Radar Network Review

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Executive Summary

As a result of the release of radar images on the Bureau's website in 2003, and the recent high profile achievements delivered through RNDSUP, including the capital city Dopplers, the web-based rainfields application, and the graphical TIFS weather warnings, the popularity of the Bureau's weather radar data has grown, and the public's demand for new radar coverage is evidenced by the large number of requests received each year.

Although RNDSUP was effective at replacing obsolete radars in the network and implementing Doppler radars and services at selected locations, there are still large parts of Australia without adequate weather radar coverage. Furthermore, almost half of the current radar network consists of dual-role radars which perform part-time balloon-tracking duties, with the operational impact being relatively long periods (up to eight hours per day) without weather watch coverage at these locations.

This document presents a review of the coverage and quality of the national weather radar network, including a comparison of the radar network performance against other countries of similar economic development, and assesses the expected economic and community benefits of new or upgraded radar infrastructure for various locations across the country.

Locations for enhanced radar coverage considered in the assessment were identified by the Regional Offices and through requests to the Bureau from the general public. The scope of radar initiatives considered include a) new radar coverage, b) high resolution Doppler upgrades including dual polarisation capability, c) conversion of dual role radars to full time weather watch, d) upgrade of older radars with digital receiver components, e) backup radar coverage, and f) a test-bed radar facility. Each location was evaluated individually, by weighing up Regional and National Service Program priorities with benefit-cost values, and with the level of public demand.

The results of the Radar Network Review are presented in Section 9, where locations for new or upgraded radar infrastructure are presented in priority order. These locations have been identified as those where new or upgraded radar infrastructure is expected to fill the gaps in radar coverage across Australia, improve the quality of warning and forecast services at existing radar sites, raise the performance of the Australian weather radar network to an international standard, and deliver considerable community and economic benefits.

1. Introduction

The Bureau's forecast, warning and information services provide the Australian community with meteorological data and information that are essential for safety of life and property, security and general well-being. While the Bureau's services are valued by the community, economic studies have also shown these services represent "value for money". The economic return for meteorological services is at an estimated benefit-cost ratio of 10:1 (WMO, 2004).

In meeting its service obligations to the community, the Bureau draws upon an observations system comprised of surface-based and space-based observations, which make use of both proven and emerging technologies via a range of manual and automated methods. Radars have played an important role in this composite observing system for over five decades, starting with balloon-tracking for measurement of upper-air winds, and evolving to weather monitoring and applications in rainfall measurement. More recently the introduction of Doppler technology has enabled the measurement of wind velocities and detection of hail, resulting in enhanced forecast and warning services for the community.

While the practical benefits of radar-derived forecasts, warnings and web displays are well-known (forecasts and warnings minimise the impact of severe weather on all sectors of the community), the economic benefits of radar-based services are difficult to gauge and are not well documented. This presents a significant challenge when assessing the potential economic benefit of new or upgraded radar infrastructure for the Australian community.

Those in a position to best determine the requirements for new or upgraded radar infrastructure and identify the communities which would benefit most from the resulting radar services are the Bureau's Regional Offices and Services areas. For this reason, in May 2007 in preparation for the Radar Network Review, the Regional Directors and Weather and Climate Services managers were requested to provide a prioritised list of the radar infrastructure requirements which would provide the greatest benefit to regional communities. The information received from each region and service area was very valuable, but the question of integrating the priorities on a national basis remained. Also, an objective assessment of priorities was considered necessary.

To consolidate the Regional and Services feedback and establish national priorities, it was necessary to draw on additional sources of information. The PerilAUS disasters database, which contains damage-related statistics of natural disaster events in Australia, was used to evaluate in economic terms the extent of damage avoided (at selected locations) as a result of more accurate (i.e. radar-based) severe weather warnings. Although the database allowed good relative comparison between the more urbanised / developed locations of Australia, the lack of statistics for less-developed communities resulted in a bias against the latter. To supplement the PerilAUS database and provide further assessment of the value of radar-based services to communities (eg. increased productivity as a result of more accurate rain forecasts and warnings), information from industries such as mining and agriculture was integrated, as were several years of documented requests from the general public for new radar services. These complementary information sources were used to balance the Regional and service area priorities and determine national priorities. A benchmark analysis comprising a comparison of Australia's existing and envisaged radar network with those of several other countries provided a "sanity check", and confirmed that Australia's radar network is currently lagging behind most developed countries in the implementation of operational Doppler systems..

1.1. Background

The current national weather radar network (59 radars[1]) provides real-time information on the severity, location and movement of tropical cyclones, thunderstorms, rain systems and other severe weather systems. This information is used by forecasters for generating weather predictions and issuing severe weather warnings, and also by the public and all weather-sensitive sectors of the economy. The archived data is used by the Bureau's researchers to better characterise weather phenomena, and to develop new and innovative forecasting tools.

In 2003 the Commonwealth Government allocated over $62 million to allow the Bureau to modernise its radar network and supplement its Severe Weather Warning capabilities in key locations around the country. The Radar Network and Doppler Services Upgrade Project (RNDSUP) involves the replacement of 15 obsolete radars in the network, and installation of enhanced Doppler radar capability in 6 locations. The new Doppler radars have allowed for the replacement of a further 5 radars in the network. All these improvements allow for an enhanced service delivery in terms of content, effectiveness and geographic coverage.

Although at present there are insufficient verification statistics to demonstrate the positive impact of the RNDSUP Doppler radars on forecasts and warnings, their overall benefits are clear. For example, with regard to US tornado warnings, a US study has verified the positive impact of the WSR-88D (Doppler) radars on tornado warnings. The US study (Simmons and Sutter, 2004) demonstrates that following the installation of Doppler radars, the percentage of tornadoes warned for increased from 35% to 60% and the mean lead time on tornado warnings increased from 5.3 minutes to 9.5 minutes. While the threat of tornadoes is not great in Australia, and while objective indicators of benefits are difficult to obtain, the overall benefits to the community are clearly documented by an overwhelming number of public and commercial requests for more radar services.

New forecast techniques and products have been implemented in the Bureau to complement the Doppler technology and enhance the quality of forecasts and warnings. For example, the "three-body scatter spike" storm signature technique (Lemon, 1998) has been implemented to improve the identification of large (>2.5cm) and damaging hail. The Warning Decision Support System (WDSS) for automatic detection of severe characteristics in thunderstorm cells, and the Thunderstorm Interactive Forecast System (TIFS) have also been implemented to improve the content and effectiveness of delivery of severe thunderstorm warning services. New radar-based products for both forecasters and the general public (via the website)

[1] at the completion of RNDSUP: 59 operational radars (31 WW only and 28 Dual). Does not include 4WF only radars, 2 research radars, and 2 training radars.

include real-time quantitative rainfall accumulation estimates for improved flood forecasting, and Doppler velocity data for enhanced diagnosis of wind speed.

The Australian community has shown an increasing demand for and dependence on weather radar data. Visits to the radar web pages have continued to grow at a rate of approximately 100 million hits per year (see Figure 1), making the Bureau's radar pages one of the most visited sites in Australia. Further evidence of the weather radar website's popularity is the large number of requests received since its inception, from individuals, industry and community groups for new radar coverage in many parts of Australia.

Despite the success of the Government's investment in radar infrastructure upgrades and service enhancements through the 2003-04 Budget, there are still:

- large parts of Australia which have no or inadequate weather radar coverage and therefore inadequate warning of approaching severe weather,
- 28 radars which perform part-time balloon-tracking duties,
- increasing demand for radar web services,
- increasing need to provide accurate observations for climate and water resource monitoring, and
- opportunities to further minimise damage costs due to hail/severe weather through early warning services from radars.

1.2. Objectives of the review

The purpose of this document is to review the coverage and quality of the national weather radar network, and identify and prioritise locations where new radar infrastructure will deliver economic and community benefits through advance warning of weather systems in economically significant locations (eg. mining and agricultural communities) and key population growth areas (eg. south west WA). The extent of such benefits are examined for locations where radar coverage is inadequate, as identified by the Bureau's Regional service delivery offices and representations from local communities and industries (via ministerials and email correspondence).

The Review addresses the radar infrastructure requirements for new radar coverage, improved warning and forecast service quality at existing radar sites, and for raising the performance of the Australian weather radar network to an international standard. Requirements and priorities for services such as display systems, enhanced warning services, quantitative rainfall applications, training, radar archive, etc have not been addressed by this review. A document which addresses such service priorities would be seen as complementary to this review.

1.3. Description of the approach

Priorities for new radar infrastructure were determined by independent consideration of each location, by weighing up Regional and Service Program priorities (summary in Section 5), with the benefit-cost results (results in Section 7), and with the level of public demand (summary in Section 6). The locations recommended for new or upgraded radar infrastructure are therefore those which are a) considered a high priority by Regional Offices, b) are supported by a high level of public demand, and/or c) are proven or supported by the benefit-cost assessment (or are locations where economic benefits are expected but benefit-cost related data is sparse). The prioritised tables of radar infrastructure requirements are presented and discussed in

Section 9 and summarised in Section 10. A comparison of Australia’s radar network with other countries is presented in the benchmark analysis in Section 8.

The benefit-cost analysis (described in detail in Appendix A) is based on the technique adopted by Gunn (2002), which resulted in an allocation of Government funding for the RNDSUP initiative in 2003. The basis for the benefit-cost analysis is that new radar infrastructure will result in an increase in damages avoided through improved warnings and forecasts. The benefit-cost analysis does not address social or non-financial benefits, nor does it adequately represent the value of radar observations to industries such as agriculture and fisheries. In order to gauge the level of the non-economic and community value of radar observations, Section 3 examines the value of radar observations to households and other sectors of the community which are not adequately represented in the benefit-cost analysis, while Section 2 illustrates the overall scope of damages caused by severe weather events in Australia. Information on the current performance of the Bureau’s radar network compared to other countries of similar economic development is presented in Section 8.

The radar infrastructure options considered by this Review are presented in Section 4, and include a) new radar infrastructure, b) new high resolution Dopplers with dual polarisation capability and upgrades of existing high resolution Dopplers to dual polarisation capability, c) conversion of dual role radars to dedicated weather watch, d) upgrade of older radars with digital receiver components, e) backup radar coverage, and f) a test-bed radar facility. The choice of radar infrastructure proposed for each location was made by careful consideration of existing radar infrastructure, Regional Office and Service Program requirements, benefit-cost implications, and OEB’s long-term plans for the surface-based and upper-air networks.

2. The cost of severe weather events in Australia

One of the criteria used in this document to assess the priorities for new radar infrastructure is the results of the benefit-cost analysis presented in Section 7 (and described in detail in Appendix A). The economic benefits are based on the assumption that an increase in damage costs resulting from weather events can be avoided through improved warning and forecast services.

An important aim of warning and forecast services is to reduce damage and loss associated with extreme weather events, and to allow the general public to take advantage of favourable conditions (Gunasekera et al, 2005). Radar-based forecast and warning services specifically contribute to “damage costs avoided” via:

- improved forecast capability of tropical cyclones,
- reduced number of false alarms, and consequent disruption to communities,
- improved estimation of rainfall rate improves flood forecasting and allows more precise short term forecasting of severe weather such as hail, damaging winds, downbursts and tornadoes, and
- better tracking of the location and strength of wind changes, which assists marine, aviation and bushfire-fighting activities.

Depending on the type of weather event, the amount of damage costs that can be avoided with an effective warning services (in this case a Doppler radar-based service) is estimated to range between 5-15% (Services Policy Branch, 1989) of the total damage costs. In an event the size of the 1983 Ash Wednesday bushfires, which caused nearly $1 billion in damages, the “damage costs avoided” would be considerable. Further evidence shows that Doppler radar services can reduce fatalities and injuries in tornado events by 45% and 40% respectively (Simmons and Sutter, 2004).

To illustrate the cost of damages caused by severe weather events in Australia, the costliest severe weather events in recent history are outlined below.

2.1. Cost by weather event type

The costs described in this section identify the scope of losses resulting from severe weather events, and represent the effect of a disaster on society as a whole. These costs are taken from “Economic Costs of Natural Disasters in Australia”[1] .

2.1.1. Bushfires

The 1983 Ash Wednesday bushfires have been the costliest fires in both lives lost and damage incurred. The fires caused $967 million in damages (in 1999 prices), and resulted in 75 lives lost and 2,676 reported injuries. In terms of risk to human life, bushfires have been Australia’s most dangerous natural hazard, with 223 fatalities and 4,185 injuries during the period 1967 to 1999.

[1] Bureau of Transport Economics (BTE), 2001

2.1.2. Floods

Flood events costing more than $10 million each between 1967-1999 resulted in a total cost of $10.4 billion. The costliest flood event was in January 1974 in Brisbane, causing $328 million in damages and resulting in 18 lives lost.

2.1.3. Severe storms

A record of the most destructive weather events since 1967 is kept by the Insurance Council of Australia. The record describes the most destructive event in metropolitan Perth in 30 years as a severe storm on 23–24 May1994. The severe winds resulted in 2 fatalities at sea, many houses unroofed, and one-third of Perth lost power. The damage cost from this one event was $37 million.

The 1999 Sydney hailstorm has been the costliest severe storm at a cost of $1.7 billion. The most common direct damage was to roofs and motor vehicles.

2.1.4. Tropical Cyclones

Since 1967, the average annual cost of cyclones is $266 million per year. Cyclone Tracy in December 1974 has been the costliest Tropical Cyclone in Australia's history. Rated a Category 4 cyclone, it caused $1.97 billion in damage (1999 prices), and resulted in 71 lives lost, 143 serious injuries and 500 minor injuries. More recently, Tropical Cyclone Larry in March 2006, also rated a Category 4 cyclone, caused an estimated $540 million in damages (Insurance Council of Australia), but no lives were lost (arguably at least partially attributable to good weather radar coverage of the area).

3. The value of radar observations

While the benefit-cost assessment (Section 7) provides a value of weather radar coverage based on recorded damage estimates of past weather events, it doesn't address social or non-financial benefits, nor does it accurately represent the value of radar observations to industries such as agriculture and fisheries. The following section examines the value of radar observations to households and other sectors of the community which may not be represented in the benefit-cost analysis.

3.1. Value to the general community

Comprehensive studies of the value or economic benefit of radar observations (for example to national economies, households, weather services etc.) are lacking, however in recent years a number of studies have explored the economic benefit of Meteorological Services as a whole (Khole and De, 2001; Freebairn and Zillman, 2002), as well as the economic benefits of specific outputs such as fire weather forecasts (Gunasekera et al 2005), and weather forecasts for agriculture (Anaman and Lellyett, 1996; Wilks and Wolfe, 1998; Fox et al. 1999), as described in greater detail later in this section. A study by Lazo (2002) estimates the value to households of potential improvements in weather forecasting services in the US is US$1.73 billion per year, or US$16 per household.

Back-of-the-envelope estimates of the value of radar observations can be made by considering both the costs of severe weather events outlined in Section 2, and the potential "damage costs avoided" that could result from using Doppler radar-based forecast and warning services. For example in the case of the 1999 Sydney hailstorm which caused $1.7 billion in losses, assuming that the use of Doppler radar-based weather services could have reduced damage losses by 15%[1], the consequent "damage costs avoided" for that one event may have been up to $255 million.

The ever-increasing number of web hits to the Bureau's radar pages is another indicator of the value of radar observations to the community. AMDISS statistics on web page hits show that the radar web site has recently been receiving on average around 1 billion hits per month. User demand for the web-based radar images is also reflected by the number of requests received by the Bureau for new radar coverage in various parts of Australia, including numerous representations from the rural and mining sectors.

The Australian community has shown an increasing demand for and dependence on weather radar data. This is despite the wide range of meteorological observations, forecasts and warning products available from the Bureau. Evidence of this is in the large number of formal requests (from community groups and local MPs) for new radars in locations well served by satellite imagery and Automatic Weather Stations.

Ever-increasing hits on the Bureau's radar web pages are further evidence of the growing popularity of the Bureau's weather radar data, which demonstrates the relevance of real-time weather information for planning daily activities. Web monitoring statistics show that hits to the Bureau's radar web pages have doubled

[1] Services Policy Branch (1989) estimates that 15% of hail damage can be prevented if an effective warning service is provided.

every 2 years since year 2000, with three times as many hits to the radar web pages than to all the other Bureau web pages combined (see Figure 1). Overall, as at May 2007, the Bureau's web pages were ranked 11th of 129,238 websites in the Australian 'All Categories', and ranked 1st of 242 websites in the 'News and Media - Weather' category (ranked by Hitwise).

