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Recharge and Discharge Estimation in Data Poor Areas

User Guide for the Recharge and Discharge Estimation Spreadsheets and MapConnect

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The Water for a Healthy Country Flagship aims to provide Australia with solutions for water resource management, creating economic gains of $3 billion per annum by 2030, while protecting or restoring our major water ecosystems. The work contained in this report is collaboration between CSIRO and Geoscience Australia.

For more information about Water for a Healthy Country Flagship or the National Research Flagship Initiative visit www.csiro.au/org/HealthyCountry.html

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Cover Photograph:

Description: Limestone tufa on the Douglas River in Northern Territory.

Photographer: Anthony O'Grady

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

EXECUTIVE SUMMARY

Determination of an accurate groundwater balance for a region requires estimation of recharge and discharge rates and, where possible, knowledge of their spatial distribution. Where the value of the resource warrants it, detailed recharge and discharge studies are commissioned. These studies provide comprehensive empirical information on spatial and temporal variability of recharge, and the relationship between recharge rates and soil, regolith, landform and vegetation parameters. Where the value of the resource does not warrant detailed research, much cruder approaches (such as the estimation of recharge as a simple percentage of rainfall or the assumption that discharge is non-existent) are used. The aim of the project described in this report was to develop a nationally consistent approach to recharge and discharge estimation for data poor areas which may serve as a halfway house between the use of simple approximations and the results of detailed field and modelling studies.

This project involved two phases, the first of which involved compiling reviews of recharge and discharge studies that have been undertaken in Australia (Crosbie *et al.*, 2010a; O'Grady *et al.*, 2010). It also involved preliminary identification of the parameters (climate, soils, regolith, near-surface geology, landforms, vegetation etc.) that determine recharge and discharge rates, along with a review of the appropriate scale mapping approaches available for these parameters (Pain *et al.*, 2011). The second phase of the project utilised empirical relationships derived from data collected in Phase 1 of the project in a decision tree methodology that guides the user to the most appropriate method of recharge/discharge estimation, given the available data.

This report provides detailed instruction in the use of both Recharge and Discharge Estimation spreadsheets and the associated GIS datasets made available via the MapConnect website (Geoscience Australia, 2011). The number of methods that can be used will depend upon the availability of climatic, hydrogeologic and land-use data but all methods are intended for areas where there have been no or few field-based studies undertaken. The intended users of the spreadsheet are hydrologists who have responsibilities in groundwater management.

The Recharge Estimation spreadsheet (Chapter 2) can provide up to three estimates of deep drainage and/or recharge using a range of empirically-based relationships with climatic, hydrogeologic and land-use parameters: Method of Last Resort (MOLR; Crosbie *et al.*, 2010b), %clay/rainfall/land-use relationship (Wohling *et al.*, 2011), and Groundwater Chloride Mass Balance (GCMB; Crosbie *et al.*, 2010a).

The Discharge Estimation spreadsheet (Chapter 3) can provide up to three estimates of groundwater discharge based on three approaches: Groundwater Risk Model (based on the Water Balance Risk Model, *WBRisk* (Howe *et al.*, 2006)), Ecological Optimality, and a groundwater discharge versus groundwater salinity function.

The MapConnect website and associated datasets (Chapter 4) provide the means to populate these spreadsheets in data poor areas.

1.   INTRODUCTION

1.1. Background

Determination of an accurate groundwater balance for a region requires estimation of recharge and discharge rates and, where possible, knowledge of their spatial distribution. Where the value of the resource warrants it, detailed recharge and discharge studies are commissioned. These studies provide comprehensive empirical information on spatial and temporal variability of recharge, and the relationship between recharge rates and soil, regolith, landform and vegetation parameters. Where the value of the resource does not warrant detailed research, much cruder approaches (such as the estimation of recharge as a simple percentage of rainfall or the assumption that discharge is non-existent) are used.

The aim of the Consistent Approach to Groundwater Recharge Determination in Data-Poor Areas project described in this report was to develop a nationally consistent approach that could be applied by groundwater managers to determine recharge and discharge fluxes in areas that have not been subject to detailed investigations. The project involved two phases, the first of which involved compiling reviews of recharge and discharge studies that have been undertaken in Australia (Crosbie *et al.*, 2010a; O'Grady *et al.*, 2010). It also involved preliminary identification of the parameters (climate, soils, regolith, near-surface geology, landforms, vegetation etc.) that determine recharge and discharge rates, along with a review of the appropriate scale mapping approaches available for these parameters (Pain *et al.*, 2011). The second phase of the project utilised empirical relationships derived from data collected in Phase 1 of the project in decision tree methodologies that guide the user to the most appropriate method of recharge/discharge estimation, given the available data. The methodologies endeavour to provide recharge and discharge flux estimations for data poor areas that fall somewhere between using very course estimates (e.g. recharge is 5% of rainfall) and carrying out very detailed field and modelling studies.

1.2. Purpose of this Report

This report provides detailed instruction in the use of the Recharge and Discharge Estimation spreadsheets developed in the project and the associated GIS datasets made available via the MapConnect website (Geoscience Australia, 2011).

1.3. Methods

Recharge estimation methods and associated uncertainties were based on empirical relationships derived from field based measurements. This was not possible for estimates of discharge due to the limited number of field based measurements. Consequently, a combination of field-based measurements and modelling has been used. Microsoft Excel spreadsheets were developed that allow the use to estimate recharge or discharge at a specific site. National-scale default data sets that can be used to provide input data for the spreadsheets (in the absence of more detailed local data) have also been prepared and are available on the MapConnect website. Also available on MapConnect are estimates of recharge and discharge conducted across Australia that were identified by the reviews of Crosbie *et al.* (2010a) and O'Grady *et al.* (2010). The user should consult these first to see if there are any estimates at their sites of interest.

Both the Recharge Estimation and Discharge Estimation spreadsheets employ a number of estimation methods whose use will depend upon the availability of climate, hydrogeological and land-use data. All methods are intended for areas where there have been no or few field-based studies undertaken. The intended users of the spreadsheets are hydrologists who have responsibilities in groundwater management. A user can choose to use either or both of the Recharge and Discharge Estimation spreadsheets depending on the management questions they are considering.

> **Note**
>
> Details on the recharge/deep drainage and discharge estimation methods and data availability are described in the accompanying Scientific Reference Guide (Leaney *et al.*, 2011) which should be read in conjunction with this User Guide.

> **Warning**
>
> The user should not attempt to use either the Recharge Estimation or Discharge Estimation spreadsheets until they have read the Scientific Reference Guide and understand the methodologies employed.

1.4. Application Structure

The Recharge Estimation spreadsheet (Chapter 2) provides up to three estimates of deep drainage and/or recharge using a range of empirically-based relationships with climatic, hydrogeologic and land-use parameters: Method of Last Resort (MOLR; Crosbie *et al.*, 2010b), %clay/rainfall/land-use relationship (Wohling *et al.*, 2011), and Groundwater Chloride Mass Balance (GCMB; Crosbie *et al.*, 2010a).

The Discharge Estimation spreadsheet (Chapter 3) provides up to three estimates of groundwater discharge based on three approaches: Groundwater Risk Model (based on the Water Balance Risk Model, *WBRisk* (Howe *et al.*, 2006)), Ecological Optimality, and a groundwater discharge versus groundwater salinity function.

The MapConnect website and associated datasets (Chapter 4) provide the means to populate these spreadsheets in data poor areas.

A user can choose to use either or both of the Recharge and Discharge Estimation spreadsheets depending on the management questions they are considering. The role of the MapConnect website is to provide consistent default data sets that the user can choose to utilise in the absence of better quality local data.

1.5. Limitations of this Approach

> **Warning**
>
> The spreadsheets should be considered as guides only and by their very nature (as tools to use in data poor areas) the results should not be relied upon without appropriate independent advice and verification.

CSIRO makes no warranty about the appropriateness or otherwise of any type or form of data that licensees may use in the Software. It is important to note that these spreadsheets have been designed to provide estimates of groundwater recharge and discharge in data poor areas. Wherever possible, field studies should be used to supplement or calibrate the estimates provided by the spreadsheets. Some of the limitations of these spreadsheets include:

- the spreadsheets should only be used in data poor areas where the value of the groundwater resource does not warrant field studies;

- the spreadsheets should not be used in irrigation areas because the methods do not account for the added difficulties associated with the wide range of crops and irrigation management;

- the spreadsheets should not be used to estimate river recharge as they do not account for the complex surface water-groundwater interactions associated with this form of recharge; and

- the approach contained in the spreadsheets is specific to diffuse recharge and as such it should not be used in areas where preferential/localised recharge, due to surface water flow being a major part of the groundwater balance, is the dominant form of recharge.

1.6. Terminology

When discussing recharge and discharge estimation, it is important to ensure consistent and correct terminology is used. In the past, the term recharge, along with terms such as deep drainage, have often been interchanged and used incorrectly. For the purpose of this report, we adopt the following definitions (Figure 1.1):

Deep drainage (D_d) or *Potential recharge* is rainfall (Rain) that moves past the root zone of vegetation after unsaturated zone evapotranspiration (ET_{uz}) has occurred. Deep drainage becomes recharge only when no impeding layers exist that would prevent water from moving down to the aquifer (i.e. causes interflow, IF).

Discharge is any loss of water from the aquifer. In the context of this project we are concerned with loss of water from the aquifer by evapotranspiration (ET_{gw}).

Gross recharge (R_g) is the rainfall that reaches the water table after interflow losses.

Net recharge (R_n) is the rainfall that flows to the aquifer boundary after discharge (ET_{gw}) losses.
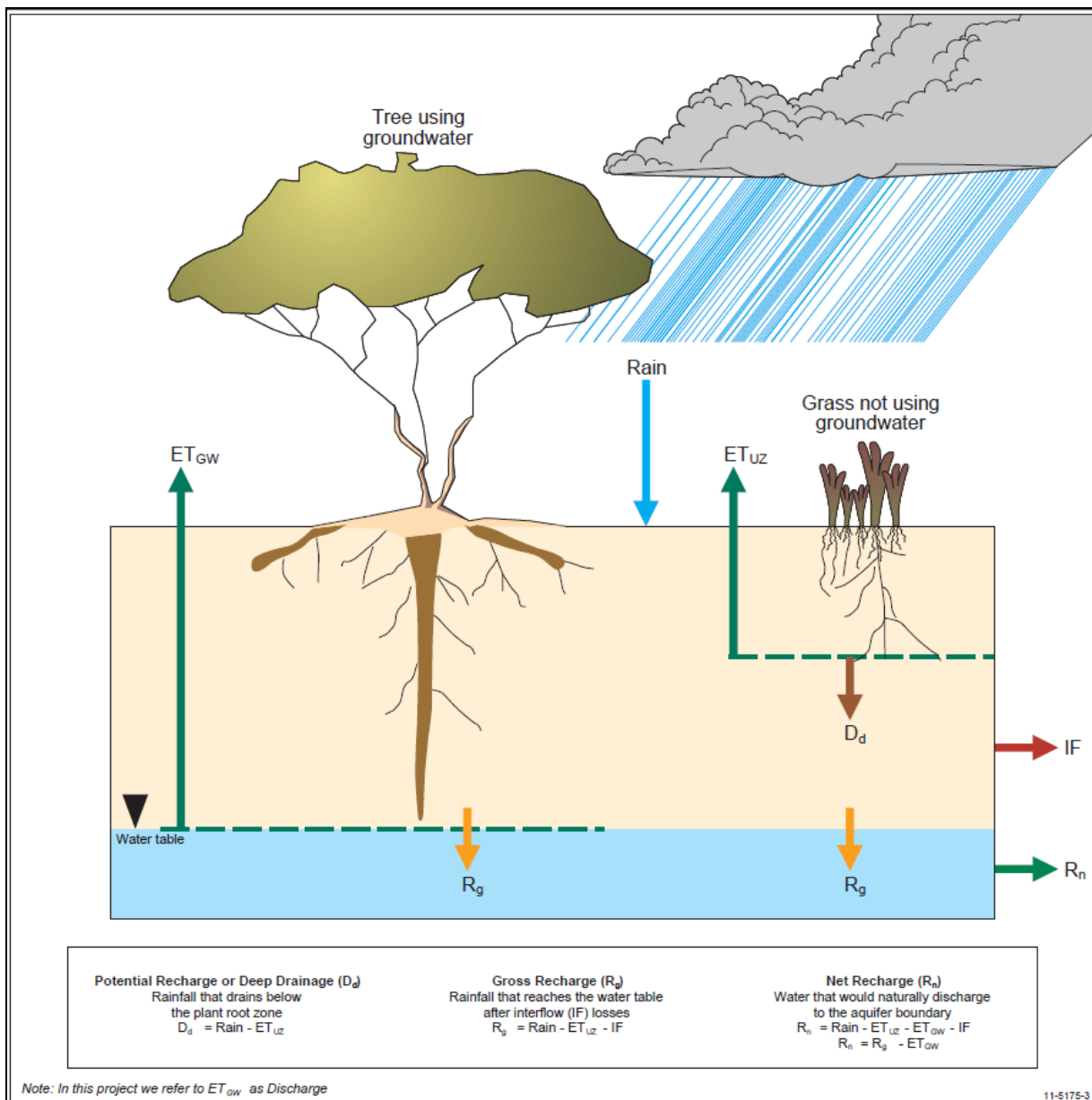
Figure 1.1. Illustration of the terms deep drainage, gross recharge, net recharge, and discharge by evapotranspiration.

1.7. Document Conventions

Certain words in this User Guide are presented in different styles to indicate that the word is part of a specific category.

<Arial bold font in braces>
    Arial bold font in angle braces indicates a key to press. For example

    "Click the **<ok>** button"

Arial bold font
    Arial bold font indicates words of phrases found in the application, such as menu items, labels etc. For example:

    "Choose **Menu -> File Save As** to save your outputs"
    "Click on the **Site Query List** tab"
    "To open the **Recharge Estimation spreadsheet**, go to …"

Additionally, this User Guide uses strategies to draw your attention to pieces of information:

Note

A note is information such as tips, shortcuts or alternative approaches, or extra information to guide you.

Warning

A warning indicates important information that must be taken into account to produce correct outputs or avoid data loss. Warnings should not be ignored.

