EXECUTIVE SUMMARY

Study context and purpose

The Namoi catchment is located in north-eastern New South Wales (NSW) and is recognised as an agricultural area of significance within Australia that includes one of the most intensively developed groundwater resources in NSW.

Coal and potentially economic coal seam gas (CSG) resources exist within the Namoi catchment. Coal is currently extracted from both open-cut and underground operations. Current CSG activity ranges from initial investigations of potential to production from seven small-scale pilot CSG sites. Substantial additional mining and gas projects are planned or being investigated and their development could impact catchment water resources.

In response to rising levels of concern within the community, in August 2010 the NSW Government commissioned a study, The Namoi Catchment Water Study (the Study), into the potential effects of coal resource development activities on catchment water resources. The purpose of the Study is "to undertake a strategic assessment of the likelihood of potential impacts posed by coal and gas development in the catchment on the quantity and quality of surface and ground water resources in the catchment".

The Study includes the construction of a three-dimensional numerical model that can be used to develop scenarios of different mining and gas developments and predict their effects on water resources. Since its commencement in 2010, the Study has progressed in four phases with each resulting in the publication of separate reports and presentations to the community. This document provides the report of the final phase of the Study.

General assessment

Water resources

The principal water resources of the catchment comprise the surface water system of the Namoi River, its tributaries, and the alluvial groundwater systems associated with the water courses. The Namoi surface water catchment drains west towards the Darling River and flows are regulated by three storages: the Keepit, Chaffey and Split Rock dams. The Upper Namoi and Lower Namoi Alluvium form the principal aquifers and are heavily utilised for irrigation.

The Namoi alluvium is characterised by high permeability and storage capacity and water quality is good, although it varies within different layers. Recharge rates are generally high due to direct association with the river and stream systems. Smaller scale pumping also occurs from the consolidated or 'hard' rocks that comprise the groundwater system surrounding the alluvium. The hard rocks are less utilised due to lower permeability, storage and recharge rates and characterisation data is sparse.

Groundwater resources have historically been managed by areas: the Lower Namoi Alluvium is treated as a single area; the Upper Namoi Alluvium is subdivided into 12 separate management zones; and the recognised hard rock units and lesser alluvial aquifers are managed as separate areas. These management areas are shown on Figure E1 and listed in Table E2. The Study has assessed the potential impacts and risks to water resources from coal and gas development in the Namoi catchment using these same management areas.

Impact pathways

Mining and CSG activities can impact water resources through pathways that are both broad-scale and highly localised. Local-scale pathways cannot be determined by a catchment-wide study. Since coal resources are hosted in below-ground, hard rock units, the main impacts are likely to be on subsurface water (groundwater). Open pit mines also have a significant footprint on the surface which results in some rainfall and surface water capture. Underground mines and CSG extraction also requires some surface infrastructure development which can impact surface water flows.

The primary broad-scale pathways by which coal mining (open-cut and underground) and CSG extraction can impact surface and groundwater quantity and quality are:

- Interception or disruption of rainfall and run-off from mine pits, surface infrastructure and subsidence. This can result in; i) reduced recharge to the groundwater system and lowering of levels and quality changes, and ii) reduced runoff and surface water flow and quality changes.

- Flow of groundwater to mine voids, mine dewatering facilities or to CSG production wells. This can result in; i) leakage from utilised aquifers, ii) mixing of different quality groundwater, iii) reduced flow from groundwater to rivers, and iv) increased leakage from rivers to groundwater.

Coal resource investigation and development activities such as drilling or hydraulic fracturing, and accidental releases or emergency releases during operations, can also pose shorter-term risks to water quality.

Proximity of water resources and coal and gas resources

A catchment-wide assessment of the location of potential coal bearing formations and their proximity to near-surface water resources is shown by Figure E2. Although the presence of coal bearing formations does not mean that either CSG development or coal mining is economically viable, the proximity assessment indicates that:

- Coal resources exist only in the western 60% (by area) of the Namoi catchment and water resources in the upstream eastern sector of the catchment are not at risk from coal development activities.

- The prospective area for coal mining extends a maximum of 50 kilometres to the west of the Upper Namoi Alluvium and beyond this the depth to coal bearing formations is likely to be excessive for mine development.

- The prospective areas for CSG extraction overlap with the prospective coal mining areas but also extend into a much greater area of the catchment where the coal seams are deeper.

- Most of the Upper Namoi Alluvium Zones are in very close proximity to coal bearing formations.

- Less than half of the area of Upper Namoi Alluvium Zone 3 is underlain by coal bearing formations indicating lower direct risk to this area.

- Upper Namoi Alluvium Zones 6, 9 and 10 and the Lower Namoi Alluvium are separated by more than 100 metres from coal bearing formations and will be at lower risk from direct impacts than other management zones.

Numerical model and scenario development

A key output of Phase 3 of the Study has been the development of numerical models (the Model) to facilitate assessment of the long-term and cumulative impacts on catchment water resources that could result from coal resource development. The Model provides a tool for future use and management that also allows the uncertainties associated with these predictions to be investigated. The Model has two main components:

I. a rainfall / runoff model - the Hydrologic Model;

II. a groundwater flow and groundwater / surface water interaction model - the Groundwater Model.

In order to assess the effect of coal resource development activities on water resources, seven future coal mining and CSG development scenarios were developed for testing (predictive simulation) by the Model. Each scenario was simulated until the year 2100 (90 year period of prediction) and the main elements of these scenarios are detailed in Table E1. The spatial distribution of coal and gas developments is illustrated in Figure E3 for Scenario 3. This scenario is the most intense future resource development option that has been simulated and reflects extensive CSG production and the annual extraction of around 60 million tonnes of coal for 90 years.

Table E1 Scenario configuration

Scenario No.	Description	Mines (number)		CSG fields (No.)
		Open-cut	Underground	
0	No current or future mining or CSG	0	0	0
1	Approved mines & CSG production	6	1	Pilot holes only
2	Approved & planned mines & CSG	10	2	2
3	Extensive & widespread mining & CSG	24	7	8
4	Extensive & widespread mining only	24	7	Pilot holes only
5	Extensive & widespread CSG only	6	1	8
6	Half underground mines beneath alluvium	24	7	8

Scenario 0 simulates no current or future coal resource development and provides a set of baseline results where the effects of climate variation and agricultural development are present. The results of all other scenarios can then be compared with Scenario 0 at any future time and location to isolate the change resulting from the particular coal resource development scenario.

Strategic assessment of likely effects of coal and gas developments

This assessment considers the conceptual and geological models developed during the Study in addition to the Model simulation results. The location, timing, type and size of the future mining and CSG developments are currently unknown and these factors will have a major effect on Model results, as does the very long predictive simulation period. The assessment needs to be viewed in this context.

At current levels of development, extensive regional scale impacts on water resources are unlikely. More local scale impacts are likely and the cumulative effects of numerous developments in close proximity will increase the risk to the water resources in those areas. This is evident in Upper Namoi Alluvium Zones 7 and 11 where numerous developments are approved or possible. However, the impacts will mainly be on groundwater levels in the hard rock units and in the vicinity of the mines or CSG fields. The Model predictions of groundwater level decline ('drawdown') from approved (Scenario 1) and possible future developments (Scenario 2) are shown in Figures E4 and E5 (respectively).

With long-term and more extensive development, especially within the Gunnedah Basin Management Area where the likelihood of further development of coal and gas resources is highest, the cumulative effect of impacts on groundwater levels in the hard rock units and alluvium will be more significant. Declines in groundwater levels predicted by the Model for extensive long-term development of coal resources (Scenario 3) are shown in Figure E6.