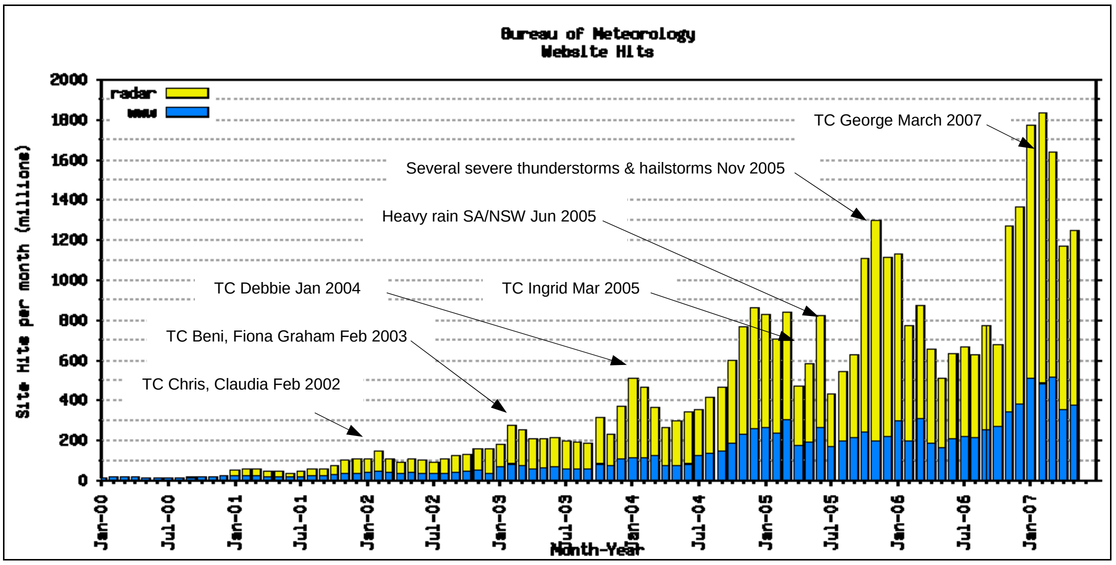

Figure 1. **Graph showing web hits to the Bureau's web pages (blue) vs Bureau's radar pages (yellow), as at May 2007**.

An important contribution that Doppler weather radar observations can make to the general community is the reduction of deaths and injuries during severe weather events. The Sutter and Simmons (2005) study mentioned previously also reports that installing Doppler radars in the United States reduced deaths by 45% and injuries by 40%. There has been similar success in Australia, when in March 2006 a number of radars along the Queensland coast monitored Tropical Cyclone Larry. The Willis Island radar first captured the intensity and speed of the cyclone. There were no deaths despite the cyclone causing $360 million damage and affecting 12,500 sq kms around Innisfail.

3.2. Value to the northern coastline regions

The greatest benefit of weather radars for Australia's northern coastline is the real-time information they provide on the movement and intensity of tropical cyclones, enabling evacuation of communities to shelters, and mooring of fishing vessels in sheltered anchorage. A mosaic of radar coverage along the length of the coastline would provide Darwin, the area's major population centre, and the numerous indigenous communities along the coastline with valuable information on severe weather systems which threaten the region every year. Figure 2 shows the paths of tropical cyclones which occurred over the Australian region between 1970 and 2002, highlighting the extent of the coastline region affected by tropical cyclones.

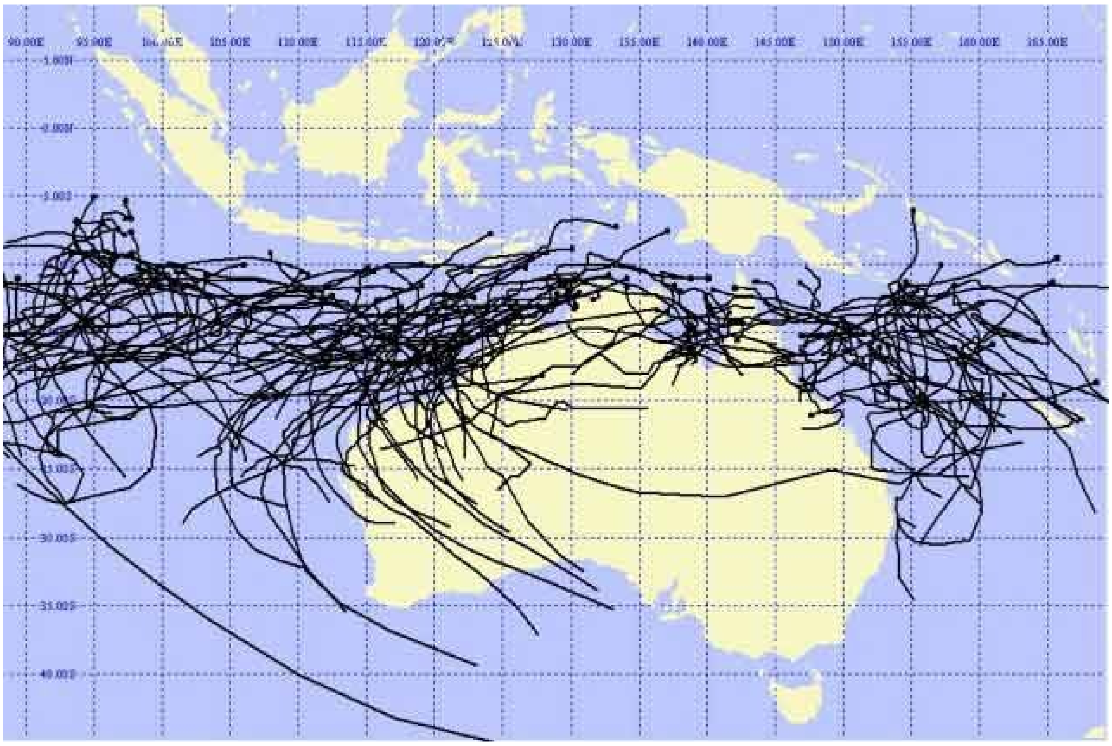

Figure 2. Tropical cyclone crossings between 1970 and 2002.

Tropical cyclones are synoptic scale systems which are initially monitored by satellite, and then by radar when they approach the coastline. The benefits resulting from filling in gaps in radar coverage along the northern coastline, in the experience of forecasters working in the TCWC, is in the reduction of false alarms. Economic benefits which may result from reducing false alarms include reducing the cost of business disruption.

While infrastructure damage costs from TC events in remote areas along the northern and northwestern coastlines can be relatively low compared with Australia’s east coast because there tends to be less infrastructure there, the damage to the environment and fishing industries can be considerable. This was illustrated recently during TC Nelson in February 2007, where 10 men were rescued from a mining barge which began taking on water in the cyclonic waves and wind. Had the vessel spilled its cargo of heavy metals into the Gulf of Carpentaria, it could have had serious consequences for the $100 million per annum fishing industry, and affected the livelihoods of many of he traditional landowners. The economic consequences of such a spill would be far more serious on the Western Australian coast, where the fishing industry there contributes $1.2 billion annually to the State’s economy (WA Fishing Industry Council web page).

3.3. Value to the rural sector

The impact of the current drought is forecast to reduce the volume of agriculture production by 11.7% or $5.5b in 2006-07 (ABS, 2006b), highlighting the sensitivity of Australia’s rural sector to weather.

The high value placed by the rural and regional communities on accurate and timely weather observations is evident in the numerous requests for regional weather radars received by the Bureau each year. Although the information provided by radars is unlikely to prevent crop damage, radar images (and radar-based warnings) enable farmers to take advantage of favourable weather conditions, and make informed decisions on an hourly basis regarding such matters as movement and protection of stock, and application of chemicals.

A handful of studies have evaluated the economic benefits of weather services used by the rural sector. In an Australian study, Anaman and Lellyett (1996) surveyed cotton producers in the Namoi region in NSW and found that cotton producers which used enhanced weather information (i.e. localised and more detailed than the basic weather service) reported an average cost reduction of 1%, resulting in annual benefits of approximately $400K for this single industry alone. In the United States, Wilks and Wolfe (1998) estimate that use of weather forecasts to optimally schedule irrigations provide added value of around US$1000 per hectare per year, mostly due to reducing crop damage from excessive soil moisture. A Canadian study (Fox et al. 1999) examines the impact of precipitation forecasts on timing harvest decisions for winter wheat, and estimate the value of these forecasts at CAD$100 per hectare per year. If this last figure is applied to Western Australia’s 12 million ha wheatbelt region, the contribution of a radar to the wheatbelt region’s economy is over $1 billion per annum.

3.4. Value to mining industries

Severe weather events such as lightning, flooding and high winds can cause substantial economic losses to mining operations. The mere threat of severe weather can disrupt mining operations, therefore accurate weather forecasts for mining areas have the potential for significant economic savings to the mining industry.

Open cut mines have to be cleared during storm events and this results in production losses. A lightning strike on loaded explosives in an open pit could result in an uncontrolled detonation causing injury or death. An estimate of the economic loss resulting from a mine’s closure during severe weather events is over $5 million per annum. (Fasching 2007).

Real-time radar information on the motion and intensity of storms have the potential to provide significant savings to the mining industry. For example, Mount Isa Mines operates a basic lightning system which resulted in a benefit of $0.5 million in the 2006/07 financial year (Fasching 2007). While a lightning sensor provides limited information on lightning location, a weather radar provides accurate information of the location of a storm cell, as well as the intensity and movement of the cell. The installation of a weather radar would further enhance a mine’s ability to further increase production outputs during the wet seasons.

Managing sulphur emissions from copper smelters and air quality control issues incur economic losses. More accurate weather forecasts would reduce smelter down-time by 20-30% and increase annual revenue at each smelter by approximately $1 million (Fasching 2007).

4. Scope of radar initiatives investigated

Based on the strategic analysis documented by this review, Section 10 makes a number of recommendations for new and upgraded infrastructure at various locations across the country. Many of the locations are gaps in radar coverage, and would therefore require new radar infrastructure, while others already have a weather radar, and require an infrastructure upgrade in order to improve the quality of weather services to the community. The scope of radar installations and upgrades that meet these varying requirements are described below.

4.1. New coverage

Many parts of Australia do not have adequate radar coverage, including cyclone prone regions along the northern coastline, as well as rural and provincial areas. Over several years the Bureau’s Regional Offices have submitted requests for new radar infrastructure to fill particular gaps in radar coverage, and meet the growing demand from the general community, and industries such as agriculture, mining, and aviation for improved forecast and warning capabilities.

It is proposed that new radar infrastructure be installed at specific locations currently without radar coverage (those locations to be identified and prioritised by this review).

4.2. High resolution Doppler upgrade

Preliminary feedback from forecasters in Adelaide, Brisbane and Melbourne, where high resolution Doppler radars have now been operational for a limited time, indicate that the Doppler velocity data has had a positive impact on forecasting services. Dickins and Wedd (2007) report that the new data has already had a direct and favourable impact on warning decisions in Brisbane, while the Adelaide S1 Doppler has made significant impact on forecast decisions for aviation services. In Melbourne, where Doppler velocity data has only been available operationally since October 2007, forecasters have reported that the Doppler data have been of value in timing and diagnosis of strength of wind changes approaching Melbourne Airport, and assessment of low level wind shear for warnings.

It is proposed that high resolution Doppler technology is installed on radars in the larger population centres, to provide enhanced forecast and warning services, and maximise the benefit from existing automated forecast and warning software applications such as WDSS and TIFS.

A high density rain gauge network within 120km of each of these radars would permit real-time calibration of the radar echoes, providing improved estimates of rainfall rate and accumulation.

4.3. Dual polarisation upgrades

One of the primary benefits of a dual-polarisation radar is the improvement of quantitative precipitation estimates. Dual-polarisation helps to significantly improve the quality of data from high resolution Doppler radars, to distinguish rain echoes from the signals caused by other scatterers (snow, hail, ground clutter, insects, birds, chaff, etc.), and to reduce the impact of drop size distribution (DSD) variability on the quality of rainfall estimation (Ryzhkov et al. 2005).

It is proposed that dual-polarisation capabilities, which continue to be developed at the Bureau's atmospheric research facility in Brisbane, are provided at locations which are vulnerable to hail damage and where more accurate quantitative rainfall estimations would be of particular benefit. The operational outcome of upgrading radars to dual-polarisation capability include:

- improved accuracy of quantitative rainfall algorithms,
- improved identification of aircraft icing conditions,
- improved quality control of the raw data, and
- improved quality of and confidence in forecasts and warnings of hail-producing storms.

4.4. Conversion from dual role to dedicated weather watch mode

The Bureau's weather radar network includes 28 radars which perform both weather watch and wind finding operations, with the operational impact being relatively long periods without weather watch coverage at these locations. During critical weather situations, this arrangement can impose additional pressure on forecast staff who may need to decide on whether to perform a valuable wind flight or continue to monitor the weather situation (e.g. as occurred at Gove during the passage of TC Monica during April 2006).

It is proposed that the dual-role radars identified by this review be converted to dedicated weather watch mode, and where necessary the radar be relocated to improve the radar coverage.

The upper-air program at these sites would be replaced by alternative technology, e.g. wind profiler, autosonde or GPS-radiosonde capabilities, as required.

4.5. Signal processing digital upgrade

Most of the older radars in the network have analogue receiver components which are becoming obsolete. Consequently the Bureau's Radar Engineering Group has developed a second generation digital receiver which will deliver benefits such as increased resolution and improved dynamic range.

Upgrading existing radars' digital receivers will deliver the following improvements:

- improved ability to detect PE (permanent echoes), better clutter suppression, improved data quality, better interference suppression,
- Doppler capability, and
- the ability to capture high resolution video of a scan (referred to as I & Q). High resolution video products of unique weather events will enable CAWCR and the Radar Engineering Group to test their algorithms, and consequently provide better quality data, and can be used for training of new mets.

4.6. Backup coverage

All radars suffer outages due to both scheduled servicing and system faults. For the most beneficial radars, the practice has been to maintain a second ("backup") radar to ensure continued weather watch function during outages of the primary radar. Currently backup radars operate in dedicated weather watch mode at Sydney (Kurnell), Brisbane (Marburg) and Adelaide (Sellicks Hill), while the backup radar is interrupted by balloon tracking (wind finding) operations at Darwin (Airport), Perth (Airport), Melbourne (Airport), Townsville (Airport) and Cairns (Airport).

This review aims to reconsider the costs and benefits of operating backup weather watch radars and consequently identify whether backup radars are required at additional locations or whether existing dual mode backup radars need to be converted to dedicated backup radars.

4.7. Innovation and training platform (Mornington Peninsula)

A radar on the Mornington Peninsula would provide three key functions:

1. coverage of the Yarra Valley and Ranges, for enhanced flood and storm warning capabilities for the region;
2. backup weather watch function for continued coverage of Melbourne during outages at Melbourne (Laverton) radar; and
3. an innovation and training platform which will facilitate a more rapid roll-out of technology improvements to the entire radar network.

5. Regional Office and Service Area requirements

In May 2007 STNM invited all RDs, as well as SSU, Climate, Hydrology, and Weather Services areas for their input to the Review of the Bureau's Radar Network. The Regions and Service areas were asked for their views on desired radar network additions and enhancements together with relative priorities, including details such as:

- prioritised listing of major cities, towns, communities, agricultural and other vulnerable industry areas, etc which are not yet serviced, or could be better serviced, by weather radar;
- a description of the service requirements that would be better met by introducing or enhancing the radar coverage at these locations; and
- any evidence of the level of community interest and support for the initiatives.

The feedback received from the Regions and Service areas is summarised below, and maps of proposed sites are at Appendix D.

5.1. WA Region priorities

WA Priority 1: South-west WA (near Cape Leeuwin)

The existing radars at Perth and Albany are unable to serve the area towards Cape Leeuwin due to their distance and the shallow nature (i.e. 5000-6000m) of the cool-season rainfall. Furthermore, given that most of the rain producing systems approach this area from the north-west and south-west, their early detection by radar is not often possible, thus limiting any prospect of providing a radar-based early warning. Approximately 260km to the east, the Albany radar is adversely affected by nearby tree plantations in the western quadrant which severely impact on the quality of the weather watch radar coverage. A new radar located on the ridge between Cape Naturaliste and Cape Leeuwin would be able to monitor approaching severe weather, and provide coverage of most of the south-west region. The radar would also provide early detection and diagnosis of severe characteristics in cold fronts approaching the Perth metropolitan area and thus offers significant service benefits to the greater metropolitan area as well as to the south-west region.

