for the use in the final plan.

### **3.3.2 Data Reduction for Fast Static Survey**

The data collected was imported into the software package, TGO to reduce the data and provide the coordinates for the base station. Once the data was in TGO the redundant base lines were disabled before running a zero constrained adjustment to ensure no gross errors. On the completion of the zero constrained adjustment, the two known points, Ananga and PSM 40382 were fixed to their known coordinates and a constrained adjustment performed to achieve a 95% pass with a Chi squares test. After reducing the data from the fast static survey the base coordinates were established allowing all other RTK GPS work to be completed.

### **3.3.3 Data Reduction for Scanner**

On collecting the scan data each of the scans was registered using the coordinates of the scanner setup position and orientated using the coordinates of the targets. Targets were located using the option “locate reflectors”, this tool finds the most reflective surfaces in a scan and selects them allowing for their uses in the registration process. This placed the scans on to the MGA coordinate system. The point data was cropped to eliminate unnecessary points from the file. The data files for each green were too large to be transferred to Terramodel as the program was not able to cope with the large volume of data, with some scans having over one million points collected. To alleviate this problem, the data was filtered to a variety of distances from 0.1 m to 0.5 m between points. This dramatically reduced the number of points and enabled the files to be transferred into Terramodel where the contouring process could be completed.

### **3.3.4 Data Reduction for RTK GPS**

As Real Time Kinematic surveying was used, the corrections are completed at the time of measurement. With the base station transmitting, via a radio link, the base observations, a solution is resolved at time of measurement. This minimises the processing required and enables the GPS files to be imported directly into Terramodel and have points automatically drafted and ready for contouring and plan creation.

### **3.3.5 Data Reduction for Robotic Total Station**

The data collected with the robotic total station was coded at time of collection minimising the reduction of the data to a few incorrectly coded points. After point codes were changed to the correct code the files were imported into Terramodel, where the Auto Draft facility was used creating the basic plan for each green.

### 3.3.6 Contour Creation

The contours from each method were created using the same program, Terramodel, so the same contouring method and algorithms were used for each surface. A DTM layer containing all points to be contoured from was created for each surface and these surfaces were contoured using the Generate Contours function. Contours were limited to the boundary string created by the fringe of each green. A contour interval was set at 0.05 metres as this was determined to provide the best representation of the surface. The contours were also smoothed using the B Spline option in the contour creation settings. Figure 3.3 shows a screen capture of the contour settings used.

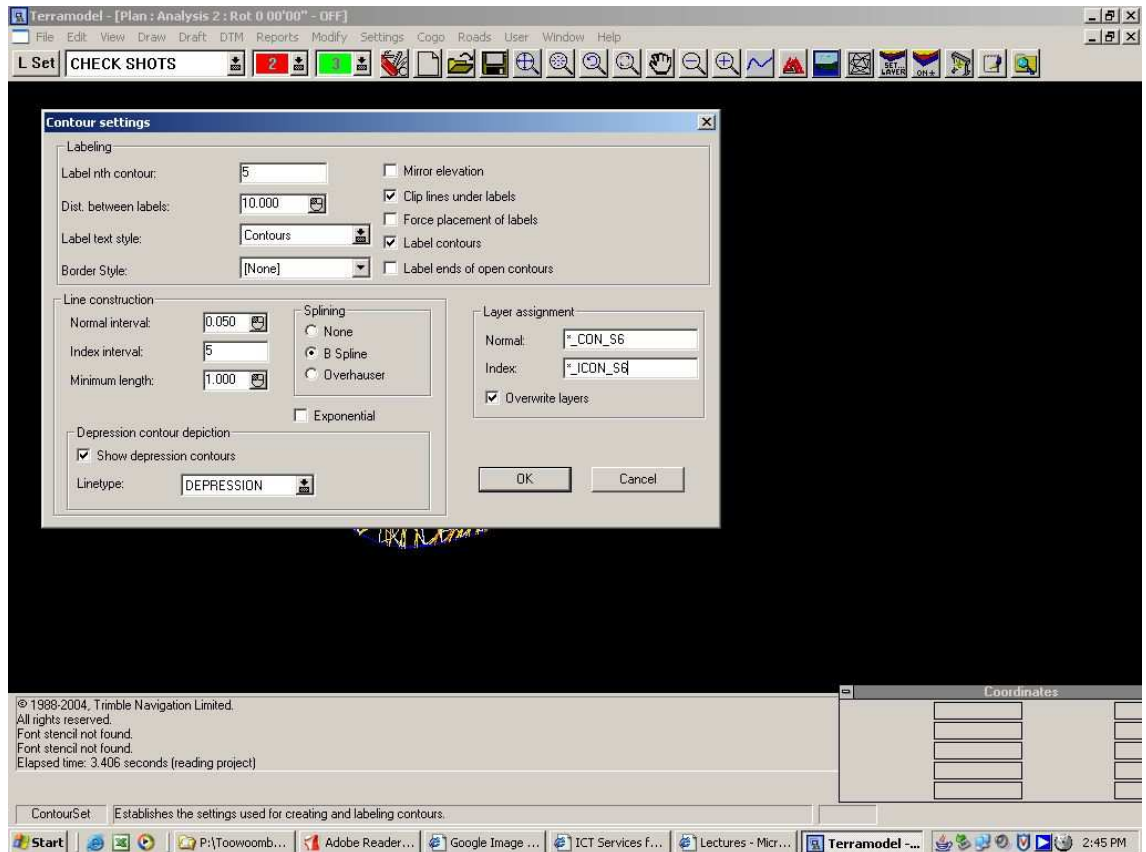


Figure 3.3 Screen capture of contour settings

## 3.4 Creation of Plans

To meet the aim of this project a number of plans are required to be produced. The first, the green plan is the update of an original plan providing an outline of each green and

## Mapping Greens at City Golf Course

hazards and the second is individual contour plans of each green. The methods involved for creating and producing each will now be discussed.

### 3.4.1 Green Plan

The green plan prepared for display at the Pro shop is to display the daily hole placement. This plan is updated by the green keepers after the hole locations are changed.

The main body of the plan was created by D Baker (2003) and this project was aimed at updating the plan to show the new greens and modifications made to existing greens. A digital copy of the plan was obtained and the modifications were made to the original plan.

The original plan provided an area for distances to be shown, as shown in Figure 3.4. This information was not used by the Club, therefore was removed to increase the scale of each green diagram and allow space to be created for the addition of a temporary green that is used during maintenance or closures of holes.

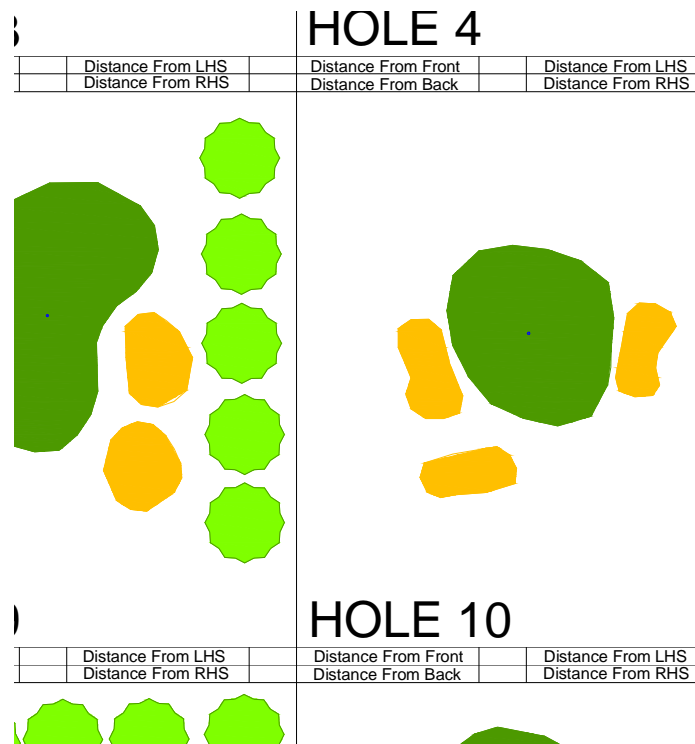


Figure 3.4

Insert from original plan



This plan was modified using AutoCAD as the original plan was in an AutoCAD format and the ease of use and manipulation features of the program. As with the original plan each of the greens was rotated to the direction of plan up the page (refer Figure 3.5). The reasoning for this was to make the plan easy for all golfers to read and orientate, minimising confusion about which direction the player is approaching the green from.

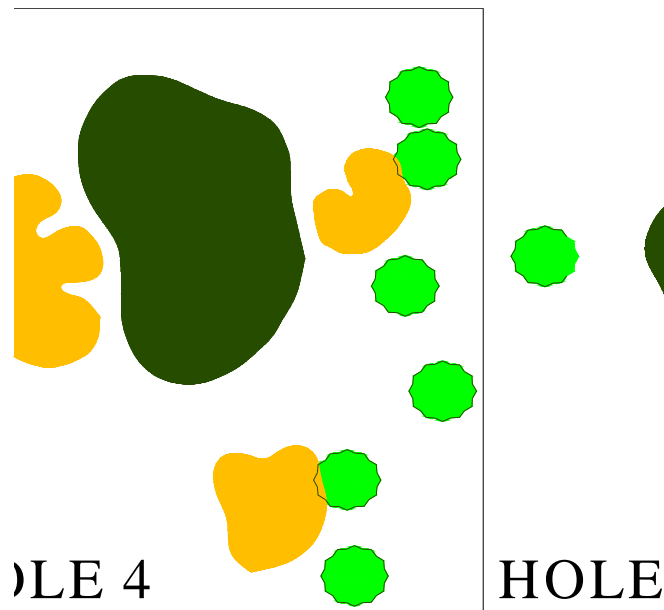


Figure 3.5

Insert from updated plan

The data for this plan was captured using the Trimble Pro XR, the mapping grade GPS receiver.

### 3.4.2 Contour Plans

After processing data was completed and contours created the data was exported from Terramodel into AutoCAD where the contour plans for each of the greens were created. AutoCAD was chosen for ease of use and also provides a suitable format that can be accessed by TCGC staff.

## Mapping Greens at City Golf Course

The design of plans was influenced by the type of information provided by other golf courses, refer figures 2.8 and 2.9. In addition to providing the contours, arrows were also placed on each green on the plan to show a clearer indication of the direction of fall.

Each of the plans has been created using the Trimble S6 data for a consistent approach and outcome and once again each plan has been orientated towards the direction of play up the page. A one metre grid has been placed around each green and a two meter dotted grid through the middle of each green as a background to the plan to assist in determining distances from any position to the hole. The dotted grid was used so as not to clutter the plan. Directional arrows were used in addition to the contours to clearly indicate the direction of the fall and allow those players, who may not be able to read contours, a clearer picture of the slopes and direction of fall.

Additional information, such as the area in meters squared and perimeter of each green, was provided along with a directional arrow indicating the direction of play to assist with approach shots.

### **3.5 Conclusion**

This chapter covered the methods this project undertook to create contour plans for each of the greens at the TCGC. In order to create the contour plans required, information needs to be obtained accurately to provide the best information possible to the Golf Club and all the golfers who wish to take advantage of the additional information.

In the collection process, what points are to be collected need to be considered in order to provide the best network of points for the contouring algorithm to output accurate contours.

## **CHAPTER 4**

### **RESULTS AND DISCUSSIONS**

#### **4.1 Introduction**

In the methodology of this project, Chapter 3, the three methods of data acquisition, a terrestrial laser scan survey, a RTK GPS survey and a traditional survey, were discussed as to their role in creating contour plans for the greens at TCGC.

This chapter's purpose is to provide an accuracy assessment of the contours produced from the three different methods of data acquisition and provide a contour plan of each of the greens in a usable format for all golfers. Also a discussion as to the advantages and disadvantage of each method of survey has been conducted to provide assistance in determining the best method for producing accurate contour plans of golf greens.

#### **4.2 Accuracy Assessment**

##### **4.2.1 Base Station Creation**

To establish the base station for use during the project, a fast static survey was conducted using Ananga, the USQ base station and its known coordinates, along with a permanent survey mark located on Stenner Street, PSM 40382.

The data was processed in TGO using a Network Adjustment on the three points. With the two known marks constrained, the adjusted coordinates of the base were determined. These coordinates are listed in Table 4.1. As part of the network adjustment, a Chi Square Test is completed and the results are required to pass with a

## Mapping Greens at City Golf Course

95% confidence interval. The results for golf base passed this test. Appendix C shows the full breakdown of the network adjustment report.

Table 4.1 Adjusted coordinated for the Golf Base Station

Point Name	Easting	Northing	Reduced Level
Golf Base 01	395501.397	6948785.123	645.318

### 4.2.2 Check Observations Results

As discussed in Chapter 3, a series of check observations were collected on the 8<sup>th</sup> green to use as control points to analyse the elevation differences between surfaces. The check observations, as outlined in Chapter 3 were collected with the Trimble S6 and levelled with a digital level. Each point was interpolated onto each of the surfaces to provide a height difference. Figure 4.1 shows the height differences obtained from each point.

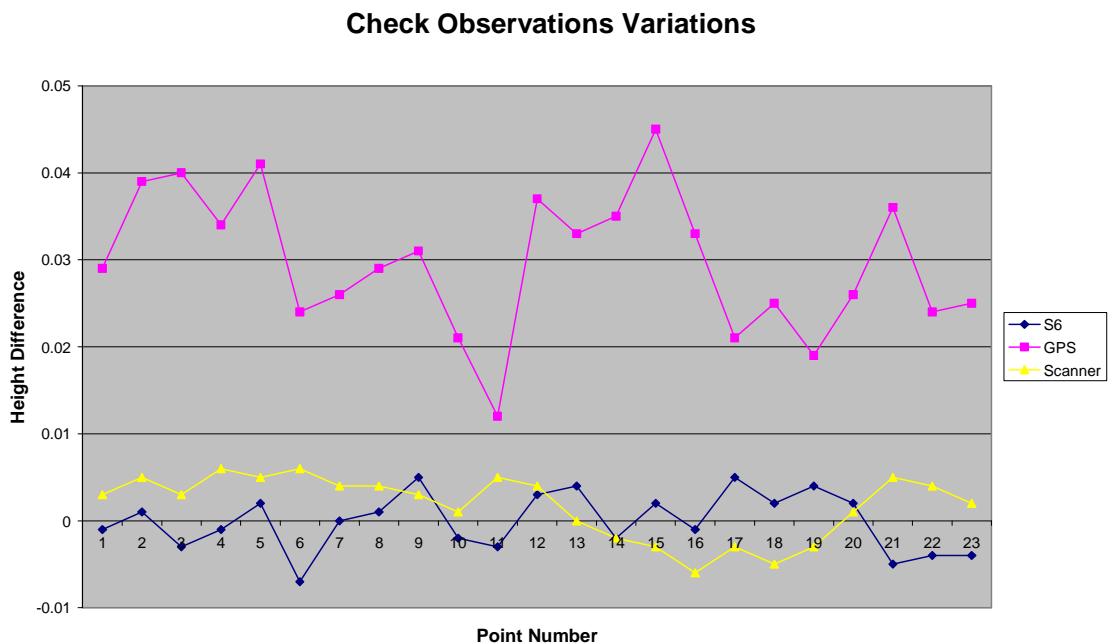


Figure 4.1 Height Variations on Check Observations

The graph clearly shows the GPS height to be inconsistent with an average height difference of 0.03 m above the check observations with one spike reaching 0.045 m above point 15. The range in height differences measured is calculated to be

## Mapping Greens at City Golf Course

0.033 m. These indicate the unreliability of the heights gained through the GPS measurements for the contouring of a surface such as golf greens where contours are to be created at small intervals.

Figure 4.1 also shows that both the scanner and the S6 measurements came in under 0.01 m and both methods recorded an average height difference of 0.003 m. This difference could be accounted for in the length of the grass as measurements were taken with a month break between scanner and S6 observations and a further month to the recordings of the check observations. Another possible reason for a difference is, the night the scanning was conducted, a heavy dew had settled on the green.

The check observations determined that 95% were within 0.1 of a contour interval for the S6, with one observation 0.002 m outside the specified range. The scanner returned with 86.5% of check observations within 0.1 of a contour interval, having three observations fall 0.001 m outside the specified range. This is shown in Table 4.2. The Table lists the elevation differences between the check observations and the surface created by the S6 observations at each of the points. The final column lists whether the observation is within 0.1 of the 0.05 metre contour interval. Table 4.3 compares the check observation with the scanner surface. The three observations that fail to be within 0.1 of the set contour interval are all 0.001 outside the tolerance level set.