Mining and CSG development will impact groundwater levels in the hard rock units with much greater magnitude, spatial extent and speed of onset compared to their effect on groundwater levels in the alluvium. Impacts that propagate to the alluvium will be of a lesser magnitude and extent and will take much longer to reach a maximum.

The main impacts to surface water flows are derived from open cut mining, with little impact predicted from CSG or underground mine developments. For Scenario 3 the long-term average flow in the Namoi River near Narrabri is predicted to reduce by up to 1.8%. As a percentage of average flow this impact is low, however, in volume terms, this is equivalent to about half the current surface water abstraction from the regulated Namoi River below Keepit Dam. Simulation of the same coal resource development scenario but using a drier future climate pattern increases the predicted reduction to 3.3%. No impacts upon the water captured by the three main storage dams are predicted.

Measurement errors inherent in data collection at surface water gauging stations are approximately 5% and the potential changes may not be distinguishable in the observed data.

Groundwater discharge to rivers ('baseflow') occurs along several reaches of the Upper Namoi and contributes to measured surface water flow. For all coal development scenarios the baseflow contribution to stream flow declines and the maximum change is usually at the end of the prediction period (year 2100). The source of these impacts is either predominantly mining or a mix between mining and CSG developments. In comparison to the 'no mining and CSG' case (Scenario 0), the maximum baseflow reduction is 5% and occurs when underground mines are placed directly beneath the alluvium (Scenario 6).

To describe the risk to groundwater resources an assessment has been undertaken using the impact trigger levels defined in the Queendland Water Act 2000 since the equivalent guidelines for NSW aquifers are in draft form and currently being re-written. The trigger levels define at what point impacts are considered acceptable and at what point mitigation measures need to be commenced. The impact trigger levels are expressed as drawdown of groundwater levels and are:

- 0.2 metres for springs;
- 2 metres for unconsolidated aquifers (such as alluvial aquifers);
- 5 metres for consolidated aquifers (such as hard rock aquifers).

Using these trigger levels, the predictive modelling results (excluding Scenario 6), and an understanding of the sensitivity of the results to model input uncertainty, the risk to groundwater in each of the Management Areas and Zones has been classified as low, moderate or high. In the Oxley Basin and Great Artesian Basin Management Areas, risks to groundwater levels are dependent on the specific location within these large zones and multiple classifications are possible. The confidence in the assessment of risk for each zone has also been classified based on the type, quantity and quality of data available. The primary cause or source of the impact is also identified and the results of the classification are summarised by Table E2 and by Figure E7 (risk) and Figure E8 (confidence).

Table E2 Risk of impacts to groundwater levels and confidence in predictions

Management Area / Zone	Risk	Confidence	Source
Upper Namoi Alluvium Zone 1	Low	Low	Mining
Upper Namoi Alluvium Zone 2	Low	High	Mining and CSG
Upper Namoi Alluvium Zone 3	Low	High	Mining
Upper Namoi Alluvium Zone 4	Moderate	High	Mining
Upper Namoi Alluvium Zone 5	Moderate	Moderate	Mining and CSG
Upper Namoi Alluvium Zone 6	Low	Low	Mining and CSG
Upper Namoi Alluvium Zone 7	High	Low	Mining
Upper Namoi Alluvium Zone 8	Moderate	Moderate	Mining
Upper Namoi Alluvium Zone 9	Moderate	Low	Mining and CSG
Upper Namoi Alluvium Zone 10	Low	Low	Mining and CSG
Upper Namoi Alluvium Zone 11	High	Moderate	Mining
Upper Namoi Alluvium Zone 12	Low	High	N/A
Lower Namoi Alluvium	Low	High	CSG
Gunnedah Basin	High	Moderate	Mining and CSG
Oxley Basin	Moderate / High	Low	CSG
Liverpool Ranges Basalt	Low	Moderate	Mining and CSG
Great Artesian Basin	Low / Moderate	Moderate	CSG
GAB Alluvial	Low	Moderate	CSG
New England Fold Belt	Low	High	N/A
Peel Valley Alluvium	Low	High	N/A
Peel Valley Fractured Rock	Low	High	N/A
Misc. Alluvium of Barwon Region	Low	High	N/A
Galarganbone Tertiary Basalt	Low	High	N/A

Note - highlight colours reversed for Risk & Confidence

Groundwater levels in four locations are determined to be at high risk from coal and gas developments: Upper Namoi Alluvium Zones 7 and 11, the Gunnedah Basin and parts of the Oxley Basin Management Areas. Confidence in the predictions for the most heavily utilised areas can be considered high (Upper Namoi Alluvium Zones 2, 3 and 4 and the Lower Namoi Alluvium) or moderate (Upper Namoi Alluvium Zones 5 and 8). In some of the lesser utilised areas, where available data is sparse, the confidence is low.

For Scenario 6, where half the underground mines (of Scenario 3) are moved to locations immediately below the Upper Namoi Alluvium, the risk to alluvial water resources is considered high, as shown by Figure E9.

For the most part, the Groundwater Dependent Ecosystems (GDEs) identified in the most recent 'State of the Catchment' report fall within low risk areas.

Analysis of the Model water balance for Scenario 3 shows that both the Lower and Upper Namoi Alluvium will experience a relatively low impact when compared to existing anthropogenic water use impacts. However, the hard rock groundwater system, particularly within the Gunnedah Basin Management Area, is likely to experience a high impact. The Model water balance also indicates that the impact on surface water flow, although likely to be a small percentage of the average flow, may peak at about half the current surface water usage level. These results are illustrated by Figure E10.

The configuration of the predictive scenarios enables assessment of the relative contribution to potential impacts from different types of coal resource development. In the Upper Namoi Alluvium, impacts to groundwater are more likely to be due to coal mining than due to CSG development. For the Lower Namoi Alluvium, the very small predicted impacts are derived mostly from CSG extraction. In the hard rock areas, the source of impacts is more mixed. To the east (Gunnedah Basin Management Area), where coal seams are shallow, it is likely that impacts would be derived mostly from mining. In the west, where coal seams become deeper, impacts would be derived mostly from CSG development.

Open cut and underground mining will impact the water resources in different ways. Open cut mines are likely to have the greatest direct impact on surface water runoff, groundwater recharge and groundwater levels, depending on pre-existing conditions and the pit configuration. Underground mines will primarily impact groundwater levels due to their depth and limited surface infrastructure and footprint. The primary impact of CSG extraction will be similar to underground mines although more diffuse and over a larger area. Re-injection to alluvial aquifers of groundwater abstracted during CSG operations has the potential to alleviate impacts, whether they are derived from CSG, mining or both.

Model simulations of different future rainfall conditions indicate the magnitude of predicted impacts on groundwater levels and on surface water flows may increase under a drier climate. The magnitude may decrease with a wetter climate, but the degree of change is less than for the drier climate simulation.

At a regional and sub-regional scale, the modelling has confirmed that mining and CSG activities have the potential to both negatively and positively impact the groundwater quality of the hard rock and alluvial aquifer systems. This would occur by the migration of water between different levels in the alluvial aquifer and between the alluvial aquifer and the bordering hard rock formations. Significantly more extensive and detailed water quality data would be required to quantify potential changes. At a regional scale, any impacts to surface water quality are likely to be too small to identify.

