Department of Resources, Energy and Tourism (DRET)

PROPOSED COMMONWEALTH RADIOACTIVE WASTE MANAGEMENT FACILITY, NORTHERN TERRITORY

Synthesis Report

PARSONS BRINCKERHOFF

Proposed Commonwealth Radioactive Waste Management Facility, Northern Territory

SYNTHESIS REPORT

13 March 2009

Department of Resources, Energy and Tourism (DRET)

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1. Introduction

The Commonwealth Department of Education, Science and Training (DEST) commissioned Parsons Brinckerhoff Australia Pty Ltd (PB) to undertake the tasks detailed in its Request for Tender for the Provision of Commonwealth Radioactive Waste Management Facility—Site Characterisation (RFT PRN 7027).

Following the general election in 2007 and reorganisation of Australian Government Departments, responsibility for the contract was transferred to the Department of Resources, Energy and Tourism (DRET).

The work detailed in the RFT, and described in this report, is the first stage of a process to establish a facility for the management of the Commonwealth's radioactive waste inventory and future arisings. The first stage can be described as:

- characterisation of the nominated sites in terms of their inherent ability to isolate radioactive waste from the biosphere, and

- identification and provision of costs for modifying the conceptual design of the facility to accommodate any site-specific issues that have a bearing on the performance of the facility.

Subsequent stages of the process will include:

- nomination (by the Commonwealth) of the preferred site
- detailed investigation of the preferred site
- preparation of an Environmental Impact Statement (EIS)
- preparation and peer-review of a 'safety case' analysis of the performance of the facility
- (should approval be granted through the EIS process) detailed engineering followed by construction, commissioning and operation: all subject to the granting of Licences under the *Australian Radiation Protection and Nuclear Safety Act 1998*.

DEST originally provided PB with three candidate sites for stage one—site characterisation. These sites are all on Commonwealth land managed by Defence. The sites are also all in the Northern Territory. Subsequently, the Traditional Owners of Muckaty Station volunteered land under their guardianship for characterisation. Muckaty Station is also in the Northern Territory.

This report details the work undertaken in accordance with the RFT and is a summary of the technical reports listed in the table of contents. References in this Synthesis Report are listed in individual technical reports, and not repeated here.

2. Background

The Commonwealth has accumulated several types and classes of radioactive waste over a period of approximately fifty years. The waste has largely been generated by the operation of the research reactor 'HIFAR' (High Flux Australian Reactor) at the Lucas Heights facility of ANSTO (Australian Nuclear Science and Technology Organisation), in Sutherland Shire south of Sydney. Some waste has also resulted from research activities by such organisations as the CSIRO (Commonwealth Science and Industry Research Organisation), and other waste has arisen from the activities of Defence. Radioactive wastes that are owned or managed by the States, Territories or private organisations and individuals are not considered in this report.

2.1 Legacy wastes

Accumulated or 'legacy' wastes can be classified into:

- low-level and short-lived intermediate level wastes
- intermediate level, long-lived wastes.

Low-level, short-lived intermediate level waste includes such items as:

- gloves, gowns and laboratory glassware, plastics and paper arising from the preparation of radiopharmaceuticals manufactured at Lucas Heights
- un-wanted, out of date and redundant sources used in research, such as agricultural and soil investigations
- contaminated soils arising from the clean-up and rehabilitation of former research and industrial sites
- redundant instruments used in research and defence applications.

There are currently approximately 2,000 such items in the Commonwealth's legacy inventory. This amounts to approximately 4,000 m^3 of material, with a mass of approximately 4,400 t. Once conditioned for transport and deposition in the waste management facility, the volume will be approximately 4,700 m^3, with a mass of 7,800 t.

2.2 Reprocessed fuel wastes

Australia currently has no intermediate level, long-lived waste arising from fuel reprocessing, although such waste will start arriving in Australia from the year 2011. This waste results from the reprocessing of fuel rods from HIFAR operations. Reprocessing is undertaken either in France, where the waste is encapsulated in a glass matrix by the process of vitrification, or in the United Kingdom, where the waste is encapsulated in a concrete matrix.

2.3 De-commissioning and demolition wastes

ANSTO has recently commissioned Australia's new reactor—OPAL (Open Pool Australian Light water reactor), which has replaced HIFAR. HIFAR has been de-commissioned and will eventually be demolished.

The process of de-commissioning and demolition will generate radioactive wastes suitable for management at the radioactive waste management facility. These wastes include parts of the fabric of the reactor that have become 'activated' by bombardment with neutrons from reactor and beam-line operations.

2.4 Future waste arisings

Australia has no current nuclear power program but will continue to use the research facilities at Lucas Heights for the production of radiopharmaceuticals, research and for non-destructive testing of materials. These activities generate radioactive wastes, the bulk of which will be low-level, short-lived intermediate level wastes in the form of gloves, gowns, laboratory glassware, plastics and paper.

Continued operation of the research reactor will generate spent fuel rods, which will be sent for reprocessing overseas. The Government of the United States has agreed not to return reprocessed spent fuel (of US origin) from the operation of the OPAL reactor until 2016. No waste from that source will be returned to Australia.

The Commonwealth's annual future arisings of radioactive waste amount to:

- 30+ m^3 low level (30 m^3 from ANSTO and up to a few cubic metres per year from the CSIRO, Defence and other sources)
- 3.5 m^3 intermediate level (2.5 m^3 from ANSTO and approximately 1 m^3 from the CSIRO and Defence).

Other future arisings include:

- 53 casks of spent fuel reprocessing waste from the operation of the HIFAR reactor (intermediate level waste)
- 4 casks of spent fuel reprocessing waste from the operation of the OPAL reactor (intermediate level waste)
- decommissioning wastes:
  - approximately 380 m^3 of intermediate level decommissioning wastes from the Moata (a small training reactor at ANSTO), HIFAR and OPAL reactors (the

volume of waste from the HIFAR reactor will depend to some extent on the decommissioning option chosen)

- approximately 300 m^3 of low level decommissioning wastes from the Moata, HIFAR and OPAL reactors.

The timing of waste generation, particularly that from decommissioning and demolition, will depend on schedules that have not been finalised.

2.5 Radioactive waste management

Australia has adopted International radioactive waste management principles and criteria. In essence, these principles and criteria are designed to isolate radioactive wastes from the biosphere for appropriate time periods.

For low level, intermediate short-lived level wastes, isolation is required for a period sufficient for the initial radioactivity of the waste to decay to levels at which it poses a low risk to the biosphere. Isolation of such wastes can be accomplished by shallow burial in a physical setting which is conducive to containment. Conditioning of such wastes prior to burial also provides a barrier to its escape into the biosphere. The design of the burial structure provides a barrier to migration of waste into the biosphere.

This ‘defence in depth’ approach is amenable to risk analysis techniques that both inform the design of the conditioning methods and the design of the repository, and allow mathematical modelling of the risks and consequences of this type of waste containment.

Intermediate, long-lived wastes require a different containment strategy, and they are not amenable to shallow ground burial. Such wastes have to be stored in facilities designed to provide the barrier between the wastes and the biosphere, until such time as the waste can be placed in a geological repository for indefinite periods of time.

Australia does not currently have a geological repository, and its intermediate, long-lived wastes require a purpose-built store.

The Commonwealth has decided to investigate sites at which both types of facility can be accommodated or ‘co-located’.

2.6 Suitability of candidate sites

The suitability of a site for the shallow-ground burial of low-level radioactive waste will depend to some extent on the physical characteristics of the site, i.e. the ‘natural’ ability of the site to limit the movement of the wastes into the biosphere.

A site’s natural ability to limit the spread of wastes into the biosphere is also amenable to engineering solutions that enhance the barriers between the wastes and the biosphere.

A store for intermediate, long-lived wastes is an engineered, above-ground facility (building), and less reliance is placed on the site’s natural ability to limit the spread of wastes into the biosphere, since the conditioning of the waste, and the building itself provide the primary barriers.

In short, most sites are candidates for the establishment of a radioactive waste facility—the difference between sites being the degree to which engineering is necessary to provide the required degree of assurance of the isolation of the wastes for the required period of time.

2.7 Siting guidelines

International bodies have developed guidance materials that outline the desirable features of candidate sites for the establishment of both shallow ground burial sites and above ground stores for radioactive wastes.

This guidance material is generic in nature and is not prescriptive. It includes the recommendation that the suitability of sites can be modified by the addition of engineering enhancements to natural barriers.

Thus there are no specific criteria that make a site unsuitable. From a radiation protection viewpoint, the only hard and fast criterion is the limitation of risk to people (and some non-human species) to acceptable levels, economic and social factors being taken into account.

Nevertheless, the following sections outline the International and Australian siting guidelines.

2.7.1 Code of Practice for the near-surface disposal of radioactive waste in Australia (1992)

The Code of Practice for the near-surface disposal of radioactive waste in Australia was first developed by the National Health and Medical Research Council (NH&MRC). The Code is now administered by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

The siting criteria for low level waste include that the:

- facility site should be located in an area of low rainfall, should be free from flooding and have good surface drainage features, and generally be stable with respect to its geomorphology
- water table in the area should be at a sufficient depth below the planned disposal structures to ensure that groundwater is unlikely to rise to within five metres of the waste, and the hydrogeological setting should be such that large fluctuations in the water table are unlikely
- geological structure and hydrogeological conditions should permit modelling of groundwater gradients and movement, and enable prediction of radionuclide migration times and patterns

- disposal site should be located away from any known or anticipated seismic, tectonic or volcanic activity which could compromise the stability of the disposal structures and the integrity of the waste

- site should be in an area of low population density and in which the projected population growth or the prospects for future development are also very low

- groundwater in the region of the site which may be affected by the presence of a facility should ideally not be suitable for human consumption, pastoral or agricultural use

- site should have suitable geochemical and geotechnical properties to inhibit migration of radionuclides and to facilitate repository operations.

2.7.2 Store criteria

In early 2001, the National Store Advisory Committee developed a set of Site Selection Themes or criteria against which the potential sites for a National Store were to be assessed. These themes were later amended following public comment on the 'Safe storage of radioactive waste' discussion paper.

The themes were designed to identify the potential issues that could be associated with the establishment and operation of a national facility for radioactive waste. It was also important that national and international standards for managing waste could be met through the development of the storage facility and the themes take these standards into account.

The main objective of the site selection themes was to consider the extent to which the location or features of the site will impact on the following factors:

- safety of the radioactive waste in the storage facility
- operational requirements for safe transport, handling, storage and retrieval of waste packages
- the safety of humans and the environment
- security of the facility
- other land uses.

A summary of site selection themes is provided in Table 2.1.

Following a period of public comment on a draft, ARPANSA published the Regulatory Guidance for Radioactive Waste Management Facilities: Near Surface Disposal Facilities; and Storage Facilities (2006).

This guideline includes the Site Evaluation Criteria shown in Table 2.2.

Table 2.1 Exclusion criteria

Theme	Description
Tenure	Those land tenures that were incompatible with a National Store. Examples of land tenures excluded included National Parks and other significant conservation features; aerodromes and airports; railways
Land use	Those land uses that were incompatible with the National Store. Examples of exclusions included: residential areas, conservation areas, commercial and retail areas.
Waterbodies	Significant water bodies, drainage lines, wetlands or areas delineated as perennial streams or rivers that were considered incompatible with the National Store.
Heritage	Areas designated as significant to post-European settlement, or as significant on the National Estate Register or the World Heritage Register
Flood risk	Those areas defined as at risk from flooding. This was identified through land form, flood data or planning schemes
Land form	Those land forms that would be inappropriate with the location of the National Store such as being subject to flooding, coastal and swamp areas or mountainous
Water storage	Significant water storages and areas designated for water production that were considered incompatible with the National Store
Planning	Any planning zones or policy areas that were considered incompatible with the National Store. This included residential and future residential areas; commercial areas, community facilities and historic zones
Transport	A distance threshold of 25 km was applied to major transport routes to exclude areas that were considered to be too far from a significant all weather road
Residential distance	An inner threshold of 1.5 kilometres was applied to all defined residential areas (areas designated as 'built-up' in the TOPO250 dataset)
Residential distance	This criterion measured the normalised distance from built-up areas based on the TOPO250 dataset
Remoteness	This criterion was based on the Access/Remoteness Index for Australia which measures remoteness
Transport distance	Normalised distance from an all-weather road
Ruggedness	Terrain ruggedness was based on the terrain ruggedness index (TRI) developed by Riley, et al. (1999). This index is a measure of 'lumpiness' in the landscape
Wetness	The Wetness Index is a common index used in catchment models. This index is a means of determining relative wetness over the landscape and can identify areas that are likely to become saturated during significant rainfall events (i.e. potential flood areas)
Other criteria	The site should have reasonable access for the transport of materials and equipment during construction and operation and for the transport of waste packages onto the site

Table 2.2 Site evaluation criteria

Criterion	Description
Earthquakes and surface faulting	The seismological and geological conditions in the region and the engineering geological aspects and geotechnical aspects of the proposed site area should be evaluated. Information on prehistorical, historical and instrumentally recorded earthquakes in the region should be collected and documented.
	Hazards due to earthquake induced ground motion should be assessed for the site with account taken of the seismotectonic characteristics of the region and specific site conditions. A thorough uncertainty analysis should be performed as part of the evaluation of seismic hazards.
	The potential for surface faulting (i.e. the fault capability) should be assessed for the site. If reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the store, an alternative site should be considered.
Extreme meteorological events and flooding	The potential for extreme wind events such as tropical cyclones should be evaluated along with extreme levels of temperature and precipitation.
	The likelihood of flooding affecting the store during its design life should be evaluated and should be extremely low.
Geotechnical hazards	The site and its vicinity should be evaluated to determine the potential for slope instability that could affect the safety of the store over a period greater than its designed life.
	Any potential for collapse, subsidence or uplift of the site surface should be evaluated. There should not be any significant potential for such occurrences during the designed life of the store.
	The potential for liquefaction of the subsurface materials of the proposed site should be evaluated by using parameters and values for the site specific ground motion. The geotechnical characteristics of the subsurface materials, including the uncertainties in them, shall be investigated and a soil profile for the site in a form suitable for design purposes shall be determined.
	The stability of the foundation material under static and seismic loading should be assessed. The groundwater regime and the chemical properties of the groundwater shall be studied.
Aircraft crashes	The potential for aircraft crashes on the site should be assessed with account taken, to the extent practicable, of characteristics of future air traffic and aircraft. If the assessment shows that there is a potential for an aircraft crash on the site that could affect the safety of the store, then an assessment of the hazards should be made. The hazards associated with an aircraft crash to be considered should include impact, fire and explosions. Installations that may give rise to missiles of any type that could affect the safety of the store should be evaluated.
Chemical explosions	Activities in the region that involve the handling, processing, transport and storage of chemicals having a potential for explosions or for the production of gas clouds capable of deflagration or detonation should be identified. Hazards associated with chemical explosions should be expressed in terms of overpressure and toxicity (if applicable), with account taken of the effect of distance.

2.7.3 International Atomic Energy Agency (IAEA)

The IAEA has issued a series of related standards and guidelines, but none specifically on site selection criteria for a Low and Intermediate Level Radioactive Waste (LILRW) storage facility, i.e. a co-located repository and store. In the Safety Series 111-F a set of principles was published with which site selection criteria should be compatible. These are summarised below:

- Principle 1: Protection of human health – Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.
- Principle 2: Protection of the environment – Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.
- Principle 3: Protection beyond national borders – Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.
- Principle 4: Protection of future generations – Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.
- Principle 5: Burdens on future generations – Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.
- Principle 6: National legal framework – Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.
- Principle 7: Control of radioactive waste generation – Generation of radioactive waste shall be kept to the minimum practicable.
- Principle 8: Radioactive waste generation and management interdependencies – Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.
- Principle 9: Safety of facilities – The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

In Safety Series 111-G-3.1iii, a set of site selection criteria for near surface Low Level Radioactive Waste (LLRW) disposal facilities (i.e. a repository) was published. While the requirements of disposal are significantly more demanding than storage, these criteria provide useful guidance. The criteria are shown in Table 2.3.

Note that the site selection criteria are not numerically precise statements, but rather general statements of what is not allowed, and what is preferred – exclusionary and preference criteria. As such, these are statements of general objectives rather than criteria.

Table 2.3 LLRW site selection criteria (IAEA)

Criterion	Description
Geology	The geological setting at the site should contribute to the isolation of waste and the limitation of releases of radionuclides to the biosphere. It should also contribute to the stability of the disposal system and provide sufficient volume and engineering properties favourable for implementing disposal.
	Preference should be given to sites with a uniform and predictable geology which can be readily characterized through geological investigative techniques.
Hydrogeology	The hydrogeological setting of the site should include low groundwater flow and long flow paths in order to restrict the transport of radionuclides. Expected changes in important hydrogeological conditions (e.g. gradient) due to natural events and the disposal should be evaluated.
	Preference should be given to sites with a simple geological setting that could make characterizing or modelling of the hydrogeological system easy. The dispersion characteristics of the hydrogeological system may also be important and should be evaluated.
Geochemistry	The geochemistry of groundwater and the geological media should contribute to limiting the release of radionuclides from the disposal facility and should not significantly reduce the longevity of engineered barriers. Preference should be given to sites where geochemical conditions promote sorption and precipitation/co-precipitation of radionuclides potentially released from the disposal system and inhibit the formation of easily transportable chemical compounds of radionuclides.
Tectonics and Seismicity	The site should be located in an area of low tectonic and seismic activity such that the isolation capability of the disposal system will not be endangered. Areas of low tectonic and seismic activity should be selected in the regional analysis. Preference should be given to areas or sites where potential for adverse tectonic, volcanic or seismic events is sufficiently low that it would not affect the ability of the disposal system to meet safety requirements.
Surface Processes	Surface processes such as flooding of the disposal site, landsliding or erosion should not occur with such frequency or intensity that they could affect the ability of the disposal system to meet safety requirements. The disposal site should be generally well drained and free of areas of flooding or frequent ponding. Accumulation of water in upstream drainage areas due to precipitation, snowmelt, failure of water control structures, channel obstruction or landsliding should be evaluated and minimized so as to decrease the amount of runoff which could erode or inundate the facility. Preference should be given to areas or sites with topographical and hydrological features which preclude the potential for flooding.
Meteorology	The site area meteorology should be characterized such that the effect of unexpected extreme meteorological conditions can be adequately considered in the design and licensing of the disposal facility. The potential for extreme meteorological events should be evaluated. Potential sites may be screened on the basis of the severity of the effects of such events.

	Description
Man-Induced Events	The site shall be located such that activities by present or future generations at or near the site will not be likely to affect the isolation capability of the disposal system. Areas in the immediate vicinity of major hazardous facilities, airports or transport routes carrying significant quantities of hazardous materials, should be evaluated. In addition, areas or sites should be evaluated where valuable geological resources or potential future resources, including groundwater suitable for irrigation or drinking, are likely to give rise to interference activities resulting in the release of radionuclides in quantities beyond the acceptable limits. A site should be considered less suitable where previous or future activities could create significant release pathways between the projected facility and the biosphere.
	Screening of potential sites should include consideration of the distance from such facilities and the associated impact.
Transportation of Waste	The site shall be located such that the access routes will allow transportation of waste with a minimal risk to the public. Parameters including cost, radiation exposure and accident potential associated with the transportation of waste to the disposal site should be taken into account.
Land Use	Land use and ownership of land should be considered in connection with foreseeable development and regional planning in the area of interest. Future uses of the land in the vicinity of the proposed site should be evaluated for potential impact on the operation and performance of the disposal facility, and vice versa. Jurisdiction over the land, or ownership, may in some countries be a significant factor with respect to economics and public acceptance. Early control or ownership of the site by the operator or government would simplify the site planning and evaluation efforts, shorten the time required for activation of the facility and reduce the problems associated with the withdrawal of land from other uses.
Population Distribution	The site should be located such that the potential hazard of the disposal system on the current population and projected future population is acceptable. Consideration should be given to avoiding areas of high population density. The selection of candidate sites should be performed on the basis of appropriate suitability factors, taking into account the likelihood of future disturbances and radiation protection aspects of the population potentially affected by the releases of radionuclides from the disposal facility.

