IrriSatSMS

Irrigation water management by satellite and SMS - A utilisation framework

John W. Hornbuckle, Nicholas J. Car, Evan W. Christen, Thomas-M. Stein and Bill Williamson

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IrriSatSMS - Irrigation water management by satellite and SMS - A utilisation framework

Authors
John W. Hornbuckle\textsuperscript{1,2}, Nicholas J. Car\textsuperscript{1,2,3}, Evan W. Christen\textsuperscript{1,2,4},
Thomas-M. Stein\textsuperscript{5} and Bill Williamson\textsuperscript{6}

Affiliations
\textsuperscript{1}CSIRO Land and Water, Griffith, NSW
\textsuperscript{2}CRC for Irrigation Futures, Griffith, NSW
\textsuperscript{3}University of Melbourne, Melbourne, Vic.
\textsuperscript{4}University of New England, Armidale, NSW
\textsuperscript{5}CRC for Irrigation Futures (Consultant), Griffith, NSW
\textsuperscript{6}CRC for Irrigation Futures, DPI Office, Dubbo, NSW

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Table of contents

Executive summary ........................................................................................................................................... 8

1. Introduction .................................................................................................................................................. 9
   1.1. Current irrigation water management .......................................................................................... 9
   1.2. Current irrigation decision support systems ........................................................................... 10
   1.3. Overview of the IrriSatSMS approach ................................................................................... 10

2. Implementation of the IrriSatSMS approach ......................................................................................... 12
   2.1. Introduction and background ................................................................................................. 12
   2.2. General considerations ........................................................................................................... 13
       2.2.1. Q 1 - What climate data ................................................................................................. 14
       2.2.2. Q 2 - What crops are grown ......................................................................................... 14
       2.2.3. Q 3 - What irrigation systems are used .......................................................................... 14
       2.2.4. Q 4 - What water management approaches are currently used .................................... 15
       2.2.5. Q 5 - What irrigation infrastructure exists ..................................................................... 15
       2.2.6. Q 6 - What capacity building infrastructure is needed ..................................................... 15
       2.2.7. Q 7 - The proximity of farms and economies of scale ..................................................... 15
   2.3. Implementation ................................................................................................................................... 15
       2.3.1. Implementation phases ..................................................................................................... 15
       2.3.2. Building the system .......................................................................................................... 16
       2.3.3. Initialisation data - field, crop and irrigation system parameters ....................................... 16
       2.3.4. Climate parameters - ET₀ and rainfall ............................................................................. 18
       2.3.5. Crop parameters ............................................................................................................... 18
       2.3.6. Crop water models and modules ....................................................................................... 22
       2.3.7. Benchmarking and auditing water use ............................................................................. 25
       2.3.8. System verification - Ground truthing and calibration ....................................................... 25
   2.4. Information technology (IT) and infrastructural framework ............................................................ 26
       2.4.1. Current IT infrastructure schema ....................................................................................... 26
       2.4.2. Networks - Phone and Internet ........................................................................................ 27
       2.4.3. Internet/Cellular network gateway service ....................................................................... 28
       2.4.4. Server platform ................................................................................................................. 29
       2.4.5. Software and interoperability (open source) ..................................................................... 32
       2.4.6. Data formats and exchange ............................................................................................... 32
       2.4.7. Alternate IT infrastructure schema and open source .......................................................... 33
   2.5. Personnel and costing framework ..................................................................................................... 35
       2.5.1. Personnel and expertise needed ........................................................................................ 35
       2.5.2. IT system development personnel .................................................................................... 35
       2.5.3. IT system maintenance personnel ..................................................................................... 35

3. Scenarios and policy considerations ........................................................................................................ 37
   3.1. Overview .............................................................................................................................................. 37
   3.2. Case study I - By government institution (GI) ............................................................................... 38
       3.2.1. Outline .................................................................................................................................. 38
       3.2.2. Advantages ........................................................................................................................ 38
       3.2.3. Disadvantages ................................................................................................................... 40
       3.2.4. Summary ........................................................................................................................ 40
   3.3. Case study II - By water user/supply organisation/company (WUA/C) ......................................... 40
       3.3.1. Outline .................................................................................................................................. 40
       3.3.2. Advantages ........................................................................................................................ 42
       3.3.3. Disadvantages ................................................................................................................... 43
       3.3.4. Summary ........................................................................................................................ 43
   3.4. Case study III - By the private sector (PS) ....................................................................................... 44
       3.4.1. Outline .................................................................................................................................. 44
       3.4.2. Advantages ........................................................................................................................ 45
       3.4.3. Disadvantages ................................................................................................................... 46
3.4.4. Summary ...................................................................................................................... 46
3.5. Case study IV - As a hybrid system (HS) ....................................................................... 47
  3.5.1. Outline .......................................................................................................................... 47
  3.5.2. Advantages .................................................................................................................. 48
  3.5.3. Disadvantages .......................................................................................................... 49
  3.5.4. Summary .................................................................................................................... 50
3.6. Summary - Development and usage matrix ................................................................. 50
4. Conclusions and recommendations ....................................................................... 54
5. Glossary and definitions ....................................................................................... 55
References .................................................................................................................. 57
List of figures

Figure 1: Components of the IrriSatSMS approach. ........................................................................ 11
Figure 2: Two SMS messages containing water balance details in mm (evaporation, precipitation and irrigation) and dripper run time information. ......................................................... 11
Figure 3: Schematic overview showing the key in and output processes and main computational flows needed for a climatic based irrigation water management IrriSatSMS tool clearly highlighting the modular design with various options and alternatives (for example greyed out) of the main input components adjustable depending on availability of data and/or specific needs and conditions. ...................................... 13
Figure 4: Brochure containing information on how to collect and report the initial data on the irrigation system including application rate, plant and row spacing etc. which may then be sent as a text message to the server. .................................................................................. 17
Figure 5: Measuring vial for determining dripper application rates distributed to irrigators. Vial contains rolled up brochure (Figure 4) with detailed description on how to sign up to the system as well as information and form on how to measure dripper application rates. .................................................................................................................................. 18
Figure 6: Example calculation of NDVI for two irrigated grapevine canopies of well developed versus scarcely developed canopy, where R being surface reflectance of near infrared (R_{nir}) and red (R_{red}) spectrum. ....................................................................................... 20
Figure 7: The process of estimating crop water use for daily irrigation water management based on crop and paddock specific crop coefficients (Kc) generated via satellite image processing in combination with on ground reference evapotranspiration (ETc) measurements through automatic weather stations. ........................................................................ 22
Figure 8: Example of a typical SMS message sent daily to irrigators containing the status of the water balance, cumulative crop water use, irrigation, rain and dripper run time information. ....................................................................................................................... 23
Figure 9: Example of a water balance graph accessible through the web page interface by an irrigator for a particular crop and paddock........................................................................ 24
Figure 10: Example of a web page interface showing benchmarking data for three growers. .... 25
Figure 11: Current IT infrastructure data schema for IrriSatSMS. ......................................................... 27
Figure 12: SMS sample message text to emphasise the brevity of a message of 160 characters (including white spaces). .............................................................................................. 27
Figure 13: Schema of the 2008/2009 server platform architecture using Microsoft Windows Server 2003 with the .NET environment. .................................................................................... 30
Figure 14: Schema of a fully open source version of the 2008/2009 server platform architecture based on a Linux server operating system.................................................................................. 34
Figure 15: Schematic overview of main functional, logical and management components of the IrriSatSMS. ................................................................................................................................. 37
Figure 16: The government run IrriSatSMS - Schematic overview of main functional, logical and management components of the predominantly government run IrriSatSMS. .............. 39
Figure 17: The water user association/company (WUA/C) run IrriSatSMS - Schematic overview of main functional, logical and management components of a IrriSatSMS predominantly run by a water user association/company.............................................................. 41
Figure 18: The private sector run IrriSatSMS - Schematic overview of main functional, logical and management components of a IrriSatSMS predominantly run by one or multiple private sector companies. ......................................................................................... 45
Figure 19: The "hybrid" IrriSatSMS - Schematic overview of main functional, logical and management components of a strongly mixed system with various modules run by government, different institutions and the private sector. ...................................................... 48
List of tables

Table 1: Percentage of irrigation scheduling techniques used in Australia by farmers in the 2002-2003 season based on Australian Bureau of Statistics and the Productivity Commission (2006) data................................................................................................... 9

Table 2: List and details of some more common satellite platforms from which NDVI can be determined from reflectance data collected in the visible red and near infrared bands. .................................................................................................................. 21

Table 3: Commonly used remote sensing software platforms which can be used to process satellite imaging data. ........................................................................................................................................ 21

Table 4: Typical SMS gateway service costs. ........................................................................................................ 29

Table 5: Some examples of dedicated server hosting provided by companies and approximated costs for servers capable of performing the required tasks needed for the IrriSatSMS. ................................................................................................................. 29

Table 6: List of main software and modules used on the server for IrriSatSMS approach during the pilot testing in the 2008/2009 season. ........................................................................................................ 30

Table 7: List of free open source software as an alternative setup for the IrriSatSMS approach. ........................................................................................................................................ 34

Table 8: Estimated server setup and IrriSatSMS customisation tasks and associated times needed by an IT professional to setup an IrriSatSMS-type system. .............................................. 36

Table 9: Estimated server maintenance tasks for an IrriSatSMS-type system ........................................................................................................ 36

Table 10: PART 1: Summary - Development and usage matrix for the four case studies. .......................... 51

Table 11: PART 2: Summary - Development and usage matrix for the four case studies. .......................... 52

Table 12: PART 3: Summary - Development and usage matrix for the four case studies. .......................... 53
Executive summary

Objective irrigation water management is a necessary requirement for the irrigation sector to make improvements in water use productivity and efficiency. An approach using satellite data and mobile phone delivery of information is being outlined. This approach has two main aims, firstly to provide growers with an easy to use and understandable daily irrigation water management service and secondly to provide a benchmarking and auditing mechanism to be used by growers and water providers.

Irrigation water management by satellite and SMS approach helps irrigators to determine how much water their crop has used and how long they need to run their pump or drip system for each day using the latest in remote sensing techniques and mobile phone based delivery services. This approach also allows irrigators to benchmark their water use, in real time, against other irrigators. By viewing a web page irrigators can see how much water they have applied and compare against other users at any time through the season. The system can also be used as an auditing tool by water providers.

In this approach, satellite images are used to determine crop coefficients for individual crops. These satellite images are collected across Australia every 14-20 days. From these images plant canopy sizes can be determined which then are used to derive specific crop coefficients. This information is then used in combination with data from on ground weather stations in order to derive crop water use. The results as daily, customised, irrigation water management information is then sent out to irrigators by SMS messaging. The service sends actual pump or dripper run times so that irrigators can easily understand and relate to the information. To date this approach has been developed and piloted in the Murrumbidgee Irrigation Area (MIA).

This document details the conceptual framework and the practical elements that need to be assembled to make such a service operational. There are three elements to the approach:

1) **Data sourcing**
   Reference evapotranspiration, satellite and/or other remote sensed data for canopy evaluation as well as ground based data for site identification or set up are sourced.

2) **Server systems**
   The server systems houses a database with information of paddocks, growers, crops and processes the data using algorithms to determine irrigation requirements. This information is automatically sent out to growers via mobile phones while inputs of actual irrigation times and rainfall are returned by the growers by SMS or a web interface.

3) **Verification**
   The verification of data accuracy is extremely important. This is undertaken by systematic comparison of calculated irrigation requirement and actual irrigation applied as well as on ground checks of canopy development.
1. Introduction

1.1. Current irrigation water management

Despite the general advances of technology usage in the agricultural sector such as computerised machinery or laser technology, relatively little has been achieved yet in respect to improved irrigation water management technologies. It is of great concern that from all water management methods mentioned during the 2002-03 ABS&PC survey (Australian Bureau of Statistics and the Productivity Commission 2006), more than 70% \(^1\) fell under the categories of "local knowledge" (61%) and "rotation scheduling" (11%), methods which indicate that water management is not based on scientific principles. Hence, there is still a great demand and urgency in implementing effective and easy to use water management techniques on a larger scale. An overview of the percentage of the various irrigation water management techniques used by irrigators in Australia is given in Table 1.

Table 1: Percentage of irrigation scheduling techniques used in Australia by farmers in the 2002-2003 season based on Australian Bureau of Statistics and the Productivity Commission (2006) data.

<table>
<thead>
<tr>
<th>Scheduling techniques used</th>
<th>Number of farms using scheduling technique(*)</th>
<th>no.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation figures</td>
<td>6825</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>Tensiometers</td>
<td>7473</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>Soil probes</td>
<td>6671</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Scheduling service</td>
<td>1646</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Rotation scheduling</td>
<td>8614</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Local knowledge</td>
<td>48982</td>
<td>61.1</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80211</strong></td>
<td><strong>100.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Some farms use more than one scheduling method and may be listed several times. The total number of all farms in relation to used scheduling techniques is set to 100%.

Australian scientists are leaders in conducting research of the soil water processes and the water uptake by plants. Australian companies have turned much of this knowledge into commercial products such as soil moisture probes etc. which support irrigation water management and are now sold worldwide. However, when it comes to local adoption of soil moisture monitoring or irrigation water management techniques and practices, uptake has been surprisingly slow and low. Stirzaker (2006) has identified and described seven obstacles to adoption of soil moisture monitoring equipment which in many ways are linked and equally applicable to overall water management. Based on his surveys the obstacles may be summarised as follows:

1. Importance of scheduling could not be seen due to limited data on the amount of water actually used, or the amount which should be used, with few good examples (champions) to learn from.
2. Entrenched culture of resistant to change and inherited knowledge or the status quo was seen to be adequate.
3. Little confidence that investments in this field would actually pay off.
4. Structural barriers that make it harder to start and adopt.
5. Concern about the complexity of tool and which ones would suit best.
6. Communication and conceptual problems and differences between irrigators' and scientists' perspectives.
7. Possibly wrong extension model.

\(^1\) Some farms use more than one scheduling method and may be listed several times.
The Irrigation water management by Satellite and SMS (IrriSatSMS) approach addresses many of the above obstacles particularly those of cost, complexity and communication problems. This approach also provides a universal type service (i.e. coverage is practically unlimited) at low cost, thus for the first time making an objective irrigation water management service widely available.

1.2. Current irrigation decision support systems

The concept of computerised decision support systems (DSS) that assist users in complex decision making processes has been around since the late 1970’s. Decision support systems that model soil, plant and weather conditions have been used to calculate when an irrigator should next irrigate, based on objective assessments of crop water requirements. It is known that if DSS-derived irrigation schedules were followed, water savings can be achieved though efficiency gains. However, the Australian Bureau of Statistics data indicates that, as of 2003, only one in five irrigators undertook any form of objective decision making (Montagu 2006). Additionally, although there are no direct statistics available on the usage of irrigation DSS, numbers are known to be very low with the most popular Australian DSS, such as the APSIM-derived Yield Prophet, only seeing usage in the order of a few hundred (Inman-Bamber and Attard 2005). Some of the reasons for the poor uptake of agricultural DSS, including irrigation DSS, are related to the perceived difficulty of use and the inability of DSS to present themselves as relevant to a particular user through the deployment of personalised information (Hayman 2004).

The IrriSatSMS approach described here addresses these difficulties by providing ease of use, both in mode and context, through mobile phone information delivery as well as through providing irrigation run times, rather than abstract measures of plant water use. Importantly, it does not replace human decision making, the decision of when to irrigate and how much is left entirely open.

1.3. Overview of the IrriSatSMS approach

The IrriSatSMS hybrid satellite and SMS system is a new approach of providing tailored but widely applicable irrigation water management services. This approach aims at delivering daily data to irrigators to support and facilitate their irrigation decision making process. Thus, all components need to run on a ‘real time’ basis.