At a project scale, mining and CSG activities both have the potential to negatively impact groundwater and surface water resources via localised pathways. These local scale pathways, conditions and effects cannot be determined with any degree of accuracy by a catchment-scale study or predicted by a model designed to assess catchment-wide, long-term and cumulative impacts. This highlights the importance of project-specific detailed investigations, supplemented by comprehensive monitoring and appropriate operational management.

Data gaps and impact management

Data gaps

During the course of the Study and model construction, a number of data gaps were identified. Those of greatest importance can be summarised as:

- The low density of relevant data away from the Upper and Lower Namoi Alluvial systems;
- The absence of test data on the hydraulic connection between rock layers and aquifers within the catchment.

To reflect the uncertainty associated with many of the input datasets to the Model, the variability of predictive results was tested by using a range of input values. This process identifies important controls on results and indicates where higher value will be derived from the collection of new data. The data gaps identified form the basis of recommended future investigations and monitoring.

Investigation and monitoring

A practical investigation and monitoring program has been outlined to: i) provide data for future maintenance, updating and improvement of the Model, and; ii) reduce the uncertainty in predictive results and enhance the Study. The higher priority elements of the recommended investigation and monitoring program are summarised in Table E3.

Table E3 Higher priority investigation and monitoring recommendations

Investigation / monitoring element	Rationale
Continued monitoring of existing sites. To include sites currently used for Model calibration and those for future calibration.	To ensure Model datasets can be updated efficiently. Comprising climate, groundwater and surface water. Sites with short monitoring records not used in current calibration will be suitable for longer-term enhancement.
Drilling and construction of new investigation and monitoring holes, primarily in:	For definition of geological and groundwater conditions and parameters in at-risk areas with sparse available data. To form new monitoring sites.
- Upper Namoi Zones 4, 6 & 10;	Alluvial zones that currently have sparse groundwater level data.
- the hard rock units across the full geological sequence;	Drill and complete as multi-level monitoring sites to determine pressures and characteristics of the hard rock units.
- areas where coal seams are at or very close to the alluvium.	To assess the hydraulic connection between the alluvium and hard rocks in areas most likely to be near new coal developments.
Groundwater quality monitoring of the alluvium and hard rock units.	There is no systematic collection of water quality samples across the catchment and insufficient data to characterise the system.
Surface water quality sampling, particularly near coal resource developments.	A more rigorous sampling regime is required to characterise the baseline hydrochemistry of the receiving waters and of any discharges.

Mitigation

The severity or seriousness of an impact can be reduced by mitigation. Prevention of an impact is generally preferable to mitigation and many prevention measures exist to minimise local-scale impacts (spills, discharges etc.). These should be included in the approvals and environmental management plan for each particular development project. On a sub-regional scale, impact prevention options are more limited, potentially placing greater reliance on mitigation.

Effective impact mitigation is reliant on establishing the impact source and having a comprehensive baseline dataset for both water quantity and quality so that impacts can be defined, tracked and mitigation implemented in time. Trigger levels for both water quantity and quality components should be set which define at what magnitude of impact the mitigation measures are activated.

For future coal resource development aligned with Scenario 3, the Model results suggest that mitigation will be required in several of the Groundwater Management Areas if NSW trigger levels are set at similar levels to those in QLD. Three of the Upper Namoi Alluvium zones include small areas where the maximum predicted impact is greater than 2 metres, and hard rock areas of the Gunnedah and Oxley Basins indicate water level declines greater than 5 metres. In addition to this there are several springs classified as high priority GDEs which are located in areas where impacts could be greater than 0.2 metres (Figure E6). A number of potential mitigation options are outlined within this report but the most appropriate choice will depend on specific local conditions.

Study value and utility

The Namoi Catchment Water Study has resulted in:

- collation, review and assessment of all relevant data and including information provided by the coal resource development industries that is confidential to those participating companies;
- compilation of digital information within a relational database that contains over 30 million records, facilitating simultaneous interrogation of multiple datasets and the production of integrated diagrams and plans;
- the integration of geological data for the entire Namoi catchment to establish the spatial (three-dimensional) extent of all unconsolidated and consolidated rock formations and the location of potential coal-bearing units.

These activities have enabled the spatial relationship between the catchment water resources and the potential coal bearing units to be identified. It allows the general location and type (open cut mining, underground mining or CSG production) of possible future coal resource development to be inferred. Plausible future mining and CSG production scenarios can then be designed.

The integrated assessment of all data has resulted in a whole of catchment conceptualisation and qualitative evaluation of the ways that the potential effects from coal resource development activities can propagate away from the source and affect water resources. The assessment also identified the general locations (at a sub-regional scale) of zones which may be most at risk from these activities.

The numerical Model constructed for the Study is based on this conceptualisation and is able to incorporate and assess a wide-range of potential future coal resource development activities. The Model provides a robust tool that can be updated with new data, recalibrated as necessary and used to assess alternative scenarios and the effects of changing other inputs and assumptions such as a change in climate.

The Model provides predictions of the long-term, cumulative effects of mining and CSG developments on water resources at a catchment-scale and identifies those areas (sub-regionally) that are most at risk from developments and quantifies the potential magnitude of impacts for different coal resource development options. Assessment of the sensitivity of the results to different inputs, and the level of confidence in these predictions, has also been undertaken.

The Model predictions must be viewed in the context of the significant uncertainty associated with the location, type, scale and timing of potential future coal resource developments and take into account the very long predictive period (90 years). The Model is not designed to predict local-scale effects and does not replace the requirement for project-specific detailed investigations, supplemented by comprehensive monitoring and appropriate operational management.

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Figure E1 Water resources of the Namoi catchment