2.8 Practical application of criteria

Australia is not alone in addressing the disposal and/or storage of radioactive wastes. Jurisdictions in which nuclear materials are generated and used developed guidance materials and site selection criteria. This section contains examples of such material, together with a brief outline of the practical application of Guidelines used in Australia for the National Radioactive Waste Repository project and the Radioactive Store Site Selection project.

The reason for including this material is to provide insight into how International criteria have been adopted into statutory instruments elsewhere. The intention is not to suggest that criteria that have been adopted elsewhere are necessarily appropriate to Australian conditions, but that there are precedents which offer additional insight into practical application of generic International guidance material. No such material has been developed in Australia to date.

2.8.1 United States Federal guidance

United States' Substitute Senate Bill 19 says that:

> *The disposal site shall comply with all criteria established in 10 C.F.R. Part 61.*

The criteria in C.F.R are intended to ensure that the facility will meet the following performance objectives:

1) protect the general population from releases of radioactive material
2) protect individuals during operations
3) ensure stability of the disposal site after it is closed, and
4) protect individuals who inadvertently intrude.

The federal criteria are listed in fact sheet RER-64, 'Selecting a Low-Level Radioactive Waste Disposal Site'. Some of those criteria are briefly summarised below:

- The disposal site shall be capable of being characterized, modelled, analysed, and monitored.
- The disposal site should be selected so that projected population growth will not affect the disposal facility's ability to meet the performance objectives.
- Areas having known natural resources should be avoided.
- The disposal site must be well drained.
- Areas having earthquakes or volcanic activity that might affect the performance of the disposal facility must be avoided.
- The disposal site must provide sufficient depth to the water table.
- The disposal site must not be located where nearby facilities or activities could adversely impact the site's ability to meet the performance objectives or the ability to be monitored.

2.8.2 National Radioactive Waste Repository

In 1992 the National Health and Medical Research Council (NH&MRC) released the *Code of practice for the near-surface disposal of radioactive waste in Australia* (1992) (NH&MRC 1992 Code). The code includes 13 criteria designed to ensure that the selected site has characteristics that will facilitate appropriate isolation of waste and the long-term stability of the site. The criteria take into account a broad range of social, technical and environmental criteria, including:

- rainfall, potential for flooding and site drainage
- depth to the watertable, and fluctuations in the height of the watertable; suitability of groundwater for other purposes
- geology, geochemical and geotechnical factors
- seismic and volcanic activity
- population density and projected population growth
- potential of the land for other uses, or significant natural resources
- access for transport
- ecological, cultural or historical significance
- land tenure.

In 1997 the Commonwealth Bureau of Resource Sciences (BRS) published a discussion paper entitled ‘A Radioactive Waste Repository for Australia—Site Selection Study - Phase 3, Regional Assessment’ (BRS 1997). This public discussion paper describes the process by which suitable regional areas were identified as potential hosts for a National Radioactive Waste Repository. The paper describes the process of selecting a suitable site using the criteria listed above. In short, a spatial information system analysis was used to narrow the search down to candidate regions by applying constraints based on the selection criteria. Once regional-level information was identified, a further selection process was applied that identified preferred target sites. Several sites were investigated, resulting in the selection of three alternative sites deemed worthy of detailed investigations.

Detailed investigation of the sites resulted in the selection of one site which was then subject to an Environmental Impact Statement process.

In May 2002 a Draft EIS was published for the ‘National Radioactive Waste Repository’ project (NRWR).

2.8.3 National Radioactive Waste Store Site Selection project

In August 2001, the Department of Industry, Science and Resources (DISR) published ‘Safe Storage of Radioactive Waste—The National Store Project, methods for choosing the right site’ (DISR 2001).

The public discussion paper lists the issues taken into consideration when siting a store as:

- geological hazards, such as earthquakes, volcanic activity and landslides
- local environmental hazards, such as flooding and fires
- natural environmental features, such as surface drainage
- access to transport, support facilities and infrastructure
- social impacts
- sites or areas of special environmental, cultural or historical significance
- security
- security of land tenure by the Commonwealth and compatibility with adjacent land use.

The site selection considerations also included:

- safety of the radioactive waste in the storage facility
- operational requirements for safe transport, handling, storage and retrieval of waste packages
- safety of humans and the environment
- security of the facility
- other land uses.

While preliminary investigations have been undertaken, the National Radioactive Store project did not proceed to a detailed investigation phase. The Store has subsequently been incorporated into the current proposal to establish a facility for the management of both low and intermediate level wastes by co-located facilities.

2.9 Use of guidance material and criteria in this study

The principles contained in National and International guideline materials have been used in the current site characterisation study. The synthesis of these materials is discussed in Section 10.

In general, the siting guidelines and criteria have been used to select those natural and engineering barriers between radioactive wastes and the biosphere that are amenable to characterisation in a Stage One study. A safety case has not been developed for any site, neither has any one of the four nominated sites been 'selected' as the most suitable.

The report presents the strengths and weaknesses of the four sites (as judged against the information presented in this section), and discusses the engineering (and cost) implications of modifying the conceptual waste management facility design to overcome inherent site limitations.

In summary, the themes selected for characterisation in this study are:

- meteorology
- flora, fauna and habitat (presence and significance of listed species)
- geology
- geotechnical properties
- seismicity, liquefaction and volcanic risks
- geochemical properties
- surface water drainage
- hydrogeological conditions
- existing land use
- Aboriginal and European heritage
- existing transport networks
- proximity to inhabited places (and potential future population growth).

2.10 Multi-barrier approach

In addition to the inherent site characteristics that prevent or restrict escape of radioactive materials into the biosphere, man-made barriers in the form of design features can further limit the potential for escape of radioactive materials.

The approach taken in this Stage One study was to document the inherent (natural) characteristics of each candidate site (listed in 2.9 above), then to consider the performance of a concept, or base-case engineered facility in light of each site's natural characteristics. Where it was considered necessary, modifications to the base-case facility were considered, together with the potential cost of their implementation.

Figure 2.1 illustrates the approach for a potential near-surface facility for low-level waste.

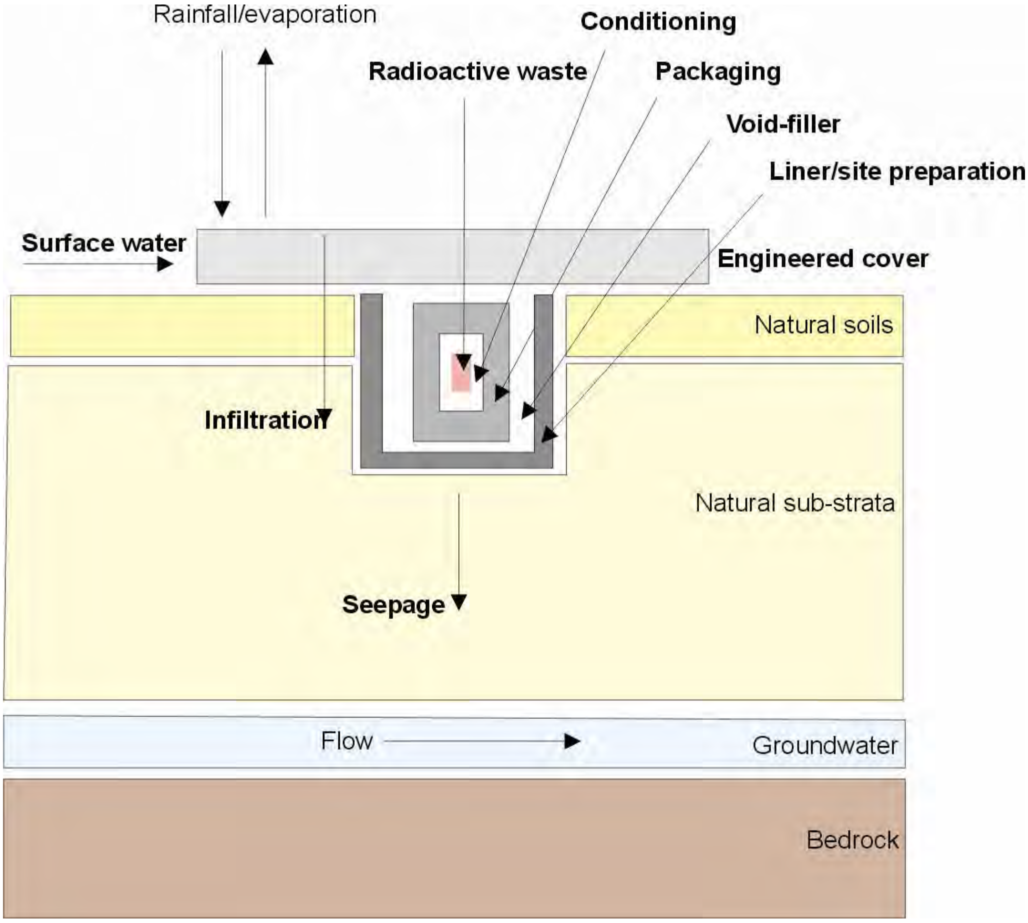


FIGURE 2.1
Multi-barriers for a near-surface facility

The labels in **bold type** indicate that the element is amenable to engineering modification to enhance the containment of radioactive materials. Thus:

- **radioactive waste** can be selected for its suitability for near-surface burial
- waste can be **conditioned** to limit its ability to migrate away from its burial position
- **packaging** can be selected to form an additional barrier to migration
- **voids** can be filled with material that has properties that reduce migration
- a **liner** (such as concrete or HDPE) can be employed as a barrier, and the site can be **prepared** (e.g. grouting of rock to reduce seepage pathways)
- the **engineered cover** can be designed to reduce infiltration of rainwater, plant roots and burrowing animals
- **surface water** can be diverted away from the repository to reduce erosion of the cover and subsequent infiltration of water
- **infiltration** and **seepage** are the principal pathways whereby radioactive materials can be transported to sub-strata and thence to groundwater. Both can be reduced by the measures listed above.

A similar multi-barrier approach has been considered in regard to the proposed radioactive store for intermediate level wastes.

Figure 2.2 shows a sketch of the approach.

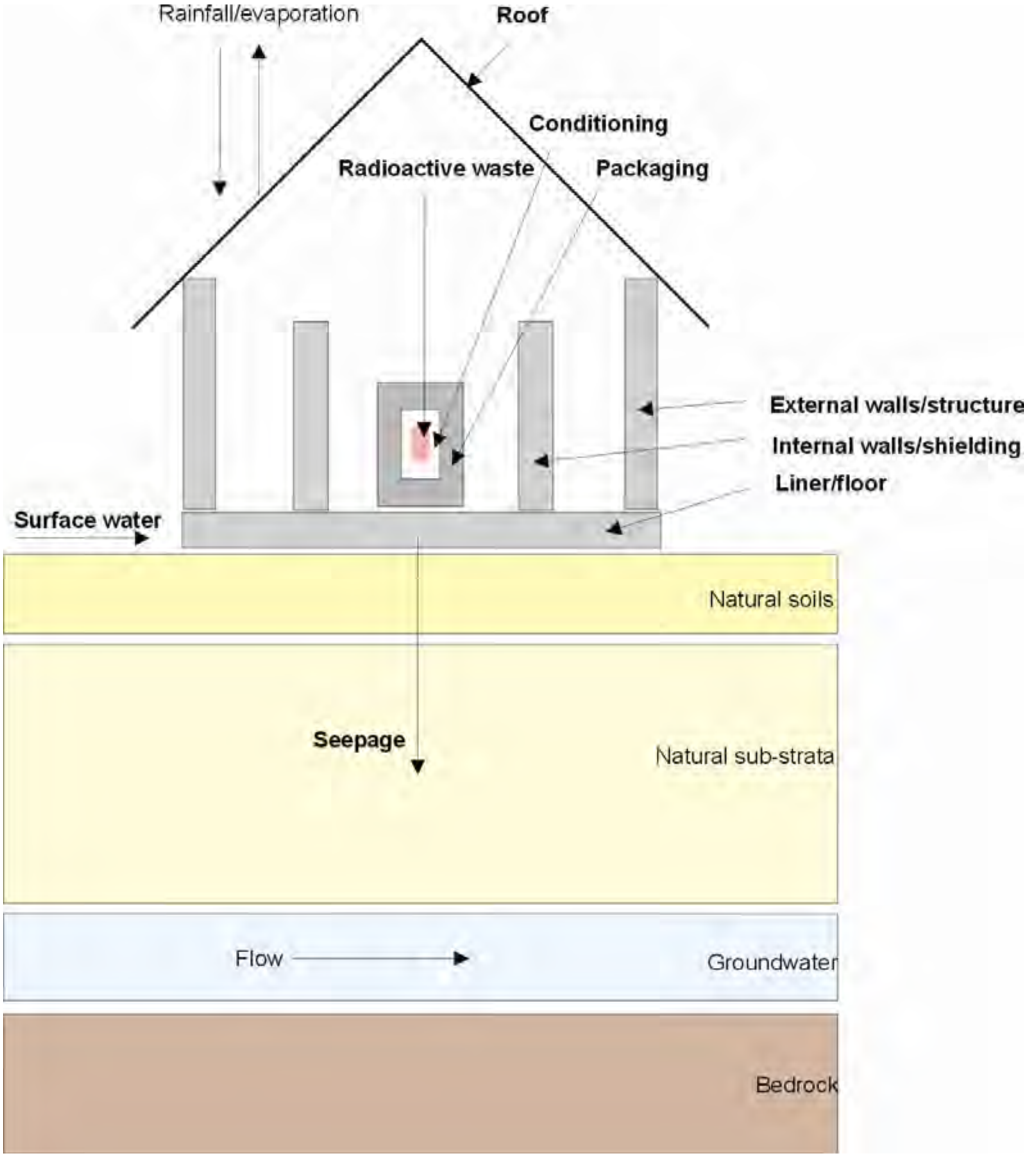


FIGURE 2.2
Multi-barriers for a radioactive store

The labels in **bold type** indicate that the element is amenable to engineering modification to enhance the restriction of radioactive materials. Thus:

- **radioactive waste** can be selected for its suitability for interim storage
- waste can be **conditioned** to limit its ability to migrate away from its storage position (e.g. vitrification or encapsulation in concrete)
- **packaging** can be selected to form an additional barrier to migration (e.g. steel canister)
- **external walls** and indeed, the **structure** of the building can be designed to withstand natural or man-made events (e.g. deliberate intrusion, earthquake, cyclone etc.)
- **internal walls** can be modified to enhance **shielding** and reduce operator exposures
- the **floor** can be modified and/or **lined** to enhance containment

- **seepage** is unlikely in a purpose-built above ground facility, but the probability of it can be modified by a combination of structural and foundation design choices
- the **roof** can be modified (e.g. pitch) to withstand extreme weather events (such as storms, lightning, cyclones etc.)
- **surface water** can be diverted away from the building to reduce intrusion and flooding.

Other facilities design concepts include:

- an above ground warehouse for low level wastes (as opposed to trench disposal)
- a below ground structure to contain intermediate level wastes within a building.

These alternatives include a combination of the design features shown in Figures 2.1 and 2.2.

2.11 Concept designs for this study

ANSTO was commissioned to provide concept designs for the CRWMF (for a repository, a warehouse and a store). ANSTO also provided a modified design concept for a repository, should it be located in an area of higher rainfall.

The concept designs are shown in Figures 2.3 to 2.9.

2.12 Exclusion from consideration in this study

While the waste form, conditioning and packaging can have considerable influence on potential for migration of radionuclides into the biosphere, and will be considered in detail in the next stage of the CRWMF project, they have not been analysed in this Stage One report.

It has been assumed that wastes will meet Acceptance Criteria for either burial or storage. The one concession that has been considered is that the CRWMF will incorporate facilities for checking the integrity of packages of waste on arrival. The conceptual design includes a health physics area, and an area in which any damaged packages can be rendered acceptable for disposal or burial by (for example) overpackaging.

Also excluded from consideration in this report are:

- waste inventory management (i.e. tracking of waste from origin the burial or storage)
- operating procedures and protocols for the CRWMF
- security arrangements for wastes in transit and at the CRWMF
- a ‘safety case’, which forms part of the formal approval and licensing processes
- radiation safety considerations for waste in transit or at the CRWMF
- the use of the CRWMF for any waste other than that managed by the Commonwealth
- community and stakeholder consultation, beyond discussions with Defence, the Northern Land Council and the Traditional Owners of Muckaty Station.

