Australian Government
Bureau of Meteorology

Groundwater Level Status and Trend Assessment

Method Report

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Introduction

In water resources reporting there is often interest in a high-level snapshot of the available resource. For surface water this snapshot is easily presented as a percent-full figure for major storages. Groundwater is more complex and there is no analogous figure to represent the status of groundwater resources.

Reporting on the status of groundwater can be a far more involved process as consideration must be given to many processes. Recharge, salinity, shallow water tables, surface water/groundwater interaction and groundwater dependent eco-systems can all be important to assess the health of a system. It is made more difficult because the resource is underground and not easily observed or measured.

The most common way to assess the resource is to look at groundwater levels measured from a bore. These are plotted as hydrographs which are assumed to represent changes in the resource over time. Trends in these hydrographs are then used to represent trends in the resource. Site specific knowledge is needed to properly interpret the cause of trends once they have been identified.

This report discusses the assessment of the groundwater resource as derived from hydrographs. It also presents a method for estimating status and trends. The aim of the report is to present a suitable robust method, that can be applied automatically with minimal need for review or visual inspection of results. However, it is not intended that this method be a standalone assessment of groundwater resources.

Purpose

Since 2015 the Bureau of Meteorology (the Bureau) has delivered a suite of Groundwater Information. A component of this information is to assess groundwater level status for a particular year and identify trends to give a snapshot of groundwater resources across Australia for non-groundwater experts. The aim of this work is to show where there is groundwater level data and calculate trends and status for these levels, where appropriate. The results are presented on a bore-by-bore basis for upper, middle and lower aquifer groups across Australia and published in the Australian Groundwater Insight (www.bom.gov.au/water/groundwater/insight). The intention is to give a snapshot of groundwater level status in the previous financial year compared to historical levels and of trends over 5, 10and 20 year periods. Examining trend and status data together is a useful way to give context to year-to-year changes. In fact, groundwater is a resource that should be available for use particularly when surface water is scarce as long as aquifers are able to recover over time, unless otherwise decided.

The method is described in the following sections.

Method

2.1. Recovery peak analysis

Groundwater data are notoriously variable, typically having sporadic temporal frequency, highly variable lengths of record, and limited quality control of the historical record. Recently, decreasing technology costs and increasing manual reading costs has seen a major improvement in the number of bores equipped with data loggers resulting in high-frequency observations becoming more common. However, this has created the problem of comparing recent high frequency observations with sporadic historical ones, making it difficult to apply a trend method across all groundwater systems in Australia. In addition, groundwater levels are influenced by several factors that vary over time. Extraction of groundwater resources is becoming a major influence on groundwater level fluctuations for high yielding aquifers.

To take these factors into consideration, the Bureau developed a method which focuses on assessing the trends and status of groundwater levels based on annual recovery peaks. The recovery peak is the maximum level observed in the bore each year due to recharge and/or water level recovery in the non-pumping season. To account for the various climatic zones and irrigation seasons across Australia, the period for the non-pumping season was selected as from July to April. The method automatically identifies recovery peaks during the non-pumping season, when the water levels are recovering or during possible recharge events associated with high rainfall, floods or streamflow, and compares them to similar groundwater levels in the historical record. This method accounts for the variability in the amount of data through time and issues with the quality of the observations. However, it is limited in its application as it requires a high frequency of water level readings for each bore.

2.2. Bore selection

To allow for direct comparison of trends and status across Australia, bores were selected based on the following criteria:

Bores must have data for the FY of interest.

Bores must have observations in at least 60% of the years in the period from the 1997-98 financial year (FY) to the FY of interest. The 1997-98 FY is considered to represent groundwater levels prior to the peak of the Millennium Drought (2001 – 2009). This gives additional context to the analysis by allowing a comparison between recent dry periods and the effect of the Millennium Drought on groundwater levels.

Bores in Tasmania have different criteria because regular observations started much later in this State. Tasmanian bores must have observations from the 2008-09 FY to the FY of interest.

For trends, bores must also have data for at least 60% of years in the relevant period for the trend analysis.

In addition, groundwater level readings outside 5 standard deviations from the mean are automatically removed as they are considered to be erroneous.