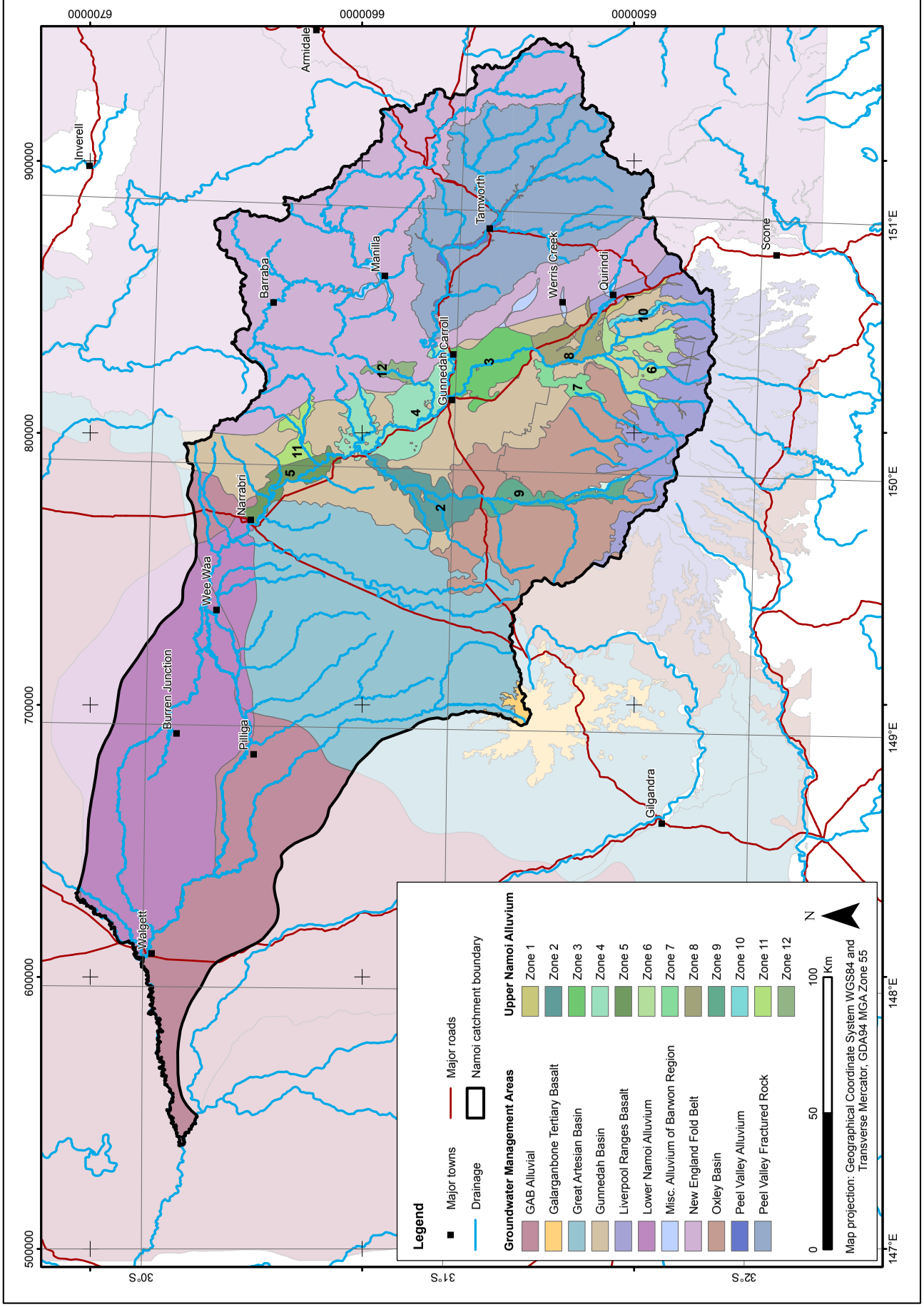

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Figure E2 Proximity between alluvial and fractured rock aquifer groundwater resources and potential coal and gas resources

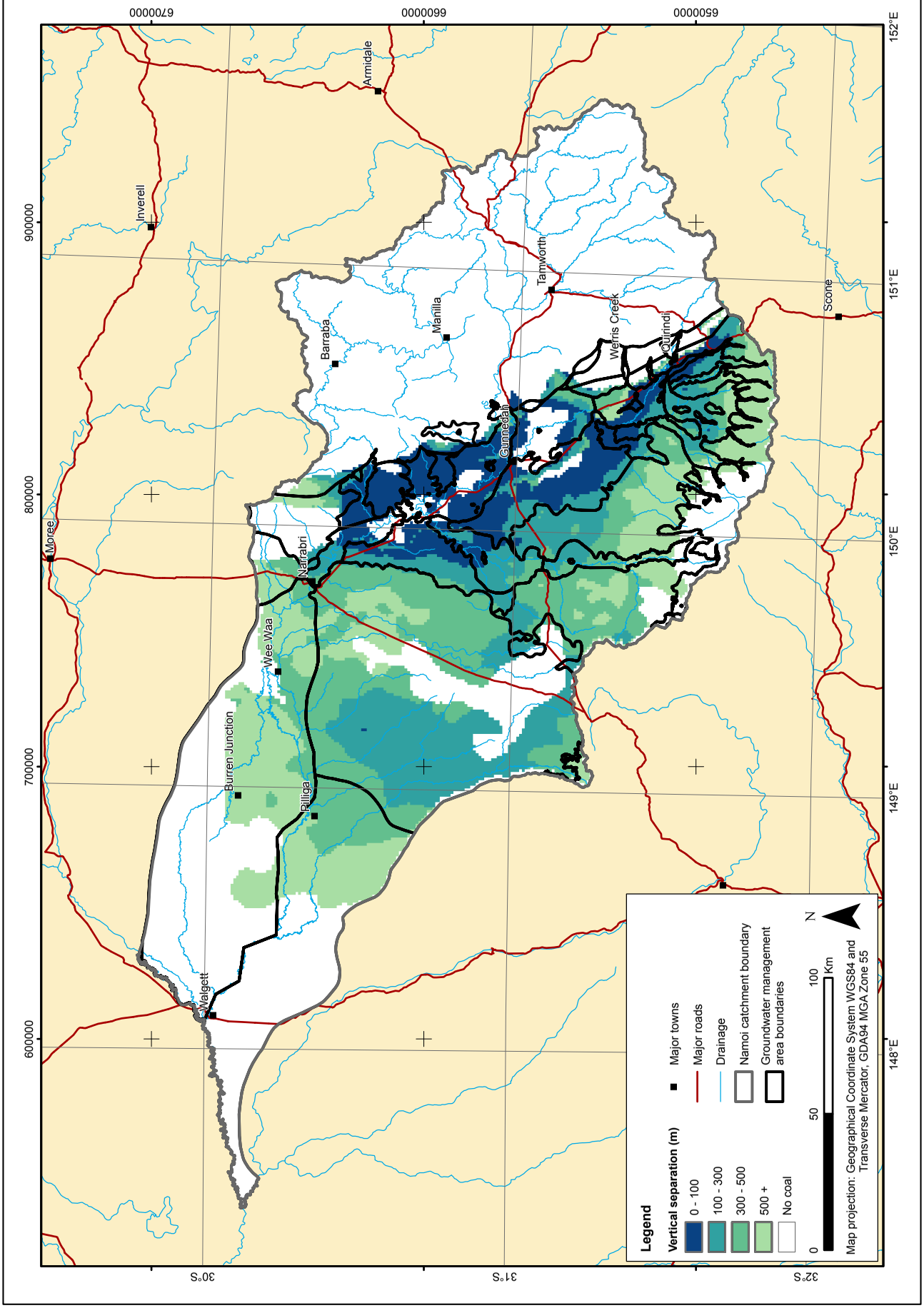

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Figure E3 Mining and coal seam gas activities simulated in the long term development scenario (Scenario 3)