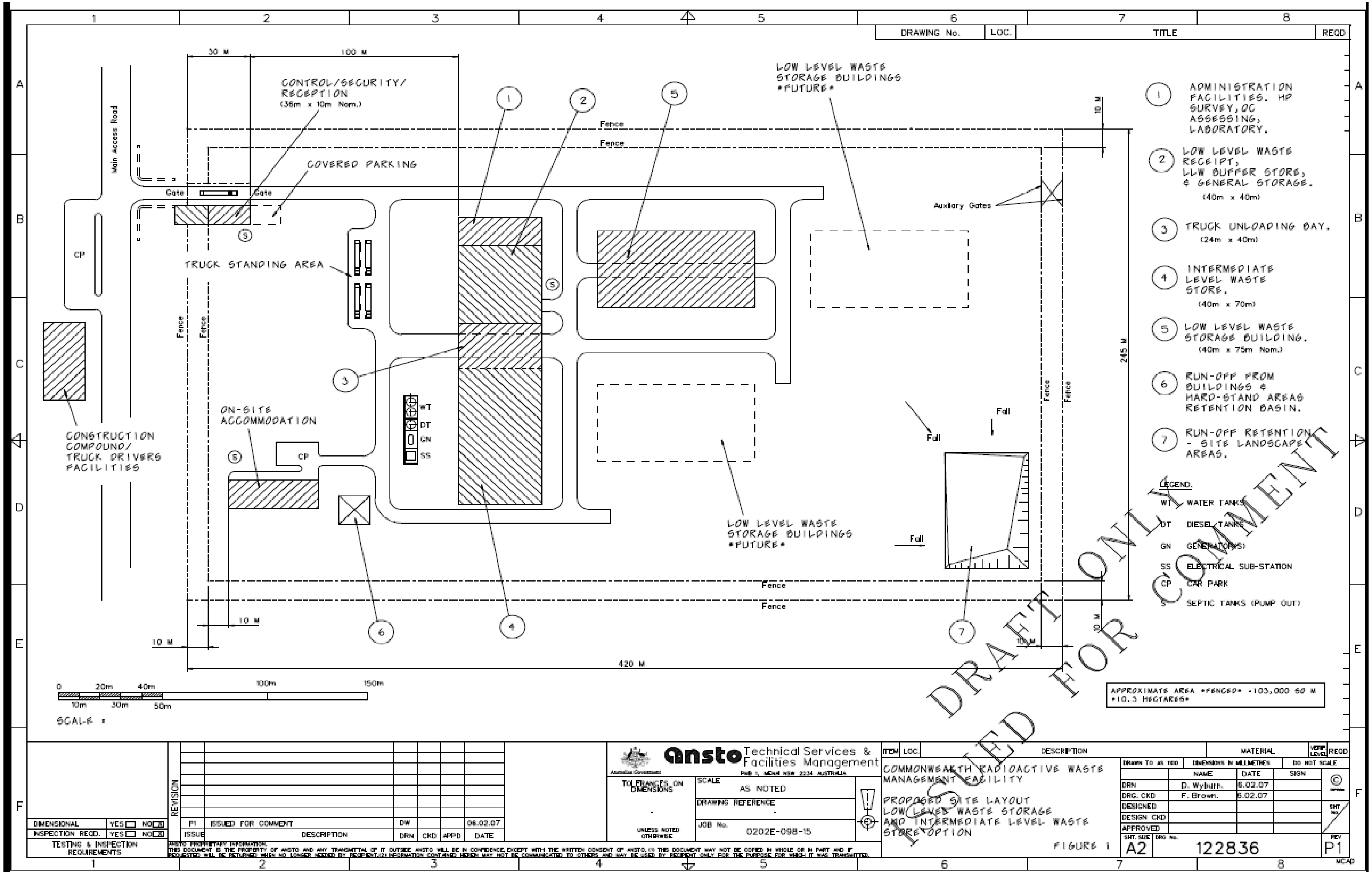


FIGURE 2.3
Proposed site layout for the LLW and ILW storage option

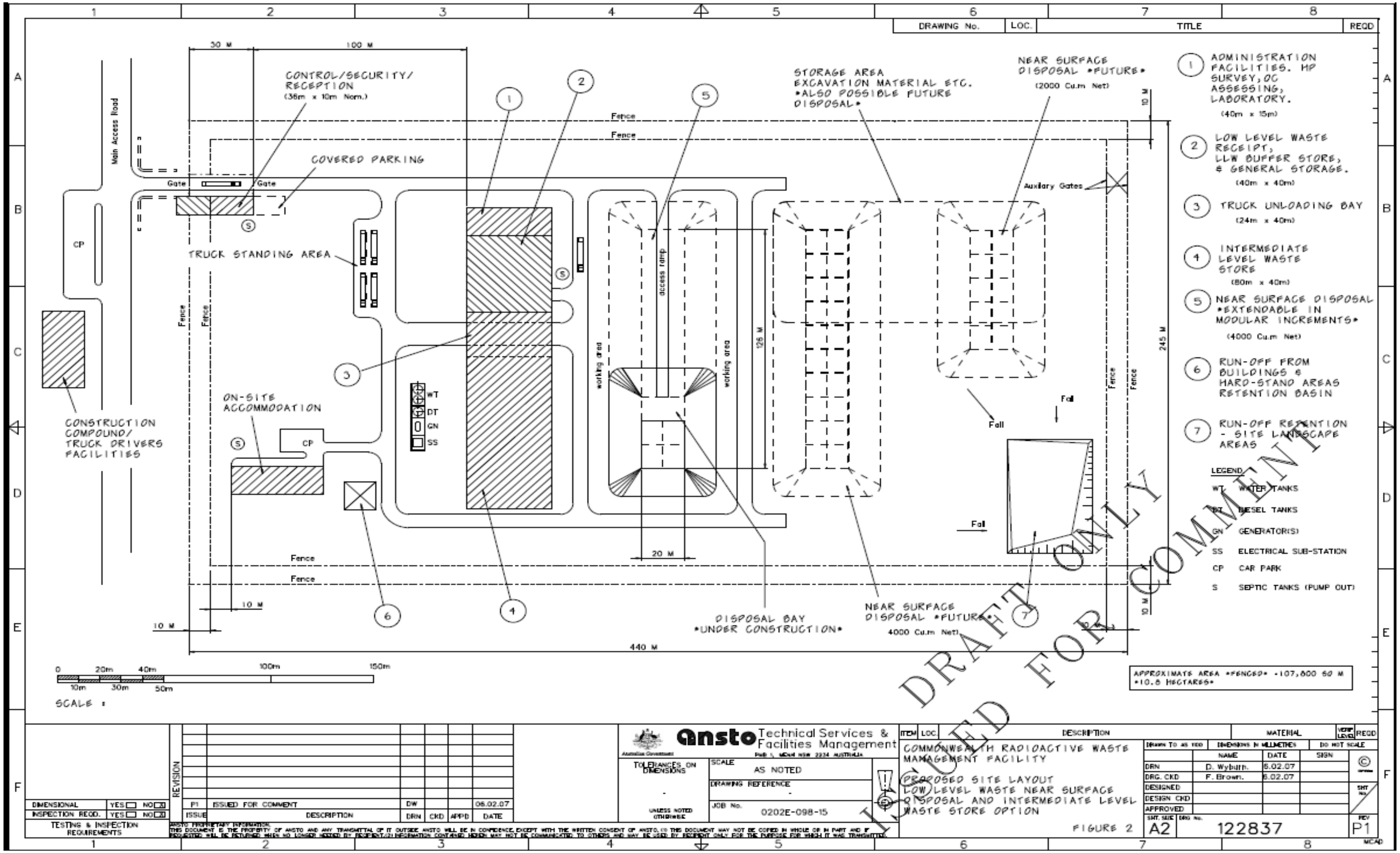


FIGURE 2.4
Design concept for a LLW near-surface disposal facility co-located with an ILW store

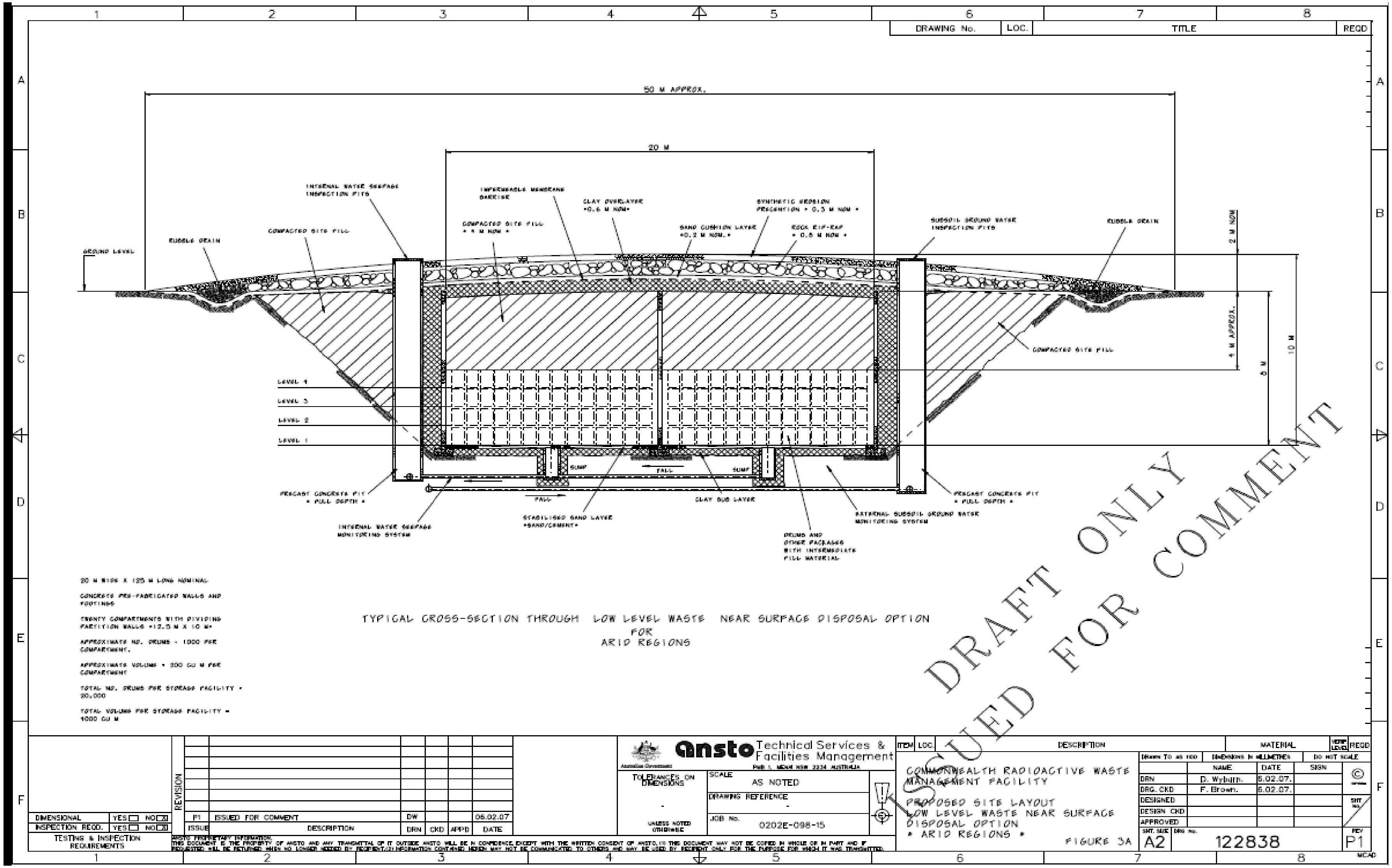


FIGURE 2.5
Conceptual design for LLW near surface disposal in an arid region

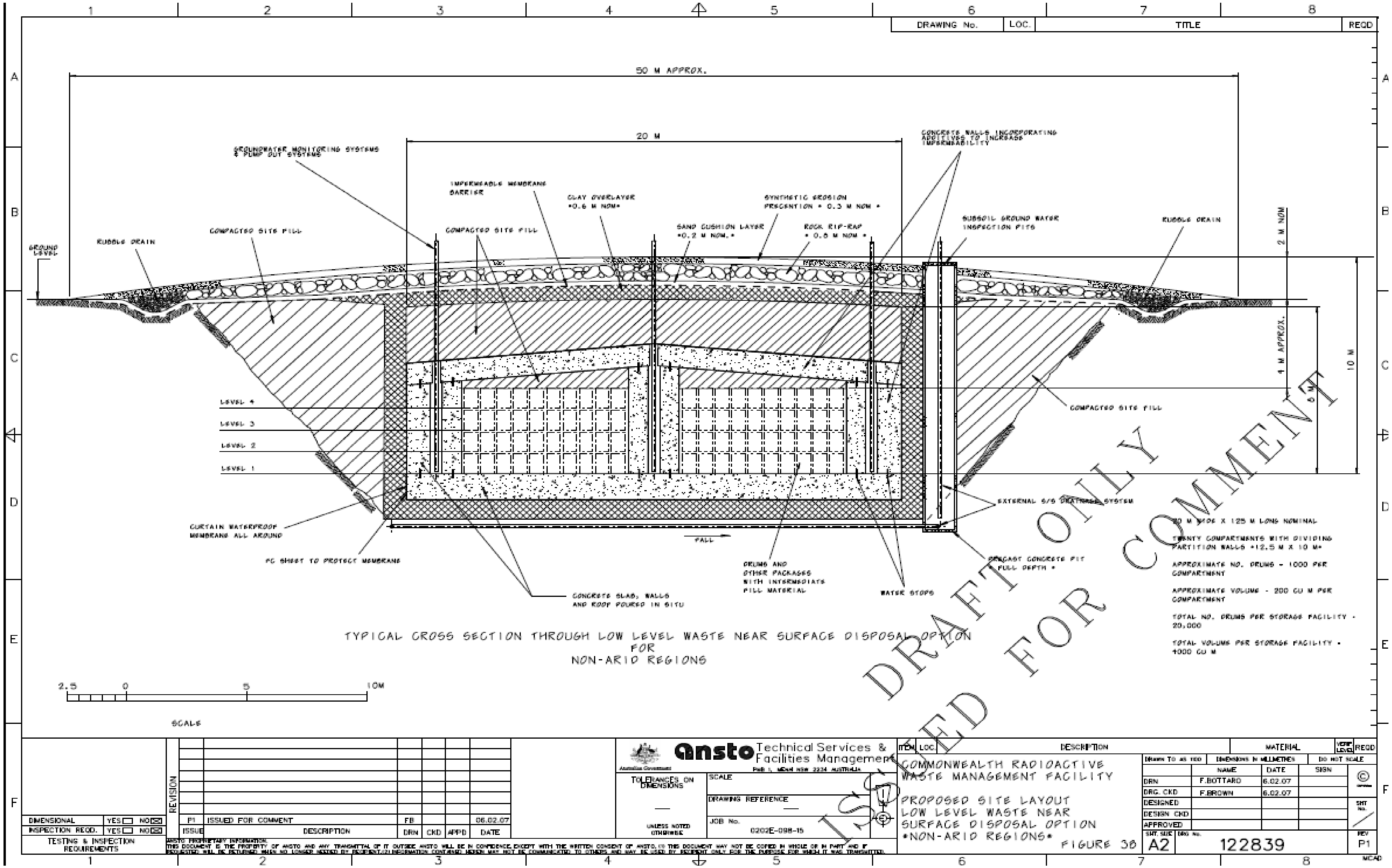


FIGURE 2.6
Design concept for LLW near surface disposal in a non-arid region

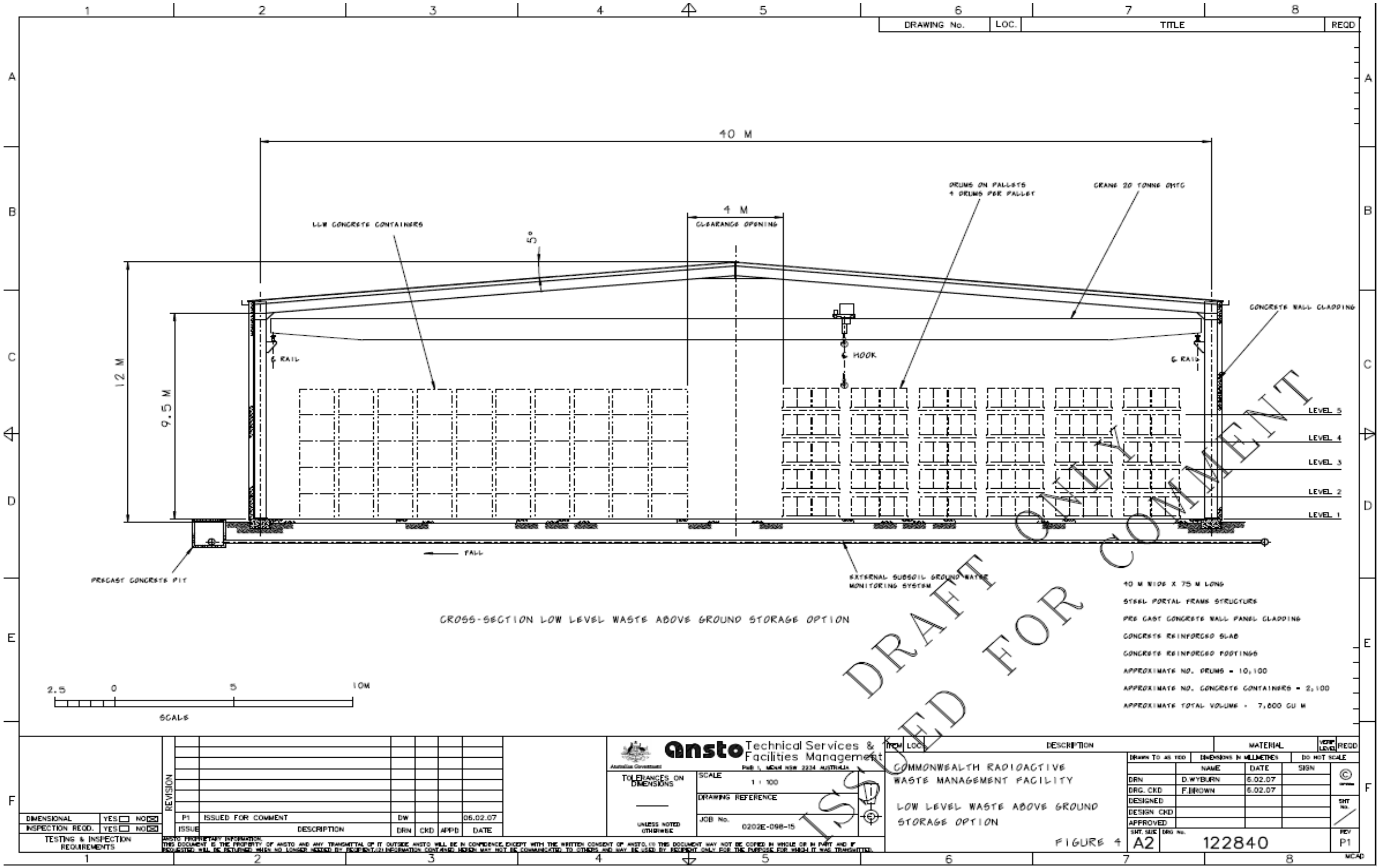


FIGURE 2.7
Design concept for the LLW above ground storage option

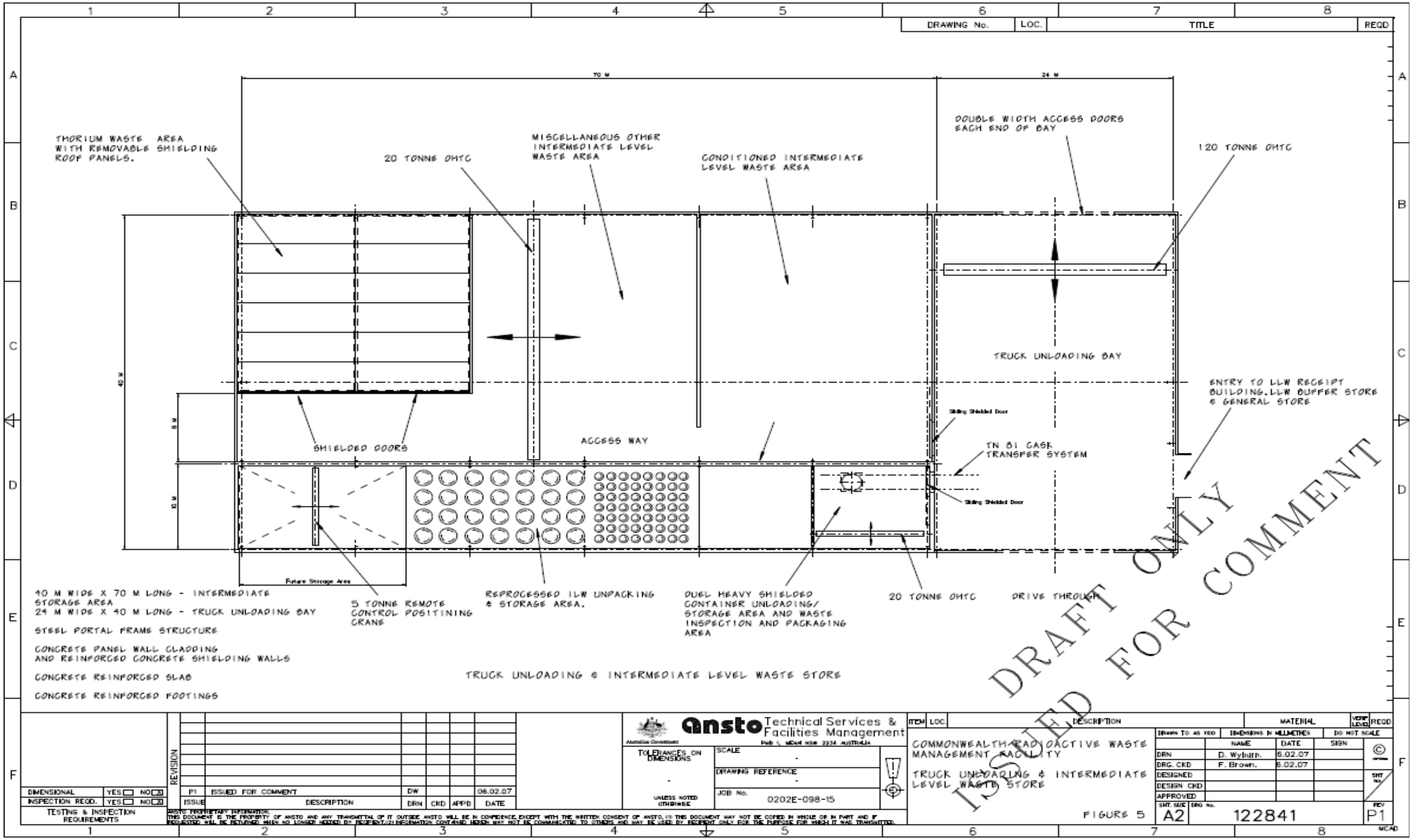


FIGURE 2.8
Conceptual design for truck unloading bay and the ILW store (plan)