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Table 4.2 Check Observations Compared to S6 Surface

Point Number	Easting	Northing	RL	S6 RL	Difference	Pass/Fail
1	395978.337	6948869.895	618.163	618.164	-0.001	pass
2	395977.781	6948865.781	618.153	618.152	0.001	pass
3	395971.893	6948865.121	617.774	617.777	-0.003	pass
4	395963.959	6948867.275	617.458	617.459	-0.001	pass
5	395965.663	6948873.272	617.507	617.505	0.002	pass
6	395969.112	6948874.947	617.619	617.626	-0.007	0.007
7	395975.505	6948874.902	618.056	618.056	0.000	pass
8	395976.285	6948877.939	618.059	618.058	0.001	pass
9	395973.343	6948878.908	617.981	617.976	0.005	pass
10	395969.806	6948878.697	617.787	617.789	-0.002	pass
11	395965.673	6948878.772	617.513	617.516	-0.003	pass
12	395966.084	6948882.580	617.674	617.671	0.003	pass
13	395970.674	6948883.993	617.854	617.850	0.004	pass
14	395974.488	6948882.656	617.978	617.980	-0.002	pass
15	395976.056	6948885.458	617.990	617.988	0.002	pass
16	395975.261	6948888.628	617.931	617.932	-0.001	pass
17	395974.176	6948892.146	617.877	617.872	0.005	pass
18	395970.748	6948891.156	617.771	617.769	0.002	pass
19	395967.491	6948889.379	617.695	617.691	0.004	pass
20	395967.875	6948884.994	617.745	617.743	0.002	pass
21	395969.940	6948874.001	617.663	617.668	-0.005	pass
22	395961.490	6948865.026	617.369	617.373	-0.004	pass
23	395963.587	6948876.245	617.431	617.435	-0.004	pass
Average Absolute Difference =					0.003	metres
95% of Total Observations =					22	points
Tolerance 0.1 of 0.05 Contour Interval =					0.005	metres

## Mapping Greens at City Golf Course

Table 4.3 Check Observations Compared to Scanner Surface

Point Number	Easting	Northing	RL	GPS RL	Diff	Pass/ Fail
1	395978.337	6948869.895	618.163	618.160	0.003	pass
2	395977.781	6948865.781	618.153	618.148	0.005	pass
3	395971.893	6948865.121	617.774	617.771	0.003	pass
4	395963.959	6948867.275	617.458	617.452	0.006	0.006
5	395965.663	6948873.272	617.507	617.502	0.005	pass
6	395969.112	6948874.947	617.619	617.613	0.006	0.006
7	395975.505	6948874.902	618.056	618.052	0.004	pass
8	395976.285	6948877.939	618.059	618.055	0.004	pass
9	395973.343	6948878.908	617.981	617.978	0.003	pass
10	395969.806	6948878.697	617.787	617.786	0.001	pass
11	395965.673	6948878.772	617.513	617.508	0.005	pass
12	395966.084	6948882.580	617.674	617.670	0.004	pass
13	395970.674	6948883.993	617.854	617.854	0.000	pass
14	395974.488	6948882.656	617.978	617.980	-0.002	pass
15	395976.056	6948885.458	617.990	617.993	-0.003	pass
16	395975.261	6948888.628	617.931	617.937	-0.006	0.006
17	395974.176	6948892.146	617.877	617.880	-0.003	pass
18	395970.748	6948891.156	617.771	617.776	-0.005	pass
19	395967.491	6948889.379	617.695	617.698	-0.003	pass
20	395967.875	6948884.994	617.745	617.744	0.001	pass
21	395969.940	6948874.001	617.663	617.658	0.005	pass
22	395961.490	6948865.026	617.369	617.365	0.004	pass
23	395963.587	6948876.245	617.431	617.429	0.002	pass
Average Absolute Difference =					0.004	metres
86% of Total Observations =					20	points
Tolerance 0.1 of 0.05 Contour Interval =					0.005	metres

The scanner and the S6 methods were deemed to meet the accuracy levels required for providing contour plans of golf greens. The GPS observations all fell outside the tolerance levels set.

### 4.2.3 Relative Comparison of Contours

A relative comparison of the contours created through Terramodel provided very similar results. Looking at the 10<sup>th</sup> green, Figure 4.2 and comparing the contours of the S6 and the scanner, it can be seen that although the contours themselves do not align together, they do still show the correct fall. The contour lines have been generated at different elevations. The three surfaces were sitting one above the other allowing all three sets of contours to provide the same relative contour information.

## Mapping Greens at City Golf Course

When contours are created at a specific base elevation, the contours fall within 0.1 m of each respective line.

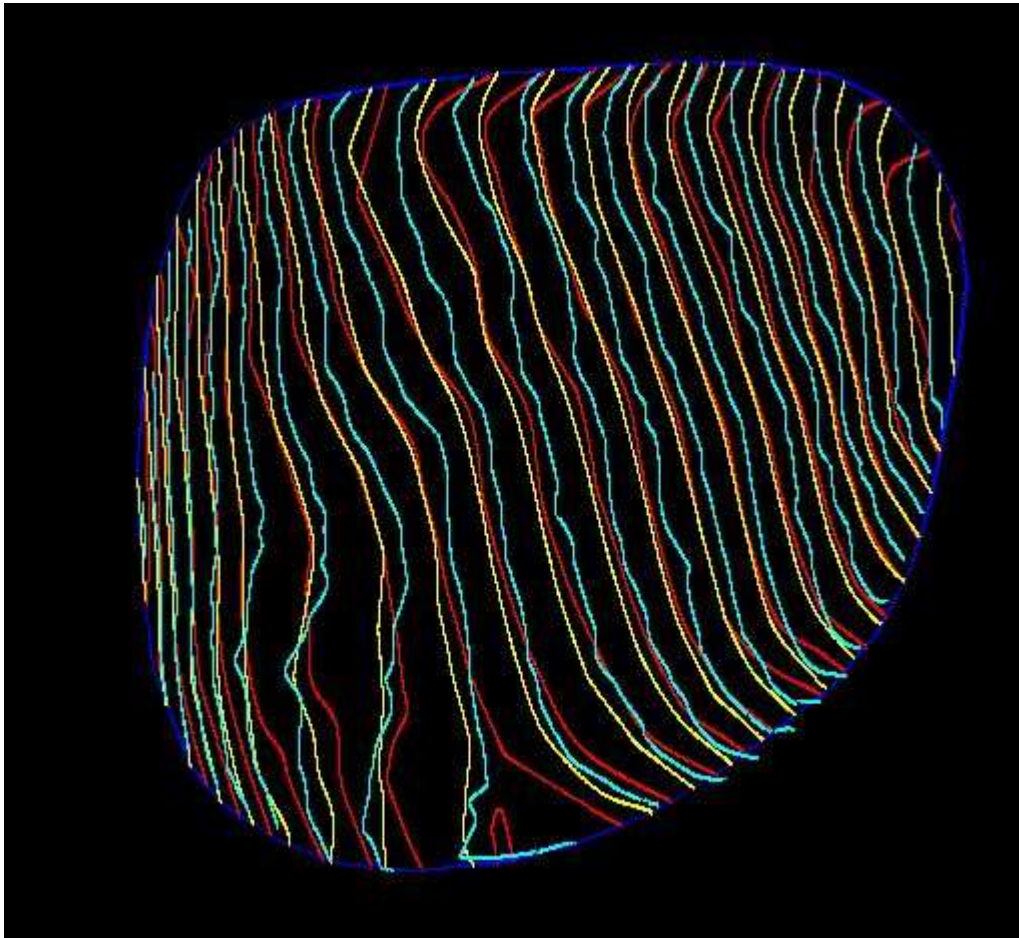


Figure 4.2 10<sup>th</sup> Green, 3 Methods Compared

The contours indicated in yellow represent the S6 surface, red represents the GPS surface and the scanner is shown in cyan. These colours represent the same surfaces in both Figures 4.2 and 4.3.

On a number of greens, the GPS contours became erratic and did not match that of the other two methods. This can be seen on the 6th green where the GPS contours are compared with those of the S6. In parts, the contours are uniform in their shape, in other areas of the green, the contour of each method crosses over showing different falls between the two methods.



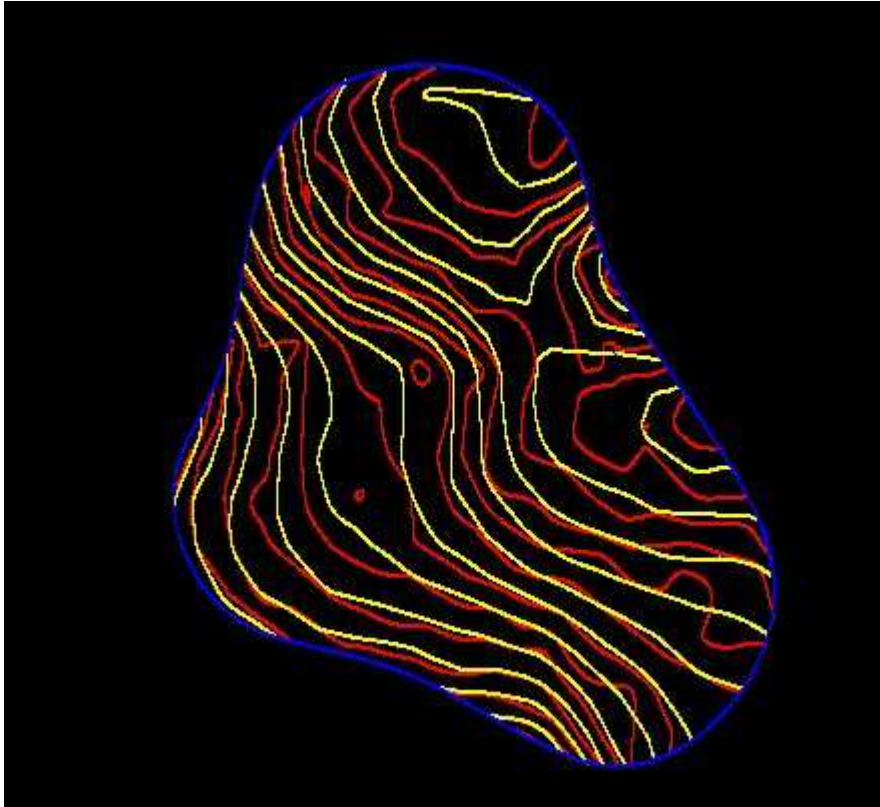


Figure 4.3 6<sup>th</sup> Green, 2 Methods Compared

#### 4.2.4 Direct Comparison

As the S6 and GPS data was collected simultaneously, it is outlined in Chapter 3, showing a direct comparison between the locations of each of the point's positions. Using the 8<sup>th</sup> green again, the differences in easting, northing, and reduced level were calculated. Figure 4.4 shows the differences calculated.

## Mapping Greens at City Golf Course

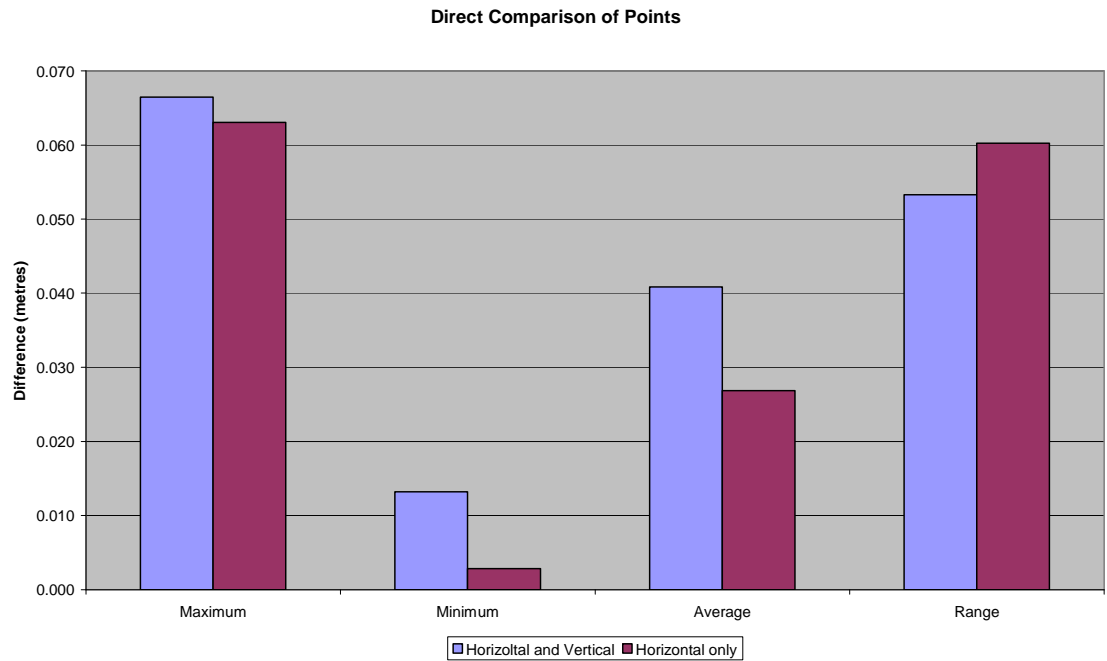


Figure 4.4 Direct Comparison of Points

From the three hundred points collected from the surface of the 8<sup>th</sup> green, on average there was a difference of 0.041 m using horizontal and vertical information. Using only the horizontal components the difference equated to 0.027 m. As demonstrated previously the GPS heights were on average 0.030 m above the control marks, this accounts for the difference between the two figures. The reason for the difference in the horizontal readings could be explained by a number of factors. Firstly, human error, through poor levelling of pole as readings were taken, inaccurate setup over marks at either the GPS base or the S6 over a sprinkler head and inaccurate measurement of instrument height. Secondly, instrument error as outlined in Chapter 2 regarding possible sources of error in GPS measurement.

### 4.2.5 Area and Perimeter

The area and perimeter for each of the greens was calculated from the boundary strings around each of the greens. The boundary strings were based on the fringe line at time of survey. The S6 and GPS files were compared and the full results table can be seen in Appendix D. The differences are listed below in table 4.4

## Mapping Greens at City Golf Course

Table 4.4 Differences between S6 and GPS area and perimeter measurements.

Green	Surveyed		Difference	
	S6	GPS	Area m <sup>2</sup>	Perimeter m
5	*	*	0.46	-0.034
6	*	*	-0.46	-0.05
7	*	*	0.79	0.079
8	*	*	0.14	0.016
10	*	*	-0.01	-0.007
11	*	*	0.06	0.037
12	*	*	-0.76	-0.057
13	*	*	-0.04	-0.016
14	*	*	-0.53	-0.066

As the figures have been rounded to whole numbers these differences became insignificant and did not affect the end figure.

### 4.3 Comparison of Survey Methods

#### 4.3.1 Methods Compared

The GPS proved to be the most unreliable of the three methods used due mainly to the problems maintaining a fixed solution to the available satellites. This was caused in the most part by the number, location and size of trees located around many of the greens. Other structures that could have affected the signal at several greens were the powerlines and metal fencing.

A stronger radio signal or a second base station set up on the other side of the golf course could also have helped with the GPS measurements.

GPS may perform more efficiently in open areas where there is minimal tree coverage and where the area is free of other features that affect the GPS signal.

The S6 proved to be the easiest to operate and the most reliable during data collection. The instrument was able to continuously maintain a lock on the prism allowing for efficient data collection at all times. Having the RTK control set up at

## Mapping Greens at City Golf Course

each of the greens enabled for quick and easy transfer between greens as a traverse was not required.

The Scanner was very efficient in collecting a large volume of data however proved very time-consuming for processing. This will be discussed in further detail in Section 4.3.2 Time Comparison.

### 4.3.2 Time Comparison

Table 4.5 below shows a break down of the average times taken to perform each of the tasks.

Table 4.5 Time comparison

<b>Task</b>	<b>Scanner</b>	<b>Robotic</b>	<b>GPS</b>
<b>Set up</b>	15 min each green	10 min each green	15 min initial base setup
<b>Collection of data</b>	5 min per scan	40 min dependant on number of points	40 min dependant on number of points
<b>Pack up</b>	10 min each green	5 min each green	10 min base pack up
<b>Processing results</b>	5 hours plus per green	1 hour per green	1 hour per green

Of the three methods used the scanner provided the quickest form of data collection. Operating the scanner on a fine scan mode and limiting the field of view of the scan to the green area, required approximately five minutes to complete each scan. This varied slightly with the size of the greens and the number of points data collected. Comparing this to the other two methods where, on average, 40 minutes was required in order to collect sufficient points to map a green. For each of the greens between two hundred and four hundred points were collected. These times do not allow for interruptions to data collection like golfers playing onto a green being surveyed, loss of lock to satellites, waiting for GPS to initialise, sprinklers on automatic timers and any other possible interruption to the data collection process.

## Mapping Greens at City Golf Course

The setup and pack up of the instruments was very similar between methods. The exception was for the GPS that only required the one setup for the whole course rather than setting up at each green with the other two methods.