WA Priority 2: Upgrade Perth to S1 and relocate C-band radar to Nowergup

Upgrading the Perth (Serpentine) radar to S1 will allow improved detection and diagnosis of severe weather (specifically large hail and severe winds), in both winter and summer, and would support improved short term rainfall forecasting. If Doppler functionality was enabled and supported with training and development staff resources then additional service benefits - particularly in the delivery of short term public, aviation and fire weather warning services - could also be realised, as has occurred in other regions.

The transfer of the primary radar site for Perth to Serpentine Aerodrome some 50km south of the Perth CBD will result in a reduction in coverage to the north and east as well as some reduction in the maximum radar range in the western quadrants. Reduced coverage to the east could be overcome by a proposal to install a weather watch radar in the Central Wheatbelt. A backup site which is capable of providing a high standard of radar coverage for the metropolitan and adjacent areas seems essential as the metropolitan area continues to expand. The transfer of the primary radar to Serpentine suggests that a site to the north of the city (a suitable site has been identified at Nowergup) or on the top of the Darling Scarp would offer the best backup and supplementary data.

WA Priority 3: Wheatbelt

Existing radar coverage only extends to the perimeter of the Wheatbelt region. This grain-growing area has a winter rainfall maximum and experiences thunderstorms during late spring and summer. Thunderstorms in November and December often cause severe losses to near-mature crops, while decaying tropical cyclones in mid to late summer can adversely impact dry feed and stock. Farmers have proven to be avid users of radar imagery where available, as radar imagery is perceived as aiding short-term decision making with regard to on-farm activities. A new radar for the Wheatbelt would enable monitoring of severe weather over most of the grain growing areas currently without radar coverage.

WA Priority 4: Kuri Bay / Browse Island

There is a significant gap in radar coverage on the northern coastline of WA in the Kuri Bay area. There are several small communities in the region and radar tracking of tropical cyclones would significantly improve the delivery of services to those communities. Mining development in the northern Kimberley region is expected to grow significantly in the coming years. Warnings of extreme precipitation and destructive wind gusts are required by these mining operations.

The area off the northwest Kimberley coast is the genesis zone for many tropical cyclones which go on to affect the Kimberley and Pilbara areas of WA. It is also the area of a massive expansion of oil and gas development. A recent meeting of the WA Tropical Cyclone Industry Liaison Committee highlighted the need for additional observations platforms in and around the Browse Basin. A radar at Browse Island, Adele Island or Scott Reef would enable better detection of these developing cyclones to provide more accurate warnings and information to the Pilbara, Kimberley and offshore installations. This includes advice relating to the shutdown and evacuation procedures for offshore installations.

A radar in this region will also improve the delivery of services to the communities in the Kimberley including the growing number of mining and associated port facilities. Aside from tropical cyclone detection, radar coverage will enable detection of severe thunderstorms that can cause very heavy rainfall and/or damaging wind gusts.

WA Priority 5: Newman

Newman has a population of approximately 5000 people. The most common industry of employment in the area is mining, with 8 open cut mines in the area.

WA Priority 6: Meekatharra

Meekatharra is a small mining town with a population of approximately 2000. There are 11 open-cut mines in the Meekatharra area. The climate of the region is strongly influenced by a band of high pressure known as the sub-tropical ridge, and in the warmer months by a trough of low pressure that extends southwards from the heat low in the tropics. For most of the year the ridge is located to the south, and east to southeast winds prevail. Occasionally during the cooler months the ridge moves far enough to the north to allow cold fronts to pass over the area. While most fronts bring little rain to Meekatharra they are sometimes linked to tropical cloud bands which deliver the most reliable rains from May to July. June is the wettest month with an average rainfall of 33.2 mm on six days. The other wet months are January to March when thunderstorms can often produce heavy localised falls in short periods. Although rare, tropical lows or weakening tropical cyclones that usually originate off the Pilbara coast can bring widespread rain to the region.

5.2. NT Region priorities

NT Priority 1: North Coast radar (Croker Island)

A "north coast radar" has been the highest priority radar upgrade requirement in the Northern Territory Region for many years, and has been the subject of several formal and informal submissions by the Region to ADS/ADO going back to at least 1994 (see File 25/6470 FN 39). There is also a record of public demand from the Northern Territory Emergency Service and members of Darwin and north coast communities, most recently in relation to the inadequate radar coverage of severe Tropical Cyclone Monica (April 2006) at landfall.

A radar in the vicinity of Croker Island would substantially reduce initial position errors of tropical cyclones in the Timor and Arafura Seas, leading to improvements in the 12-24 hour forecasts, and would optimise cyclone tracking and early warning for the Darwin area, as well as fill in the radar gap along the north coast between Darwin and Gove to provide continuous cyclone surveillance for north coast communities. There are also potential economic benefits for the Northern Prawn Fishery, which contributes $64 million to the Northern Territory economy.

The key advantage from the Darwin TCWC viewpoint is that this location has the largest and most northern area of coverage over the ocean – maximising the view over the area where the most cyclone tracks and the more intense cyclones occur in the Arafura Sea, including off the north coast of the Tiwi Islands.

NT Priority 2: Borroloola

The southwest Gulf of Carpentaria has a history of severe tropical cyclones, most notably Kathy (Category 5, 1984), Sandy (Category 4, 1985) and Rosa (Cat. 4, 1979). There is a significant "blind spot" in the southwest Gulf of Carpentaria, beyond the range of Gove and Mornington Island radars, which would be nicely filled in by a radar at Borroloola. Borroloola is the major community of the southwest Gulf country, located on the McArthur River about 50 km inland from the coast. At the 2001 census, the population of Borroloola and surrounds was 2074.

The area includes the McArthur River silver-lead-zinc mine (70 km south-southwest of Borroloola) and associated major Bing Bong Port facilities at the mouth of the Roper River, the nearby Merlin diamond mine (one of only three in operation in Australia), the King Ash Bay fishing village 40 km northeast of Borroloola, and aquaculture projects at Port Roper.

A radar at Borroloola would also improve radar coverage for the community of Numbulwar (population 1200) which is vulnerable to inundation by storm surge, and also the substantial mining and aboriginal communities on Groote Eylandt (at the outer ranges of the radar). A radar would also support improved public weather and aviation forecasts for Borroloola, as well as for routine aerodrome forecasts for

McArthur River, Ngukurr (Roper River) and Numbulwar, where there are relatively high frequencies of convective weather.

NT Priority 3: Port Keats

It is Darwin TCWC's experience that radar coverage at the outer limits of Darwin and Wyndham's radars is not adequate for tropical cyclone tracking in the Timor Sea. For example, when TC George developed as the low moved offshore into the Joseph Bonaparte Gulf in March 2007, radar coverage was very poor. A radar at Port Keats would dramatically improve cyclone surveillance in the Timor Sea to the southwest of Darwin, by filling in the gap between Darwin and Wyndham.

Improved tracking of cyclones in the area would benefit the communities of the Daly region (a developing area for agriculture) and the north Kimberley, as well as offshore mining and exploration ventures. The Bonaparte Basin is experiencing increasing exploration and development activity, for example the Australian Pipeline Trust contracted by the NT Government's Power and Water Corporation is building a 275 km pipeline that will transport gas from an onshore plant near Wadeye to near Adelaide River, to join the existing gas pipeline that carries gas from the gas fields in Central Australia to Darwin, at a cost of $130 million.

NT Priority 4: Upgrade Berrimah radar to S1

Darwin is the capital city of the Northern Territory, and is the hub for government, administrative and commercial activities. Substantial and increasing economic activity takes place in the area, including tourism, mining, agriculture and service industries. Darwin contains an international airport, a major sea port and rail head, is the base for Timor Sea oil and gas exploration, and is the country's closest link to southeast Asia. It is a strategic military location with major assets therein.

More than 50% of the Territory's population lives within range of the existing radar at Berrimah, which provides 24-hour weather watch Doppler coverage for Darwin and surrounding areas. The area within radar range of Darwin is subject to a wide range of high impact severe weather threats, including tropical cyclones, widespread convective weather, severe thunderstorms, heavy rain, floods, wildfire etc.

In terms of meteorological research, there is much to be learned about tropical convection that would be revealed by a high resolution S1 radar at Darwin, with widespread applicability to other tropical locations in Australia and overseas. An S1 Doppler would improve the (semi-automated) detection and nowcasting of severe thunderstorms, as well as the radar estimation of rainfall. The Doppler velocity data from the current C-band radar is affected by artefacts due to unfolding errors which at times result in warning errors. Upgrading the radar to S-band would increase the nyquist velocity and reduce aliasing, which would be of benefit during tropical cyclone events.

Nt Priority 5: Yulara

Yulara is a purpose built town to cater for the large number of tourists who principally visit Uluru-Kata Tjuta National Park (containing Ayers Rock and the Olgas). Adjacent to this national park is the Watarrka National Park, the home of Kings Canyon. The population of Yulara is about 1800, but the transient tourist population is considerably greater with up to 4000 visitors a day. Overall, tourism contributes of the order of $474 million (2004 figure) to central Australia, 40% of the NT share. Other economic activity includes the mining and pastoral (Curtin Springs cattle station) industries, and there's significant airline and light aircraft traffic at Yulara airport.

Yulara is in a radar coverage gap between Giles and Alice Springs radars. Significant weather threats in this area include thunderstorms, hail, tropical rain depressions, northwest cloud bands etc. as well as wildfire and dust storms in drier years. A radar at Yulara would allow better monitoring, forecast and warning capabilities for this area, and would also permit better tracking of low level troughs and fronts across the western Alice Springs district - an area where the surface observation network is extremely sparse.

5.3. NSW Region priorities

NSW Priority 1: Dubbo/Parkes/Peak Hill area

Dubbo and Orange have populations of approx 40,000 each, and there are more than 20 towns in the area with up to 10,000 people. A new radar in this area will improve the timing of wind changes and enhance the radar mosaic to allow an extension of an enhanced severe thunderstorm warning service. Given the majority of significant weather affecting the greater Sydney area from the west, this radar would fill an important and large upstream gap. The NSW grain belt cuts right through this area, therefore its significance from an agricultural point of view is very high.

NSW Priority 2: Bourke area (near Mt Oxley)

The area consists of least four towns of less than 10,000 people, plus a number of smaller communities. The Darling and Barwon rivers have quite heavy irrigation farming - both horticulture (oranges & grapes), and cropping (including cotton). Elsewhere it is a major cattle and wool area, and, the outer eastern coverage intersects the NSW grain belt. Damaging thunderstorms are less frequent than in locations closer to the ranges and coast, but main river flooding is a major issue. A radar in this area would provide upstream detection of squall lines and fronts which may have embedded storms as they track eastward, and when mosaiced with eastern radars would allow extension of polygon based thunderstorm warning services to western NSW. Furthermore, the passage of more benign rainbands and NW cloud bands would be better detected as they approached higher population areas, allowing for better downstream nowcasting and warnings.

NSW Priority 3: Improved coverage of mid-north coast

The area around Kempsey, which comprises mixed agriculture of mainly smaller intense farms, is close to the limits of both the Grafton and Newcastle radars. The steep face of the Great Divide provides a trigger for storm development and gives rise to a high level vulnerability to flash floods, as demonstrated in the 1996 flash floods in the vicinity of Coffs Harbour. Installing or upgrading the radar infrastructure in this area will lead to improved coverage of southerly changes traversing the Kempsey area.

NSW Priority 4: Retain (and relocate) Letterbox

This radar provides backup coverage over the Sydney Basin (more than 4.5million people), about 200,000 in Wollongong (Australia's 9th largest city) and a numerous additional smaller locations of up to 40,000 people each. The steep face of the Wollongong escarpment provides a trigger for storm development and gives rise to a high level vulnerability to flash floods, as demonstrated in the devastating 1998

Wollongong flash flood. This radar provides an enhanced ability to track the non-linear passage of southerly busters approaching Wollongong and Sydney.

NSW Priority 5: Far west NSW eg. Fowler's gap

A new radar in this area will provide radar coverage of Broken Hill (population 20,000), the largest town in western NSW. Several other small townships without any coverage at present would also be served. This radar would allow the provision of more detailed severe thunderstorm warning services, as well as significant upstream notification of systems approaching the NSW western border, and advanced notification of significant systems heading toward more populated and infrastructure-rich eastern parts of the State. This is mainly a sheep and cattle area, except for irrigation farming in the Menindee Lakes area.

NSW Priority 6: Upgrade Grafton to S1

This is the highest rainfall area of NSW, and is prone to the occurrence of large supercell thunderstorms (likely more so than any other area in NSW). The area is also prone to tropical cyclone impacts. An S1 Doppler would provide the means to enhance severe thunderstorm warning in the area. This is a mixed agriculture area of mainly smaller intense farms, with significant dairy and cattle on the higher ground.

NSW Priority 7: SE corner of NSW

The southeast tip of NSW is vulnerable to high wind events when vigorous cold fronts travelling through Bass Strait transform into Southerly Busters that propagate northward up the NSW coast. A radar in this area would provide enhanced low level radar coverage to an area covered only by the very elevated Captains Flat radar, and would improve the advance notice of Southerly Buster formation on the NSW south coast.

NSW Priority 8: Upgrade Mildura to WW only

Conversion of the radar to dedicated weather watch (and relocation to improve the skyline) will improve upstream warning and tracking of approaching cold fronts which may have embedded storms. Agricultural activities in the area include intensive irrigation farming along the Murray, but sheep and cattle toward the interior of NSW.

NSW Priority 9: Upgrade Wagga Wagga to WW only

Forecasting the movement of frontal passages over the Snowy mountains is complex and gaining a better fix on this is important for improved certainty of fire weather forecasting over southeast NSW. Relocation would better serve the NSW grain belt, particularly the Murrumbidgee irrigation area.

NSW Priority 10: Upgrade Sydney S1 to dual polar

The Sydney basin is arguably the most hail prone location in the country. The area comprises major infrastructure and high population density.

NSW Priority 11: Central western NSW (near Ivanhoe)

Coverage over this area would improve the tracking of cold fronts and active systems linking fronts to northwest cloud bands that often carry a dense line of embedded storms. This radar would provide continuity with a new radar at Fowler's gap to provide advanced upstream warnings for the most populous and infrastructure rich parts of eastern NSW. The area is dominated by sheep and cattle, and the far east intersects the NSW grain belt.

NSW Priority 12: Implement Doppler capability throughout NSW

This will be extremely important in both storm prone areas to identify super cell storms, and, in bushfire prone areas to allow accurate prediction of wind changes.

NSW Priority 13: Improve continuity of 24/7 radar coverage into SE QLD, through conversion of Moree radar to weather watch, preferably also with relocation

Damaging thunderstorms are less frequent than in locations closer to the ranges and coast, but main river flooding is a major issue. Fulltime weather watch and mosaicing with eastern radars would allow extension of more detailed thunderstorm warning services. This radar would provide advanced notification of systems traversing the NSW-QLD border. The QLD Darling Downs is an important agriculture area and cotton production area, as is the northern grain belt of NSW.

NSW Priority 14: 24/7 radar coverage for Lord Howe Island

Lord Howe Island is potentially vulnerable to tropical cyclones, and, with no alternates it is an aviation weather sensitive location.

NSW Priority 15: Develop an operational dual Doppler capability in NSW

An operational dual Doppler capability would ultimately lead to a better understanding of storm structure and behaviour that will lead to improved warning services. It could also ultimately lead to improved model based forecasts through assimilation of detailed VAD information.

NSW Priority 16: dual polarisation capability on the Grafton S1 Doppler for better rainfall and hail discrimination over the northeast of NSW

This is the highest rainfall area of NSW, and is prone to the occurrence of large supercell thunderstorms. The ability to better discriminate precipitation types would be valuable in improving forecast and warning services.

5.4. Vic Region priorities

Vic Priority 1: Birchip

This area is heavily farmed and the existing coverage from Mt. Gambier, Melbourne and Mildura is at the extremities of useful radar range. There have been written representations for a new weather watch radar in this area from the Shire of Buloke as well as verbal communications from members of the farming community. This correspondence suggests that the current radar coverage is not detecting the location and intensity of precipitation over the area well. This is affecting decision making for farmers. In fact the current coverage is misleading in that farmers are “making hay” when no rain shows on the radars, and then getting caught out when showers move “under the radar”.

Vic priority 2: Upgrade Mildura

The radar at Mildura needs to be upgraded to full 24/7 weather watch mode and placed on a 22.5 metre tower to achieve uninterrupted coverage to the northwest of Mildura.