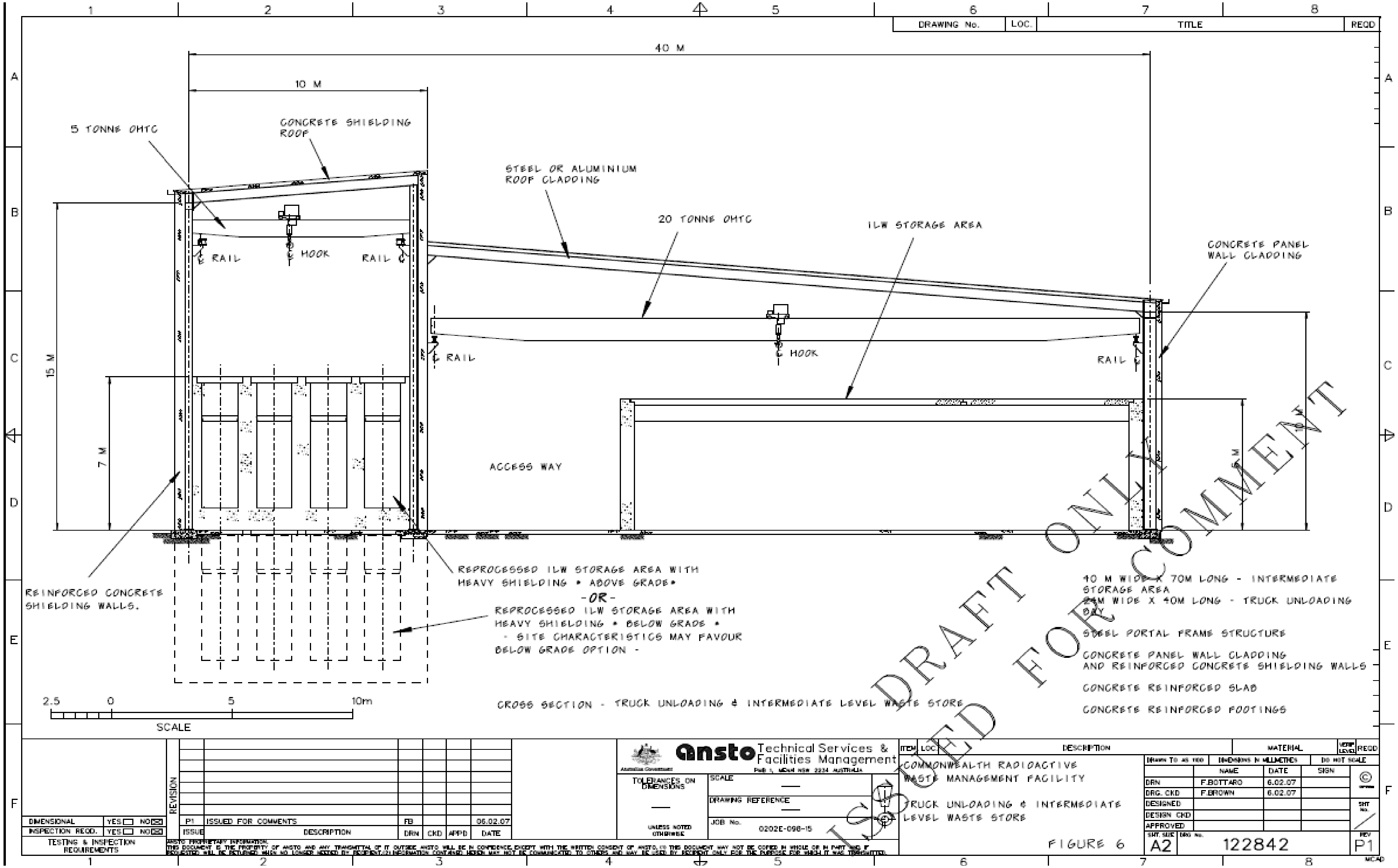


FIGURE 2.9
Conceptual design for truck unloading bay and the ILW store (elevation)

3. General description of nominated sites

DEST provided PB with four sites for characterisation. Three sites had been nominated by Defence following a request by DEST to Defence to provide it with candidate sites for a radioactive waste management facility. The fourth site was volunteered by the Traditional Owners of Muckaty Station.

Figure 3.1 shows the location of the four sites.

3.1 Mount Everard

The Mount Everard site is a receiver station for an over-the-horizon high frequency radar, and is located approximately 25 km north-west of Alice Springs (Figure 3.1). The existing facility occupies an area of approximately 12 km^2.

The area of interest (the site) for the field investigations is located immediately to the south east of the existing radar facility and associated buildings, in an area covering approximately 1.5 km^2.

The site is currently owned by the Department of Defence (DoD) and is under the management of the No.1 Radar Surveillance Unit of the Royal Australian Air Force. The site is understood to be operated by British Aerospace.

Access to the radar facility is via the Tanami Road, a sealed road. However, access to the test locations and the site is along existing dirt tracks and firebreaks.

The site is generally flat with elevations within the site's boundaries from 726 m AHD to 732 m AHD. No major water courses or major overland flow paths were noted within the site.

Vegetation within the site includes native grasses and shrubs as well as weeds with some areas being cleared of all vegetation to accommodate some of the facility's infrastructure (Figure 3.2).

3.1.1 Operational and siting constraints

Defence has indicated that operation of the radar receiving station requires a quiet radio-frequency environment, to avoid interference. It is noted that the facilities associated with the radar receiver are equipped with Faraday devices to reduce radio-frequency noise.

Defence suggested that any construction activity associated with the establishment of a CRWMF may need to be conducted in non-operational windows in the radar facility's schedule. It is possible that this condition may apply to the timing of waste movements into the CRWMF, although operation of the facility between campaigns is unlikely to be subject to these constraints.

Defence also required that any sites for a potential CRWMF be located behind the operational radar array, thus reducing considerably the area in which field investigations took place.

There is a small research radar array located near the south eastern corner of the property. It has not been possible to get definitive advice as to whether or not this facility is required. The array has not been used for up to eleven years (Defence pers. com. 2006). If the area currently occupied by the research array were to become available, options for siting the CRWMF would be broader than they currently are.

More recently, Defence stated that it wished to install additional antennae in the general vicinity of the site chosen for this study. The exact location and number of additional infrastructure elements are not known.

The Mount Everard site is the closest to public roads of the four sites investigated. Without screening, the facility would be clearly visible from the Tanami Road.

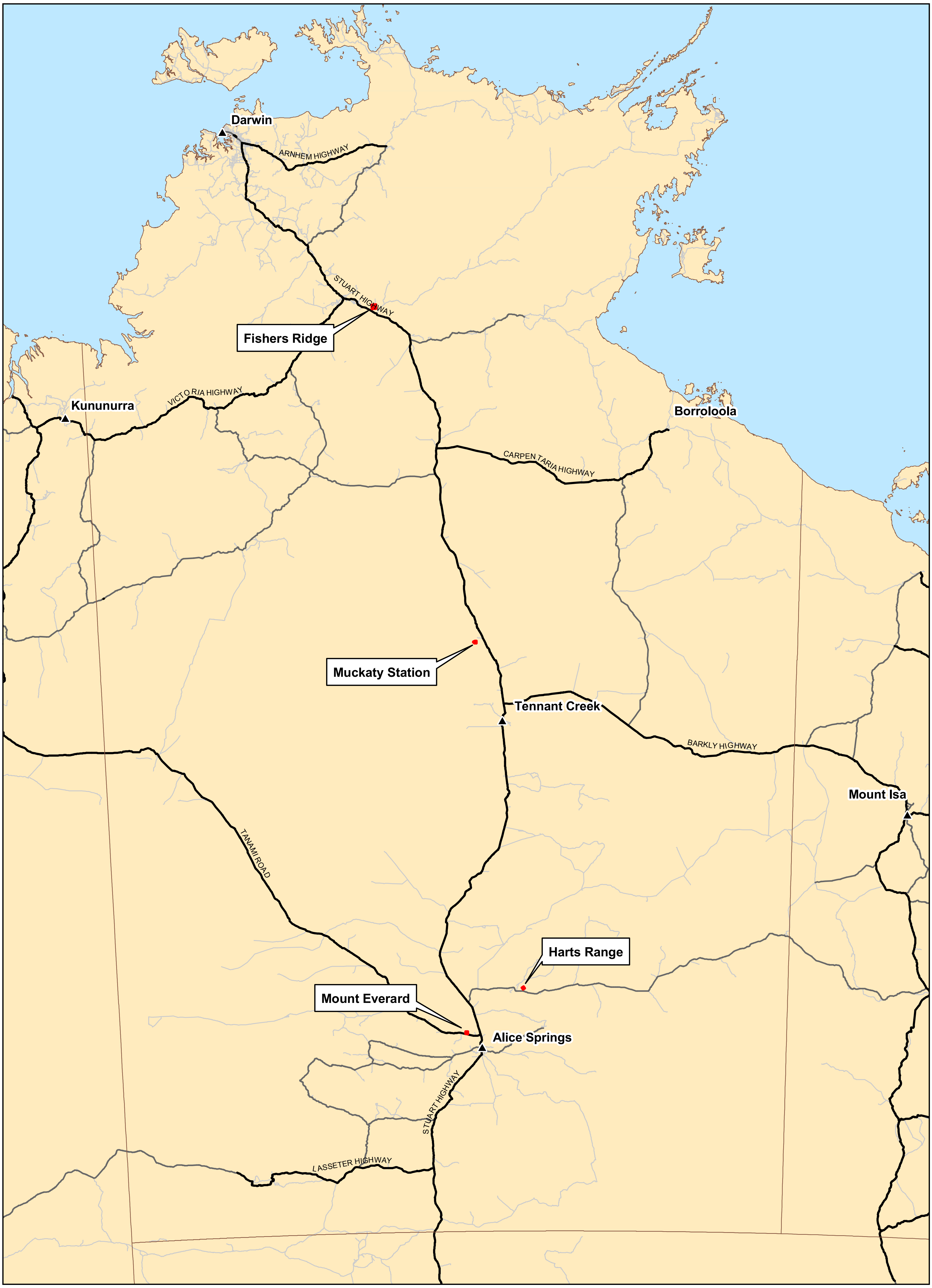
3.2 Harts Range

The Harts Range site is a transmitter station for an over-the-horizon high frequency radar, and is located approximately 100 km north-east of Alice Springs (Figure 3.1). The existing facility occupies an area of approximately 12 km^2.

The area of interest (the site) for the field investigations is located immediately to the east and southeast of the existing facility and associated buildings and covers an area of approximately 1.5 km^2. The site is owned by DoD and the management and operation arrangements are similar to that of the Mount Everard facility.

Access to the radar facility is via the Plenty Highway, a sealed road. However, access to the test locations and the site is along existing dirt tracks and firebreaks.

The site is generally flat with elevations within the site's boundaries ranging from 652 m AHD to 660 m AHD. Surface drainage tends towards Annamurra Creek to the west and Ongeva Creek to the east. A minor drainage channel was noted trending approximately north-south in the central northern part of the investigated site. The channel was dry at the time of the investigations. Vegetation within the site includes native grasses and shrubs as well as weeds with some areas being cleared of all vegetation to accommodate some of the facility's infrastructure (Figure 3.3).



Department of Resources, Energy and Tourism	1:5,000,000 at A3 0 100 200 kilometres	Drawing No.: 2102701A_GIS_F099	**Commonwealth Radioactive Waste Management Facility Site Characterisation** Proposed repository sites **Figure 3.1**
PB 100 YEARS	Source: Geoscience Australia	Revision: A / Date: 22/07/2008	
	Coord.: GDA94 MGA53	Drawn By: BHB / Checked by: JAG	
		Client Ref: RADWASTE	

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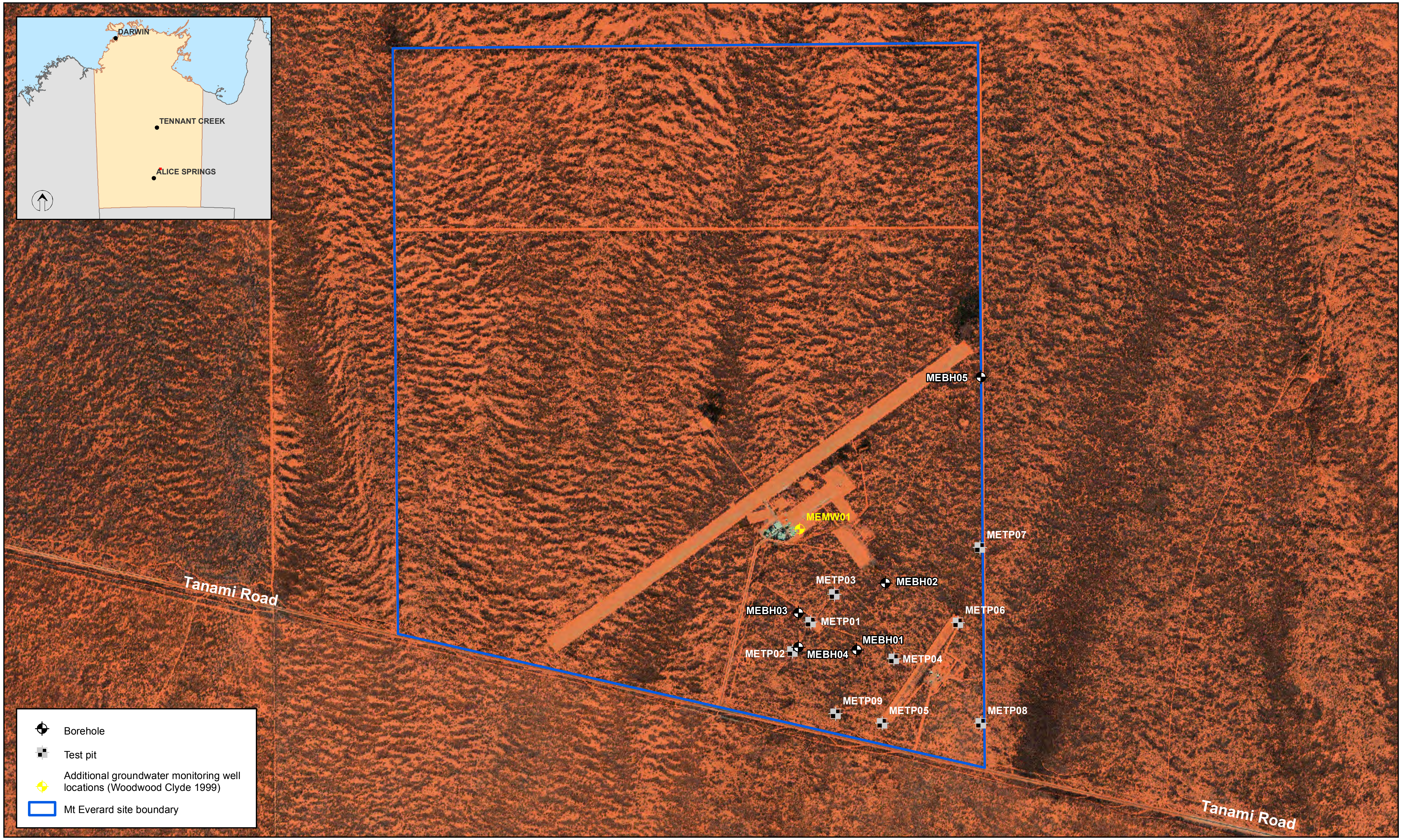

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Commonwealth Radioactive Waste Management Facility
Site Characterisation
Mt Everard field investigations
Figure 3.2

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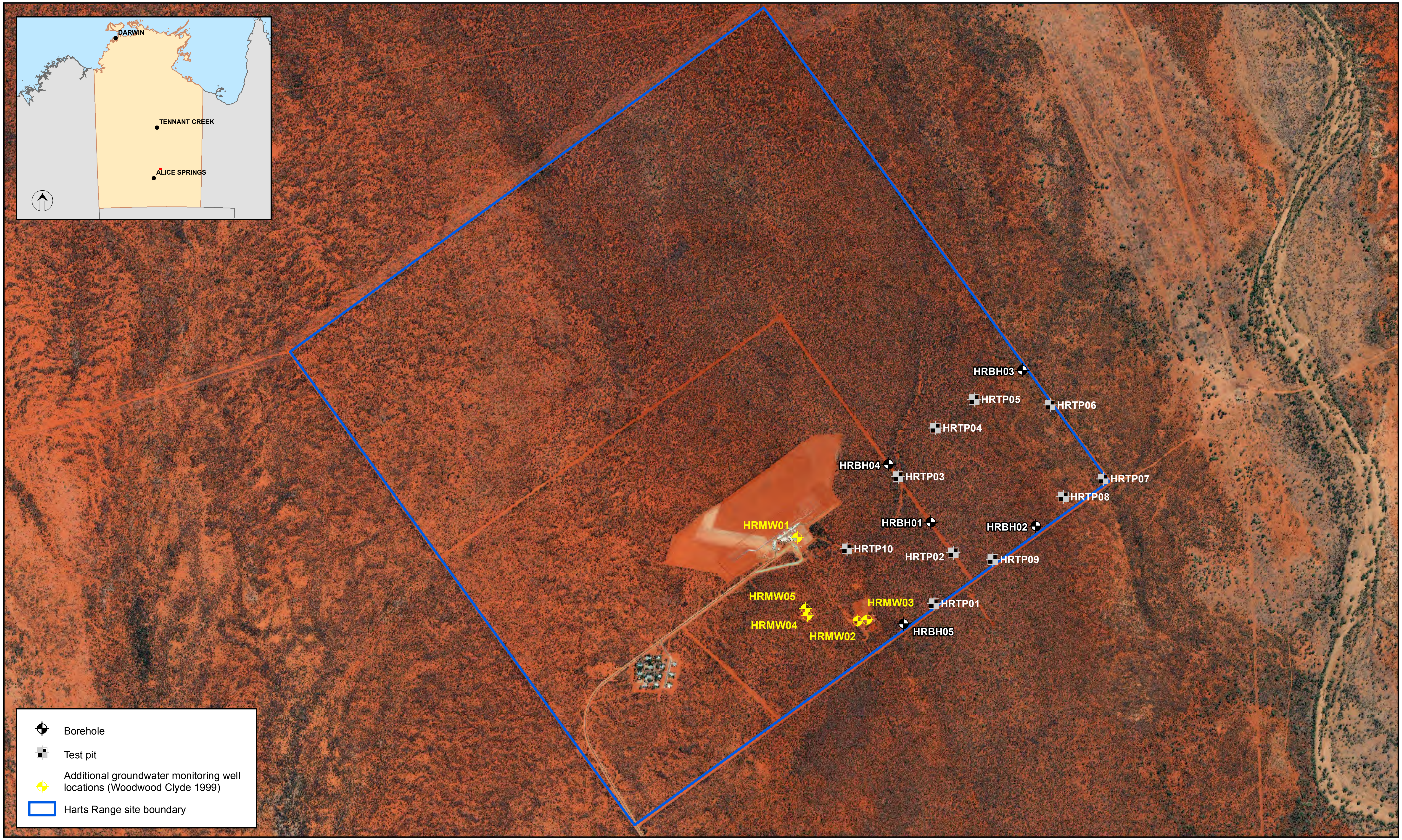

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	0 250 500 metres		Revision: A	Date: 23/07/2008	Site Characterisation
PB 100 YEARS	Data Source: Geoscience Australia, DOD,		Drawn By: RP	Checked by: MD	Harts Range field investigations
	Coord. Sys.: GDA94 MGA53		Client Ref:	RADWASTE	Figure 3.3

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3.2.1 Operational and siting constraints

The radar transmitter presents a non-ionising radiation hazard which extends in a zone forward of the array. Defence has not provided information on the forward extent of the hazard zone, thus all investigations to date have been to the rear of the array.

