Chapter 10 – Recommended Future Workplan

Based on the potential groundwater supply and storage targets outlined in Chapter 9, we would recommend that further feasibility studies should be focussed on the most prospective groundwater options for Broken Hill, including:

1. Use of intermediate-depth aquifers to store Menindee surface water by implementing an aquifer storage and recovery (ASR) scheme at Menindee, and possibly at other locations along the existing Broken Hill pipeline, e.g., Yancowinna Creek;

2. Contingency pumping of fresh to brackish groundwater from the shallow alluvial aquifer system in the vicinity of Menindee, and possibly at suitable locations further upstream towards Wilcannia;

3. Enhanced recharge of shallow alluvial aquifers (with surface water) by bank filtration, infiltration basins or borehole injection, especially near Stephens Creek;

4. Possible extraction of groundwater from intermediate- and deep-level (and currently unexplored) aquifers in the Murray Geological Basin and the Darling Geological Basin in the vicinity of the Menindee Trough; and

5. Investigation of the potential for groundwater extraction from parts of the Mundi Mundi Alluvial Fan system near the Umberumberka Reservoir.

From this list of options it is apparent that the main focus of future groundwater investigations should be on the Menindee Lakes–Darling River Floodplain region. Here, multiple aquifers at different stratigraphic levels are located in proximity to the regional surface water storages and associated water supply infrastructure (Figure 9.8). We recommend a comprehensive and integrated hydrogeological assessment of the entire geological profile be undertaken in this area, including the near-surface materials and landforms, shallow alluvial systems, intermediate Murray Geological Basin sediments and deep Menindee Trough sedimentary formations.

Two additional study areas have also been identified along the Menindee–Broken Hill pipeline. These are secondary targets for aquifer storage, namely Murray Geological Basin sediments in the Yancowinna Creek area and shallow alluvial deposits associated with Stephens Creek. Preliminary hydrogeological investigations (such as mapping, drilling and geophysics) could also be undertaken in these areas, to complement the main workplan in the Darling River corridor. Similarly, the Mundi Mundi Alluvial Fans near the Umberumberka Reservoir to the west of Broken Hill are also a target for baseline hydrogeological data acquisition and interpretation. These targets all have the advantage of being readily incorporated into the existing water supply infrastructure.

As shown in Figure 10.1, a phased approach is recommended for assessing and implementing a conjunctive water management approach that combines groundwater storage and supply options with current water supply strategies. Analysis of similar managed aquifer recharge (MAR) schemes has shown that a staged approach involving careful testing and design is a key element to success (Pyne, 2005; Murray et al., 2007).

Figure 10.1: *Phased approach to assessing and implementing Broken Hill groundwater options (orange = objectives, green = activities, blue = outputs, purple = est. timeframe).*