When it came to the processing of the data for each of the methods, the robotic total station and GPS provided the same information and file formats that the processing times were comparable.

The scanner required a lot more processing than the other methods. This is due to a number of reasons. Firstly, a lack of knowledge of the processing software, I-Site and many hours trial and error in order to achieve the desired results. Having to learn the program while processing data, is not an ideal situation. The processing power and the storage capacities of the computer used to run the I-Site software was not powerful enough to run and operate the program effectively. A lot of time was spent waiting for the program to execute a command.

### **4.3.3 Costs Comparison**

For the cost comparison hourly rates and times are approximate and do vary between firms. The hourly rate for the scanner is based on the Trimble GX Series for which the daily hire rate as at October 2006 is \$2600.00 + GST. This rate includes;

- Trimble GX Scanner
- Trimble GX Scanner accessories – batteries, tripods, targets etc.
- Trimble 3Dipsos and RealWorks software licenses
- Trimble GX Scanning specialist

As an experienced person is available for the operation of the scanner and processing software, the processing time for the scanner has been reduced to be equivalent to that of the other two methods. With a daily hire rate, the processing is therefore charged at the same hourly rate as the collection of data.

Table 4.6 shows a simple break down of the cost for conducting this type of survey. Additional costs such as travel, accommodation (if required) and freight have not been included into the costs. The time required for the scanner was assumed to be

## Mapping Greens at City Golf Course

for one scan per green, this may not be possible due to the level of undulations in which case multiple scans may be required to acquire a complete coverage of the green. Control for the site was considered to be the same cost for each method and therefore not included in the breakdown.

Table 4.6 Approximate costs for conducting survey

Method	Task	Time hours	Hourly Rate	Quantity	Cost
<b>S6</b>	Collection	1	\$150.00	19	\$2,850.00
	Processing	1	\$100.00	19	\$1,900.00
				<b>Total Cost</b>	\$4,750.00
Method	Task	Time hours	Hourly Rate	Quantity	Cost
<b>GPS</b>	Collection	0.7	\$200.00	19	\$2,660.00
	Processing	1	\$100.00	19	\$1,900.00
				<b>Total Cost</b>	\$4,560.00
Method	Task	Time hours	Hourly Rate	Quantity	Cost
<b>Scanner</b>	Collection	0.5	\$325.00	19	\$3,087.50
	Processing	1	\$325.00	19	\$6,175.00
				<b>Total Cost</b>	\$9,262.50

It can be seen from the costing used that the GPS and S6 methods are comparable in price. The cost of using a scanner is significantly higher than the other two methods. The significant difference is due to the hourly rate processing of data being the same as the rate for collection of data. This could be significantly reduced if the firm had the facilities to be able to process the data in-house rather than relying on the scanning specialist.

### 4.3.4 Advantages and Disadvantages

Each method of data capture has its advantages and disadvantages and these need to be considered when determining the best method of data capture for the specific

## Mapping Greens at City Golf Course

project. The advantages and disadvantages of using a scanner for the collection of golf green surfaces include:

### Advantages

- Large point cloud
- Quick acquisition time – Reduced field time.
- Minimum hazards to workers as data can be collected remotely as no prisms are required
- Can operate under all lighting conditions (24 hours a day)
- Map obscured areas (tree canopy, under bridges, culverts, tunnels, shadows)

### Disadvantages

- Can give a lot more data than required
- Longer processing times
- Can be more expensive
- Second method still required to coordinate scans onto a coordinate system.

The advantages and disadvantages of using a Robotic Total Station system include:

### Advantages

- One person operation – The S6 provides for easy operation for a single person when collecting point data. The instrument provides a smooth tracking operation and the target can be easily located through a touch screen joystick control.
- Accurate coding of points is achievable as the surveyor is at the location of the point being captured not at the instrument some distance away. Not so much an issue on small featureless areas such as golf greens.
- Error minimisation – no communication errors between field party members as only the surveyor is required.
- High levels of accuracy obtainable – eliminates human sighting errors

### Disadvantages

- multiple setups required
- line of sight required

The advantages and disadvantages of using a GPS include:

### Advantages

## Mapping Greens at City Golf Course

- Only one setup required – the base station when using RTK surveying
- Quick collection time – when the signal is fixed
- No line of sight required

### Disadvantages

- Many obstructions to signal on established golf courses – Trees, power lines, fences.
- Vertical heights are not as accurate as other methods.

## 4.4 Plans Created

A number of plans have been created throughout this project. Firstly a ‘map of greens’ was created and secondly individual contour plans were created for each green. The created plans will now be discussed and shown.

### 4.4.1 Green Plan

The map of greens is a plan showing the shape of each green and the location of any hazards in the immediate area. Hazards identified are trees, bunkers and water hazards. The plan created is an update on a plan created by Daniel Baker, 2003. A copy of the original file was obtained and modified to remove unused information and provide the new updated plan including the addition of a 19<sup>th</sup> green used as a spare during hole closures and maintenance. The purpose of this plan is to show players the daily hole placements. To achieve this the plan is printed at an A1 size and been laminated before being framed behind a sheet of Perspex to allow hole locations to be easily changed.

Figure 4.5 shows a diagram of the new plan on display outside the Pro Shop at TCGC.

This plan is accurate as at time of display on the 3<sup>rd</sup> of August 2006. Course modifications after this date are not shown as part of this project.



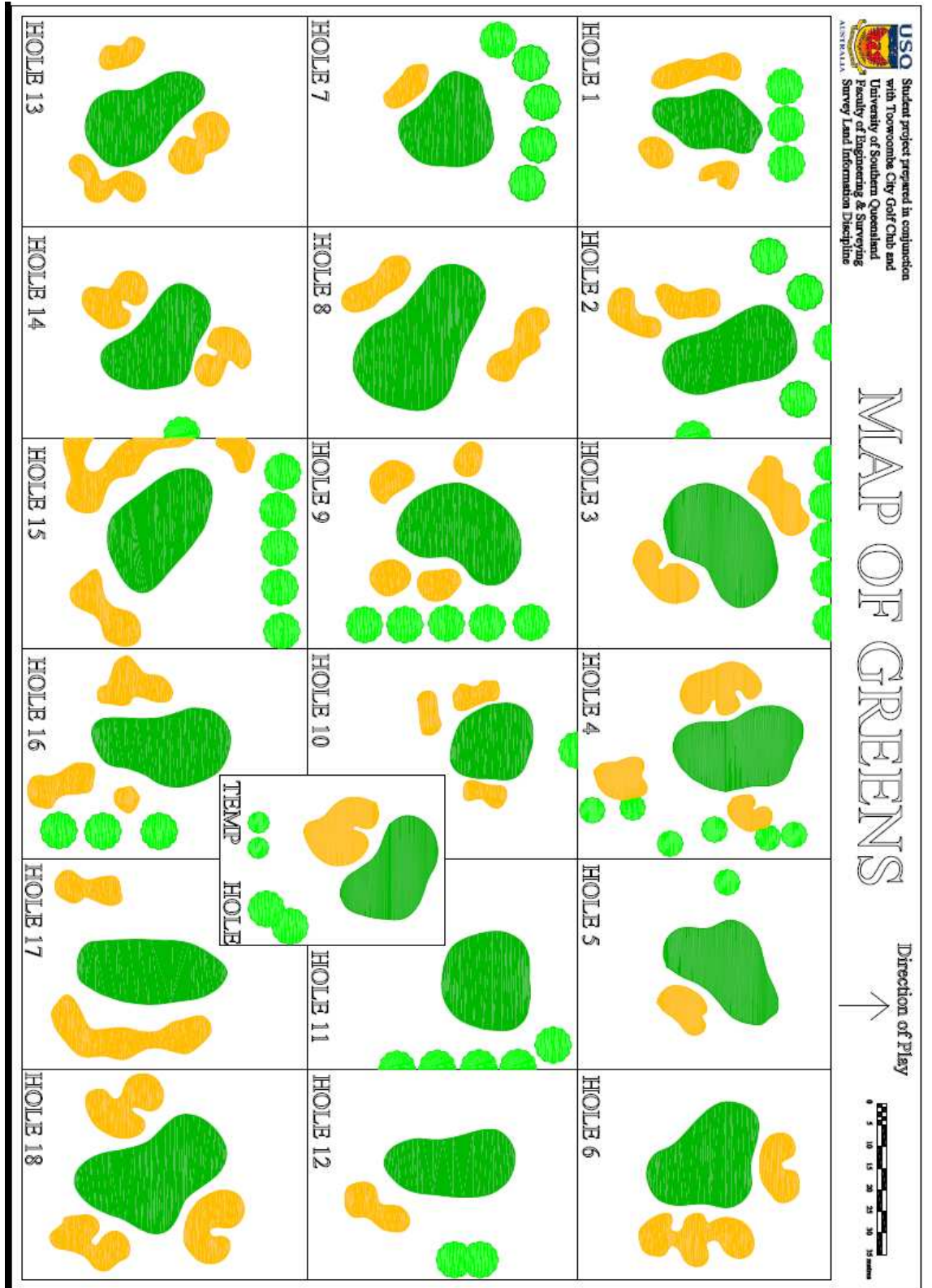


Figure 4.5 New plan on display at Toowoomba City Golf Course

#### **4.4.2 Contour Plans**

These plans have been designed by merging the ideas of a contour plan, while utilising the ideas of existing green plans provided by other golf courses, as outlined in Chapter 2. As shown in Figure 4.6 arrows have been added to the 0.05 mm contours to indicate the direction of fall across each green.

# Mapping Greens at City Golf Course

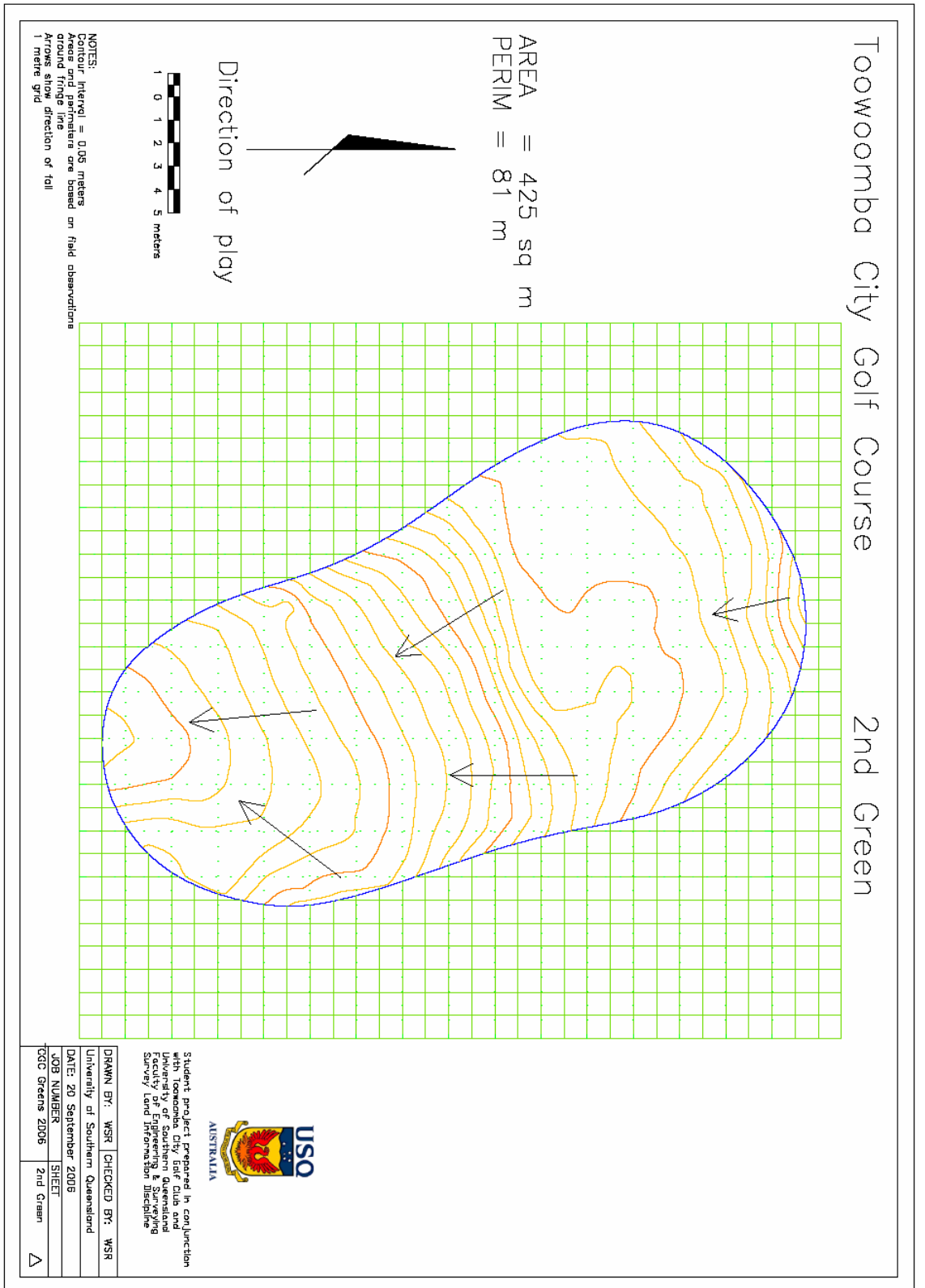


Figure 4.6 Final Plan for 2<sup>nd</sup> Green.

## **4.5 Conclusion**

The aim of the project is to map the shape and slope of the greens at Toowoomba City Golf Course (TCGC) and provide a contour plan of each green. Each of the greens has had a contour plan produced using conventional surveying techniques to capture the data. The reasoning behind the use of the S6 data to provide the contour plans is due to it proving to be the most efficient and easy to use method of the three used.

RTK GPS was the easiest of the three methods for data capture. With little in the way of setup required, GPS provided for easy transfer between green as a line of sight was not required. Although easy to operate and collect data, there were many problems maintaining a fixed solution due mainly to the number and size of trees located around the greens. Due to this and the unreliable height measurements GPS was determined to be not accurate enough for the purpose of mapping golf greens.

The scanner while the most efficient at collecting data the processing of the results was very time consuming. Scanning was also determined to be the most expensive and there was no gain in the level of accuracy obtained over the robotic total station.

While the most time consuming process was determined to be the most efficient method the capture data. The S6 is an easy to use instrument that provided the highest level of accuracy with 95% of check observations within 0.1 of a contour interval. This method was chosen to produce the plans required as it provided the most accurate output as well as user friendly operation of the instrument.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Introduction

There are a number of different methods and techniques used in the surveying industry today that can be adapted to perform most surveying jobs. In this project three different types of data collection were used to provide a contour plan of the greens at TCGC.

As stated throughout this project, the three methods used are GPS, robotic total station and digital scanner. Each of these methods has their own advantages and disadvantages that are used to determine the best instrument for particular project.

This chapter will discuss the outcomes and conclusions from this project and put forward further recommendations to expand on this project.

#### 5.2 Discussion

The aim of the project, as stated in Chapter 1 *“is to map the shape and slope of the greens at Toowoomba City Golf Course and provide a contour plan of each green”*. Contour plans for the 19 greens in play at TCGC have been created and appear in Appendix E 1 to 19.

For the purpose of this project RTK GPS was determined to be the easiest of the three methods for data capture providing a initialisation could be maintained. This proved to be a problem with the location of many of the greens around large trees or in close proximity to one of the two power lines running through the course. With only the base setup required, GPS allowed for easy transfer between green as a line of sight was not required. The heights obtained through GPS were found to be on average 0.03 m above

## Mapping Greens at City Golf Course

the control points collected with a range of 0.033 m. The height measurements were not as consistent as the other two methods and this caused for some of the contours created to cross a number of contour lines formed by the other methods. This returned an incorrect representation of the greens surface.

Scanning was the most efficient method at collecting data, providing large quantities of information for processing. This required a program specifically designed to handle these large volumes of data. The processing and filtering of the information was performed in I-Site Studio. Processing was very time consuming due to a lack of knowledge of the program. The time taken to process the files would only be reduced with some training and frequent use. Scanning was also determined to be the most expensive and there was no gain in the level of accuracy obtained compared the robotic total station.

While the most time consuming process was determined to be the most efficient method the capture data. The S6 is an easy to use instrument that provided the highest level of accuracy with 95% of check observations within 0.1 of a contour interval. This method was used to produce the contour plans as it provided the most accurate output, as well as user friendly operation of the instrument.

### **5.3 Implications**

The implications of this project will be to assist golfers in planning approach shots and reading the roll of a ball over a green during both social and competitive play. The information has been provided to the Toowoomba City Golf Club, in a digital form allowing the information to be linked through to Clubs internet site. This opens the information up to players of all levels wishing to play the course.