The operation of the radar will not be affected by radio interference caused by construction or operation of a CRWMF located behind the array.

The Harts Range site has ready access to the Plenty Highway, however internal roads would need to be provided to access the potential CRWMF site.

The creek to the east of the site has the potential to flood the eastern section of the area. At this stage flood mapping has not been undertaken, however it appears as if there is enough room to locate a CRWMF sufficiently to the west to avoid potential flooding.

There is a small cluster of Defence housing to the south-west of the site. Defence is contemplating the decommissioning of this facility, with continued operations being serviced from Alice Springs. The timing of any decision on this has not been stated.

3.3 Fishers Ridge

The Fishers Ridge site is located approximately 40 km east of Katherine and 5 km along an unsealed track to Banatjarl indigenous community located on the northern side of the Stuart Highway (Figure 3.1).

The area of interest (the site) for the field investigations is bounded by the King River and Roper Creek on the west and east respectively and covers an approximate area of 36 km^2 (6 km x 6 km). The site is currently under Commonwealth ownership and management and is leased to local pastoralists for the grazing of livestock.

Recorded elevations across the site range from 191 mAHD to 219 mAHD. The site drains to the southwest as indicated by the general flow direction of the adjacent King River and Roper Creek. Numerous wash-outs were encountered along the access track within the site with a maximum depth of approximately 0.3 m. Figure 3.4 shows a general view of the site.

3.3.1 Operational and siting constraints

The site has never been used by Defence and no plans for its future use have been forthcoming. At present, the site is used for grazing, under an arrangement between Defence and local property owners. The access road is used by people travelling to and from the Aboriginal outstation. Anecdotal evidence suggests that recreational anglers traverse the site to access nearby creeks.

The area is in a climate zone that means annual average rainfall is higher than at the three more southerly sites, and is on the southern border of the tropical monsoon belt to the north.

Higher rainfall and the potential for cyclonic winds will require any construction to be undertaken in accordance with the relevant building codes for cyclone zones.

The higher rainfall at the site is off-set to some extent by the fact that the site appears to be well-drained. The topographic character of the site provides an opportunity to locate a CRWMF on a dome which drains to the north, south and east. The catchment up-stream of the site appears to be small but would require diversion bunds to direct surface water flows around a facility.

3.4 Muckaty Station

Muckaty Station is owned by an Aboriginal Land Trust. Following initial discussions between the Commonwealth, the Northern Land Council and the Traditional Owners of Muckaty Station, a large area was identified for characterisation. This site was Gazetted by the Commonwealth prior to characterisation. Some work was also carried out at a regional site on Muckaty Station in the course of undertaking regional contextual investigations

Muckaty Station is approximately 110 km north of Tennant Creek, within the Tomkinson Creek Province of the Tennant Region, in Central Northern Territory. Muckaty Station homestead is located approximately 8 km west of the Stuart Highway, 60 km east of the Alice Springs-Darwin railway, and 45 km east of the gas pipeline that connects the Amadeus Basin gasfields to Darwin. Muckaty Station is a pastoral station used for cattle and horse grazing and is under the guardianship of several Aboriginal clans within the Land Trust agreement. The Muckaty site is an area of Ngapa clan guardianship and is not used for pastoral purposes.

The Muckaty site is located to the south of the station homestead and is accessible off the Bootu Creek haul road (from the south) and station tracks from the north. Figure 3.5 shows a general view of the Muckaty site.

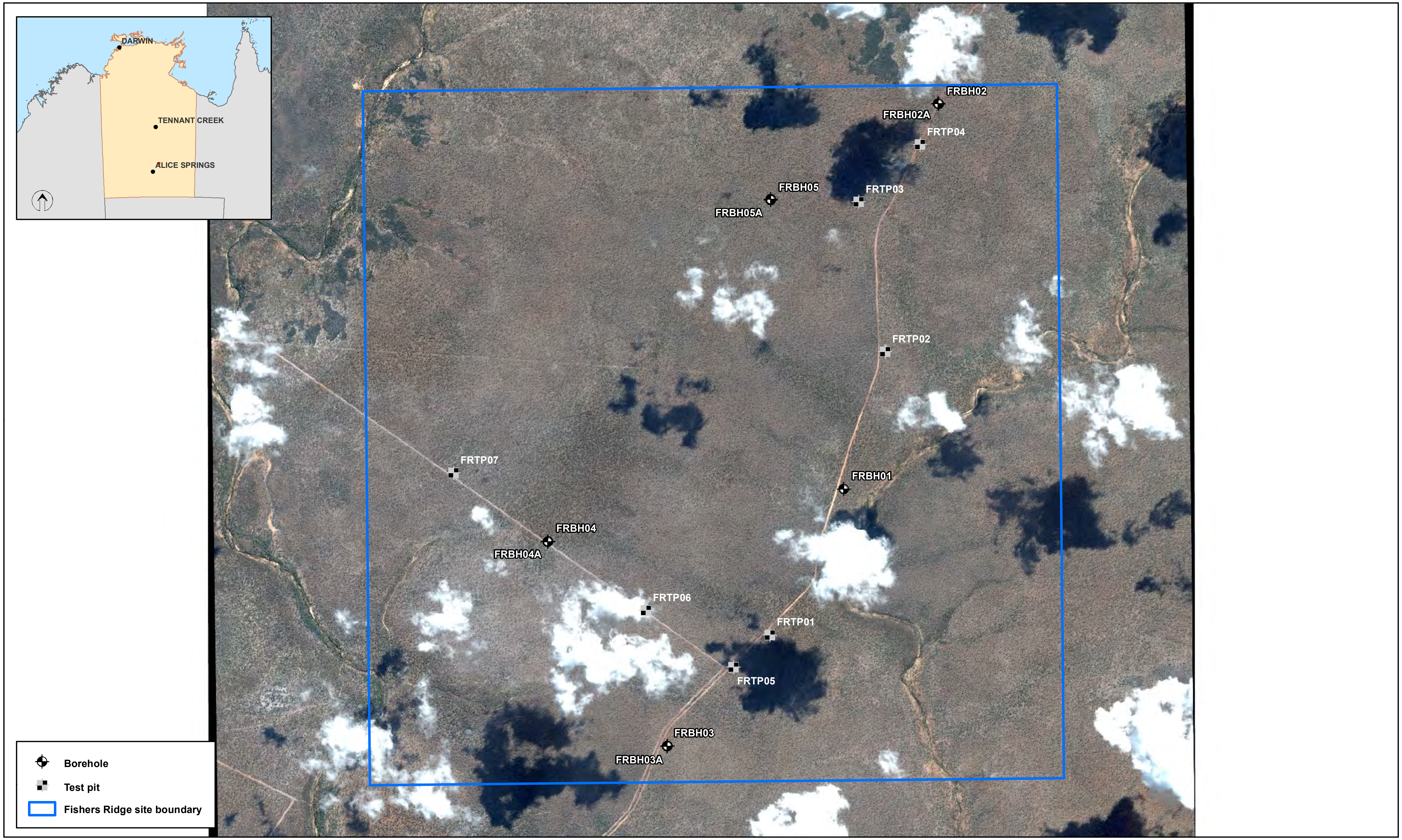
The area for regional contextual studies is located on the northern fringe of Muckaty Station, approximately 2 km west of the Stuart Highway. Figure 3.5 shows a general view of the regional area in relation to the Muckaty site and Muckaty Station.

3.4.1 Operational and siting constraints

Land on Muckaty Station is under the guardianship of several Aboriginal clan groups. Not all groups are willing to allow their land to be considered for the CRWMF. The Ngapa Clan has volunteered its area of the Muckaty Station, thus there is a social constraint on the choice of potential sites. The Muckaty site and the regional contextual area are both within land spoken for by the Ngapa Clan.

Within the Ngapa Clan area there are a number of culturally significant sites that the Clan wishes to be protected from any development. Prior to the site characterisation visits, permission was sought to form tracks along which drilling rigs could access the study areas.

The haul-road parallel to the southern boundary of Muckaty Station (from which there is ready access to the Muckaty site) is used by the Bootu Creek manganese mine to access a rail-head on the Alice Spring-Darwin rail line, from which manganese is exported. The haul-road is a single-lane, sealed road with very limited passing room. It is used twenty-four hours per day. If consideration were to be given to using the Muckaty site, and the haul-road for access to the CRWMF, arrangements for ownership and operation of the haul-road would need to be negotiated.



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Commonwealth Radioactive Waste Management Facility
Site Characterisation
Fishers Ridge field investigations
Figure 3.4

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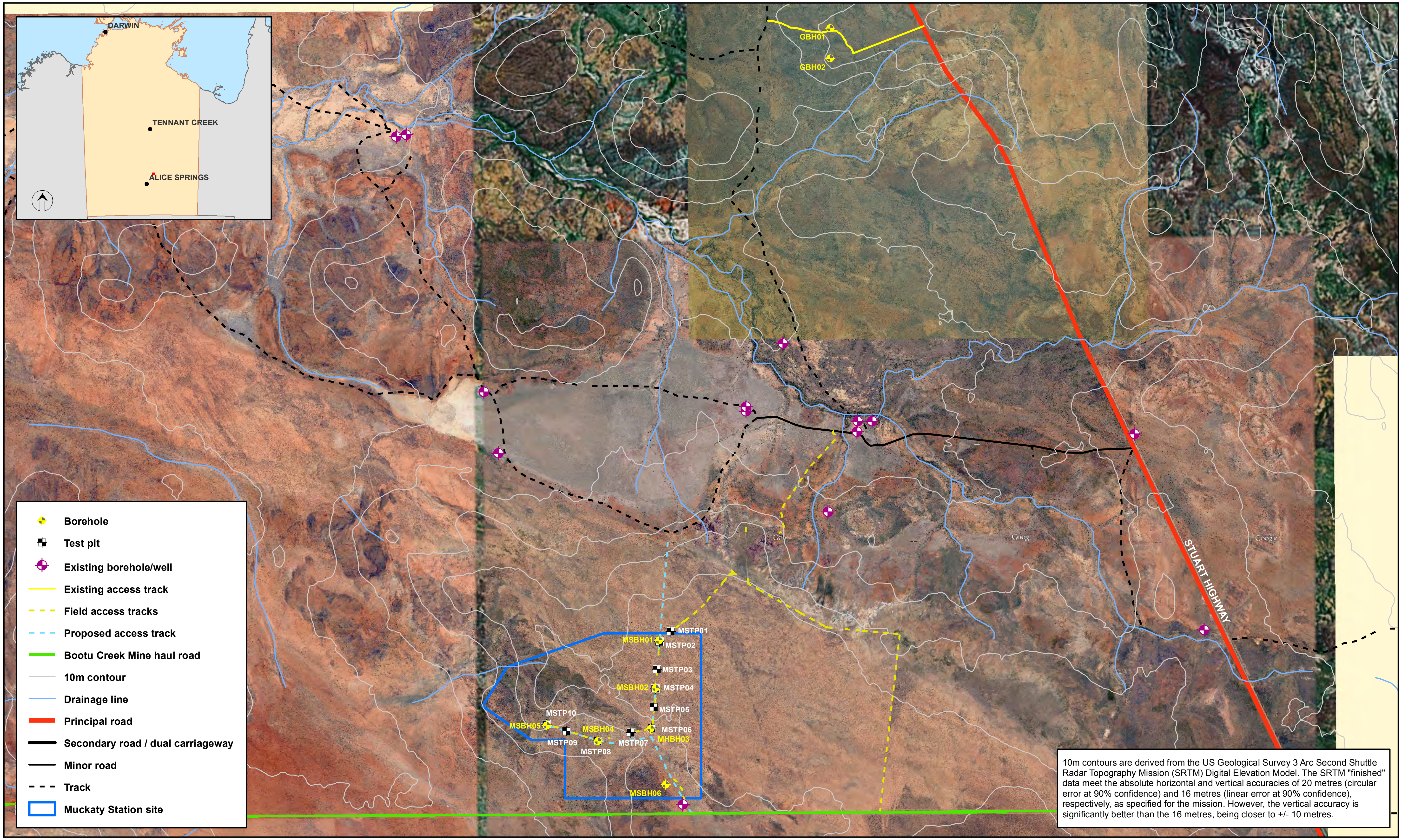

Department of Resourses, Energy and Tourism

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Data Source: Geoscience Australia, DOD, Google Earth

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Commonwealth Radioactive Waste Management Facility
Site Characterisation
Muckarty Station field investigations
Figure 3.5

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4. Site characterisation methodology

The first step in the site characterisation study was to undertake a reconnaissance tour of each site. This enabled the team to confirm physical, biological and operational features determined from maps and aerial photographs of the sites, and narrow the target zones at each site down to areas slated for more in-depth investigations. The information in Section 3 (above) was largely derived from the reconnaissance visits.

This section describes the work undertaken to develop the site characterisations.

4.1 Desk-top study

Prior to conducting any field work, data were obtained for each site. The data sets included:

- aerial photography
- topography
- demography (from the Australian Bureau of Statistics census)
- cadastral information (property boundaries and land use)
- registered well data
- meteorology (from the Bureau of Meteorology)
- Environment Protection and Biodiversity Conservation databases (which contain lists of flora and fauna species potentially present in the relevant areas, and records of Nationally-significant ecological areas such as wetlands and National Parks or Conservation zones)
- Northern Territory records of flora and fauna of conservation significance, and the location of Parks and Reserves
- airborne magnetic surveys
- Geoscience Australia earthquake database
- NT Strike
- geological maps
- hydrogeology maps
- traffic data.

The desk-top review of these data sets enabled the team to plan both the rapid reconnaissance tour and subsequent field investigations. The review also provides a regional context for data obtained in the field.

A Geographic Information System (GIS) was used to capture spatial data and provide maps of key features at each site.

4.2 Reconnaissance tour

A small team visited each of the four sites to undertake reconnaissance tasks and to determine zones ('target zones') within the boundaries of each site which were suitable for more detailed investigations by field teams. The visits also provided an opportunity to discuss operational issues with representative organisations at each site. The timing and logistics associated with the visits were aided by:

- Department of Defence (for Mount Everard, Harts Range and Fishers Ridge)
- British Aerospace (for Mount Everard and Harts Range)
- Northern Land Council (for Muckaty Station)
- Traditional Owners (the Ngapa Clan, Muckaty Station)
- OM Manganese (Bootu Creek Mine, for Muckaty Station and haul-road).

Target zones were delineated at each of the four sites, and captured by Global Positioning System (GPS) for later mapping. Features that informed the choice of target zones included:

- topography
- surface drainage
- evidence of flooding (erosion, scouring etc.)
- operational constraints (current site infrastructure and land uses)
- visible surface geology and soils
- flora, fauna and habitat
- proximity to national and regional transport networks
- existing roads and tracks.

4.3 Confirmation of target zones

Information from the reconnaissance tour, together with data from the desk-top study were combined to produce site maps. A Workshop was held to discuss the choice of target zones and to identify potential impediments to their confirmation. The Workshop was also convened to allow the wider team membership to participate (the reconnaissance tour involved only a few people).

With minor modifications, the target zones were confirmed.

The final maps of target zones were provided to the leaders of the field teams to allow them to plan the field studies prior to deployment to the sites.

4.4 Field studies

Field teams were assembled to undertake the following work:

- flora and fauna surveys
- geology, geotechnical and geochemical sampling
  - surface mapping
  - drilling (diamond cores and Rotary Air Boring [RAB])
  - test-pitting
- hydrogeological sampling
  - drill holes converted to water monitoring bores using PVC standpipe
  - depth to groundwater
  - groundwater depth variability
  - pH, EC and hydraulic conductivity
  - conductivity, resistivity
  - yield (L/s)
  - permeability (falling-head tests)
- hydrogeochemistry
- surface hydrology
  - catchment areas
  - flow paths
- transport
  - national and Northern Territory major roads
  - minor roads
  - tracks
  - traffic analysis
  - safety considerations (turning areas, slip lanes, road width and passing etc.)

Samples collected in the field were subjected to a number of laboratory tests. These are described in Section 4.6.

4.5 Field data collection methodology

This section outlines data collection and analysis methodologies. Additional detail is contained in the individual technical reports listed in the Table of Contents above.

4.5.1 Flora

Quadrats were established at each site. The location of all sites were recorded using a differential Global Positioning System (dGPS) and Trimble Datalogger. Photographs were recorded of each site.

Voucher specimens were collected for all species that could not be positively identified in the field and the identity of these were determined out of the field.

4.5.2 Fauna

Ethics Committee approval was obtained prior to any fieldwork. Several methods were used for the fauna surveys. They included:

- trapping
  - pitfall
  - Elliot
- observations
  - scats and pellets
  - burrows
  - dens
  - paw-prints
  - scratches
  - food source and type
  - birds.
- interviews (with staff of the Defence sites and Aboriginal people at Muckaty)
- bats (no direct measurements taken, but likelihood based on habitat and food sources was assessed).

4.5.3 Surface soils

Test pits were excavated at each site to provide information on the soil profile and potential excavation conditions to 3–4 m depth (or refusal). Bulk samples of representative soil units were collected for laboratory testing.

4.5.4 Sub-surface geology

A drilling investigation program was undertaken using a combination of methods to provide information on soil and rock profiles at each of the sites to a maximum depth of 100 m.

Five investigation boreholes were drilled at each of the Mount Everard, Harts Range and Fishers Ridge sites. Two holes at each of these sites were drilled using HQ3 diamond coring techniques to provide detailed information on the soil and rock strata profile at each location. The cored boreholes were drilled to a depth to intercept the underlying basement rock or to a maximum depth of 100 m. All recovered rock core was retained on PVC splits, sealed in clear PVC tubing and stored in metal core trays.

The remaining three boreholes at each site were drilled using rotary air boring (RAB) methods to at least 5 m below the groundwater level to supplement the cored borehole information.

All five boreholes on each site were converted to groundwater monitoring wells using 50 mm diameter Class 9 and Class 18 PVC standpipe.

At Fishers Ridge additional shallow boreholes to 6 m depth were drilled at four of the five borehole locations to provide shallow groundwater monitoring wells. As with the other three sites, all boreholes were converted to groundwater monitoring wells.

A total of eight boreholes were drilled at Muckaty Station, four HQ3 diamond boreholes and four RAB. Six boreholes were drilled at the Muckaty site, three open hole RAB boreholes and three HQ3 cored boreholes, covering the two provinces. The remaining two boreholes were drilled at the regional contextual site, comprising one open hole and one cored borehole to provide regional geological and hydrogeological information. All boreholes, with the exception of one, were converted to groundwater monitoring well, with installations of 50 mm Class 18 PVC. The cored borehole

(GBH02) collapsed on withdrawal of the drill rods and the PVC standpipe could not be installed. The borehole was subsequently grouted to surface.