2. RECHARGE ESTIMATION SPREADSHEET

2.1. Introduction

The Recharge Estimation spreadsheet provides up to three estimates of deep drainage and/or recharge using a range of empirically-based relationships with climatic, hydrogeologic and land-use parameters: MOLR, %clay/rainfall/land-use relationship, and GCMB. Where possible it should be populated with data specific to the location of interest. The user can also obtain data from the MapConnect website.

2.2. Licensing

The Recharge Estimation spreadsheet is made available under a Non-Commercial Software Licence Agreement between CSIRO and yourself. The terms and conditions of this license can be found at http://www.csiro.au/science/Recharge-Discharge-Estimator-Suite.html.

2.3. System Requirements

The Recharge Estimation spreadsheet is in the Microsoft Excel 1997-2003 format (i.e. has a file extension of .xls) and requires Macros be enabled in the security options of the spreadsheet. It has been tested on Excel 2003 and Excel 2007. It has very modest memory and CPU requirements and as such should work on most PC's. It has not been tested on any of the Apple Mac versions of Excel, or on any version of OpenOffice, and so it is unlikely to work on either of these platforms.

2.4. Getting Started

2.4.1. Obtaining the software

The Recharge Estimation spreadsheet can be downloaded from http://www.csiro.au/science/Recharge-Discharge-Estimator-Suite.html. You will need to agree to the license conditions specified and register before being allowed to download the spreadsheet.

2.4.2. Installation

There are no special installation requirements other than to make sure you have either Excel 2003 or Excel 2007 for PC, and you have macros enabled in the security options of the spreadsheet. To do this in Excel 2003 you go to menu **Tools -> Options**, then click on the **<Security>** tab, then click the **<Macro Security>** button, and then on the **<Security Level>** tab click the **<Medium>** radio button. In Excel 2007 you click on the **<Microsoft Office>** button (Microsoft Office Icon in top left corner of the Excel window), then click on the **<Excel Options>** button, then click on **<Trust Center>** menu list item, then click on **<Trust Center Settings button>**, then click on **<Macro Settings>** menu list item, and then click on the **<Disable all macros with notification>** radio button.

2.5. Using the Software

2.5.1. Opening the spreadsheet

Open the spreadsheet named **RechargeEstimationSpreadsheet.xls** (Figure 2.1). The worksheet named **Instructions** will be the only one initially visible and a pop-up screen will appear asking you to read the material on this worksheet and you will have to click on the **<OK>** button on this pop-screen to continue. The **Instructions** worksheet provides a brief summary of the recharge estimation methods employed and instructions on how the spreadsheet should and should not be used. Once the Introduction, Limitations, Instructions and Disclaimer sections have been read scroll down and click on the **<Agree>** button at the

bottom of the worksheet to proceed to the worksheet named **Deep Drainage&Recharge Summary**.
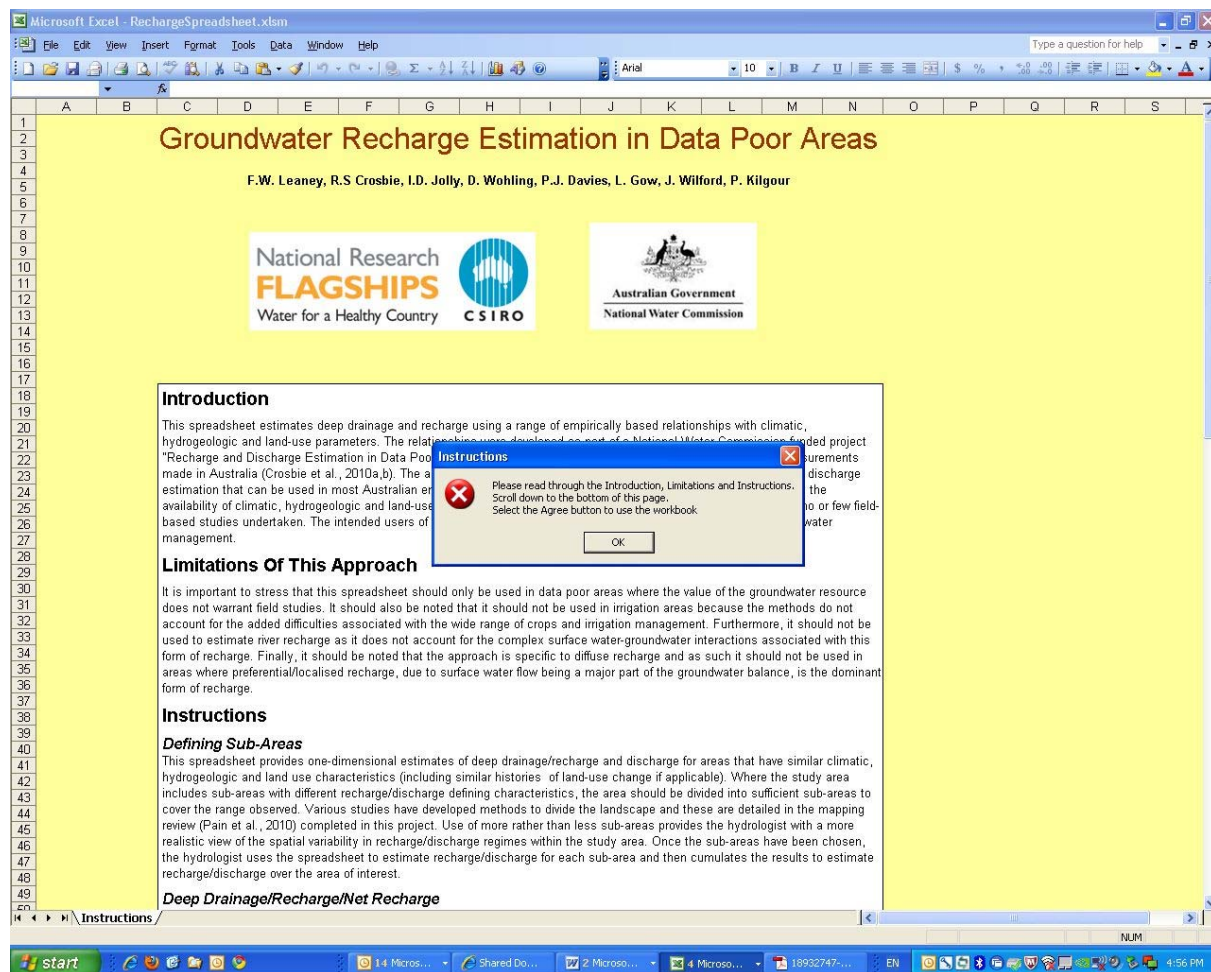
Figure 2.1. The Instructions worksheet.

2.5.2. Defining the recharge regimes

As discussed in the Scientific Reference Guide (Leaney *et al.*, 2011), before using the spreadsheet, the user should assess the spatial variability of key parameters (e.g. rainfall, vegetation type, land-use history and soils) within their area of interest. Variability in these parameters will impact recharge discharge fluxes. Consequently, the user should identify sub-areas based on these parameters and apply the spreadsheet calculations to each sub-area independently. If the user requires a total recharge estimate for several sub-areas combined, the results should be cumulated taking into consideration the areal extent of each of the sub-areas.

2.5.3. Data input

You enter all input data in the worksheet named **Deep Drainage&Recharge Summary** based on a series of questions (Figure 2.2).

Figure 2.2. The Deep Drainage&Recharge Summary worksheet.

Input rainfall parameters

Figure 2.3. Screenshot of the Input Rainfall Parameters section.

In this section you enter the mean annual rainfall (mm/yr) and the mean, minimum and maximum annual rainfall chloride flux (kg/ha) for your site (Figure 2.3). The mean annual rainfall can be obtained from either a nearby rainfall station or the long-term Average Annual (1900-2009) Rainfall surface for Australia available on the MapConnect website. Annual rainfall chloride flux values can also be obtained via MapConnect. These inputs are used in the Method of Last Resort (MOLR) and the Groundwater Chloride Mass Balance (GCMB) methods for estimating deep drainage/recharge (the mean annual rainfall is also used in the %clay method).

Define groundwater characteristics

Figure 2.4. Screenshot of the Define Groundwater Characteristics section.

In this section you enter the groundwater characteristics of the aquifer underlying your site (chloride concentration (mg/L), water table depth (m), mean depth of the screens of the bores (m)) (Figure 2.4). Note that the depths here refer to depth below the land surface not the height above/below the Australian Height Datum. This information will need to be derived from local bore information as no suitable national scale GIS datasets currently exist. This information is best sourced from State and Territory groundwater databases and reports. These inputs are used in the GCMB method for estimating deep drainage/recharge, and for the calculation of the lag time for deep drainage to become recharge when there has been a land-use change at the site. If there has been land-use change in the sub-area, it is

advisable to choose bores with screens located close to the watertable. Otherwise, it is likely that the system may be in a transient phase with regard to recharge and the GCMB method for estimating recharge cannot be applied. If there are not a large number of bores available in the sub-area and/or there is significant variability in depth to water and/or depth of screen, it may be useful to run the spreadsheet at each bore site. In this way, several estimates using the GCMB method can be made.

Define surface soil characteristics

Define Surface Soil Characteristics			
Please enter the measured average % clay for the top 2 m of soil (0 if not available)			25 %
What is the soil order in the Australian Soil Classification?			Dermosol

Figure 2.5. Screenshot of the Define Surface Soil Characteristics section.

In this section you enter the surface soil characteristics of your site (Figure 2.5). The %clay and the soil order data are used to estimate deep drainage (and possibly recharge) using the %clay/rainfall/land-use relationship (Wohling *et al.*, 2011) and the MOLR (Crosbie *et al.*, 2010b; Leaney *et al.*, 2011) respectively. The %clay relationship requires %clay measurements to be made for the top 2 metres of soil (usually samples taken at 0.5 m intervals and averaged) at one or more representative sites in the sub-area. Soil order information can be obtained from MapConnect (see Chapter 4) while %clay needs to be measured *in situ*.

Define vegetation characteristics

Define Vegetation Characteristics			
What is the current vegetation type?			Annuals
Has there been land use change?			Yes
How many years ago was the land use change? (0 if not known)			10 years

Figure 2.6. Screenshot of the Define Vegetation Characteristics section.

In this section you enter the vegetation characteristics of your site (Figure 2.6).The relationships available for the %clay and MOLR methods of estimation require information on current vegetation type (annuals, perennials or trees) which is available via MapConnect and is entered into the spreadsheet via a drop-down box. The spreadsheet uses the same relationships for trees and perennials due to a paucity of data for these vegetation types. However, this could be changed in the future should more field site measurement data become available from further recharge studies in perennial-dominated areas. The user has to specify via a drop down box as to whether there has been a land use change. If so, deep drainage rates are likely to have changed and there may or may not have been sufficient time for the increased deep drainage rate to be have impacted the watertable (as an increased recharge rate). In the spreadsheet, estimates of lag times (for increased deep drainage to reach the watertable and/or screen depth) are used to determine whether a new steady state recharge rate has been reached. The time since vegetation clearance is used in these calculations (along with the geological layer information described below) and this must be provided by the user.

> **Warning**
>
> The spreadsheet is unable to account for any land-use changes other than clearing. If other land-use changes have been made (e.g. introduction of irrigation), no recharge or deep drainage estimations are possible. The Vegetation Clearing dataset on the MapConnect website provides a guide to whether clearing has occurred.

Define geological layers

Define Geological Layers (only required if there has been land clearing and only input da	
What is the layer 1 soil type?	Sand
What is the thickness of soil layer 1?	2 m
What is the layer 2 soil type?	Loam
What is the thickness of soil layer 2?	0 m
What is the unconsolidated material beneath the soil layers?	Sandy Clay Loam
What is the thickness of the unconsolidated material?	10 m
What is the weathered rock material beneath the unconsolidated layer?	Sandy Clay
What is the thickness of the weathered rock material?	10 m
What is degree of weathering?	Slightly
What is the % porosity of the unweathered rock beneath the weathered rock layer?	5 %

Figure 2.7. Screenshot of the Define Geological Layers section.

In this section you enter information on the geological layers underlying your site (Figure 2.7). The data in this section is also used in the estimation of lag time. You can choose to input data for up to 5 layers (soil A horizon, soil B horizon, unconsolidated sediments, weathered rock, and unweathered rock) which are shown in Figure 2.8.
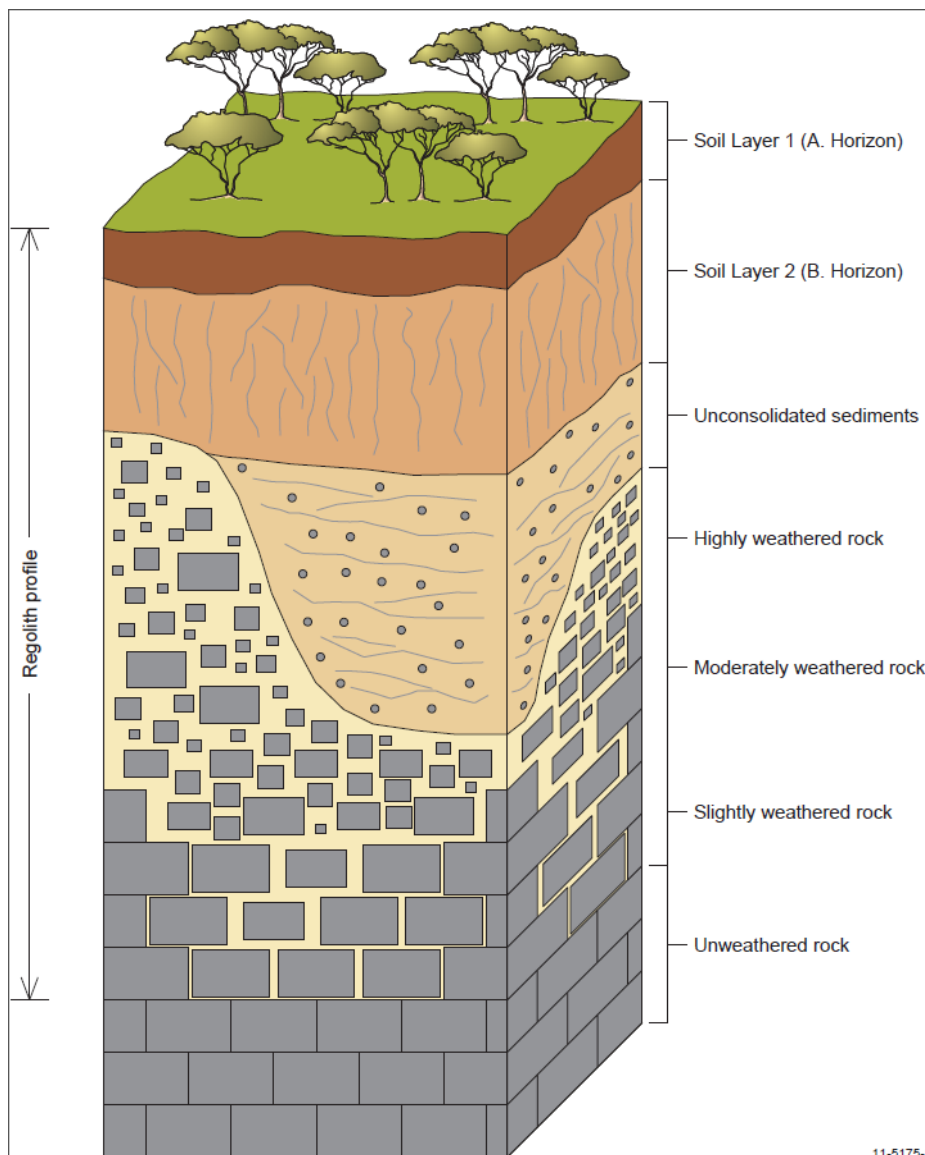
Figure 2.8. Illustration of the 5 soil/geological layers used in the estimation of the time lag following land-use change.

