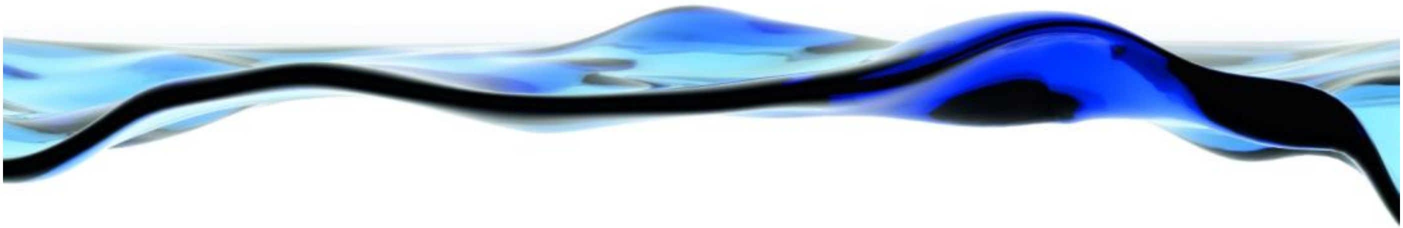
Facilitating Long-term Outback Water Solutions (G-FLOWS Stage-1): Hydrogeological Framework

Munday T, Abdat T, Ley-Cooper Y, Gilfedder M



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Project Background

Water is a critical resource for the growth and sustainability of the resources sector, particularly in outback regions of South Australia. This includes potable and non-potable sources that are used in ore-processing, slurry transport, dust suppression, human water consumption and in the maintenance of environmental and cultural assets. Planned and potential mining and energy development in South Australia's arid regions is set to have significant consequences for their water resources. Given that the resource sector generates significant economic value to the State their support remains a priority for the Government. The scale of the planned developments and the potential from current exploration programs facilitated by the South Australian Government through the Plan for Accelerating Exploration Initiative (PACE 2020) will result in a substantial increase in infrastructure requirements, including access to water resources and Aboriginal lands for exploration and potential mine developments.

In response to this increasing demand for information about water source options, the Goyder Institute for Water research (Goyder Institute) sought to complement work being undertaken by the Department of Environment, Water and National Resources (DEWNR). This was done by focusing in more detail on previously identified priority areas for resource development (Figure 1) as defined by the Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE). These areas include the Musgrave Province, the north east and north west Gawler Craton, parts of the Frome Embayment in the east, and the northern Eyre Peninsula. Presently, knowledge about the character and variability of groundwater resources, the sustainability of this resource and its relationship to environmental and cultural assets remains very poor in these areas, despite limited previous groundwater resource investigations having been undertaken.

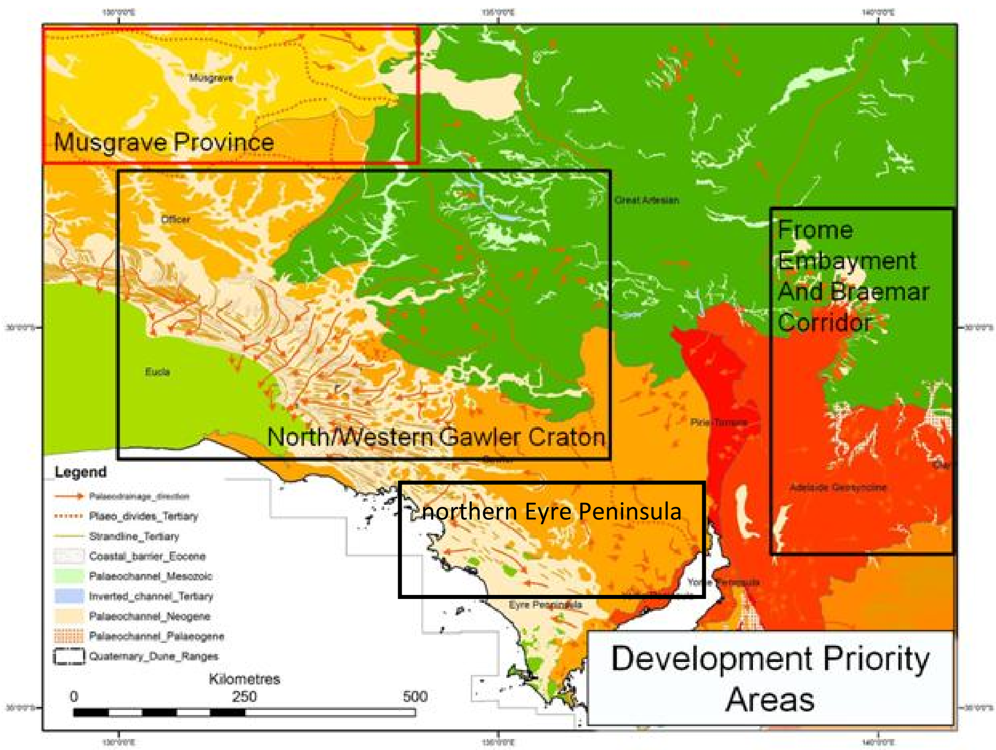


Figure 1. Priority areas for Industry development in the far north of South Australia. The areas defined are superimposed on a map of the main groundwater management units defined for South Australia.

Overview of this Report

This report provides an overview of a methodology for developing a physical hydrogeological framework. This methodology draws on the combined interpretation of local scale airborne electromagnetic (AEM) data sets, regional scale magnetic and terrain data, coupled with existing geological and regolith information.

This work was undertaken as part of Stage 1 of the Goyder FLOWS Project (G-FLOWS Stage-1). The broad outcomes and results from the project are summarised in Gilfedder and Munday (2013).

The method employs an upscaling approach that takes hydrogeological information determined from fine (prospect)-scale exploration and Government data sets and uses the derived knowledge to extend the information out to regional scales. We show the application of this methodology for the Musgrave Province of South Australia.

Critical steps in the process are the accurate processing and interpretation of the local scale AEM data sets. This permits the extrapolation of concepts and relationships across areas and regions. The derived physical framework provides a basis for interpreting existing hydrogeological data and would serve to assist industry in determining the available water resources for mine, infrastructure and community developments.

This report is intended to be distributed together with the spatial information packages produced as part of the Goyder FLOWS Stage-1 project.

Development of a Physical Hydrogeological Framework

The development of new hydrogeological framework for the Musgrave province is a key output from Goyder FLOWS Stage-1. The multi-disciplinary nature of the project has allowed it to encompass results from:

- Regional geophysical data (magnetic surveys),
- Local airborne geophysical surveys (industry supplied AEM data sets),
- Terrain indices derived from surface topography analysis,
- Existing regolith and geological data (sourced from DMITRE)
- Existing hydrogeological data (sourced from DEWNR)
- Groundwater isotope analysis.
- Definition of key groundwater recharge and discharge processes.

A key objective of the G-FLOWS Stage-1 project was to develop a methodology by which a physical hydrogeological framework could be developed. Such a framework has several useful purposes:

- Provides a way to best incorporate regional and local scale geophysical data sets, along with existing point and/or spatial data.
- Can help target locations and appropriate approaches for finer-scale groundwater resource assessments by Government or industry as required.
- Offer a basis for interpreting spatial patterns of groundwater quality and character obtained from individual and sometimes isolated bores.
- Provides a framework for interpreting patterns of groundwater recharge such as those developed in Task 6 of this project for the Musgrave Province (Leaney et al. 2013).

To illustrate the application and usefulness of such a framework, this report outlines the procedure as it is applied to mapping the physical hydrogeology of the Musgrave Province, following the five steps shown in Figure 2.

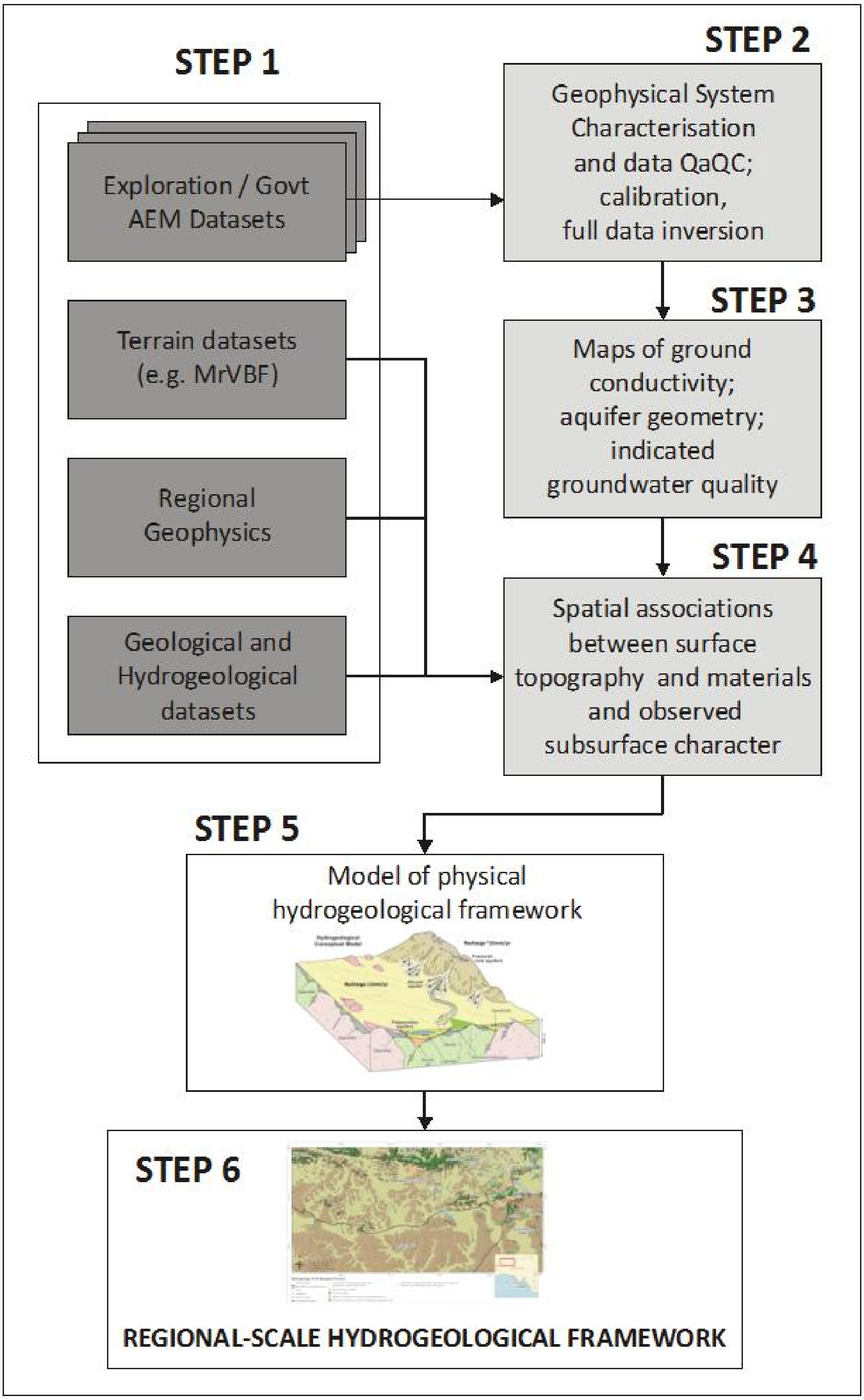


Figure 2. Methodology used to develop a regional-scale hydrogeological framework.