2.3. Status by bore

2.3.1. Method

The status analysis is a decile ranking of the groundwater level recovery peak for the financial year of interest for each bore, against each annual recovery peak in the historical record since 1996/1997 (refer to Figure 1). Bores with a level between the 30th and 70th percentile are classified as "average" while bores at or above the 70th percentile are "above average" and bores below the 30th percentile are "below average". This broad aggregation in 3 classes is considered necessary due to the unknown and often limited quality control of the historical record.

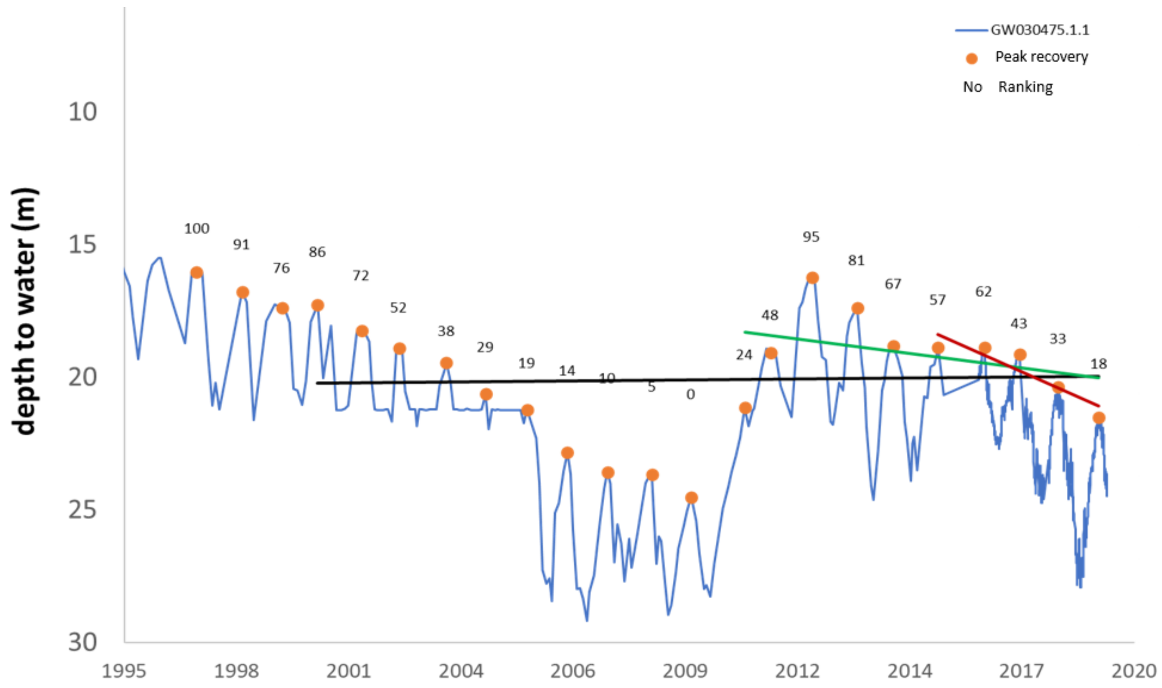

Figure 1: hydrograph GW030475.1.1, bore depth 83m, New South Wales, showing annual recovery peaks and their percent ranking. The status for 2019-20 peak (18) is below average.

An assessment of the results across a variety of bores indicated:
Not all recovery peaks are identified correctly, however, including sites with more than 20 years of data mitigates this and provides an overall assessment of the response in levels to changes through time (Figure 2)
A review of sites affected by rainfall or streamflow recharge (Figure 3) and sites with no or occasional recovery shows that the method still represents hydrographs status and trends (Figure 4).