For each layer the soil type or material (defined as soil texture) is selected from drop-down boxes and the thickness is entered in metres. A layer thickness of 0 m should be entered if any layers are not present or not required. Table 1 suggests soil textures for common unconsolidated material and types of weathered rock in addition to porosities for common rock types. Geology/regolith and soil order data (available via MapConnect) can assist in completing this section.

Table 1. Suggested translation between soil texture and unconsolidated, weathered rock materials, and porosity ranges for unweathered rock materials.

Unconsolidated material (e.g. Alluvium, aeolian, lacustrine sediments)	Soil texture
Aeolian sand and clay	sand or loamy sand
Aeolian sand	sand
Sand, silt and clay, minor gravel	loam
Clays; minor sand and silt	clay or silty clay
Sands; minor clay and silt	sand or loamy sand
Weathered rock material	**Soil texture**
Basalt	clay
Coarse grained intrusives (e.g. Granite, diorite, syenite)	loam or sandy clay loam
Fine grained volcanics (e.g. Rhyolite, dacite, andersite)	Silty loam or clay loam
Gneiss and other high grade metamorphics	loam or sandy clay loam
Meta-carbonates	clay or silty clay
Sandstone, minor shale and conglomerate	sand or sandy loam
Schist and minor phyllite	clay, silty loam, sandy clay loam
Sedimentary carbonate and calcrete	clay
Shale, mudstone, siltstone; minor sst, phyllite and conglomerate	clay or silty loam or silty clay
Fe duricrust and silcrete	sand
Unweathered rock	**Porosity (%)**
Coarse grained intrusives (e.g. Granite, diorite, syenite)	1 to 5
Fine grained volcanics (e.g. Rhyolite, dacite, andersite)	1 to 10
Gneiss and other high grade metamorphics	0.8 to 1.6
Meta-carbonates	1 to 10
Sandstone, minor shale and conglomerate	10 to 20
Schist and minor phyllite	0.6 to 1.5
Sedimentary carbonate and calcrete	1 to 20
Shale, mudstone, siltstone; minor sst, phyllite and conglomerate	1 to 10
Banded ironstones and quartzite	1 to 5*

Note: Porosity values are a guide only. * denotes materials that typically have low porosity but potentially very high permeability if fractured, faulted or jointed.

2.6. Interpreting the Results

Once all of the input data has been entered the results are printed out below the Define Geological Layers section (example given in Figure 2.9). Up to three estimates of deep drainage/recharge are provided depending on the available input data and whether a land

use change had occurred. The interpretation of the results is described below, commencing with a discussion of how lag times affects the results when there has been a change in land use.

Results				
GCMB estimate				
It is not possible to estimate recharge or deep drainage using GCMB				
% Clay estimate				
It is not possible to estimate recharge using relationship with measured % clay and rainfall				
MOLR estimate				
It is not possible to estimate recharge using MOLR				
Because there has been land use change and the watertable has not reached a new steady state no recharge estimates are possible				
Deep drainage estimate using relationship with measured % clay and rainfall is		Mean	46	mm/yr
		Minimum	4.9	mm/yr
		Maximum	430	mm/yr
Deep drainage estimate using MOLR is		Mean	45	mm/yr
		Minimum	8.5	mm/yr
		Maximum	230	mm/yr
Steady state at the watertable?				
The cumulative amount of deep drainage required to reach a new steady state at the watertable is			1	metres
The time required to reach a new steady state at the watertable is			29	years
Steady state at the screen?				
The cumulative amount of deep drainage required to reach a new steady state at the screen is			3.7	metres
The time required to reach a new steady state at the screen is			81	years

Figure 2.9. Screenshot of the Results section.

2.6.1. Lag time calculations

If there has been no land-use change in the sub-area, the hydrological system is considered to be in steady state with respect to recharge at both the watertable and at the depth of the bore screens. Mean recharge estimates and associated maximum and minimum estimates at 95% confidence intervals will be given using up to 3 methods (MOLR, %clay and GCMB). Conversely, if there has been land-use change, the system may or may not have reached a new steady state and it will be necessary to undertake estimates of lag time for new deep drainage to reach the watertable and the depth of the screen. Currently, the spreadsheet can only estimate lag times when the change in land-use is from trees/perennials to annuals. If other land-use changes have been made (e.g. introduction of irrigation), no recharge or deep drainage estimations are possible.

The lag time is calculated assuming one dimensional piston flow in both saturated and unsaturated zones. The total amount of drainage required to reach a new steady state at the depth of a bore screen is calculated as the sum of the amounts required for both the saturated and unsaturated zones to return to steady state conditions.

For the unsaturated zone, the amount of cumulative drainage required to change from an unsaturated zone water content associated with deep rooted vegetation (trees/perennials) to one associated with shallow rooted crops and pasture is calculated. This amount of water is then divided by the deep drainage rate to produce a lag time. The deep drainage rate used

may be calculated using one of two methods. First, if a measurement is available for %clay (0-2m depth), the deep drainage estimate used in the lag time calculation is that from the %clay relationship. Otherwise, if no measurement for %clay is available, then the estimate for deep drainage using the MOLR approach is used. The amount of recharge required to return the saturated zone at the depth of the bore screen to steady state conditions is calculated assuming piston flow, where total porosity is assumed. The saturated zone lag time is then calculated by dividing the total amount of water by the estimated drainage rate. The total lag time to the depth of the bore screen is the sum of the unsaturated zone and saturated zone lag times.

If the time since land clearance exceeds the lag time for drainage to reach the watertable, the system is considered to be at steady state at the watertable. If so, recharge rates can be estimated using both the MOLR and the %clay method; otherwise deep drainage estimates can only be made using the MOLR and %clay method.

Similarly, if the time since land clearance exceeds the lag time required for drainage to reach the depth of the bore screen then the system is considered to be at steady state at the screen and the GCMB approach can be used to estimate recharge. If the system is not at steady state at the watertable, then deep drainage estimates only can be made using the MOLR and %clay method (and no estimates at all using the GCMB method).

2.6.2. GCMB estimates

The relationships used in the GCMB approach are given in the accompanying Scientific Reference Guide (Leaney *et al.*, 2011). The GCMB approach can be used to estimate recharge for almost all parts of Australia where there has been no land-use change. The greatest limitation to the approach is in areas where there has been land-use change because the system needs to be in a steady state with regards to recharge at the depth of the bore screen for the method to apply. The spreadsheet is able to estimate lag time and suggest whether a new steady state has been reached if there has been clearing of native vegetation and replanting with crops or pastures. If the land-use change is not clearing (e.g. irrigation development or forest replanting) then no estimate of lag time is possible and hence no recharge estimate is possible.

> **Warning**
>
> If the system has not reached a steady state at the bore screen interval, then neither recharge nor deep drainage can be estimated using the GCMB method. If so, the spreadsheet will indicate this via the messages "It is not possible to estimate recharge using the %clay method" or "There is insufficient data to estimate deep drainage using %clay".

2.6.3. %Clay estimates

The relationships used in the %clay approach are given in Wohling *et al.* (2011) and in the accompanying Scientific Reference Guide (Leaney *et al.*, 2011). In order to use this approach, the %clay must be measured at one of several locations within the sub-area. In addition, the rainfall and %clay data must be within the range of data used to develop the relationship. This means that the clay content needs to be less than 60% and the rainfall for annual vegetation between 260 and 731 mm/yr and for trees and perennial vegetation between 460 and 1266 mm/yr.

If no deep drainage or recharge estimate is possible for the sub-area using the %clay method, the spreadsheet will indicate this via the messages "It is not possible to estimate recharge using the %clay method" or "There is insufficient data to estimate deep drainage using %clay".

2.6.4. MOLR estimates

The relationships used in the MOLR approach are given in Crosbie *et al*. (2010b) and in the accompanying Scientific Reference Guide (Leaney *et al*., 2011). The MOLR approach uses data that is readily available and, as such, is able to provide deep drainage (and possibly recharge) estimates for ~80% of Australia. Areas where the method is not applicable are those for which there is no statistically significant relationship between the variables and/or the mean annual rainfall is outside of the range of data used in determining the relationships (this varies with soil order and vegetation, see Leaney *et al*. (2011) for details). Note also that a default map of the MOLR for Australia is available on the MapConnect website.

If no deep drainage or recharge estimate is possible for the sub-area using the MOLR method, the spreadsheet will indicate this via the messages "It is not possible to estimate recharge using MOLR" or "There is insufficient data to estimate deep drainage using MOLR".

3. DISCHARGE ESTIMATION SPREADSHEET

3.1. Introduction

The Discharge Estimation spreadsheet provides up to three estimates of groundwater discharge based on three approaches: a Groundwater Risk Model, Ecological Optimality theory, and a groundwater discharge versus groundwater salinity function. Where possible it should be populated with data specific to the location of interest. The user can also obtain data from the MapConnect website.

3.2. Licensing

The Discharge Estimation spreadsheet is made available under a Non-Commercial Software Licence Agreement between CSIRO and yourself. The terms and conditions of this license can be found at http://www.csiro.au/science/Recharge-Discharge-Estimator-Suite.html.

3.3. System Requirements

The Discharge Estimation spreadsheet is in the Microsoft Excel 1997-2003 format (i.e. has a file extension of .xls) and requires Macros be enabled in the security options of the spreadsheet. It has been tested on Excel 2003 and Excel 2007. It has very modest memory and CPU requirements and as such should work on most PC's. It has not been tested on any of the Apple Mac versions of Excel, or on any version of OpenOffice, and so it is unlikely to work on either of these platforms.

3.4. Getting Started

3.4.1. Obtaining the software

The Discharge Estimation spreadsheet can be downloaded from http://www.csiro.au/science/Recharge-Discharge-Estimator-Suite.html. You will need to agree to the license conditions specified and register before being allowed to download the spreadsheet.

3.4.2. Installation

There are no special installation requirements other than to make sure you have either Excel 2003 or Excel 2007 for PC, and you have macros enabled in the security options of the spreadsheet. To do this in Excel 2003 you go to menu **Tools -> Options**, then click on the **<Security>** tab, then click the **<Macro Security>** button, and then on the **<Security Level>** tab click the **<Medium>** radio button. In Excel 2007 you click on the **<Microsoft Office>** button (Microsoft Office Icon in top left corner of the Excel window), then click on the **<Excel Options>** button, then click on **<Trust Center>** menu list item, then click on **<Trust Center Settings button>**, then click on **<Macro Settings>** menu list item, and then click on the **<Disable all macros with notification>** radio button.

3.5. Using the Software

3.5.1. Opening the spreadsheet

Open the spreadsheet named **DischargeEstimationSpreadsheet.xls**. The spreadsheet consists of four worksheets, **Introduction**, **Model Start**, **Model Finish** and **Useful References.** The spreadsheet will default to the **Introduction** worksheet (Figure 3.1). A pop-up screen will appear informing you that you have to agree to the disclaimer below and you will have to click on the **<OK>** button on this pop-screen to continue. After reading all of the material scroll down to the bottom and click on the **<I agree, go to model start>** button. This will take you to the **Model Start** worksheet.
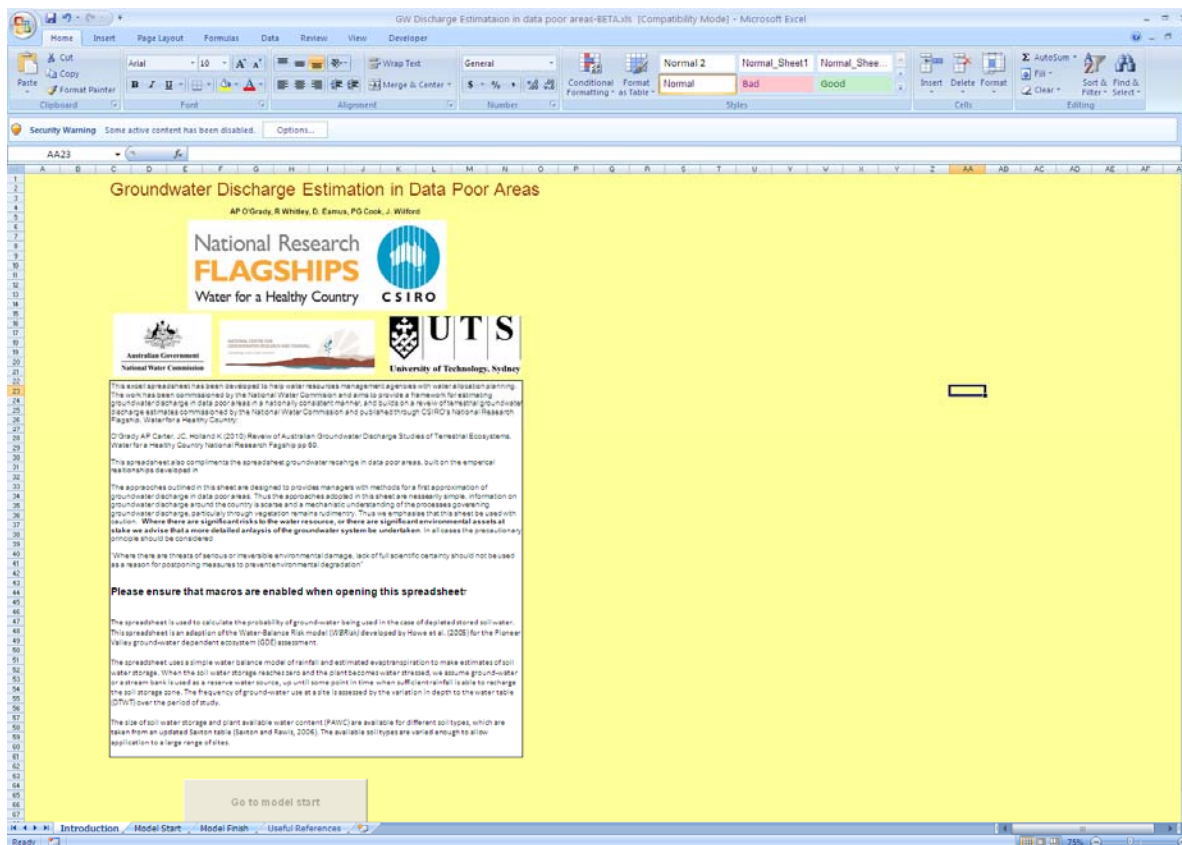
Figure 3.1. Screenshot of the Introduction worksheet.