Boreholes were logged, and samples photographed, sealed for storage and collected for laboratory testing of representative units.

4.5.5 Survey

All test locations were initially surveyed using a hand held GPS with a horizontal accuracy of ±5 m. A more detailed follow-on survey was then conducted at Mount Everard and Harts Range sites by GHD Pty. Ltd of Alice Springs and (for the Fishers Ridge and Muckaty Station sites) by Ausurv Pty Ltd of Darwin. The surveys were conducted to obtain elevations of the test locations and of the general site areas. The test locations are all reported in the GDA94 coordinate system to a sub-metre horizontal accuracy and Australian Height Datum (AHD) to a vertical accuracy of 0.05 m. Additional survey points, tracks and traverses were undertaken at each site to provide georeferencing points (for aerial photographs) and cross sectional information. The collar locations and elevations of nearby wells and water bores were also surveyed.

4.5.6 Groundwater

The groundwater monitoring wells were installed at depths determined by the groundwater levels recorded at each of the sites. At two borehole locations (Harts Range: HRBH01 and Fishers Ridge: FRBH01) the base of the deep cored boreholes was backfilled with grout to below the screen level which was installed at the groundwater level. Groundwater monitoring data loggers were installed in two of the boreholes at each site, to record potential fluctuations in the groundwater table from climatic and seasonal variations.

4.5.7 Permeability testing

Three falling head permeability tests (FHT) were performed adjacent to boreholes on each site. Three boreholes were drilled to 1 m, 5 m and 10 m depths using RAB methods with the test being performed within a non-slotted 50 mm diameter PVC open-ended standpipe. The tests were carried out in accordance with BS 5930:1981 (Hvorslev Method) which involved the measurement of the falling water level with the standpipes over a period of time. Each standpipe was filled twice to facilitate saturation of the surrounding soil prior to conducting the falling head test.

4.5.8 Surface features

Height contour data were initially taken from published information (Geoscience Australia). The quality of these data varied from site to site and in general did not provide contours with intervals of less than 10 m.

Subsequent data were obtained from satellite radar missions. In terrain with highly variable topography, radar data may not be able to resolve height differences of 16 or more metres, however in relatively flat terrain the resolution can be better than 3 m.

Height data were converted to Digital Terrain Models (DTM) for each site. This information was then used to study catchment areas, drainage lines and water flow paths.

4.5.9 Access and internal roads

Measurements were made of road and seal widths for major roads, minor roads and tracks. Assessments were made of the condition of roads, and the degree to which they may have to be upgraded to function for the CRWMF.

Assessments were made of the arrangements that would have to be made to provide safe turn-offs into the sites from major roads (e.g. turning radii and slip lanes).

All junctions were photographed for future reference.

4.5.10 Social and cultural issues

No data were collected in the field on social and cultural issues. Data published in the Census and obtained from cadastral databases were used to determine current land use, demography and proximity of the sites to residences.

4.5.11 Meteorology and climate

No field data were collected on meteorology at any site. Data from the Australian Bureau of Meteorology (from the closest registered sites) were used to characterise regional climate data, specifically rainfall and extreme events.

4.5.12 Prospectivity

Samples obtained from the drilling and test pitting program at each site were retained for analysis of commercial minerals. The objective being to determine if the sites were likely to host commercially-exploitable ore bodies, which might militate against their candidacy for the CRWMF.

4.6 Post fieldwork analyses

4.6.1 Flora

Quadrat data were recorded in the field and used with published regional data and aerial photography to provide vegetation association maps for each site: the quadrat data providing a form of ground-truthing.

Understorey and canopy densities were assessed. Biodiversity was estimated.

Factors that may have influenced the field observations were noted. These included:

- current and historical land use (e.g. active grazing)
- fire regime (either deliberate or natural)

- recent rainfall (within the last few growing seasons)
- presence of feral herbivores (e.g. rabbits)
- competition by exotic (weed) species.

Maps of vegetation communities were constructed.

Species lists compiled from field surveys were compared with National and Northern Territory databases to determine their status (e.g. rare, vulnerable, threatened, data deficient etc.).

Introduced species were identified and the risk they represent to the natural environment assessed against National and Northern Territory registers of weed species.

Voucher specimens of material collected in the field, that could not be immediately identified, were analysed later using standard reference works.

Processes that have the potential to threaten biodiversity were recorded.

4.6.2 Fauna

Species lists of both native and introduced fauna were compiled for each site. The conservation significance of each species was determined from National and Northern Territory databases.

4.6.3 Soils and rocks

Soil and rock samples were collected from each site during the test-pitting and drilling programs, and submitted to Coffey Geotechnics, a NATA-accredited testing laboratory in Adelaide.

Mineralogical x-ray diffraction (XRD) studies on selected rock samples were sent to specialist laboratory AMDEL, whilst petrographic analyses were conducted by Pontifex & Associates.

Chemical/physical testing included:

- chloride (mg/kg)
- sulphate (mg/kg)
- pH
- electrical conductivity (dS/m)
- resistivity (Ohm m).

Rock tests included:

- point-load testing ((Is_{50} MPa)
- uniaxial compressive strength (MPa).

Soil tests included:

- sand fraction (%)
- clay fraction (%)

- liquid limit (%)
- plasticity index (%)
- linear shrinkage (%)
- Maximum Dry Density (MDD) (t/m^3)
- Optimum Moisture Content (OMC) (%)
- coefficient of permeability (m/s)
- 4-day soaked California Bearing Ratio (CBR) (%)
- un-soaked CBR (%)
- Emerson number.

4.6.4 Groundwater

Groundwater levels at each site, in each of the observation wells established, were used to infer groundwater level contours and therefore flow directions. This information, together with hydraulic conductivity, was used to infer groundwater flow rates. A combination of flow direction, rate and topography was used to infer groundwater fate (e.g. its potential surface expression).

Data from groundwater level dataloggers were used to examine fluctuations in groundwater levels, and to infer (from climate data) factors that might influence groundwater levels (e.g. re-charge from storm events).

Samples obtained by the 'micropurge method' were preserved and sent to a laboratory for testing. Field analytes included:

- pH
- EC (electrical conductivity)
- Eh (redox potential)
- DO (dissolved oxygen)
- temperature.

Laboratory analytes included:

- major ions
  - Ca, Mg, Na, K, Cl, HCO3/CO3, SO4, NO3, ion balance, lab. EC, lab. pH, lab. TDS, nitrate, total alkalinity
- minor elements
  - F, Br, I, B, filterable and total P, dissolved Silica, sulphide
- trace elements (filtered, acidified, low-level)
  - Aluminium, Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Copper, Gallium, Lead, Iron, Manganese, Mercury, Molybdenum, Nickel, Selenium, Strontium, Tin, Thorium, Uranium, Ytterbium, Vanadium, Zinc
- turbidity, total organic carbon, total inorganic carbon
- dissolved organic matter characterisation
- stable isotopes
  - Deuterium, oxygen-18.

4.6.5 Seismicity and tectonics

While no direct measurements of seismicity were made during field investigations, characterisation of the underlying geology at each site, coupled with published earthquake occurrence (focus, intensity and frequency) and relevant Australian Standards were used to assess the potential influence of earthquakes at each site.

4.7 Assessment of published data sets

Published data sets were accessed in addition to field data. This section outlines the data sets used in this Stage One assessment.

4.7.1 Meteorology

Comprehensive meteorological data sets have not been collected at any of the four sites, although there are relatively short-term rainfall data available at Muckaty Station and Mount Everard. The approach taken was to access data from the nearest meteorological stations and to compare data sites at each nearby site. The objective being to gain an understanding of regional weather conditions, and variations between closely-spaced climate stations. In this way it was deemed possible to assess the likely climate at each of the four sites. Thus for example, data from five nearby stations were analysed for the Fishers Ridge site. These data came from:

- Cutta Cutta weather station
- Maranboy weather station
- Tindal RAAF weather station
- Katherine Council weather station
- Katherine Aviation Museum weather station.

The data from seven stations were used in the analysis undertaken for Harts Range. Three stations were used for Mount Everard, and seven for Muckaty Station.

Data were analysed to produce:

- mean monthly rainfall
- number of rain days per month
- highest monthly rainfall (extreme events)
- daily mean temperature (maximum and minimum)
- extreme daily temperature (maximum and minimum)
- 09:00 and 15:00 wind speed
- highest recorded monthly wind gust
- 09:00 and 15:00 relative humidity.

Records were also searched for cyclonic events, bushfires and floods at each site. Lightning strike records (annual average ground strike density) were also used to inform an assessment of bush-fire risk.

Full data sets and analyses are shown in the Meteorological Technical Report.

4.7.2 Demography and population

The principal sources of land use and demographic information were the Australian Bureau of Statistics (ABS) and the Government of the Northern Territory (full details of data sources are listed in the Land Use and Demography Technical Report).

4.7.3 Geology and soils

The principal sources of information of geology, soils and mineral prospectivity were the Northern Territory Geological Survey and Geosciences Australia (full details of data sources are listed in the Geology and Geotechnical Technical Report and Mineral Prospectivity Technical Report).

4.7.4 Groundwater and hydrology

Data on groundwater and surface hydrology tend to be site-specific, thus numerous information and data sources were accessed (full details of data sources are listed in the Hydrogeology and Hydrology Technical Report).

4.8 Limitations of the Stage One study

This Stage One study has compared and contrasted the four sites in terms of the themes chosen to reflect National and International siting guidelines.

Data collection at each of the sites has been limited to that necessary to enable a comparative suitability assessment.

It is recognised that more detailed investigations will need to be made at the site chosen by the Commonwealth to host the CRWMF, and that the analyses to date do not constitute an environmental impact assessment.

5. Site characterisation processes

Previous sections of this report have outlined the:

- guidelines used to develop characterisation themes for this study
- desk top analyses and field work planning
- field data collection methodologies
- post fieldwork analyses.

This section contains a description of how the results of the analyses were brought together with the concept design to produce a synthesis and preliminary costing.

5.1 Issues workshop

Information from desk top, field and post-fieldwork components of the study were presented at an Issues Workshop. The objectives of the workshop were to:

- agree a set of issues, aspects and impacts with which to conduct the site characterisation
- prioritise the issues, aspects and impacts by ranking them in terms of siting Guidelines
- rapidly identify 'showstoppers' for any of the sites (i.e. any issue that would render further investigation or consideration of a particular site redundant)
- differentiate between those aspects that are amenable to control (for example by engineering), and those aspects for which there are no control mechanisms.

The meeting took the form of a modified 'ENVID' workshop. An ENVID study is carried out by a team of competent scientists and engineers from a mixture of relevant disciplines and is facilitated by a person who is experienced in the ENVID technique. Each geographic and functional area of the site is considered against a checklist of issues. Where it is agreed that an issue exists in a particular area, the risk presented by the issue is considered, and all possible means of either eliminating the issue or controlling the risk and/or the necessity for further study are noted on a worksheet. Actions are assigned to either discipline groups or individuals to ensure the mitigating measure is documented, or further study is completed.

The ENVID worksheet contained 'Topics', 'Guidewords' and 'Expanders'. Table 5.1 shows an example worksheet. Key words and issues were informed by National and International siting Guidelines.

Table 5.1 Example ENVID worksheet

Topic	Guideword	Expander
Natural Hazards	Extreme Weather	Temperature extremes
		Wind
		Dust
		Flooding
		Sandstorms
	Lightning	Bushfire
	Seismic Activity	Liquefaction
	Erosion	Ground slide
		Riverine
		Soil structure
	Subsidence	Ground structure
		Foundations

5.2 Suitability workshop

The second workshop was designed to:

- compare and contrast the 'natural' suitability of each of the sites. That is their inherent suitability to host the CRWMF
- identify those natural aspects of each site that could be easily modified to enhance the site's suitability as a host for the CRWMF
- apply weightings to each site that reflected both their natural and enhanced (modified) suitability.

The objective of the workshop was to understand the interfaces between the site characteristics and the concept designs prepared by ANSTO. This was the preparation for the Concept and Concept Modification Workshops.

5.3 Concept development workshop

DRET commissioned ANSTO to develop a Concept Design for the CRWMF. The original ANSTO report and design were the subject of a Concept Development Workshop conducted at Lucas Heights.

Site characteristics were discussed with ANSTO personnel, and a decision made to develop an alternate to the original Concept Design that took into account the potential for the site to be located in an area of higher rainfall than had been assumed for the original design.

Additional discussions revolved around the material handling arrangements to determine if the Concept Design needed to be modified to take into account either integrated cranes (gantry cranes) to handle the intermediate level waste shipping casks, or mobile cranes that would be used on a campaign basis.

The result of the workshop was a concept in two parts: one for potential ‘dry’ climates, and one for ‘wet’ climates. The principal difference between the designs being the need or otherwise to line any sub-ground structures (for low-level and intermediate level wastes) with additional infiltration and seepage controls.

5.4 Concept modification workshop

The final Workshop was held to bring the site characterisations together with the concept designs to determine site-by-site modifications to the design that would take into account natural, site-specific characteristics.

No site is unsuitable to host the CRWMF, but each site has natural characteristics that require modifications to the Concept Designs in order to make them ‘fit’ the site.

The objective of the Workshop was to provide cost engineers with sufficient details of any modifications in order to cost any additional works at each site.

6. Site summary – Mount Everard

This section summarises the findings of the site characterisation process for Mount Everard. Additional details can be found in the accompanying reports.

6.1 Physical issues

6.1.1 Regional geological setting

The Alice Springs 1:250,000 Geological Series presents the site as underlain by a thick (up to 200 m) sequence of Quaternary and Tertiary sediments consisting of clay, silt, sand, gravel and conglomerates. The site is covered by a thin Quaternary layer of red clayey and sandy soil, red earth and oxidised clayey silty sand.

The underlying Tertiary rocks include siltstone, limestone, sandstones, pebbly sandstones with kaolinitic quartzose sandstone, siltstone and mudstones grading to poorly graded coarse grained conglomerate (Hale Formation) towards the base.

Mount Everard is located within the Amadeus Basin which covers an area of approximately 170,000 km^2 in the southern region of the Northern Territory. The Amadeus Basin is an intracontinental structural sedimentary basin, which forms part of what is known as the adjacent Centralian Superbasin which also includes the Officer, Ngalia and Georgina Basins.

The Amadeus Basin’s sediments range from Neoproterozoic (>800 Ma) to Devonian (~350 Ma) and include dolostone, sandstone, limestone, quartzite, shale and evaporates deposited in a shallow marine environment. However, other sedimentary environments are also represented, including fluvial, glacial, barred basin, supratidal, shallow restricted carbonate shelves and open shallow to deep marine.

The basement geology of the area is complex, derived from the underlying and nearby metamorphic sequences which form the MacDonnell Ranges. To the immediate southwest is Mt Solitaire, composed of Charles River Gneiss. The metamorphics of the McDonnell Ranges are highly folded and deformed, with the main structural discontinuities steeply dipping to the north and associated with an anticline located to the south. Dykes, migmatites, pegmatitic seams and intense folding and faulting are common in the metamorphics. These metamorphics are likely to underlie the Tertiary sediments on the site.

6.1.2 Site geology

Table 6.1 shows a summary of the soil and geological profile at Mount Everard.

Table 6.1 Summary of soil and geology at Mount Everard

Average depth (m)	Material description	Age/Formation
0 – 0.15	Clayey Silty Sand (SM), red-brown, dry, loose	Quarternary
0.15 – 0.5	Sandy Clay (CL/CI)/Clayey SAND (SC), red-brown, dry very stiff-hard	
0.5 – ~2.5	Sandy Gravelly Clay (CL/CI), purple-brown, dry very stiff-hard	
2.5 – 5	Calcrete, recovered as clayey Gravel and gravelly Clay, poorly to well cemented	
5 – 49	Sandstone, fine to coarse grained with some pebbly zones and abundant fines throughout, extremely low to low strength with occasional moderate strength layers, generally highly weathered with extremely weathered zones, noticeable porosity in upper 30 m, variable fracture spacing averaging 100 mm – 300 mm. Indistinct bedding to massive, however noted fining upwards sequences in upper 30 m	Tertiary (Arltunga Beds grading towards Hale Formation at depth)
	Conglomerate, occasional beds (max. 3.5 m – MEBH02), matrix supported, angular, max. clast size 50 mm, polymictic, no orientation noted, clasts fractured and infilled	
49 – 53	Quartzite, coarse grained, extremely low to low strength, extremely to highly weathered, fracture spacing 30 mm – 300 mm, massive	
53 – 62	Claystone, some fine to medium grained sand visible with some sandy layers throughout, very low strength, extremely to highly weathered, massive, fracture spacing generally > 1 m	
62 – 69.7	Interbedded Sandstone and Claystone. Sandstone fine to coarse grained, very thinly bedded, very low to moderate strength, highly to moderately weathered, fracture spacing 300 m	

6.1.3 Permeability

Falling head tests conducted both during the field investigations for this report and during earlier tests concluded that the permeability of soils underlying Mount Everard can be classified as low to very low, in accordance with Terzaghi and Peck (1967). Laboratory permeability testing on compacted clay samples reported $K = 3.7 \times 10^{-10}$ m/s, which is classified as very low to practically impermeable.

6.1.4 Mineralogy and petrology

Mineralogical and petrographic analysis of the upper sandstones/quartzitic rocks (5.0 to 49 m) determined a composition of up to 75% of unsorted angular quartz (dominant) with plagioclase and k-spar (trace/accessory), with muscovite/illite (15%) with minor kaolinite occurs as a weak clay cementing agent. Analysis of the underlying Claystone (53–62 m) reported crudely layered, pisolitic/nodular texture, predominantly composed of muscovite/illite (60%) with inter-particle carbonate (calcite, 25%). Minor, weakly layered, medium sand sized quartz grains occur throughout.

6.1.5 Mineral prospectivity

A number of mineral exploration projects have taken place in the region, with limited amounts of mining. The majority of mineral occurrences in the region are generally located 40 km to 70 km north-east of the site in outcropping basement rocks. The overlying Tertiary sequence is up to 200 m thick and this is likely to make any underlying mineral occurrence in bedrock sub-economic.

The Mount Everard site has an exploration licence (EL26006) granted over the site which is held by Arunta Uranium Pty Limited. Arunta Uranium (a wholly owned subsidiary of Callabonna Uranium Limited) currently holds three ELs in the Arunta block and is exploring for regolith uranium deposits.

6.1.6 Groundwater

Groundwater was encountered in all of the Mount Everard boreholes and ranged in depth from 33.2 m to 35.0 m below ground level (mbgl).

6.1.7 Geotechnical issues

In accordance with AS2870-1996 ‘Residential Slabs and Footings’, all four sites are classified as Class S (less than 20 mm movement) due to the sandy and clayey sand sites underlain by calcrete or laterite to 4 m depth and weathered rock below. Sites with rocky outcrops would be classified as Class A.

Conventional excavation machinery is considered suitable for excavations to approximately 5 m depth below existing surface levels at Mount Everard. Below this depth larger machinery and/or hydraulic rock breakers may be required to aid excavation of medium strength rock materials.

6.1.8 Earthquake and liquefaction

The Site Hazard factor for Mount Everard is 0.8 (AS1170.4-2007 ‘Structural design actions – Earthquake actions in Australia’). The potential for liquefaction is low (due to the unsaturated underlying soils and the depth to groundwater).

This assessment is made on the basis of a 1:500 risk profile (adopted for all sites due to the long time span in which wastes will be managed).

6.1.9 Construction materials

The Mount Everard site has the best range of construction materials available on-site (of the four sites characterised). From the preliminary investigations, some of the construction materials for pavements, building pads, embankments and clay liners may be sourced on site.