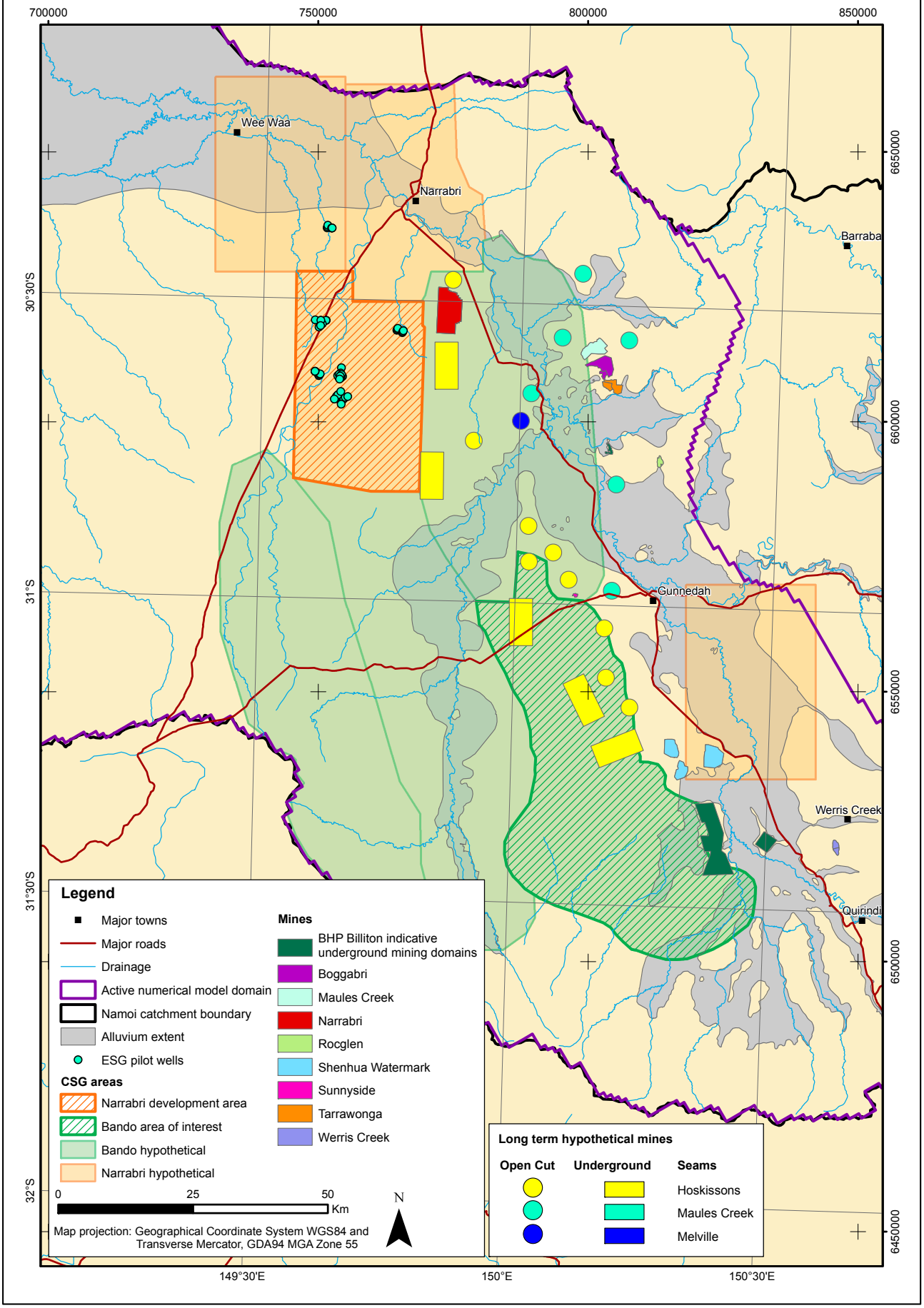

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Figure E4 Long term predicted maximum impacts on groundwater levels (Scenario 1)

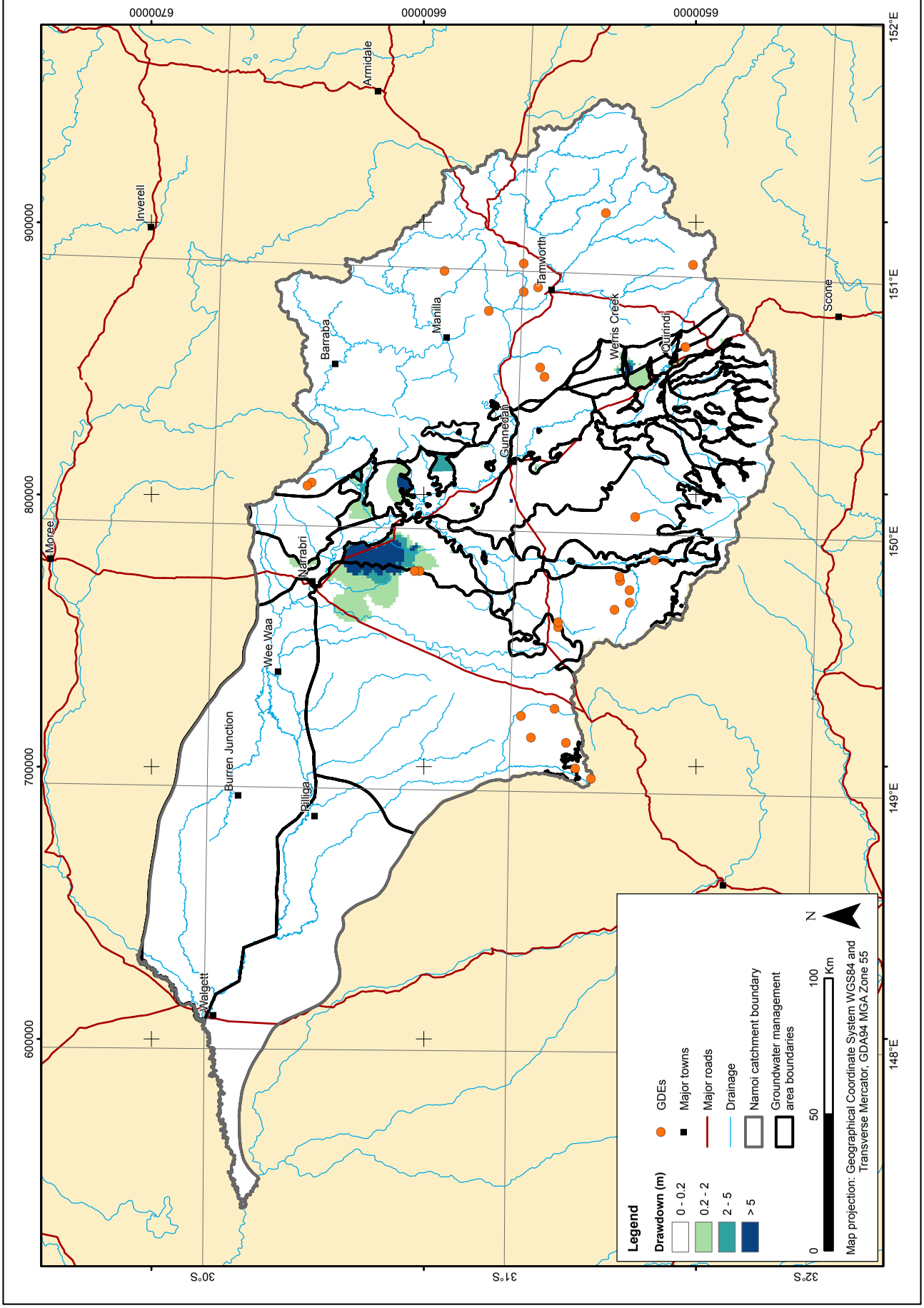

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Figure E5 Long term predicted maximum impacts on groundwater levels (Scenario 2)