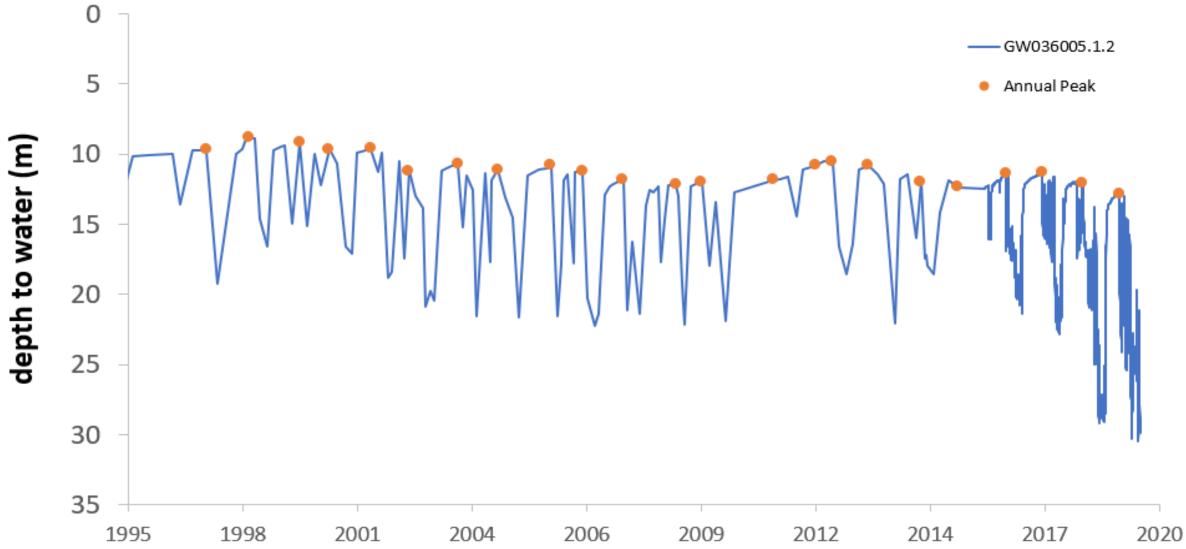

Figure 2: hydrograph GW036005.1.2, bore depth 84m, New South Wales.

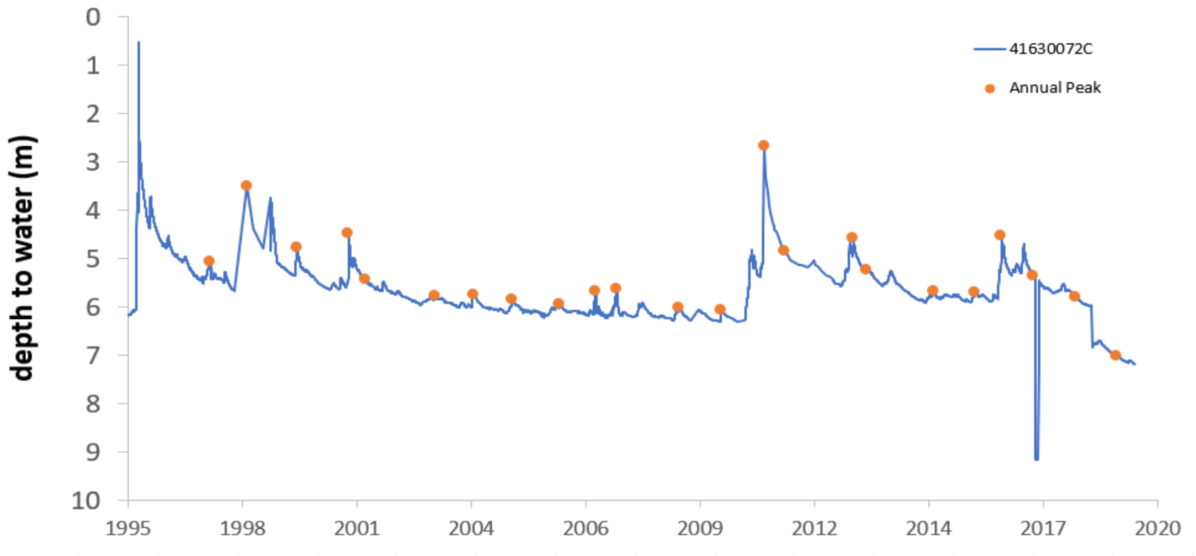

Figure 3: hydrograph for bore 41630072C, bore depth 10m, Queensland.