The plans also allow the club to use the information as a marketing tool, to assist in attracting a higher level of competition such as state and national titles.

## **5.4 Further research and recommendations**

Further research can be carried out in the area of a slope analysis of each of the greens to provide details as to the gradients and further slope information. 3 dimensional modelling of the course would also be possible, tying together the green details of this project and previously gathered course information. In creating this it would open up the possibility of creating a 'fly through' along each hole or even just over the green to provide a clearer picture of which direction the ball will roll.

The golf course may be able to provide digital information to players for his/her GPS mapping devices to accurately obtain a distance to the centre of a green from any location on the course.

## **5.5 Conclusion**

This research has resulted in the conclusion that the most efficient and accurate method of collecting data for the purpose of producing contour plans of golf greens is through the use of a robotic total station. As stated the total station used for this project was the Trimble S6.

In conclusion, the requirements and aim of this dissertation as stated in Chapter 1 have been successfully completed. This is evident with the production of contour plans for the greens at TCGC. These plans are following in Appendix E. and the main plan is shown in Figure 4.5.

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**APPENDIX A**

**PROJECT SPECIFICATION**

Mapping Greens at City Golf Course

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

**ENG 4111/4112 Research Project**

**PROJECT SPECIFICATION**

FOR: WADE REYNOLDS

TOPIC: MAPPING GREENS AT CITY GOLF CLUB

SUPERVISORS: Peter Gibbings  
Frank Young

PROJECT AIM: The aim of the project is to map the greens at Toowoomba City Golf Course and provide a contour plan of each green.

PROGRAMME: Issue A, 14<sup>th</sup> March 2006

1. Undertake a review of literature on mapping with the various methods.
2. Establish and verify control points to use during the mapping process.
3. Map areas using a combination of method, (GPS, robotic total stations and digital scanner) and create a hard copy map of greens and adjacent features and a digital contour plan of the greens at Toowoomba City Golf Course.
4. Analyse the accuracies achieved in the mapping and contouring using the different methods.
5. Report and document results

AGREED:

Student: Wade Reynolds      Supervisor: Peter Gibbings      Supervisor: Frank Young

Date:    \_\_\_/\_\_\_/\_\_\_                                      \_\_\_/\_\_\_/\_\_\_                                      \_\_\_/\_\_\_/\_\_\_

**APPENDIX B**

**TECHNICAL DATA LMS-Z210**

## Technical Data 3D Scanner Hardware *RIEGL*

### LMS-Z210



#### Rangefinder Performance: <sup>1)</sup>

Eye safety class  
according to IEC60825-1:1993+A1:1997+A2:2001



Measurement range <sup>2)</sup>  
for natural targets,  $\rho \geq 80\%$   
for natural targets,  $\rho \geq 10\%$

up to 400 m  
up to 120 m

Minimum range

4 m

Measurement accuracy <sup>3)</sup>

typ.  $\pm 15$  mm (averaged)  
typ.  $\pm 25$  mm (single shot)

Measurement resolution

5 mm

Measurement rate

up to 12 000 pts/sec @ low  
scanning rate (oscillating mirror) <sup>4)</sup>  
up to 8 000 pts/sec @ high  
scanning rates (rotating mirror)

Laser wavelength

near infrared

Beam divergence <sup>5)</sup>

3 mrad

#### Scanner Performance:

##### Vertical (line) scan

Scanning range

0° to 80°

Scanning mechanism

rotating / oscillating mirror

Scanning rate <sup>6)</sup>

1 scan/sec to 20 scans/sec @  
80° scanning range

Minimum angle stepwidth

0.01°

Angular resolution

0.005°

##### Horizontal (frame) scan

Scanning range

0° to 360°

Scanning mechanism

rotating optical head

Scanning rate <sup>6) 7)</sup>

0.01 %/sec to 15 %/sec

Minimum angle stepwidth

0.01°

## Mapping Greens at City Golf Course

Angular resolution	0.005°
<a href="#"><u>Inclination Sensors</u></a>	optional (specification to be found in separate datasheet)
<a href="#"><u>Internal Sync Timer</u></a> for external GPS/INS synchronization	optional (specification to be found in separate datasheet)

---

### True Color Channel

The optional True Color Channel, integrated in the LMS-Z210i, provides the color of the target's surface as an additional information to each laser measurement. Color data are included in the binary data stream of the LMS-Z210i. The color channel allows straightforward texturing of 3D models by unequivocal correspondence of color pixels and range measurement.

---

### General Technical Data

Main dimensions	437 mm x 210 mm (Length x Diameter)
Weight	approx. 13 kg
Interface:	Ethernet TCP/IP, 10/100 MBit/sec
for configuration & data output	RS232, 19.2 kBd
for configuration	parallel, ECP standard
for data output	(enhanced capability port)
Power supply input voltage	12 - 28 V DC
Power consumption	typ. 78 W max. 96 W
Current consumption	
@ 12 V DC	typ. 6.5 A max 8 A
@ 24 V DC	typ. 3.25 A max 4 A
Temperature range	-10°C to +50°C (operation), -20°C to +60°C (storage)
Protection class	IP64, dust and splash-water proof

---

- 1) First, last, or alternating target mode selectable from scan line to scan line.
  - 2) Typical values for average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter and near to normal incidence of the laser beam. In bright sunlight, the operational range is considerably shorter than under an overcast sky.
  - 3) Standard deviation, plus distance depending error  $\leq \pm 20$ ppm.
  - 4) Without true color channel.
  - 5) 3mrad correspond to 30 cm beamwidth per 100 m of range.
  - 6) Scanning rates selectable via RS232.
  - 7) Horizontal scan can be disabled, providing 2D-scanner operation.
-

**APPENDIX C**

**NETWORK ADJUSTMENT REPORT**

# Network Adjustment Report

## *Project : Golf Course Base Setup*

<b>User name</b>	W0008843	<b>Date &amp; Time</b>	4:27:08 PM 16/05/2006
<b>Coordinate System</b>	Map Grid of Australia (GDA)	<b>Zone</b>	Zone 56
<b>Project Datum</b>	ITRF		
<b>Vertical Datum</b>		<b>Geoid Model</b>	AUSGEOID98 (Australia)
<b>Coordinate Units</b>	Meters		
<b>Distance Units</b>	Meters		
<b>Height Units</b>	Meters		

---

## Adjustment Style Settings - 95% Confidence Limits

### Residual Tolerances

To End Iterations : 0.000010m

Final Convergence Cutoff : 0.005000m

### Covariance Display

#### Horizontal

Propagated Linear Error [E] : U.S.

Constant Term [C] : 0.00000000m

Scale on Linear Error [S] : 1.96

#### Three-Dimensional

Propagated Linear Error [E] : U.S.

Constant Term [C] : 0.00000000m

Scale on Linear Error [S] : 1.96

Elevation Errors were used in the calculations.

### Adjustment Controls

Compute Correlations for Geoid : False

Horizontal and Vertical adjustment performed

### Set-up Errors

GPS

Error in Height of Antenna : 0.002m

Centering Error : 0.002m

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## Statistical Summary

Successful Adjustment in 2 iteration(s)

Network Reference Factor : 0.93

Chi Square Test ( $\alpha=95\%$ ) : PASS

Degrees of Freedom : 3.00

### GPS Observation Statistics

Reference Factor : 0.93

Redundancy Number (r) : 3.00

### Individual GPS Observation Statistics

Observation ID	Reference Factor	Redundancy Number
B4	0.91	0.95
B5	0.95	1.03
B7	0.93	1.02

### Weighting Strategies

#### GPS Observations

Default Scalar Applied to All Observations

Scalar : 1.00

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## Adjusted Coordinates

Adjustment performed in **WGS-84**

Number of Points : 3

Number of Constrained Points : 0

### Adjusted Grid Coordinates

Errors are reported using  $1.96\sigma$ .

Point Name	Easting	E error	Northing	N error	Elevation	e error	Fix
psm40382	396349.033m	0.003m	6947411.372m	0.003m	N/A	N/A	
golf base 01	395501.379m	0.003m	6948785.050m	0.003m	N/A	N/A	
ANANGA	394586.997m	0.003m	6946490.530m	0.003m	N/A	N/A	

### Adjusted Geodetic Coordinates

Errors are reported using  $1.96\sigma$ .



## Mapping Greens at City Golf Course

Point Name	Latitude	E error	Longitude	N error	Height	h error	Fix
psm40382	27°35'35.78640"S	0.003m	151°56'59.12635"E	0.003m	698.046m	0.004m	
golf base 01	27°34'50.91439"S	0.003m	151°56'28.63955"E	0.003m	686.396m	0.004m	
ANANGA	27°36'05.21839"S	0.003m	151°55'54.57152"E	0.003m	761.769m	0.004m	

### Coordinate Deltas

Point Name	ΔEastin g	ΔNorthin g	ΔElevatio n	ΔHeigh t	ΔGeoid Separation
psm40382	0.013m	-0.071m	N/A	-1.011m	N/A
golf base 01	-0.024m	0.180m	N/A	-0.129m	N/A
ANANGA	0.012m	-0.109m	N/A	1.140m	N/A

### Control Coordinate Comparisons

Values shown are control coord minus adjusted coord.

Point Name	ΔEastin g	ΔNorthin g	ΔElevatio n	ΔHeigh t
psm40382	-0.013m	0.071m	N/A	1.011m
ANANGA	-0.012m	0.109m	N/A	0.938m

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## Adjusted Observations

Adjustment performed in **WGS-84**

### GPS Observations

Number of Observations : 3

Number of Outliers : 0

Observation Adjustment (Critical Tau = 1.72). Any outliers are in **red**.

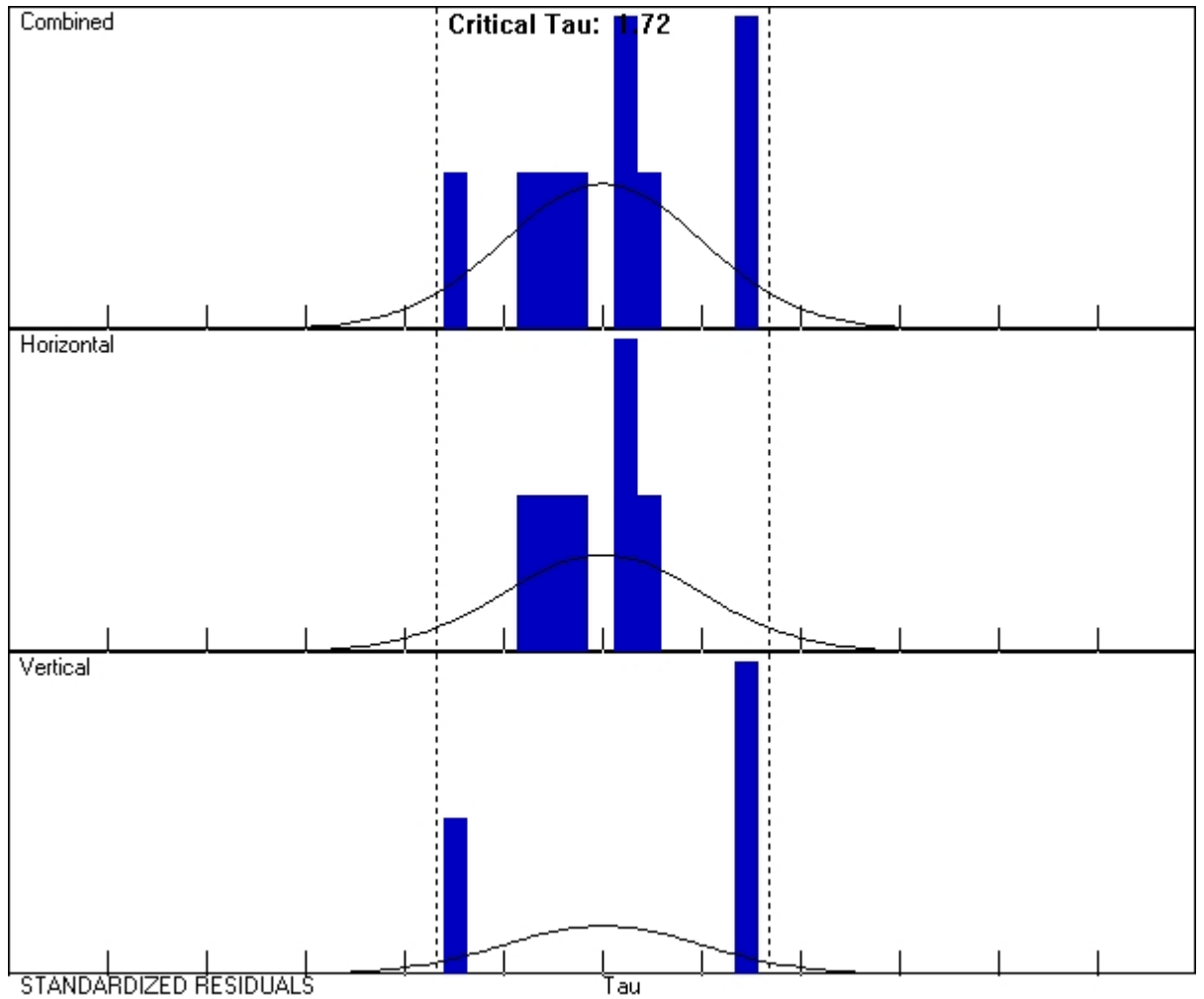
Obs. ID	From Pt.	To Pt.		Observation	A-posteriori Error (1.96σ)	Residual	Stand. Residual
B7	ANANGA	psm40382	<b>Az.</b>	62°54'11.7007"	0°00'00.4694"	0°00'00.0394"	-0.23
			<b>ΔHt.</b>	-63.724m	0.007m	0.004m	1.58
			<b>Dist.</b>	1988.672m	0.004m	-0.001m	-0.65
B5	ANANGA	golf base 01	<b>Az.</b>	22°13'20.6591"	0°00'00.3770"	0°00'00.0795"	0.58
			<b>ΔHt.</b>	-75.373m	0.007m	-0.004m	-1.57

## Mapping Greens at City Golf Course

			<b>Dist.</b>	2470.656m	0.004m	0.001m	0.34
B4	psm40382	golf base 01	<b>Az.</b>	328°48'32.2891"	0°00'00.5689"	0°00'00.1217"	-0.60
			<b>ΔHt.</b>	-11.650m	0.006m	0.003m	1.57
			<b>Dist.</b>	1614.588m	0.004m	0.000m	0.32

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## Histograms of Standardized Residuals

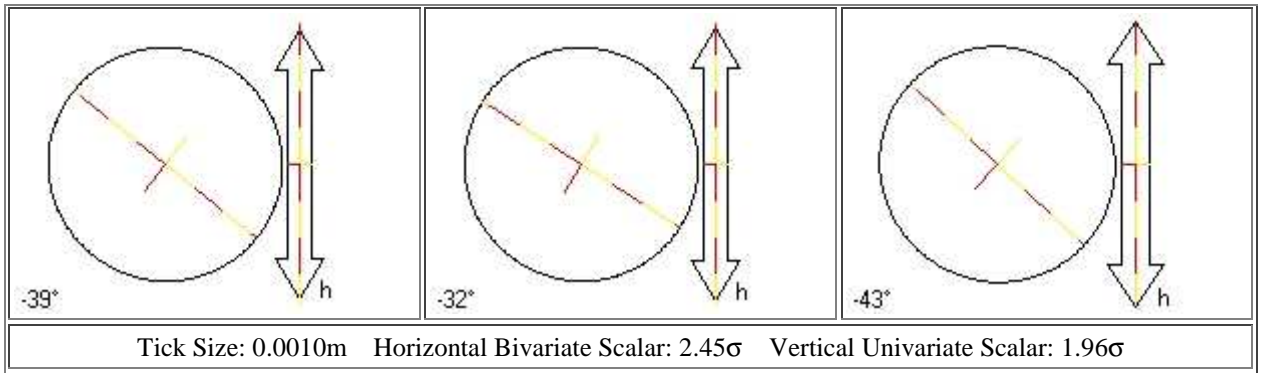


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## Point Error Ellipses

psm40382	golf base 01	ANANGA
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## Mapping Greens at City Golf Course



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## Covariant Terms

Adjustment performed in **WGS-84**

From Point	To Point		Components	A-posteriori Error (1.96 $\sigma$ )	Horiz. Precision (Ratio)	3D Precision (Ratio)
psm40382	golf base 01	<b>Az.</b>	328°48'32.2891"	0°00'00.5689"	1:361416	1:361416
		<b><math>\Delta</math>Ht.</b>	-11.650m	0.006m		
		<b><math>\Delta</math>Elev</b>	?	?		
		<b>Dist.</b>	1614.588m	0.004m		
psm40382	ANANGA	<b>Az.</b>	242°53'41.7953"	0°00'00.4694"	1:444884	1:444884
		<b><math>\Delta</math>Ht.</b>	63.724m	0.007m		
		<b><math>\Delta</math>Elev</b>	?	?		
		<b>Dist.</b>	1988.672m	0.004m		
golf base 01	ANANGA	<b>Az.</b>	202°13'04.8802"	0°00'00.3769"	1:553264	1:553264
		<b><math>\Delta</math>Ht.</b>	75.373m	0.007m		
		<b><math>\Delta</math>Elev</b>	?	?		
		<b>Dist.</b>	2470.656m	0.004m		