This IrriSatSMS approach is based on the computation of crop water requirements based on weather data and crop related coefficients which then translate into a water balance and the required irrigation demand. A schematic representation of the IrriSatSMS approach is given in Figure 1 showing the specific and main components of the system. The IrriSatSMS approach undertakes all the tedious calculations needed to convert weather station based reference evapotranspiration (ET₀) data and crop coefficient data (Kc) to useful water management information for the irrigator.

The system uses the known application rate data of the individual irrigation system and provides a simple determination in minutes of how long the system should be run in order to replace the crop evapotranspiration. Suggested irrigation run times to replace plant water use for the previous 1-7 days are given. Example messages are shown in Figure 2. This is done on a daily basis and information is delivered directly to the irrigator through SMS providing the irrigator with the information where and when it is needed in a format suitable to make a management decision. Conversion to a pump run time in minutes provides the irrigator with a direct, understandable measure which can be used as a basis for water management.

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2 SMS stands for short message service and is often called text messaging or texting mainly used on mobile phone devices. It is a simple text message with a limited length of 160 characters (more under Glossary and definitions).
Figure 1: Components of the IrriSatSMS approach.

Figure 2: Two SMS messages containing water balance details in mm (evaporation, precipitation and irrigation) and dripper run time information.
A feedback loop is provided as irrigation run times as well as rainfall data are sent back by the irrigator to the server by using SMS or a web interface. This data is used to update the water balance. All values are centrally stored for further use allowing, for example, system benchmarking to be performed. All results can be presented on a web page instantly and may be securely accessed by the irrigators.

The system relies mainly on an SMS interface for communicating with irrigators (Car et al. 2007a,b). However other interfaces such as the web may also be implemented as an alternative or in combination with SMS. The system has the ability to collect information from SMS messages that are sent to it via an SMS gateway. In the current pilot implementation, incoming SMS messages are related to initialisation data, dripper run times and rainfall amounts.

To date this approach has been developed and piloted in the Murrumbidgee Irrigation Area (MIA). However the IrriSatSMS approach is scalable, from hundreds to thousands of individual users and/or paddocks. The server (database) and SMS systems may easily handle such numbers of operations. The geographic spread of the area has little limitation as satellite coverage is universal, only some cost constraints may occur if there are relatively few users in an image. Crop variety can also be handled as the relationships between Normalised Vegetation Index (NDVI), crop canopy and crop coefficient are robust and have been developed for a number of crops. These elements are outlined in more detailed in the ‘Implementation of the IrriSatSMS approach’ section of this report (Chapter 2).

2. Implementation of the IrriSatSMS approach

2.1. Introduction and background

Irrigation scheduling is defined as the "process of determining when to irrigate and how much water to apply to an irrigated crop in order to maximise net returns" (ABS&PC, 2006). There are varying different approaches to irrigation scheduling, which is better termed ‘water management’. The one adopted here, and which suits best the objective of flexibility and simplicity to the end user, is based on the computation of crop water requirements based on weather data and crop related coefficients which then translate into a water balance and the required irrigation application rates. This data, to assist water management, is provided as water used and water needed with system irrigation run times to the farmers via SMS or other mobile, semi-mobile or fixed network devices such as a computer. There are several feedback, control and input mechanisms provided during the process allowing targeted interactions between end user, the IrriSatSMS system and service provider. While the underlying processes are fairly complex, the entire system still remains easy to use and is designed with some flexibility to the end user in respect to how information is retrieved and communicated back to the system.

A schematic overview showing the key input and output processes and main computational steps needed for a climatic based irrigation water management tool such as IrriSatSMS are shown in Figure 3. It depicts the various stages starting from the climate data gathering via automatic weather stations or alternatively through the SILO3 system (Bureau of Meteorology 2008) in order to calculate the reference crop evapotranspiration (ET₀) which forms the basis for crop water requirement calculations. During the next stage a specific crop coefficient is derived which is computed by using the satellite based Normal Difference Vegetation Index (NDVI). By combining the reference crop evapotranspiration (ET₀) values with a specific crop coefficient (Kᵉ) the actual crop water requirement (ETᵉ) can be computed which forms the basis for the irrigation water management model.

Based on site and crop specific data provided by the irrigator or the service provider in combination with the computed crop water use, paddock specific irrigation water management support is derived and delivered. Various flexible interfaces can be used such as SMS or MMS message but equally through the Internet by using general web and mobile phone specific WAP4 (Wireless Application

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3 SILO - ‘Special Information for Land Owners’ (see also Chapter 5).
4 Wireless Application Protocol (WAP) pages are Internet pages specifically written to be accessible by mobile phones (see Chapter 5).
This schematic overview describes a sequence and version of key components well suited for this approach. However, this modular design also clearly highlights the advantages such a modular system has allowing for various components (for example greyed out dashed lines) to be exchanged and swapped depending on availability of data and/or specific conditions and demands.

Figure 3: Schematic overview showing the key in and output processes and main computational flows needed for a climatic based irrigation water management IrriSatSMS tool clearly highlighting the modular design with various options and alternatives (for example greyed out) of the main input components adjustable depending on availability of data and/or specific needs and conditions.

2.2. General considerations

The IrriSatSMS approach has been designed to be flexible, easy to use and easily transferable to new regions and crops. When a new region or field is being approached for IrriSatSMS application, certain components of this framework need to be explored and evaluated in order to highlight the best approach, possible pitfalls and costs involved for implementation. The following set of questions may be used as guidance in order to check and gather the necessary data needed.

(Q 1) What climate data
(Q 2) What crops are grown
(Q 3) What irrigation systems are used
(Q 4) What water management approaches are currently used
(Q 5) What irrigation infrastructure exists
(Q 6) What capacity building infrastructure is needed
2.2.1. Q 1 - What climate data

Climate data is required for the calculation of reference crop evapotranspiration \((E_{\text{T}_0})\) which forms the basis for the crop water requirement calculation. This data needs to have a good regional as well site specific coverage and it is also essential that it is readily available on a daily basis. Thus, automation and reliability are critical factors. Means of data access, costs and the data format are other factors which need consideration. There are three broad options:

1. **Automatic weather stations (AWS)**
   Automatic weather stations are a good source for weather data and are quite common. However, only a smaller proportion are actually networked and therefore the data remains inaccessible. An upgrade with a radio or mobile phone link could be considered for newer stations. Otherwise a new station with a network or mobile phone link serving a larger area may actually be more appropriate, cost effective for a group and most likely less troublesome. They are becoming increasingly popular and are reasonably priced. The main parameters needed to calculate \(E_{\text{T}_0}\) are air temperature, humidity, radiation and wind speed. Precipitation values may also be included but would preferably be collected at field level by growers, as rainfall tends to be highly variable.

2. **Synthetic climate data**
   Alternatively the use of synthetic climate data that has complete national coverage may be explored. Such data is provided by services such as SILO\(^5\) which provide meteorological and agricultural data and generate \(E_{\text{T}_0}\) values for every geographical location within Australia. Fees apply and data access needs to be negotiated.

3. **Hybrid climate data**
   The provision of data which is derived from a combination of direct observation and synthetic means and which is managed using national standards may prove to be a more robust option. Such a service might use local observations from AWS of temperature, humidity, wind speed and rainfall, and derive more problematic parameters such as radiation from modelling based on satellite observations. The Bureau of Meteorology is likely to meet this need in the future, and has the appropriate quality control mechanisms.

2.2.2. Q 2 - What crops are grown

Irrigation water management is based on the water used by a specific type of crop balanced against natural precipitation and irrigation as well as the soil water holding capacity. Crop type(s) and development needs to be explored in relation to specific water needs as well as cropping patterns and agronomic and market practices. Most data related to general crop needs and general crop water requirements are well established.

2.2.3. Q 3 - What irrigation systems are used

While the IrriSatSMS approach is generally applicable to most irrigation methods it is best suited to systems with a high degree of control on water application as found in pressurised irrigation systems such as sprinkler or drip. However, planned or actual modernisation moves for example from flood to drip or sprinkler to drip may well be a good starting point in order to support and introduce a paradigm change towards modern irrigation water management and management. This irrigation water management approach can be used for flood irrigation, but the main difficulty in current situations lies in knowing how much water is applied to a paddock, and ultimately in identifying losses. If this is measured or can be accurately estimated, then the IrriSatSMS is applicable. If there is no measure then an approach that assumes complete soil refill can be adopted, but with higher levels of uncertainty.

\(^5\) Currently SILO is being run by the Bureau of Meteorology and the Queensland Department of Natural Resources and Water and is supported by Agriculture, Fisheries & Forestry Australia (AFFA) and the Australia’s Rural Industries Research & Development Corporation (RIRDC) under the Climate Variability in Agriculture R&D Program (CVAP).
2.2.4. **Q 4 - What water management approaches are currently used**

There are strong regional, system and commodity related differences not only related to water management methods used but also on the levels of acceptance of certain approaches and tools (Stirzaker 2006). It has therefore to be established what water management methods are in use and which ones would actually need replacement. An assessment is required of the position of this approach in the marketplace for irrigation water management. Certain areas may already have a well established and functioning network and support system for certain water management methods and tools and it has to be evaluated how this approach may be integrated with the other approaches and service providers in existence.

2.2.5. **Q 5 - What irrigation infrastructure exists**

There are certain infrastructural frameworks (also related to water supply) which may pose an obstacle in introducing more advanced water management systems. For example, if water is being conveyed in open channels it is difficult to run a tight irrigation water management system requiring an on demand water supply. Lead times may be too long, channel capacity too low and rotational constraints too rigid to be able to serve the irrigation system at the right time. However, many supply systems are gradually being converted to pressurised systems causing a move to modernisation of irrigation systems and hence, also provide an opportunity to establish a new water management approach within a region.

2.2.6. **Q 6 - What capacity building infrastructure is needed**

In order to provide effective services to growers and irrigators, an analysis of the broader support services in training and education is necessary as the service implementer or provider will not necessarily be able to deal with all growers and all their problems on an individual basis. In a full production system that may encompass hundreds or thousands of growers a well targeted capacity building process may need to be put in place in order to provide necessary understanding and knowledge needed to apply modern water management approaches. Thus, capacity building in relation to the broader framework as well as training in specific aspects of irrigation and irrigation water management needs to be considered.

2.2.7. **Q 7 - The proximity of farms and economies of scale**

The number and size of farms/paddocks potentially suitable for a new water management approach needs to be considered. Aspects such as type of irrigation, sensitivity of crops and scarcity of water supply are important. The higher the concentration of potential users, the lower the expected unit costs, as the costs of satellite data relate to “scenes” and are offset when a large number of farms are captured in each image.

2.3. **Implementation**

2.3.1. **Implementation phases**

The implementation of the IrriSatSMS approach involves assembling a set of IT based tools and attracting users to the service. Thus, there has to be a body (company, organisation, government entity) ready to provide such a service and a suitable market ready to pick up such service. However, this is not a trivial exercise and requires some specific skills in fields such as IT, agronomy and communications. The program needs to be embedded within a technical and organisational framework. From conceptualisation to a full production service it is expected to take approximately three years:
Year 1 - Setup and testing phase
During the ‘setup and testing phase’ the system hardware and software is setup and refined and water management data is delivered to a limited number of growers (~10 - 30). This is done for a range of crops and conditions that would represent the broad target user groups. There would be close monitoring of the system and verification that the water management data provided is accurate. This will need strong engagement with the various growers to ensure that the service is adequately tailored to the local conditions and their requirements.

Year 2 - Pilot phase
During the subsequent ‘pilot phase’ system adaptations and corrections elaborated during the first year would be implemented and the number of growers increased (~100), aiming at running the system as a full implementation. This pilot phase would still allow some detailed verification and additional bug fixing. This phase would also test the support framework and the degree of support needed by the growers.

Year 3 - Production phase
The ‘production phase’ starts with the full roll out of the system and increase in number of users. The service would be open to all interested and wishing to subscribe. The implementation/extension program would be fully implemented to ensure a rapid uptake and maximum coverage. This program could initially be targeted at specific groups or regions where greatest demand of water savings are required and a high degree of efficacy of service could be expected.

2.3.2. Building the system
The following sections outlines how the IrriSatSMS water management system is built highlighting the requirements, infrastructure and methods associated with each component of the system as presented schematically in Figure 1 (Chapter 1.3). More specifically the IrriSatSMS approach consists of the following main building blocks:

- Initialisation data - field, crop and irrigation system parameters
- Climate parameters - ET₀ and rainfall
- Crop parameters - NDVI
- Crop water models - water balance calculation
- Data delivery and collection - via SMS
- Benchmarking, auditing and calibration

2.3.3. Initialisation data - field, crop and irrigation system parameters
In order to successfully implement an irrigation water management system such as IrriSatSMS, the parameters identifying and defining the irrigation system operational environment need to be determined for any irrigation system and irrigator. These metadata needed cover some identification or personal details such as the grower's name, telephone number, paddock identification, geographical location and area as well as type and application rate of the irrigation system. In a production service, this data is being collected during the initialisation and subscription process to the IrriSatSMS irrigation water management and is used to identify the grower and their data.

This process may be done either online or offline. However, a well accepted approach currently used is to distribute a hardcopy brochure (Figure 4) to irrigators containing information on how to subscribe to the system in conjunction with a measuring cylinder (Figure 5) which is used to evaluate the current irrigation system by collecting application rate data from the specific system or field.

---

 Metadata are defined as ‘data about data’ and are used to describe and facilitate the understanding, characteristics, management and the usage of the data (further details in Chapter 5).
Figure 4: Brochure containing information on how to collect and report the initial data on the irrigation system including application rate, plant and row spacing etc. which may then be sent as a text message to the server.
After the subscription process, which is currently done by the service providers, the initial data about the irrigation system including application rate, plant and row spacing may be sent through a text message to the server which stores this information on a database for later use in providing water management data and calculated application rates provided as for example irrigation times.

Figure 4 and Figure 5 show an example of the IrriSatSMS subscription and system evaluation brochure currently used in the MIA for wine grape growers and the measuring vial for dripper application rate measurements and evaluation.

**Figure 5:** Measuring vial for determining dripper application rates distributed to irrigators. Vial contains rolled up brochure (Figure 4) with detailed description on how to sign up to the system as well as information and form on how to measure dripper application rates.

### 2.3.4. Climate parameters - ET<sub>o</sub> and rainfall

The two important climate parameters which are needed for the IrriSatSMS water management approach are reference evapotranspiration (ET<sub>o</sub>) and rainfall. These weather data can be sourced in different ways and more detail is given in Chapter 2.2.1.

ET<sub>o</sub> data for the pilot system in the MIA is sourced from a local weather station that provides reference evapotranspiration values already derived from various measured weather parameters. ET<sub>o</sub> data in conjunction with other weather measurements are directly placed on the web. ET<sub>o</sub> data from the CSIRO Griffith Laboratory weather station may be accessed through the CSIRO server through the following address:

http://www.clw.csiro.au/services/weather

This particular data is directly available on the Internet and can be accessed by the public.

For the IrriSatSMS approach basically any relevant source of ET<sub>o</sub> data can be integrated and used. If no reliable locally measured ground ET<sub>o</sub> information is available the system can potentially also run using the SILO climatic database. SILO (Special Information for Land Owners) is currently provided through the Bureau of Meteorology (BoM) website (http://www.bom.gov.au/silo) and ET<sub>o</sub> values may be generated synthetically for every geographical location within Australia.

The second important weather parameter which needs to be collected is rainfall. Rainfall can be gathered either from automatic weather stations (AWS) or through the SILO systems. However, due to the highly variable nature of rainfall values gathered at the AWS or provided through SILO may not adequately represent the conditions found at paddock level. It is therefore highly recommended that rainfall data is collected by the irrigator at the farm or paddock level. Subscribers to the service should report rainfall events with date and amount via SMS in a predefined form which will automatically update the water balance for that paddock in the system.