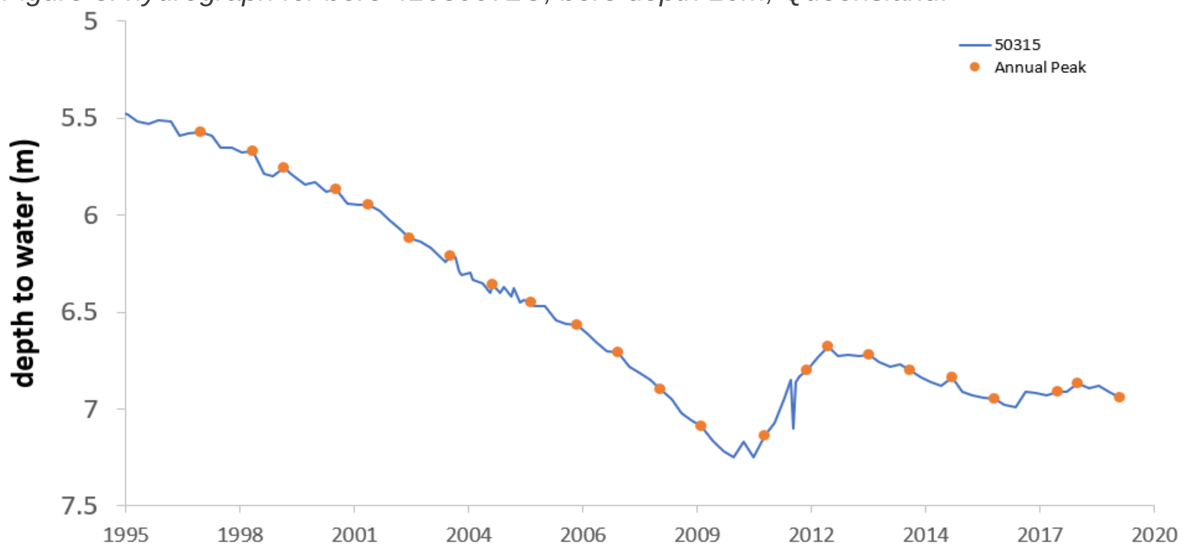

Figure 4: hydrograph 50315 bore depth 70m, Victoria.

2.4. Trends by bore

2.4.1. Why look at groundwater trends?

Measurements of groundwater level taken from a bore are the only direct measure of groundwater in an aquifer and are viewed as the most important data for hydrogeological analysis. Trends in groundwater level over time are of interest as they are often assumed to reflect the trend in groundwater resources in general.

Many studies have estimated trends in groundwater (e.g. Russo et al., 2014) and several methods have been used. These range from the simple linear regression through to complex statistical methods. Each method has varying levels of success, depending largely on the quality and quantity of data, and the desired level of detail in the results.

No method is currently accepted as the authoritative approach, simply because trends are estimated using highly variable datasets. The more sophisticated methods are typically only suitable for regularly spaced, high frequency time series data. Data sets of this quality are rare within Australia, where the use of electronic loggers for groundwater measurement is relatively sparse and recent. Based on the data delivered to the Bureau, it is estimated that around ~4000 bores across Australia are currently telemetered or are equipped with data loggers. Simpler methods are more appropriate for most of the data, though they tend to make large assumptions about the nature of the data they represent.

It is worth considering why groundwater trends are so commonly reported on. The reason seems to be that they give a simplification of what is typically complex and poor-quality data. Finding the trend in a hydrograph is viewed as one way to sum up what is happening in the aquifer at a location and condensing it to a single metric. This is usually a gross simplification of the actual hydrogeological processes that are occurring, which can be many and varied. However, it serves a useful purpose for communication and initial assessment. When applied spatially it can also highlight areas where levels are similar and where they are different.

2.4.2. Method

The trend assessment was carried out on the annual recovery peaks only (Figure 1). This was done to avoid distortion caused by the variation in frequency of groundwater observations over the period of assessment and more weight being placed on the recent high-frequency data than on the low frequency historical observations. The trend in the annual recovery peaks assesses the groundwater level recovery. For an in-depth discussion of methods used to calculate trends please refer to the Appendix.

The direction and magnitude of the trend is determined by applying the Ordinary Least Squares Linear regression (Method 1 in Appendix) to the annual recovery peaks as identified above. Among other things the choice of this method is due to its simplicity and common use. A detail discussion of the selection of the method is available in the Appendix.