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**APPENDIX D**

**GREEN AREAS AND PERIMETER**

Mapping Greens at City Golf Course

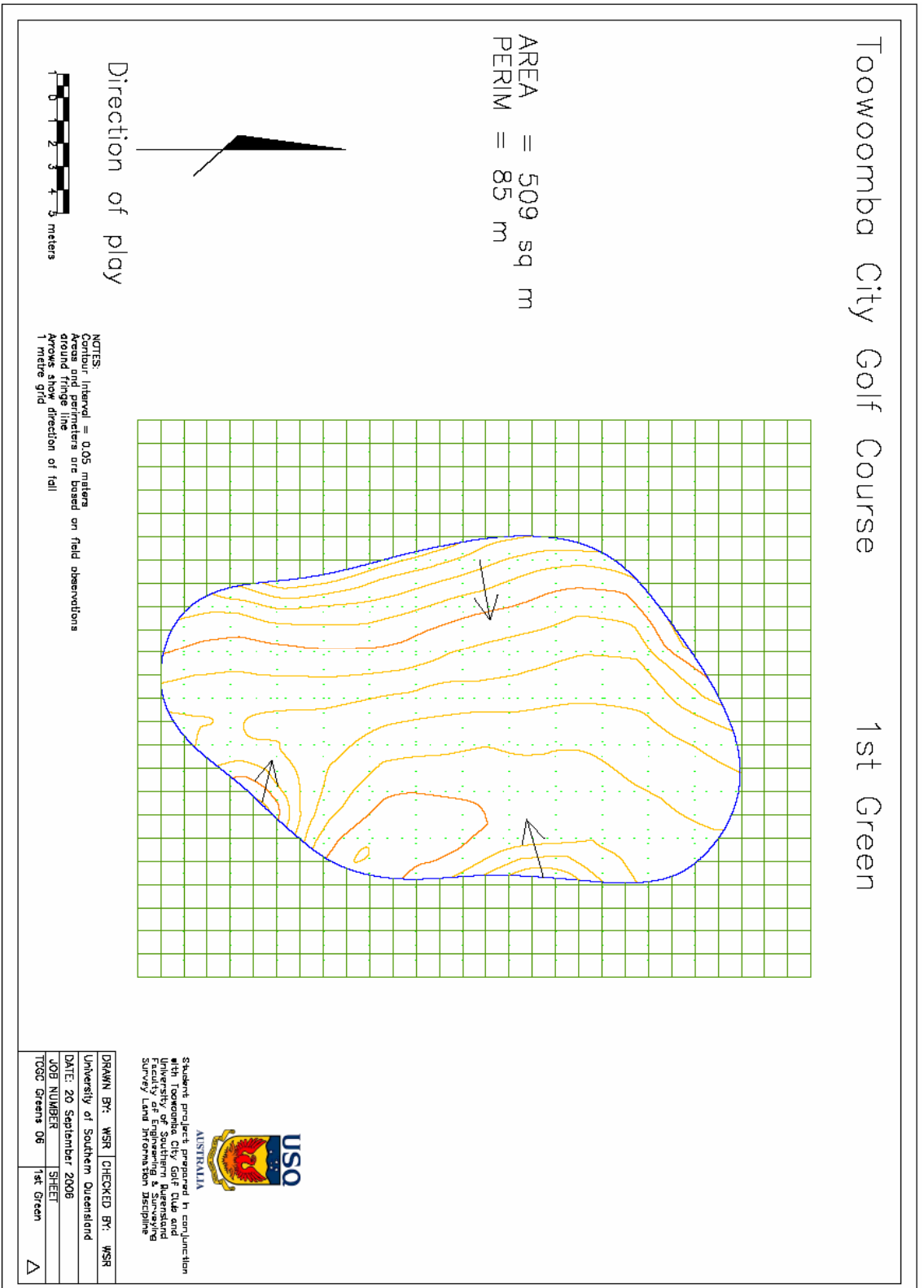
Green	Surveyed			S6		GPS		Difference	
	S6	GPS	Scanner	Area m <sup>2</sup>	Perimeter m	Area m <sup>2</sup>	Perimeter m	Area m <sup>2</sup>	Perimeter m
1	*		*	289.28	65.224				
2	*		*	424.6	80.699				
3	*			508.49	85.162				
4	*			406.69	77.867				
5	*	*	*	384.44	78.895	383.98	78.929	0.46	-0.034
6	*	*		431.46	79.912	431.92	79.962	-0.46	-0.05
7	*	*	*	310.43	65.103	309.64	65.024	0.79	0.079
8	*	*	*	624.45	98.359	624.31	98.343	0.14	0.016
9	*			446.76	81.244				
10	*	*	*	253.59	57.831	253.6	57.838	-0.01	-0.007
11	*	*		368.35	69.031	368.29	68.994	0.06	0.037
12	*	*		357.3	74.874	358.06	74.931	-0.76	-0.057
13	*	*		354.08	74.517	354.12	74.533	-0.04	-0.016
14	*	*		375.25	76.507	375.78	76.573	-0.53	-0.066
15	*			426.16	78.693				
16	*			413.11	81.356				
17	*			400.52	80.376				
18	*			563.15	94.916				
Spare	*			337.31	71.687				

**APPENDIX E**

**CONTOUR PLANS**

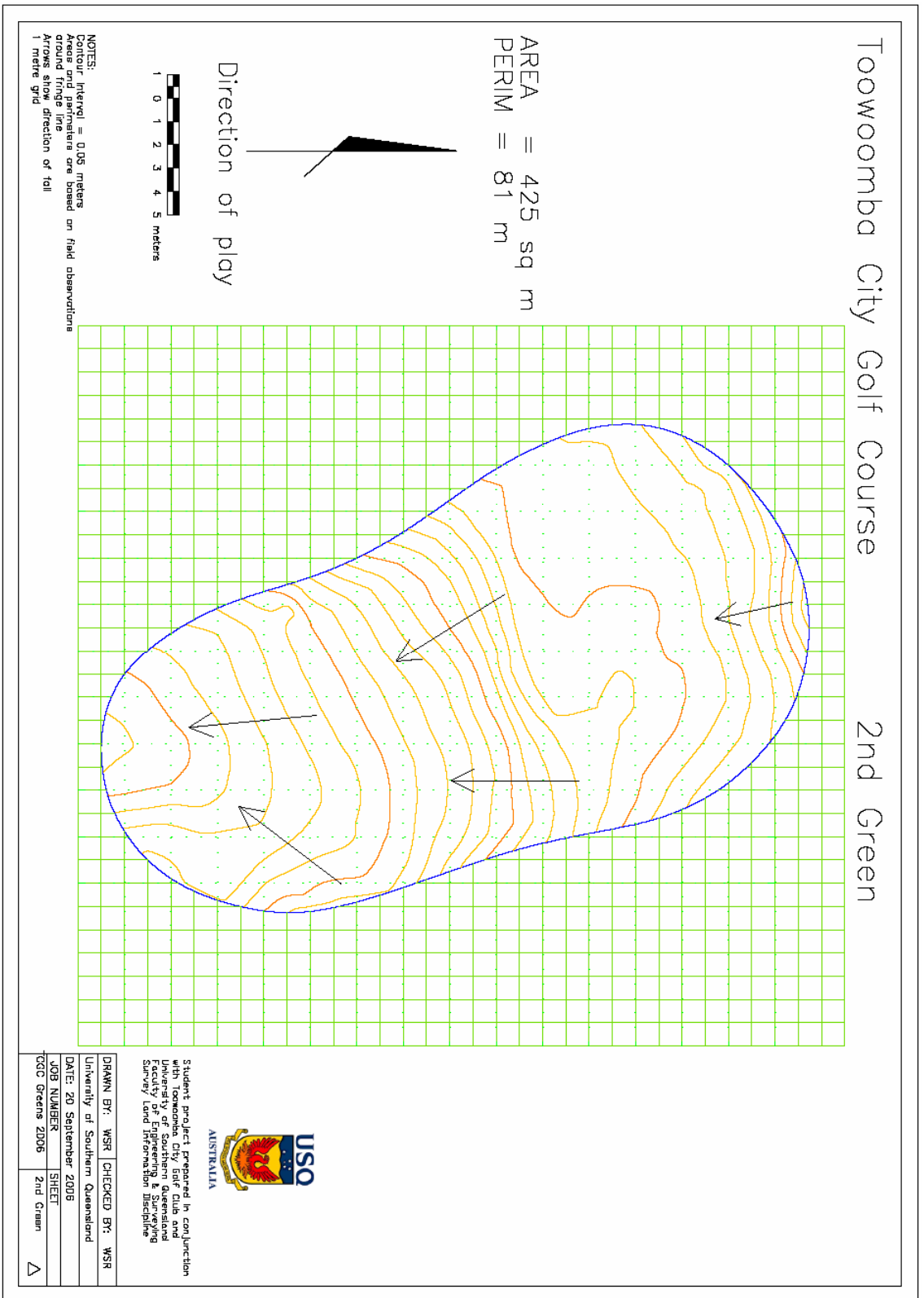
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 1. 1<sup>st</sup> Green



# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 1. 2nd Green





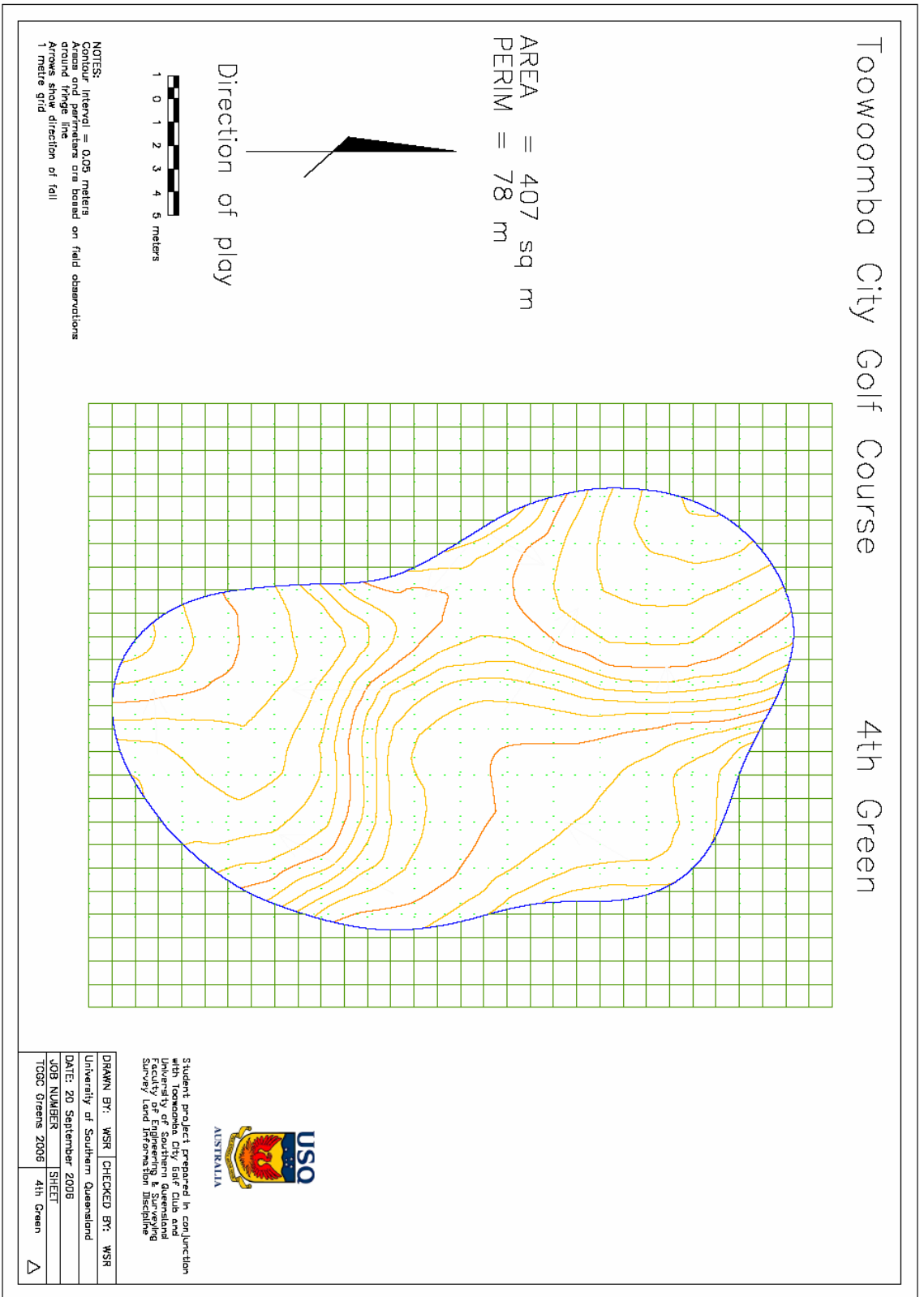
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 3. 3rd Green



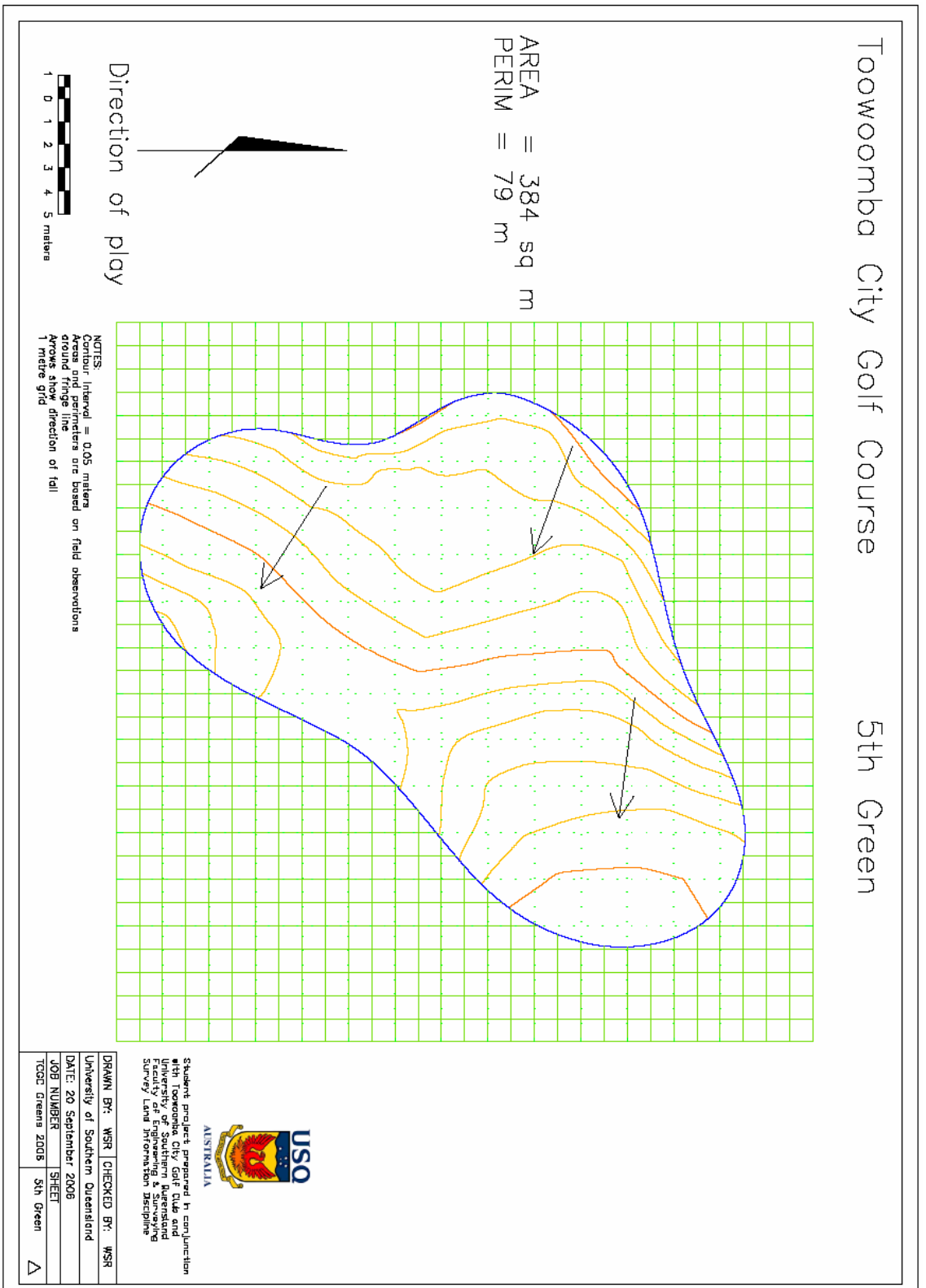
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 4. 4th Green