### 2.3.5. Crop parameters

The crop parameter required for the calculation of water use is the crop coefficient (K<sub>c</sub>). This is used in the approach known as FAO-24 (Doorenbos and Pruitt, 1977) with the updated version FAO-56 given
by Allen et al. (1998) and is widely accepted as a standard procedure for crop water requirement estimation worldwide. This is based on the application of reference station evapotranspiration figures which are collected over a grass reference surface (ET₀). This reference evapotranspiration is used to represent the climatic conditions under which evapotranspiration takes place, which is then used to calculate actual evapotranspiration (ETₐ) for specific crops by multiplying the ET₀ by a specific crop coefficient (Kc). Generally four Kc values are used over the growing season, representing the various crop development stages - initial, mid, full and late. The crop coefficient takes into account differences in canopy cover, stomatal characteristics, aerodynamic properties and albedo, which affect the rate at which crops transpire compared to the reference crop ET₀. Therefore ETₐ for a specific crop is given by:

\[
\text{ET}_a = \text{ET}_0 \times K_c
\]

A limitation of this approach has been that the Kc value is specific to a particular crop, irrigation system, soil and management. There have been a number of approaches used to derive crop coefficients which measure actual crop evapotranspiration and compare this to reference evapotranspiration allowing a Kc to be developed for that crop. However, these methods (for example eddy covariance, Bowen ratio, water balance) are expensive and require a high level of expertise to implement. Slight changes in agronomic management, soils and irrigation regimes affect the crop coefficient which makes it difficult to derive a specific crop coefficient for an individual crop. Weather station information for determining ET₀ is commonly available through nearly all of the irrigation regions in Australia.

2.3.5.1. Empirical crop coefficients

Published values of Kc although generally broadly applicable for irrigation planning are generally not adequate for irrigation water management. Crop coefficients are affected by management (irrigation, fertiliser etc), soil type and varietal differences and often show variation even within crops in the same region due to these factors. This has proven a major limitation when applying reference evapotranspiration with a crop coefficient approach for providing practical water management information on a per paddock basis.

In a setup phase of an IrriSatSMS approach empirical crop coefficients can still be used for a particular crop in a region but should be used as a first estimate and as a comparison value only. The approach recommended here is to derive unique crop factors for each paddock through every season by deriving specific crop indices directly related to the actual crop and its development, as described in the sections below.

2.3.5.2. Crop cover indices - NDVI

Recent advances in remote sensing have seen the use of visible and near infrared light wavelengths used for determining vegetation indexes. These indexes, particularly the Normalised Difference Vegetation Index (NDVI) have the potential to be used for providing site specific crop coefficient information. A number of authors have found linear relationships between NDVI and crop coefficients for a broad range of crops. These relationships allow a practical method which can be used to gain large scale, low cost, site specific crop coefficient information which can then be used with reference evapotranspiration from weather stations to provide paddock specific water management information.

A number of authors have observed and reported strong correlations between vegetation indexes and canopy cover over a range of irrigated crops (Hunsaker et al. 2005; Hunsaker et al. 2006; Consoli et al. 2006; Johnson & Scholach 2005; Rafn et al. 2008 and Trout et al. 2008). Recently, Trout et al. (2008) reported on findings showing strong relationships between satellite derived measurements of NDVI and crop canopy cover which can be directly related to crop water use in a number of horticultural crops in the San Joaquin Valley in California. The NDVI is an index generally expressed as a ratio between 0-1 of the red and near infrared reflectance by plants. Larger, greener canopies
give higher NDVI values than smaller less healthy plant canopies. An example calculation for two irrigated grape vine canopies (well developed, versus scarcely developed canopy) is given in Figure 6.

Canopy cover is a direct driver of crop water use and hence allows a direct relationship to be developed between NDVI satellite derived values and crop coefficients which take into consideration specific agronomic and management conditions for individual crops. This allows a specific crop coefficient to be derived on an area as small as 30 x 30 m when data from the commonly available Landsat 5 satellite is used. Trout and Johnson (2007) provide NDVI:Kc relationships between a number of horticultural crops based on Landsat 5 derived NDVI data and results from lysimeter studies relating canopy cover measurements to crop coefficients. The system detailed in this paper has been largely tested with winegrape producers and relies on NDVI to crop coefficient relationships detailed in Johnson and Scholasch (2005).

\[
\text{NDVI} = \frac{R_{NIR} - R_{red}}{R_{NIR} + R_{red}} = \frac{0.6 - 0.2}{0.6 + 0.2} = 0.5
\]

\[
\text{NDVI} = \frac{R_{NIR} - R_{red}}{R_{NIR} + R_{red}} = \frac{0.5 - 0.3}{0.5 + 0.3} = 0.25
\]

**Figure 6**: Example calculation of NDVI for two irrigated grapevine canopies of well developed versus scarcely developed canopy, where R being surface reflectance of near infrared (R_NIR) and red (R_red) spectrum.

NDVI data can be collected from a variety of satellite platforms which are commercially available. Table 2 lists some of the more common platforms from which NDVI can be determined from reflectance data collected in the visible red and near infrared bands.
Table 2: List and details of some more common satellite platforms from which NDVI can be determined from reflectance data collected in the visible red and near infrared bands.

<table>
<thead>
<tr>
<th>Satellite platform</th>
<th>Band widths</th>
<th>Pixel resolution</th>
<th>Temporal resolution</th>
<th>Distributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 5/7 Enhanced Thematic Mapper</td>
<td>450-1250 (7 bands)</td>
<td>30 m</td>
<td>16 days</td>
<td>ACRES GEOIMAGE</td>
</tr>
<tr>
<td>Spot5</td>
<td>500-1750 (4 bands)</td>
<td>20 m</td>
<td>1-4 days</td>
<td>CNES</td>
</tr>
<tr>
<td>480-710 (4 bands)</td>
<td>5 m</td>
<td>1-4 days</td>
<td>CNES</td>
<td></td>
</tr>
<tr>
<td>IKONOS</td>
<td>445-853 (4 bands)</td>
<td>4 m</td>
<td>3 days</td>
<td>GeoEye</td>
</tr>
<tr>
<td>450-900 (4 bands)</td>
<td>1 m</td>
<td>3 days</td>
<td>GeoEye</td>
<td></td>
</tr>
<tr>
<td>Quickbird</td>
<td>450-900 (4 bands)</td>
<td>2.8 m</td>
<td>1-3.5 days</td>
<td>DigitalGlobe</td>
</tr>
<tr>
<td>Terra/ASTER</td>
<td>520-600 (3 bands)</td>
<td>15 m</td>
<td>On request</td>
<td>ACRES</td>
</tr>
<tr>
<td>MODIS</td>
<td>620-14385 (36 bands)</td>
<td>250 m</td>
<td>1 day</td>
<td>ACRES</td>
</tr>
<tr>
<td>Rapideye</td>
<td>440-510</td>
<td>5 m</td>
<td>1 day</td>
<td>Rapideye</td>
</tr>
<tr>
<td>520-590</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>630-730</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>760-850</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When selecting a satellite platform both spatial as well as temporal resolutions need to be taken into account for the desired application. The number of available satellite platforms is rapidly increasing along with spatial and temporal resolution for NDVI based reflectance data. The necessary processing of the data in order to convert the reflectance values from the satellite image to an NDVI value for individual pixels within an image can be either undertaken in-house or be commissioned out to a number of commercial providers. A list of some of the more common remote sensing software platforms which can be used to process the data is given in Table 3.

Table 3: Commonly used remote sensing software platforms which can be used to process satellite imaging data.

<table>
<thead>
<tr>
<th>Software platform</th>
<th>Distributor</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Mapper</td>
<td>Leica Geosystems</td>
<td><a href="http://www.ermapper.com/">http://www.ermapper.com/</a></td>
</tr>
<tr>
<td>ENVI</td>
<td>ITT</td>
<td><a href="http://rsinc.com/envi/whatsnew.asp">http://rsinc.com/envi/whatsnew.asp</a></td>
</tr>
<tr>
<td>ERDAS Imagine</td>
<td>Leica Geosystems</td>
<td><a href="http://gi.leica-geosystems.com/LGISub1x33x0.aspx">http://gi.leica-geosystems.com/LGISub1x33x0.aspx</a></td>
</tr>
<tr>
<td>Multispec</td>
<td>Purdue University</td>
<td><a href="http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/index.html">http://cobweb.ecn.purdue.edu/~biehl/MultiSpec/index.html</a></td>
</tr>
<tr>
<td>IDRISI</td>
<td>Clark Labs</td>
<td><a href="http://www.clarklabs.org/">http://www.clarklabs.org/</a></td>
</tr>
<tr>
<td>Beam - VISAT</td>
<td>European Space Agency</td>
<td><a href="http://www.brockmann-consult.de/beam/">http://www.brockmann-consult.de/beam/</a></td>
</tr>
</tbody>
</table>

Once the NDVI data has been derived for a particular crop and paddock it is then converted to a $K_c$ value and used to determine the crop water use by combining the $K_c$ with the $ET_o$ data as shown in Figure 7.
2.3.6. Crop water models and modules

The IrriSatSMS uses a daily water balance calculation considering rainfall and irrigations as the water inputs and crop evapotranspiration (ETc) as the loss. The water balance for a particular irrigation block, in millimetres, can then be calculated using the formula:

\[ WB = R + I - ET_c \]

Where
- **WB** = water balance (mm)
- **R** = rainfall depth (mm)
- **I** = irrigation volumes (mm/area)
- **ETc** = crop evapotranspiration (mm/area)

In this implementation approach, the IrriSatSMS water balance does not include water stored in the soil profile. This is a deliberate simplification as it avoids the difficulty of trying to build a complex system reliant on accurate soil moisture accounting, that in many circumstances adds little benefit as the other agronomic or cultural preferences are unknown. The system operating in this mode does therefore not tell irrigators when to irrigate, but provides an indication on how much water the crop has used since last irrigation. The decision when to irrigate is up to the grower based upon all the agronomic, economic and social/cultural considerations. When the decision to irrigate is made then the grower can refer to the latest SMS and apply the appropriate amount and provide the feedback to the system in order to update the water balance data stored on the server.

In order to reduce any risks of plants suffering from water stress, with this implementation the water balance calculation for each irrigator was started following a large start-up irrigation event after which
it was assumed that the soil profile was full, thus the water balance was zero. The water balance calculation was run on a daily time step with daily ET<sub>c</sub> being calculated from measured ET<sub:o</sub> and K<sub>c</sub> as described in Chapters 2.3.5 and 2.3.5.2.

To convert the resultant daily water balance value, in mm, to a drip run time (DRT) in minutes, the following equation is used:

\[
DRT = \frac{ET_c \times Es \times Rs}{Ap} \times 60
\]

Where
- \( Ap \) = drip system application rate (L/hr/emitter)
- \( Es \) = emitter spacing (m)
- \( Rs \) = row spacing (m)
- \( ET_c \) = crop water use (mm)
- \( DRT \) = drip run time (minutes)

The multiplication by 60 converts run times in hours to run times in minutes which is the standard unit used to program irrigation controllers. These irrigation system parameters were collected from the irrigators as described in Chapter 2.3.3. As ET<sub:o</sub> was calculated each night based on that day’s weather readings, the results from these calculations were sent to irrigators each morning giving them the water balance for their block for the irrigation season until the previous day.

2.3.6.1. Data delivery and collection

2.3.6.1.1. Irrigation run times and rainfall

As ET<sub:o</sub> is calculated early morning based on the previous day’s weather readings, the results from these calculations are sent to irrigators each morning giving them the water balance for their block for the period until midnight. Such a typical SMS message is shown in Figure 8.

![Example of a typical SMS message](image)

**Figure 8:** Example of a typical SMS message sent daily to irrigators containing the status of the water balance, cumulative crop water use, irrigation, rain and dripper run time information.
Irrigation and rainfall values required to calculate the daily water balance are supplied by the growers and are sent through SMS messages back to the IrriSatSMS server. An example of the text of an SMS sent by an irrigator describing an irrigation event (i) of 240 minutes duration for the paddock number 1 (pad1) would be:

\[ i \text{ pad1 } 240 \]

For a 13 mm rain (r) event on paddock ‘west’ the message sent by the irrigator would contain the following line:

\[ r \text{ west } 13 \]

This brief format is used to keep the effort required by the irrigator at a minimum. Irrigators are asked to send in the messages as soon as possible after an event has occurred. This means that the ‘date stamp’ (date) on the SMS message is taken as the day when either irrigation was applied or when a rainfall event occurred. This reduces the need for dates to be typed specifically into the text message or for growers to keep separate records. Another feedback mechanism which can be made available to the irrigator is a web page through which rainfall and irrigation events could be entered similarly to the SMS feedback.

2.3.6.1.2. Reviewing seasonal data

Since all water balance results and all input values are calculated daily by the IrriSatSMS models and stored centrally in a single database on the IrriSatSMS server, all the information can also be reviewed easily from any Internet connected computer. This allows registered irrigators to review the messages they have sent in and check their water balance by logging in to their account on the server. This data is especially useful for irrigators in order to track water use to date against budgeted allocation for a particular crop. An example of the graphical presentation of water balance data on the IrriSatSMS is given in Figure 9.

![Waterbalance for Shiraz Blk 3](Image)

**Figure 9:** Example of a water balance graph accessible through the web page interface by an irrigator for a particular crop and paddock.
2.3.7. Benchmarking and auditing water use

As the IrriSatSMS system is an automated database system it allows scope for benchmarking, record keeping and auditing of water use. Growers can compare their water use with that of other irrigators running similar crops in similar environments through the IrriSatSMS Internet web page. An example benchmarking table is given in Figure 10. Importantly, as data is evaluated, on-the-fly benchmarking can be undertaken at any time within season, rather than at the end as traditional retrospective benchmarking is done. This allows growers to compare and adjust their water use accordingly during the season.

An important benefit of the IrriSatSMS approach is that records are kept automatically of all irrigation and rainfall events. This data can be supplied back to the grower at the end of the season for their record keeping. This may become even more valuable to the irrigator in the future when more formal auditing procedures related to water use on farms may be required. The current system provides the necessary functionality allowing irrigators to access and download the required data with little extra effort.

The approach provided through IrriSatSMS also allows auditing of water use against metered use in order to estimate water use efficiency.

![Figure 10: Example of a web page interface showing benchmarking data for three growers.](image)

2.3.8. System verification - Ground truthing and calibration

During the setup phase and pilot phase there needs to be a concerted effort to ensure that the information delivered to growers is accurate. There also needs to be a large degree of communication in order to ensure that the service is providing adequately tailored data. Steps in this process are:

1. In this phase the service providers need to determine that assessments of crop factors using the satellite imagery are accurately following the cropping regimes. This requires some basic estimates of groundcover to be made several times during the season. This can be done independently or in collaboration with the growers. Groundcover estimation can be undertaken with a number of approaches and with varying accuracy and cost; visual estimation, measurement of estimated area of shade, and photosynthetically active radiation (PAR) measurement using a ceptometer (lightbar). The visual estimation and manual measurements are simple, therefore growers can be asked to undertake these.
2. Where growers have soil moisture probes then analysis of this data in comparison with the suggested irrigation regime can determine if there is systematic over or under watering.
3. Comparison with soil moisture probe readings.
4. Direct comparison of suggested pump run times with actual irrigator behaviour. This is done by the server automatically comparing the actual run times and rainfall which irrigators input with the calculated requirements.
5. Qualitative feedback on the suggested run times. Grower response regarding the suggested run times is important. This is when feedback regarding their particular environment, agronomic requirements and system operation can be discussed. This discussion and use of the feedback is designed to tailor the system better to grower needs and engender confidence in the system. It is not to entrench the status quo.

Once the production phase is established then points 1 and 2 above only need to be undertaken when a new set of circumstances is encountered, for example new crops being grown in the region, significant change of irrigation systems, etc. Items 4 and 5 above are ongoing requirements. Item 4 is automatic and provides a ‘trigger’ mechanism to discuss water management with growers who are significantly over or under applying water as calculated by the service. This is required to establish whether their management is a deliberate variation from that recommended, inadvertent due to lack of understanding, management skill or poor system design. If the management action is deliberate and justifiable then there may need to be an adjustment made to the service to reflect the new grower requirement, through an ongoing tailoring process. The continued gathering of qualitative feedback (item 5 above) is essential to ensure that growers are satisfied with the service, are using it properly and can provide feedback on the improvements required.