Step 1 – Collation of Data Sets

This involves the collation of regional and local, prospect scale, geophysical data sets, through engagement with State agencies (DMITRE/PACE) and exploration companies who may commonly acquire high resolution airborne data sets for targeting mineralisation. The latter are a valuable resource, particularly airborne electromagnetic (AEM) data, as these offer insights into the subsurface character of aquifer systems. Across the Musgrave Province, data sets included data acquired by a range of geophysical systems, collectively referred to as Time Domain Electromagnetic (TDEM) Systems. They included data from fixed wing TDEM systems - TEMPEST, SPECTREM; and helicopter-borne TDEM systems – HOISTEM, REPTEM, VTEM, and SkyTEM. Coverage of these data in any particular groundwater region or priority area can be biased (technology-wise and spatially) depending on a range of factors including:

a) Tenement distribution, holdings, and status (present and historical),
b) A particular company's exploration strategy and technology preferences,
c) System suitability given the target and commodity being sought,
d) Geological setting and regolith cover.

In the Musgrave Province the distribution of exploration AEM geophysical data sets acquired by different companies over the past fifteen years and used in the G-FLOWS Stage-1 study is illustrated in Figure 3. This coverage is not comprehensive as there are other AEM data sets covering parts of the Province that exist, but that were not employed for this study, for a variety of reasons including availability.

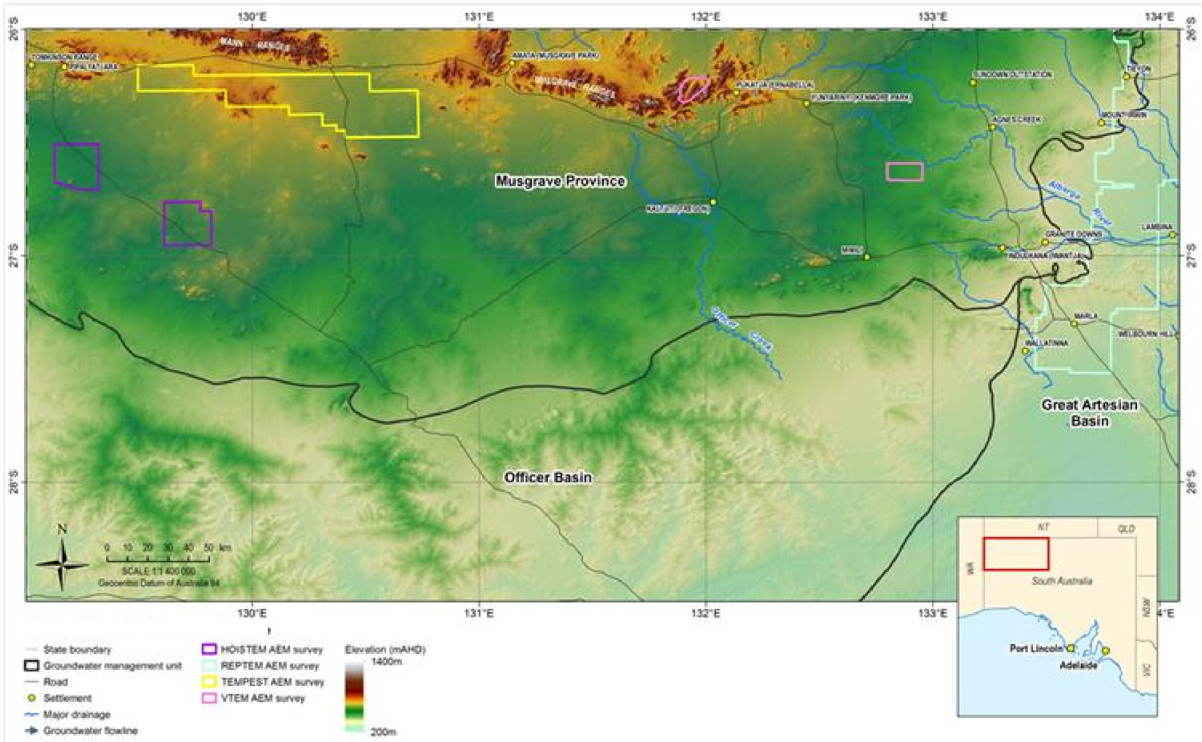


Figure 3. Regional DEM of the Musgrave Province with polygons of AEM data sets and system types used in G-FLOWS Stage-1.

Step 2 Geophysical System Characterisation and data QaQC; calibration, full data inversion

Once acquired, the AEM data are then subject to a quality assurance quality control (QaQc) process to determine their quality and suitability for resolving near surface features or features at depth. Other considerations are the availability of information about the system characteristics including knowledge of the waveform employed in the transmitter, base frequency used, window times used when sampling the defined secondary ground response, noise levels, filtering and other pre-processing steps undertaken by the contractors employed to acquire the data. This information is important when it comes to interpreting the data. Also an understanding of line spacing used in the survey is important as that can determine the scale of spatial features that might be resolved in the subsurface (as illustrated in Figure 4).

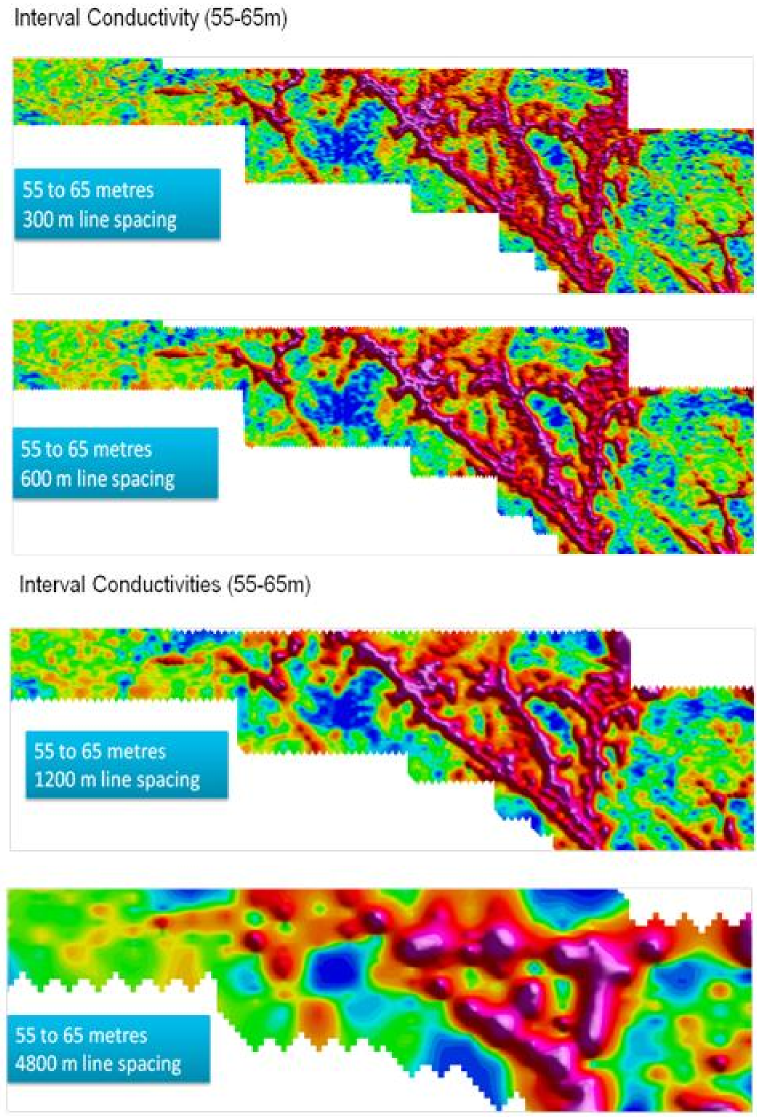


Figure 4. A map of ground conductivity derived from an AEM survey, illustrating the effects of changing line spacing on the ability to resolve spatial detail. The survey was undertaken in the Musgrave Province. Top image is a conductivity map for 55-65 m below the ground surface, gridded at a line spacing of 300 m. The bottom image is the same data but gridded for an equivalent line spacing of 4.5 km. High conductivities appear in red and pink, and low conductivities in green and blue. The images show that the ability to resolve the cause of a subsurface conductivity pattern (in this instance a sediment-filled palaeovalley drainage pattern) is influenced by the line spacing of the survey.

Commonly AEM data sets are supplied by contractors with limited interpretation. It is usually in the form of fast approximate transforms - products that describe how an approximated ground conductivity may vary both with depth and spatially. It is argued here that in order to compare and interpret the results for data acquired by different systems, it is appropriate to consider their full inversion, where a model of ground conductivity varying with depth is derived for each sample point measured by the system. This allows for a more direct comparison of results from different data sets and systems acquired in various geographic locations at different times. There are a variety of approaches and algorithms that can be employed for these purposes. Where possible a common inversion kernel (or algorithm) should be used, although that may not always be possible.

Figure 5 illustrates this approach, and in this instance shows the results from using a smooth model 1D Layered Earth Inversion applied to several different AEM systems over a common, coincident, flight line. This line of data is from the western part of the Musgrave Province, and shows a relatively conductive valley fill, which occupies what are interpreted as a set of palaeovalleys located in the region.