6.1.10 Sub-surface migration

Falling head permeability tests carried out at the four sites indicate that up to a depth of 10 m below existing surface levels, migration of fluids would be greatly impeded by the very low permeability of the existing soil and rock profiles.

At depth, recovered rock core had a high clay content, which is considered to be a result of in-situ weathering resulting in a reduction of the porosity and therefore overall permeability of the profile.

However, highly fractured zones with occasional mineral infilling were noted, indicating that some potential fluid flow may occur along these fractures.

6.1.11 Hydrogeology

Groundwater at the Mount Everard site was encountered between 30 and 35 m below ground level at an elevation of 696 to 697.3 m AHD in mostly low-permeability sandstone and quartzite rock. Flow direction was to the northeast with low hydraulic gradient (0.08%).

Available data suggest water levels can fluctuate by 0.5 to 1.5 m over the medium term (several years). Hydraulic conductivity was variable over nearly four orders of magnitude, from 5×10^{-9} to 2.5×10^{-5} m/s, and salinity between fresh (0.585 mS/cm) to brackish (5.57 mS/cm) with near-neutral pH. Groundwater chemistry was dominated by sodium chloride with other major ions present.

The main influence on the hydrogeology of this site appears to be local variability of the profile (affecting recharge rates and salinity) and rock mass itself (hydraulic conductivity).

The behaviour of the shallowest groundwater is likely to be mixed porous medium–fractured rock in nature, with local fractures causing individually higher hydraulic conductivities.

6.1.12 Surface hydrology

There are few surface water issues at Mount Everard, which has no significant drainage lines crossing or near to the site. Local ponding after rain, including effects on trafficability, should be taken into account. Minor, ill-defined channels that may collect water and flow in very heavy rain may need to be diverted around any future structures.

6.1.13 Meteorology

The parameter most relevant to this phase of the investigations is rainfall, particularly that associated with extreme events.

The 1:1,000 annual return interval (ARI) for a five-minute period is 26.2 mm, and that for a 72-hour period is 480.7 mm.

6.2 Biological issues

6.2.1 Vegetation – regional setting

The Mount Everard Defence area and the site are within the Burt Plains Bioregion Subregion 3 Woinarski (1992). The region is dominated by earthy, alluvial soils with sandy plains of Acacia shrubland and tussock and hummock grasslands. Land use within the Bioregion is predominantly pastoralism (>80% of the region) (NRETA 2006). The bioregion is currently classified as very poorly reserved with especially poor representation of the dominant Mulga Woodlands (NRETA 2006).

Morgan (2001) states that the landscape stress of this subregion is moderate to high with a continental landscape stress score of 3 assigned. This assessment translates to a subregion that is moderately to severely impacted by land use. Native vegetation extent is estimated at >90% of the subregion with high impacts from total grazing pressure.

Wilson et al. (1990) recorded the dominant vegetation of the plains adjacent to Mount Everard as isolated patches of *Acacia aneura* (Mulga) mixed species low open woodland with open grassland understorey. The dominant vegetation community is described as *Acacia aneura* (Mulga)/mixed species low open-woodland with open-grassland understorey. Other species common in Acacia communities of this region include *Acacia kempeana, Eremophila latrobei, Atalaya hemiglauca, Einadia nutans, Ptilotus obovatus* and *Sclerolaena lanicuspis*.

Wilson et al. (1990) notes that this community often merges into the *A. aneura* tall sparse-shrubland with which it is extensively associated. This community is differentiated from the *A. estrophiolata* woodland by the greater abundance of Mulga, although floristically the upper layers are very similar.

The Northern Territory flora data base lists 26 native species and 3 introduced species for the region 3 km from the site. This reflects the limited amount of assessment and collection of common, widespread species in the area.

6.2.2 Conservation status of vegetation species and communities

No species or communities of conservation concern were observed during the September 2006 survey. A review of previous literature for the region and data supplied by the Northern Territory Government indicates that no species of conservation significance occur on site

With the exception of *Sclerolaena birchii*, which was recorded near the site adjacent to the Tanami Road, it is unlikely that most of the species listed as ‘threatened and data deficient flora of the Northern Territory for this region' are present on site. It is possible that a few annual species of significance may be present following above average rainfall.

The site was composed of regrowing, moderately degraded and depauperate communities of Mulga with a few areas of relatively intact Mulga thickets adjacent to the site. Cattle grazing and years of drought have adversely impacted the biodiversity in this area. Based on species described in Wilson et al. (1990), the site contains approximately 20% of the species normally associated with this vegetation community.

6.2.3 Introduced plants

Two introduced plants were recorded in the site and eight species for the general area. Of these, Buffel grass and Couch grass was present along the main access road to the site and at a few cleared areas in the area.

6.2.4 Fauna

6.2.4.1 Ground mammals

Red kangaroo and echidna were the only species recorded at the site. No small mammals were present and there is no key habitat available for the species which have been recorded or which could occur in the region. The Northern Territory records five species of small mammals in the wider region. It is possible that Sandy inland mouse or Striped-face dunnart could occur, although they would require more understorey vegetation than is currently present. Site staff have also recorded various pest species.

6.2.4.2 Bats

No assessment was undertaken, primarily because only feeding habitat is provided by the site (i.e. not breeding habitat). Up to 12 species may occur in the wider region.

6.2.4.3 Birds

The Northern Territory database lists 34 species for a 3 km area around the site. Kinhill (1992) notes that over 80 species have been recorded in the wider region. The site assessment recorded 23 species with the most common being Singing honeyeater, White-browed babbler, Grey butcherbird and Splendid fairy-wren. No species of particular conservation significance was recorded. Site staff have recorded Common boobook owl and Barn owl at the site during the past five years. The presence of a permanent water supply in the Defence facility is a major attraction for many species.

6.2.4.4 Reptiles and amphibians

Ctenotus schomburgkii (Sandplain ctenotus) and *C. leonhardii* (Common desert ctenotus) were recorded by trapping, with Sand (Gould's) goanna, Central bearded dragon and Gilbert's dragon observed. Fifteen species have been recorded in the region by the NT BRS and most data date to 1994/95. Centralian blind snake, a data deficient species for the Northern Territory, has been reported for the area and could occur at the site. Site staff records include King brown snake (also data deficient for the NT), Perentie, a blue-tongue lizard (presumably Centralian) and geckoes.

No species of amphibian was recorded during the field assessment and one species is recorded in the NT BRS. It is possible that a further 5 species could occur in the region.

6.2.4.5 Other species

Termites, especially low mound building species, are present throughout this site and area. Mound building species are useful indicators of disturbance and habitat fragmentation; they are also an important food source for a number of vertebrates, especially reptiles, throughout the region. Mulga ants are equally abundant in the site.

6.2.4.6 Introduced species

European rabbit and cattle were present adjacent to the site. Facility staff indicated that European rabbit can be abundant and is increasing in number after a number of years of low population (presumably due to the impact of RCD (calici-virus). House mouse and feral cat are relatively common, with the former species being seasonally abundant at times. Dingo and dingo-dog hybrids, are relatively common. Arabian camel, horse, donkey and Red fox are present, but rarely recorded for the region. Rock dove (feral pigeon) and House sparrow have also been present at the facility in the past. They were not recorded during 2006. No introduced invertebrates were recorded and none have been reported by Defence contractor staff. A number of introduced ant species have been reported recently in Alice Springs, but not at the site.

6.2.5 Conservation status of fauna species

A search of the EPBC Act Protected Matters Database and Northern Territory Parks and Wildlife Schedules showed that a number of threatened fauna species or their potential habitat may occur in the area. These species are as follows:

- Desert sand-skipper (*Croitana aerstiva*) – Endangered (Commonwealth and Territory)

  The Desert sand-skipper is endemic to the Northern Territory. The species is known only from a small number of specimens collected in 1966, 1972 and 2007 at various locations west of Alice Springs in the MacDonnell Ranges.

  The species requires native grasslands as breeding habitat, and is not known to occur in Mulga woodlands. It is therefore highly unlikely to occur at this site.

- Mulgara (*Dasycercus criticauda*) – Vulnerable (Commonwealth and Territory)

  The Mulgara is widespread but patchily distributed in the arid and semi-arid sandy regions of central Australia. In the Northern Territory it now occurs mostly in sandy desert regions. Its strongholds appear to be the Tanami and Great Sandy Desert bioregions. It is not known to occur in the Burt Plains Bioregion. This species preferred habitat is the Spinifex grasslands of the Tanami and Great Sandy Desert.

- Black-footed rock-wallaby (*Petrogale lauteralis*) MacDonnell Ranges race) – Vulnerable (Commonwealth), Near threatened (Territory).

  Black-footed rock-wallabies occur in rocky outcrops and associated steep rocky slopes common to the MacDonnell Ranges Bioregion. The species is not known to occur in the Burt Plains Bioregion as its preference is for rocky terrain.

- Greater bilby (*Macrotis lagotis*) – Vulnerable (Commonwealth), Endangered (Territory).

  The Greater bilby lives in sandy desert areas in spinifex (Triodia species) grasslands. They are known to occur in the sandplain country of the Tanami and Greater Simpson Desert regions.

- Oriental plover (*Charadrius veredus*) – Listed Migratory Bird Species (Commonwealth)

  This species prefers open plains, bare, rolling country often far from water. It is common to coastal and northern inland Australia and could occur as a vagrant in this area, especially following floods.

- Oriental pratincole – Listed Migratory Bird Species (Commonwealth)

  This species prefers be in the vicinity of water on inland plains or coastal floodplains or swamp areas. It is not believed to occur within the Mount Everard site due to the lack of water and severe drought conditions. It could occur anywhere in the region following floods.

6.3 Land use and demography

6.3.1 Site tenure and use

The site was purchase by Defence in 1973 and is currently operated by BAE Systems under contract to the Over the Horizon Radar Systems Program Office (OTHRSPO). The original use of the site was for cattle grazing which started in the early 1880's.

6.3.2 Surrounding land use

Population in the area is sparse and characterised by homesteads associated with cattle stations. The area is within the Burt Surface Water Management Area which is not currently used as a water resource.

6.3.3 Heritage sites

No sites of significance have been documented for the Mount Everard site itself, although there are several in the general area (20–25 km distant). No detailed investigations have taken place to further refine the listed sites or their exact location and proximity to the Mount Everard site itself.

6.3.4 Zoning

The site is not within a planning scheme area and no past or current planning schemes apply. Further, it is unlikely that any amendments to the current planning provisions for the area will occur.

Since the Mount Everard site is close to the Tanami Road, note should be taken of the Northern Territory's Planning Scheme which seeks to preserve the safety and amenity of designated roads. If the CRWMF were to be placed within 500 m of the road, it is likely that suitable screening would be required.

6.3.5 Proximity to occupied places

6.3.5.1 Aboriginal

There are two 'family outstations' within 5 km of the Mount Everard site. A family outstation is defined as a place where up to 20 people may reside full- or part-time. There are a minimum of facilities, but there is likely to be a source of potable water.

A further 48 communities lie within 50 km of the Mount Everard site, many of which are 'town camps' near Alice Springs (which lies approximately 17.5 km to the south east as the crow flies).

6.3.5.2 European

Alice Springs is the only population centre of any size in the region.

6.3.6 Population density and potential for growth

The Mount Everard site lies in the Sandover-Bal Statistical Local area. The population density of this area is 38 km^2 per person. The site is within a smaller Census Collection District, which has a population density of 27.8 km^2 per person.

The potential for population growth in the area is low, given the climate and lack of local amenities. The ABS statistics show a gradual increase in the number of local Aboriginal people, however the ABS cautions against making predictions based on this numeric increase, since it believes the increase is more likely to be due to improvements in statistical methods and recordkeeping.

6.4 Transport issues

6.4.1 National networks

The Mount Everard site lies adjacent to the Tanami Road (an NT Rural Arterial Road), which leads off the Stuart Highway (a National Highway, between Alice Springs and Darwin). Thus it is connected to Australia's major road systems.

The Adelaide to Darwin railway passes through Alice Springs where there is a freight terminal and intermodal facility.

6.4.2 Site access and interior roads

There is an existing sealed road leading from the Tanami Road to the radar facility and an un-sealed road leading to the potential CRWMF area.

Upgrading the access roads (and making provision for safe turnoff the Tanami Road) is relatively straightforward since there is little likelihood of flooding.

The Mount Everard site is likely to be the least costly in terms of civil roadwork upgrades.

7. Site summary – Harts Range

This section summarises the findings of the site characterisation process for Harts Range. Additional details can be found in the accompanying reports.

7.1 Physical issues

7.1.1 Regional geological setting

The site is underlain by Quaternary red earth clayey and sandy soils and aeolian sands with Quaternary/Recent alluvial sediments associated with watercourses to the west (Annamurra Creek) and east (Ongeva Creek).

The underlying Tertiary (Lower) deeply weathered (leached, mottled, ferruginised and in part kaolinitic and pisolitic) rocks include siltstone, sandstone and pebbly sandstone with minor conglomerate.

The basement geology of the area is complex, derived from the underlying and nearby metamorphic sequences which form the Harts Range Complex. These lower to middle Proterozoic aged rocks have a complicated structural and metamorphic history typical of the Arunta Block. The Harts Range Complex has been described as forming a cover-basement relationship with the Irindina Gneiss forming the lowest part of the sequence.

The Arunta Block is located to the north and northeast of the Amadeus Basin and is contained within the Centralian Superbasin. The relations between rock units in the Arunta Block (crystalline basement) are complex.

The Harts Range Complex rocks are thought to be a volcano-sedimentary suite deposited in a possible continental rift or failed rift of the basement about 1780 million years ago. Basic and ultrabasic volcanism and/or plutonism followed the initial rifting and sandstones, mudstones and some limestones were also deposited in the resultant basin. These sediments then underwent heating and deformation resulting from compression of the crust caused by the continuation of the Strangways event, ending at around 1730 million years ago. This later amphibolite facies metamorphism (involving folding and faulting) virtually destroyed the original characteristics of the rock except for the gross lithological variations which are now recognisable as compositional layering.

Other later orogenic events recorded elsewhere in the Arunta Block played a minor role in this area. The numerous crosscutting pegmatites are much younger and represent the conclusion of a tectonothermal phenomenon that occurred about 520 million years ago (Cambrian Period). The interaction of the pegmatites and the surrounding meta-sediments and meta-igneous rocks provides the right conditions for the formation of large, high-quality mineral specimens.

The Alice Springs Orogeny (Devonian to Carboniferous, 300–400 million years ago) is responsible for the latest major uplift which has brought these rocks sufficiently close to the surface for their ultimate exposure through erosion.

7.1.2 Site geology

Table 7.1 summarises the subsurface conditions at Harts Range.

Table 7.1 Summary of soil and geology at Harts Range

Average depth (m)	Material Description	Age/formation
0 – 0.25	Clayey Silty Sand (SM)/Sand (SW), red-brown, dry, loose	Quarternary
0.25 – 3.0	Clayey Sand (SC), red-brown, generally dry, medium dense to very dense	
3.0 – 7.0	Clayey Sand, Sand with some Calcrete and alluvial deposits (as encountered in test pits)	
7.0 – 20	Pebbly Sandstone (HRBH01), fine to coarse grained with variable composition and grain size throughout, extremely low to low strength, extremely to highly weathered, defect spacing generally 1000 mm with some core loss and occasional highly fractured sections, maximum particle size 50 mm, massive, clast supported in upper portion, clasts include quartz, gneiss, sandstone Minor Conglomerate, fine to coarse grained, maximum particle size 30 mm, angular to sub-rounded clasts, matrix supported, massive.	Lower Tertiary
20 – 49	Sandstone, fine to coarse grained with some pebbly zones and abundant fines throughout, extremely low to low strength, generally highly weathered with extremely weathered zones, variable fracture spacing averaging 300 mm – 1000 mm. Indistinct bedding to massive, black veining throughout (organic)	
49 – 55	Siltstone, very low to low strength, extremely to highly weathered, fracture spacing generally 1000 mm.	
	Interbedded with Sandstone (as above)	
55 – 71	Sandstone, fine to coarse grained with some pebbly zones and abundant fines throughout, extremely low to low strength, generally highly weathered with extremely weathered zones, variable fracture spacing averaging 300 mm – 1000 mm. Indistinct bedding to massive, black veining throughout (carbonaceous?)	
71 – 100	Interbedded Sandstone and Siltstone, extremely low to low strength, extremely to highly weathered, fracture spacing generally 300 mm–1000 mm	

7.1.3 Permeability

Tests on site and previous tests undertaken earlier show that permeability if low to very low, approximately 2.65 x 10^{-7} m/s.

The permeability of the underlying soils at Harts Range may be classified as low in accordance with Terzaghi & Peck (1967). Laboratory permeability test results of K = 6.2 x 10^{-10} m/s on clayey sand samples from HRTP01 is classified as very low to practicably impermeable.

7.1.4 Mineralogy and petrology

Mineralogical and petrographic analysis of the sandstone determined the mineralogy is dominated by angular to rounded quartz with abundant plagioclase, k-spar and detrital micas. Cementing in upper sequence is predominantly muscovite/illite with an increase in kaolinite cement with depth. Quartz content also decreases with depth. Various heavy mineral species were noted in the upper 10 m sequence to unknown depth.

7.1.5 Mineral prospectivity

There are no known historic mineral occurrences in the Harts Range site. A number of mineral exploration projects and small scale mining operations occur in the Harts Range region. The majority of mineral occurrences in the region are located 40 km to 70 km north-east of the site in outcropping basement rocks. The overlying Tertiary sequence is up to 200 m thick and this is likely to make any underlying mineral occurrence in bedrock sub-economic.

Olympia Resources is in the process of opening an abrasive sands quarry, extracting both garnet and hornblende. This is located approximately 30 km east of the Harts Range site. At the time of this report, mining had not commenced but was imminent. Soil analyses for heavy minerals were carried out on samples from the Harts Range site due to this nearby heavy mineral occurrence and results showed the presence of both garnet and hornblende but in sub-economic quantities.

7.1.6 Groundwater

The groundwater levels ranged from approximately 15 m to 28 m below ground level.

7.1.7 Geotechnical issues

In accordance with AS2870-1996 ‘Residential Slabs and Footings’, all four sites are classified as Class S (less than 20 mm movement) due to the sandy and clayey sand sites underlain by calcrete or laterite to 4 m depth and weathered rock below. Sites with rocky outcrops would be classified as Class A.

Conventional excavation machinery is considered suitable for excavations to approximately 5 m depth below existing surface levels at Mount Everard. Below this depth larger machinery and/or hydraulic rock breakers may be required to aid excavation of medium strength rock materials.

7.1.8 Earthquake and liquefaction

The Site Hazard factor for Harts Range is the same as that for Mount Everard i.e. 0.8 (AS1170.4-2007 'Structural design actions – Earthquake actions in Australia'). The potential for liquefaction is low (due to the unsaturated underlying soils and the depth to groundwater).

This assessment is made on the basis of a 1:500 risk profile (adopted for all sites due to the long time span in which wastes will be managed).

7.1.9 Construction materials

The Harts Range site has sand and clayey sand available on site but much of the construction material would have to be borrowed from other sources in the area.

7.1.10 Sub-surface migration

The sub-surface conditions at Harts Range are similar in terms of migration to the Mount Everard site.