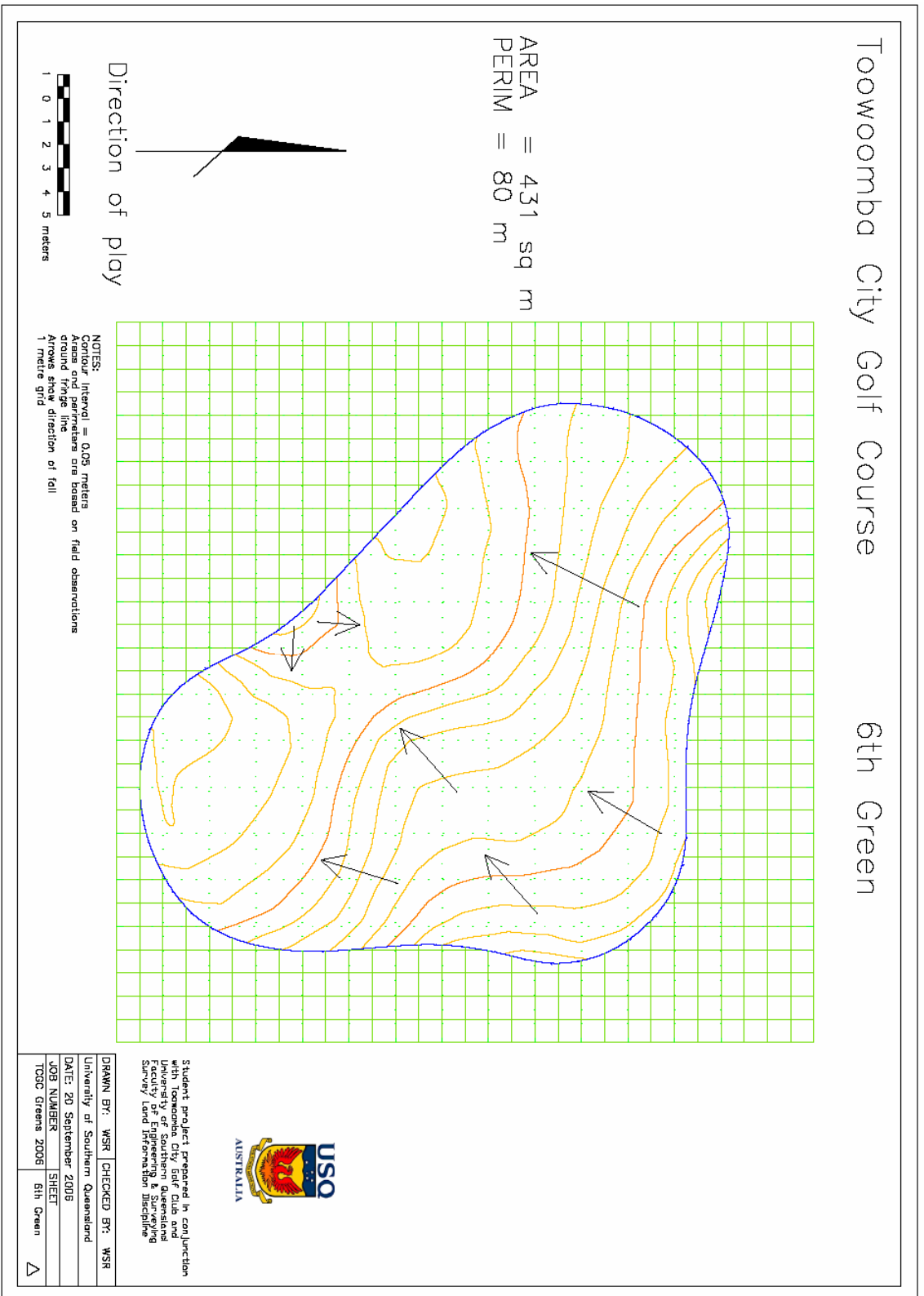
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 5. 5th Green

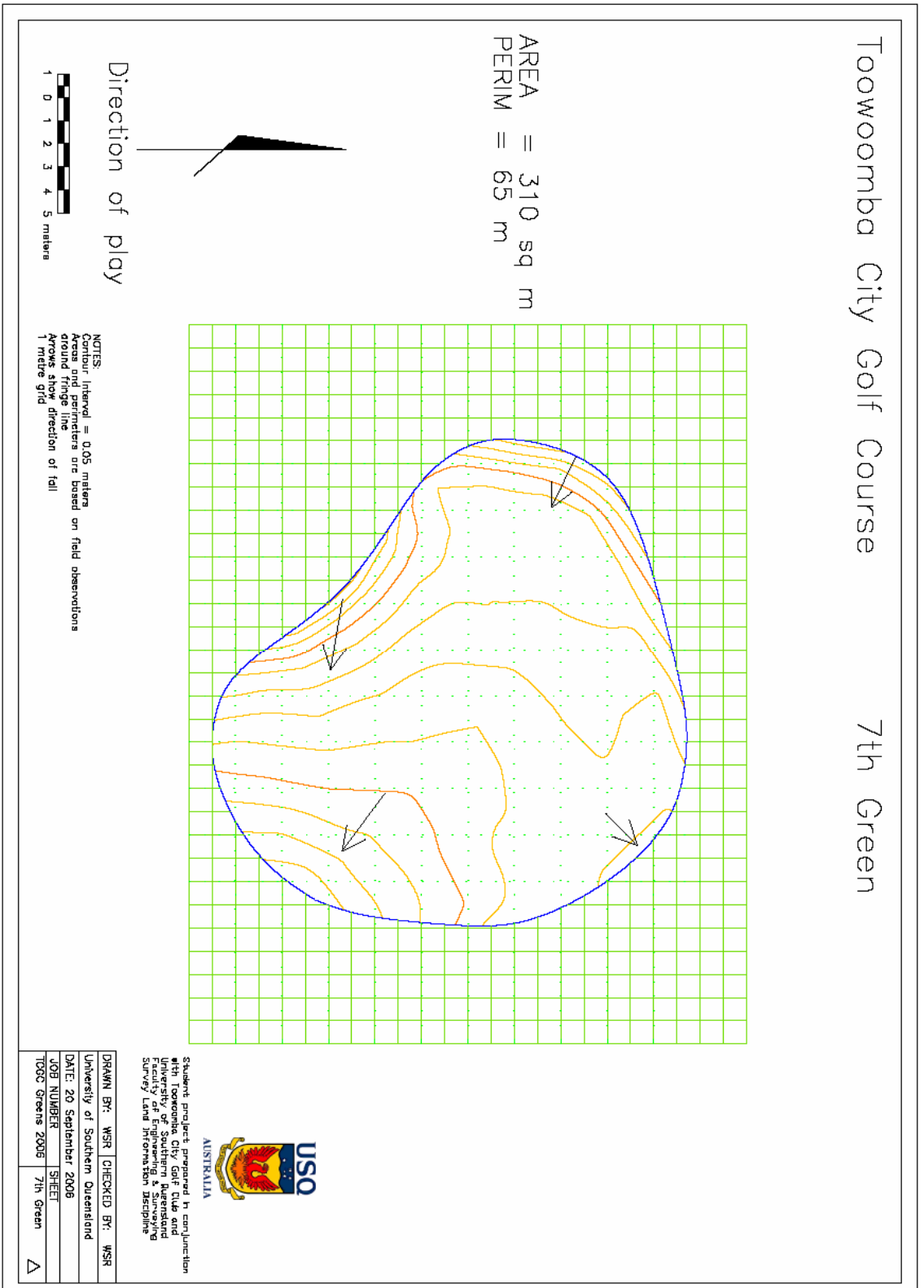


# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 6. 6th Green

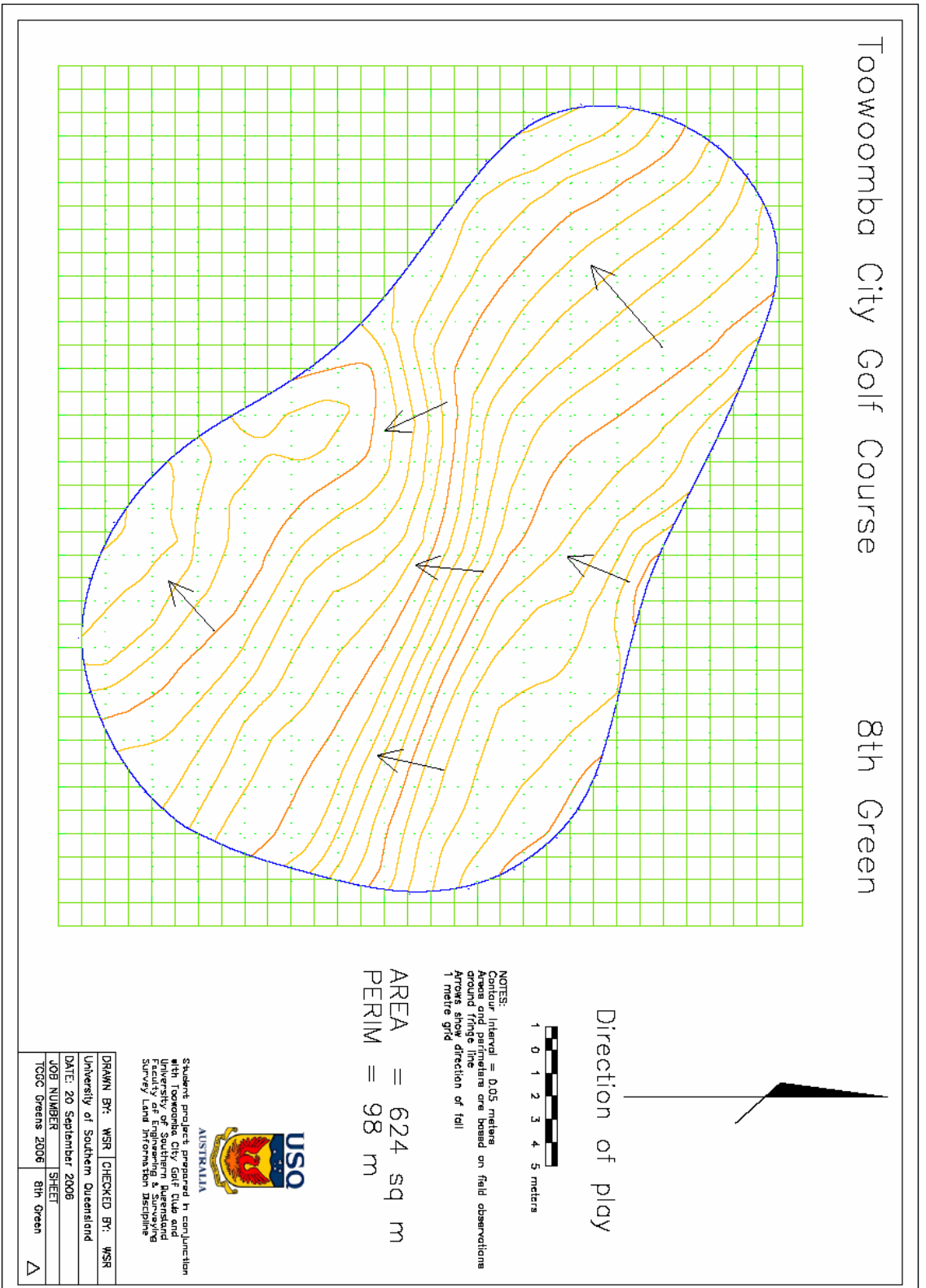


Appendix E Contour Green Plans  
7. 7<sup>th</sup> Green



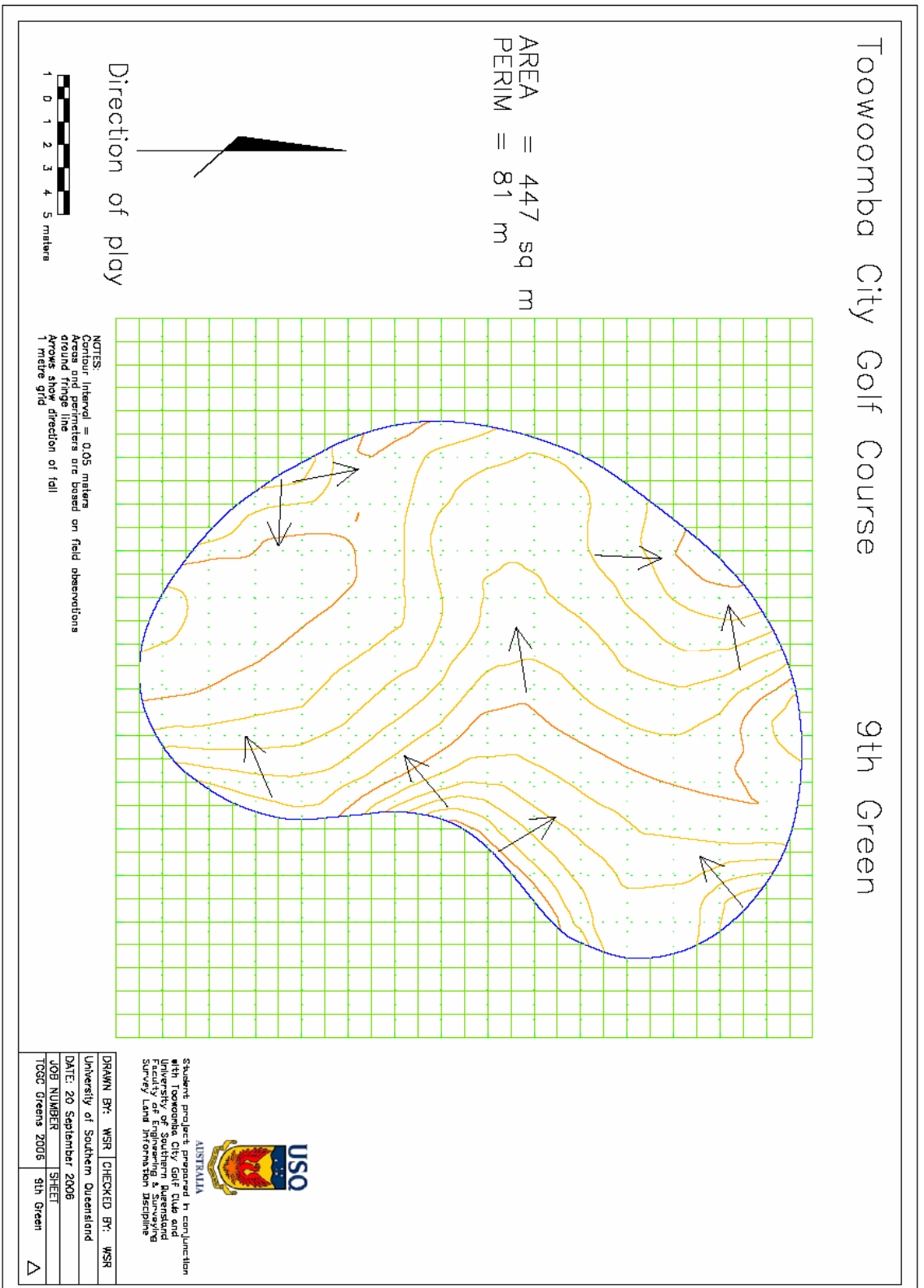
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 8. 8th Green