The process of data inversion commonly yields a set of maps showing spatial patterns of ground conductivity varying with depth below the surface. The process is summarised in Figure 6.

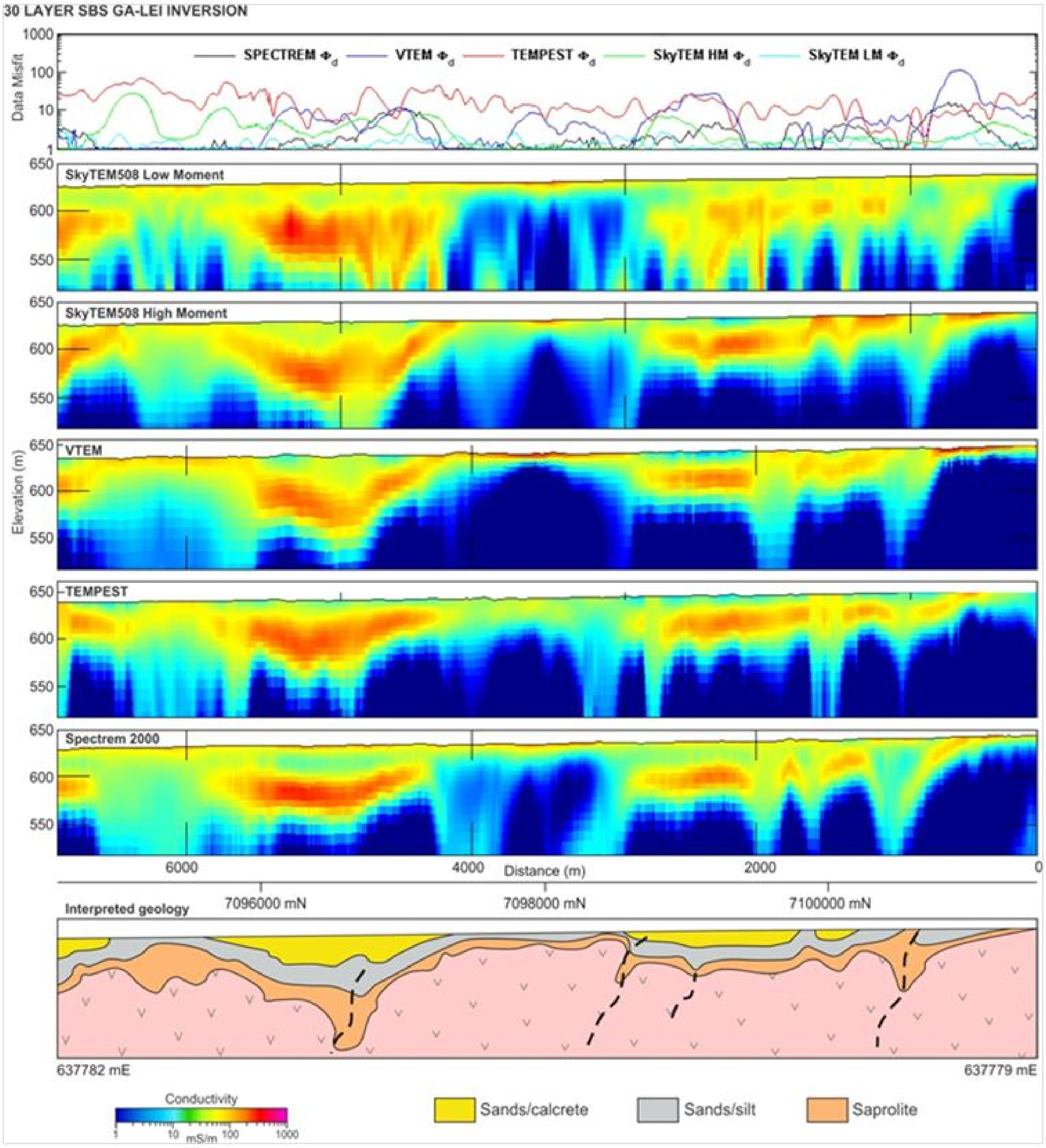


Figure 5. Stitched conductivity-depth sections generated for a single line using a common inversion kernel (the Geoscience Australia LEI) applied to data from a range of fixed wing and helicopter TDEM systems. A schematic interpreted geological section is also plotted at the bottom. The top panel indicates the quality of the fit of the inversion for each system – the lower the number the better the fit and the more likely the derived model of ground conductivity. The model shown is a smooth model inversion, where ground conductivity is defined for 30 layers of fixed thickness. The results indicate that the modelled ground conductivity structure is similar regardless of the system used.

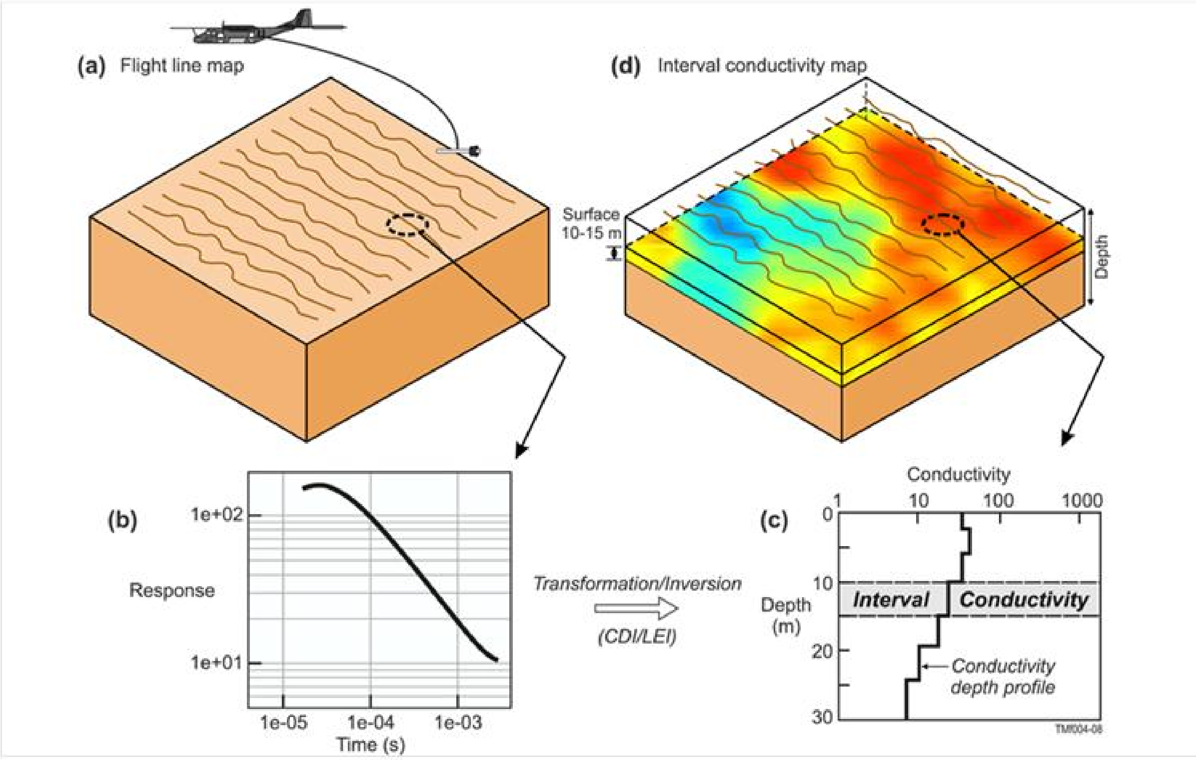


Figure 6. Schematic representation of airborne electromagnetic (in this example a fixed wing time domain electromagnetic system) data acquisition and interpretation: A) Data are acquired along parallel flight lines, with data recorded at regular intervals along each flight line; B) The electromagnetic transmitter is looped around the fuselage of the aircraft and the receiver are towed behind and beneath the aircraft, with the receiver measuring the secondary magnetic field responses induced in the ground as a function of time; C) The measured response is used to determine the conductivity-depth function by transformation or inversion; D) Conductivity-depth values can be calculated for each observation, taking account of the elevation of the system above the ground, and then stitched together into sections to provide a representation of the 2D variation of conductivity, sometimes referred to as a 'para-section' (see Figure 4). Conductivity depth profiles can be combined into a 3D gridded volume from which arbitrary sections, horizontal depth slices (or interval conductivity images) and iso-surfaces can be derived showing the spatial distribution of conductivity as it varies with depth. These maps can be shown as elevations (mAHD) or as depth intervals below the ground surface ground surface.

Step 3 Maps of ground conductivity; aquifer geometry; indicated groundwater quality

Figure 7 shows maps of ground conductivity for an interval ~60 m below the ground surface, overlain on the DEM for an area in the NW part of the Musgrave Province.

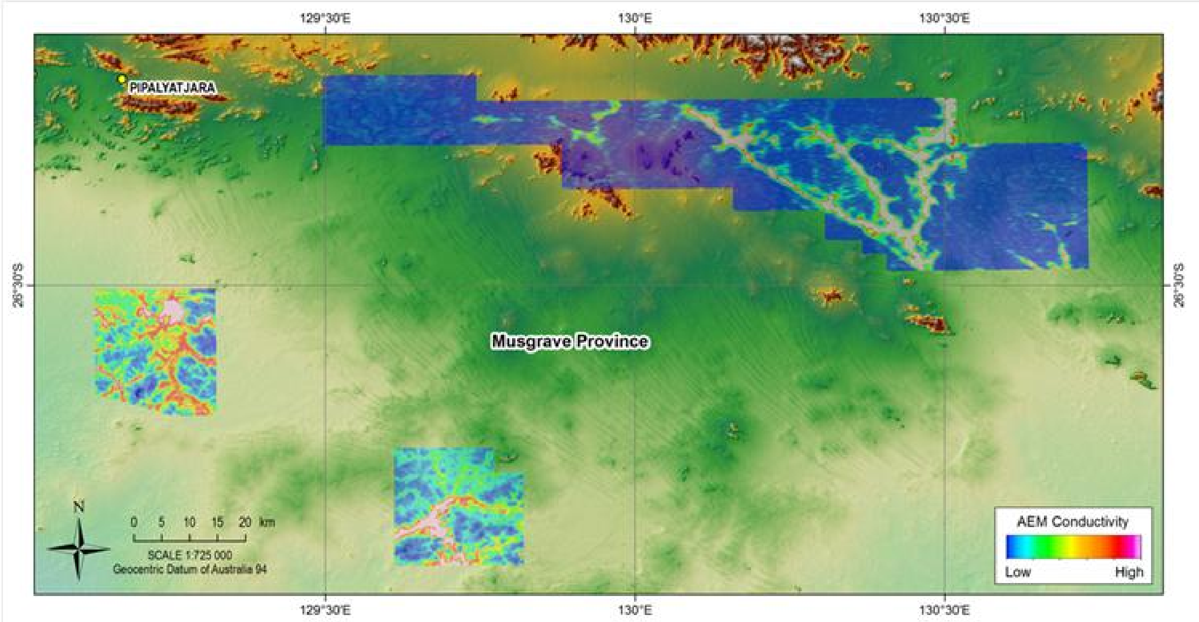


Figure 7. Contemporary elevation model with the interval conductivity for a slice ~60 m below the ground surface shown for three AEM surveys.