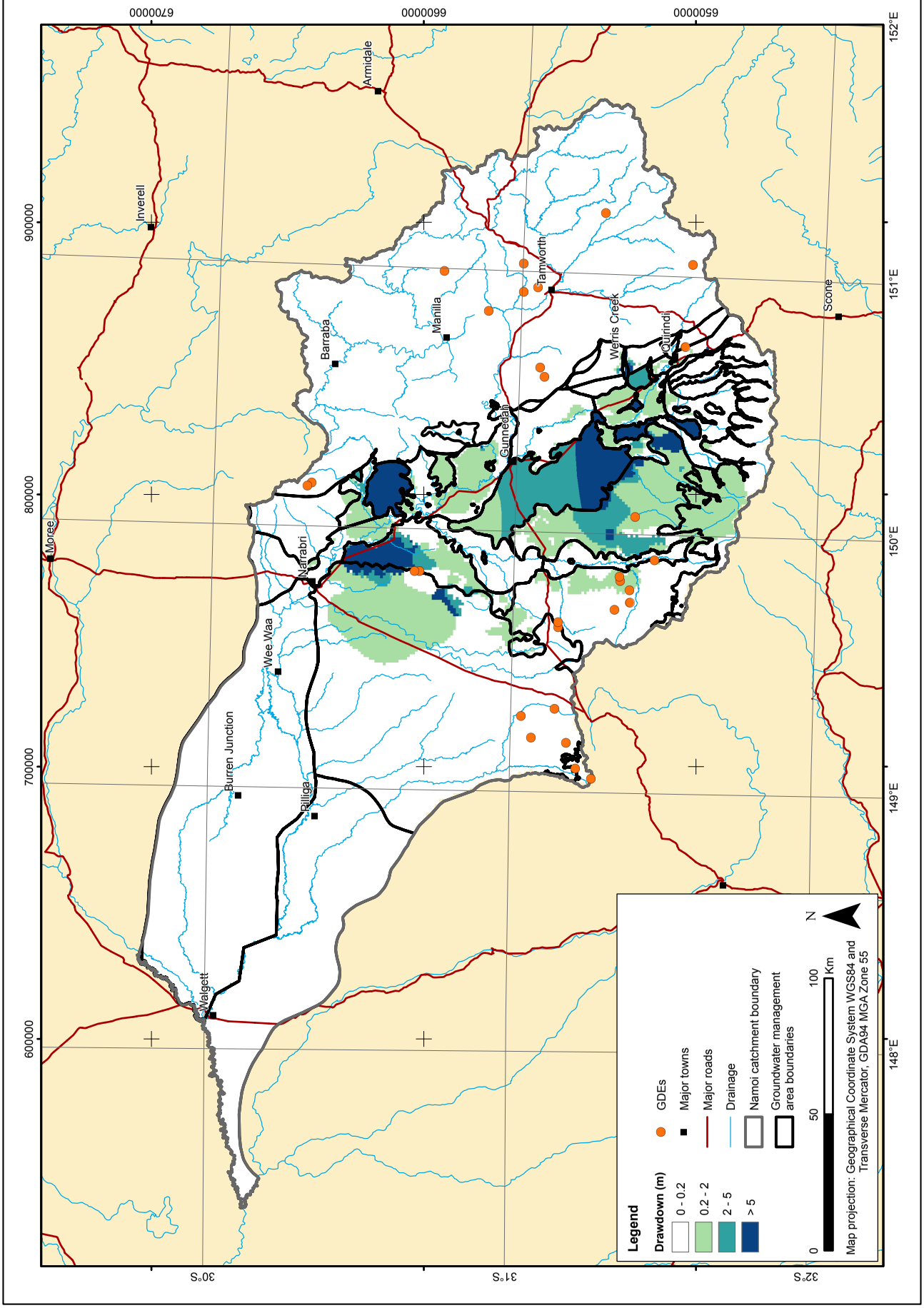

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Figure E6 Long term predicted maximum impacts on groundwater levels (Scenario 3)

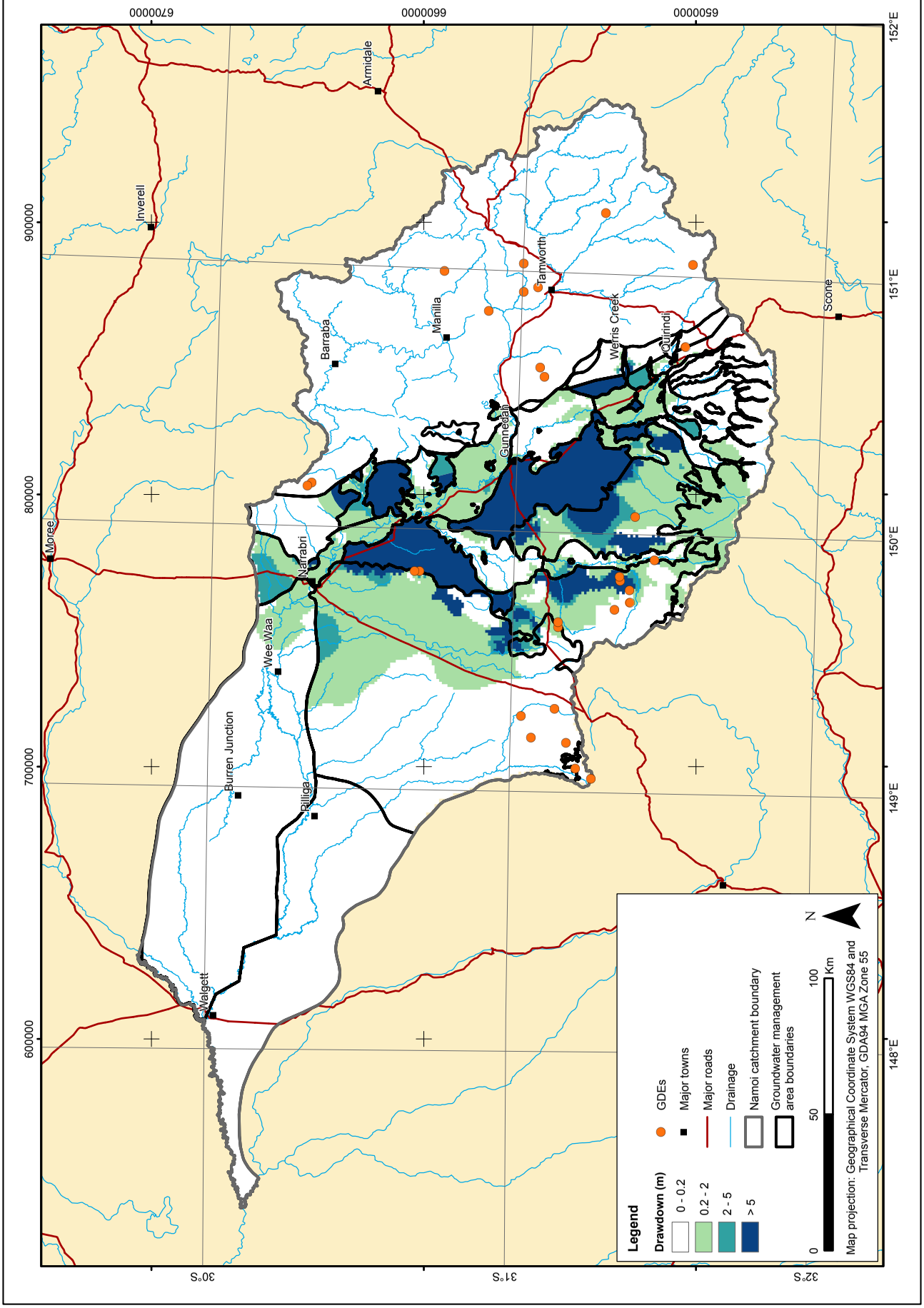

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Figure E7 Potential risk to groundwater resource (quantity)