3.5.2. Defining the discharge regimes

As discussed in the Scientific Reference Guide (Leaney *et al.*, 2011), before using the spreadsheet, the user should assess the spatial variability of key parameters (e.g. rainfall, vegetation type, land-use history and soils) within their area of interest. Variability in these parameters will impact discharge fluxes. Consequently, the user should identify sub-areas based on these parameters and apply the spreadsheet calculations to each sub-area independently. If the user requires a total discharge estimate for several sub-areas combined, the results should be cumulated taking into consideration the areal extent of each of the sub-areas.

3.5.3. Data input

The **Model Start** worksheet (Figure 3.2) is used to set up the model parameters for the groundwater discharge estimation. The main parameters required to run the model are rainfall, evaporation, depth to water table and knowledge of the soil profile down to the water table depth. Coloured cells are locked for editing to protect formulas and assumptions. Do not attempt to change these cells. All data input should be in cells with no fill colour.
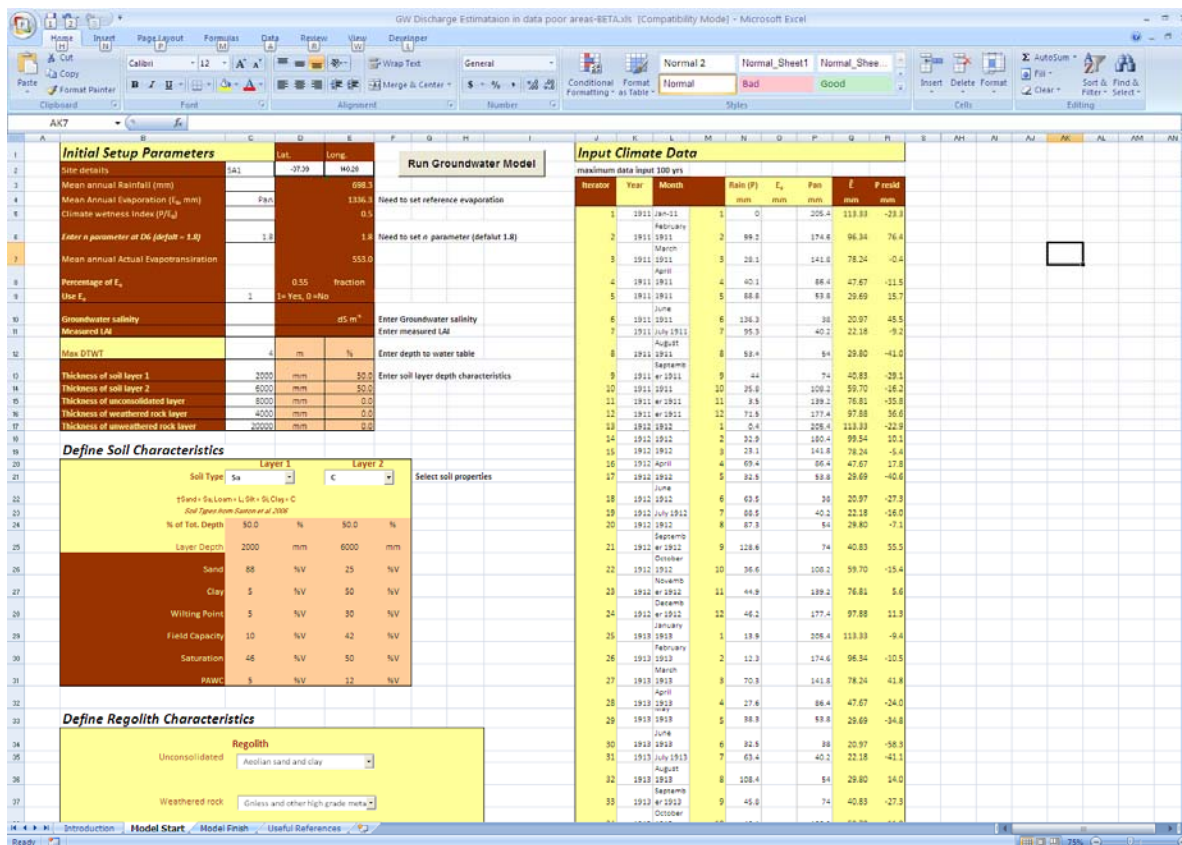
Figure 3.2. Screenshot of the Model Start worksheet.

The Model Start worksheet consists of four boxes, each of which requires initialisation:
- **Initial Setup Parameters** - defines site characteristics
- **Define Soil Characteristics** - defines the soil textural classes for soil layers 1 and 2
- **Define Regolith Characteristics** - defines the regolith characteristics and determines the water availability for each of three regolith layers
- **Input Climate Data** – you enter monthly rainfall and evaporation data here

Initial setup parameters

The layout of the Initial Setup parameters is shown in Figure 3.3. You must:

- Enter the site details

- Set the reference evaporation type

- Enter an "*n*" parameter

- Decide if you want to use reference E or real ET data (if available)

- Enter the Depth to water table

- Enter the thickness of each of five soil layers.

If additional data is available on Leaf Area Index (LAI) and groundwater salinity (in units of dS/m) then you can enter these here.

Initial Setup Parameters		Lat.	Long.
Site details	SA1	-37.39	140.28
Mean annual Rainfall (mm)			698.3
Mean Annual Evaporation (E_o, mm)	Pan		1336.3
Climate wetness Index (P/E_0)			0.5
Enter n parameter at D6 (default = 1.8)	1.8		1.8
Mean annual Actual Evapotransiration			553.0
Percentage of E_o		0.55	fraction
Use E_o	1	1= Yes, 0 =No	
Groundwater salinity			dS m^{-1}
Measured LAI			
Max DTWT	4	m	%
Thickness of soil layer 1	2000	mm	50.0
Thickness of soil layer 2	6000	mm	50.0
Thickness of unconsolidated layer	8000	mm	0.0
Thickness of weathered rock layer	4000	mm	0.0
Thickness of unweathered rock layer	20000	mm	0.0

Figure 3.3. Screenshot of the Initial Setup Parameters box on the Model Start worksheet.

Required inputs

Site name and location

You should enter the site name in **cell C2,** while site latitude and longitude (in decimal degrees) should be entered in **cells D2** and **E2** respectively.

Reference evaporation

The user must select the type of reference evaporation being used by selecting a reference evaporation (E_0) from the drop down box in **cell C4**. The choice of reference evaporation is limited to Pan, Penman, Priestly-Taylor, Morton and Thornwaite. If Pan is chosen, the reference evaporation rate is then calculated as Pan * 0.75 (Roderick and Farquhar, 2009).

"n" parameter

The "*n*" parameter determines the shape of the E_a/E_0 (E_a is the actual evaporation) curve represented in the Budyko (1974) framework and is related to the properties of the catchment being studied. The parameter is used to determine the ratio of actual ET to reference ET. More detail relating to this parameter can be found in Choudhury (1999), Yang *et al.* (2008) and Leaney *et al.* (2011). The default setting is 1.8; however, a range of values can be selected from the drop down box in **cell C6**.

Maximum depth to water table

You enter the depth to water table *(DTWT*, in m) in **cell C12**. Note that this is the depth below the land surface not the height above/below the Australian Height Datum.

Soil profile characteristics

The thickness of each soil layer (mm) is defined in **cells C13:C17**. A schematic of the soil profile is shown in Figure 2.8.

Optional inputs

Measured LAI

If LAI data is available, you can enter this in **cell C11**. Ideally this would be a long-term average LAI. Entering LAI here invokes the calculation of groundwater discharge using the Ecological Optimality approach outlined in Leaney *et al.* (2011).

Groundwater salinity

If information on groundwater salinity (dS/m) is available then you can enter this in **cell C10**. Entering groundwater salinity invokes the calculation of groundwater discharge using the function shown in Figure 3.4.
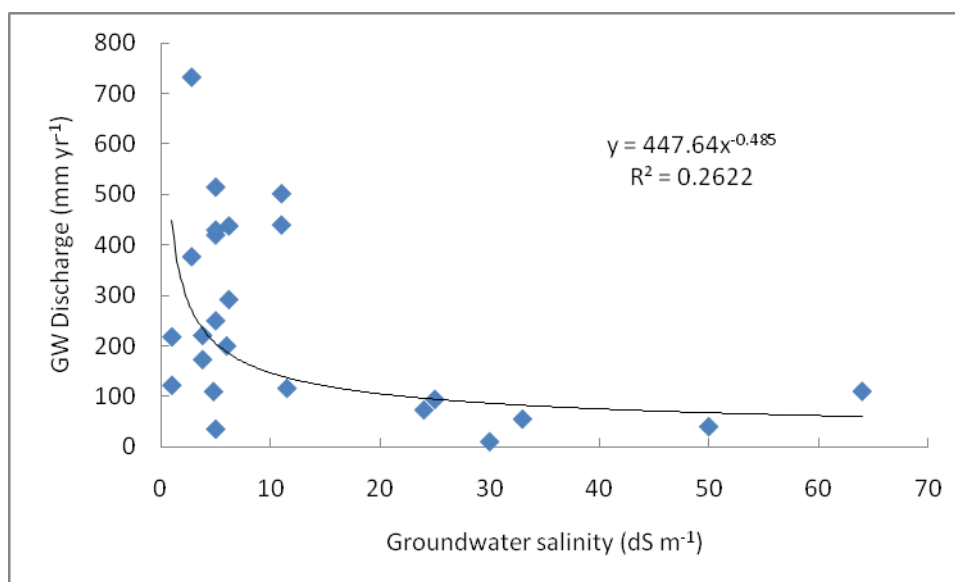
Figure 3.4. Groundwater discharge as a function of groundwater salinity from O'Grady *et al*. (2010).

Define soil characteristics

Soil characteristics for layer 1 and 2 are defined in the box ***Define Soil Characteristics*** (Figure 3.5). In this box the user must set up the textual classes for soils in layers one and two of the soil profile (soil horizon A and B). The user selects a soil type that closely matches the soils for the site from the eleven textual classes listed in each of the drop down boxes. The textural classes represented in each layer have been adapted from McDonald *et al*. (1998) and more detail for each soil class can be also found in the accompanying Scientific Reference Guide (Leaney *et al*., 2011). The textual classes define the water holding capacity for each layer and these are taken from Saxton and Rawls (2006). Available soil water in each layer is calculated as the product of the Plant Available Water Content (PAWC) associated with each textural class and the depth of each soil layer as defined in **cells C13:C14**. A layer thickness of 0 m should be chosen if layer 2 is not present or required.

Figure 3.5. Screenshot of the soil parameterisation for soil layer 1 and soil layer 2.

Define regolith characteristics

Regolith properties have been included in the model to more realistically represent the characteristics of the Australian land surface. Regolith properties are defined within the **Define Regolith Characteristics** box (Figure 3.6). The user may choose to input data for up to 3 geological layers (unconsolidated sediments, weathered rock, and unweathered rock) as shown in Figure 2.8Figure 2.2. A layer thickness of 0 m should be chosen if any layers are not present or not required. The porosity sheet suggests soil types for common unconsolidated material and types of weathered rock in addition to porosities for common rock types.

The user must select the geological characteristics that most closely match the site being described from each of the three drop down lists. Geology/regolith and soil order data (available via MapConnect) can assist the user in completing this section. In some cases, a lose association exists between soil orders (e.g. podosol) and soil type (e.g. sand). Similarly, surface geology can be used to identify unconsolidated and weathered materials.

The user must then assign a degree of weathering for each layer, defined as a percentage. These percentages are defined in **cells D41, F41** and **H41**. The model assumes that the regolith weathers to one of the 11 soil textural classes described above. The plant available water content within each layer is then calculated as a function of the PAWC for the defined weathering product multiplied by the percentage of weathering specified (in **cells D41, F41** and **H41**) and by the depth of the regolith layer. Geology/regolith and soil order data (available at the MapConnect website) can assist the user in completing this section. In some cases, an association exists between soil orders (e.g. podosol) and soil type (e.g. sand). Similarly, surface geology can be used to identify unconsolidated and weathered materials.

Define Regolith Characteristics

Regolith

Unconsolidated: Aeolian sand and clay

Weathered rock: Gniess and other high grade meta

Unweathered rock: Gniess and other high grade meta

	Depth	%	Depth	%	Depth	%
% of Tot. Depth	0	90	0	1	0	1
Layer Depth	0.00		0		0	
Sand	50	45	80	0.8	80	0.8
Clay	40	36	5	0.05	5	0.05
Wilting Point	25	22.5	5	0.05	5	0.05
Field Capacity	36	32.4	12	0.12	12	0.12
Saturation	44	39.6	46	0.46	46	0.46
PAWC	11	9.9	7	0.07	7	0.07

Figure 3.6. Screenshot of the Regolith Characteristics box.