2.4. Information technology (IT) and infrastructural framework

The IT infrastructure required for this system can be realised in several different ways. Presented below in Figure 11 is the schema for the infrastructure used in the current pilot trial hosted at the CSIRO in the MIA. Each component of the IT infrastructure is then considered in detail in the following subsections. In addition to the current setup, alternative IT software infrastructure based on open source products is presented in Chapter 2.4.7.

2.4.1. Current IT infrastructure schema

The IT infrastructure process flow consists of both manual and automatic data handling processes. All processes have been listed in Figure 11 so that all elements of the water management system may be compared to alternate schema.
2.4.2. Networks - Phone and Internet

The most basic data that can be sent to a mobile phone on a 2.5G network is the Short Messaging Service (SMS) message. This is a simple text message which may be up to 160 characters long. All mobile phones currently in use in Australia can both send and receive SMS messages. The following Figure 12 contains a SMS sample message text to emphasise the brevity of such a message of 160 characters in length (spaces are included as part of the 160 characters):

| A message from the irriGATEWAY team on 01/08/08: Mary had a little lamb, its fleece was white as snow, and everywhere that Mary went, the lamb was sure to go!! |

Figure 12: SMS sample message text to emphasise the brevity of a message of 160 characters (including white spaces).

Basic formatting such as line breaks can be applied to the text message but no colours or bold text etc. These sorts of messages are well received by irrigators due to their simplicity. Figure 8 shows a real-world example of a water management data message on a mobile phone screen.

Automatically triggered text messages may be generated by server-based software that combine data and formatting and then send the message out to mobile phones via an Internet cellular network gateway services as shown in Figure 11 and described in further details in Chapter 2.4.3.

---

7 2G and 3G are official standards whereas 2.5G is often used to describe some advances implemented towards full 3G network (further details in Chapter 5).
High speed, third generation (3G) mobile phone networks that already cover most regional irrigation areas in Australia (such as Telstra’s NextG and Optus’ 3G services) have allowed for greater reliability of service as well as enhanced data and Internet services. 3G phones can not only send SMS but can also send extended multimedia messages through multimedia messaging services (MMS) that have the capacity of up to 300 KB of text, pictures, sound or videos. In contrast to the 160 character SMS, the length of a text message sent as a MMS message would cover approximately 1,900 SMS messages or approximately 300,000 instead of 160 characters of plain text (including spaces). The extended capability of a MMS allows for the delivery of not only significant more text but also graphs and for example paddock and block images to irrigators via mobile phones.

2.4.3.  Internet/Cellular network gateway service

Along with the provision of 2.5 and 3G networks by large telecom firms such as Optus, Telstra and Vodafone, there has been a growth in the number of smaller technology companies that provide cellular network and Internet gateway services. These services allow the sending of SMS and MMS messages from desktop computers, web pages, email clients and custom server software for a small fee.

2.4.3.1. Service technical implementation

Since the daily SMS sent to each of the irrigators is automatically generated via custom written server code, the method used is to deliver text to the gateway service that then becomes the SMS message is automated as Web Service8. This means that as message content is generated, a call to the gateway service provider’s IT system is made that delivers the content that is then passed to the cellular networks in the form of an SMS text message. Manual web delivery of SMS can also be used to communicate with the irrigators in addition to the automated Web Services delivery. This is done by accessing a web page provided by the gateway service provider which is similar in the functions found with web-mail providers such as MSN Hotmail, Yahoo!, etc., and then typing out a less-than 160 character message and sending it to a mobile phone number list.

The use of Web Services to send messages requires some custom software code to be placed on a server with an Internet connection. Web Services that call (contact) the IT systems of gateway service providers can be written in one of many modern high-level programming languages, such as Microsoft’s C#.NET and Visual Basic.NET or the open source Java or web scripting languages such as PHP, Perl or Python. The Web Services used by the current pilot scheme is written in C#.NET and PHP.

A full send and receive cycle covering SMS message content generation, followed by a Web Services call to the gateway service provider and then followed by the SMS message delivery, typically takes only about six seconds. In this form it is possible to send many thousands of messages to the gateway service provider via Web Services without experiencing any difficulty at either end.

2.4.3.2. Service costs

A basic indication of the costs involved for purchasing an account with such a gateway service provider and then sending SMS messages is given in Table 4. MMS messages cost considerably more but the prices are expected to drop with more firms offering such services.

Based on the cost structure given in Table 4 a total gateway service costs for one month sending out a daily SMS message to 50 irrigators while receiving rainfall and irrigations feedback could be estimated to be:

---

8 Web Services, in this case as defined by the W3C® World Wide Web Consortium, are programmatic routines that operate from one Internet server to another over the Internet. They use XML-based textual communication written to a standard by the World Wide Web Consortium (W3C) allowing for communication between machines with no knowledge of the underlying software or hardware architectures required (for further details see http://www.w3.org/TR/ws-arch/).
65 + 25 + (30 \times 50 \times 0.2) = $350 per month

This assumes that no additional SMS gateway services are used beyond the standard services.

### Table 4: Typical SMS gateway service costs.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description and additional details</th>
<th>Costs in $AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Account setup</td>
<td>One-off fee</td>
<td>180</td>
</tr>
<tr>
<td>Monthly Account fee</td>
<td>Bundled with a certain number of 'free' SMS (in this case 200)</td>
<td>65</td>
</tr>
<tr>
<td>Per SMS fee</td>
<td>Charged for monthly usage beyond bundled limit</td>
<td>0.20</td>
</tr>
<tr>
<td>Monthly virtual mobile number</td>
<td>Allows inbound SMS</td>
<td>25</td>
</tr>
<tr>
<td>Inbound SMS</td>
<td>No charge</td>
<td>0</td>
</tr>
</tbody>
</table>

### 2.4.4. Server platform

The central piece of IT infrastructure for the IrriSatSMS approach is an Internet server. For the current trial this is known as the "irriGATEWAY" server. This machine provides the capacity for the bulk of the computing processes required by the current IrriSatSMS pilot trial. It is crucial to have a central IT platform that is dedicated to the IrriSatSMS task only. A stand-alone server is neither costly nor hard to implement therefore it is the recommended central IT platform for this tool.

For companies or organisations that do not have managed servers of their own that they could dedicated to this task, the purchase or renting of managed dedicated server hosting would be an option. Some examples of companies and costs for servers capable of performing the required tasks are provided in Table 5. These are a few examples of the many package options that are available. All of the packages mentioned can be configured to replicate the irriGATEWAY server as described in the following sections.

### Table 5: Some examples of dedicated server hosting provided by companies and approximated costs for servers capable of performing the required tasks needed for the IrriSatSMS.

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
<th>Costs/month</th>
<th>Add information</th>
</tr>
</thead>
</table>

(*) This list is by no means intended to be representative or complete or does endorse any of the companies or their services but shall only provide an indicative overview of what would be needed and approximate server costs to be expected to run IrriSatSMS-type services.

### 2.4.4.1. Server software

The main software platform used throughout the trial phase was the Microsoft .NET platform installed on the irriGATEWAY server. This platform automatically collected data from the automatic weather stations, manipulated database data, calculated data, processed incoming SMS messages, used Web Services to sent outgoing SMS messages through a cellular network gateway service provider and generated the web pages viewed by irrigators for water management information in addition to the daily SMS messages. This platform is a series of standard code libraries that can be accessed by
custom code. It requires a computer running one of the many server versions of the Windows operating systems or specially configured Linux\(^9\) operating systems to run. For the 2008/2009 season, the irriGATEWAY server ran the Microsoft Windows Server 2003 R2 operating system.

The Microsoft .NET platform was selected for use due to the need to maintain compatibility of programming platforms within CSIRO Land & Water (Figure 13). Any generic programming platform, such as the Open source (free) Python or Java platforms could be used just as effectively. Often free open source platforms would be a better choice than .NET if software cost minimisation were a goal (Chapter 2.4.7). A full schema of the current irriGATEWAY server programs using the .NET programming environment and the Windows Server 2003 operating system is given in Figure 13.

![Figure 13: Schema of the 2008/2009 server platform architecture using Microsoft Windows Server 2003 with the .NET environment.](image)

In addition to the general .NET programming environment and the Windows Server 2003 R2 operating system, several other programs are interfacing with the programming software and the operating system. The main installed server packages are summarised in Table 6.

<table>
<thead>
<tr>
<th>Name of software</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MySQL</td>
<td>Database program</td>
</tr>
<tr>
<td>MySQL ODBC Connector for .NET</td>
<td>Connector plug-in to connect database with .NET</td>
</tr>
<tr>
<td>SQLYog</td>
<td>Graphical database management and viewing program</td>
</tr>
<tr>
<td>Microsoft Internet Information Server</td>
<td>Microsoft Internet web server (IIS)</td>
</tr>
<tr>
<td>ZedGraph</td>
<td>Graphical .NET plug-in to draw charts</td>
</tr>
<tr>
<td>Microsoft .NET</td>
<td>.NET programming framework and environment</td>
</tr>
<tr>
<td>Microsoft Windows Server 2003 R2</td>
<td>Microsoft server operating system</td>
</tr>
</tbody>
</table>

\(^9\) See the Mono project for details of how to run .NET client and server programs on Linux: http://www.mono-project.com/

Linux is a free Unix-type operating system originally created by Linus Torvalds with the assistance of developers around the world. Linux is a registered trademark of Linus Torvalds. There are many free Linux distributions such as Ubuntu Linux.
MySQL\textsuperscript{10} is a free, open source, enterprise database program and is the most used database program for dynamic and data driven web sites. It features a high-level functionality including stored procedures and database functions that can be used to effectively manipulate data.

The \textit{MySQL ODBC connector for .NET}\textsuperscript{11}, is developed by MySQL and is a very small, free plug-in for .NET that allows .NET to communicate with MySQL.

The SQLYog\textsuperscript{12} database viewing program is a graphical MySQL management tool that comes in both free and non-free versions. The free version was used for the 2008/2009 season and should be sufficient for all types of database management required by IrriSatSMS like systems.

The \textit{Microsoft Internet Information Server} (Microsoft IIS) is an Internet web server that is an optional add-on part of the Windows Server 2003 operating system.

ZedGraph\textsuperscript{13} is a free graphing plug-in code library for the .NET platform that allows line and bar charts to be generated dynamically from any source accessible via .NET and saved as images for displaying on a web page.

The generic libraries of the .NET program allowed timed scripts (running using the Windows Server 2003 R2's Task Scheduler program) to automatically download AWS data from the Internet. The interpretation of the AWS data, which was presented in formatted text files, was also carried out in .NET code. This data was then stored in the MySQL database which was connected via the MySQL ODBC connector for the .NET program. Any data that was manually entered in the MySQL database program, and general database management, was carried out using the SQLYog MySQL database interface program.

The generation, sending, receiving and manipulation of SMS messages was accomplished using the .NET platform through Web Services over the Internet to communicate with the cellular network gateway service. Web Services are managed natively in .NET and do not require additional software.

Web pages containing water management information were hosted on the irriGATEWAY server using Microsoft's IIS web server. The data content of the pages was generated dynamically from data stored in the database and manipulated through MySQL database routines and .NET custom code. This information content data was then written to web pages as HTML tables and graphs which were generated by the free .NET plug-in called ZedGraph. An example is given in Figure 9.

2.4.4.2. Server hardware

The hardware requirements for effectively implementing the services required by the IrriSatSMS approach through the software listed above are very basic. All of the tasks that the irriGATEWAY server undertakes can be completed by a basic desktop computer. The processing time for data downloads, irrigation run time calculations and message sending is so small that a basic desktop computer equivalent could provide support to 5,000 irrigators and still only remain actively engaged in operations for a few minutes. Data storage (hard drive space) is also small and was a couple of gigabytes, aside from the operating system, for the entire tool databases, website and other information needs.

The critical measure of the server’s performance is availability: i.e. the percentage of ‘up-time’ that the server has. This ensures that the server is on and capable of performing its tasks, such as downloading weather station data and sending SMS messages, when it needs to. Commercial dedicated hosting companies offer servers with up-times in the order of 99.999%. Any machine specified to have an up time of about 99.9% can be expected to be out of service for at most a few hours over an irrigation season. A down time of a few hours, would probably not affect the usefulness

\textsuperscript{10} For MySQL database software products see http://www.mysql.com/
\textsuperscript{11} MySQL ODBC connector may be downloaded from http://dev.mysql.com/doc/refman/5.0/es/myodbc-connector.html
\textsuperscript{12} SQLYog database viewing and management program is available from http://www.webyog.com/en/
\textsuperscript{13} ZedGraph plug-in information and links to download pages from http://www.zedgraph.org/
of water management data delivered. It may just delay the sending of daily SMS messages by a few hours.

Another critical factor is data and system safety as a measure against hardware failure (or theft) which will require an adequate backup system and procedures to be put in place. In addition a RAID system could be used allowing for automatic mirroring of the hard disk reducing the risk of data loss through hard disk failures. Any backups are crucial not only to guarantee the continuation of service but also to provide the data basis for long term monitoring and auditing. As complex systems such as IrriSatSMS naturally contain a lot of specific software and configurations programmed to communicate with each other with including a significant amount of customised code, it is of utmost importance that not only the data is being backed up, but that the entire system could be easily and swiftly restored from a backup media.

The conclusion here is that basically any commercial dedicated or virtual dedicated server would probably cater for the needs of an IrriSatSMS-style tool with the single caveat that adequate access to the machine must be given to the tool developers to enable them to configure the software described in the previous section.

2.4.5. Software and interoperability (open source)

One of the great challenges when implementing a tool like the IrriSatSMS will be the construction of the IT infrastructure for the tool that fits within existing IT infrastructure of the company or organisation. It is recommended that open source software should be used wherever possible to facilitate the flexibility and continued maintenance of systems. This is not always guaranteed when proprietary formats and software are used.

The use of open source software will also reduce costs by avoiding costly software licensing fees which often are required not only during purchase but also with every update or even are payable on a recurring basis. For these reasons, the section ‘Alternate IT infrastructure schema’ (Chapter 2.4.7) gives an example of a fully Open Source version of the existing IrriSatSMS tool software architecture.

In addition to the potential use of open source programs in future implementations of IrriSatSMS, standards compliance should also be adhered to. This will ensure the easy redevelopment of future systems if the need for expansion or reconfiguration due to changed datasets of perhaps cellular network gateway service providers occurs.

2.4.6. Data formats and exchange

Tools such as the IrriSatSMS require the interaction of many IT systems that are physically, conceptually and by the nature of ownership, separate from one another. It may therefore not be possible for the developers of an IrriSatSMS like system to alter the presentation of the data sources required for its operation. This can potentially result in significant manual work needed to, for example, download weather station data from a network and correctly insert it into the server platform’s database. Recommended here is the use of simple, non proprietary, data exchange formats and methodologies to allow sections of the tool to be modularised. Areas where this occurs are between the data sources (weather stations, cellular network service providers, satellite data) and the central processing platform (the server).

The term RAID stands for "Redundant Array of Inexpensive Disks" or sometimes also described as "Redundant Array of Independent Disks". A RAID systems increasing performance but also reliability of data on hard disk drives allowing data to be restored even if one of the disks in the array fails.

Additional information about Open Source software is found under:
http://www.opensource.org/ and
The data exchange between the AWS network and the server platform is done through standard text files which are located on the Internet. The data provided in these files are presented in a human-readable form and could therefore also be manually read and entered into the server if needed. However, the form vastly used by the majority of the IrrisatSMS weather station information retrieval operations is automatic text file parsing. Text file parsing is a process by which data presented in a text file is being analysed and processed in order to extract the data components and then transferred to the next program or process. Modules (software) which allow the integration of text file parsing into the processes are available in all programming languages and platforms.