Phase 1	*Phase 2*	*Phase 3*	*Phase 4*	*Phase 5*
Commencement	**Data Acquisition and Interpretation**	**Detailed Feasibility Study**	**Pilot Trials**	**Implementation**
Determine regional water budget and parameters	Acquire and interpret baseline hydrological and geological data	Assess feasibility of extraction and storage options for groundwater	Implement and test preferred groundwater extraction and storage option at a small operational scale	Construct and operate groundwater extraction/storage option
• Evaluate surface water status, availability and ownership • Determine historical supply rate, variability and projected water use for Broken Hill • Identify approvals process for MAR and discuss with regulatory bodies • Assess volume, frequency and timing of water for MAR • Evaluate quality of surface water and pipeline water • Investigate recovery and efficiency of recharge water	• Compilation of existing data and mapping • Hydrogeological mapping • Geomorphic mapping and topographic analysis • Geophysical surveys • Drilling of investigation bores • Pump testing • Sediment analysis • Remote sensing • Water sampling and analysis • Establish hydrologic monitoring network	• Groundwater flow and solute transport model • Geochemical modelling (water compatibility) • Pre/post treatment requirements (e.g. clogging prevention, desalination) • Infrastructure design and optimisation • Socio-economic analysis • Policy and entitlement requirements (eg property rights of injected water) • Environmental impact assessment • Integration with surface water storages and management • Re-evaluate surface water availability for projected future supply (accounting for climate change) • Drilling of ASR well and additional monitoring wells with cored intervals • Establish baseline monitoring of water level, EC and temperature in monitoring wells and for source water	• Construct bores and associated infrastructure • Pump testing • Tracer testing • Operate cycles of injection and recovery • Monitor performance indicators • Establish pilot pre-treatment (if required) to enable injection • Develop and implement a risk management plan • Perform validation and verification monitoring • Submit results of trial studies to regulatory body	• Complete construction of infrastructure (eg bores, basins, pipelines, treatment facilities) • Operate scheme in conjunction with other surface water and groundwater strategies • Maintain monitoring networks • Assess, report and review operational performance and efficiency • Monitor and review defined potential impacts (eg ecosystems, salinity) • Develop standard operating procedures and train staff • verify recovery efficiency and recovered water quality • Update groundwater models used for site operations • Document the project in a paper for submission to the ISMAR7 symposium and international journals
• Preliminary understanding of likely costs involved for surface water and groundwater options • Knowledge of storage and recovery characteristics of alternative systems • In-principle support of plan from stakeholders and regulatory bodies	• 3-D geological model including aquifer structure and properties • Detailed topographic and geomorphic mapping • Overview of groundwater quality and chemistry • Identification of groundwater-dependent ecosystems and surface water-groundwater connectivity • Conceptual model of groundwater systems • Baseline monitoring network	• Borefield/MAR Design • Conjunctive management strategy • Budget and project plan • Monitoring and review strategies • Impact assessment • Energy audit • Water allocation and licensing requirements • Jurisdictional approvals • Refined cost estimates and finalised system design for MAR • Risk management plan for pilot trails, protecting human health and the environment (Draft MAR guidelines)	• Reconfiguration and optimisation of engineering design and operation procedures • Improved groundwater model • Definition of information gaps • Documented commissioning trial • Documented post-commissioning residual risk assessment plan with identified preventive measures for implementation in Phase 5	**Successful conjunctive operation of groundwater extraction/storage schemes within an integrated water resource plan**
6 months	18 months	12 months	12 months	12–18 months

Note: Some activities in Phases 1, 2 and 3 can be jointly undertaken within the same timeframe.

10.1. PHASE 1 – COMMENCEMENT

Our recommended approach for further investigations and feasibility studies begins with a thorough assessment of surface water resources and existing water infrastructure within the region. This commencement phase can include:

1. Evaluation of the status, availability and existing ownership rights of surface water resources in the region. This would include investigation of historical supply records and the variability of the regional hydrological system. Additionally, projected trends for Broken Hill's water usage would need to be factored into future planning, especially in light of predicted climate change scenarios;

2. Identifying the approvals process for undertaking any managed aquifer recharge developments, and consulting with various stakeholder groups, including the relevant MAR regulatory bodies which would oversee the development;

3. Detailed study of the quality and chemical composition of the regional surface water resources, especially those suggested for aquifer storage. Knowledge of the quality of water in the pipeline, and any spatial or temporal variations would also be important. These factors will influence the type and degree of treatment which may need to be undertaken at Menindee and Broken Hill;

4. Preliminary economic evaluation of system development and implementation, combined with understanding of the storage and recovery characteristics of alternative systems; and

5. Determination of the likely volume, frequency and timing of water to be supplied for MAR.

10.2. PHASE 2 – DATA ACQUISITION AND INTERPRETATION

It is important that adequate baseline information is collected at an early stage to support the design and implementation of a conjunctive water supply scheme. Hence, extensive hydrogeological data acquisition and interpretation is a critical step in the work plan (Figure 10.1). This phase can include:

1. Collation of existing data and information, covering aspects such as **mapping** (e.g., surface geology, soils, geomorphology, topography, vegetation, land use, land tenure, infrastructure), **geophysics** (e.g. radiometrics, aeromagnetics, gravity), **remote sensing** (e.g., Landsat, SPOT, LiDAR), and **groundwater monitoring** (e.g., drilling, groundwater levels, pump testing, streamflows, water chemistry). Many of these datasets have already been collated as part of this regional groundwater resource assessment;

2. Regional airborne electromagnetic (AEM) surveys to map changes in electrical conductivity of geological materials with depth. Similar surveys have been used to map zones of fresh groundwater, leakage from surface water bodies or saline clay layers, e.g., Lawrie et al., 2008. Appendix 5 gives examples of interpreted products generated from AEM surveys undertaken along the floodplain of the River Murray. Due diligence would be required to test the effectiveness of the geophysical technique in this environment before any investment in data acquisition. This includes forward modelling to predict likely geophysical signatures and to optimise survey design;

3. Other airborne surveys would also be useful for investigating unconfined aquifer systems. These would include acquisition of high-resolution LiDAR and radiometric data along the floodplain corridor, if existing survey data is inadequate. LiDAR (or light detection and ranging) uses an airborne pulsed laser system to survey the land surface and generate an accurate digital elevation model. Radiometric surveys (also called gamma-ray spectrometry) measure gamma rays emitted with the decay of naturally occurring radioactive elements, principally from potassium (K), thorium (Th) and uranium (U). Radiometrics can be used to map characteristics of the soil and its parent geological material, including surface texture, weathering, leaching, soil depth, moisture and clay mineralogy (Bierwirth, 1997). The combination of LiDAR, topographic analysis and radiometrics can be used to compile detailed

geomorphic mapping that supports the interpretation of the AEM and helps identify the critical landscape elements and floodplain characteristics (such as infiltration rates). Additionally, these methods can also be used to derive products such as flush zone maps (Clarke et al., 2008);

4. Land-based geophysical surveys such as electromagnetics (EM), ground penetrating radar (GPR) or shallow seismic traverses would also help validate the AEM survey data, and provide complementary data to help interpret aquifer geometry and hydraulic properties, particularly when interpolating between boreholes. These methods would primarily be used to investigate unconfined aquifer systems;

5. An investigative drilling program to obtain geological samples, define stratigraphic profiles, and construct monitoring bores. This allows the opportunity to directly sample and analyse aquifer material (such as grain size distribution, palynology to assign geological age, pore water chemistry, permeameter measurements, and mineralogical analysis using X-ray diffraction and anisotropy). These sediment samples are also critical for laboratory analyses designed to address specific ASR issues, such as vulnerability to clogging or chemical compatibility with source water;

6. Downhole geophysical logging (such as EM, resistivity and gamma) to aid in geological interpretation, to calibrate the AEM survey data and assist with placement and sizing of screens for monitoring and ASR wells. There may be the opportunity to undertake cross-well tomography, where an acoustic signal transmitted in one bore is measured by a receiver in another bore, to map the properties of the intervening geological material;

7. Comprehensive water sampling (including rainfall, surface water and groundwater) to assess water quality criteria and undertake hydrochemical analysis to understand hydrological processes. This includes analysis of major, minor and trace elements and isotopes (such as deuterium and oxygen-18), nutrients, DOC, TOC (total organic carbon), pH, Eh, DO, and temperature, and on a less frequent basis, pesticides or other organics known to be used in the surface water catchment;

8. Pump testing of monitoring bores to estimate hydraulic properties (such as transmissivity and storage coefficients) and to define how aquifers respond to pumping (in terms of drawdown of groundwater levels or changes in groundwater chemistry);

9. Establishment of a baseline hydrological monitoring network including logging of groundwater levels and salinity, and also any required upgrading of the surface water network (such as monitoring of river stage, stream flow or electrical conductivity);

10. Processing and interpretation of satellite imagery to support key mapping datasets. An example is time-series analysis to identify the dynamics of vegetation health (particularly maintenance of vigour during prolonged dry periods). This can be used to assess the degree to which native vegetation communities are reliant on access to shallow groundwater for their moisture requirements. Other image processing techniques can be used to map flood inundation and clay distribution. This is mainly applicable to unconfined aquifer systems;