Vic Priority 3: Backup radar for Melbourne

There is a requirement for a second high quality 24/7 weather watch radar which would act as backup for the Laverton radar. This is required so that continuous weather watch coverage can be achieved when the Doppler radar at Laverton is down for maintenance or fails. The second radar should be situated southeast or east of Melbourne and on an elevated site. This will ensure that the “dead hole” close to Laverton is covered. It will also provide much improved coverage over the mountains to the northeast of Melbourne which is required for flood warning purposes.

Vic Priority 4: East Gippsland/ SE NSW

This is required to give better coverage over far east Gippsland and southeast NSW over the coastal plains and into the mountains and will help with flood warning capability. It would also be of great assistance in locating and estimating the intensity of east coast lows. Doppler capability would be particularly useful for this purpose.

Vic Priority 5: Inland SA (between Woomera and Mildura)

Farmers across northern Victoria look over inland SA for northwest could bands. There is little coverage over this area. A radar in this area would be useful, but not high priority.

5.5. Tas/Ant Region priorities

Tas Priority 1: Hobart replacement

There is unequivocal evidence that the siting of the existing radar at the Hobart International Airport is most unsuitable for the effective operation of the WWR. The corollary to this is that Hobart is the only capital city in Australia without adequate WWR coverage. The Region has documented evidence of the numerous severe weather events for which the existing radar has provided inadequate coverage, either because the radar was in wind-finding mode, or because of poor coverage.

Tas Priority 2: NE Tas

While it is generally the opinion of the Regional Office that the installation of a southeast Tasmanian radar is a matter of highest priority, there is considerable Regional interest in planning for a radar installation in the northeast of the state. The catchments of several of the most flood-prone rivers in the state lie in the northeast, but there is currently almost no radar coverage of the region. The anticipated increasing reliance of hydrological modelling on radar data is likely to highlight the lack of radar coverage as a significant problem in future. The problem is compounded by the fact that the northeast’s Esk river system drains through Tasmania’s second largest city, Launceston, several districts of which are vulnerable to flooding, and which has been subject to one of the most significant flood events in Australian history.

Tas Priority 3: SW Tas

The location of a radar well west of the SE agricultural districts would allow monitoring of cold frontal systems/troughs etc. as they cross from west to east. The Huon Flood Warning Project is a new initiative with which the Bureau is closely involved. Radar coverage of southwest Tasmania, in particular the Huon catchment, would be a valuable supplement to the project.

5.6. SA Region priorities

SA Priority 1: Cummins (lower Eyre Peninsula)

There is currently no effective coverage of Eastern and Lower Eyre Peninsula. Potential benefits of a radar in this area include improved short term severe weather/thunderstorm warnings for several rural communities and Port Lincoln, improved short term fire weather services, improved short-term regional forecast services for aviation industry including the airport at Port Lincoln, improved detection of rainfall systems for the extensive broad acre farming, coastal aquaculture and fisheries, and improved detection of significant weather developments upstream from Adelaide.

SA Priority 2: Lameroo (Murraylands)

Existing radar coverage does not extend to the Upper Southeast, Murraylands and Riverland Districts. The potential benefits of radar coverage of this area include improved severe weather/TS warnings for the large towns of Keith, Loxton, Renmark, improved detection of rainfall systems for the extensive broad acre farming, horticulture, viticulture and fisheries, quantitative rainfall accumulation data for water management in Murray River basin, improved spot fire forecasts, and improved detection of rainfall systems over western Victoria and weather developments upstream from Melbourne.

SA Priority 3: Whyalla (eastern Eyre peninsula)

A new radar for Whyalla would fill the coverage gaps over the Eastern Eyre Peninsula, southern Flinders and northern Mid North districts. Potential benefits include improved severe weather/TS warnings for Whyalla, Port Augusta and Port Pirie, improved spot fire forecasts, improved detection of rainfall systems, improved detection of rainfall/TS systems and quantitative rainfall estimates upstream from Adelaide, improved aviation services including regional airport at Whyalla, and improved wind and weather detection for heavily trafficked northern Spencer Gulf.

SA Priority 4: Broken Hill

A Broken Hill radar would fill coverage gaps in the Northeast Pastoral district. Potential benefits include improved severe weather/TS warnings for Broken Hill, improved detection of rainfall/TS systems upstream from Riverland/Sunraysia districts, improved spot fire forecasts, improved detection of rainfall systems over western Murray Darling Basin, and improved detection of low level weather systems impacting on aviation in the Broken Hill area

5.7. Qld Region priorities

Qld Priority 1: Mount Isa

A radar in this region would improve the ability to track TCs over land and other significant weather systems.

Qld Priority 2: Lockhart River (Cape York Peninsula)

The gap in coastal coverage for monitoring TCs in this region is evident to the public and leads to requests for improved coverage. This was highlighted during the recent TC Ingrid and TC Monica coastal crossings.

Qld Priority 3: Darling Downs

Major agricultural area with one of the highest incidence of large hail producing thunderstorms in Queensland.

Qld Priority 4: Upgrade Mackay to WW only

The only principal radar in the cyclone belt not full-time.

Qld Priority 5: Upgrade Gympie to S1

Doppler radar is particularly required in this area that is subject to a high incidence of severe thunderstorms. A service requirement for cell-based thunderstorm warnings in this region is anticipated.

Qld Priority 6: Upgrade Gladstone to Doppler

Qld Priority 7: Flinders (Hughenden)

Qld Priority 8: Innisfail

Due to topography, this region is not well covered by neighbouring radars, especially for provision of flood warning services. The recent impact of TC Larry and difficulties in post-analysis highlight the need for improved radar coverage in this area.

Qld Priority 9: Goldfields (Georgetown)

Qld Priority 10: Birdsville

5.8. WSPB priorities

Particular Comments

1. fill gaps along the northern coastline for tropical cyclone tracking
2. upgrade and relocate Hobart radar
3. fill gaps in key agricultural areas in NSW, SA, SW-WA

Service priorities

1. Complete coverage of Australia by dedicated weather watch radars to match the Bureau's forecast and warning responsibility;
2. No reduction to existing weather watch coverage levels, either spatially or temporally;
3. Provide consistent and spatially continuous radar coverage for detection of tropical cyclone movement and intensity along the whole of the tropical Australian coastline;
4. If complete coverage of Australia is not considered possible, then equitable access to basic radar coverage should be provided. This might be most easily achieved by ensuring that towns and communities past a certain population threshold number (say 10,000 to 20,000) are ensured coverage by radar within 150km;
5. Provide temporally and spatially continuous radar network coverage for 500km in all directions (where feasible) from a major city (population > 100,000);
6. Provide uninterrupted temporal coverage from sites currently served by 'part-time' weather radars;
7. Provide temporally continuous coverage of major airports, and along major air-routes;
8. Provide coverage of areas of major contribution to the regional and national economy;
9. Doppler signal processing capability and permanent volumetric scanning at all radars;
10. Supporting telecommunications, data processing and data quality management systems;
11. Adopt new technologies to provide clear identification of hail presence and size and improved rainfall estimation for those areas vulnerable to this type of severe weather.
12. Continue to introduce more comprehensive end-to-end monitoring systems to notify internal and external stakeholders of product outages.

5.9. Climate and Hydrology Program priorities

Climate:

1. accurate estimates of point rainfall accumulated over hours or days. (To be useful this requires a dense & reliable network)
2. QC/QA of point rainfall accumulations
3. Data management

Hydrology:

1. radar for improved rainfall measurement for flood (incl flash flood) warning
2. adequate data archiving

5.10. Water Division requirements

Under the Bureau's expanded role in water data management and accounting, there is an opportunity to contribute new data sets to enhance the understanding of Australia's water resources. While quantitative rainfall applications are considered valuable for significantly enhancing the Bureau's flood and severe weather warning services, the value of radar data for water accounting purposes is still unproven, and therefore new radar infrastructure is not considered a priority for the Water Division in meeting it's new responsibilities.

6. External requests for weather radar initiatives

More than a few community groups have put enormous effort, over several years, into documenting their requirements for weather radar coverage. The Bureau has received repeated requests from each of the communities of Mount Isa and Cobar and WA's wheatbelt, which describe in detail the value they would get from weather radar coverage. Email requests for radars are also regularly received by the Bureau, particularly from landowners in central-west NSW. In South Australia a petition with 600 signatories was received from the residents of SA's Eyre Peninsula. Other requests for radar initiatives have been received from major water and fire authorities, for example in Tasmania (for an adequate Hobart radar), and emergency services groups (for Maningrida and Eyre Peninsula radar coverage).

Communities which are prolific in their submissions for radar coverage are summarised below.

Darling Downs (Qld): Requests from local community groups and individuals for a new radar have been received by the Bureau, which describe the potential value a radar would provide on approaching storm fronts, thereby contributing to the management and safety on their farms.

Dubbo (NSW): The Bureau has received numerous requests from community groups, private individuals, farmers and business people requesting radar coverage for central NSW. Farmers in particular have noted the value of radar services during harvest, sowing and seeding times, and for timing of crop sprays.

Eyre Peninsula (SA): There is strong community demand for a radar, given that there is currently no effective radar coverage of eastern and lower Eyre Peninsula. The Bureau has received numerous radar requests from community groups and industries, including Primary Industries and Resources SA (PIRSA), Flinders Ports, the State Emergency Service, Forestry SA, the SA Recreational Fishing Association, as well as a petition with 600 signatories in support of an Eyre Peninsula radar.

Hobart (Tas): The Bureau has received numerous requests from members of the community and organisations including the State Fire Management Council, the Flood Warning Consultative Committee Tasmania and Tasmanian Farmers and Graziers, requesting improved radar coverage for Tasmania. A new radar at a carefully selected location in the south-east of Tasmania would provide significantly improved coverage for Hobart, as well as a large proportion of the State.

Mackay (Qld): The Bureau have received requests from the community (including a local charter airline) to upgrade the radar to full-time weather watch.

Mallee (Vic): The Bureau has received requests from local councils seeking radar coverage for the area, including requests from Buloke Shire and Swan Hill Council seeking adequate warning of storm events. A Buloke Shire councillor, in a separate radar request, reports that the gross value of grains and livestock within 100km of Birchip is worth $644 million per annum, and that the benefits of a weather radar in the Birchip area would be delivered to farmers in the form of up-to-date weather information used for minimising damages and planning the application herbicide products.

Mount Isa (Qld): Over several years the Bureau has received many of requests from the local community and Members of Parliament seeking weather watch radar coverage for the Mount Isa area.

Wheatbelt (WA): Recent requests for radar coverage of the area which have received from the WA Farmers Federation and from the North Eastern Wheatbelt Regional Organisation, argue that the weather radar information provided by the distant surrounding radars is not accurate for the Wheatbelt, leading to costly decisions by farmers. The Wheatbelt region consists of 12.5 million hectares of agricultural land, and accounts for over $4 billion of the WA’s Gross Regional Product (Department of Local Government and Regional Development, 2005/06)

Wollongong (NSW): The HMAS ALBATROSS has also formally appealed to the Bureau to maintain the current level of coverage provided by the Letterbox radar. Their concern is that a reduction in coverage will seriously impact the operations at the Naval Air Station.

7. Benefit-cost analysis and priority ranking

The benefit-cost ratios presented in this Section are used in Section 9 as input to the priority assessment for new and upgraded radar sites.

The methodology used to perform the benefit-cost analysis is described at Appendix A. The calculated benefit-cost ratios are displayed in the following tables (Table 1 and Table 2). With the exception of the Perth radar (see Table 3), all radar costs relate to the full establishment cost of a new (Doppler capable) radar – see Appendix B for a description of relevant costs.

7.1. Benefit-cost analysis results

The benefit-cost results are presented in the following two tables. A benefit-cost ratio of greater than one indicates that there is a calculated economic return for a radar at the proposed location.

Table 1 lists locations currently without adequate radar coverage[1] and the associated benefit cost of **installing a radar at these locations,** in order of most cost-effective to least cost-effective.

Table 2 presents the benefit-cost ratio of **upgrading existing radars to high resolution S1 radar with dual-polarization capability**, in order of most cost-effective to least cost-effective. Site acquisition and establishment costs have been included into the assessment, given that the radar may require relocation to optimise the weather watch coverage. Costs for upgrading the Perth (Serpentine) radar to S1 (the site was recently acquired and established under RNDSUP for a C-band radar), includes the cost of relocating the C-band radar to a site north of Perth near Nowergup.

The following options were not evaluated in the benefit-cost analysis, but rather were prioritised according to Regional Office and Service Program feedback (as described in Chapter 6):

1) upgrade of S1 Doppler radars installed under the RNDSUP initiative to dual-polarization capability,
2) conversion of existing dual role radars to dedicated weather watch mode, and
3) retrofit older radars with digital receiver components.

[1] Three locations in the list have existing but inadequate radar coverage, these are Hobart, Wollongong and Melbourne. Hobart AP radar is SE Tasmania's only radar and is dual-role with poor weather watch radar coverage. Wollongong will be without weather radar coverage when Letterbox radar is decommissioned. Unlike Sydney and Brisbane, Melbourne does not have a backup radar, therefore the Mornington Peninsula radar would become a backup radar for Melbourne.

New radars				
Proposed Site Name	**BENEFIT-COST RATIOS by radar type**			
	C-band	**S-band**	**1°C-band + Dual Pol'n**	**1°S-band + Dual Pol'n**
Mt Isa (Qld)	21.4	13.1		
Whyalla (SA)	17.6			
Meekatharra (WA)	12.8			
Newman (WA)	9.3			
Cobar/Bourke (NSW)	8.0			
Broken Hill (NSW)	7.4			
Wollongong (NSW)	7.2			
Dubbo (NSW)	6.1			
Innisfail/Tully (Qld)	3.1	1.8		
Hobart (Tas)	3.0			
Darling Downs (Qld)	2.7			
SE Melbourne (Vic)	2.2	1.2		
Eden (NSW)	1.9			
Wheat Belt (WA)	1.6			
Lower Eyre Peninsula (SA)	1.3			
Kuri Bay / Browse Reef (WA)	1.3			
Wimmera (Vic)	0.7			
SW (WA)	0.1			
St Helens (Tas)	0.1			
Goldfields (Georgetown) (Qld)	0.1			
Borolloola (NT)	0.1			
Croker Island / Maningrida (NT)	n/a			
SE Gulf Carp (Qld)	n/a			
Yulara (NT)	n/a			
Flinders - Hughenden (Qld)	n/a			
Lameroo (SA)	n/a			
Port Keats (NT)	n/a			
Birdsville (Qld)	n/a			
NE Cape York (Qld)	n/a			
SW Tas	n/a			

Table 1. Locations currently without adequate radar coverage and the associated benefit cost of installing a radar at these locations, in order of most cost-effective to least cost-effective.

Upgrade existing radars to high resolution Doppler with dual-polarization				
Site name	**BENEFIT-COST RATIOS by radar type**			
	C-band	**S-band**	**1°C-band Doppler + Dual Pol'n**	**1°S-band Doppler + Dual Pol'n**
Perth (WA)			8.7	8.8
Darwin (NT)			4.9	5.2
Grafton (NSW)			0.5	0.5

Table 2. Benefit-cost ratios of upgrading existing radars to high resolution S1 radar with dual-polarization capability, in order of most cost-effective to least cost-effective.

8. Benchmarking

Benchmarking provides a set of socio-economic and geographic indicators which allow international comparison. The primary purpose of the indicators is to provide information on the current performance of the Bureau's radar network compared to other countries of similar economic development.

8.1. *Overview of Australia's radar network*

The Bureau operates 59 weather radars[1], of which 32 are dedicated weather watch and 26 are dual role. The total area of Australia's land area with radar coverage is 1.8 million sq km, and the total area of land and water with radar coverage is 4.4 million sq km. Figure 3 shows the locations and spatial coverage of all radars in the network, and highlights the gaps in radar coverage, particularly along the northern coastline and west of Adelaide.