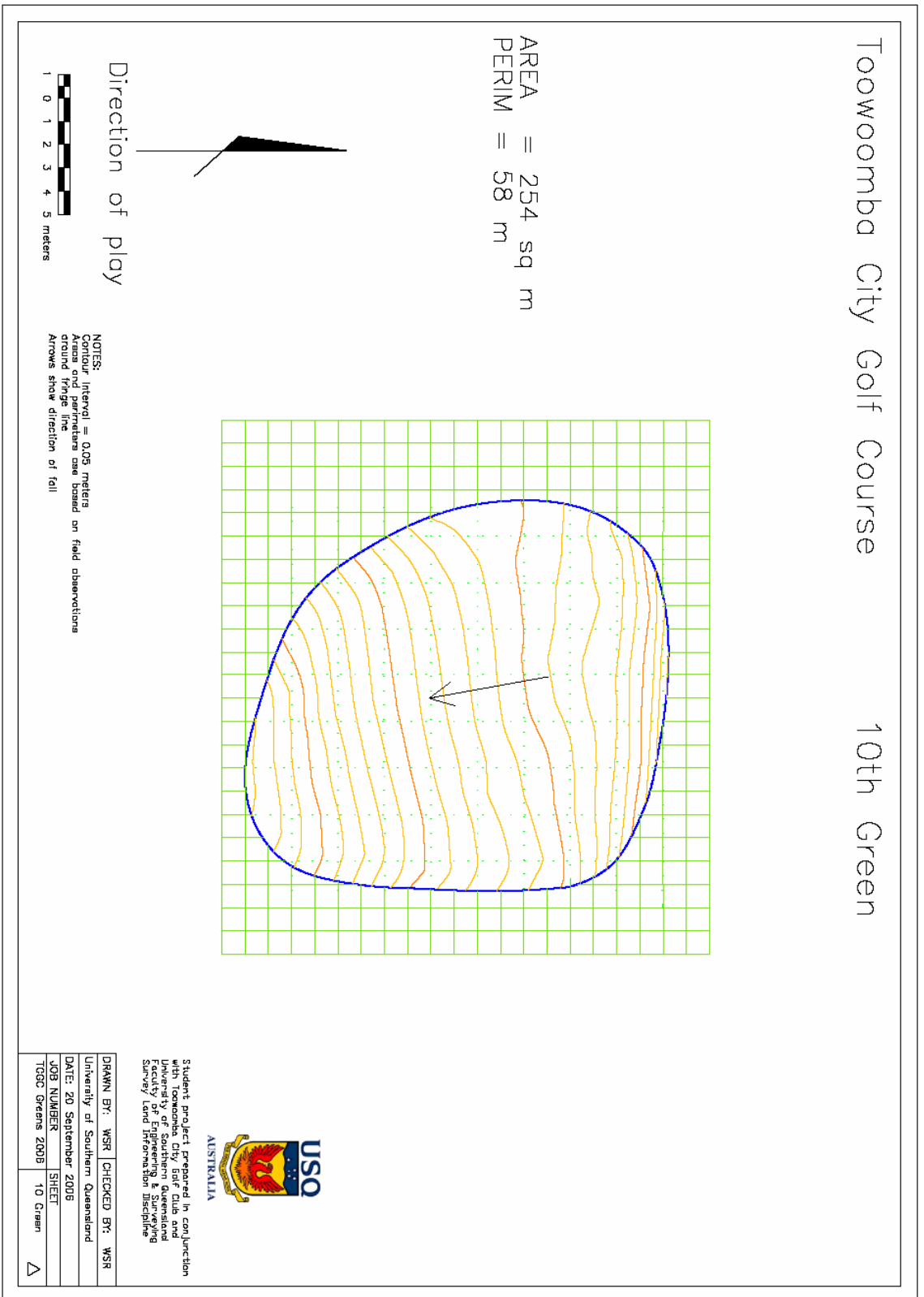
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 9. 9th Green



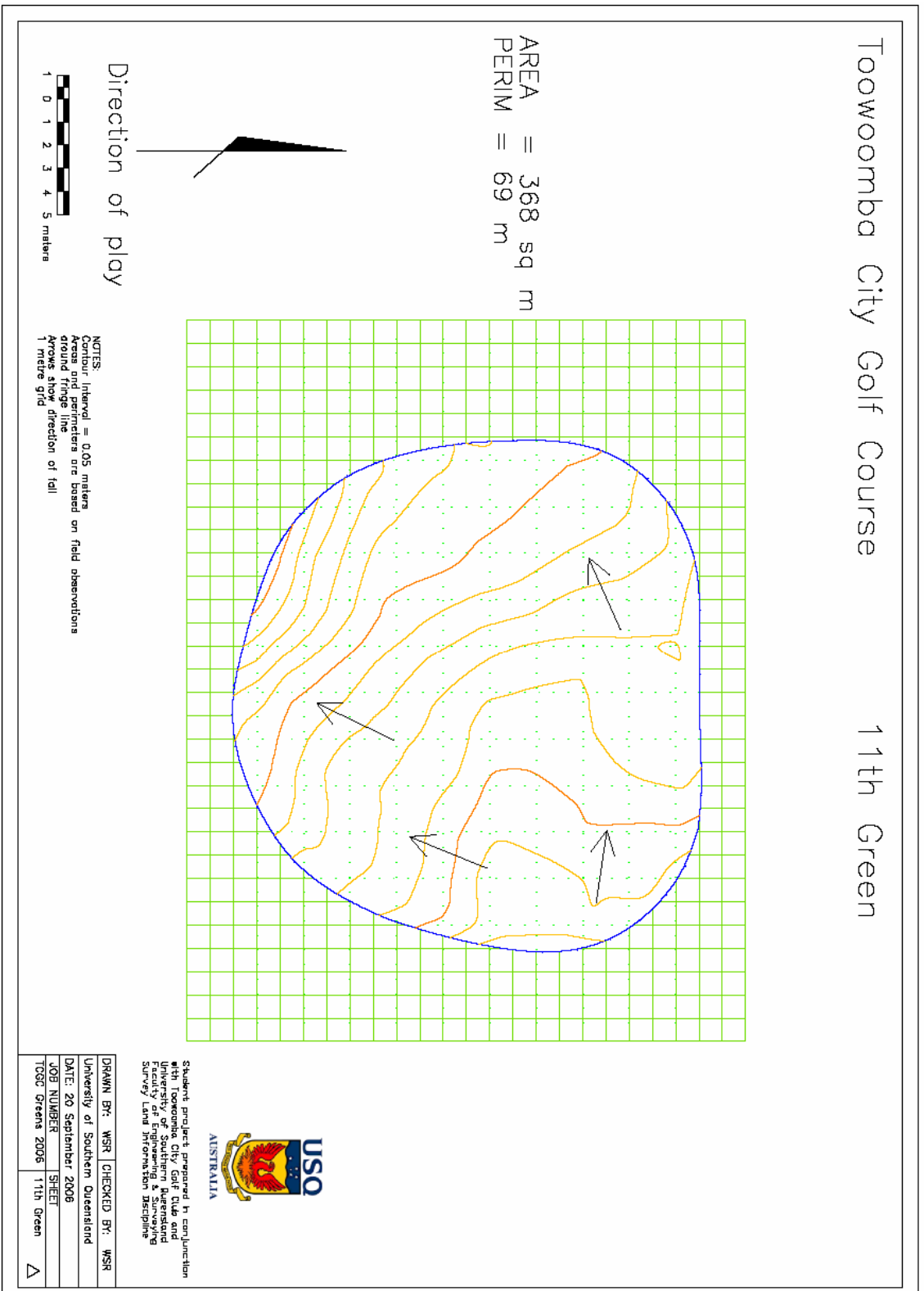
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 10. 10th Green



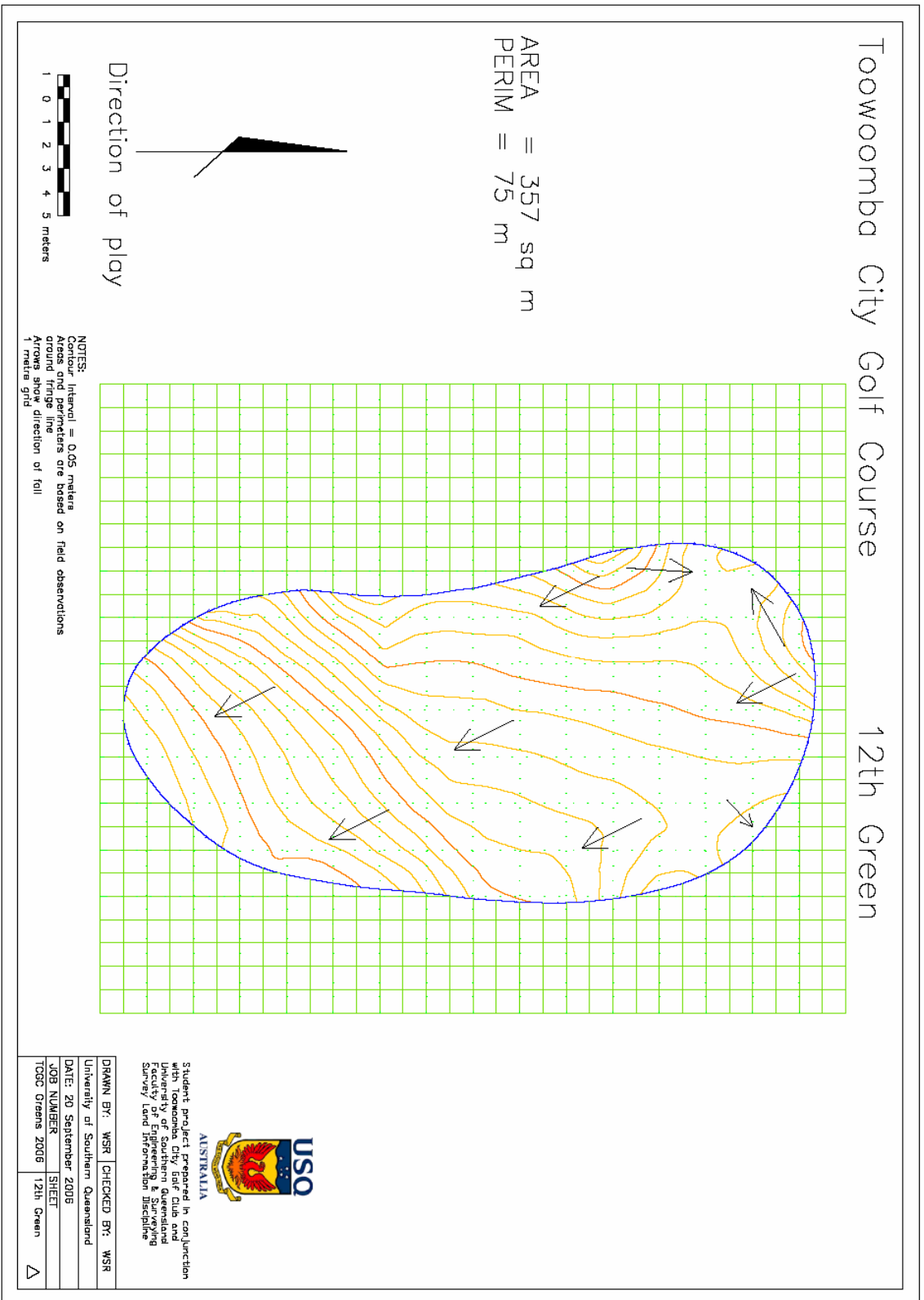


Appendix E Contour Green Plans  
11. 11th Green



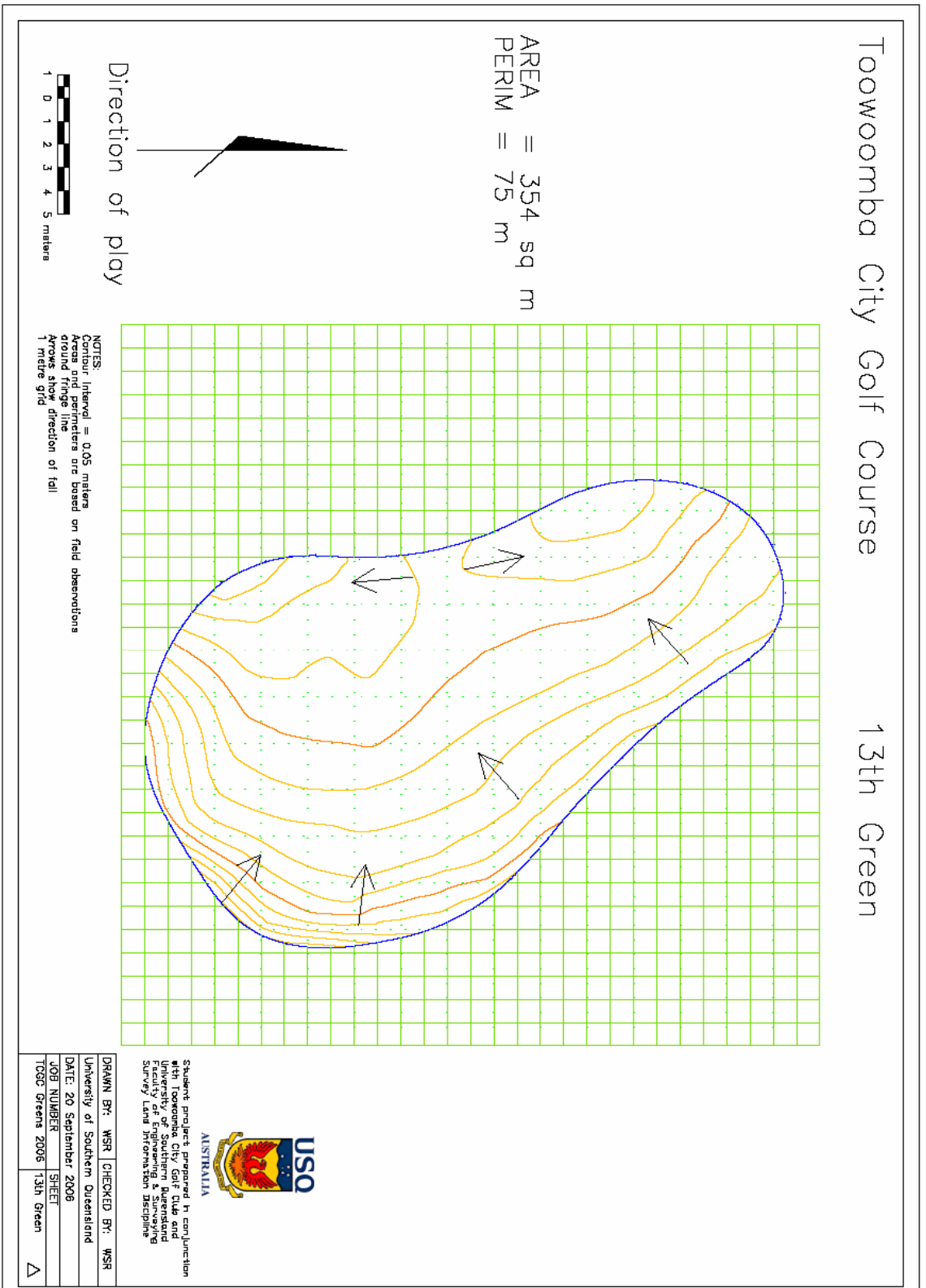
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 12. 12th Green



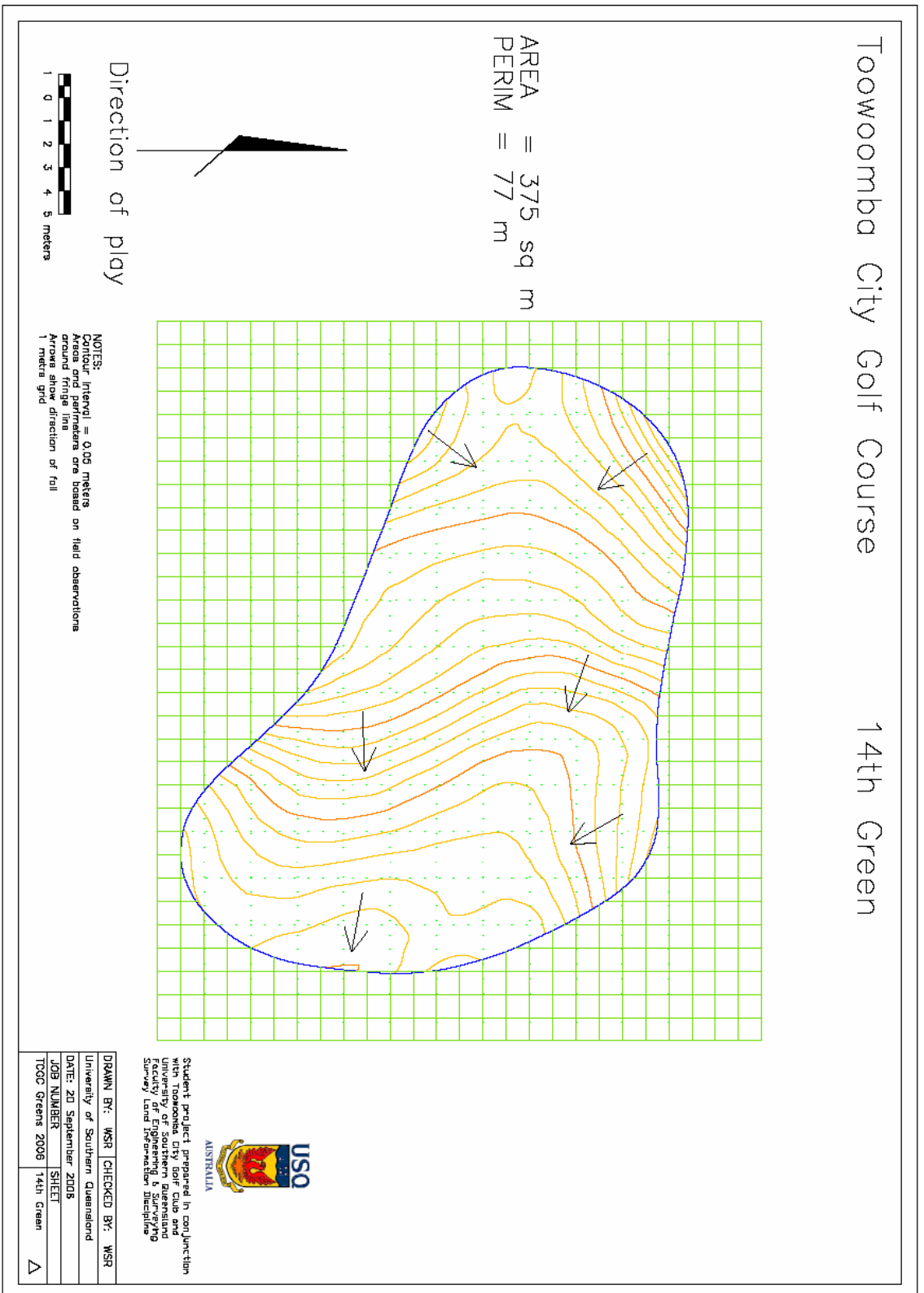
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 13. 13th Green