Data exchange between the database and the .NET platform was facilitated through the MySQL ODBC .NET connector and standard .NET routines. In order to minimise future time consuming redevelopments and programming exercises when software platform changes would be necessary, as many data processing and calculations functions as possible were integrated within the database itself. In that way, simple mathematical functions such as 

\[ ETC = ETo \times Kc \]

were carried out within the database itself rather than through external programs and scripts. This means that where a software platform change would be required (say a move from the Windows-based .NET to the Unix-based Python) redevelopment time would be minimised drastically. MySQL databases are themselves programmed using Standardised Query Language (SQL) which can easily be transferred from one database to another.

Basic data, such as \( Kc \), \( ETo \) data and irrigation and rainfall data as well as irrigator information stored in the MySQL database were all stored in simple database tables using standard MySQL data types that can also be easily be transferred from one database to another.

Water management data web pages were encoded in World Wide Web Consortium (W3C) standards compliant web HTML mark up, XHMTL 1.0, as automatically generated by the .NET v2.0 platform. The use of standards compliant XHTML allows web pages to be rendered on all web browsers effectively. Pages can be checked for compliance using the fee Internet Markup Validation Service from the World Wide Web Consortium at http://validator.w3.org/.

Communication between the .NET platform and the cellular network gateway service was carried out using the Web Services standard as previously described (Chapter 2.4.3). Outgoing messages were generated as text strings of less than 160 characters length. Incoming messages were parsed using the .NET’s built in string parsing functions and stored in the MySQL database. In this form it would guarantee that after a redevelopment of the IrrisatSMS system the same cellular network gateway service Web Service functions could still be accessed from any one of a number of programming languages.

2.4.7. Alternate IT infrastructure schema and open source

An alternate IT infrastructure schema is provided here aiding the adaptation of the IrrisatSMS to different environments. The schema presented here is based on a single server model which should be appropriate for many cases. However, depending on specific demands alternative approaches with distributed computing through load and function sharing by various servers could also be implemented. Water supply companies and government departments who own much IT capability will have their own IT procedures that will guide their developments in using and combining multiple machines, such as database servers, web server, etc. to one cluster. However, while physically distributed over various servers the system could still be viewed and present itself as a single system.

An alternate schema for a server platform and programs using only free and open source software is given in Figure 14. This suggested open source alternative schema could function in the same way as the irriGATEWAY server platform and programs used in the pilot testing in the MIA in the 2008/2009 season as previously described in Chapter 2.4.4.1.

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16 The World Wide Web Consortium (W3C) develops interoperable technologies such as specifications, guidelines, software, and tools Further information is found under: http://www.w3.org/

17 Further information is found under http://msdn.microsoft.com/en-us/library/exc57y7e.aspx
One of the fundamental principles of open source is that software is available not only in its compiled and unchangeable binary format but also as source code allowing for code changes and additions to be performed if required. In addition all software is freely accessible through the Internet and can be used as long as one of the Open Source Initiative (OSI) licenses, such as the GPL, is being respected. All of the software and plug-ins shown in Figure 14 and Table 7 in can be downloaded and used for free.

Figure 14: Schema of a fully open source version of the 2008/2009 server platform architecture based on a Linux server operating system.

A list of the main free open source software suggested as an alternative setup for the IrriSatSMS and their download sites are given in Table 7.

Table 7: List of free open source software as an alternative setup for the IrriSatSMS approach.

<table>
<thead>
<tr>
<th>Open source software</th>
<th>Information site/download link</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHP GD graphics module</td>
<td><a href="http://www.libgd.org/Main_Page">http://www.libgd.org/Main_Page</a></td>
</tr>
<tr>
<td>Apache web server</td>
<td><a href="http://www.apache.org">http://www.apache.org</a></td>
</tr>
<tr>
<td>PHP scripting engine</td>
<td><a href="http://www.php.net">http://www.php.net</a></td>
</tr>
<tr>
<td>NuSOAP PHP Web Services module</td>
<td><a href="http://www.sourceforge.net/projects/nusoap">http://www.sourceforge.net/projects/nusoap</a></td>
</tr>
<tr>
<td>MySQL database</td>
<td><a href="http://www.mysql.com">http://www.mysql.com</a></td>
</tr>
<tr>
<td>mysqlgui database interface</td>
<td><a href="http://dev.mysql.com/downloads/">http://dev.mysql.com/downloads/</a></td>
</tr>
<tr>
<td>Ubuntu Server 8.04 Linux</td>
<td><a href="http://www.ubuntu.com/getubuntu/download">http://www.ubuntu.com/getubuntu/download</a></td>
</tr>
</tbody>
</table>

The Open Source Initiative (OSI) is a non-profit corporation formed to educate about and advocate for the benefits of open source and as a standards body also maintains the Open Source Definition for the good of the community. More information is given under Chapter 5.

The GNU General Public License (GPL) is one of the widely used open source licences under which many open source software products are distributed (see also Chapter 5). http://www.opensource.org/licenses/gpl-license.php
2.5. Personnel and costing framework

2.5.1. Personnel and expertise needed

The hardware systems used in the IrriSatSMS pilot phase could be acquired ‘off the shelf’ and could be assembled in a matter of days by any IT professional familiar with servers. However, the software systems used were more complicated and significantly more time and knowledge was needed. If in contrast to the Microsoft based software and server platform the alternative open source schema could be implemented, the majority of the software could be installed at zero license cost.

2.5.2. IT system development personnel

In addition to the hardware setup, it is estimated that an experienced IT professional familiar with servers as well as the software product lines would need realistically to factor in approximately another three days to setup the basic system which would include the operating system, standard software modules and updates on the server as well as implement the various security measures. What is required in addition, and which is the most time consuming part, is the customised programming in order to build the IrriSatSMS specific functionality. This would include the programming and setting up of the database for the user management, the waterbalance and model coding, Web Services functions implementation and finally the SMS message generation functionality. The total time needed will vary significantly depending on what environment is found and what obstacles are encountered in customising the system to the specific environment.

An overview of setup costs with time estimates for each of the tasks involved with setting up the server IT system as presented in Figure 14 is given in Table 8. These tasks (and under some circumstances minus hardware acquisition and part of the software installation) are still of relevance to system implementations where IrriSatSMS-type systems would be integrated into existing and company or organisational owned IT infrastructures. It has also to be noted that while the cost estimates (Table 8) feature an open source setup it would similarly apply to for example Windows server based platform and schema as described in Chapter 2.4.4.1. Regardless which of the two schema is used, an IT professional with software engineering or IT server systems background and significant programming experience within the specific software environments would be needed to develop and implement the IrriSatSMS-type system.

2.5.3. IT system maintenance personnel

In contrast to off-the-shelf standard systems and applications, maintenance costs for highly customised software systems, such as the IrriSatSMS, are hard to estimate. While the actual hours of maintenance could be few it is more likely to be more than what would be needed with standard widely used server setups and services. A well set up system, with good failure alert systems, will require very little maintenance for ordinary operations. Some likely maintenance tasks that could be encountered are summarised in Table 9.

In addition very good system knowledge must be held by the system administrator as the majority of code and processes would be customised and custom written with little documentation to build on. It is therefore important that documentation is built up during development and personnel transitions are well planned with enough overlap for introduction and transfer.
Table 8: Estimated server setup and IrriSatSMS customisation tasks and associated times needed by an IT professional to setup an IrriSatSMS-type system.

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Time details (1)</th>
<th>Time in days (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware acquisition</td>
<td>As noted earlier, there are many companies that offer managed servers if an organisation wishing to set up a server do not own their own server management capabilities.</td>
<td>A few hours of administration (once specifications have been decided)</td>
<td>1.0</td>
</tr>
<tr>
<td>Software installation</td>
<td>Operating systems and web server programs, such as Apache, database software, such as MySQL, scripting programs such as PHP come pre installed with most managed servers. Updates and installation of security bug fixes. NuSOAP or other Web Service packages may be pre installed but if not are simple to install.</td>
<td>A few hours of installation time for Web Services. Less than an hour’s installation time for graphics module if not pre installed.</td>
<td>1.5 0.5 0.5</td>
</tr>
<tr>
<td>Programming AWS data collection</td>
<td>The complexity of this task is entirely dependent on the AWS data access. If FTP or web-based, this is simple.</td>
<td>A few hours for FTP or web-based AWS data access.</td>
<td>1.0</td>
</tr>
<tr>
<td>Programming cellular network gateway interface interactions</td>
<td>Web Service programming</td>
<td>A few hours</td>
<td>1.0</td>
</tr>
<tr>
<td>Programming incoming SMS message handler</td>
<td>Desktop programming and includes incoming message error checking</td>
<td>A day</td>
<td>1.5</td>
</tr>
<tr>
<td>Programming water balance model</td>
<td>Simple model involving database persistence and limited mathematics</td>
<td>A couple of days</td>
<td>3.0</td>
</tr>
<tr>
<td>Programming benchmarking functionality</td>
<td>This task will depend on the particulars of the irrigators involved and the level of specificity of the benchmarking (general water use, varietal water use etc)</td>
<td>A couple of days</td>
<td>4.0</td>
</tr>
<tr>
<td>Programming Database user management</td>
<td>(incorporated with web development below)</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Web development (basic)</td>
<td>Basic web user logins, data display, graphing</td>
<td>Several days</td>
<td>7.0</td>
</tr>
<tr>
<td>Web development (pretty)</td>
<td>The look and feel of the web pages will depend on the organisation’s web policy and may vary significantly. The sky is the limit</td>
<td></td>
<td>5.0</td>
</tr>
<tr>
<td>Server scheduled tasks including daily SMS generation</td>
<td>This set of tasks involves several areas of knowledge from basic server administration to Web Service knowledge and database programming</td>
<td>A couple of days</td>
<td>4.0</td>
</tr>
<tr>
<td>Process to bring in satellite data</td>
<td>Once satellite data has been distilled to a format that can be used by an SSIS-like system, it needs to be able to be entered in an efficient manner. This will require some form of database entry. (note: this estimate does not include manual satellite image processing time)</td>
<td>A day</td>
<td>3.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>~ 17 days</td>
<td>~ 34 days</td>
</tr>
</tbody>
</table>

Note: 
(1) Time details and estimates for ideal conditions theoretically needed to setup, install, configure or program a system. 
(2) Real-world estimates which in addition to (1) include planning, problem solving, necessary testing and corrections. Time needed to setup IT system is often grossly underestimated leading to false expectations and unsatisfactory solutions with expected pitfalls at a later stage.

Table 9: Estimated server maintenance tasks for an IrriSatSMS-type system.

<table>
<thead>
<tr>
<th>Task</th>
<th>Time details (1)</th>
<th>Time in h/m (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Server update maintenance</td>
<td>Very few hours over a year</td>
<td>1.0</td>
</tr>
<tr>
<td>Server recovery from unscheduled power outages</td>
<td>Minimal if a managed server is used or an uninterruptible power source (UPS) is implemented.</td>
<td>0.1</td>
</tr>
<tr>
<td>SMS Message checking</td>
<td>An hour per week checking incoming messages that do not conform to preset formats. This is essentially a user interaction task.</td>
<td>4.0</td>
</tr>
<tr>
<td>Satellite data entry</td>
<td>An hour per fortnight</td>
<td>2.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>~ 7 h/m</td>
</tr>
</tbody>
</table>
3. Scenarios and policy considerations

3.1. Overview

The proposed IrriSatSMS approach is based on strong network capabilities and a modular design which provides a great deal of flexibility and a range of advantages especially when it comes to implementation. Four theoretical case studies have been drawn up which are meant to provide an overview on the various managerial and technical implementation options which may be envisaged now and for the future. These case studies only provide some simplified snapshots of a few possible implementation examples covering a spectrum from government run to purely private sector implementations as well as hybrid or a mixed system in between. A general schematic layout of the technical as well as logical or management modules is shown in Figure 15.

![Figure 15: Schematic overview of main functional, logical and management components of the IrriSatSMS.](image)

Technically the IrriSatSMS is a server based system accessing spatial data from various sources (for example local weather stations, SILO, etc.) in order to model and generate localised and site specific information which then is sent out to the subscribers via the mobile phone gateway (SMS/MMS) or becomes accessible on-line through the WEB/WAP server interface. The system is based on data provided on-line and through the Internet and hence can serve centrally any location within Australia.
Ownership, funding, maintenance, communication and management issues may play an important role when considering the various implementation scenarios and may override technical imperatives.

The system consists of numerous technical as well as logical or management modules which are all linked through network capabilities. While this provides a great deal of flexibility allowing to for example geographically separate components by placing them within the environment best suited for a particular purpose (for example institution, server farm, etc.), this strong 'scattering' may on the other hand also create larger challenges when it comes to the increased management and communication demand. Which combination and setup to be selected is finally determined by the objectives of the project and facilities and infrastructure available. A further description of various possible institutional and managerial options are described in the case studies I to IV in the Chapters 3.2 to 3.5.

3.2. Case study I - By government institution (GI)

3.2.1. Outline
Despite tendencies to increasingly privatise larger sectors of formally government (state or federal) services in the water and irrigation sectors, it might be worthwhile revisiting such a scenario where one or various government institutions (GI) play a predominant role in providing what can be very broad coverage of water management services. This could be especially the case when the following objectives are to be met:

(A 1) Broad regional coverage.
(A 2) Coverage including remote areas with few users.
(A 3) Inclusive and not exclusive as not limiting to specific user groups, member of associations, companies etc.
(A 4) Coverage of a wider range of crops.
(A 5) Provision of nationwide standardised and compatible modules.
(A 6) Government vested interest in promoting increased efficiency of irrigation water use.
(A 7) Securing best technical linkages between complex services already provided by government agencies.
(A 8) Best and most economic use of the broad existing network, hard and software infrastructure.
(A 9) Incorporation of other already existing (for example SILO) as well as related services (for example extension).
(A 10) Providing sustainable long-term services.

Disadvantages could however be:

(D 1) A large system with less short-term flexibility.
(D 2) Bureaucratic overheads.
(D 3) Centrally versus de-centrally management structure.
(D 4) State and federal agency co-operations.
(D 5) Limited user/stakeholder base involvement.

3.2.2. Advantages
One of the clear advantages of the proposed IrriSatSMS is that while the infrastructure may initially be fairly complex to setup for one region it can be easily expanded in geographic coverage (A 1) with only marginal additional cost. The IrriSatSMS however, could directly serve even remote areas with limited additional costs providing equal opportunities for regional "advantaged" and "disadvantaged" user communities (A 2). Based on a government mandate this would guarantee a wide coverage right from the start and would send a strong signal towards serious changes towards high water use efficiencies (A 6) to be introduced and a will to introduce a system not hampered by technical incompatibilities and government boundaries (A 5) (A 7). Part of the necessary functionality is already available or is even being provided by government agencies such as crucial climate and evaporation data (A 9) as
supplied by the BoM and if the system would be operated within government agencies, better linkages are to be expected (A 5). The system could be easily integrated into other related and existing government run services for example as provided by the various Department of Primary Industries (DPI’s) or equally picked by individuals, water user association (WUA), companies, advisory services, etc. (A 3), without excluding groups based on the mandate. Figure 16 provides a schematic overview on such an approach to establishing IrriSatSMS indicating government responsibilities for the various functional, logical and management components highlighted as greyed sections.

Figure 16: The government run IrriSatSMS - Schematic overview of main functional, logical and management components of the predominantly government run IrriSatSMS.