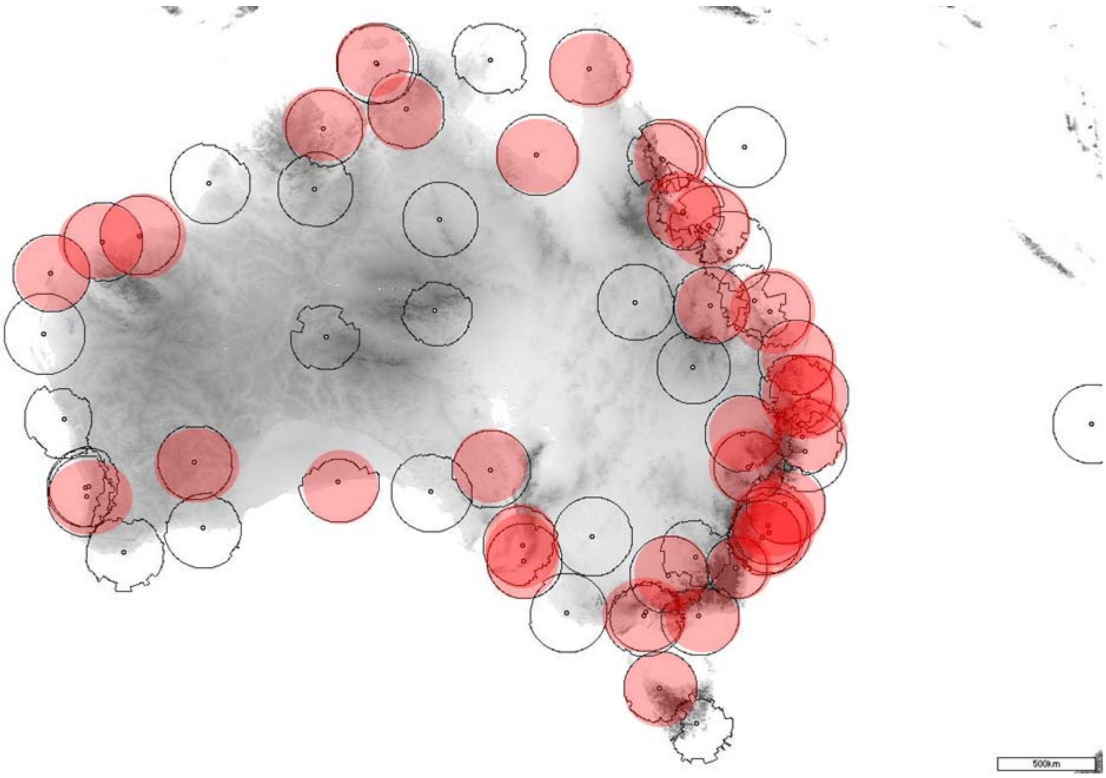

Figure 3. The Bureau's network of weather watch (red circles) and dual role radars. Rings indicate the radar coverage, which is affected by topography and other obstructions.

8.2. *How Australia compares*

Geographic and socio-economic indicators as well as radar network statistics have been compiled for 16 countries (and the EU) in Table 3. Indicators were selected to allow valid comparisons, which are nonetheless complicated due to the varying topography, economic status, climates and population distributions between countries. However some conclusions can be made.

[1] At the completion of RNDSUP

The statistics in Table 3 show that although more than 90% of the population of Australia has radar coverage, less than 50% of the land surface is monitored by radar. The US in comparison, which has similar (greater) land area, has 98% radar coverage.

Australia is affected by an average of 6 tropical cyclones per year, compared with Canada and the US which average 5 per year, China which averages 7, and Japan which averages 2.5 per year. Of the countries whose coastlines are impacted by tropical cyclones each year, Australia’s coastline is similar in length to that of US, China and Japan, which all have (or plan to have in a few years, in China’s case) near complete radar coverage. Not only does Australia have less than 50% radar coverage, but the vulnerable northern coastline has significant gaps in spatial (and temporal in the case of Gove) radar coverage.

The country which most closely compares with Australia in terms of economic status, population density, proportion of land area with radar coverage, and proportion of population covered by a radar is Canada. The main difference between the radar networks is Canada’s entire network has been upgraded to Doppler capability.

Compared with most developed countries, Australia is clearly behind in it’s implementation of operational Doppler systems. In fact the USA National Weather Service commissioned their first NEXRAD Doppler radar in 1994. Australia’s operational implementation of dual polarisation capabilities (statistics not listed in Table 3) on the other hand is not yet as far behind, with many countries transitioning from research installations to operational systems only in the last few years.

Name	Country statistics				Radar Statistics							Climate statistics
	Area km^2	Coast line km	Population	GDP US $billion (2006)	No. of radars	Dedicated WW	Population per WW or Dual role radar	No. of Doppler radars	GDP $US billion per radar	% land area covered	% pop'n covered	TC per year (average)
Australia	7,692,000	25,760	20,500,000	743.70	59	27	353,448	5	13	<50	>90	6
Canada	9,971,000	202,080	32,200,000	1,273.10	31	31	1,038,710	31	41	<50	>95	5
China	9,561,000	14,500	1,307,600,000	2,554.20	286	126	4,572,028	126	9	100*	100*	7
EU	3,989,000	65,993	459,100,000	14,206.00	159	159	2,887,421	118	89	100	100	-
Japan	378,000	29,751	127,700,000	4,302.10	20	20	6,385,000	?	215	100	100	2.5
New Zealand	271,000	15,134	4,100,000	101.80	4	4	1,025,000	4	25	90	>95	-
UK	243,000	12,429	60,200,000	2,357.60	13	13	4,630,769	2	181	100	100	-
USA	9,364,000	19,924	296,600,000	13,262.10	140	140	2,118,571	140	95	98	~ 99	5
France	552,000	3,427	62,700,000	2,227.30	24	23	2,726,087	24	97	100	100	-
Germany	357,000	2,389	82,500,000	2,890.10	16	16	5,156,250	16	181	100	100	-
India	3,287,000	7,000	1,094,300,000	854.50	38	21	28,797,368	5	22	>50	~50	3
Korea, South	99,000	2,413	48,300,000	877.20	10	10	4,830,000	10	88	100	100	-
Malaysia	330,000	4,675	26,000,000	147.00	9	9	2,888,889	1	16	>90	>95	-
Mexico	1,958,000	9,330	104,100,000	897.30	12	12	8,675,000	12	75	>80	>85	-
South Africa	1,219,000	2,798	46,900,000	256.50	12	12	3,908,333	5	21	50	>60	-
Spain	506,000	4,964	41,400,000	1,216.70	14	14	2,957,143	14	87	100	100	-

Table 3. Comparative statistics. Where WW = weather watch only, TC = tropical cyclone, * China is planning complete radar coverage of the country by 2010.

9. Assessment

This section presents the results of the Radar Network Review, and identifies in priority order, locations where new or upgraded radar infrastructure is expected to fill the gaps in radar coverage across Australia, improve the quality of warning and forecast services at existing radar sites, raise the performance of the Australian weather radar network to an international standard, and deliver considerable community and economic benefits.

9.1. Assessment criteria

Locations identified for new/upgraded radar infrastructure have been prioritised by considering each site individually, by weighing up National and Regional Service Program priorities (as described in Section 5), with the benefit-cost results (where data was available) (presented in Section 7), and with the level of public demand (Section 6). The locations recommended for new or upgraded radar infrastructure are therefore those which:

a) are considered a high priority by the National and Regional Service programs, and
b) are supported by a high level of public demand, and
c) are proven or supported by the benefit-cost assessment, or
   where cost-benefits are expected but benefit-cost related data is sparse.

Each site has been individually assessed using these criteria to determine the benefit of new or upgraded weather radar coverage to the community and wider region. This approach is considered to be necessary to account for the shortcomings of the PerilAUS natural disasters database (which was used to estimate the economic benefit of radar infrastructure at specified locations – see Appendix 1 for details), in which economic data was sparse for most non-capital city locations.

9.2. Results and recommendations

This section presents a number of recommendations for new and enhanced radar infrastructure, which are required to fill the gaps in radar coverage across Australia, improve the quality of warning and forecast services at existing radar sites, and raise the performance of the Australian weather radar network to an international standard.

Recommendations for new and enhanced radar infrastructure are summarised in Table 4 (new or upgraded radar infrastructure), Table 5 (RNDSUP S1 radars recommended for upgrade to dual polarisation capability), Table 6 (current dual role radars recommended for conversion to dedicated weather watch), and Table 7 (current weather watch radars recommended for digital receiver upgrades). The tabled summaries are grouped according to (national) priority, i.e. very high priority, high priority, medium priority and lower priority, and are presented along with their associated regional priorities and benefit-cost assessment results. These results are described in detail in Section 9.2.1.

Note that the recommendations in Tables 5-7 were not evaluated by a benefit-cost assessment and are prioritised only by Regional Office and Services Program requirements.

Site name (Alphabetical order)	Regional priority	Benefit-Cost result	Typical weather	Who benefits
Overall priority for new or upgraded radar infrastructure – very high				
Croker Island/ Maningrida	1	n/a	• Tropical cyclones	• Darwin • Indigenous communities
Dubbo/Parkes	1	6.1	• Severe storms • Upstream from Sydney	• Pop'n 65,000 • Grain belt
Hobart	1	3.0	• Non-precipitating wind changes affecting bushfires • Heavy rainfall	• Capital city, pop'n: 240,000 • Farmers and graziers
Lower Eyre Peninsula	1	1.3 (data sparse)	• Severe storms • Bushfires	• Farming, aviation, fisheries
*Mallee	1 (Vic) 2 (SA)	0.7 (data sparse)	• Rain	• Farming
Mount Isa	1	21.4	• Inland movement of Tropical Cyclones	• Pop'n 30,000 • Mining
SW WA	1	0.1 (data sparse)	• Squalls, riverine and flash flooding • Supercells once every 1-2 yrs	• Construction, agriculture, aviation, marine users
Wollongong	4	7.2	• Flash Floods • Southerly busters	• Sydney Basin pop'n 4.5 mill • Wollongong pop'n 200,000
Overall priority for new or upgraded radar infrastructure – high				
Borroloola	2	0.1	• Tropical cyclones	• Indigenous communities • Mining
NE Cape York	3	n/a	• Tropical cyclones	• Indigenous communities • Mining
NE Tas	2	0.1	• River flooding	• Agriculture, forestry, tourism, fishing
SE Gulf Carp	?	n/a	• River flooding	• Normanton community, tourism
Upper west NSW (Cobar/Bourke)	2	8.0	• River flooding • Squalls	• Farming, cattle, wool
Wheatbelt WA	4	1.6	• Heavy rain, hail • Severe winds	• 12 million hectares of wheat farms

Overall priority for new or upgraded radar infrastructure – medium				
Broken Hill / Fowlers Gap	5 (NSW) 4 (SA)	7.4	• thunderstorms	• Sheep and cattle, irrigation farming • Pop'n of 20,000
Darling Downs	4	2.7	• hail producing thunderstorms	• Agriculture
Eden	4 (Vic) 7 (NSW)	1.9	• East coast lows • Southerly buster formation	• Pop'n of 50,000 • Advance weather warning for Sydney • Enhanced flood warning capability for far-east Gippsland
Whyalla (SA)	3	17.6	• Severe thunderstorms • Bushfires	• Pop'n of 50,000 • Improved spot-fire forecasts • Shipping from Spencer Gulf • Aviation
Overall priority for new or upgraded radar infrastructure – lower				
Birdsville (Qld)	11	0.0 (no data)	• Cold fronts with embedded storms	• Upstream detection of storms for more populated eastern NSW
Flinders –Hughenden (Qld)	8	0.0 (no data)		• Cattle properties • Pop'n: 2,000
Innisfail/Tully (Qld)	9	3.1	• Flood • Tropical cyclones	• Sugar plantations • Pop'n: 8,000
Kuri Bay / Browse Reef (WA)	4	1.3	• Tropical cyclones	• Indigenous communities • Mining
Meekatharra(WA)	6	12.8		• Mining
Newman (WA)	5	9.3		• Mining
Port Keats (NT)	3	0.0 (no data)	• Tropical cyclones	• Timor Sea, Daly region • Industry development in the Bonaparte Basin
SW Tas	3	0.0 (data sparse)	• Frontal systems	• Huon Flood Warning Project
Yulara (NT)	5	0.0 (no data)	• thunderstorms, hail, tropical rain depressions, northwest cloud bands	• Tourism, mining, pastoral

Table 4. Locations recommended for new or upgraded radar infrastructure. Note: The *Mallee radar refers to a Wimmera (Vic) or Lameroo (SA) radar.

High resolution Doppler radars	Priority	Priority
Test bed radar (Melbourne)	Very high	Very high
Perth S1 plus Nowergup	Very high	High
Grafton S1	Very high	medium
Darwin S1	High	medium
Melbourne (Laverton)	-	High
Brisbane (Mt Stapylton)	-	High
Adelaide (Buckland Park)	-	High
Sydney (Terrey Hills)	-	High

Table 5. New high resolution radars, and upgrades to existing high resolution radars. The PerthS1 radar includes an upgrade of Perth (Serpentine) to S1 plus relocation of the C-band radar to new site at Nowergup.

Conversion of dual role radars to WW	Priority
Mildura *	Very high
Mackay *	Very high
Coffs Harbour *	Very high
Wagga Wagga *	Very high
Mount Gambier	Very high
Gove	Very high
Albany *	Very high
Townsville *	Very high
Broome	Very high
Ceduna	Lower
Alice Springs *	Lower
Esperance	Lower
Geraldton	Lower
Norfolk Island	Lower
Rockhampton *	Lower
Halls Creek *	Lower
Longreach	Lower
Carnarvon	Lower

Table 6. Current dual role radars which are recommended for conversion to dedicated weather watch (includes digital conversion). The upper-air program at these sites would need to be replaced by alternative technology, e.g. profiler, autosonde or GPS-radiosonde capabilities, as required. Note: * indicates that relocation of the radar for improving the coverage would have considerable merit.

Digital conversions	Priority
Brisbane (Marburg)	Very high
Port Hedland	Very high
West Takone	Very high
Adelaide (Sellicks Hill)	Very high
Newcastle	Very high
Dampier	Very high
Saddle Mountain	Very high
Learmonth (Cape Range)	High
Bowen	High
Woomera	High
Wyndham	High
Mornington Island	High
Weipa	Medium
Tindal	Medium
Gladstone	Medium
Canberra (Captains Flat)	Medium

Table 7. Current weather watch radars which are recommended for digital receiver upgrades (priority list provided by the Chair of the RUCG in May 2006).

9.2.1. Discussion

9.2.1.1. Very High Priority radar infrastructure

The assessment identified eight (8) locations (**Croker Is/Maningrida, Dubbo/Parkes, Hobart, Lower Eyre Peninsula, Mallee**[1]**, Mount Isa, SW WA, Wollongong**) where new radar coverage would deliver significant economic and community benefits. All eight candidate sites have been identified as highest priority by Regional Offices, and benefit-cost ratios are high for those sites where data was available. The case for new radar coverage at these locations is supported by a large volume of radar requests received from the general public over many years. Note that Hobart is the only capital city in Australia without a dedicated weather watch radar. The low benefit-cost ratio (due to a small proportion of documented damage costs) for a new Hobart radar is unlikely to be indicative of the expected economic benefit. Similarly for the Lower Eyre Peninsula, economic benefits are expected for the various industries (eg aquaculture, agriculture, aviation) as a result of new radar coverage. The high benefit-cost ratio for Wollongong is due to the large number of disaster entries in the PerilAUS database for the areas around Sydney, particularly some high impact bushfire and hailstorm events.

New high resolution Doppler radars are considered very high priority for three (3) locations. These locations include **Perth, Grafton, plus an innovation and training platform with dual-polarisation capability** on the Mornington Peninsula.

Conversion of dual role radars to dedicated weather watch functionality is considered very high priority at nine (9) locations (**Mildura, Mackay, Coffs Harbour, Wagga Wagga, Mount Gambier, Gove, Albany, Townsville, Broome**). It is anticipated that six (6) of these existing radars will require relocation to improve the radar coverage. Alternative upper-air technology will be required at these sites to replace the balloon-tracking function of the radar.

The upgrade of seven (7) of the network's older technology radars with digital receiver components is considered very high priority for radars at **Brisbane (Marburg), Port Hedland, West Takone, Adelaide (Sellicks Hill), Newcastle, Dampier, Saddle Mountain)**. The priorities for these radars were defined by the Radar Users Coordination Group (RUCG) in 2006.

9.2.1.2. High Priority radar infrastructure

New radar coverage is considered high priority for a further six (6) locations (**Borroloola, NE Cape York, NE Tas, SE Gulf of Carpentaria, Upper west NSW (Cobar), Wheatbelt WA**). New radar infrastructure at these locations will fill key coverage gaps along the northern coastline, provide coverage of flood-prone catchments in Tasmania, and will deliver considerable economic and community benefits to the provincial towns near Cobar and the Wheatbelt, where public demand for radar coverage has been high.