Input climate data

You enter monthly rainfall and evaporation data in **columns N** and **P**. If actual evapotranspiration data are available (i.e. from water balance studies or from an installation such as an eddy flux tower) they can be entered in **column O**. This model will allow input of a maximum 100 years of monthly climate data. You enter the year and month of each climate record in **columns K** and **L**.

Once all parameters and climate data have been entered click on the **Run Groundwater Model** button. The model will then calculate the long term groundwater discharge values and you will be taken to the **Model Finish** worksheet.

3.6. Interpreting the results

Model output is summarised on the **Model Finish** worksheet. A summary of the key results is given in the **Key results summary-Groundwater discharge estimates** table (Figure 3.7). The table will summarise the model runs and output up to three estimates of groundwater discharge, depending on the data inputs. In addition to this summary, the model outputs are explored in more detail on this worksheet and include:

- Detailed output of the monthly soil water balance (Monthly soil water balance table)
- A summary of average monthly climatic characteristics and groundwater discharge estimates (Monthly climate and groundwater properties table).
- Cumulative rainfall residual for the climate record.
- A graphical representation of key results from the model scenario (Figure 3.8).

Key results summary -Groundwater discharge estimates

Site location			
Sites		SA1	
Lats		-37.39	
Longs		140.3	
Site characteristics			
Depth to water table		4.0	m
Layer 1		2	m
Layer 2		2.0	m
Output		**Climatic characteristics**	
Mean annual rainfall		698.3	mm
Mean Annual evaporation	Pan	1336.3	mm
Mean annual rainfall residual		**10.9**	mm
		Discharge estimate	
Groundwater discharge (Groundwater risk model)		**-45**	mm
Groundwater discharge (Salinity function)		NA	mm
Groundwater discharge (Ecological optimality)		NA	mm
Average runoff/recharge		**4**	mm

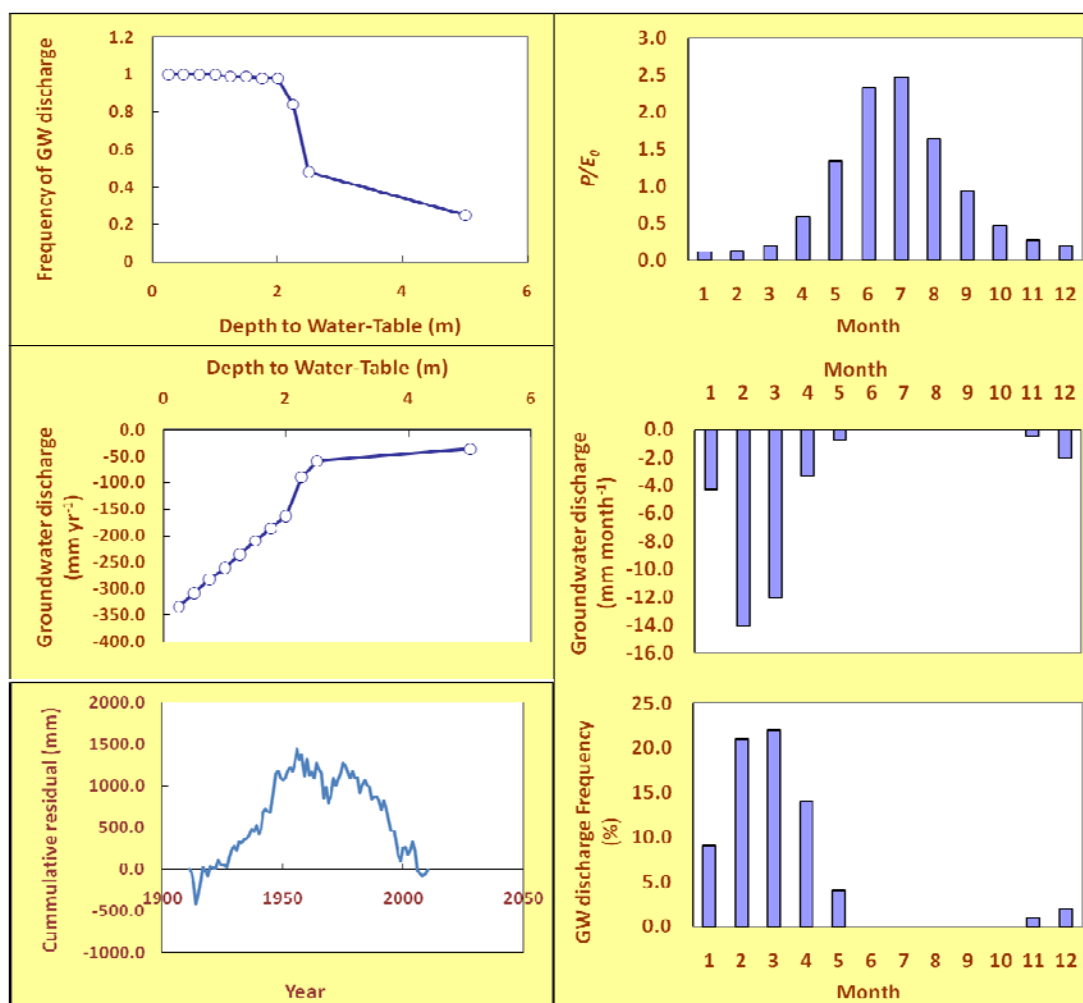**Figure 3.7. Screenshot of the Key results summary table on the Model Finish worksheet.**

Figure 3.8. Screenshot of the graphical representation of results from the monthly water balance model.

4. MAPCONNECT USER GUIDE

4.1. Introduction

The user can obtain many of the data required in the Recharge and Discharge Estimation Spreadsheets via MapConnect. This chapter will detail:

- What MapConnect is;

- How to access MapConnect and the general interface;

- Finding and defining areas and sub-areas;

- Acquiring data for input into the Recharge and Discharge Estimation spreadsheets; and

- Obtaining previously reported recharge and/or discharge field measurements to validate against any estimated values derived from the Recharge and Discharge Estimation spreadsheets.

4.2. Introduction to MapConnect

MapConnect is an interactive mapping service. It is a convenient and user-friendly way to access map data and print maps. It contains four mapping 'themes':

- **250K** allows the user to preview, interrogate and download 1:250,000 scale topographic data;

- **Global Map** accurately describes the present status of the global environment in international cooperation of respective National Mapping Organizations (NMOs) around the world;

- **Geology** contains the seamless 1:2.5 million and 1:1 million scale Surface Geology of Australia maps; and

- **Groundwater** provides input data to the Recharge and Discharge Estimation spreadsheets.

4.2.1. Disclaimers

The data, information and materials available through MapConnect may not be owned by CSIRO. CSIRO makes no warranties or representations with respect to the data, information and materials available through MapConnect and no reliance should be placed upon it without seeking prior professional, scientific and technical advice.

To the extent permitted by law, CSIRO (and its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs expenses and any other compensation, arising directly or indirectly from any use of the data, information or materials (in whole or in part) available from MapConnect.

4.2.2. Licensing

MapConnect operates under Creative Commons Attribution 3.0 Australia. More information is available from MapConnect or http://creativecommons.org.au/.

4.2.3. Use limitations

The datasets made available via the Groundwater theme of MapConnect are developed specifically for use with the Recharge and Discharge spreadsheets and should not be used for other purposes.

4.3. System Requirements

MapConnect requires the user to have internet access and a web-browser. The system has been tested against Internet Explorer and Mozilla Firefox, but is assumed to operate on all web-browsers.

4.4. Getting Started

4.4.1. Obtaining the software

MapConnect can be obtained simply by navigating via a web-browser to http://www.ga.gov.au/mapconnect/.

4.4.2. Installation

There are no installation requirements for MapConnect.

4.5. Using the Software

4.5.1. Accessing MapConnect

MapConnect is accessed by going to http://www.ga.gov.au/mapconnect/. This will take you to the Geoscience Australia MapConnect Disclaimer page (Figure 4.1). Select the theme of interest, agree to the terms and conditions outlined on the webpage by checking the box, and click on **<Enter MapConnect>**. This will take you to the main MapConnect interface page.

Figure 4.1. Geoscience Australia MapConnect disclaimer webpage, including selection of themes (A), disclaimer agreement (B) and Enter MapConnect button (C).

4.5.2. MapConnect interface

Figure 4.2 displays the basic MapConnect interface including themes, toolbar, map frame, tabs and interactive scale bar.
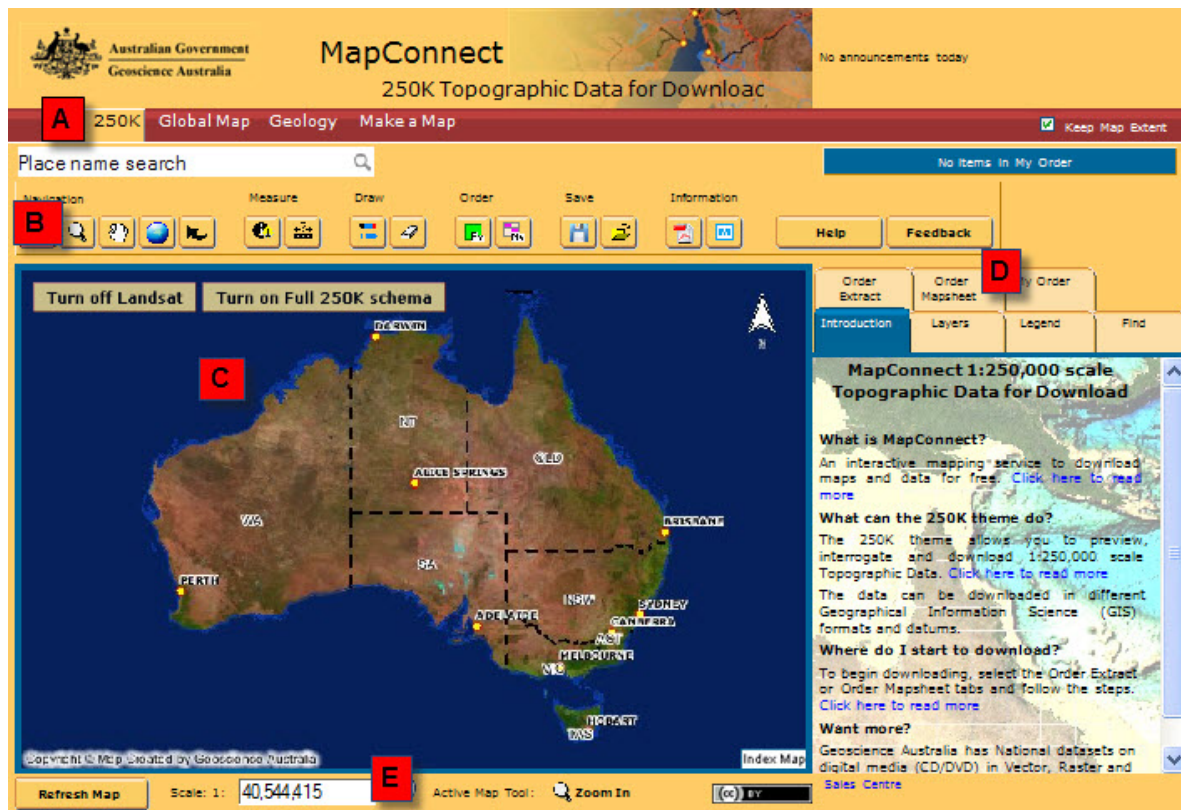
Figure 4.2. MapConnect interface including MapConnect themes (A) toolbar (B), map frame (C) used for zooming, panning, identifying and measuring, tabs (D) used to display different panels of information, and interactive scale bar (E).

> **Note**
>
> For the purposes of this report, we are only interested in the Groundwater Theme functionality as it relates directly to the Recharge and Discharge Estimation spreadsheets.

4.5.3. Groundwater theme interface

The Groundwater theme can be selected by clicking on **Groundwater** in the MapConnect theme list (Figure 4.3). Tools on the toolbar are divided into:

- **Navigation**: Zoom In, Zoom Out, Pan, Full Extent and Previous Extent;

- **Measure**: Drill Down Identify and Measure Distance;

- **Draw**: Open MarkupTools and Erase Tools;

- **Select**: Select Site Data and Select Sites For Download;