As mentioned previously, accurate system characterisation is necessary to derive accurate models of ground conductivity. This may necessitate the use of external calibration procedures. It may also require the incorporation of other parameters in the inversion, including system geometry. Studies in the inversion of some data sets over the Musgrave Province indicated that failure to take account of system geometry could result in significant errors in the definition of aquifer thickness and character.

Step 4 - Spatial associations between surface topography and materials and observed subsurface character

Once derived, maps and sections of ground conductivity can be examined against regional geophysical data sets to better understand geological/hydrogeological process. Derived products can also be generated. Figure 8 is a map of regolith (aquifer) thickness derived using conductance of the conductive layer above the geological basement for the northwest part of the Musgrave Province.

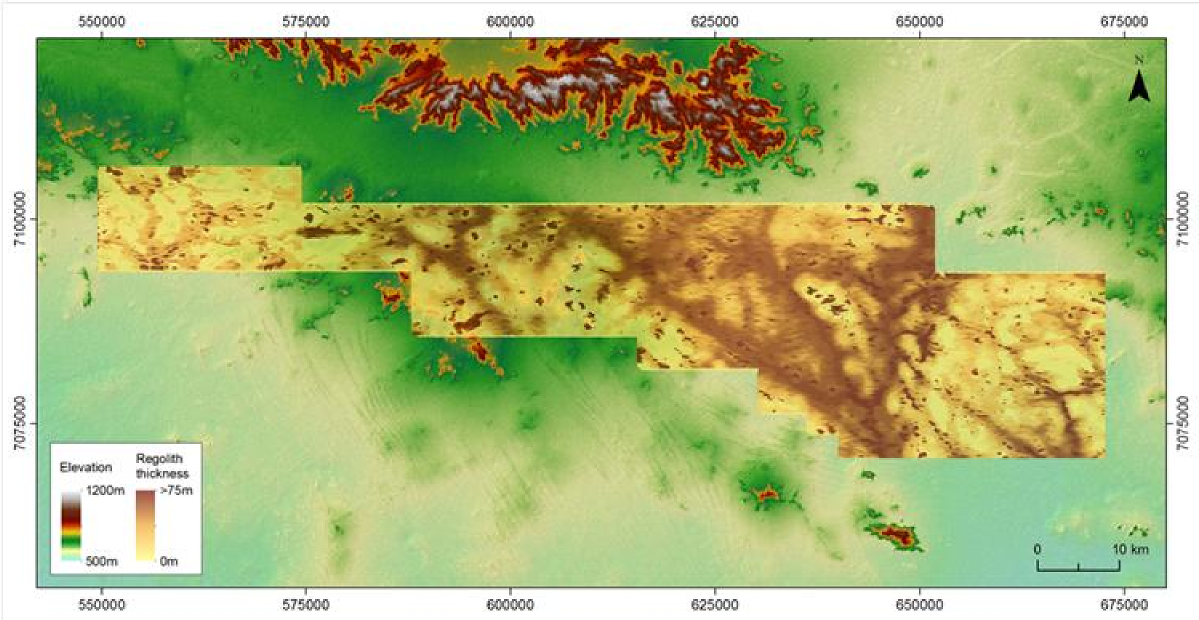


Figure 8. Map of regolith thickness derived from an inverted AEM data in the western part of the Musgrave Province. The regolith in this instance comprises sediment filled –palaeovalleys. The pattern displayed indicates a well developed palaeo-drainage system with valleys once in excess of 100 m in places.

The structure and pattern of the conductive materials present in the various AEM data sets across the Province have been attributed to a palaeo-channel fill of Pliocene to Pleistocene sediments and overlying Quaternary sand occupying a previously complex pre-Pliocene palaeo-drainage system that evolved over the basement (Figure 9). The AEM data sets permit the definition of aquifer bounds and their geometry; in this case the boundary between the fractured rock aquifer system in the basement and the overlying alluvial aquifers that make up the palaeovalley fill.

The result also indicates the relative importance of various drainage lines. In this instance the deepest drainage line, interpreted as the trunk system, is represented by a north-south system, which would have had its headwaters in the Northern Territory. The trunk drainage meets NW-SE oriented tributaries and probably also changes direction and heads SE.

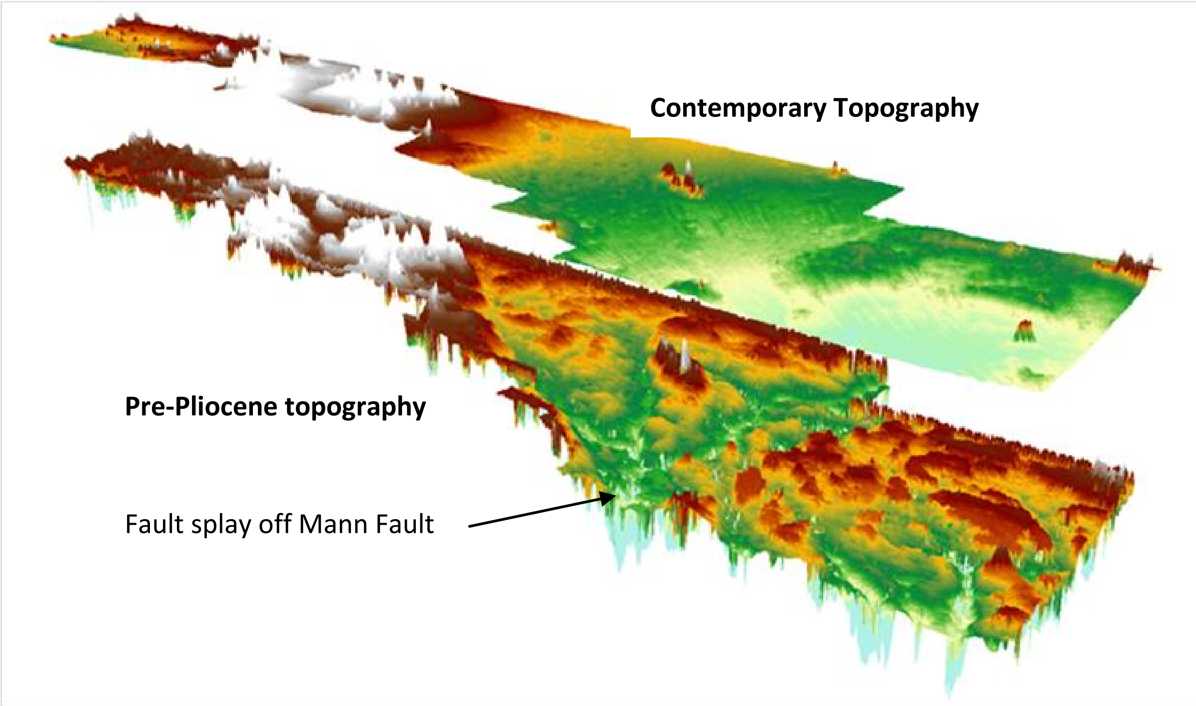


Figure 9. A perspective view (looking north) of current land surface (top), and basement topography (bottom) for the area shown in Figure 8. The image shows a complex, deeply incised drainage system (valleys up to 120 m deep) draining south from the Mann Ranges.

The palaeovalleys are coincident with broad lows that characterise the contemporary landscape (Figure 10). In this case we have used the "Multi-resolution Valley Bottom Flatness" index (MrVBF: Gallant and Dowling 2003) on the 1sec SRTM elevation data to delimit contemporary valleys or low points in the landscape. MrVBF is a topographic index designed to identify areas of deposited material at a range of scales based on the observations that valley bottoms are low and flat relative to their surroundings and that large valley bottoms are flatter than smaller ones. The conductivity depth sections from the various AEM data sets show a complex, well defined and relatively narrow set of valleys that contrast with those depicted in the contemporary landscape. This is borne out in Figure 9. Nonetheless, the results suggest that the position of the broad low valley systems is a good starting point for locating the position of the deeper portions of the older valley system. The inference is that the contemporary valleys, or landscape lows, represent areas most likely to contain buried sequences of thick alluvial sediments, and by association alluvial aquifers.

Examination of the palaeo-channel system, as determined by the AEM data, against the regional magnetics (1^{ST} Vertical Derivative) indicates that both lithology and structure exerted a significant influence the development of the palaeo-drainage system. The orientation of some of the defined valley systems follow major structures observed in the magnetics (Figure 11).