Technically the tool consists of various soft and hardware components linked together through a network and the Internet structure allowing most processes to be easily automated as schematically shown in Figure 1, Figure 11 and Figure 13. The core of the system is a server as a central processing and distribution unit which gathers and receives the data and information needed, then performs the necessary processing and modelling and finally passes the information on to a SMS, WAP and WEB gateway. In respect to a government based tool, many of these components would already exist and could jointly be used for this purpose, slowly extending capacity based on demand. In addition, more specific hardware and software could be easily hosted and in-house expertise in IT, hydrology and agronomy (A 4) could be used and extended rather than newly established (A 7)(A 8)(A 9). In this...
respect a government based tool would have significant advantages and would provide some stronger commitment for long-term availability of such a service (A 10).

3.2.3. Disadvantages
Larger and 'institutionalised' systems may on one hand provide stronger and more sustainable long-term orientation/objectives and outputs with great benefits to a larger group of users. However, there might be also some possible shortfalls when situations would develop which would need a quick response or a more flexible approach such as addressing specific needs of smaller or marginal user groups i.e. such as the introduction of a new trial crop or use of non-standard equipment and automatic weather stations (D 1). Larger institutions tend to develop stronger bureaucratic overheads and procedures. Smaller units such as a tool placed within a larger system naturally inherits the administrative structure which provides some advantage and load sharing but which may also prove less appropriate for smaller units. for example decentralised management for centrally stored and maintained resources (for example server facilities) might prove to be a challenge (D 2)(D 3). If systems are being operated across state boundaries, different jurisdictions, system incompatibilities or different funding models may need to be addressed on a state to state or state to federal level (D 4) to assure smooth operations. Government based initiatives may tend to be larger and more complex in their approach with stronger challenges when it comes to larger user base involvement in defining system functionality, operation and management (D 5).

3.2.4. Summary
Predominantly, a government based irrigation tool appears to be the most appropriate when the final objective would be to provide the basis in order to build water management systems aimed at universal coverage and promoting water use efficiency in the public good.

3.3. Case study II - By water user/supply organisation/company (WUA/C)

3.3.1. Outline
Irrigation water management systems predominantly run by water user organisations/companies (WUA/C) may form an intermediate framework located somewhere between predominant government owned and purely commercially run approaches. The term WUA/C is being defined here as water user association or water delivery associations of larger user and stakeholder driven bodies which organise or commission overall water delivery, usage and disposal such as Coleambally Irrigation, Murrumbidgee Irrigation or Goulburn-Murray Water, etc. It also includes technical or sectoral associations/bodies which represent part of the industry such as Irrigation Australia, the Rice Growers Association, etc. These WUA/C have in common that they represent larger groups of stakeholders spread out through the industry or with larger regional coverage. The organisational structure would also provide some opportunities to extend services beyond association boundaries to interested users from related industries. Depending on specifics of the particular IrriSatSMS setup and cooperation agreement reached with other institutions it may be advisable that some of the more specific resources or modules would be outsourced and provided by other institutions allowing for best and most cost effective operations, as indicated in the schematic overview in Figure 17. ET₀ data may be obtained through SILO or directly through BoM rather than being derived locally. Processes for the establishment of site and crop specific crop coefficients may be undertaken in-house, or commissioned to government agencies or consulting firms. However, the main component (hard and software) and responsibilities for accessing, merging and processing of the data and the final delivery

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20 While many 'water user association' are strictly speaking 'water supply organisations' they are also largely user/stakeholder/shareholder driven through membership and shares covering costs for water and infrastructure. The term 'water user association' is being used here in a more general sense covering user as well as supply organisations but also industry associations such as the IAL. For further details on WUA and WUA/C see 'Glossary and definitions' in Chapter 5.

21 Many of these associations have a stronger commercial structure and are run as companies, hence the use of the acronym WUA/C is being preferred.
of the water management service should still reside entirely with the WUA/C. In relation to other components such as extension services or performance auditing, existing and traditionally established structures may be used and extended while some other components, such as ground-truthing, could be provided by farmers themselves after some training was completed.

Figure 17: The water user association/company (WUA/C) run IrriSatSMS - Schematic overview of main functional, logical and management components of a IrriSatSMS predominantly run by a water user association/company.

The advantages for implementation and use of IrriSatSMS systems within WUA/C frameworks could be summarised as follows:

(A 1) Good regional or industry coverage.
(A 2) Streamlined administrative framework.
(A 3) Little external interferences.
(A 4) Some extensibility beyond the association/industry boundaries.
(A 5) Stronger support through ownership by stakeholders/shareholders.
(A 6) Well targeted and stronger flexibility towards component/modules and services provided.
(A 7) Larger technical support base related to IT and irrigation water management.
(A 8) Moderate financial strains through shared cost structure across the WUA/C.
Efficient use of equipment such as automatic weather stations.

Strength in negotiations with government and other agencies for additional services to be provided due to a larger user base.

Disadvantages could however be:

Costs for implementation and management.

Replacement and update costs - danger of outdated systems (code sharing).

More isolated operation.

Isolated developments (pockets) resulting in possible incompatibility to other implementation. This is a public good concern, rather than a technical difficulty.

Operational conflicts and limitations of resource sharing beyond WUA/C boundaries.

### 3.3.2. Advantages

If an irrigation water management system is to be implemented, a good support base and infrastructure would be an advantage allowing a swift and extended implementation. WUA/C's provide well developed administrative structures as well as a large user base which may more easily be reached. Additional important linkages could be common interests such as related to the commodity produced, joint regional affiliation for example related to the irrigation district or even more technical related linkages such as related to the technology used (irrigation). Once endorsed by the governing body, implementation could be considered 'state of the art' and 'the way forward' by the user community supported by standardised equipment (for example AWS) and accompanied by training and support provided through the WUA/C. This could create a 'normative state' and would strongly boost the initial implementation and spread throughout a region or association members (A 1)(A 2). In contrast to more anonymous structures as may be provided through government agencies, WUA/C are stakeholder owned and driven, leading to stronger commitment through direct ownership of the new system (A 5). However, despite ownership related to a certain administrative or organisational unit (WUA/C), some usage may also be easily extended to and permitted for other groups, companies or individuals within that region who are not part of the association but could use components or even all of the services provided. This sharing and 'sub-contracting' may extend the usage and regional coverage of the system or components thereof, making best use of existing resources while no or little additional costs would occur (A 4) which however could be recuperated through usage fees if applicable.

In relation to the type and extent of services provided, WUA/C are less governed by outside forces or external ideas on what or how the systems should be implemented (A 3) allowing for a more targeted approach tailored to specific needs and preferences expressed by the stakeholder community (A 6). Some may prefer the use of centrally generated data such as provided by BoM, others may prefer a specific AWS brand which has a good reputation and locally supported retail network or give preferences to combined water management and agronomic services based on services provided in the past.

The implementation and the day to day running within the WUA/C, direct technical support in relation to IT, mobile phone usage (SMS, WEB or WAP), the handling of certain weather stations or the understanding of water management process and data might be provided by a WUA/C more effectively than through anonymous providers. As equipment and processes would be fairly similar, users could assist each other or support could be organised by the association which wouldn't be too far away. It is more likely that similar problems might have already come up at one of the neighbours and hence finding a solution may be simple (A 7).

Assuming stronger coverage in a certain region within a WUA/C costs would be reduced as more equipment, services and support may be shared. For example, there would only be one setup and server needed which could cover equally 50 or 5000 and more users with no or only minimal additional costs occurring. Depending on the regional setup the same AWS could serve a few or similarly many growers and ground-truthing works could be combined for several adjacent farms reducing costs similarly, etc. (A 8) (A 9).
In respect to external relations with state or Commonwealth agencies or other companies, strong WUA/C's may have better standing with regard to negotiating specific services, conditions or grants than privately run and smaller groups would have. The usage and incorporation of external sources (for example SILO, etc.), the exchange of data knowledge or updates of existing modules or additional research works may more easily be negotiated. Even part or the entire service may be subcontracted or outsourced to an external commercial provider as described as one of the options under Chapter 3.4 and 3.5 (A 10).

3.3.3. Disadvantages

Predominantly WUA/C run IrrisatSMS face constraints in comparison with government run systems. For smaller groups of stakeholders the ultimate installation and running costs may be higher per user. While the initial hard and software acquisition may seem moderately priced, the real pitfall may come with higher demand for expert and IT knowledge if a reliable and crucially uninterrupted service is to be provided. Furthermore, the need for regular updates and replacements are additional costs often overlooked which need to be covered and budgeted appropriately as developments in this field are fast with short replacement and write-off times being very common.

These types of systems are very powerful and with proper design can be widely applicable. However, they do not come as ‘off-the-shelf’ and ‘plug-and-play’ systems and significant knowledge is needed to keep systems up-to-date. Lack of knowledge may lead to fewer or no update cycles being performed easily leading to outdated and vulnerable systems, both in respect to security but also in relation to reliability of services provided. As most software components are or should be based on free and ‘open source’ code (also for cost, security, and flexibility reasons and for independence from software providers), some code-sharing agreement with base system providers or other similar system providers would be crucial for long-term operations. However, this always comes with additional inputs of human resources (D 2).

Related to more regional or organisational isolated implementations, sharing of code with the other base of users or other entities running similar systems may be sporadic and seemingly of no direct benefit. Developments may therefore be conducted on a local basis gradually adding user specific functionality or even adjusting system behaviour and core functionality to suit a specific need. If no code sharing basis and procedure is being used, systems may easily and quickly drift apart becoming increasingly incompatible to each other. Not only would that ultimately diminish the functionality supplied by excluding the benefits of using code and modules developed elsewhere but would also create major constraints (and costs) when systems are to be expanded and for example previously independently operated systems are to be merged (D 3)(D 4). Assuming a constantly growing popularity of an IrrisatSMS system this is very likely to happen.

WUA/C based water management systems have a clear mandate towards their user base. They are purely stakeholder owned and driven. However such IrrisatSMS may cover a geographical region with WUA/C members forming only a sub-set of potential users, who could theoretically also benefit from the system. For example, if a winegrowers association implemented the IrrisatSMS approach, this could well be used by the entire irrigation sector. While a government run system would be more widely and openly available to the entire community more specific systems may form a bottleneck when a wider approach in adopting comprehensive water saving policies are pursued. A more open approach where the WUA/C's would provide stakeholder related services as well as acting as a service provider for other users and industry could be one good way of resolving this conflict (D 5) while providing wider regional coverage.

3.3.4. Summary

Predominantly, WUA/C run irrigation water management tools are attractive for the provision of comprehensive and effective water management services to well defined larger user groups, regions or industries. They are well embedded in existing structures, provide a good degree of flexibility within a moderate costing framework and could guarantee some sustainable outputs over time. Some
potential exists in extending services beyond the direct mandate by acting as a service provider to other communities and industries. Avoiding isolation in adaptation/improvement and potential development of incompatibilities with other similar IrrisatSMS could be significant drawbacks in developing more flexibility and functionality for the future. A well established code sharing basis and procedure would be highly advisable.

3.4. Case study III - By the private sector (PS)

3.4.1. Outline

Private sector (PS) involvement in implementation of IrrisatSMS approach may provide significant solutions for various specific demands. The degree of involvement may vary from case to case ranging from fully commercially run systems providing a complete range of (close to) all-encompassing services, as predominantly highlighted in this Chapter. For the predominantly PS run IrrisatSMS, a wide range of approaches may be envisaged probably best classified by the extent of services provided also in relation to number of users and extent of regional coverage.

A small system may be very effective in providing very targeted and flexible services to a small group of users within a smaller region. Such service could be provided by a company which would like to extend its extension and agronomic services by adding irrigation water management services to their program. However, problems with economies of scale, for such a small user number, could be significant and make small scale implementation unjustifiable.

System and services which would be economically more viable and technically effective would need to be able to cover the significant cost in relation to equipment, development, ground-truthing etc through a stronger user base by tapping into a larger region or larger number of users spread over different regions. From the setup and extent of such systems this could be very comparable or similar to the WUA/C run systems described in Chapter 3.3.

Such a PS run IrrisatSMS is schematically outlined in Figure 18. It would be expected that government involvement in provision of some significant components would be less likely than it could be expected for WUA/C run systems. However, some services might still be convenient to tap into such as ET0 data provided by BoM saving significant costs in setting up AWS for example for single users or smaller groups of users in remote areas.

Another variant which has strong PS involvement is the provision of specific and specialised building blocks which providers such a WUA/C could use to complement their system for missing services or components. Examples of such building blocks could be the provision of satellite based NDVI indices, the offering of ground-truthing services or supply of customised and networked AWS which could be integrated into existing systems.

Predominantly PS run IrrisatSMS would have advantages which could be summarised as follows:

- (A 1) Standard off-the-shelf systems (production line) are made available to retailers/distributors.
- (A 2) Higher degree of flexibility, functionality and cost related graded system.
- (A 3) Bundled systems and services.
- (A 4) Market and competitive forces (price reduction).
- (A 5) Limited or no bureaucratic hurdles (in relation to end users).
- (A 6) Swift implementation.

Disadvantages could however be:

- (D 1) Higher price and little incentive to cover remote and small user communities.
- (D 2) Lower adaptation rates.
- (D 3) Proprietary solutions binding to provider and no source code access - black box.
- (D 4) Incompatibility to other systems.
3.4.2. Advantages

One of the advantages of the strong involvement of the PS in providing irrigation water management systems - either as a direct service, a product/tool for implementation or a combination of both - is that the standard off-the-shelf systems may be available allowing organisations trying to provide the service, to easily choose the type of services needed from a set of options (A 1). A major distributor of these services and equipment may provide a selection of specific functionality with a staggered cost structure related to the number of options and functions, quality of services and type of equipment needed (A 2). The services provided through one outlet could be manifold ranging from the provision of fairly specific services, over a combination of services and equipment to possible bundling with
other related services such as agronomic and irrigation advice or even the trading of the product grown. A larger winery could be an example, purchasing a preset IrriSatSMS while using that system to provide water management data to the winegrowers assuring that best results and quality is being achieved for the grapes delivered to the winery (A 3).

Competition may play another positive role in this setup assuring some bidding amongst providers would take place. In contrast the government or WUA/C run systems would leave less flexibility for individual demands or preferences (A 4).

When dealing with PS companies bureaucratic hurdles may be limited as the objectives are related to providing the best services to the paying client and what financially could be justified (A 5). WUA/C in contrast may have a longer lead time which is needed to find common ground in respect to what equipment and services are to be acquired or provided in-house and whether such a service would be needed at all. In this respect PS implementations may be swifter when it comes to implementation (A 6).

### 3.4.3. Disadvantages

The PS already provides a range of different water management services to the irrigation community throughout Australia. Many of these services are related to companies providing certain products such moisture probes or weather stations. However, IrriSatSMS requires a different skill base and inputs before good and reliable services can be provided. These higher initial costs rely on a larger user base to cover the expenses. While less of an issue in regions with a higher density of potential users, little incentive is provided for the companies to cover remote and small user communities (D 1). In respect to a broader and more encompassing adaptation of water saving and irrigation water management practices, PS implementations may serve some regions well but would cover other (remote) regions sporadically. In addition, it is expected that the adoption rate might be lower as there may be reliance on the marketing aptitude of a company with little community and policy driven support as would more likely be found in WUA/C or government based setups (D 2).

Conceptually the PS has little or no desire to openly share knowledge with competing parties or the general public, thus interoperability or open source transparency for best user services provision (D 3) may be limited. This may reduce the value of such systems, especially when it comes to combination of systems for better regional coverage and more efficient use of resources or the streamlining of different products to create new and more powerful services. While some standards exist allowing easier data exchanges between different products not all products, are expected to provide appropriate interfaces or follow generally accepted standards creating larger challenges (D 4).

In comparison to more government run programs, PS projects operate in a tighter and more competitive economic framework. Companies may discontinue support for certain regions/crops, increasing the risk for the end user (D 6). Similarly, strong PS involvement may result in lower or only moderate regional coverage (D 7). The stronger profit objectives versus general public interest may therefore be an issue to be considered when the type and degree of PS involvement is being set out in policies towards the development of an IrriSatSMS system (D 8).