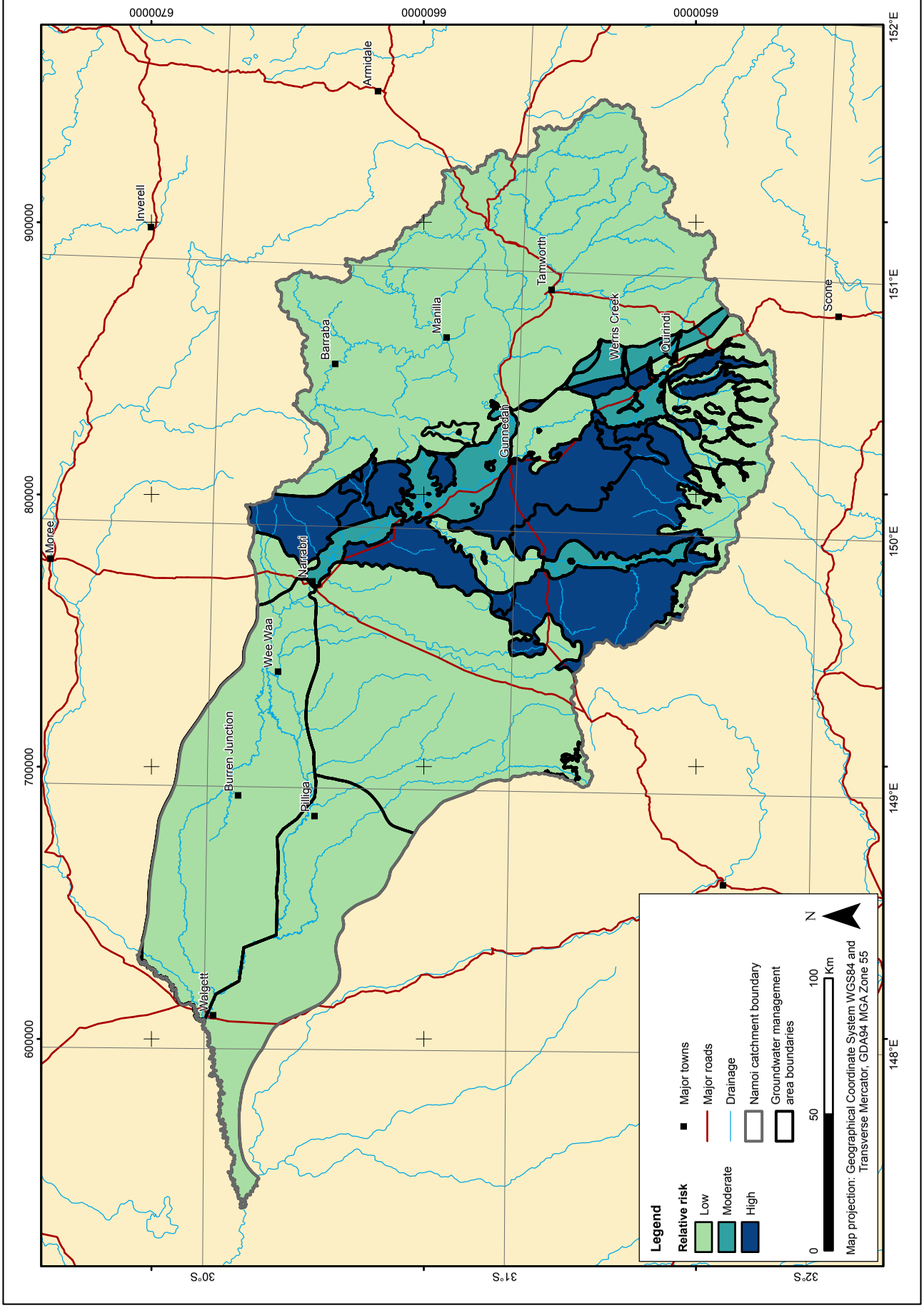

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Figure E8 Assessment of confidence in predicted groundwater impacts