11. Interpretation of the overall hydrostratigraphy, including mapping of aquifer geometry, thickness and structure; geological properties such as lithological composition, facies variability and heterogeneity, sediment mineralogy and grain size; aquifer properties such as permeability, porosity and potential yield; groundwater conditions such as potentiometric surfaces, flow paths, watertable depth, level of confinement, lateral and vertical hydraulic gradients; and groundwater chemistry such as salinity, major/minor/trace element concentrations, pH, redox and temperature. Myriad diverse data can also be encapsulated in a 3-D hydrogeological model of the study area; and, finally

12. Based on the integration and interpretation of these datasets, development of a conceptual model of the groundwater systems and key processes (such as flow paths, surface water

connectivity, recharge and discharge). This conceptual model forms the basis for any subsequent numerical groundwater flow or solute transport model (Phase 3).

10.3. PHASE 3 – DETAILED FEASIBILITY STUDIES

The comprehensive data acquisition and interpretation stage will help target the specific location and nature of groundwater storage and supply options in the study area. The second phase investigates the feasibility of these options, including initial design in the context of the overall water supply and management strategy. Components of this feasibility assessment can include:

1. Construction and calibration of a numerical groundwater flow model to provide the capacity to predict the outcomes and impacts of implementing various groundwater extraction and storage options (such as changes in groundwater levels and flow paths). A three-dimensional, multi-layered model is recommended, accounting for surface water interactions and density effects (due to salinity differences). The model should also include a solute transport component to predict the movement of salt due to groundwater pumping or injection, and allow determination of subsurface residence time for various operating strategies and runoff scenarios for risk assessment purposes;

2. Specific investigations to assess potential impacts of active groundwater recharge and extraction (as outlined in Figure 10.2). This includes better understanding of the seepage flux between the river and the shallow aquifers using techniques such as temperature monitoring, hydrographic analysis, seepage meters or environmental tracers such as Radon-222 (Brodie et al., 2007). More detailed field investigations may also be undertaken on the groundwater dependency of native vegetation. Appropriate strategies need to be designed to monitor and review the defined impacts;

3. MAR assessment of pre- and post-treatment requirements such as prevention of physical clogging, chemical precipitation, clay swelling, air entrapment, or microbial growth that can impede MAR performance (Dillon and Pavelic, 1996). This can include biogeochemical characterisation of the Menindee source water and native groundwater systems, and bench-scale laboratory testing of aquifer samples or geochemical modelling to predict the fate and residence time of recharged water, and clogging and pre-treatment requirements to avert it;

4. Engineering design and planning of proposed infrastructure (such as diversion structures, additional water treatment, production bores, injection and recovery bores, sampling and monitoring, valves and pipelines, control systems etc.) and the overall conjunctive operational strategy. This includes defining thresholds for parameters such as groundwater levels, injection pressure, turbidity, salinity, and pH or dissolved oxygen concentrations (Healthy Waterways, 2006). It also involves maintenance and contingency planning to deal with system stoppages or failures (such as power outages, pollution incidences, flood events, etc). A potential issue is the availability of suitable management and technical capacity to operate any MAR scheme;

5. Economic analysis of proposed groundwater extraction and storage options. A key outcome is detailed project planning that includes budgets, milestones, timelines and identified risks of the options;

6. Analysis of the social, cultural and heritage impacts associated with any implemented scheme, addressing issues such as land tenure and access, protection of sites of aboriginal importance, and community engagement;

7. Resolution of any water policy, entitlement or regulatory requirements. Institutional issues have been identified as major impediments to implementing conjunctive water strategies (UDWR, 2005). In particular, any implementation of managed aquifer recharge (MAR) requires definition of the property rights associated with the recharge water. There may also be a need to translate existing surface water entitlements (relating to Menindee water storage) into the groundwater management regime. The roles, responsibilities and requirements of key organisations (such as regional water authorities, State regulatory agencies, funding sources)

also need to be adequately defined. The specific requirements for jurisdictional approvals (such as environmental impact assessments and license applications) require preparation for this stage;