The upgrade of one (1) existing radar to high resolution S1 capability (**, Darwin**), plus upgrade of the five (5) S1 radars (**Melbourne, Brisbane, Adelaide, Sydney, Perth**) to dual polarisation capability is considered a high priority (note that the high benefit-cost value for Darwin was due largely to the significant impact on infrastructure and lives lost during Cyclone Tracy in 1974). The additional benefit of dual polarisation capability is improved

[1] In order to meet Vic Region's requirements for Birchip coverage, and also meet SA Region's requirements for radar coverage of the Murraylands District, a Mallee radar is proposed.

forecasts and warnings of hail producing storms with a higher level of confidence than ever before.

The upgrade of five (5) of the network's older technology radars with digital receiver components is a high priority at **Learmonth (Cape Range), Bowen, Woomera, Wyndham, Mornington Island**. The priorities for these radars were defined by the Radar Users Coordination Group (RUCG) in 2006.

9.2.1.3. Medium Priority radar infrastructure

New radar coverage is considered to be a moderate priority for a further four (4) locations (**Broken Hill / Fowlers Gap, Darling Downs, Eden, Whyalla**). Economic benefits are expected for agricultural areas such as Broken Hill and Darling Downs, where real-time rainfall information can influence farming decisions such as when to spray fertilisers etc. Community benefits are also expected, particularly for Eden and Whyalla where low-level coverage can enhance local flood and fire warnings, and provide upstream detection of severe weather for major cities.

The upgrade of four (4) of the network's older radars with digital receiver components is a moderate priority at **Weipa, Tindal, Gladstone, Canberra (Captains Flat)**.

9.2.1.4. Lower Priority radar infrastructure

The following nine (9) locations are considered lower priority locations (compared to the locations identified above) for new radar coverage **- Birdsville, Flinders/Hughenden, Innisfail/Tully, Kuri Bay/Browse Reef, Meekatharra, Newman, Port Keats, SW Tas, Yulara**. Although these sites have been identified by Regional Offices as being a priority for Regional weather service provision, the assessment indicates that other locations are expected to deliver greater community and economic benefit in the foreseeable future. The assessment has noted that many of these locations support industries which contribute to the local and national economy, and which are likely to benefit from weather radar coverage, and as such should be considered in future funding proposals. In the case of Kuri Bay specifically, due to the very high expected costs of this installation, as well as the high costs of ongoing power and maintenance requirements, the site should be reprioritised when the area becomes more developed.

Conversion of dual role radars to dedicated weather watch functionality is also considered lower priority for nine (9) locations (**Ceduna, Alice Springs, Esperance, Geraldton, Norfolk Island, Rockhampton, Halls Creek, Longreach, Carnarvon**). It is anticipated that four (4) of these radar will require relocation to optimise the weather radar coverage. Alternative upper-air technology will be required at these sites to replace the balloon-tracking function of the radar.

10. Summary of recommendations

On the basis of the assessment results presented in this document, the following radar installations and technology upgrades are recommended in order to enhance radar coverage across Australia, improve the quality of warning and forecast services at existing radar sites, and raise the performance of the Australian weather radar network to an international standard:

1. It is strongly recommended that the radar infrastructure installations and enhancements identified **<u>very high priority</u>** are implemented at the earliest opportunity, i.e.:
   a. 8 new radars in locations which do not have adequate radar coverage,
   b. 2 new S1 radar facilities with dual polarisation capabilities.
   c. a development and innovation platform on the Mornington Peninsula which will provide coverage of the Yarra Valley and Ranges, and backup coverage of Melbourne. It will also provide the capability to reduce commissioning time of operational radars and therefore relieve pressure on Radar Engineering staff; will reduce duration of outages; will facilitate a more rapid roll-out of improvements to the entire radar network
   d. 9 dual-role radars converted to dedicated weather watch, and
   e. 7 of the network's older radars are upgraded with digital receiver components to improve the data quality and provide a low cost Dopplerisation.

2. It is recommended that the radars identified as **<u>high priority</u>** are implemented subsequent to those identified as very high priority. These include:
   a. a further 7 new radars in locations which do not have adequate radar coverage,
   b. 2 radars are upgraded to S1 with dual-polarisation capability,
   c. 4 RNDSUP S1 radars are retrofitted with dual-polarisation capability, and
   d. a further 6 of the network's older radars are upgraded with digital receiver components to improve the data quality and provide a low cost Dopplerisation.

3. That consideration be given to radars identified as **<u>medium priority</u>**. Although these radars are of lower priority than those identified above, most are still within the top 5 priorities for the Regions, and their potential value to forecasting quality is still considerable. These radars include:
   a. a further 4 new radars in locations which do not have adequate radar coverage,
   b. a further 4 of the network's older radars are upgraded with digital receiver components to improve the data quality and provide a low cost Dopplerisation.

4. That further consideration be given to radars identified as **<u>lower priority</u>**. As the popularity of the Bureau's radar web pages continues to grow, and the quality of the radar-based weather warnings continue to improve, the priority for the following radar infrastructure is likely to escalate:
   a. a further 9 new radars in locations which do not have adequate radar coverage,
   b. a further 9 dual-role radars are converted to dedicated weather watch, and alternative upper-air technology is installed to perform wind-flights.

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Appendix A

Benefit-cost analysis methodology

The benefit-cost method used here is based on that used by Gunn (2002) in the PDP for the RNDSU Project.

Methodology

This analysis assumes that improved spatial and temporal radar coverage resulting from new or upgraded radar infrastructure will lead to economic benefits derived from the increase in damage avoided through more accurate severe weather warnings.

1. Determine the cost of natural disaster events in Australia

To derive the avoidable damage costs to property and ensuing economic benefits, it was necessary to determine the costs of natural disaster events in Australia. Gunn used the PerilAUS disasters database from the Natural Hazards Research Centre at Macquarie University to determine the damage costs to property caused by natural disaster events over a 14 year period. The PerilAUS database, which Gunn found to be the most comprehensive catalogue of natural disaster events and related damages in Australia, catalogues damage to buildings (as a proportion of replacement value), and the proportion of buildings completely destroyed by each natural disaster event. Note that the damage costs in the database are estimates of actual damage, and damage costs relating to house contents, motor vehicles, aircraft, bridges, roads and other infrastructure are excluded. More information about the database and the method used to extract data from the PerilAUS database can be found in Gunn (2002).

Damage costs caused by natural disaster events were determined for numerous locations across the country. These locations were chosen on the basis of a) known radar coverage gaps, b) requests received for new radars from Regional Offices, and c) requests received for new radars from the general community. Using the graphical interface in the PerilAUS software, a circle of 120km radius was drawn around each potential radar location to extract damage cost statistics [2].

The lack of disaster events recorded in the PerilAUS database for regional areas was discovered early in the analysis process. In an attempt to rectify this imbalance, the Emergency Management Australia (EMA) disasters database was used to extract disaster event statistics that were not recorded in PerilAUS.

Disaster event costs in this analysis include lives lost. Although a contentious issue, a “cost of life” has been attributed, based on the derived average values from a report by the Bureau of

[2] One of the differences between this assessment and Gunn’s work is in the type of disaster events extracted from PerilAUS database to derive damage costs (which impacts on derived economic benefits). Based on the assumption that the forecasting tools being developed for the RNDSUP Doppler radars would not benefit tropical cyclone forecasting as much as severe thunderstorm, bushfire and flood forecasting, Gunn excluded the damage costs from tropical cyclone events. In contrast, the network review has focussed on filling coverage gaps, including along the northern coastline where inadequate radar coverage impacts on the accuracy of warnings to communities such as Maningrida. Tropical cyclone damage costs have therefore been included in this assessment, based on the assumption that gap-filling radars along the northern coastline will provide more accurate information on the location and intensity of cyclones.

Transport Economics (2001), in 1998 dollars, where $1.3 million is the cost of a natural disaster fatality, $317 000 for a serious injury and $10 600 for a minor injury.

An attempt has been made to include the costs of natural disasters at locations with mining operations. Estimates of weather-related damages to open-cut mining operations and the potential economic benefit of weather radar coverage were obtained from Mr Hermann Fasching, District Inspector of mines, Department of Mines and Energy, Queensland.

2. Determine the proportion of damages avoidable (i.e. the "benefit")

To determine the proportion of damages avoidable i.e. through more accurate severe weather warnings, damage values for each weather phenomenon[3] were extracted from the PerilAUS database according to locality, and then summed. Each of these totals was then weighted by a factor which estimates the proportion of damage that can be avoided if a warning of severe weather is provided (Table 8). These figures were then multiplied by a probability of detection (POD) factor, which is the difference between the existing POD at each locality, and the POD possible with a new or upgraded radar. The resulting value is the "benefit" (in "house equivalent" units – see footnote).

Phenomenon	**Avoidable Damage %**
Bushfires	2%
Flash Flood	10%
Gust	10%
Hail	15%
Tornado	5%
Tropical Cyclones*	10%

Table 8. Estimates of proportion of additional damage that can be avoided if a warning of severe weather is provided – from "Plan for upgrading of severe thunderstorm services", Severe Weather Warning Services Program Office, Services Policy Branch, 9 May 1989. File reference 70/366. *Avoidable damage for Tropical Cyclone events was estimated to be 10%, assuming that the spatial scale of TC events was similar to Flash Floods and Gusts.

To convert the benefit values obtained from this assessment to dollar value benefits, each "house equivalent" unit (see footnote) was multiplied by a value of $0.338 million, as adopted by Gunn (2002). These figures were then normalised to 2008 dollars to enable the later comparison with radar costs.

3. Determine the cost of a radar system (i.e. the "cost")

The next step towards calculating benefit-cost ratios requires cost estimates for each radar system. Radar system costs used in the analysis include the radar, radar tower and dome, site acquisition, siteworks, installation (ASL), initial spares, AWS network, comms, support systems. Asset costs are amortised over a 15 year depreciation cycle, and then ongoing costs for G&S and ASL are added. See Table 9.

Benefit-cost ratio results for each location are presented in Table 1 and Table 2.

[3] The PerilAUS database reports damage costs in 'house equivalent' or HE units, where 1 HE relates to one completely destroyed house.

Limitations and biases of the benefit-cost assessment

The benefit-cost results are influenced by biases in the input data. Those biases are listed below:

- The PerilAUS database lists many more events in Sydney and NSW than elsewhere in Australia (the database was developed by Macquarie Uni). This has resulted in a bias in the analysis results towards Sydney regions.
- Disaster events in rural and regional areas were not well represented in the PerilAUS database, resulting in a bias against these regions. An attempt has been made to rectify this, by including disaster events from the EMA database.
- The benefit-cost ratio results for regional locations with open-cut mining operations were boosted by the inclusion of the economic benefit estimates provided by Mr Hermann Fasching, Inspector of Mines, Mount Isa.. The inclusion of these benefit estimates had significant impact on the benefit-cost values for mining areas, especially for Meekatharra and Newman.
- The lack of weather-related damage estimates for the northern coastline regions (largely due to the relatively small number of building damages in these remote regions) resulted in a bias against the northern coastline communities.

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Appendix B

Radar costs used for the benefit-cost analysis

	Costs: $'000	Cost of new radar	Site Acquisition	Siteworks	Installation (ASL costs)	Initial Spares	AWS network	Comms Costs	Support Systems	Ongoing G&S and ASL (p/a)	Install Nowergup radar (Perth only)	Asset total
New Radars	1 deg c-band Doppler	1,050	100	700	245	100	265	78	200	359		2,738
	1 deg s-band Doppler	2,530	100	1,400	245	170	825	78	200	640		5,548
	1 deg c-band Doppler + dual pol	1,350	100	1,400	245	100	825	44	200	670		4,264
	1 deg s-band Doppler + dual pol	2,830	100	1,400	245	170	825	44	200	670		5,814
Perth (existing C-band)	Dopplerise existing C-band radar	0	0	0	0	100	265	0	200	105	1423	1,988
	1 deg s-band Doppler	2,530	0	0	245	170	825	78	200	640		5,470
	1 deg c-band Doppler + dual pol	1,000	0	0	245	100	825	44	200	496		3,836
	1 deg s-band Doppler + dual pol	2,830	0	0	245	170	825	44	200	670		5,736

Table 9. The total annual cost (annual depreciation + ongoing ASL/G&S) was used as input to the benefit-cost analysis. Radar assets have been depreciated over a 15 year cycle.

Additional data used in the benefit-cost analysis		
Value	**Reference**	**Annual benefit**
Value of improved weather forecasts to households	• Lazo (2002) estimates annual value per household of improved weather forecasts is USD$16 *Convert to AUS$ - as a proportion of income* → Aust median gross household income: approx $40k (1999 dollars, ABS) → US median household income $42k (1999 dollars, Bureau of Labour Stats) → approx 7 million Australian households in 1999	Annual value per household: $15
Value of radar coverage to the mining industry	• Based on correspondence from Fasching (2007), installation of a **lightning sensor** resulted in $0.5 million benefit for Xstrata mines. Weather-related losses at the nearby Incitec Pivot mine (with similar operational scale to Xstrata) are estimated at $5.2 million. i.e. avoidable damage from a lightning sensor installation is 10% of the total damage. → A **weather radar** would provide increased accuracy of storm cell location and movement, so assume that 15% of damage is avoidable, i.e. $0.75 million per mine.	$10 to 40 million per mining community, calculated using the number of open cut mines in each area.