- **Save**: Save Session and Open Session; and

- **Information**: Quick Print and Metadata.
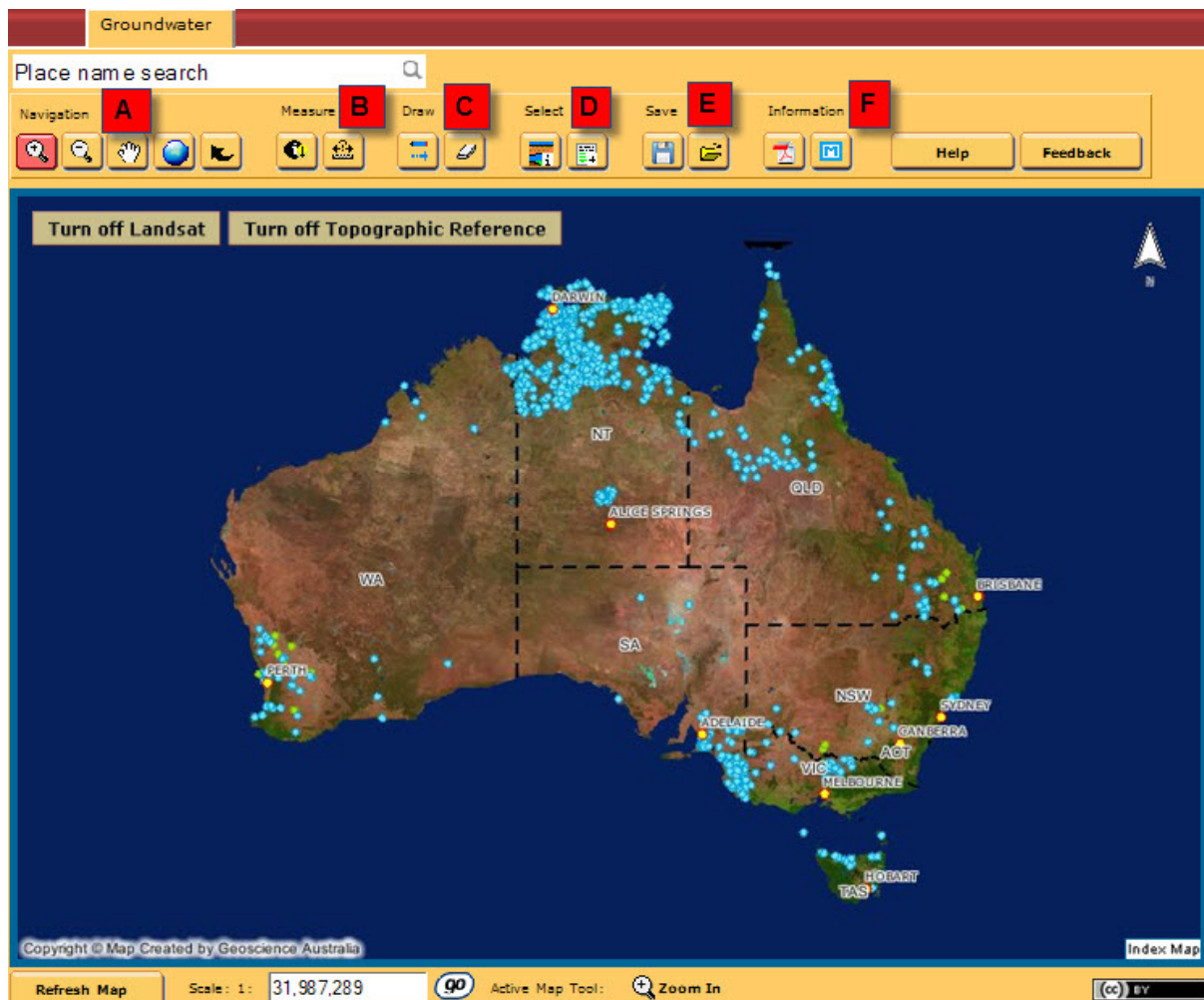
Figure 4.3. Groundwater theme toolbar including navigation (A), measure (B), draw (C), select (D), save (E) and information tools (F).

There is also a button to navigate to **Help** and also **Feedback**. The **Measure** and **Draw** tools are standard to all MapConnect themes but are not directly applicable to the Groundwater theme.

There are also a number of tabs (Figure 4.4), including:

- **Introduction:** provides basic background information about MapConnect, the purpose of the Groundwater theme, and supplementary information.

- **Layers:** lists the various layers available within the Groundwater theme. This includes basic topographic information such as roads, watercourses and towns, as well as the ten national scale datasets complied specifically for input into the Recharge and Discharge Estimation spreadsheets.

- **Legend**: describes all icons and colour schemes/classifications for all active layers (checked in the Layers tab).

- **Find**: provides four different means of zooming in – Zoom State, Find Geodata Index Feature, Advanced Find, and Zoom Coordinate.

- **Field Site Data**: means by which recharge and/or discharge field measurements can be viewed, including title, author and year of publications of the source, latitude and longitude of specific field measurement, vegetation information, depth to watertable (if available), either the groundwater recharge or discharge estimation, and the technique used.

- **Site Query List**: site query results from recharge and discharge specific data layers, including, latitude and longitude, potential evapotranspiration, annual average rainfall, soil classification, geology/regolith, vegetation clearing, vegetation type, MOLR recharge estimation, and chloride deposition in rainfall.

- **My Order**: This tab is no applicable to the Groundwater theme
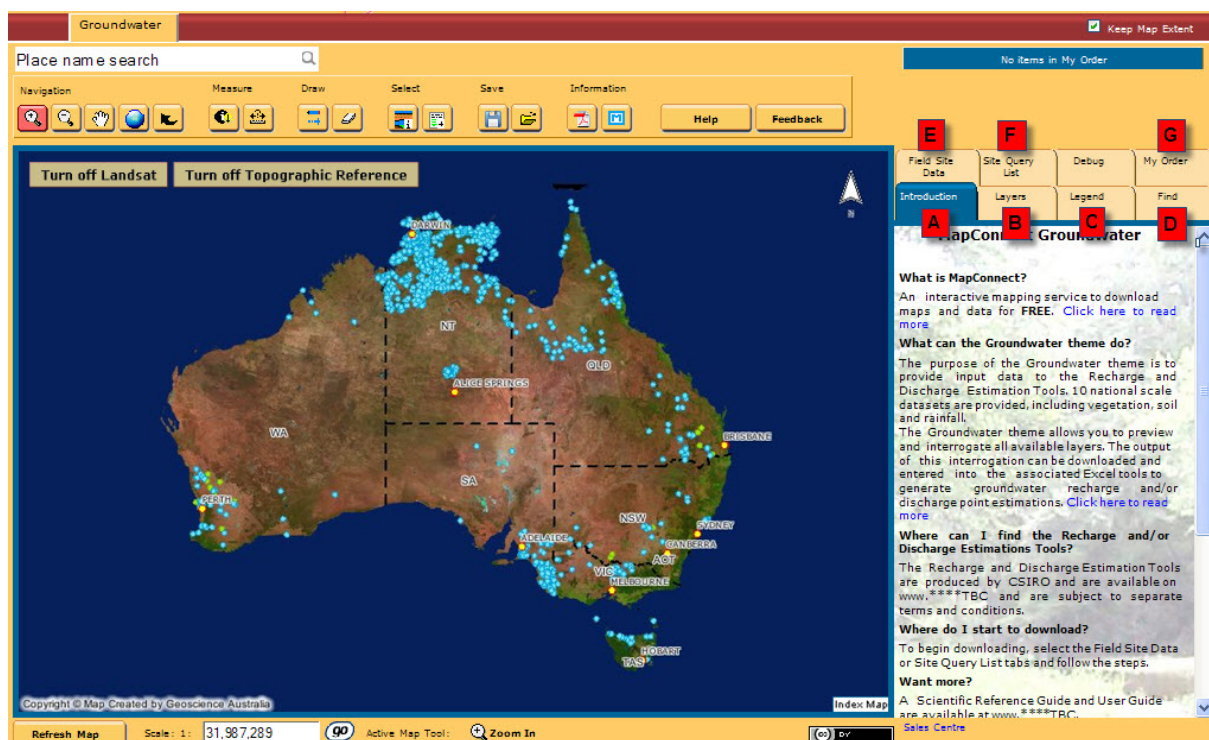
Figure 4.4. Groundwater theme tabs including introduction (A), layers (B), legend (C), find (D), field site data (E), site query list (F) and my order (G).

4.5.4. Finding your area of interest

Recharge and/or discharge estimations can be obtained from point locations across the entire country. This however is not particularly useful to the user. Instead, to appropriately apply the Recharge and Discharge Estimation spreadsheets, the user must first decide where to obtain recharge and/or discharge estimations (area of interest). The authors recommend the area of interest be approximately catchment size however this is at the discretion of the user. There are a number of ways to navigate to the predetermined specific area of interest, by:

- Manually searching using the **Zoom In**, **Zoom Out** or **Pan** tools, located in the toolbar (Figure 4.3);

- **Zooming by State**, located in the **Find** tab (Figure 4.5);

- Selecting a **Geodata Index Name** (map sheet), located in the **Find** tab (Figure 4.5);

- Using the **Advanced Find** to locate a place of interest, located in the **Find** tab (Figure 4.5); and

- Entering specific **Zoom Coordinate**, located in the **Find** tab (Figure 4.5).
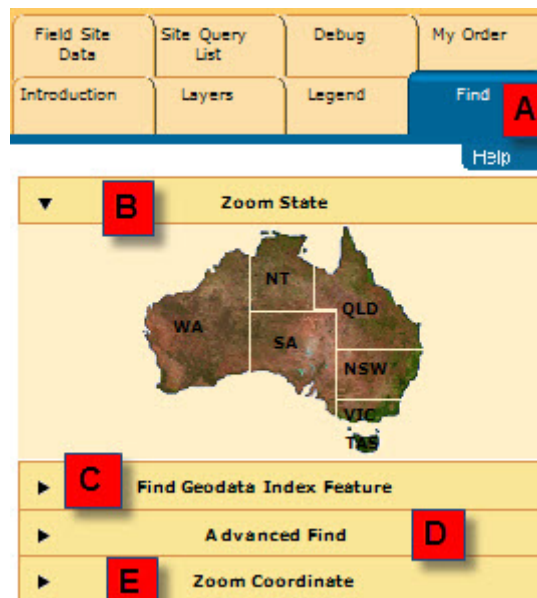
Figure 4.5. Groundwater theme Find tab (A), displaying find functions – Zoom State (B), Find Geodata Index Feature (C), Advanced Find (D) and Zoom Coordinate (D).

Turning on and off layers

There are two groups of data within the **Layers** tab: **Topographic Layers** and **Groundwater** data. **Topographic Layer** (Figure 4.6) data is useful when locating your area of interest as discussed above. **Groundwater** data (Figure 4.6) is the information required to populate the Recharge and Discharge Estimation spreadsheets discussed in Chapters 2 and 3. There are three icons next to each layer. They are in order from left to right: **toggle labels**, **zoom in or out to visible resolution**, and **zoom to extent** (Figure 4.6**)**.
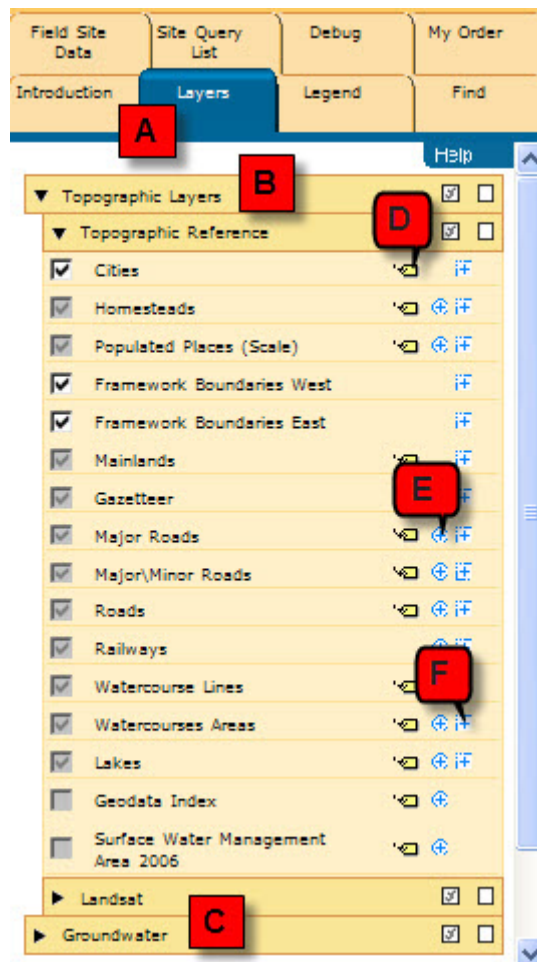
Figure 4.6. Layers tab (A) within Groundwater theme, including Topographic Layers (B), Groundwater data (C) and associated icons Toggle Labels (D), Zoom In or Out to Visible Resolution (E), and Zoom to Extent (F).

Topographic Layers data

Topographic Layers data is grouped into **Topographic References**, such as capital cities, homesteads, populated places roads, railways, watercourses and lakes; and Landsat which is the default image displayed in the map frame (Figure 4.7). Depending on your level of zoom, **Topographic Reference** layers will automatically become visible to assist you in getting your bearings.Figure 4.7. Topographic Layers data within the Groundwater theme, including Topographic Reference (A) and Landsat data (B) displayed as a default in the map frame (C). Note the 'greyed' out tick boxes (D).

Table 2 provides the resolution at which the various layers become available. You can also turn on and off the various layers listed in the **Layers** tab by checking the boxes (Figure 4.7).
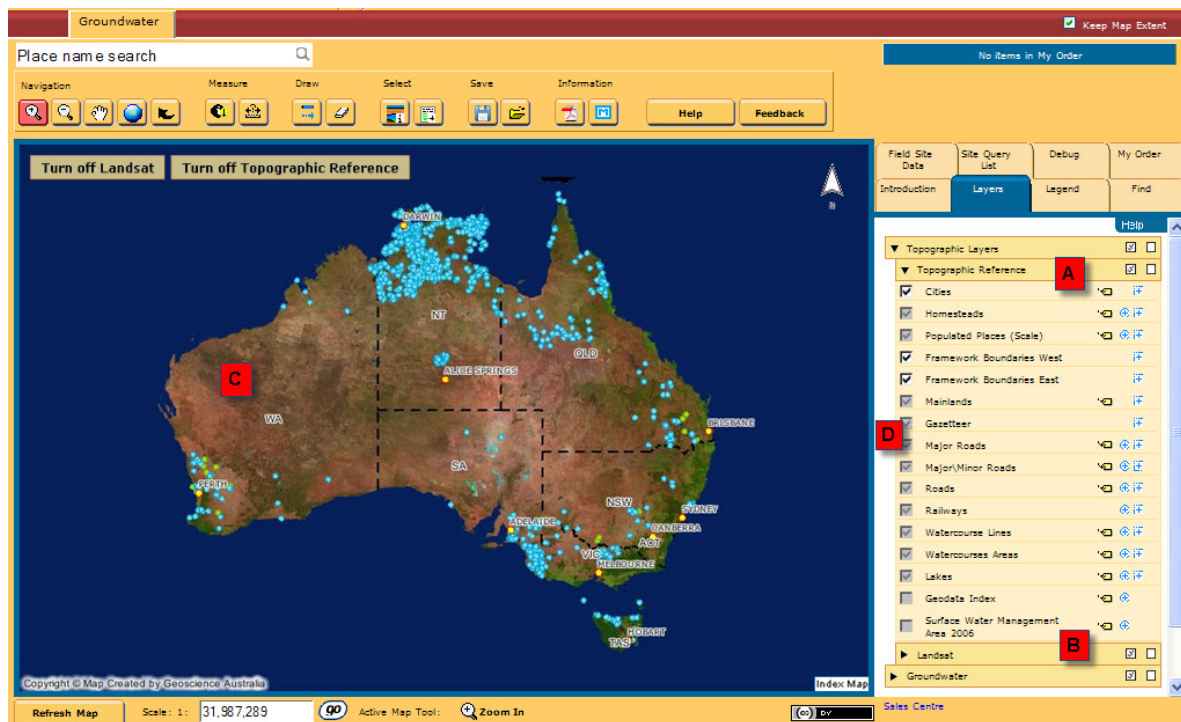
Figure 4.7. Topographic Layers data within the Groundwater theme, including Topographic Reference (A) and Landsat data (B) displayed as a default in the map frame (C). Note the 'greyed' out tick boxes (D).