### 3.4.4. Summary

The PS may play a crucial role when it comes to providing irrigation water management services such as IrriSatSMS to the irrigation or water use community. Strength lies in its flexibility to quickly address user needs and provide specific turn-key solutions to specific medium sized entities or groups. Disadvantages may be related to economic and commercial pressures resulting in limited regional coverage, development of restricted proprietary solutions, reduced interoperability with other systems and increased risk of failure of continuation of service provision.

A strength of PS involvement in respect to the wider regional/national coverage could be identified in providing crucial building blocks within the modular layout of IrriSatSMS rather than in provision of
complete systems as described in more detail in Chapter 3.5.

3.5. Case study IV - As a hybrid system (HS)

3.5.1. Outline

What is being defined as hybrid systems (HS's) here are IrriSatSMS services which have diverse groups of players involved in the realisation of irrigation water management systems and services rather than being run or provided by one or more dominant group or institution as described in the other case studies I to III in Chapters 3.2 to 3.4. HS's are based on the assumption that certain institutions, groups or the PS could provide specific and specialised building blocks in a field they have the most expertise in. While in theory all the described systems under case studies I to III are somehow HS's it is the degree by which one institution such as a WUA/C, is managing the overall provision or is overseeing the entire system delivery which defines them as 'predominant government run' or 'predominant WUA/C run' which distinguishes them from the HS described here where responsibility may only go one level up or below in linking with the next service.

A hybrid IrriSatSMS has a great degree of flexibility in choosing or assigning the various build blocks. An exemplary overview of one variant of such a HS is provided in Figure 19. In this example the government run institutions would provide most of the climate and direct crop water related data and calculation, handing them over to a WUA/C for further processing in irrigation water management models and modules and the distribution to irrigators and advisory services through their water management services. The PS would provide crucial support in providing extension and ground truthing services or by filling in other services where most flexibility would be needed. In this form, the government would provide the more general overarching services spanning across state boundaries, then passing data on to certain regions or industries such as represented by WUA/C who would have a more specific mandate serving larger user groups and finally letting the PS cover the 'last mile' in directly working with the farmers and irrigators at the paddock or farm level.

This HS concept has a great deal of potential to be adapted to specific needs. One of the key roles it could therefore play would be that it could be implemented as a transitional system allowing the pilot testing of concepts, methods and linkages in real life environments with enough flexibility for experimental changes ultimately merging into the more appropriate management structures which could well be or related to one of the concepts and scenarios described under I to III. The Griffith based CSIRO run and CRC IF funded pilot system (Hornbuckle et al. 2008) could be considered an example of such a HS in transition. While not yet fully implemented, it already has the main building blocks in place providing basic but accurate water management services to a community of irrigators.

The advantages and disadvantages of hybrid IrriSatSMS are summarised as follows:

Advantages:

(A 1) High degree on flexibility in implementation and management.
(A 2) Optimised for specific purpose.
(A 3) Stronger individual ownership.

Disadvantages could however be:

(D 1) High degree of communication and management demand.
(D 2) Multiple focal points (dispersed) related to implementation and servicing.
(D 3) High degree of individual incentives.
(D 4) Market forces.
(D 5) Limited or no guarantees for long-term support.
(D 6) Low or moderate regional coverage.
(D 7) Little incentive to cover remote and small user communities.
(D 8) Possible incompatibilities when joining or extending systems.
(D 9) Individual and corporate objectives versus policy driven approaches.
(D 10) Weakness when negotiation with government agencies etc.

Figure 19: The "hybrid" IrriSatSMS - Schematic overview of main functional, logical and management components of a strongly mixed system with various modules run by government, different institutions and the private sector.

3.5.2. Advantages

One of the key advantages of a hybrid IrriSatSMS is that it provides a high degree of flexibility when it comes to implementation and management. As shown in Figure 19 work loads and responsibilities are spread out over various institutions, government and WUA/C alike, and the PS. However, other combinations could be easily envisaged and would depend on regional or users specifics. There could be many differing scenarios conceivable not only with different players covering the four main building blocks "INPUT ET_c", "INPUT ET_crop", "OUTPUT Application" and "Extension, Feedback & Control" (Figure 19) but also with variations within those building blocks. A system could be made available in a certain area and most users could share those services which would be most appropriate for most of them. Individual users however may have different demands or preferences. Some may prefer to use AWS rather than the SILO services and AWS could then be provided by the PS or nearby stations could be used already implemented by WUA/C in that region etc. (A 1) (A 2). Also in respect to the
staged implementation of HS’s, they may have some added flexibility in becoming operational even before more advanced system components could be made available. For instance, crop factors could be derived using standard traditional procedures until NDVI indices could be made available either through government services or through a company which specialises on satellite imaging etc.

Such a HS has many connected modules but is not necessarily centrally owned. Its functioning will therefore greatly depend on the individual involvement and directly addressing demand. End users will need to have strong interest in the proper operation of the system and will more likely adopt it as being their own. Strong ownership will advance and promote the system allowing for reliable services to develop (A 3).

3.5.3. Disadvantages

A hybrid IrriSatSMS is basically a strongly decentralised system with a larger group of different players involved. Structurally it may still suggest some stronger linkages towards one of the institutions which happens to provide key services or is hosting the main server and web facilities. However, despite these stronger linkages towards one provider, it is still specifically designed to be overall less rigidly structured and more decentralised in contrast to the systems described under case studies I to III. While this may at a first glance provide a less bureaucratic system it nevertheless throws up significant challenges when it comes to financial, communication and management demands in order to get the overall system and service up and running (D 1). While institutionally less entangled with one of the major players it is still expected that stronger incentives from individuals or smaller groups would still be needed to be the driving force behind such a system (D 3).

From management as well as the user point of view, such HS’s would provide additional barriers when it comes to problem solving or harmonisation of services. Centrally run systems have clearer structures with generally well designed responsibilities. HS’s do not necessarily have such central nodes and clearly defined structures hence user requests would need to be addressed to one of the several (dispersed) focal points. If problems are not easily pinned down these problems could take valuable time to be resolved (D 2). Missing central structures or less formally organised user groups may also provide weaker positions when more complex services and data access needs to be negotiated for example with government agencies. Well established associations with a strong formalised user base could address concerns and demands much more effectively than small scale incentives more likely to be found with HS’s (D 10).

One approach for HS’s could be to outsource or sub-contract as many of the components as possible in order to avoid major technical shortfalls. However, when niche and specialised ‘markets’ are covered, market forces may work less favourably for the system allowing single suppliers to dictate costs and time for products and services provided (D 4). With many suppliers in a HS limited or no guarantee for long-term support might be the case. This may be acceptable with project based pilot testing systems, however, it would be highly unsuitable for larger scale production systems where the provision of sustainable and reliable services provided would be paramount (D 5).

The advantages of HS's created by the larger degree of flexibility on one side may create disadvantages by posing higher complexities and work loads on the other side especially when system expansion and extended regional coverage is being considered. The complexity of decentralised management and linking up of a larger number of different modules, providers and recipients is to be expected to increase significantly when systems start to grow. This poses some limitations in respect to the degree of growth and regional coverage which could be expected by a HS (D 6). Similarly, this may also be a hindrance when remote and small user communities need to be linked up posing additional costs towards fringe groups; costs which may not be buffered by a stronger user community as it would be expected to be with a WUA/C or government run system (D 7).

While the modular design still constitutes the underlying concept of all systems discussed so far, niche developments may quickly develop especially when little or no overall development structure beyond system boundaries is being followed. Incompatibilities may quickly develop which later may pose serious hindrances when systems are to be linked up or even partly merged (D 8). Cooperation and
code sharing agreements with other existing systems could form the basis for better system compatibilities (Stein, 2007) not only in respect to HS's.

Individual or corporate objectives on the one hand and policy driven approaches on the other hand, seem to be two different underlying concepts and driving forces for the implementation of irrigation water management and water saving approaches. These overall objectives and the extent to which they should be followed need to be defined not only for HS's but equally for the other systems described in order to find the best system for the approach chosen. HS's have an important role to play when systems are being developed or are in transition. However, if long term and more encompassing strategies need to be followed in order to induce water management changes at the state or national level, HS's could form the first development block for testing leading into more structured systems such as described in case studies I and II which then could be more easily and effectively be expanded on a larger scale (D 9).

3.5.4. Summary

Hybrid IrriSatSMS are defined as systems having diverse groups of players involved in the implementation of irrigation water management systems and services. Work and functional blocks are divided up and negotiated with institutions, groups or the PS representatives based on expertise and availability. HS's may be very flexible when it comes to provision of specialised, often regionally confined services. However, the management and organisation of the overall system may pose a major challenge with possible limitations towards regional coverage and "pocketed" and incompatible developments. One of the key roles such a HS could play would be that it could act as a development system for field and pilot testing of concepts, methods and linkages in real life environments with enough flexibility for experimental changes, ultimately merging into a more appropriate and final management structure which then could be expanded beyond regional or industry boundaries.

3.6. Summary - Development and usage matrix

A comparison of these potential four implementation scenarios (I, II, III and IV) of IrriSatSMS, is provided in Table 10 to 12, outlining the attributes and expected requirements of each constellation during an establishing phase, while in full production and if an expansion is performed.
<table>
<thead>
<tr>
<th>Attributes</th>
<th>Case study I: By government institution (GI)</th>
<th>Case study II: By water user organisation/company (WUA/C)</th>
<th>Case study III: By the private sector (PS)</th>
<th>Case study IV: As a hybrid system (HS)</th>
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<td>low</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>Incompatibility</td>
<td>risk</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Components usage</td>
<td>flexibility</td>
<td>low</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Equipment sharing</td>
<td>probability</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Standardised systems</td>
<td>likelihood</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Implementation - basic services</td>
<td>speed</td>
<td>fast</td>
<td>fast</td>
<td>fast</td>
</tr>
<tr>
<td>Implementation - total service</td>
<td>speed</td>
<td>fast</td>
<td>medium</td>
<td>slow</td>
</tr>
<tr>
<td><strong>Crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop types - implemented</td>
<td>diversity</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Crop types - implemented</td>
<td>speed</td>
<td>slow</td>
<td>fast</td>
<td>fast</td>
</tr>
<tr>
<td>NDVIs accessible</td>
<td>speed</td>
<td>fast</td>
<td>fast</td>
<td>fats</td>
</tr>
</tbody>
</table>

22 Initial: Establishing phase of system with pilot testing etc but with intention to lead into production. Number of users may be slowly expanding.
23 Production: System is in full production and has all major components and services in place. Number of users stable.
24 Expansion: System had been in production but moves into an expansion phase towards increasing the number of users (or user groups) as well as achieving greater geographical coverage. Types of services may increase slightly.
25 Implementation - basic services; consisting of: ET<sub>a</sub> and ET<sub>crop</sub>, water management data (sms/web).
26 Implementation - total service; consisting of ET<sub>a</sub> and ET<sub>crop</sub>, water management data (sms/web), ground truthing and extension.
27 Crop types - implemented; specific crop coefficients and NDVI's established and accessible.
28 Normalised Difference Vegetation Index (NDVI) is a numerical indicator used to analyse remote sensing data. Accessibility of satellite images and services is crucial.
Table 11: PART 2: Summary - Development and usage matrix for the four case studies.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Case study I</th>
<th>Case study II</th>
<th>Case study III</th>
<th>Case study IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By government institution (GI)</td>
<td>By water user organisation/company (WUA/C)</td>
<td>By the private sector (PS)</td>
<td>As a hybrid system (HS)</td>
</tr>
</tbody>
</table>
|            | INITIAL | PROD.
| Coverage of services |   |     |   |   |
| - Regional (local) | speed | fast | fast | fast | medium | fast | slow | fast | medium | medium | slow | slow | slow |
| - National (state) | speed | fast | fast | fast | slow | slow | slow | slow | slow | slow | slow | slow | slow |
| - Federal (across states) | speed | fast | fast | fast | slow | unlikely | unlikely | slow | slow | unlikely | unlikely | unlikely | unlikely |
| - Trans-regional (linking regions) | likelyhood | high | high | high | medium | medium | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely |
| - Remote areas | likelyhood | high | high | high | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely | unlikely |
| - Outside industry & user groups | openness to | medium | high | high | low | medium | low | low | low | low | low | low | low |
| - Flexibility | degree | medium | medium | medium | medium | medium | high | high | medium | low | low | low | low |
| - Expansion of coverage | speed | high | high | high | medium | medium | medium | medium | slow | slow | slow | slow | slow |

Institutional framework

| - Synergies with other systems | probability | medium | high | high | medium | medium | medium | low | low | low | very low | very low | low |
| - Complexity | degree | high | high | high | medium | medium | medium | low | low | low | very high | very high | high |
| - Communications demand | low | medium | high | low | medium | low | medium | high | low | low | very high | very high | very high |
| - Bureaucracy degree | high | very high | very high | low | low | low | low | medium | high | high | high | high | high |
| - Centralised / decentralised type | central | central | central | central | central | central | central | central | central | central | central | central | central |
| - Government cooperation | likelihood | high | high | high | low | medium | low | medium | high | high | high | high | high |
| - Administration demand | high | high | high | low | medium | low | medium | high | high | high | high | high | high |
| - Representation / negotiation | strength | low | medium | high | low | medium | high | high | high | high | high | high | high |
| - Market & competitive forces exposure | low | low | low | medium | medium | medium | high | high | high | high | high | high | high |
| - Licence and IP restrictions | low | low | low | medium | medium | medium | high | high | high | high | high | high | high |

Development framework

| - Objectives / target forces | main driver | policy | policy | policy | mixed | mixed | mixed | commerce | commerce | commerce | mixed | mixed | commerce |
| - System adoption rate | low | high | very high | low | medium | medium | high | low | low | medium | low | low | low |
| - System sustainability | degree | medium | high | very high | medium | medium | medium | high | low | medium | low | low | low |

29 Initial: Establishing phase of system with pilot testing etc but with intention to lead into production. Number of users may be slowly expanding.
30 Production: System is in full production and has all major components and services in place. Number of users stable.
31 Expansion: System had been in production but moves into an expansion phase towards increasing the number of users (or user groups) as well as achieving greater geographical coverage. Types of services may increase slightly.
32 Openness to outside (specific) industry and user groups which are not main target group or stakeholder.
33 Synergies with other systems such as jointly using services provided by other groups, departments etc. (for example SILO, weather stations, etc.)
34 Could government cooperation be expected or not and to what extent.
35 Strength of user or stakeholder groups (through representation, lobbying, etc.) in negotiation with for example government or other agencies in providing assistance etc.
36 Main objectives and target forces driving development and expansion of system. (1) Policy driven for example to initiate widespread changes in efficiencies, (2) mixed with policy and commercial drivers, and (3) predominant commercial drivers.
37 System sustainability indicates the resilience of the system to be continued and used by end users and providers.
Table 12: PART 3: Summary - Development and usage matrix for the four case studies.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Case study I By government institution (GI)</th>
<th>Case study II By water user organisation/company (WUA/C)</th>
<th>Case study III By the private sector (PS)</th>
<th>Case study IV As a hybrid system (HS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INITIAL</td>
<td>PROD.</td>
<td>EXPAN.</td>
<td>INITIAL</td>
</tr>
<tr>
<td>Network</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Internet</td>
<td>usage</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>- Proprietary solutions</td>
<td>likelihood</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>- Synergies</td>
<td>likelihood</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Sustainability</td>
<td>degree</td>
<td>medium</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td>- Technical</td>
<td>degree</td>
<td>high</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td>- Service provision</td>
<td>degree</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
</tr>
<tr>
<td>- Organisational</td>
<td>degree</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Costs structure (relative)</td>
<td>exposure</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>- Costing stream for users</td>
<td>exposure</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>- Costing stream for management</td>
<td>exposure</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>- Costing stream for technology</td>
<td>exposure</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
</tbody>
</table>

38 Initial: Establishing phase of system with pilot testing etc but with intention to lead into production. Number of users may be slowly expanding.
39 Production: System is in full production and has all major components and services in place. Number of users stable.
40 Expansion: System had been in production but moves into an expansion phase towards increasing the number of users (or user groups) as well as achieving greater geographical coverage. Types of services may increase slightly.
41 Synergies with other services or networks in respect to openness of exchange.
4. Conclusions and recommendations

Coupling of satellite-derived crop coefficients and reference evapotranspiration and the SMS delivery service now offers the potential to provide low cost, site specific and personalised (for crop type and management conditions) irrigation water management information to individual irrigators across an irrigation district or region. Other benefits also include high spatial resolution of water management information (approx. 30 m x 30 m using Landsat 5) which allows irrigators to better manage spatial variability to maximise production, minimise costs and environmental impacts, such as deep drainage.