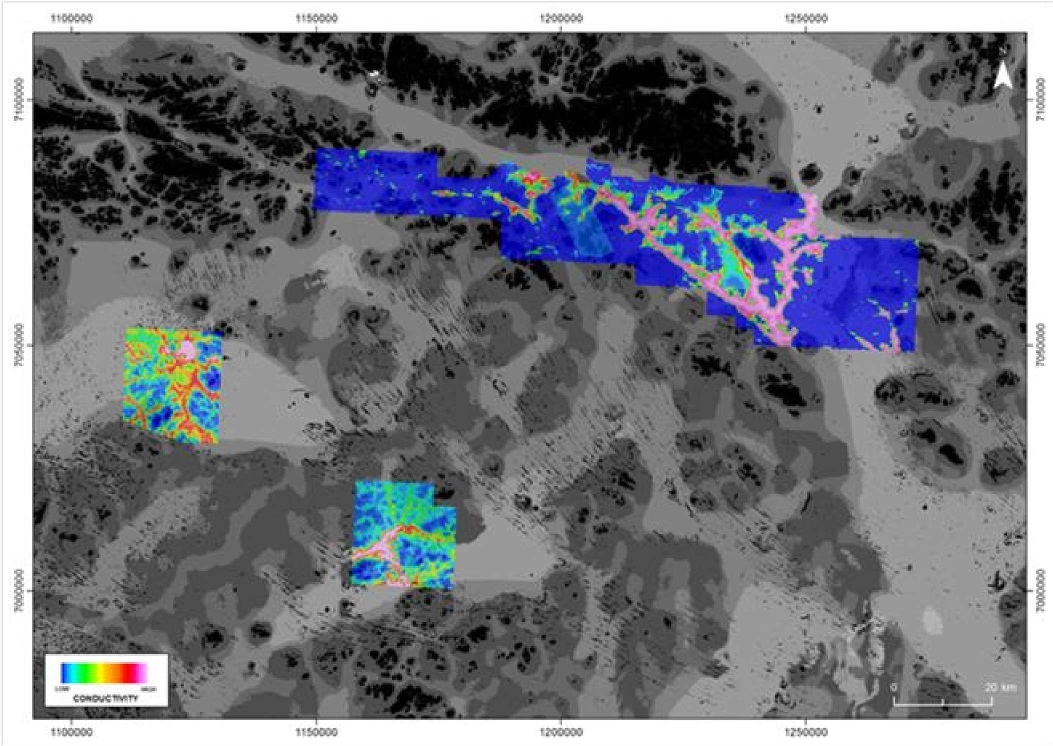


Figure 10. Conductivity-depth interval for 70 m below ground level for TEMPEST (top) and HOISTEM (lower left) TDEM data sets superimposed on the Multi-resolution Valley Bottom Flatness index (MrVBF). The more conductive elements of the palaeovalley systems are located within, or on the margins, of the low flat areas (pale shades of grey) in the landscape.

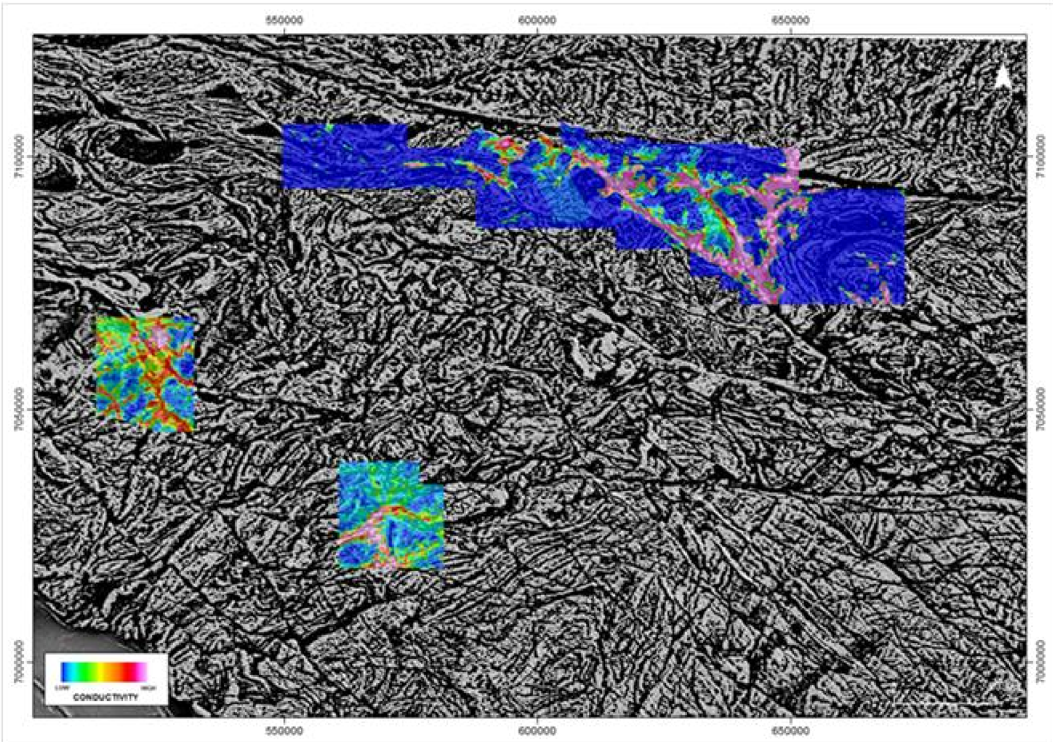
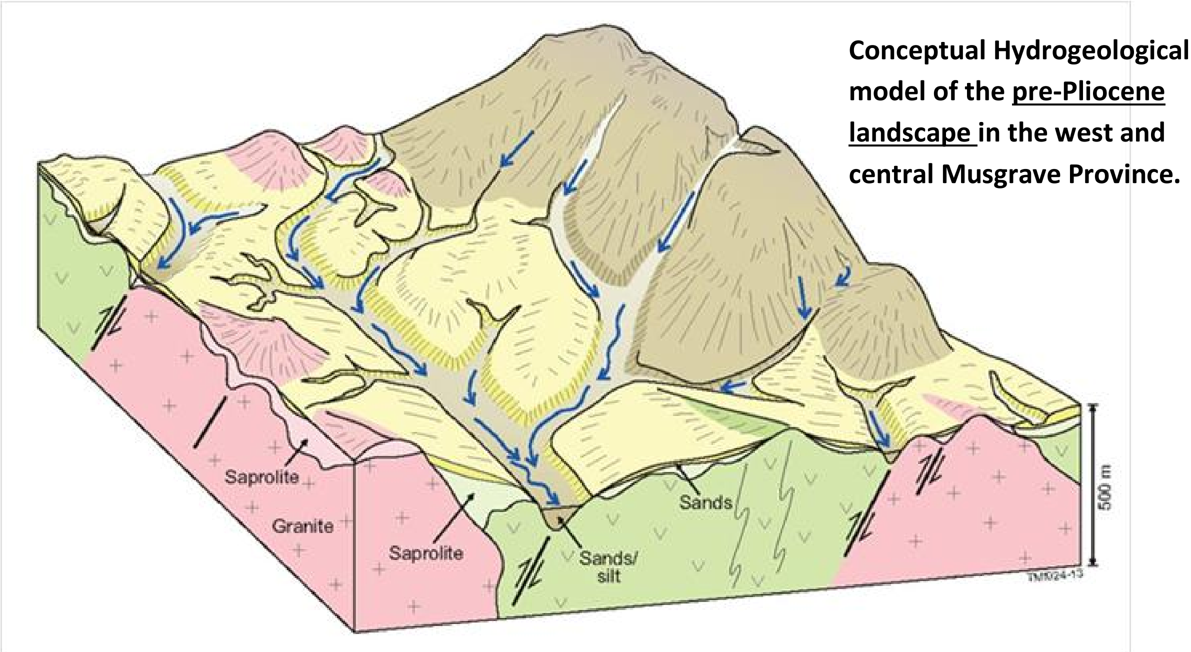


Figure 11. Conductivity-depth interval for 70 m below ground level for TEMPEST (top) and HOISTEM (lower left) TDEM data sets superimposed an image of the 1st VD of the regional magnetics. The deep conductive structure is associated with the litho-structural breaks observed in the magnetics.

Step 5 Model of physical hydrogeological framework

The combined interpretation of the local scale AEM data, the regional magnetic and contemporary topography has contributed to the development of an updated hydrogeological conceptual model (Figure 12) and a framework for groundwater resource assessment. This model indicates the relative extent and significance of the palaeovalley fill sediments in the Musgrave Province. Limited drilling has confirmed that these sediments contain a significant groundwater resource. However, their full extent and geometry remains largely hidden from view and at present, largely untested.



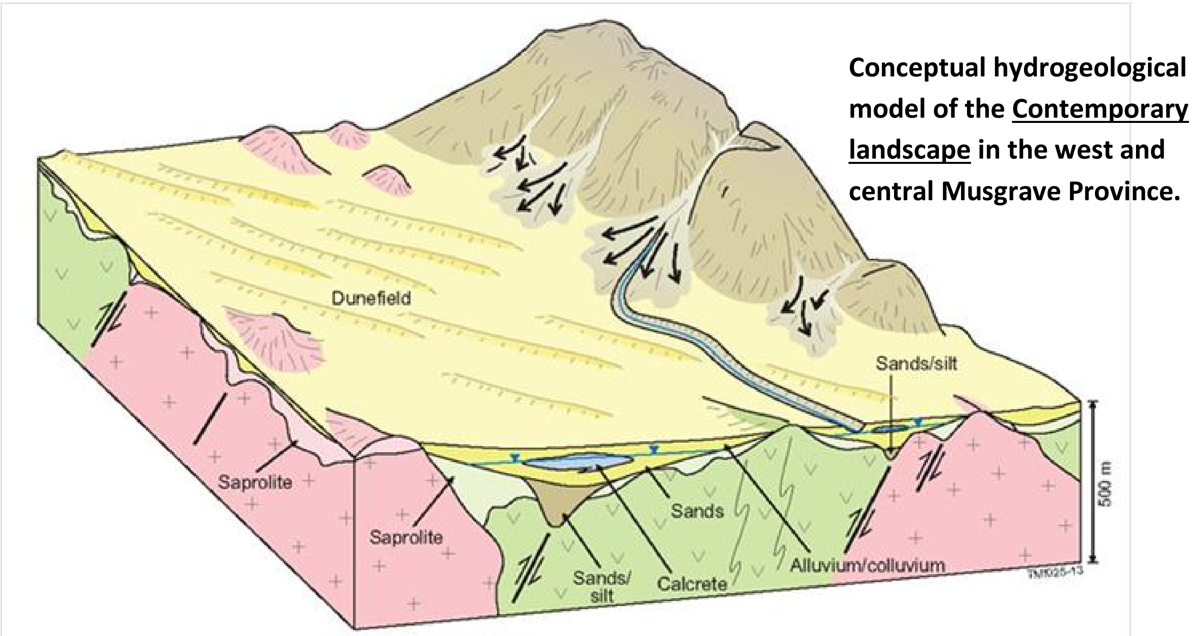


Figure 12. Hydrogeological conceptual model for the NW and central parts of the Musgrave Province developed from AEM, airborne magnetic and DEM interpretation. Block diagram at the top shows a conceptual model for the pre-Pliocene landscape. The block diagram at the bottom shows the contemporary landscape with the palaeovalleys filled with sediment.