8. Analysis of energy requirements particularly related to water delivery (injection, recovery and transport) and treatment (disinfection, desalination). This includes investigation of options to reduce greenhouse gas emissions, such as use of carbon-neutral energy sources such as geothermal, wind or solar-thermal energy (or a combination of these). Also, any upgrading of desalination capacity would require an assessment of brine disposal options;

9. Re-evaluate surface water availability for the projected future supply requirements, accounting for projected future climate change scenarios;

10. Drilling of ASR wells and additional monitoring wells, obtaining drill core over targeted intervals;

11. Establish baseline monitoring network including water levels, electrical conductivity and temperature transducers; both in monitoring wells and for source water;

12. Refine economic estimates and finalise system design; and

13. Develop a risk management plan for pilot trials, in order to protect human health and the environment, based on recommendations in draft MAR guideline documents. There are various guideline documents of relevance to this feasibility stage, such as Dillon and Pavelic (1996), ASCE (2001), Dillon (2005a), Pyne (2005) and Dillon and Molloy (2006). These provide useful background material for the feasibility assessment of managed aquifer recharge schemes.

10.4. PHASE 4 – PILOT TRIALS

The groundwater supply and storage options defined by the feasibility assessment would require initial testing via preliminary small-scale trials (Figure 10.2). Managed aquifer recharge schemes are usually developed incrementally, where increases in capacity are based on the performance of the system during initial operations (Murray et al., 2007). This is part of a risk management approach to identify and resolve issues before full implementation. For groundwater extraction, this involves construction and pump testing of a production bore at selected key sites. For ASR operations, a bore is constructed and operated over a number of injection and recovery cycles. Associated monitoring (such as nearby piezometers) are used to measure performance indicators such as thresholds for groundwater drawdown rates and levels, injection volumes or pressures, or changes in groundwater salinity. This monitoring is used to make changes to the design or operational procedures for the scheme, or to instigate specific investigations to resolve identified issues. This includes aspects such as ecological impacts, clogging susceptibility, density and buoyancy properties of the stored fresh water, overpressure and the potential for hydrofracturing, viability of treatment technology and evaluation of recovery efficiency (CERP, 2006). Such trials also provide valuable data to improve the calibration of any groundwater flow or solute transport modelling undertaken during Phase 3. Additional work which could be included here involves:

1. Establishment of pilot pre-treatment facilities (if required) to enable injection;

2. Development and implementation of a system-wide risk management plan;

3. Ongoing validation and verification monitoring; and

4. Documentation of the commissioning trial and post-commissioning residual risk assessment, with preventive measures identified for implementation in the final phase. These should be submitted for review and approval to the appropriate regulatory bodies.

10.5. PHASE 5 – SCHEME IMPLEMENTATION

Through the process of baseline data acquisition and interpretation, detailed feasibility assessment and pilot trials, the risks associated with fully implementing groundwater supply and storage options can be identified and reduced. Full implementation is characterised by:

1. Complete and efficient construction and testing of the water infrastructure;
2. Operation of the scheme integrated with surface water supply and management strategies. Conjunctive strategies can be implemented where the reliance on groundwater options changes with existing and forecasted climate conditions; there is added scope for contingency extraction for emergency supplies and an overall enhancement of water storage capacity and efficiency;
3. Scheme construction and operation in accordance with defined guidelines and thresholds (such as water entitlement conditions, water quality criteria, occupational health and safety, drilling and bore construction, operational budgets and timelines, environmental impact); and
4. Maintenance of comprehensive monitoring networks and a regular process of assessment, reporting and review of operational performance, efficiency and impacts.
5. Develop standard operating procedures and train the operating staff;
6. Verify the recovery efficiency and recovered water quality;
7. Update any groundwater models which are in use for site operations; and finally
8. Document the entire project in a paper for submission at relevant conference or symposium (e.g., the ISMAR7 Symposium), as well as appropriate international journals.