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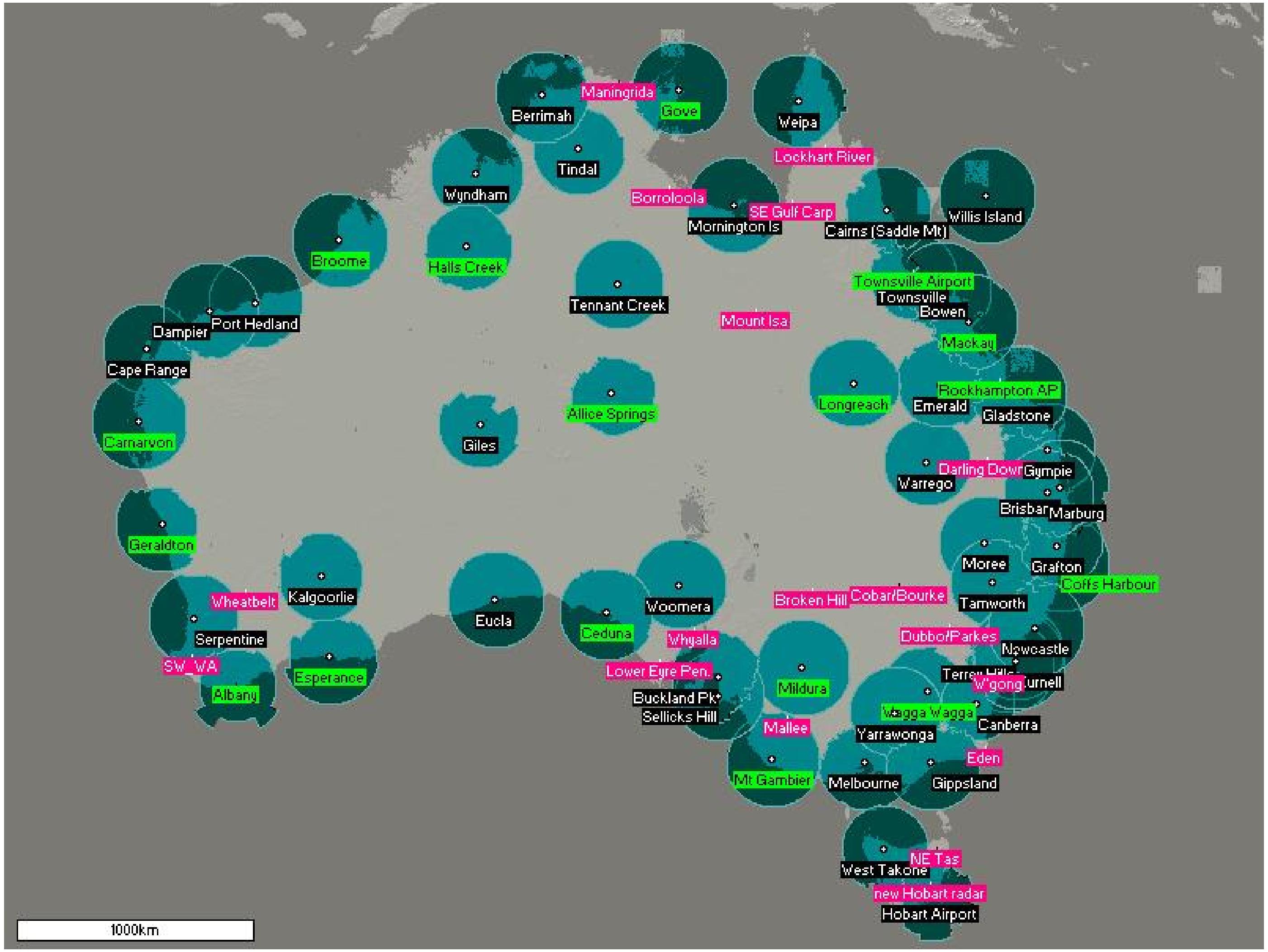
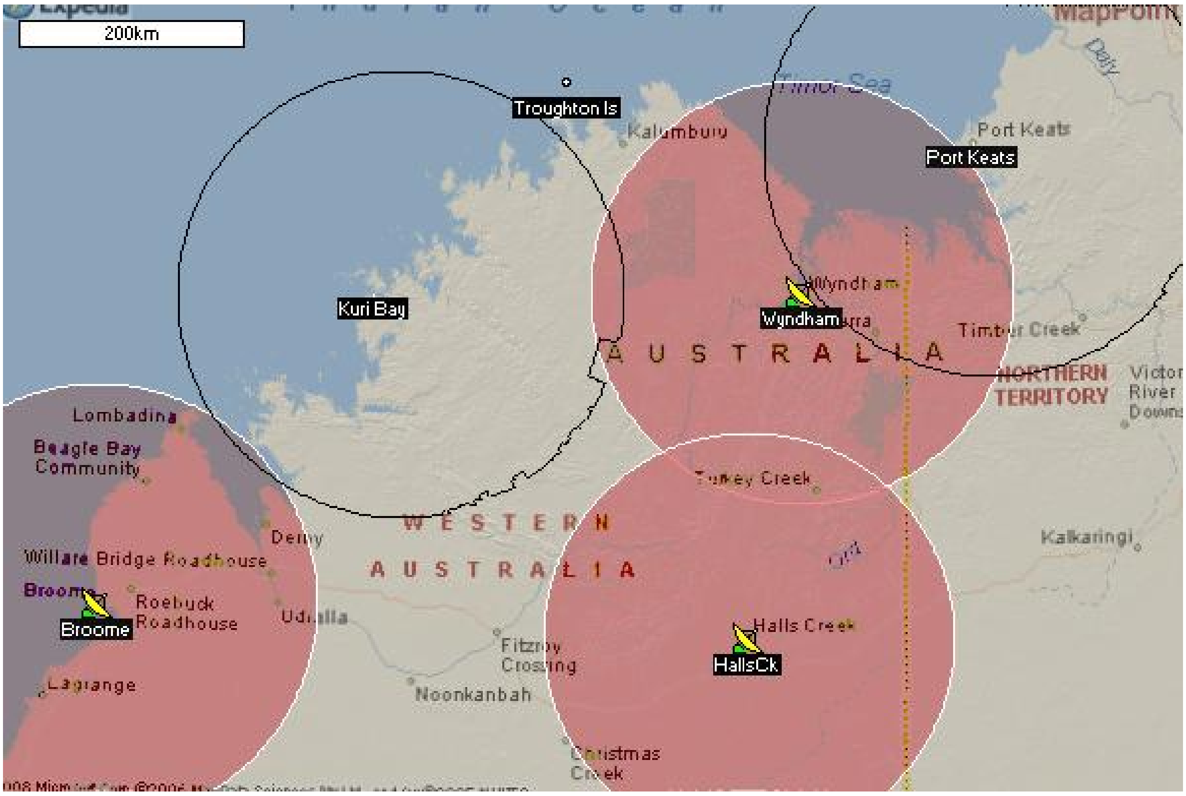
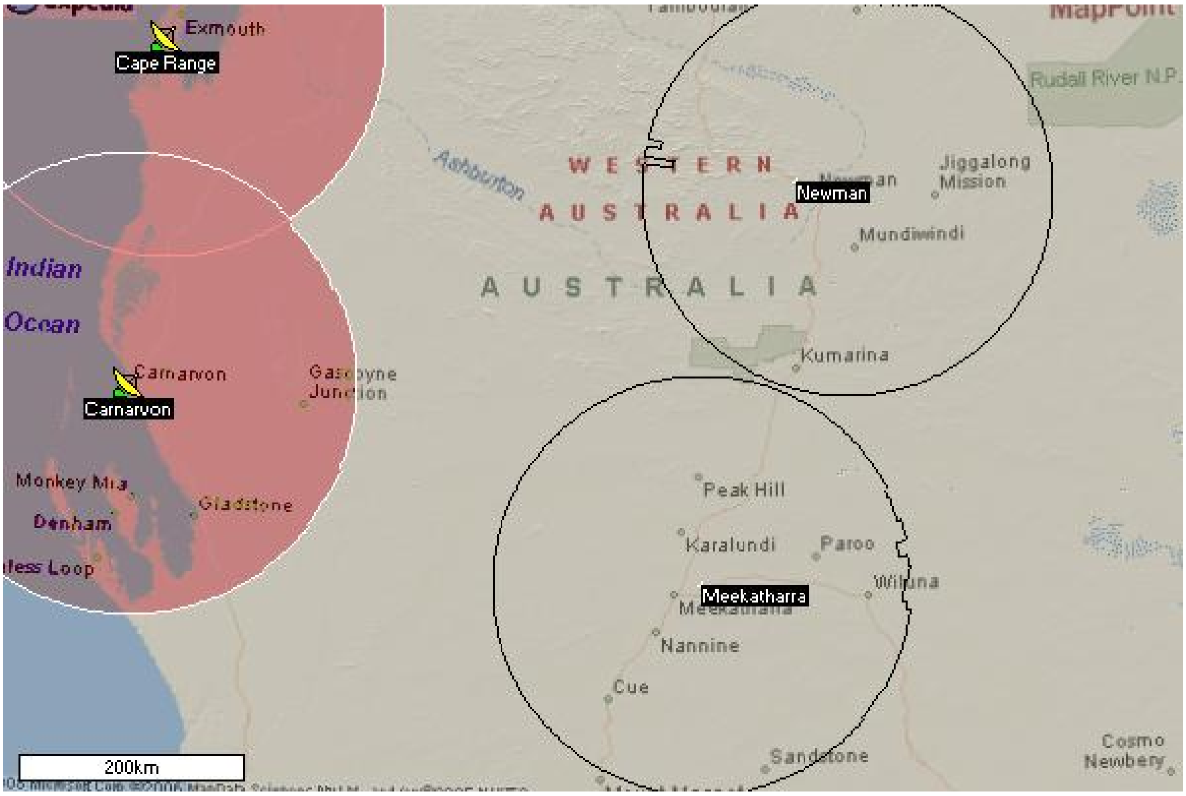
Appendix D

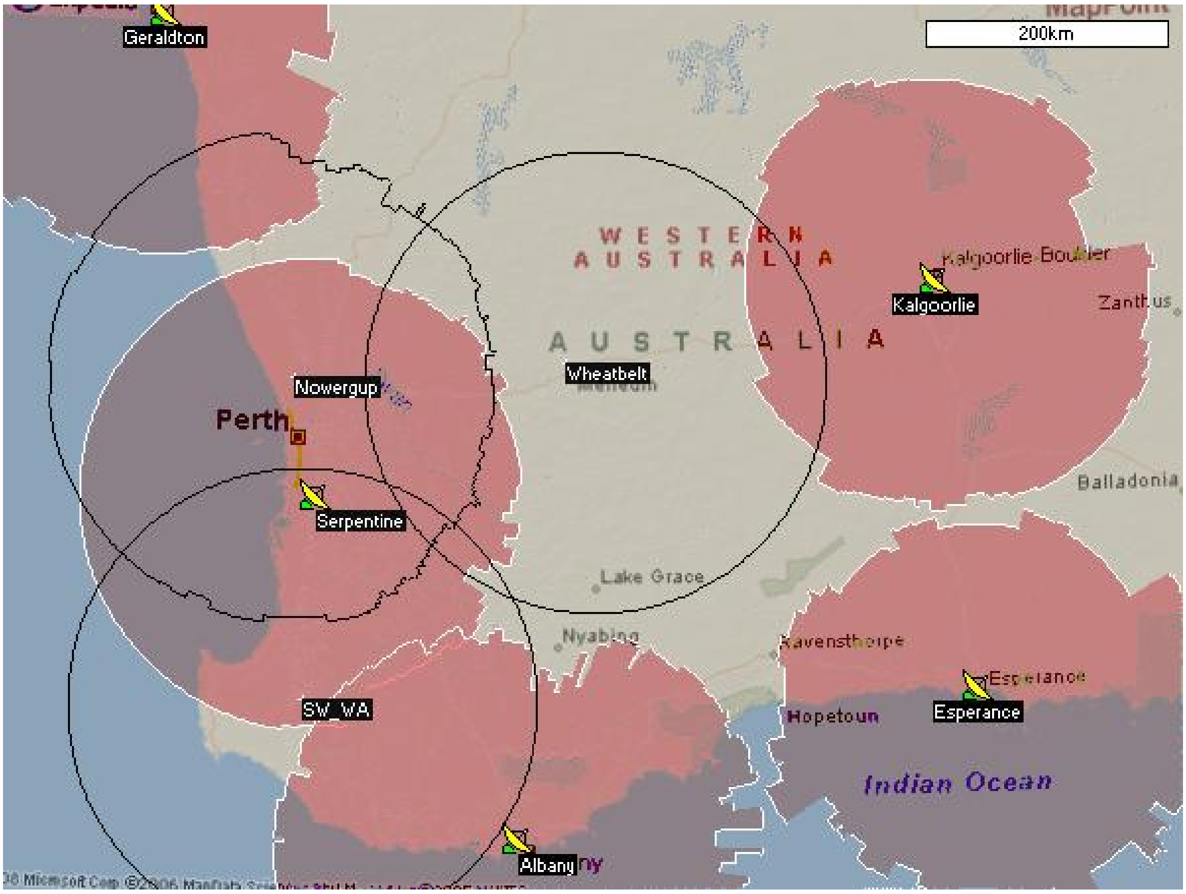


Existing radar coverage (indicative only - blue rings), dual role weather radars proposed for conversion to full time weather watch (green labels), and very high to medium priority radars to fill gaps in radar coverage (pink labels).

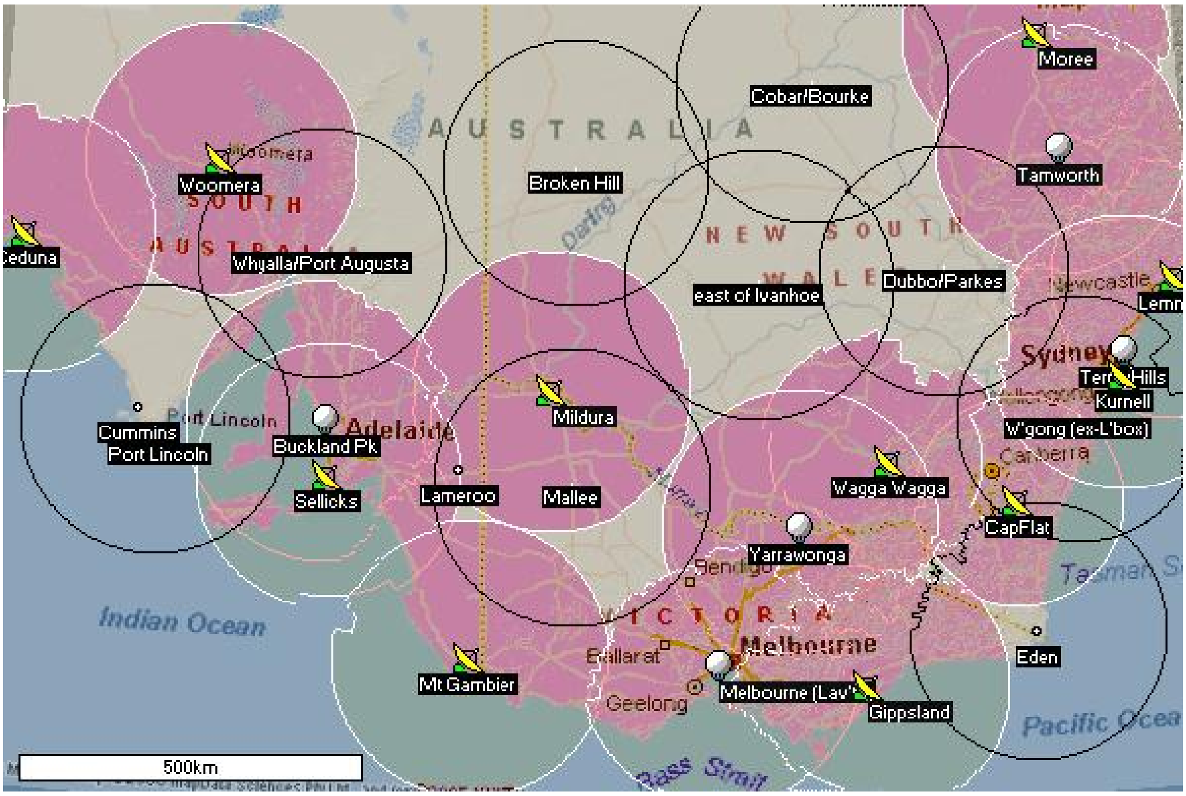




Coverage of existing radars (shaded) and indicative coverage of radars requested by WA Region (in black outline) and NT Region (Port Keats). Note: Halls Creek, Brooome and Carnarvon are dual role radars.



Coverage of existing radars (shaded) and indicative coverage of radars requested by WA Region (in black outline). Note that the Albany radar coverage shown here is not accurate as it does not show the missing wedges to the west caused by trees obstructing the skyline. Serpentine C1 radar is scheduled to be installed in 2008-09 as part of the RNDSUP initiative.



Coverage of existing radars (shaded) and indicative coverage of radars requested by Vic, SA and NSW Regions (black outline). Note that the actual coverage from Mildura radar is affected by blockages (caused by nearby trees), which is not accurately represented in this figure.

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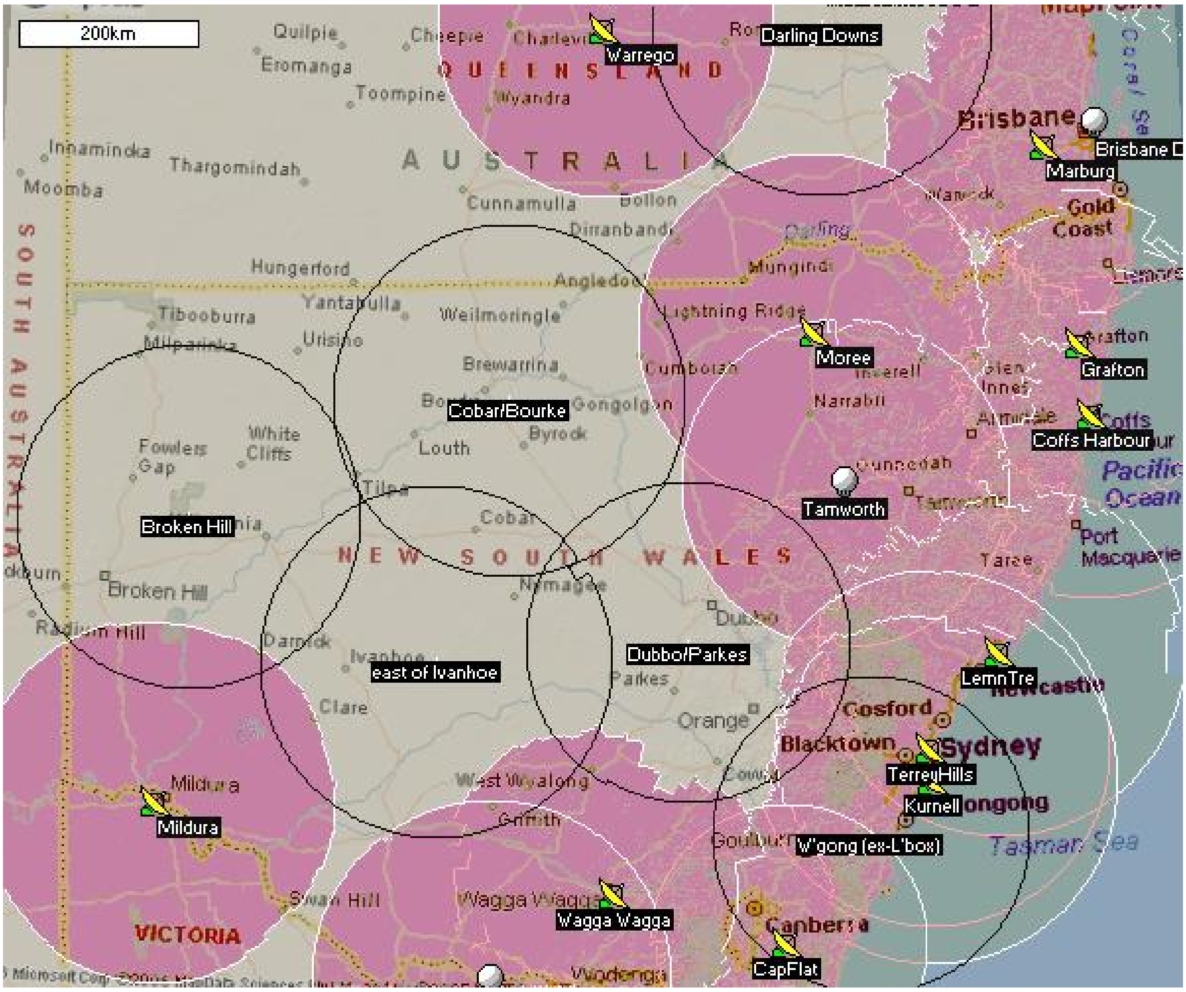

Coverage of existing radars (shaded) and indicative coverage of radars requested by NSW and Qld Regions (black outline). Note: Sydney (Letterbox) radar is to be relocated to Terrey Hills as part of the RNDSUP initiative. Wagga Wagga is a dual-role radar.