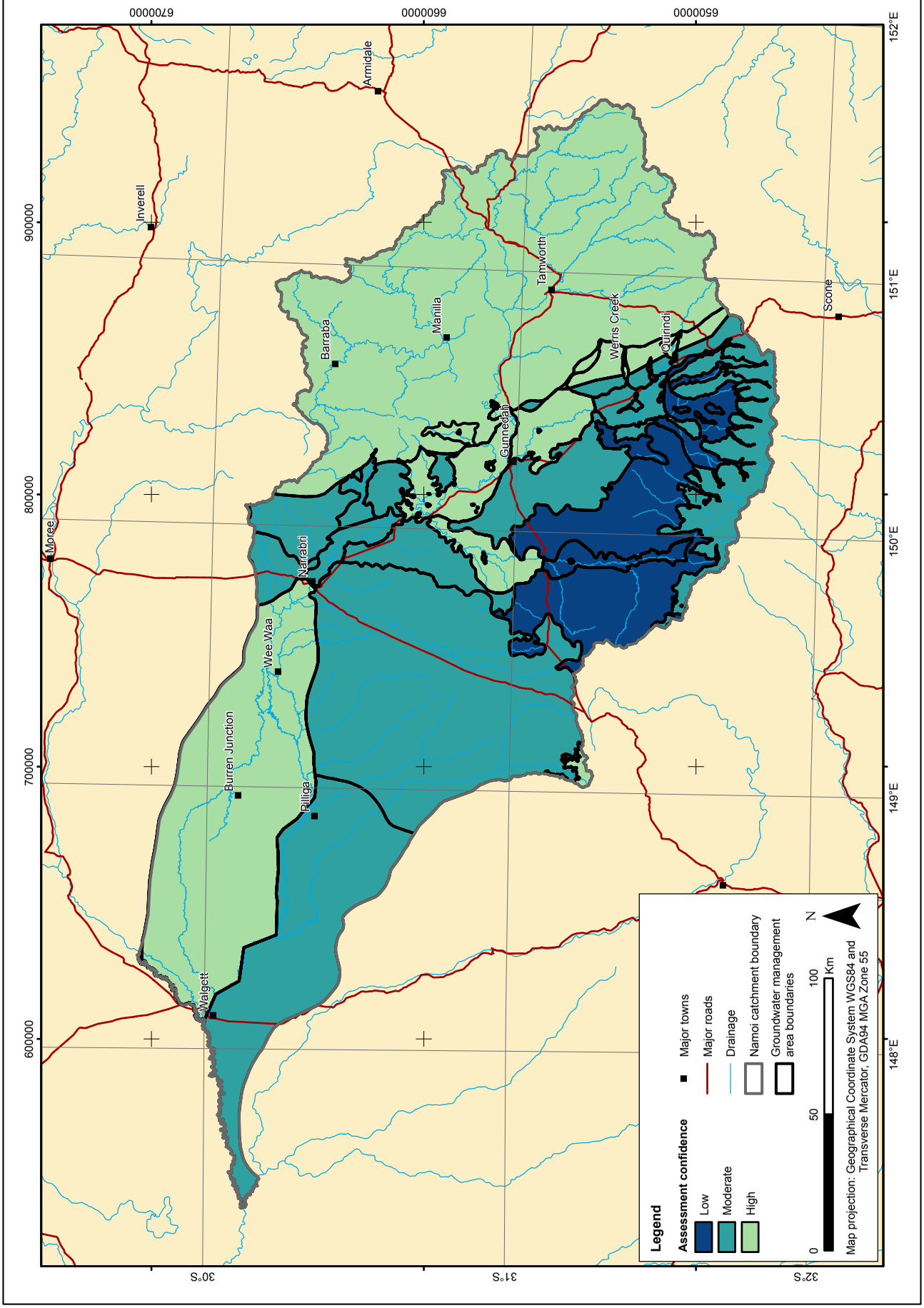

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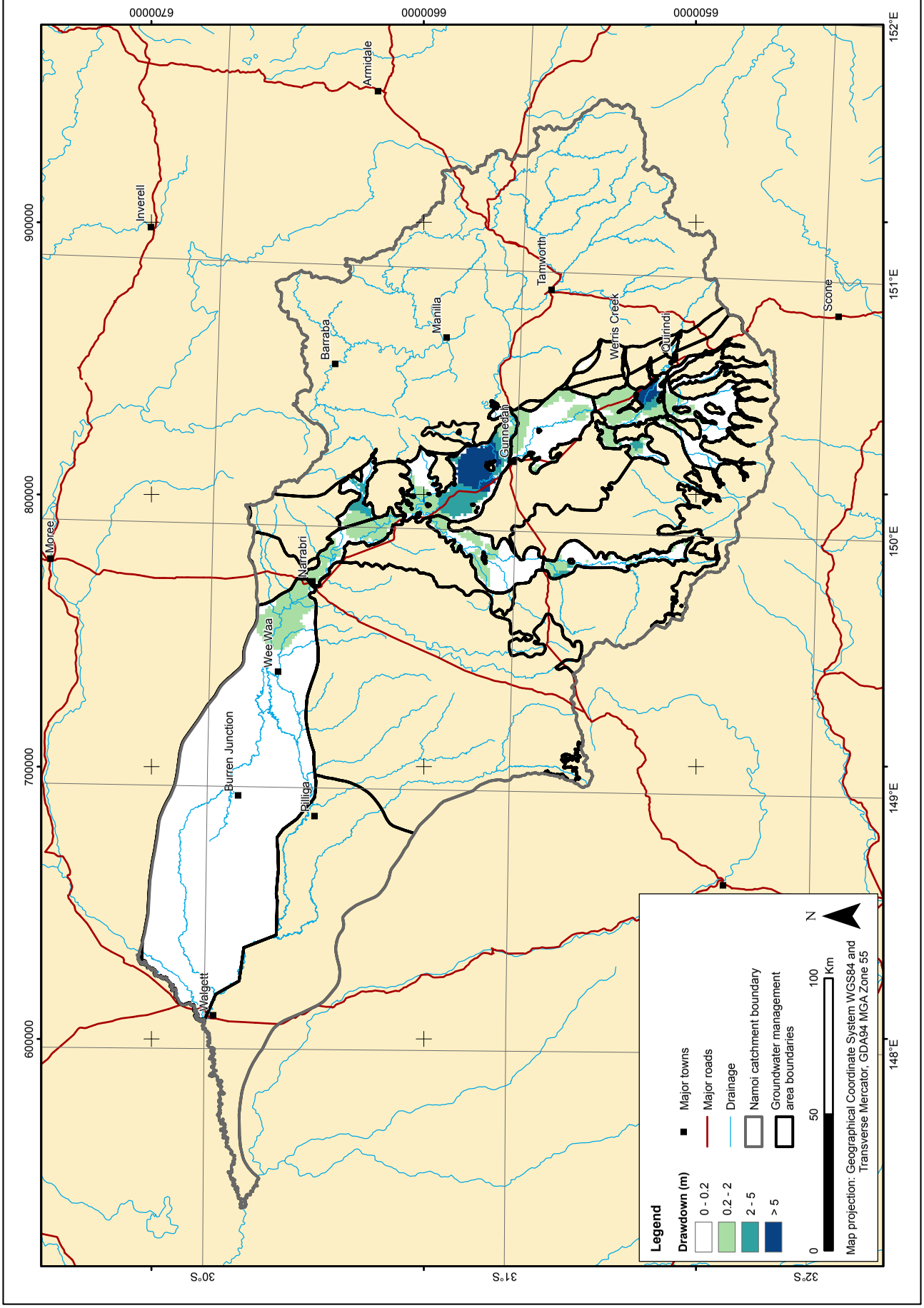
Figure E9 Long term predicted maximum impacts on alluvial groundwater levels (Scenario 6)



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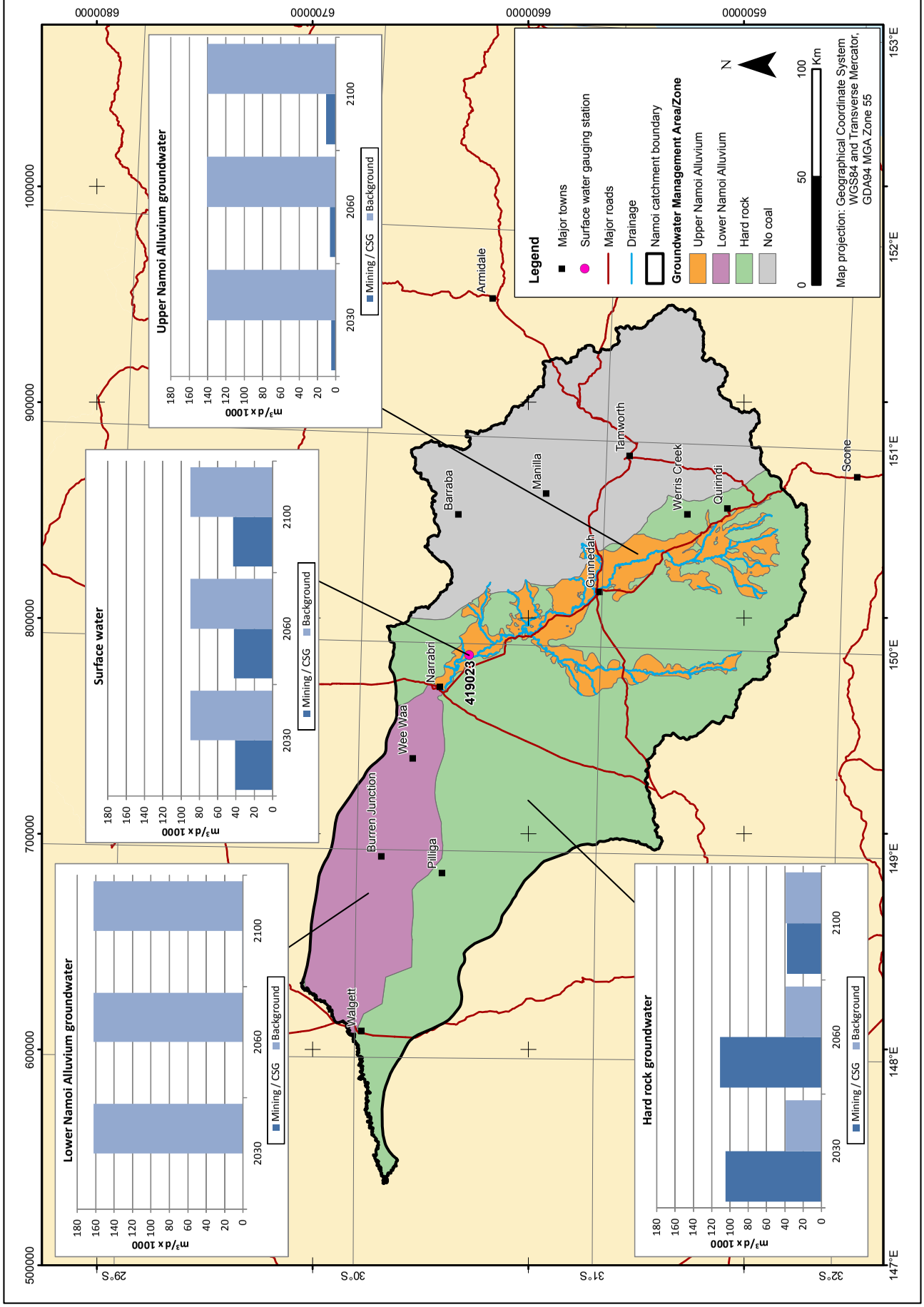
Figure E.10 Predicted impacts on water availability from coal and gas developments compared to non-coal related activities (Scenario 3)