The periods over which trends will be examined are 5, 10 and 20 years. This is to show context around trends, highlighting where and when they change and how they vary in time. Bores must have data for at least 60% of the years in the relevant trend period to be used in the analysis. The threshold for a "stable" trend is ±10cm/year. This value has been chosen to reflect the typical accuracy of the groundwater level measurements including historical manual ones and is consistent with other Bureau publications (Water in Australia, AWRA 2012 and State of the Climate 2019). A negative trend is classified as "declining" and a positive trend is classified as "rising."

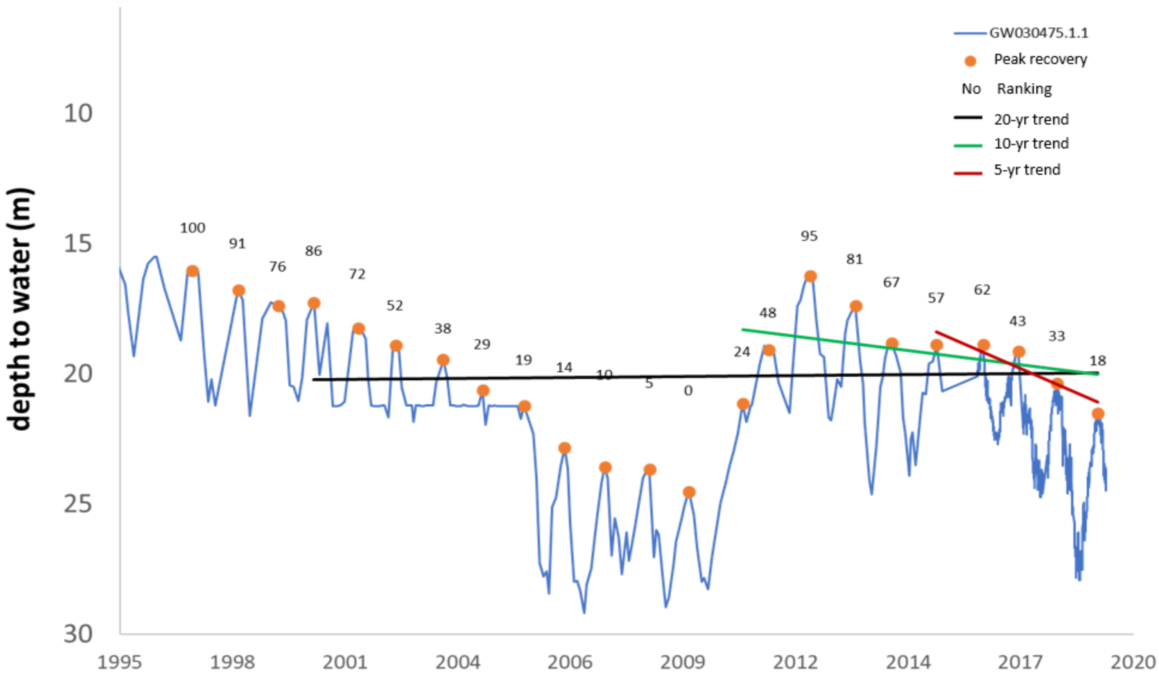

Figure 5: hydrograph GW030475.1.1, bore depth 83m, New South Wales.

Appendix - Selection of method for estimating trends in groundwater level (Sharples, 2015)

Components of trend

A trend is composed of three parts: a direction, a magnitude and a period. A groundwater level hydrograph might be described as 'declining significantly over the last two decades', and just as accurately 'rising moderately over the last few years. The example below demonstrates this.

Figure A1: hydrograph 109467, Victoria. Scale DTW: 5m

Yet if we compare this hydrograph using another y axis scale we might decide that the magnitude of the trend is insignificant in the context of our application and label it as 'stable'.