Step 6 Upscaling the physical hydrogeological framework

With an appreciation of local scale relationships, the next step is to employ regional scale data sets and upscale the physical hydrogeological framework. At a local scale the MrVBF index was used in conjunction with the AEM, and existing geological and regolith information to define a set of aquifer units. These are shown in plan form in Figure 13.

Five hydrogeological units have been defined:

1. alluvial and calcrete aquifers with buried palaeovalley aquifers present
2. alluvial/colluvial aquifers
3. colluvial aquifers
4. aquifers in saprolite and fractured highly weathered rocks
5. fractured rock aquifers in fresh to moderately weathered rocks

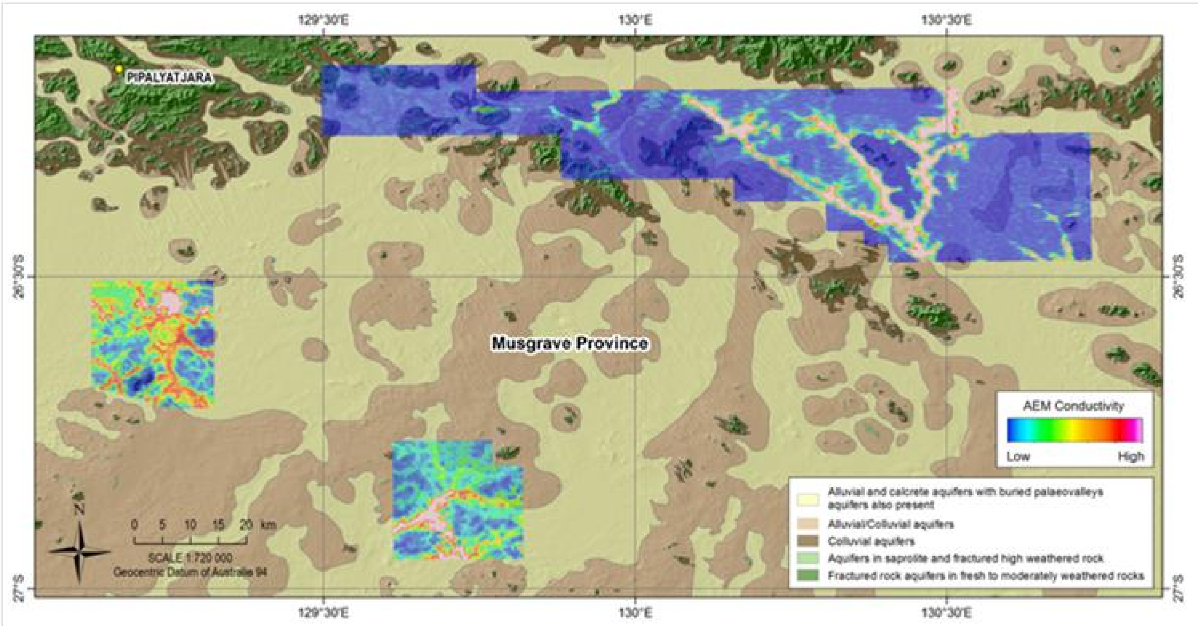


Figure 13. Conductivity-depth interval for 70 m below ground level for TEMPEST (top) and HOISTEM (lower left) TDEM data sets superimposed on a map of hydrogeological units defined for the northwest region of the Musgrave Province. The more conductive aquifers associated with the palaeovalley fill sequence are primarily found in association with the alluvial aquifers. These sediments consist, in places, of loose running sands, fine quartz sands to granule conglomerates (probably developed in braided stream systems similar to that seen today), fine- to medium-grained quartz sand, silt and minor clay, coarser-grained carbonaceous and lignitic sediments. Nodular calcretes are developed in many places. Some of these units have high transmissivities. Groundwater quality is variable, but interpreted to be brackish to saline in the deeper aquifers of the palaeovalleys.

The relationship of the mapped hydrogeological units to the overlying sand sheet of the Great Victorian desert is shown in Figure 14. This aeolian sands unit was taken from DMITRE's state-wide regolith coverage.

Upscaling the physical hydrogeology to the rest of the Musgrave Province was then completed. The resulting map with available AEM data sets employed in this exercise is shown in Figure 15. The regional distribution of aquifer systems is presented in Figure 16. The same map, including the known distribution of the aeolian sand sheet in the region is shown in Figure 17.

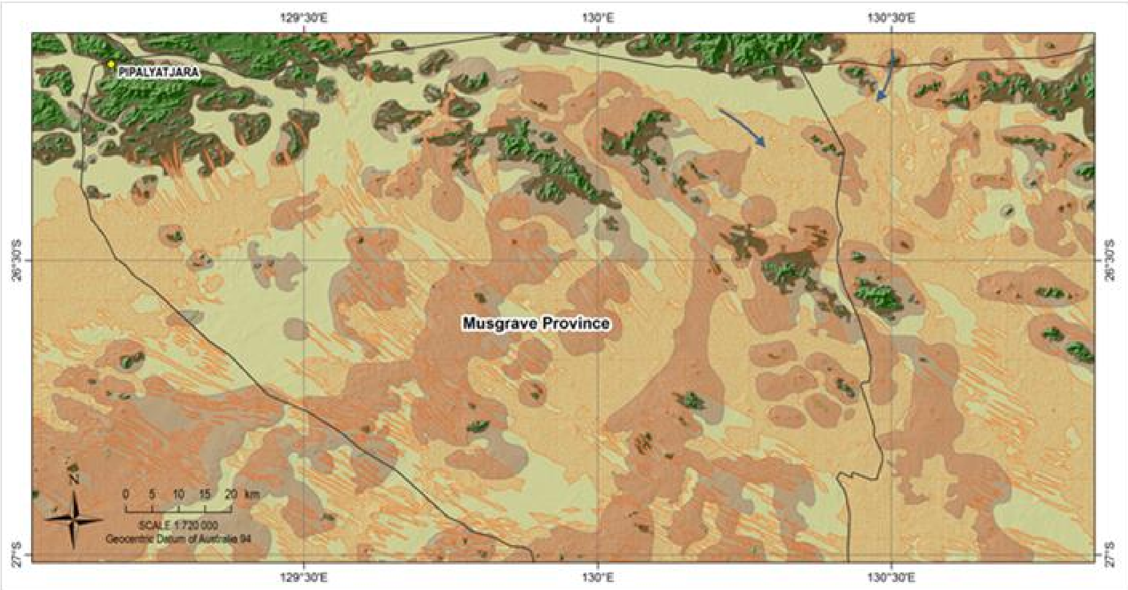


Figure 14. Hydrogeological units shown in Figure 15 with overlying aeolian sand sequence in orange.

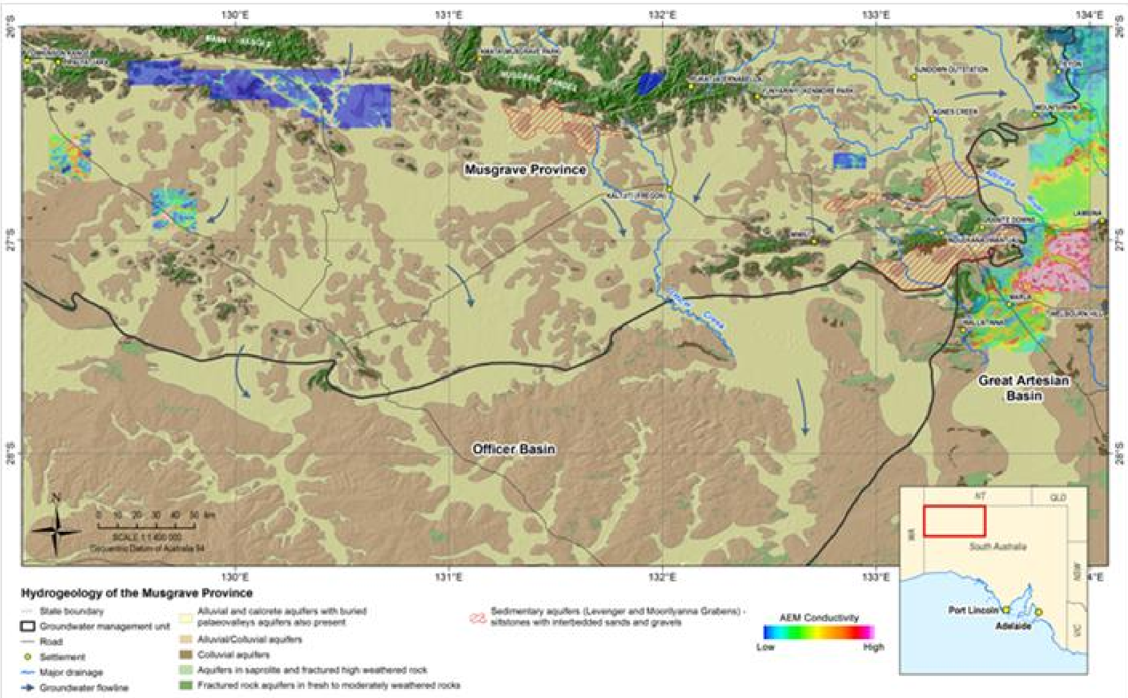


Figure 15. Hydrogeological map of the Musgrave Province showing the AEM data sets used in the upscaling exercise.