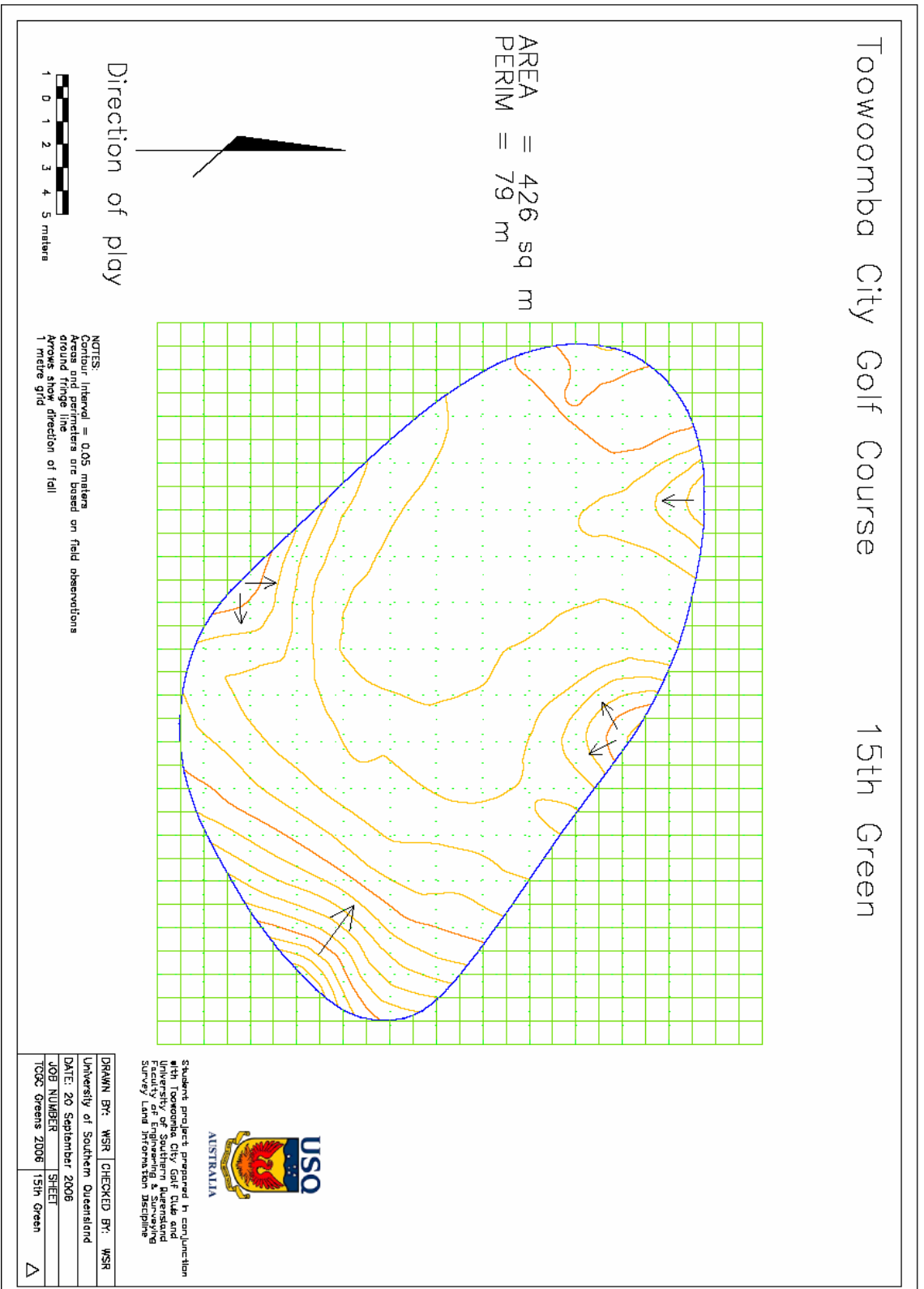


# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 14. 14th Green

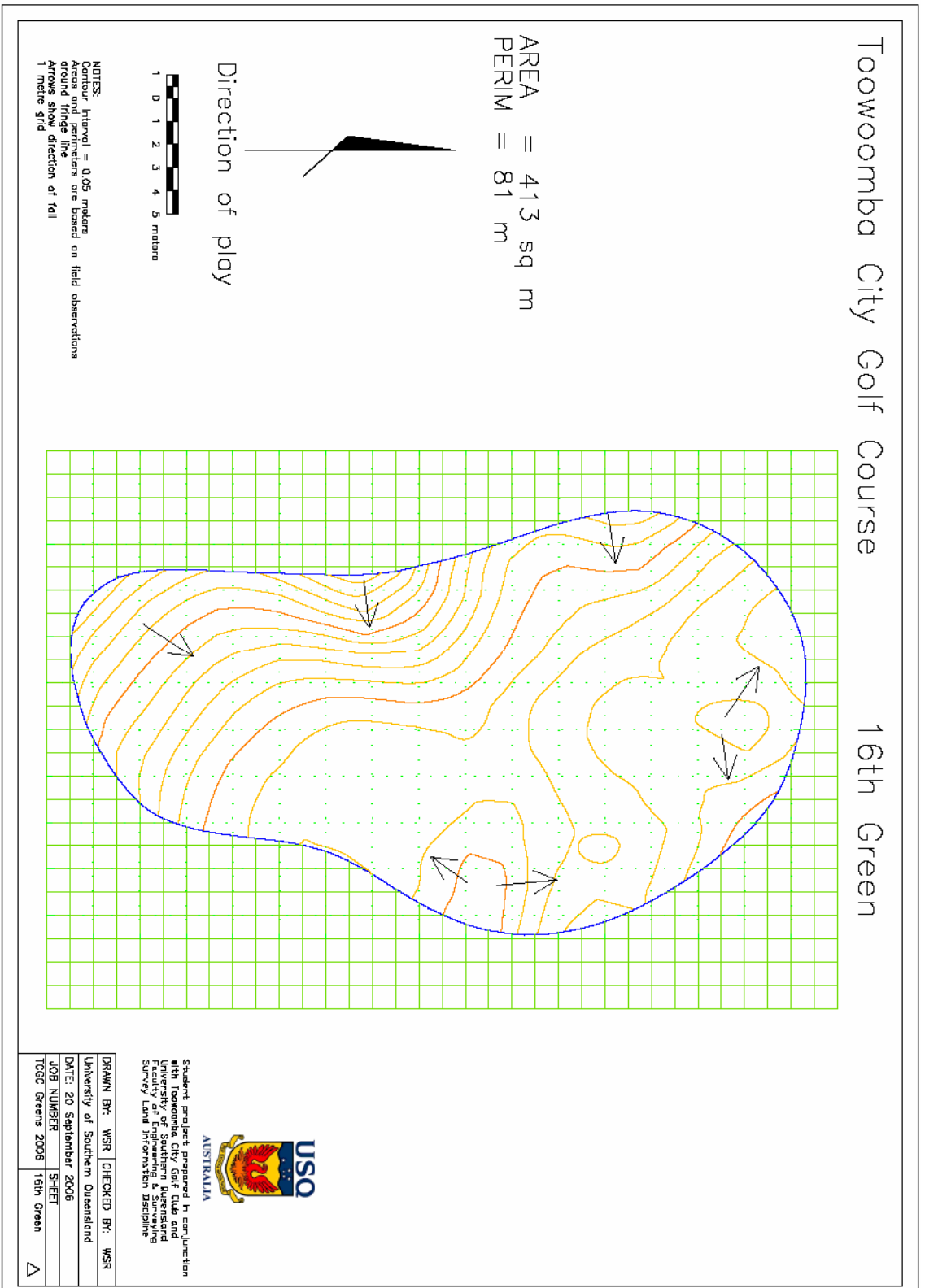


Appendix E Contour Green Plans  
15. 15th Green



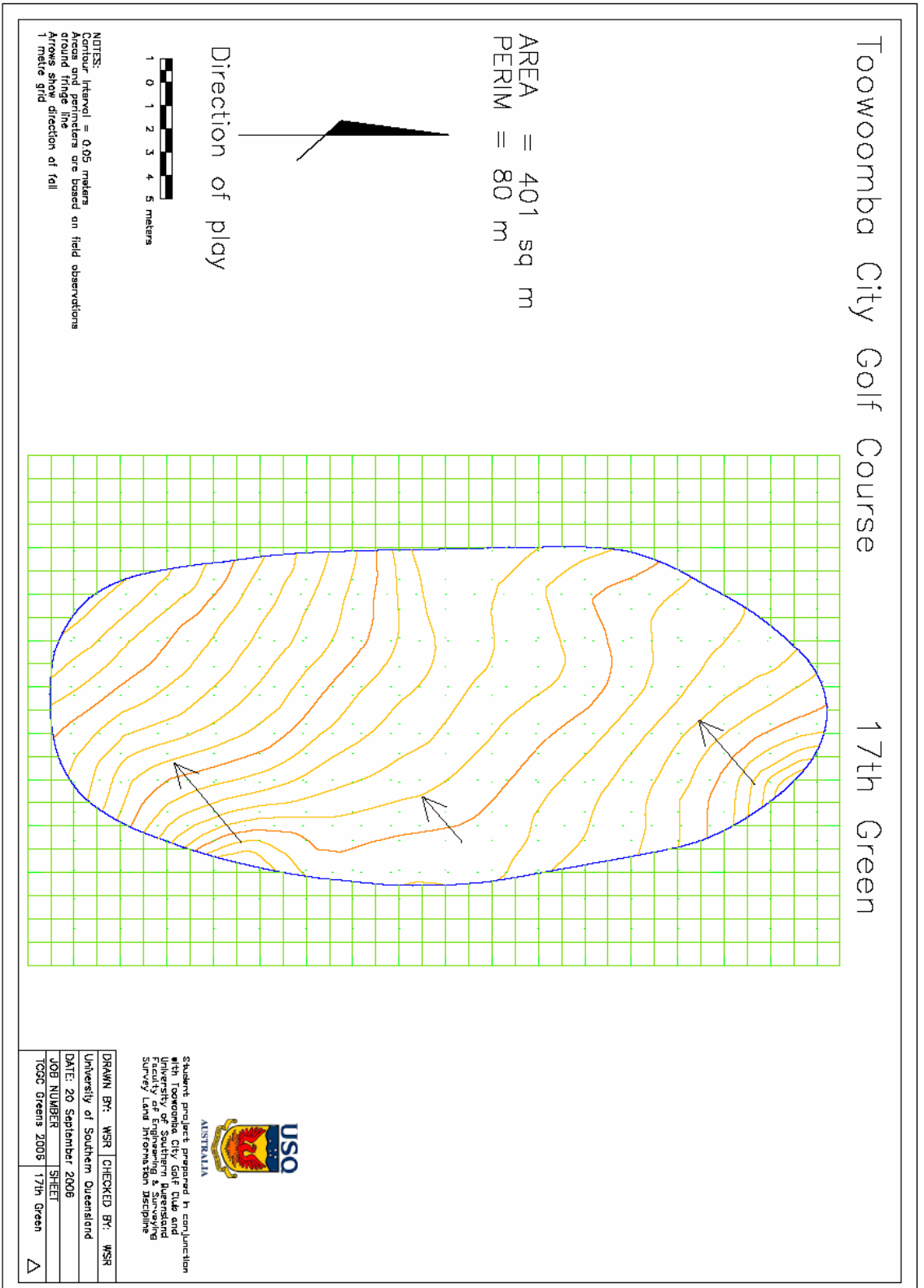
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 16. 16th Green



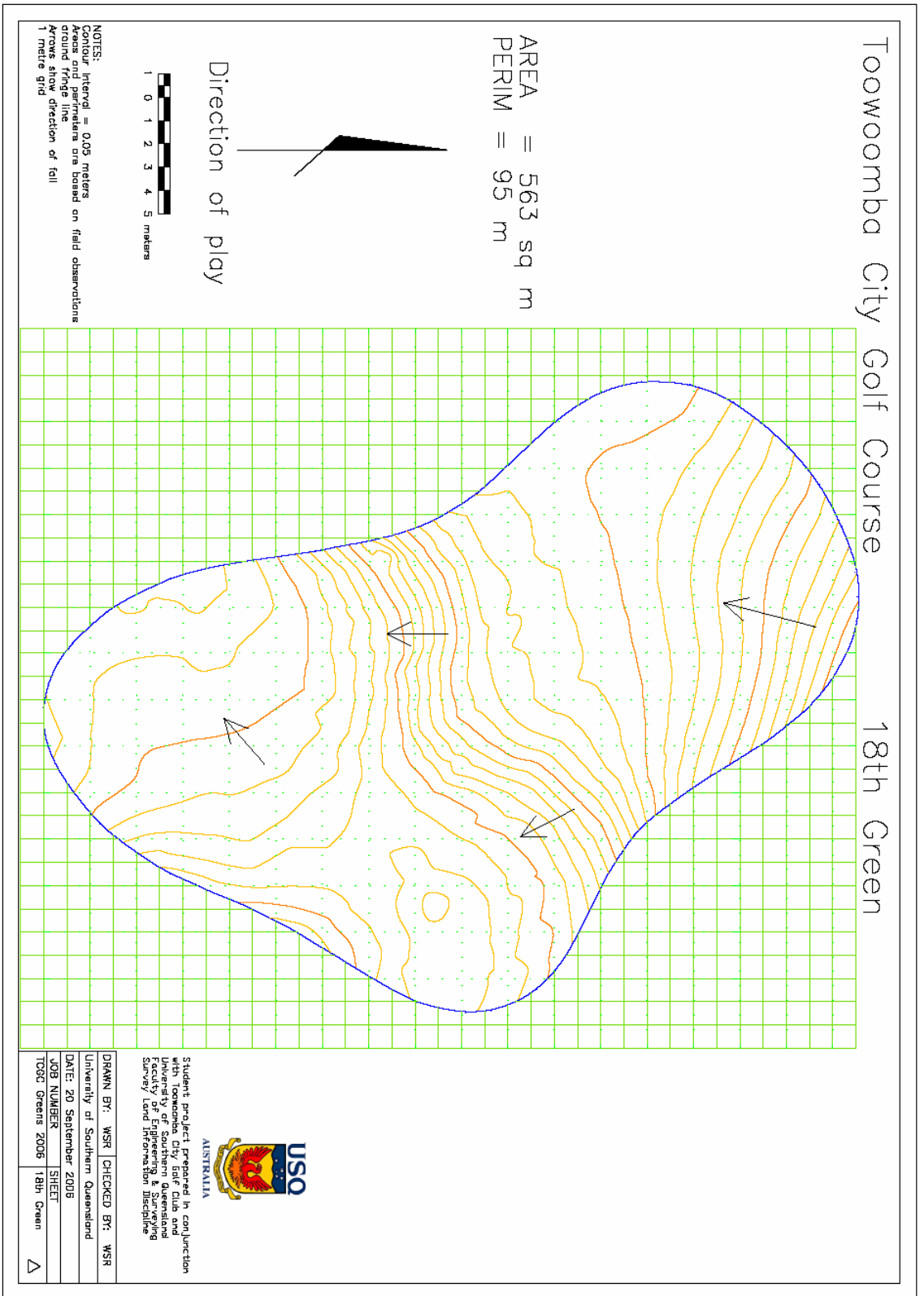
# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 17. 17th Green



# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 18. 18th Green





# Mapping Greens at City Golf Course

## Appendix E Contour Green Plans 19. Temporary Green