The benefits to the Australian irrigator sector are a potential significant step in providing low cost ($1 a day) personalised, crop specific and management specific irrigation water management systems with potentially universal coverage, catapulting the remaining 50 - 70 % of irrigators into the benefits of high tech, quantifiable irrigation water management techniques. The system and framework as developed has the potential to be easily rolled out over numerous crops and regions once this work has been completed.

A series of possible implementation strategies have also been developed to allow the discussion of wide scale implementation to be further investigated.
5. Glossary and definitions

2.5G 2G and 3G are official standards whereas 2.5G is often used to describe some advances implemented towards full 3G network (see 3G). 2.5G provides some of the benefits of 3G and can use some of the existing 2G infrastructure.

3G 3G describes the third generation of developments in wireless technology, especially in mobile (phone) communications. Optus also uses the term 3G to describe their broadband mobile network services.

AWS Automatic weather stations (AWS) provide a cost effective way of monitoring meteorological parameter at short intervals and store data locally for later retrieval or send them via cable or telemetry link to a central server. Many modern AWS can be linked to and accessed through modern mobile phone data networks.

BoM Bureau of Meteorology.

CDMA Code-Division Multiple Access is a wireless protocol used by mobile phones. CDMA networks are classified as second generation (2G) networks and were widely used specially in countryside Australia. They had been phased out in early 2008 and are replaced by for example 3G and Next G™ networks.

CRC IF Cooperative Research Centre for Irrigation Futures

CSIRO Commonwealth Scientific and Industrial Research Organisation

DSS Decision support systems are software packages and information/knowledge systems aimed at supporting decision making activities and processes.

ETc The crop evapotranspiration is the evapotranspiration from a disease-free, well-fertilised and under optimal soil-water and agronomic conditions growing crop (ETc = ETo * Kc).

ETo Reference crop evapotranspiration (or reference evapotranspiration) is defined as the evapotranspiration rate (for example mm day⁻¹) from a reference surface which is hypothetically a well watered grass crop with specific characteristics.

GL Giga litre. The symbol "G" is a prefix denoting the number 10⁹ or 1,000,000,000. GL is frequently used to describe larger volumes (flows) as for example found in rivers or when describing the overall extraction from a water system.

GPL The GNU General Public License (GPL) is one of the widely used open source licences under which many open source software products are distributed. More information on GPL as well as other open source licences is found under: http://www.opensource.org/licenses

IrriSatSMS Irrigation water management by Satellite and SMS.

Kc The crop coefficient (Kc) is an experimentally determined coefficient relating ETc to ETo (ETc = ETo * Kc).

Linux Linux is a free Unix-type operating system originally created by Linus Torvalds with the assistance of developers around the world. Linux is a registered trademark of Linus Torvalds. There are many free Linux distributions such as Ubunutu Linux. Linux is widely used worldwide not only on servers but increasingly also on desktop computers. It is one of the best and widely known examples of free software and open source development and initiative. Further information on Linux is found through the link below. http://en.wikipedia.org/wiki/Linux

Metadata Metadata are defined as 'data about data' describing the usage and the environment of the data. They are used to facilitate the understanding, characteristics, management and usage of the data. Without metadata, data may become completely useless as no link describing their meaning is being provided. If for example rainfall data (as numeric values) are presented, metadata such as type of data (rainfall), units (for example mm), location, time and date need to be attached to them in order to make any sense.
MIA Murrumbidgee Irrigation Area

MMS Multimedia Messaging Service extends the SMS capabilities by allowing the sending of messages that include text as well as multimedia objects such as images, audio, video, and formatted text.

NDVI Normalised Difference Vegetation Index (NDVI) is a numerical indicator used to analyse remote sensing data in respect to vegetation cover based on solar radiation in the red and near-infrared reflectance of plants. This can be directly related to crop water use.

Next G™ Next G™ is Telstra's high speed broadband mobile network which was launched in October 2006. It is classified as a third generation (3G) network.

OSI or Open Source Initiative As to the OSI (2008) "Open source is a development method for software that harnesses the power of distributed peer review and transparency of process. The promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in". Organisational wise the "Open Source Initiative (OSI) is a non-profit corporation formed to educate about and advocate for the benefits of open source and to build bridges among different constituencies in the open-source community" and "One of our most important activities is as a standards body, maintaining the Open Source Definition for the good of the community. The Open Source Initiative Approved License trademark and program creates a nexus of trust around which developers, users, corporations and governments can organize open-source cooperation."
http://www.opensource.org/

PAR Photosynthetically active radiation (PAR) describes solar light which is used by plants during photosynthesis (spectral range from 400 - 700 nanometres).

RAID Redundant Array of Inexpensive Disks or sometimes described as Redundant Array of Independent Disks. A RAID system increases performance but also reliability of data on hard disk drives allowing data to be restored even if one of the disks in the array fails.

SILO SILO - Special Information for Land Owners - is a product of the Bureau of Meteorology (BoM) and provides specific meteorological and agricultural data such as ET$_{c}$ to anyone involved in the agricultural arena (service charges apply).

SMS Short Message Service is often called text messaging or texting mainly used on mobile phone devices. It is a simple text message with a limitation of 160 characters. Longer messages will automatically be split in two and most recipient modern mobile phones join those messages automatically to one again.

W3C The World Wide Web Consortium (W3C®) develops interoperable technologies such as specifications, guidelines, software, and tools in order to provide the Web with the necessary basis to develop its full potential. W3C is a forum for information, commerce, communication, and collective understanding.
http://www.w3.org/

WAP Wireless Application Protocol (WAP) sites are Internet sites or pages specifically created for mobile phones using text and graphics to fit the dimensions of mobile phone screens. WAP websites may also be accessed with normal computer based browsers.

WUA Water User Association or water delivery (supply) associations of larger user and stakeholder driven bodies which organise or commission overall water delivery, usage and disposal such as Coleambally Irrigation, Murrumbidgee Irrigation or Goulburn-Murray Water, etc. It also includes technical or sectoral associations/bodies which represent part of the industry such as the Irrigation Australia (formerly Irrigation Association of Australia). Many of these associations have a stronger commercial structure and are run as companies, hence the acronym WUA/C is being preferred.

WUA/C Water user association or delivery associations/companies, see WUA.
References


Appendix

A.1 Commercial software list used for IrriSATSMS

Imagine Analysis:
- Irdas Imagine 9.3

Information technology (IT):
- Windows Server 2003
- Microsoft .NET Framework (v2.5)
- MySQL ODBC Connector for .NET
- ZedGraph
- SQLYog
- MySQL
- Esendex Web Services (3rd Party)

Figure A.1: Reproduction of figure 13: Schema of the 2008/2009 server platform architecture using Microsoft Windows Server 2003 with the .NET environment.

A.2 Custom Code

A.2.1 Webpage Code

Microsoft Active Server Pages for .NET (extension .aspx) were used for the website. The main page that irrigators used was a ‘home’ page which generated graphs of their waterbalance from MySQL data using ZedGraph for the graph image itself.

A range of functions were available for irrigators to use including:

- Adding new irrigation and rainfall events
- Viewing past irrigation and rainfall events
- Viewing their start of season-to-current-date waterbalance graph
• Viewing local 7 day weather forecast

A.2.2 Data Collection Code

Incoming SMS were delivered to the irriGATEWAY server from Esendex Pty Ltd via a Web Services hosted at http://www.irrigateway.net/SmsIncomingHandler.asmx. Descriptions of the functions conforming to Esendex’s specification can be read from that web page.

The SMS message content was processed using a custom handler with the basic structure as shown in Figure A.2 and further details in Figure A.3.

```csharp
switch (args[1]) {
    case "demo":
        democ
        break;
    case "i":
        i -irrigation
        break;
    case "r":
        r -rain
        break;
    case "w":
        w -width
        break;
    default:
        unrecognised
        break;
}
```

Figure A.2: C# .NET code of the top level switch used to process incoming SMS messages. `args[1]` is the first character of the SMS which, if it was an `i` would identify the message as containing an irrigation event. `args[1]` being an `r` would denote rainfall event reporting, `w`, `width` and everything else would be interpreted as unrecognised triggering the sending of an error response SMS to the sender.

```csharp
case "i":
    #region i -irrigation
    Check message contents
    Write irrigation details to DB
    #endregion
    break;
```

Figure A.3: C# .NET code of the lower level handling of an irrigation SMS denoted by the first message character being an `i`.

Weather information, including reference evapotranspiration, was collected from the CSIRO’s Griffith weather station, which posts data online, using custom web scraping code. The data, available up-to-date every day at http://www.clw.csiro.au/services/weather/Gri7.dat was given in a custom textual format which was processed by code such as in figure A.4 and stored in the irriGATEWAY database.
A.2.3 Database Code

The databases for the irrigGATEWAY server were all MySQL databases housed locally. The main database house irrigator details, incoming and outgoing SMS records, daily waterbalance figures and irrigator vine block coordinates. All incoming messages were stored 'as is' and successfully processed results from these incoming messages were stored in tables such as `waterbal_irrig` and `waterbal_rain` with `waterbal_etc` storing daily ETc for each irrigator calculated using daily ETo values with either a reference crop factor from `kc_reference` or an adjusted crop factor using the difference between a day's `kc_reference` crop factor and an input crop factor from `kc_input`.

Some incoming data processing was undertaken by the database including an effective rainfall function which reduced rainfall reported by irrigators by certain percentages to reflect runoff losses. Such processing was undertaken by MySQL database Trigger. The MySQL SQL trigger code for effective rainfall is given in Figure A.5.

```sql
DELIMITER $$

DROP TRIGGER /^150032 IF EXISTS */'ssis','effective_rainfall'$$

CREATE /
^150017 DEFINER = 'root'@'%' */
TRIGGER 'effective_rainfall' BEFORE INSERT ON 'waterbal_rain'
FOR EACH ROW BEGIN
 IF NEW.input > 100 THEN
   SET NEW.value = 30;
 ELSEIF NEW.input > 50 AND NEW.input <= 100 THEN
   SET NEW.value = 26.5;
 ELSEIF NEW.input > 40 AND NEW.input <= 50 THEN
   SET NEW.value = 22.5 + 0.25 * (NEW.input - 40); /* max = 26.5, min = 25 */
 ELSEIF NEW.input > 30 AND NEW.value <= 40 THEN
   SET NEW.value = 22.5 + 0.25 * (NEW.input - 40); /* max = 25, min = 22.5 */
 ELSEIF NEW.input > 20 AND NEW.value <= 50 THEN
   SET NEW.value = 17.5 + 0.5 * (NEW.input - 30); /* max = 22.5, min = 17.5 */
 ELSEIF NEW.input > 10 AND NEW.value <= 20 THEN
   SET NEW.value = 10 + 0.75 * (NEW.input - 10); /* max = 17.5, min = 10 */
 ELSE /* rain <= 10mm */
   SET NEW.value = NEW.input; /* effective rain = actual rain */
 END IF;
$$

DELIMITER ;
```

Figure A.5: MySQL effective rainfall function. The incoming value (NEW.input in the code) is
reduced by set amounts according to predetermined ranges and both the input and the reduced values are saved in the table waterbal_rain.

A.2.3 Waterbalance Code

The waterbalances for individual irrigators were calculated at 6am within the MySQL database using MySQL Stored Procedures each day. This was done by summing season-to-date cumulative ETc, rainfall and irrigations. ETc was generated from ETo x Kc for a particular day where the Kc was either taken from the kc_reference database table giving reference kc values for each day or from an altered reference kc which was adjusted according to the difference between the latest kc_input table value (Kc from satellite images) value for a particular irrigator and the kc_reference table kc value for that day. The full code for ETc generation is shown in Figure A.6.

```
DELIMITER $$
DROP PROCEDURE IF EXISTS 'sys'.'Daily_ETc_generator'$$
CREATE DEFINER='root'@'%' PROCEDURE 'Daily_ETc_generator'(var_endate DATE)
BEGIN
  DECLARE done INT DEFAULT 0;
  DECLARE var_number VARCHAR(15);
  DECLARE var_name VARCHAR(5);
  DECLARE var_etc DOUBLE;
  DECLARE var_etc_num DOUBLE;
  DECLARE curi CURSOR FOR SELECT number, name FROM blocks WHERE startdate < CURDATE();
  OPEN curi;
  REPEAT
    FETCH curi INTO var_number, var_name;
    IF NOT done THEN
      /*
       * Calculate this irrigator's ETc
       */
      SET var_etc = 
      SELECT ROUND((kc_reference_copy.kc - 
                    SELECT kc_input.kc - kc_input.kc AS kc_diff 
                    FROM kc_input INNER JOIN kc_reference_copy
                    ON kc_input.date = kc_reference_copy.date 
                    WHERE kc_input.number = var_number AND kc_input.block = var_name) 
                        waterbal_evap.value AS ETc 
                    FROM kc_reference_copy INNER JOIN waterbal_evap 
                    ON kc_reference_copy.date = waterbal_evap.date 
                    WHERE kc_reference_copy.date = var_endate 
                        AND waterbal_evap.location = (SELECT id FROM locations WHERE name = 'Griffith')
                    ) 
      END IF;
      IF var_etc IS NULL THEN
        SET var_etc = ROUND((SELECT kc * VALUE FROM kc_reference_copy INNER JOIN waterbal_evap 
                          ON kc_reference_copy.date = waterbal_evap.date 
                          WHERE kc_reference_copy.date = var_endate 
                          AND waterbal_evap.location = (SELECT id FROM locations WHERE name = 'Griffith')),2)
      END IF;
      SET var_etc_num = var_etc + (SELECT etc_num FROM waterbal_etc WHERE number = var_number AND block = var_name)
      IF var_etc_num IS NULL THEN
        SET var_etc_num = var_etc;
      END IF;
      INSERT INTO waterbal_etc (DATE, number, block, etc, etc_num) VALUES (var_endate, var_number, var_name, var_etc, var_etc_num);
    END IF;
  UNTIL done END REPEAT;
  CLOSE curi;
END$$
DELIMITER ;
```

Figure A.6: MySQL Stored Procedure used to generate ETc values for each irrigator daily.

A.2.4 SMS generation Code
The code used to generate the daily SMS messages was again custom C# code. An example of the loop function that formatted the SMS message from irrigators’ waterbalance variables that had been generated by the waterbalance code is given in Figure A.7.

```csharp
using (OdbcDataReader reader = cmd.ExecuteReader())
{
    while (reader.Read())
    {
        string message = "irriGATEWAY: " + DateTime.Now.ToString("dd/MM") + "\n" + "Rain: " + reader["rain"].ToString() + "\n" + "Irrig: " + reader["irrig"].ToString() + "\n" + "Evap: " + reader["evap"].ToString() + "\n" + "Balance: " + reader["balance"].ToString() + "\n" + "Run Time: " + reader["minutes"].ToString() + "\n";
        try
        {
            Console.WriteLine(reader["number"].ToString() + ": " + message);
            EsendexFunctions.Send(reader["number"].ToString(), message);
        }
        catch (Exception ex)
        {
            Email("ScheduleSender SMS sending error", ex.Message);
        }
    }
}
```

Figure A.7 C#.Net custom SMS formatting code. Limited to 160 characters.