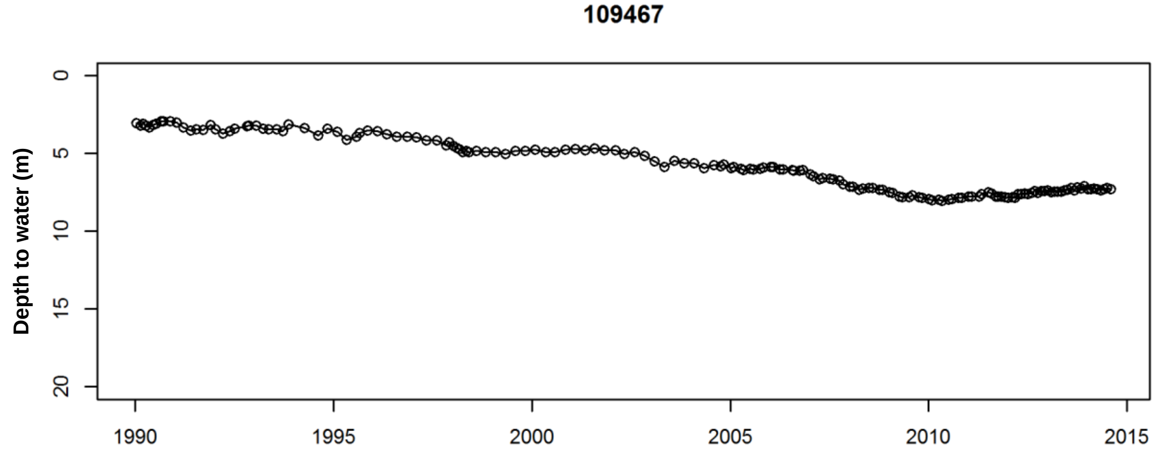

Figure A2: hydrograph 109467, Victoria. Scale DTW: 20 m

Methods for trend estimation

The Bureau requires a method for automatically estimating groundwater level trends at bores to be used in the Australian Groundwater Insight. Deriving a method to automatically estimate a trend is not trivial given the limitations of trend analysis methods. The approach

taken was to review and test 3 methods. The advantages and disadvantages of each method is presented below.
The first method assumes that the largest change is the most important; the second assumes that the trend is determined by the majority of the data points and the third offers a highly simplified approach.

Method 1 – Ordinary Least Squares

The first method discussed is the Ordinary Least Squares (OLS) linear regression (Goldberg, 1964). This is a very common statistical method applied in many applications, including groundwater.
OLS linear regression considers all data points equally and fits a line such that the sum of the square of the distance of each point from the line is minimised. The 'trend' in the hydrograph is estimated as the gradient of the fitted line.
This method tends to reflect the greatest magnitude change in the data. Applied to the example given below it produced a rising trends of 0.13 m/yr from 2007 to 2011 (see Figure A3).

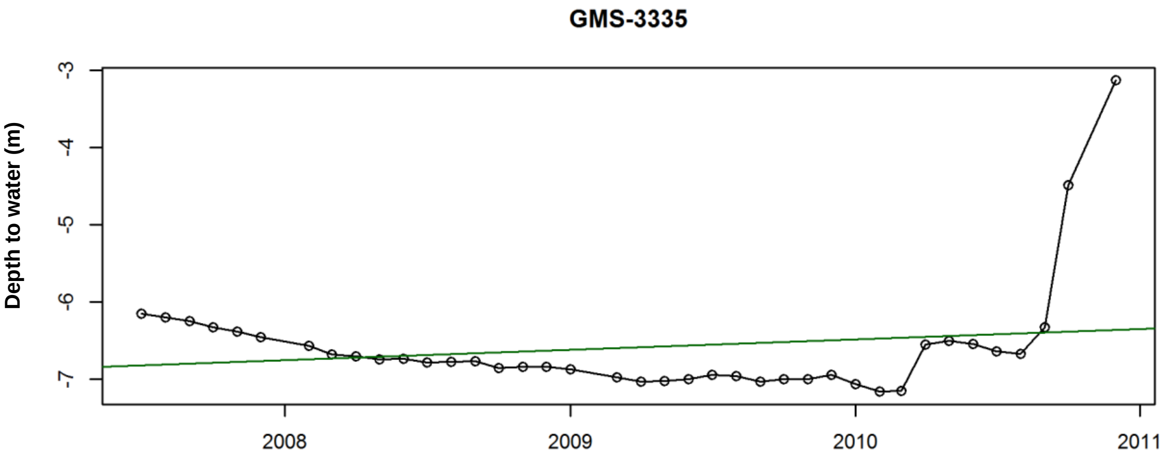

Figure A3: hydrograph GMS-3335, green line = Ordinary Least Squares linear regression.