Table 2. Spatial resolution at which various topographic reference layers are displayed.

Topographic Reference	Resolution
Cities	>1:5M
Homesteads	<1:500k
Populated Places	<1:5M
Framework Boundaries West	>1:250k
Framework Boundaries East	>1:250k
Gazetteer	>1:10M
Major Roads	1:10M-1:5M
Major\Minor Roads	<:5M
Roads	<1:500k
Railways	<1:10M
Watercourse Lines	<1:100k
Watercourse Areas	<1:5M
Lakes	<1:5M
Geodata Index	1:15M-1:500k
Surface Water Management Area 2006	<1:3M

Note

If a layer tick box is *greyed* out (Figure 4.7), this means you have not zoomed in sufficiently and the layer cannot display. The **interactive scale bar** (Figure 4.2) is a quick way of ensuring the appropriate zoom level has been reached. The **zoom in or out to visible extent** icon can also be used to zoom to the appropriate spatial resolution.

Groundwater data

The Groundwater datasets shown in the **Layers** tab (Figure 4.8) include the following:

Recharge Database - Estimates of recharge conducted across Australia as identified by the review of Crosbie *et al.* (2010a).

Discharge Database - This data set compiles information on components of the water balance from plot scale studies around Australia and in particular those studies that have identified groundwater discharge through vegetation as a component of the water balance. The data has been collated from published literature in journal article and reports. It provides spatial coverage of field estimates of discharge conducted across Australia as identified by the review of O'Grady et al. (2010).

Geology/Regolith - The Geology/Regolith dataset is a generalised version based on regolith type of the Surface Geology of Australia (2010 edition) released by Geoscience Australia.

Soil Classification - The soil landscapes map showing the soil landscape classes from the ten sheets of the Atlas of Australian Soils. Attributes include the Atlas of Australian Soils map unit (soil landscape) and dominant soil type attributes.

Vegetation Clearing - This dataset is a union of the Integrated Vegetation Cover 2009 (IVC) obtained from Australian Bureau of Agricultural and Resources Economics and Sciences (ABARES) and the draft version of the Dynamic Land Cover Map based on Moderate Resolution Imaging Spectrometer (MODIS) Data, obtained from Geoscience Australia. The categories are No, Yes, Requires further investigation, and Null, associated with urban areas or water bodies.

Vegetation Type - The source data for this dataset is the draft version of the Dynamic Land Cover Map based on MODIS Data, obtained from Geoscience Australia. This dataset was reclassified into Annuals, Perennials, Water Bodies and Urban Areas.

MOLR - This dataset (and the derivative 95% confidence interval for upper and lower datasets) were created by CSIRO and provides a spatial coverage of estimates of the long term average annual recharge estimates across Australia. It is based upon regression equations between soil order, vegetation type and long term average annual rainfall. More details on the method used to estimate this dataset are provided in the Scientific Reference Guide (Leaney *et al.*, 2011).

Average Annual Rainfall - This average precipitation grid are current as at 10/3/2011 and is version 3 of the Australian Water Availability Project at the Bureau of Meteorology. It is the average precipitation for all months from January 1900 until December 2010.

Potential Evapotranspiration - This dataset is the mean annual surface evaporation between 1981 and 2006 and estimates potential evaporation using a variety of methods as well as intermediary datasets.

Chloride Deposition in Rainfall - The chloride deposition dataset is created by taking observational chloride in rainfall data from 291 sites across Australia and interpolating it to form a gridded data set at a resolution of 0.05° x 0.05° for the region of Australia. This dataset (and the derivative 95% confidence interval for upper and lower datasets) were created by CSIRO.
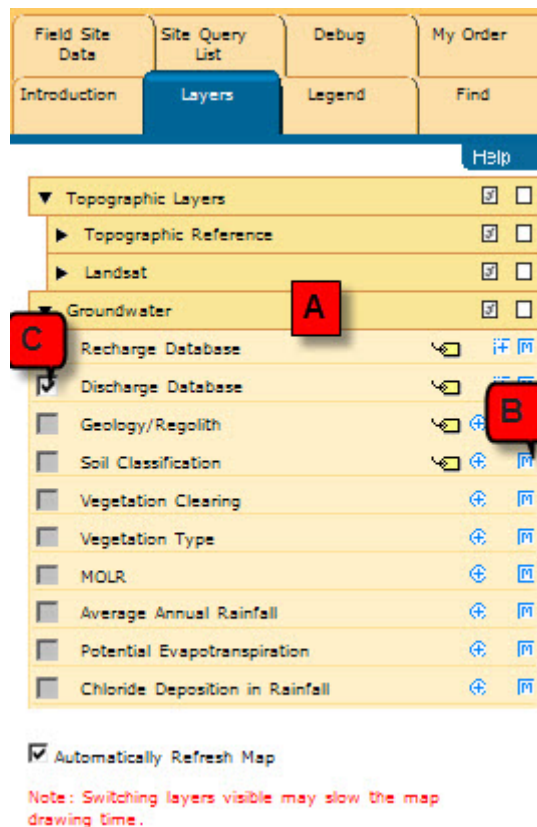
Figure 4.8. Groundwater data (A) within Groundwater theme, including Metadata icon (B) and tick boxes (C).

Further metadata is available for each layer by clicking the **M** icon next to the appropriate layer title (Figure 4.8) or referring to the accompanying Scientific Reference Guide (Leaney *et al.*, 2011). As was the case with the **Topographic Layer** data, each of these layers can be turned on and off by checking the boxes in the **Layers** tab (Figure 4.8).

> **Note**
>
> The **Recharge** and **Discharge Databases** are visible at the national scale while the other layers can be viewed at a scale of 1:3 million or less. Again the **interactive scale bar** (Figure 4.2) can be used to zoom to the appropriate resolution. With the exception of the **Recharge** and **Discharge Database** layers, only one **Groundwater** layer will be visible at one time. Any number can be ticked but only one will be displayed.

What does it all mean?

The **Legend** tab provides information about what is currently selected in the **Layers** tab and displayed in the map frame (Figure 4.9). This will help you make sense of what you are seeing. The **Legend** includes icons as well as colour schemes of the various **Groundwater** layers. This information will be useful when you come to defining sub-areas.
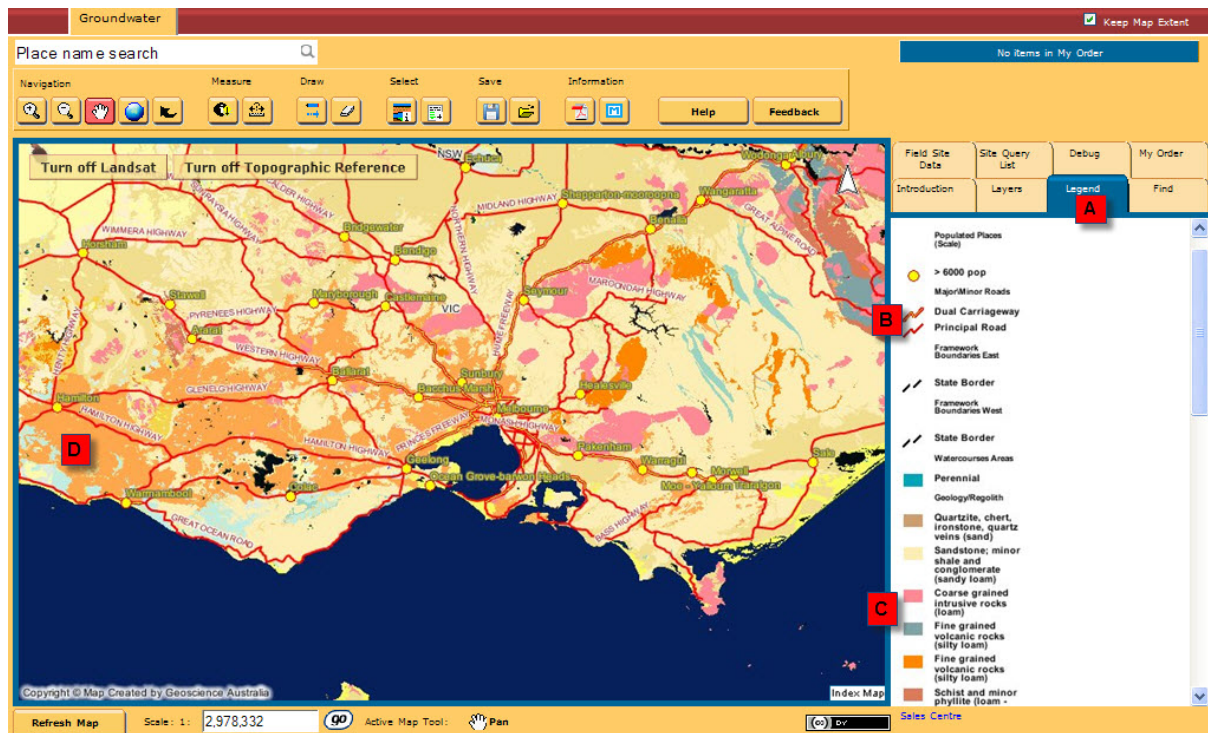
Figure 4.9. Groundwater theme Legend tab (A), including icons (B) and colour schemes (C) of the displayed datasets in map frame (D).

4.5.5. Defining sub-areas within your area of interest

You have now zoomed to your area of interest. Obtaining a single estimate of recharge and discharge somewhere within this area is unlikely to be representative of the whole area, hence an average estimate is required. Groundwater recharge and discharge fluxes vary with a number of key parameters, principally depth to watertable, soil, vegetation and rainfall. If these parameters vary spatial within your area of interest, then the authors strongly recommend the discretization of the area of interest into sub-areas based on combinations of the key parameters. This can be checked by turning on and off the various **Groundwater** layers (see Section 0 for information on turning on and off layers). Where a different combination occurs, it is recommended that the relevant groundwater data be acquired for each combination, except where the areal extent of the sub-area is negligible in relation to the area of interest as a whole. More details relating to defining sub-areas and some case study examples can be found in the Scientific Reference Guide (Leaney *et al.*, 2011).

4.5.6. Acquiring groundwater data

As discussed in Chapter 2 and 3, a number of questions must be answered in the Recharge and Discharge Estimation spreadsheets to generate an estimate. To assist in this process, eight national scale datasets (referred to in Section 0) are available to query. The categories used in these datasets are directly applicable to the Recharge and Discharge Estimation spreadsheets.

To query the data either click the **<Select Sites for Download>** tool or the **Site Query List** tab (Figure 4.10). By clicking any point on the map, information from all eight Groundwater layers will be displayed in the **Site Query List** at that location (Figure 4.10).

> **Note**
>
> In some instances, the following error message **Problem retrieving data** will be displayed in the **Site Query List** tab (Figure 4.10). If this occurs, click on the **Refresh Query** button (Figure 4.10). Ensure all information is retrieved.

This point can then be assigned a **Point ID** (Figure 4.10) or name and saved as a query by clicking on **<Add to List>** (Figure 4.10). The point and name will then be displayed on the map (Figure 4.11) and the display in the **Site Query List** tab changes to that shown in Figure 4.11. Continue to add as many points as desired. The most recently queried site will be displayed in full, while other saved query sites will be listed but in collapsed format (Figure 4.11). The full information for any site can be viewed by clicking on the **expand/collapse** icon (Figure 4.11). If you wish to remove a selected site, click on the **X** next to the relevant site **Point ID** (Figure 4.11).