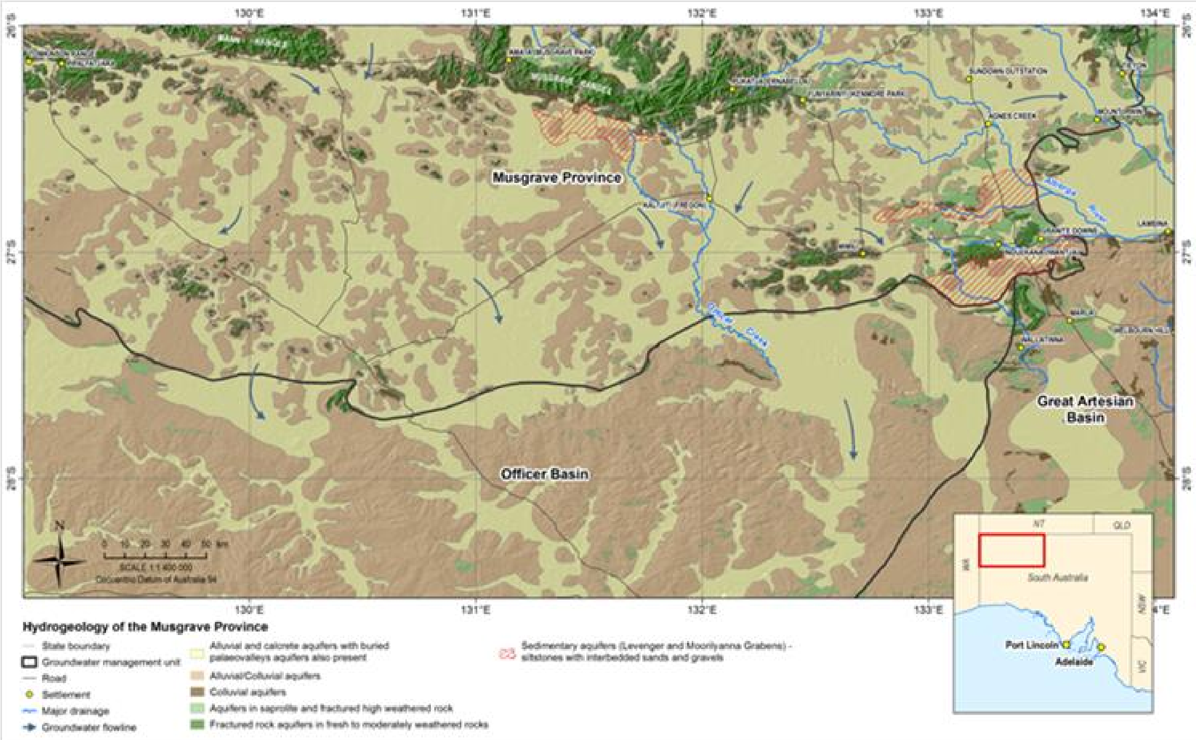


Figure 16. Regional scale hydrogeological map of the Musgrave Province.

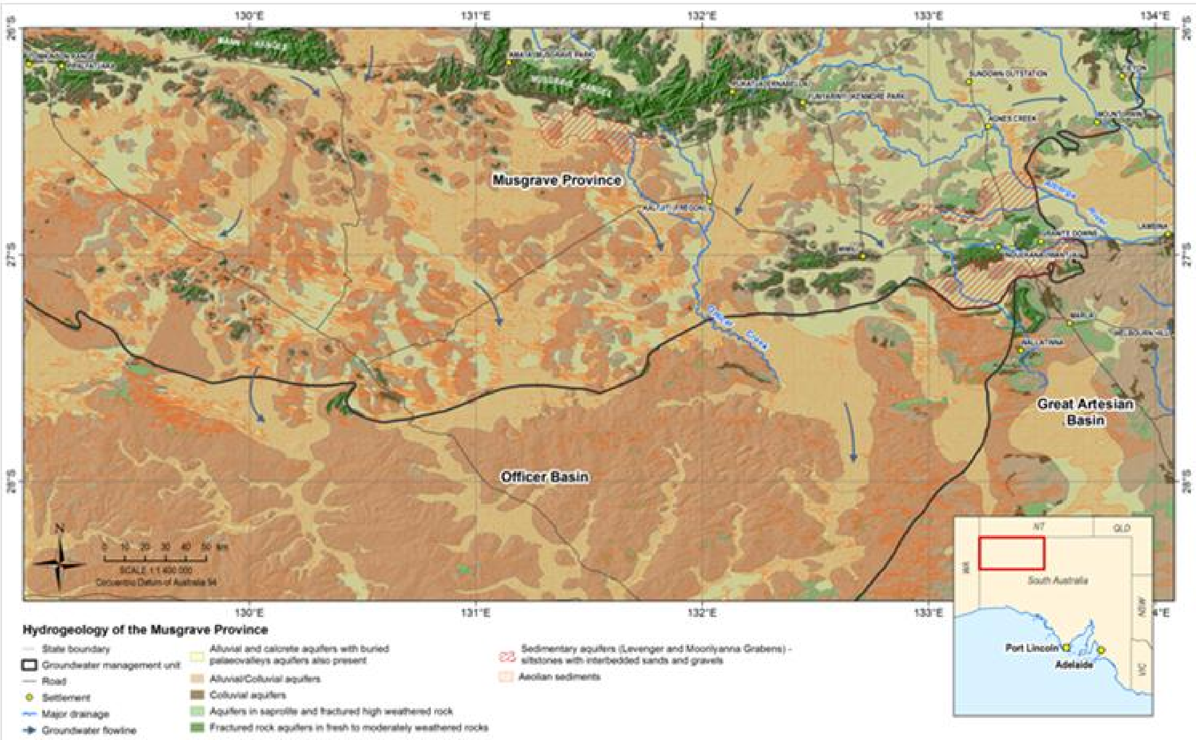


Figure 17. Regional scale hydrogeological map of the Musgrave Province with distribution of aeolian sand sheet superimposed.

A more detailed definition of the distribution of Palaeozoic sediments in the Levenger and Moorilyanna Grabens (a Graben is a depressed area bordered by faults) was undertaken using the regional scale airborne magnetic (Figure 18). The resulting map provides a framework for examining the groundwater elevation, salinity and aquifer yields for existing bores in the Province (Figure 19, 20, 21).

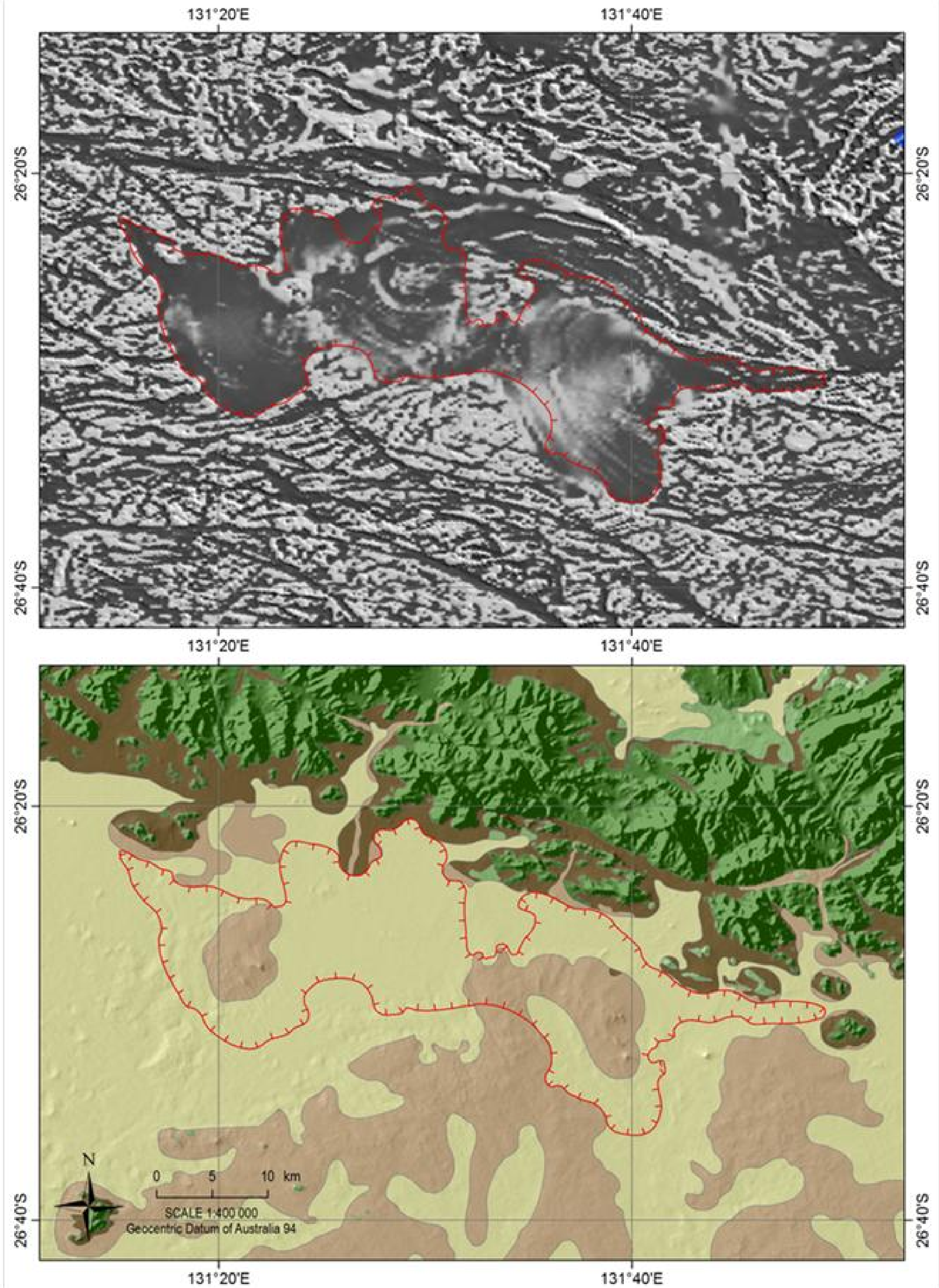


Figure 18. Definition of the extent of Palaeozoic sediments associated with the Levenger Graben involved delimiting the area with a subdued magnetic response in the 1st Vertical Derivative of the regional magnetics (top Panel). This was then added as a unit to the regional hydrogeological framework (lower panel). A similar approach was taken with the Moorilyanna Graben in the east.