Method 2 – Theil-Sen method

The second method discussed is the Theil-Sen method (Sen 1968 and Theil, 1950). It also fits a linear line however it does not weight all data equally. Rather, it fits a line which best reflects the majority of the data points. Essentially this method ignores outliers, or data that look like an outlier (e.g. the last two points in Figure A4) and fits a line that closely approximates the most data points.
The Theil-Sen single median method computes slopes of lines crossing all possible pairs of points, when x coordinates differ. After calculating these n(n-1)/2 slopes (these values are true only if x is distinct), the median of them is taken as slope estimator. This slope is used to estimate the hydrograph trend.
This method has been applied to groundwater to assess trend by Russo et al. (2014). The figure below shows the resulting fit when applying this method to the example hydrograph.

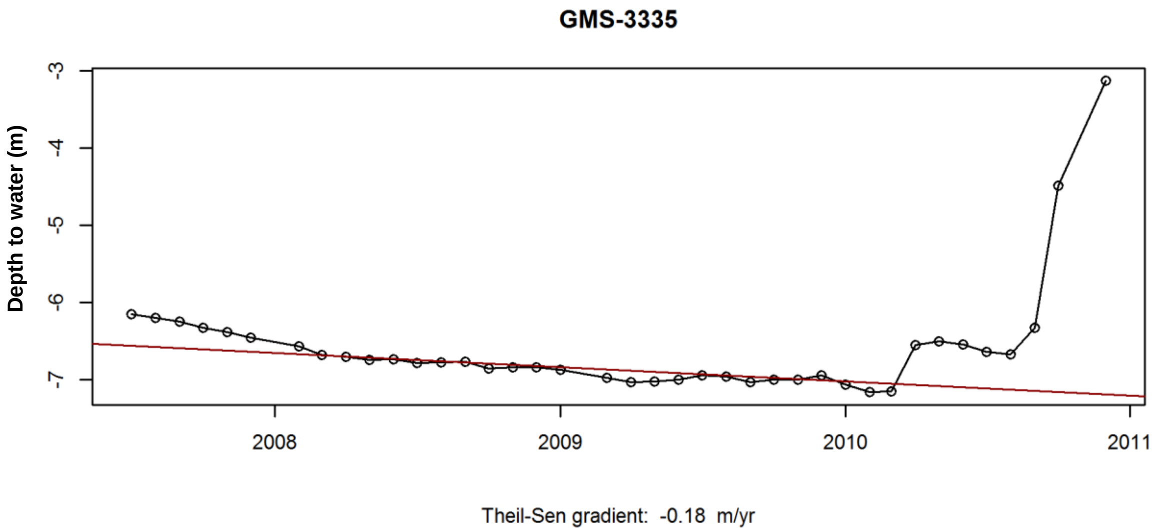

Figure A4: hydrograph GMS-3335, red line = Theil-Sen method liner trend.

The result is a trend of -0.18 m/yr from 2007 to 2011. Note that this is opposite in direction to the trend estimated by method 1.

Method 3 – Simple data comparison

Lastly a simple comparison between the first half and last half of the data is discussed. The method takes the average of the first half of the data and compares it to the average of the last half. If the average of the latter half of the data is above the first half we assume the trend is rising and vice versa if the latter half average is below the first half average. See Figure A5 below.
This is not recommended as a robust method but can be useful as a 'sanity check' of the methods listed above.