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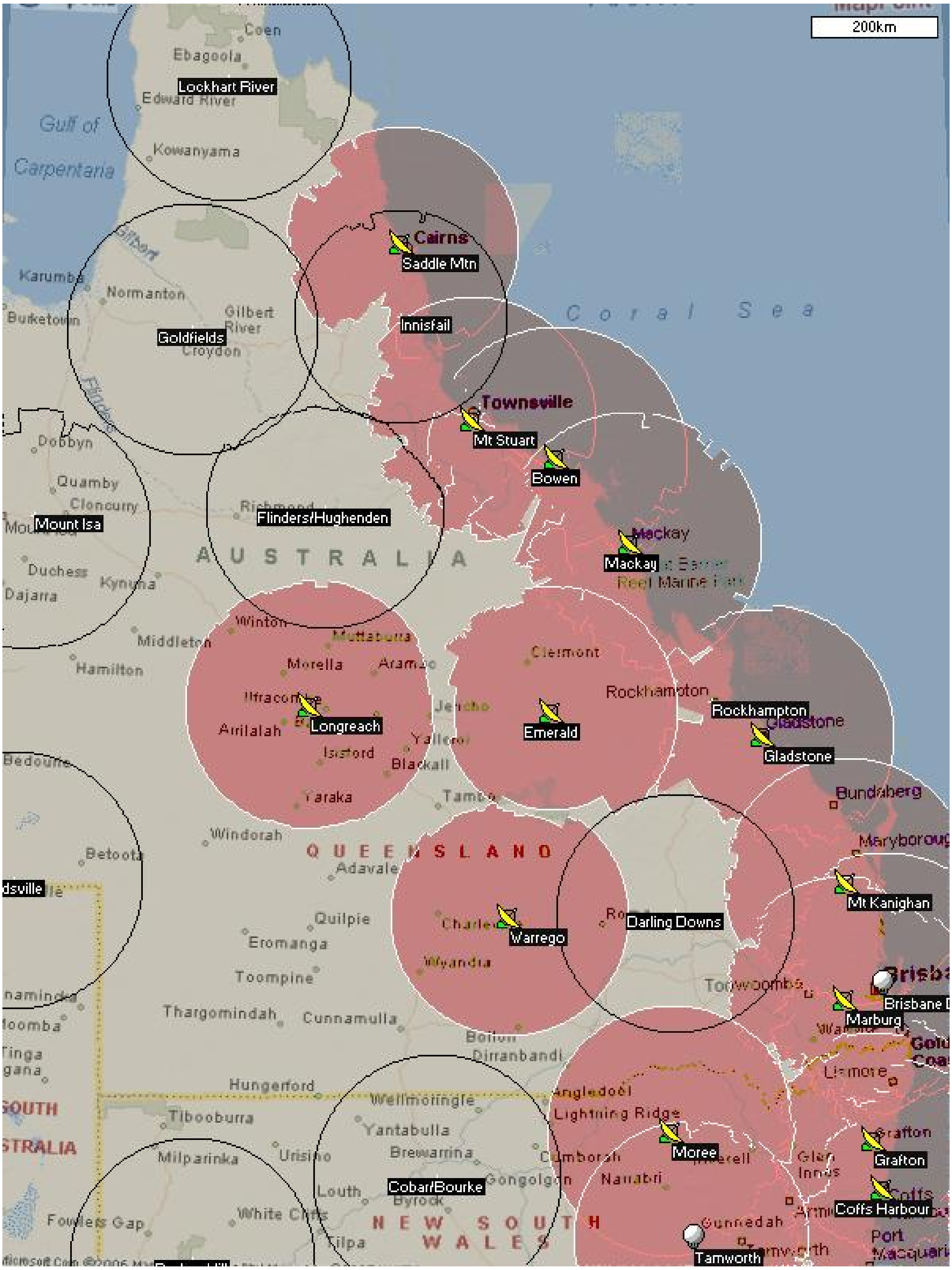
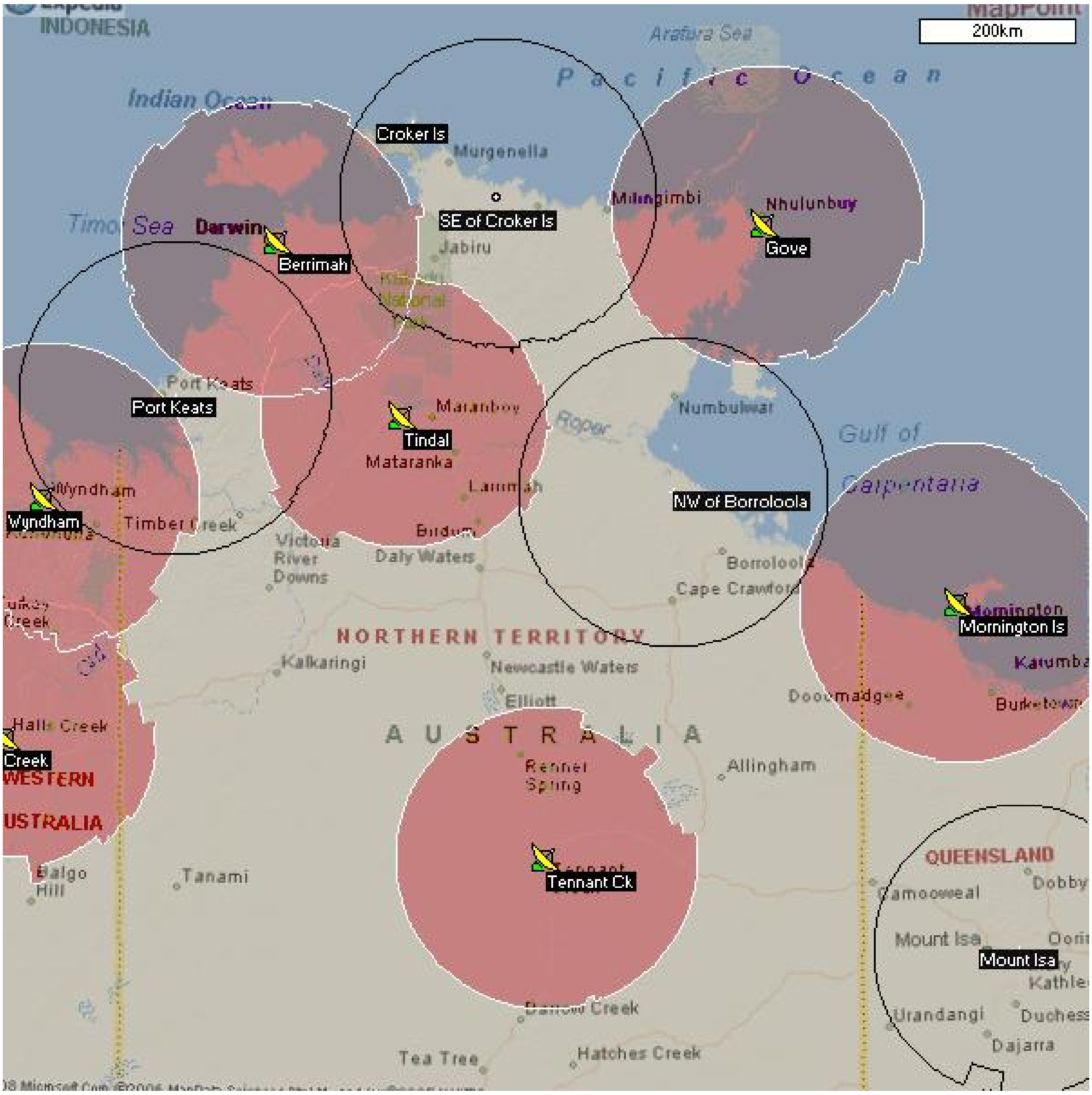
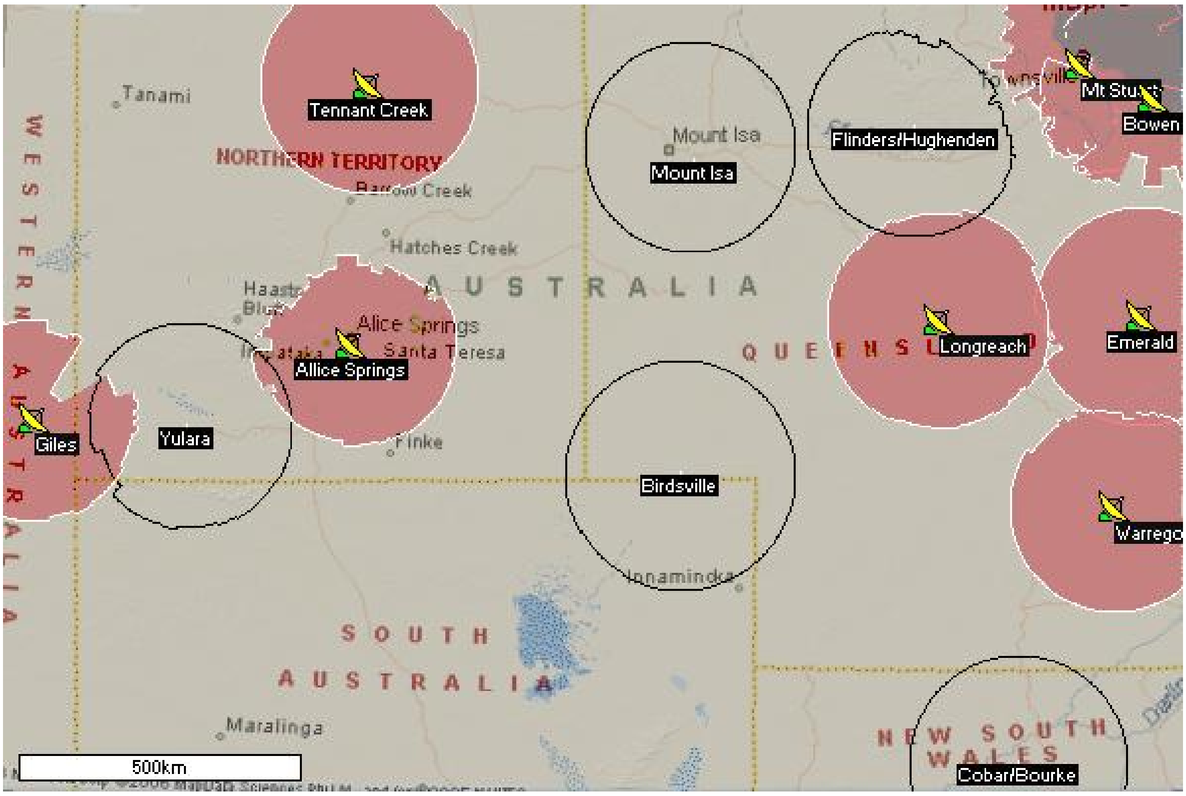


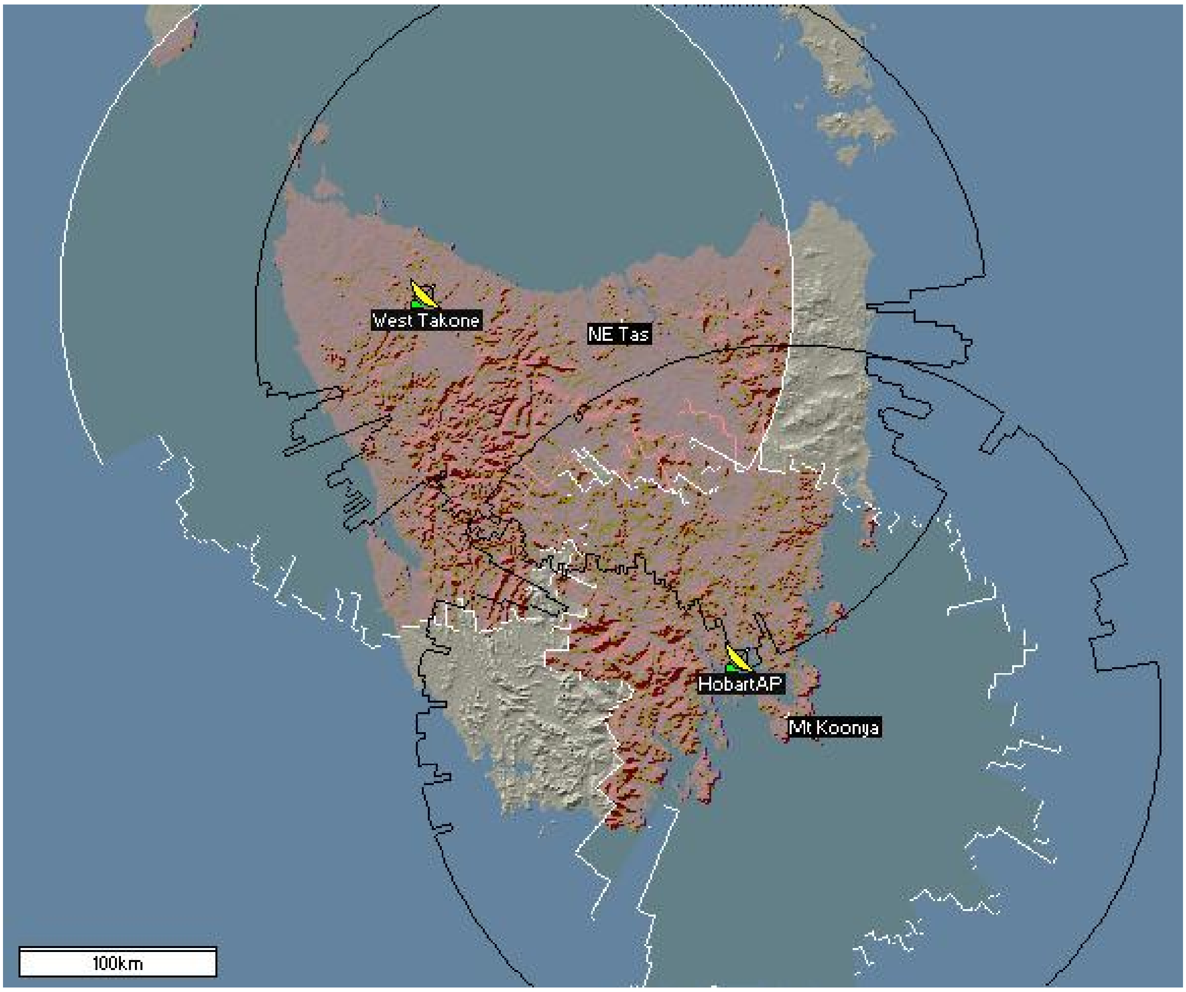
Coverage of existing radars (shaded) and indicate coverage of radars requested by Qld and NSW Regions (black outline).



Coverage of existing radars (shaded) and indicative coverage of radars requested by NT Region (in black outline). Note: Tennant Creek, Gove and Halls Creek radars are dual-role radars.



Coverage of existing radars (shaded) and indicative coverage of radars requested by SA, Qld and NSW Regions (black outline).



Coverage of existing radars (shaded) and indicative coverage of a Hobart radar from a superior site, as well as a NE Tas radar (black outline).