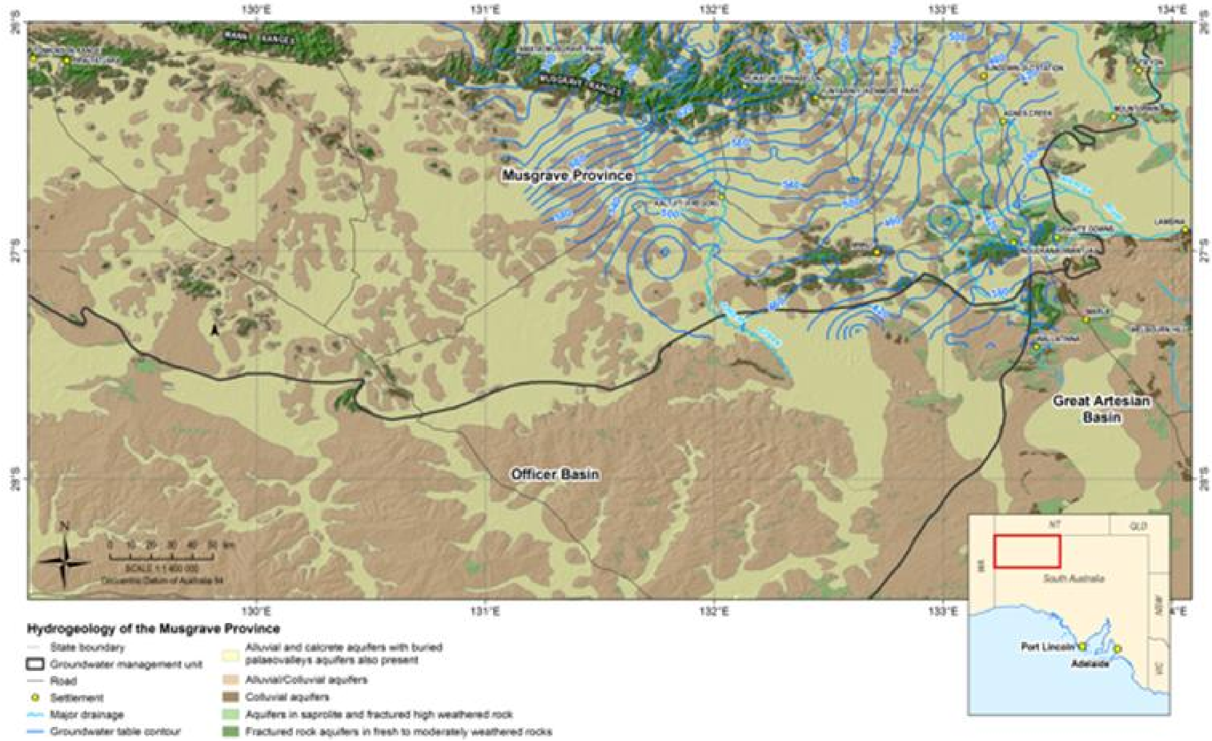


Figure 19. Groundwater table elevation for eastern part of Musgrave Province (sourced from Varma 2012), overlaying regional hydrogeological framework for the Musgrave Province.

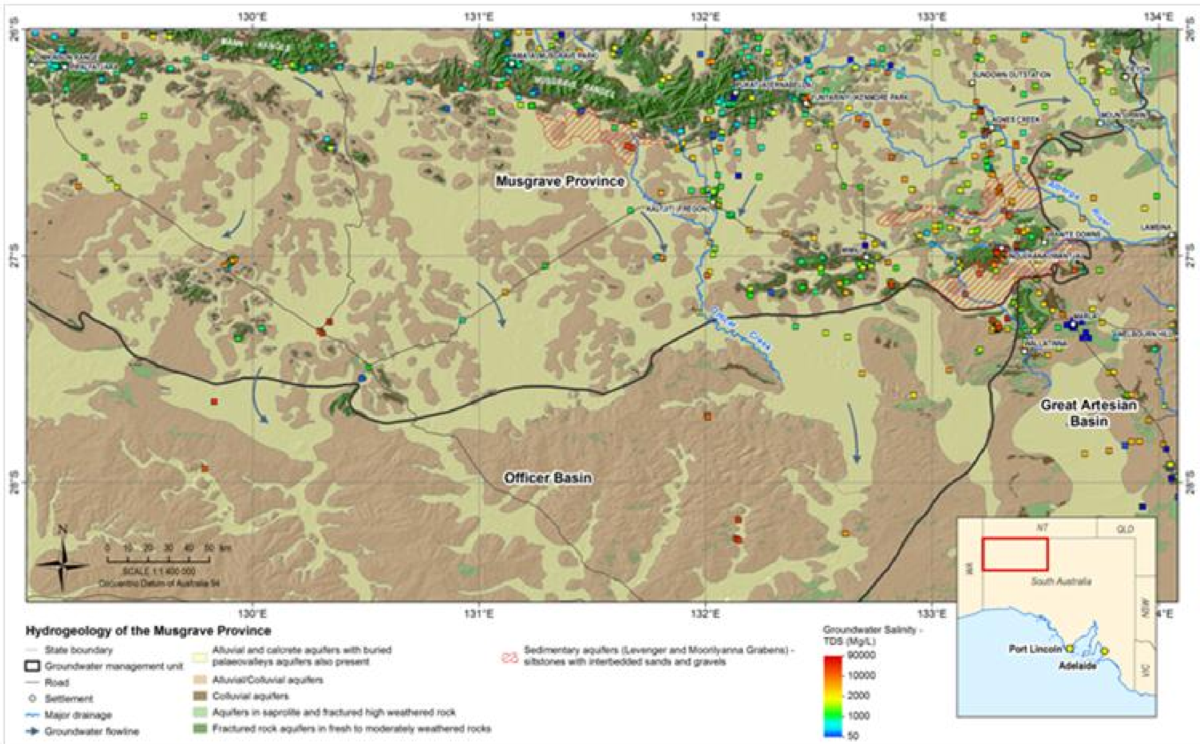


Figure 20. Regional distribution of groundwater salinity across the Musgrave Province.

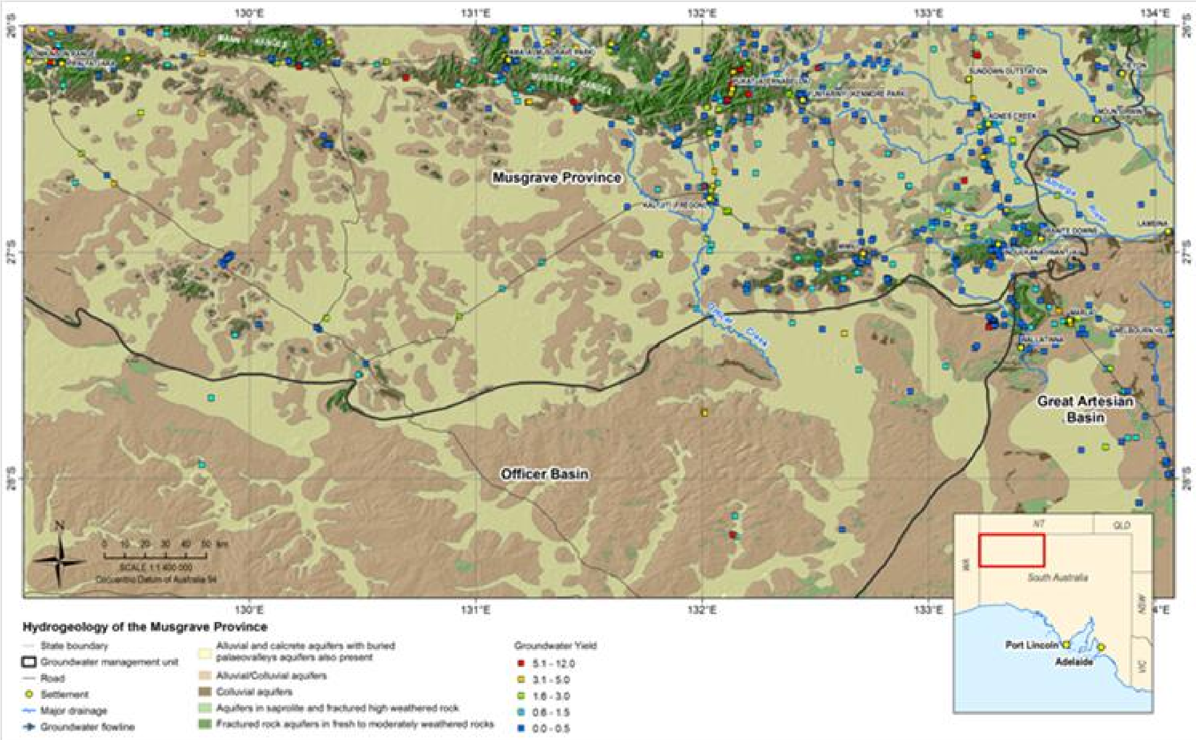


Figure 21. Regional distribution of groundwater yield across the Musgrave Province.

Summary and Conclusions

A method for developing a physical hydrogeological framework has been defined. This draws on the combined interpretation of local scale airborne EM data sets, regional scale magnetic and terrain data, coupled with existing geological and regolith information.

The method employs an upscaling approach that takes hydrogeological information determined from fine (prospect)-scale exploration and Government data sets and uses the derived knowledge to extend the information out to regional scales. It has been tested in the Musgrave province of South Australia. The approach would have application in other parts of outback South Australia, including the SAA Lands, but also other parts of the Alinytjara Wilurara NRM Region. It would also be applicable to the northern Eyre Peninsula.

Critical steps in the process are the accurate processing and interpretation of the local scale AEM data sets. This permits the extrapolation of concepts and relationships across areas and regions. The derived physical framework provides a basis for interpreting existing hydrogeological data and would serve to assist industry in determining the available water resources for mine, infrastructure and community developments. The Musgrave Province case-study indicates that a substantial reserve of groundwater may exist in deep sedimentary aquifers that occupy an extensive, but buried network of palaeovalleys. However, scrutiny of existing available hydrogeological data is poor (especially for deep groundwater systems), and this potential remains to be fully determined.

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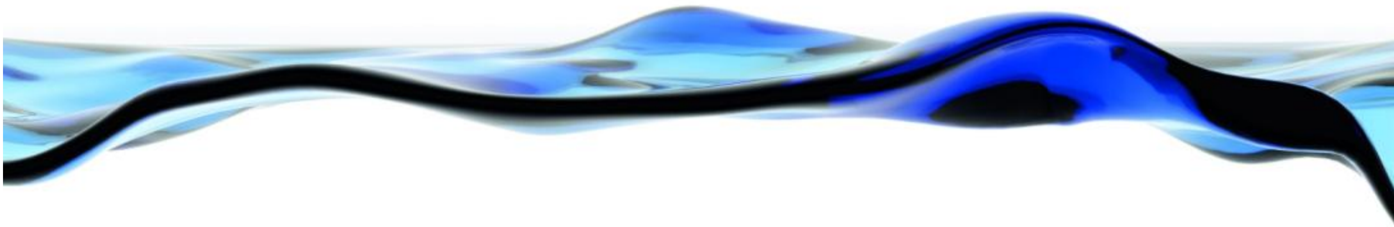

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