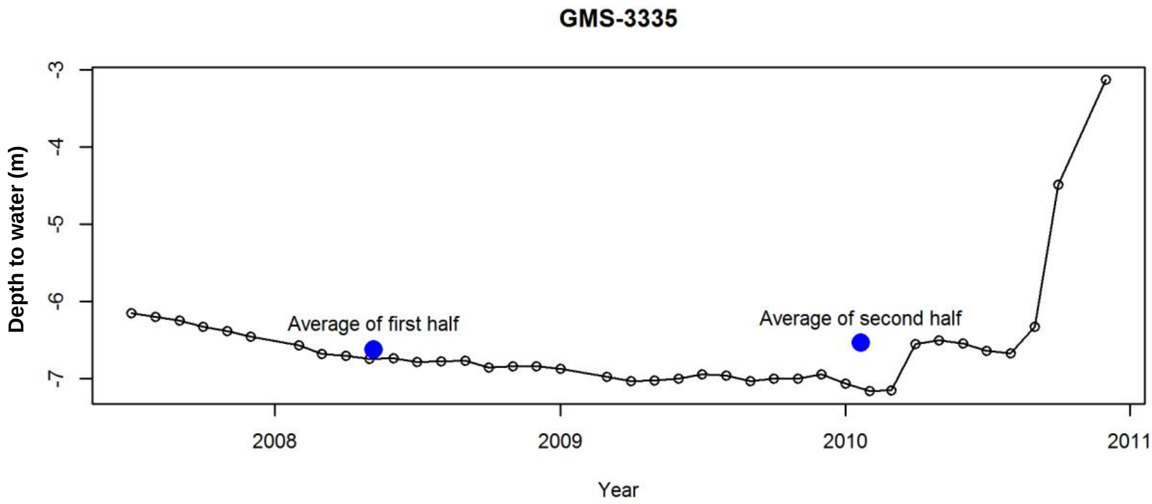

Figure A5: hydrograph GMS-3335. Blue dots are used to compare the average groundwater level from 2007 to 2009 to the average of the second period. A line fitted through these points will give a rising trend.

When is a trend stable? A subjective choice

The methods described above give both a direction and magnitude of a trend for a specific period. However, in practical application the magnitude of the calculated trend is often too low to be meaningful. For example, a rising trend of 0.1 cm/year is below the accuracy threshold for most equipment and could not confidently be attributed to a rise in groundwater levels rather than errors in measurements.

In these cases, an automated method to assess the trend as ‘stable’ is required. With an automated approach this can be achieved by setting a threshold on the magnitude of the trend. For example, any trend with a magnitude greater than ± 10 cm/year might be considered meaningful, whereas trends with a lower magnitude are not considered as meaningful, and are labelled ‘stable’.

The choice of threshold is arbitrary and should be chosen to suit the analysis being undertaken. Trends due to climate in a deep unconfined aquifer may be quite subtle, whereas those from pumping in a confined aquifer are likely to be large. Some hydrogeological experience is required when choosing this threshold.

Trends and statistical significance

Methods 1 and 2 can both give a statistic of fit when applying them to data. In the case of Method 1 (OLS) the statistic is the commonly used R^2, which offers an assessment of how close the linear fit is to the actual data. Similarly, a Kendall’s tau-b test can be performed in Method 2 to evaluate the significance of the trend, denoted (τ) (as done in Russo, 2014).

The use of a threshold value for a statistic to test a trend is often based on expert knowledge. Each statistic only gives a value, the threshold for this value needs to be chosen to suit the intended analysis. For example, an R^2 of 0.9 might be desirable for some applications whereas 0.8 might be sufficient in a different case.

It should also be noted that both the statistical tests (R^2 and τ) will return a value of zero when applied to a flat hydrograph. It is not appropriate to filter trends based on one of these statistics if ‘stable’ trends are of interest.

Both these methods are for estimating a linear relationship. Since processes influencing groundwater levels are not linear processes the results from applying these statistics are typically poor. Groundwater data in Australia are also typically measured infrequently, with loggers only being used more commonly in the last few years. This paucity of historical data, in particular, means that statistical methods are often applied to datasets with few data points, further reducing their usefulness.

Careful thought needs to be given when considering the application of one of these statistics.

Conclusion

Each trend method is different and will produce different results depending on the data and expectations of the user. For small scale applications each method can be applied and then the results reviewed to determine which is the best for the specific application. As the focus of the Australian Groundwater Insight is automation for application across Australia, the preferred approach is to minimise the amount of effort and interpretation required by a person and maximise the use of automatic rules. In this case, Method 1 is recommended. The audience for the Groundwater Insight is likely to be familiar with this simple type of linear regression and have some understanding of how it works. Clear communication of methods is viewed as desirable for this application.

References

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