> **Note**
>
> This list will only be retained within the current MapConnect session. The data must now be downloaded.
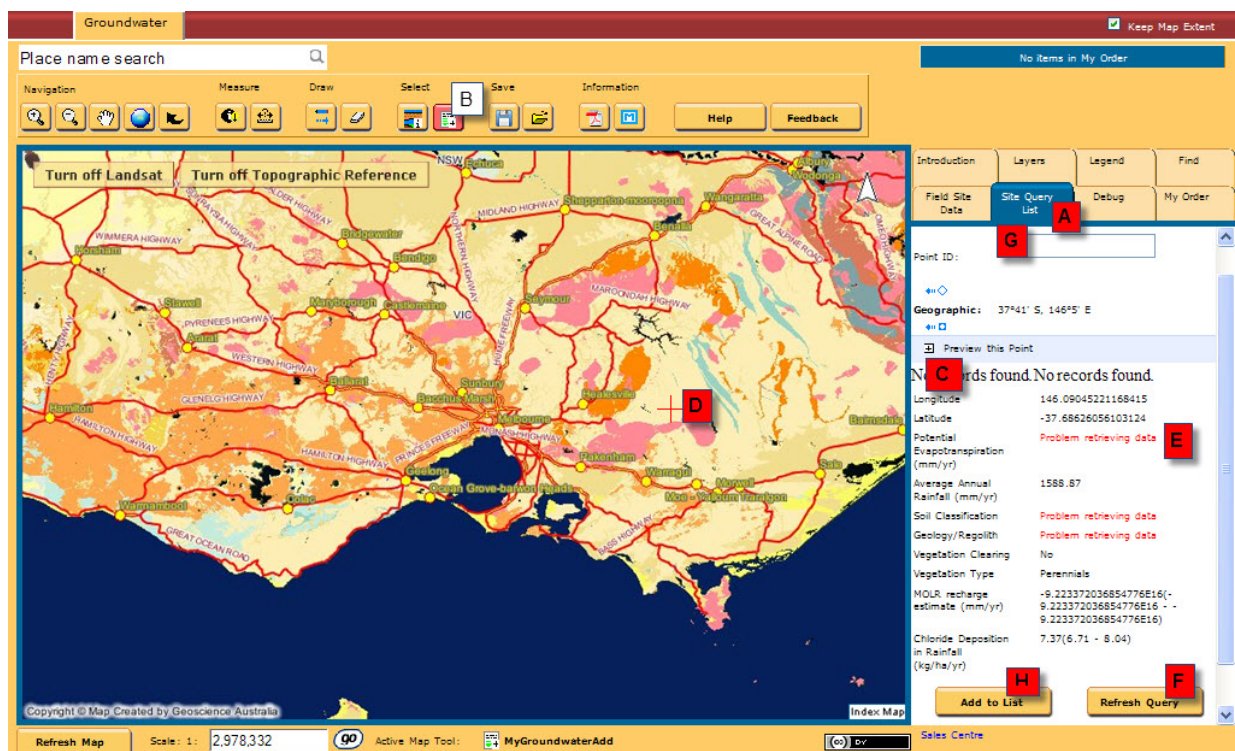
Figure 4.10. Site Query List tab (A) and Select Sites for Download tool (B). Data from the various Groundwater datasets is displayed in the Site Query List tab (C) for the particular location selected in the map frame (D). In same cases, not all information is retrieved (see error message in red; E). If this occurs, click on the Refresh Query button (F) until all data is displayed. Then type in a Point ID in the available field (G) and click Add to List button (H).
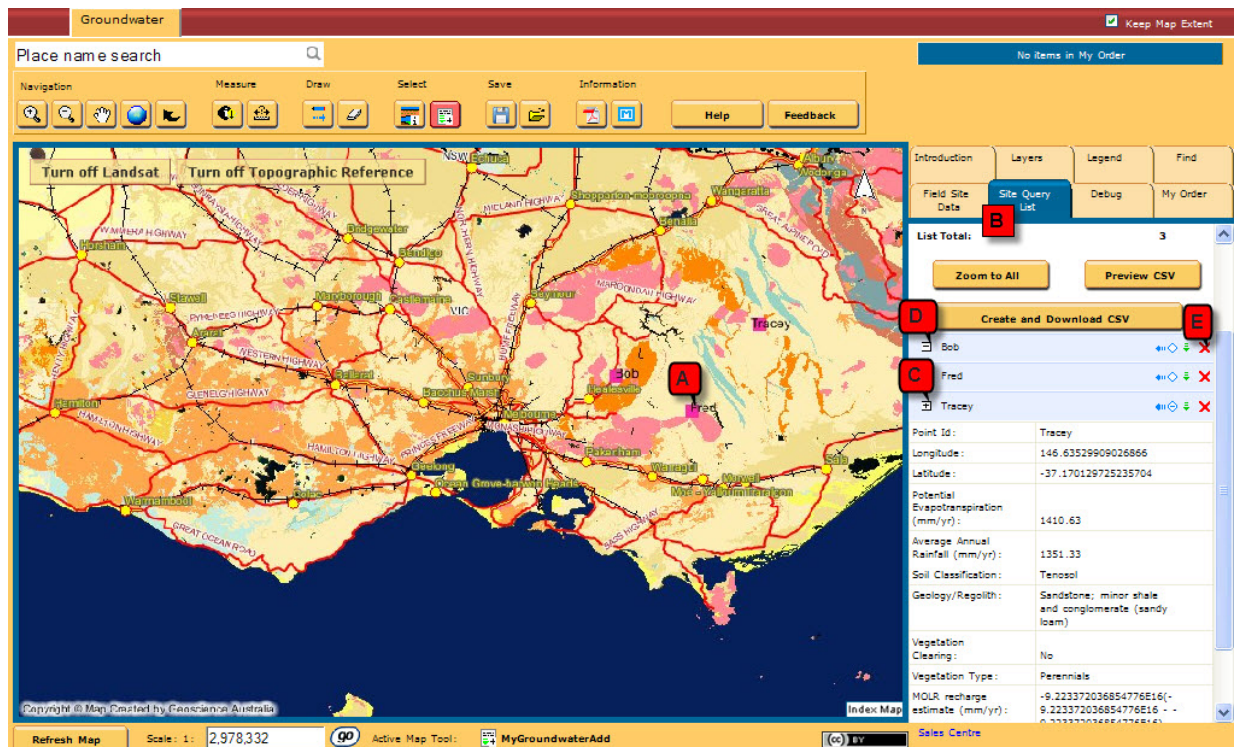
Figure 4.11. Map frame with query site marked and labelled (A) and associated Site Query List tab (B). The most recently acquired point is shown in full (C) and all others are collapsed (D). Collapsed records can be expanded by clicking on the expand/collapse icon (D). Records can also be deleted by clicking on the Delete Point icon (E).

4.5.7. Downloading data

Data can be downloaded on a site by site basis or for the full list shown in the **Site Query List** tab at any one time. The download file format is a .csv file that can be opened in Microsoft Excel. The data can be either previewed as a CSV file (**Preview CSV**) or downloaded (**Create and Download CSV**) as shown in Figure 4.12. Use this data to manually populate the Recharge and Discharge Estimation spreadsheets.

Figure 4.12. Site Query List tab (A) with Preview CSV button (B), Create and Download CSV button (C) which allows the user to download all listed points, and Download this Point icon (D) which only downloads the particular point selected.

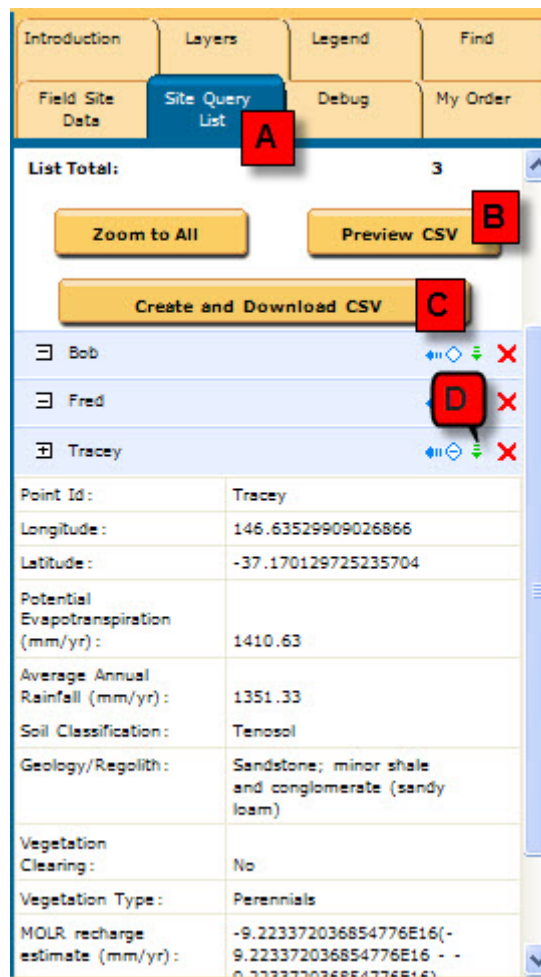### 4.5.8. Validating results from the recharge and discharge estimation spreadsheets

The purpose of the Groundwater theme is to provide input data for the Recharge and Discharge Estimation spreadsheets however it can in some areas also be used to validate estimates generated from the Recharge and Discharge Estimation spreadsheets. There are two datasets in the **Layers** tab under **Groundwater** (Figure 4.8) that are not queried with the **Select Sites For Download** tool as discussed in Section 4.5.6. These are the **Recharge** and **Discharge Database**. As mentioned in Section 0, these are a collection of field point measurements of groundwater recharge and discharge. If any site is in close proximity to your area of interest, it can be used to compare against results from the Recharge and Discharge Estimation spreadsheets.

To view the Recharge and/or Discharge Database, either click on **<Select Sites Data>** tool in the toolbar or select the **Field Site Data** tab and click on the **< >**icon shown in the tab. This will make active the selection tool. Click on any of the blue or green dots shown on the map.

> **Note**
>
> If no dots are visible, check that the **Recharge** and **Discharge Database Groundwater** layers have been checked in the **Layer** tab. If not, check them. The distribution of data points is very patchy therefore you may need to zoom out to locate any nearby sites.

Once you have selected a site, information about that site will be displayed in the **Field Site Data** tab (Figure 4.13). This includes the title, author and year of publication in which the measurement appears; location at which the measurement was taken, vegetation type and rainfall at the location; groundwater recharge or discharge estimate and the technique used to acquire the measurement. This information can only be viewed in this fashion and is not downloadable.
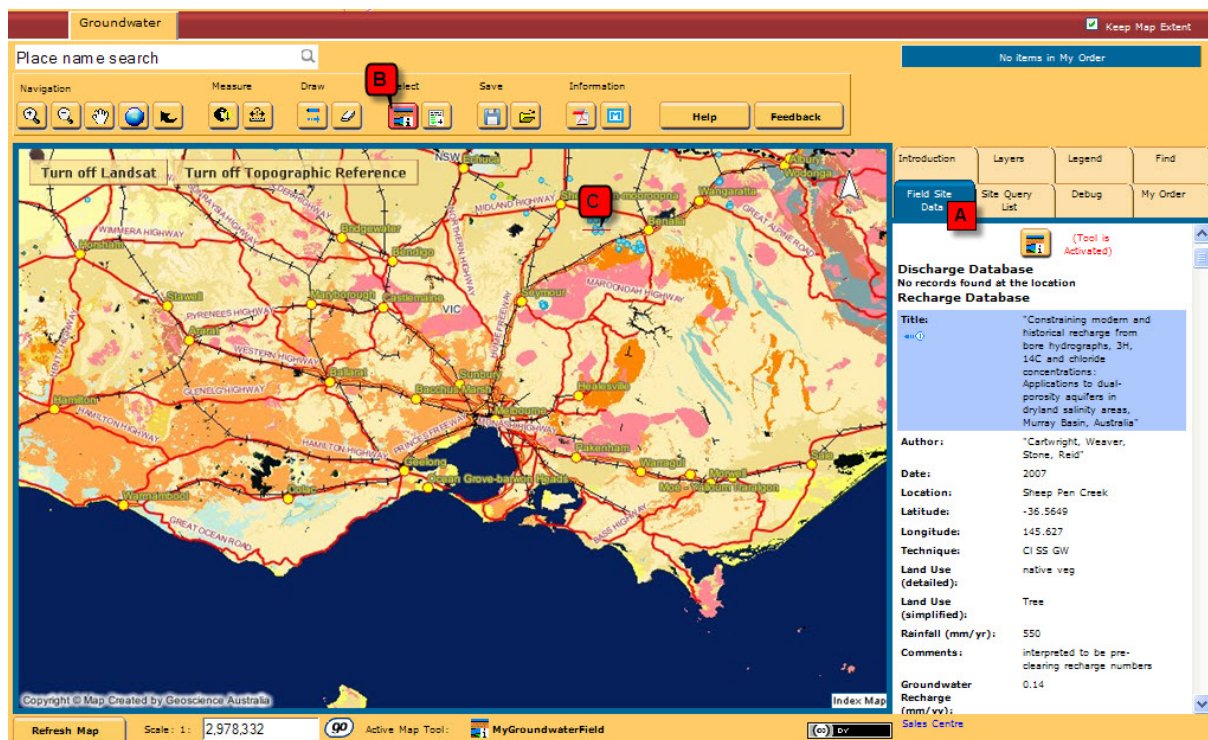

Figure 4.13. Field Site Data tab (A) and Select Site Data tool (B). By clicking on a recharge of discharge database point (C) information about that point is displayed in the Field Site Data tab.

4.6. Troubleshooting

My map is taking a long time to refresh when I turn on and off layers

Some of the layers are quite large and can take a little while to display, particularly if layers are quickly being turned on and off. If it has been longer than a minute or two, click on the Refresh Map button in the bottom left hand corner.

I have selected a Site for Download or a Recharge or Discharge Database point and its taking a long time to display

On occasion, the system will 'freeze' when trying to query the data or display information is the side tabs. If it has been longer than 2 minutes, reselect the point or location.

I can't turn any of the layers on or off

You most likely have not zoomed in or out to the appropriate spatial resolution. Refer to Section 0 for further information.

The Groundwater layer I have selected is not displaying

You may have to turn off some of the other Groundwater layers to display the particular layer of interest. Refer to Section 0 for further information.

I'm getting a null for the MOLR recharge estimate in the Site Query List tab

This dataset does not cover the whole country. There are some places that a relationship could not be established between the key variables of rainfall, vegetation type and soil order, hence a null value was assigned. For more information, refer to the Scientific Reference Guide (Leaney *et al.*, 2011).

I'm getting a Problem retrieving data error message in the Site Query List tab

There has been an issue querying that particular layer. Click on the Refresh Query button in the Site Query List tab until information for all relevant fields is displayed. At this point, click on Add to List to save the information. Refer to Section 4.5.6 for further information.

I can't find any Recharge or Discharge Database points

You might have turned off the relevant layers or be zoomed in to an extent that does not have any field site measurements. Check that the layers have been turned on and zoom out. Refer to Section 4.5.4 for further information.

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GLOSSARY

Aquifer
Saturated permeable soil or geologic strata that can transmit significant quantities of groundwater under a hydraulic gradient.

Aquitard
Saturated soil or geologic strata whose permeability is so low it cannot transmit any useful amount of water.

Discharge
Loss of water from an aquifer (i) to the atmosphere by evaporation, springs and/or transpiration, or (ii) to a surface water body (in the case of rivers it is generally referred to as base flow) or the ocean, or (iii) by extraction.

Groundwater
Sub-surface water in soils and geologic strata that have all of their pore space filled with water (i.e. are saturated).

Hydraulic gradient
Change in hydraulic head in an aquifer with either horizontal or vertical distance, in the direction of groundwater flow.

Recharge
Addition of water to an aquifer, most commonly through infiltration of a portion of rainfall, surface water or irrigation water that moves down beyond the plant root zone to an aquifer.

Vadose or unsaturated zone
Zone between land surface and the watertable within which the moisture content is less than saturation (except in the capillary fringe).

Watertable
Level of groundwater in an unconfined aquifer. The soil pores and geologic strata below the watertable are saturated with water.

Area of interest
Specific area of the landscape in which the user is interested in obtaining groundwater recharge and/or discharge estimations. This can be as large or as small as the user wishes but for realistic estimates, a catchment size area is recommended.

Sub-area
Smaller areas within the Area of Interest. Discretization is important as groundwater recharge and discharge can vary spatial depending on key parameters such as soil, rainfall, vegetation and depth to watertable.

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