7.1.11 Hydrogeology

Groundwater at the Harts Range site was encountered between 15 and 26 m below ground level at an elevation of 629 to 637.5 m AHD in mostly low-permeability sandstone and siltstone rock. Flow direction is to the southwest becoming westerly, with gradient varying between 1% to 0.2% away from the bed of the Ongeva Creek. Available data suggest water levels can fluctuate by 0.5 to 2.5 m over the medium term (several years). Hydraulic conductivity was variable over nearly five orders of magnitude, from less than 10^{-9} to 10^{-5} m/s, and salinity between fresh (0.853 mS/cm) to brackish (6.18 mS/cm) with near neutral pH. Groundwater chemistry was dominated by sodium chloride with other major ions present.

Both proximity to Ongeva Creek, an inferred groundwater recharge zone, and local variability (as described for Mouth Everard) appear to be the main influences on the hydrogeology of this site. The behaviour of the shallowest groundwater is likely to be mixed porous medium–fractured rock in nature, with local fractures causing individually higher hydraulic conductivities.

The same local issues as Mount Everard apply. Of more potential importance is the presence of Ongeva Creek, which comes to within 1 km of the eastern boundary of the Defence site near the part of the site where a facility might be considered.

7.1.12 Surface hydrology

Based on aerial photograph interpretation and site inspection, Ongeva Creek has an ill-defined floodplain that may extend to within 500 m of the site boundary. Further study would be needed to determine if flooding could credibly extend to the site.

The issue of rare catastrophic floods that can change the beds of creeks such as the Ongeva may require consideration if this site goes to the next stage of investigation.

7.1.13 Meteorology

The Harts Range region is a desert environment with dry conditions and clear skies from April to September with some rainfall in the hottest months between October and March. The average annual rainfall for the region is between 275 and 300 mm.

The 1:1,000 annual return interval (ARI) for a five-minute period is 24.7 mm, and that for a 72-hour period is 553.2 mm, slightly higher than for the Mount Everard site.

7.2 Biological issues

7.2.1 Vegetation – regional setting

The Harts Range site is within the Burt Plains Bioregion Subregion 2 as described in Woinarski (1992). The region is dominated by earthy, alluvial soils with sandy plains of Acacia woodland and shrubland, and tussock and hummock grasslands. Land use within the area is predominantly pastoralism (cattle) on unimproved native vegetation (NRETA 2006). The bioregion is currently classified as very poorly reserved within the NT conservation system with especially poor representation of the dominant Mulga Woodlands (NRETA 2006).

The whole of this bioregion includes 971 plant species, of which 7 are endemic to the bioregion, 35 are endemic to the Northern Territory and 3 are listed as threatened under Commonwealth or NT legislation (NRETA 2006).

Morgan (2001) states that the landscape stress of this subregion is moderate with a continental landscape stress score of 4. This assessment translates to a subregion that is moderately impacted by land use. Vegetation extent is estimated at >90% of the subregion with moderate to high impacts from total grazing pressure.

Wilson et al. (1990) recorded the dominant vegetation of the Harts Range region as isolated patches of *Acacia aneura* (Mulga) mixed species low open woodland with open grassland understorey. A second dominant vegetation community in the region is *Acacia estrophiolata* (Ironwood), *Atalaya hemiglauca* (Whitewood) low open-woodland with open grassland understorey. This community often overlaps with *A. aneura* woodland. Other species recorded in this community included *Senna artemisoides* nothossp. *artemisiodes*, *Ptilotus obovatus, Sclerolaena bicornis* and *Einadia nutans.*

The Northern Territory BRS for flora has records of 60 indigenous plant species, 3 exotic species and 1 cosmopolitan species for a 3 km radius around the site. MBS Environmental Services (2004) recorded 122 indigenous species and 9 exotic species in the region immediately east of the site. The latter report is the most detailed, applicable and current assessment of the region.

7.2.2 Conservation status of vegetation species and communities

No plant communities or species of listed conservation status (Commonwealth and Territory) were present on the Harts Range site at the time of the survey. At a national level, there are no eucalypt or acacia species endemic to the Burt Plain Bioregion (NRETA 2006).

On a regional level the site contains communities which are common throughout the Burt Plains Bioregion and Subregions. However, the bioregion is poorly reserved particularly in relation to Mulga Woodlands with only 0.26% of the area of the bioregion covered by a formal reserve agreement.

Three plant species (*Eleocharis papillose* [Dwarf Desert Spike-rush], *Ipomoea sp. Stirling* [Bush Potato] and *Macrozamia macdonnellii* [MacDonnell Ranges Cycad]) are listed as vulnerable at the national level, while some 65 species are listed as 'Data Deficient' by the Northern Territory. This is a reflection of a lack of knowledge of their abundance rather than their rarity or vulnerability.

7.2.3 Introduced plants

Weed diversity in the Alice Springs region is relatively low, excluding areas of high disturbance such as around township and settlement sites, roadsides and some stock grazing properties. Eleven introduced plant species were recorded on the wider area of which four were present in the site. Most are typical low impact and low risk weed species. However, four high or higher impact (risk) species were present.

Buffel grass (*Cenchrus ciliaris*) occurs throughout the region and site. Saffron thistle (*Carthamus lanatus*) and Mexican poppy (*Argemone ochroleuca*) were recorded in the wider area, including adjacent to quadrat 3, near the rubbish dump and in areas used for stockpiling materials. Both species are declared weeds under the *Weeds Management Act 2001* (NT). Buffel grass and Mexican poppy are listed as significant management issues for the region (NRETA 2006).

In addition, the vigorous form of *Salsola kali*, which is a cosmopolitan species, may also be a significant weed species.

7.2.4 Fauna

7.2.4.1 Ground mammals

Sminthopsis youngsoni (Lesser hairy-footed dunnart, Desert dunnart) was the only species recorded by trapping (Site 3) and Red kangaroo was observed throughout the site. Dingo was recorded adjacent to the site. Based on regional biological records, 13 other species are predicted to potentially occur and 14 other species are listed as extinct for the region. By observation, no unusual or critical habitat for mammals is present in the site.

Defence contractor staff have recorded Echidna, Euro, House mouse, feral cat, European rabbit, Red fox, dingo and dingo-dog hybrids, cattle, camel and an unknown species of dunnart in the past.

7.2.4.2 Bats

No assessment was undertaken of this group due to unsuitable weather conditions at the time of survey, although site staff have recorded at least two different species around the buildings. Within the region, at least nine species could occur, although there does not appear to have been a recent systematic survey of this group (Terry Reardon, SA Museum, pers. comm. Nov. 2006). All are relatively common and most would be associated with the roosting habitat provided by mature trees with hollows along the major watercourses and in the rocky hills and with any source of free water.

7.2.4.3 Birds

38 species were recorded in the wider region west of the site in MBS Environmental (2004) and the NT BRS fauna database. The current survey recorded 31 species and it and the MBS Environmental assessment constitute the most detailed and recent bird records for the region.

During the current, brief survey Singing honey-eater, Yellow-throated miner, Rufous whistler, Yellow-rumped thornbill, and Grey-crowned babbler were the most numerous species. Species of interest recorded as single observations were Mistletoe bird, Chiming wedgebill and Crested bellbird.

7.2.4.4 Reptiles and amphibians

Within the wider region about 54 reptile species have been recorded (Kinhill 1992), although five species only were recorded in MBS Environmental (2004). Trapping and observations during this survey in the site recorded *Pogona vitticeps* (Central bearded dragon), *Heteronotia binoei* (Bynoe's gecko), *Gehyra variegata, Varanus giganteus* (Perentie), *Lerista labialis* (Eastern two-toed slider), *Menetia greyii* (Dwarf skink) and *Ctenotus schomburgkii* (Sandplain ctenotus).

Additional species observed by facility staff are King brown snake (Mulga snake, *Pseudechis australis*) (data deficient in the NT), *Morelia spilota* (Carpet snake), *Tiliqua multifasciata* (Centralian bluetongue lizard) and "several small skinks and geckoes". Carpet snake has decreased in numbers in the region in recent years, so this record is of particular interest. Species observed in the region along the main road, including road kill, were *Ctenophorus nuchalis* (Central netted dragon) and Sand goanna (*Varanus gouldii*).

Site staff reported that a burrowing frog (possibly a species of *Cyclorana* or *Neobatrachus*) and a small brown tree frog (possibly *Litoria rubella*) occur at the facility. An additional 4 species may occur in the region.

7.2.4.5 Introduced species

No introduced species were observed at the site, although there was evidence of cattle having been present. Facility staff indicated that House mouse and feral cat are relatively common, with the former species being seasonally abundant at times. Dingo and dingo-dog hybrids, and very rarely, Red fox and European rabbit also occur. Arabian camel, horse and donkey are also rarely recorded for the region. No introduced birds or invertebrates were recorded and none has been reported by Defence contractor staff. A feral European honey-bee colony was recorded adjacent to the property in Ongeva Creek. A number of introduced ant species have been reported recently in Alice Springs, but not at the site.

7.2.5 Conservation status of fauna species

A search of the EPBC Act Protected Matters Database and Northern Territory Parks and Wildlife Schedules showed that four threatened species or species habitat may occur in the area. These species are as follows:

- Desert sand-skipper (*Croitana aerstiva*) – Endangered (Commonwealth and Territory)

  The Desert sand-skipper is endemic to the Northern Territory. The species is known only from specimens collected in 1966, 1972 and 2007 west of Alice Springs in the MacDonnell Ranges. It is apparently confined to native grasslands in these ranges. It is therefore highly unlikely to occur at this site.

- Mulgara (*Dasycercus criticauda*) – Vulnerable (Commonwealth and Territory)

  The Mulgara is widespread but patchily distributed in the arid and semi-arid sandy regions of central Australia (sand plains and dune fields). In the Northern Territory it is almost entirely confined to these sandy desert regions. Its strongholds appear to be the Tanami and Great Sandy Desert bioregions. It is not known to occur in the Burt Plains Bioregion.

- Black-footed rock-wallaby (*Petrogale lateralis*) MacDonnell Ranges race) – Vulnerable (Commonwealth), Near threatened (Territory).

  Black-footed rock-wallabies occur in rocky outcrops and associated steep rocky slopes common to the MacDonnell Ranges Bioregion. If the species occurred in this section of the Burt Plains Bioregion, it would be confined to Harts Ranges south of the site. The species has not been recorded at the facility by Defence contractor staff.

- Australian painted snipe

  The Australian painted snipe is found in shallow inland wetlands, either freshwater or brackish, that are either permanently or temporarily filled. Usually only single birds are seen, though larger groups of up to 30 have been recorded. It nests on the ground amongst tall reed-like vegetation near water, and feeds near the water's edge and on mudflats, taking invertebrates, such as insects and worms, and seeds (DEH 2003). No permanent wetlands or watercourses were present, therefore the likelihood of this species occurring is minimal.

7.3 Land use and demography

7.3.1 Site tenure and use

The site is on Commonwealth-owned land, and managed by the Department of Defence. BEA Systems is commissioned to operate the radar facility.

Defence has facilities on-site for families of staff operating the radar facility. It is understood that Defence is considering remote operation of the site, and thus closure of the on-site accommodation for families. No timetable has been provided for this study.

7.3.2 Surrounding land use

Adjoining land is under perpetual land use agreements, and Indigenous Land Use Agreements (ILUAs) exist 4 km west and 5 km south of the site.

Activities in the area include dry-land cattle grazing, mining and tourism.

7.3.3 Heritage sites

No sites have been recorded on the Harts Range site itself, however three ‘recorded sacred sites’ have been identified in the immediate vicinity. Nine Indigenous Places of Interest were identified from a search of extant records, however their exact location and description cannot be accessed at this stage of the investigations.

7.3.4 Zoning

The site is 90 km directly NNE of the Alice Springs municipal planning zone, and is not subject to local plans. However the site is near Aboriginal Land Living Areas (ALLA), which are subject to control plans. Since the site is on Commonwealth-owned land, and is not proximal to ALLAs, it is unlikely that current or future plans will affect the establishment of a CRWMF.

7.3.5 Proximity to occupied places

7.3.5.1 Aboriginal

There are no Aboriginal communities within 10 km of the site. The nearest community is 15 km north of the site and has a population of approximately 70 people (the Engawala community). The only major centre of Aboriginal population is the Atitjere community, some 48 km east of the site.

7.3.5.2 European

Approximately 20 km west of the site lies the Gem Tree Caravan Park, which is predominantly a tourist location, although there are some permanent residents.

Alcoota Station is a cattle station approximately 14 km north of the site, and has a population of approximately 130 people, which includes the Engawala community mention above.

The only major population centre in the region as a whole is Alice Springs, which is approximately 100 km to the south-west of the site.

7.3.6 Population density and potential for growth

The site is within the Sandover-Bal Census district which has an overall population density of 38 km^2 per person. The site itself is in a CCD area with a population of 215 km^2 per person.

There is little immediate likelihood of population growth.

7.4 Transport issues

7.4.1 National networks

The Harts Range site lies off the Plenty Highway, which is a Northern Territory Rural Arterial Road. The Plenty Highway joins the Stuart Highway north of Alice Springs. The Adelaide to Darwin railway runs through Alice Springs where there is a large freight and intermodal facility.

7.4.2 Site access and interior roads

The radar site is accessed by a sealed road off the Plenty Highway, however to reach the potential site of the CRWMF an upgrade to the existing un-sealed road would be required. There is an alternative access route from the highway to the site, which is currently used occasionally by road trains to collect cattle from a mustering point near the site. This unsealed road would have to be substantially upgraded.

8. Site summary – Fishers Ridge

This section summarises the findings of the site characterisation process for Fishers Ridge. Additional details can be found in the accompanying reports.

8.1 Physical issues

8.1.1 Regional geological setting

The Katherine 1:250,000 geological map presents the site is underlain by Quaternary to Neogene laterite and ferricrete mantel. Underlying this mantel are Cretaceous sandstone, siltstone and claystones with minor pebble conglomerates of fluvial, lacustrine and marine origins.

The Daly River Group underlies the site and consists of Ordovician to Cambrian fossiliferous dolomitic sandstone and dolostone of the Oolloo Dolostone and maroon to green siliclastic siltstone, dolomitic sandstone and siltstone interbeds, ooid dolograinstone dolomicrostone, dolomicrosparstone and dolomitic quartz sandstone, which are understood to originate from low to moderate energy peritidal and tidal flat environments.

The basal unit of the Daly River Group is the Tindall Limestone and consists of grey massive, bioclastic, mottled cryptomicrobial, onkoid and minor fenestral limestone with minor grey mudstone and maroon siltstone.

The Daly Basin is a result of extensive marine transgression across the central and northern Australian craton, beginning in the early Middle Cambrian. Initially peritidal siltstone was succeeded by dominantly open shelf marine conditions and accumulations of fossiliferous limestone (Tindall Limestone). Deposition of low energy, fine dolomitic-siliciclastic sediments (Jinduckin Formation) followed on peritidal flats during at least the latest Cambrian and earliest Ordovician. The succeeding Early Ordovician Oolloo Dolostone marks a more offshore ooid shoal facies.

Regional sedimentation then ceased until the Early Cretaceous, when pre-existing rock were mantled by a thin veneer of shallow marine to continental sands and silts during periods of sea level highstands. Paleogene, Neogene and Quaternary activity has been limited to processes of erosion, floodplain deposition and regolith, colluvium and local laterite development.

8.1.2 Site geology

Table 8.1 summarises the subsurface conditions at Fishers Ridge.

Table 8.1 Summary of soil and geology at Fishers Ridge

Average depth (m)	Material description	Age/formation
0 – 0.1	Silty Sand (SM), fine to medium grained, loose, dry	Quaternary
0.1 – 0.55	Silty Sandy Gravel (GP), Silty Gravelly Sand (SP), fine to coarse grained, medium dense to very dense, dry (FRTP01, FRTP02, FRTP05, FRTP06, FRTP07)	
0.55 – 1.6	Laterite, massive, moderate to high strength, excavated as sandy gravel, fine to coarse grained, very dense, dry.	
1.6 – 4.5	Silty Sand (SM), Silty Sandy Gravel (GP), Silty Gravelly Sand (SP) and Laterite. Generally medium dense to very dense, dry (as encountered in test pits)	
4.5 – 68 (FRBH01 only)	Sandstone, very fine to coarse grained, extremely low to low strength, extremely to high weathered.	Cretaceous
	Occasional Claystone and Conglomerate beds.	
4.5 – 18 (FRBH02)	Siltstone, light grey – maroon, extremely low to low strength with occasional harder layers, extremely to highly weathered, generally highly fractured/brecciated and infilled.	Ordovician (Oolloo Dolostone) Over Cambrian (Jinduckin Formation)
	Occasional fine, fine to medium grained sandstone layers.	
	Abundant angular siltstone fragments in very fine grained matrix in places (FRBH02–FRBH05)	
	Sandstone, fine to coarse grained, angular to sub angular grains, extremely to highly weathered, massive, occasional Claystone and Conglomerate layers (matrix supported, momomictic, max clast size 20 mm) (FRBH01)	
18 – 25	Interbedded Siltstone and Sandstone, extremely low to low strength, extremely to highly weathered	
25 – 68	Sandstone, fine to coarse grained (FRBH02-FRBH05), very fine to fine grained (FRBH01-gradually increasing grainsize to fine to coarse grained at ~32 m), mottled light brown, orange brown, grey, angular to sub angular grains, extremely low to low strength, extremely to highly weathered, recovered as sandy clay in places. Faint horizontal bedding planes noted at 33 m. significant core loss between 31 m – 42 m and 53 m – 68 m.	
	Conglomerate, medium to coarse grained, max particle size 30 mm, polymictic, no orientation noted, matrix supported, extremely low strength	

		Age/formation
68 – 77	Siltstone, maroon with orange brown mottling, extremely low to very low strength, extremely to highly weathered, generally recovered as clayey silt/silty clay, occasional bands of fine to coarse grained angular gravel	
77 – > 80.6	Limestone, very fine to fine grained, orange brown to grey with some black veining, high to very high strength, highly weathered, massive, crystalline texture, siliclastic, abundant solution cavities infilled with calcite and quartz, some Fe staining, highly fractures throughout	Cambrian (Tindall Limestone)

8.1.3 Permeability

Permeability ranged from 9.8 x 10^{-10} to 3.5 x 10^{-7} m/s. The permeability of the underlying soils at Fishers Ridge may be classified as low to very low in accordance with Terzaghi & Peck (1967). Laboratory permeability test results on gravelly clayey sands from Fishers Ridge recorded K = 1.5 x 10^{-8}, classified as low to very low.

8.1.4 Mineralogy and petrology

Mineralogical and petrographic analysis of the sandstones from borehole FRBH01 reports the mineralogy to be dominated by fine grained, sub rounded to rounded Quartz and Kaolinitic cement. Samples analysed from borehole FRBH02 report the mineralogy is dominated by Kaolinite with sub-dominant/co-dominant Quartz. Although mineralogy is similar in both boreholes grain sizes vary significantly with the coarser grained Quartz rich Sandstone in borehole FRBH01 absent from the sequence encountered in borehole FRBH02.

8.1.5 Mineral prospectivity

There are no known historic mineral occurrences in the Fishers Ridge site. The region hosts a number of mineral deposits, with the majority concentrated in a number of mineral fields. Proterozoic mineral deposits on the geological sheet ‘Katherine’ are categorised into vein, stratabound, stratiform or placer deposits. Most mineralisation, including most of the gold and tin deposits, is hosted by metasediments of the Tollis Formation and Burrell Creek Formation thus the likelihood of mineral deposits at the site is low.

8.1.6 Groundwater

Table 8.2 shows the groundwater levels measured at installation and on subsequent sampling eleven weeks after installation.

Table 8.2 Recorded groundwater levels at Fishers Ridge

Borehole	Recorded depth (mbgl)	
	Installation	Sampling
FRBH01	17.6	24.86
FRBH02	27.2	Nil
FRBH02a	Nil	Nil
FRBH03	27.2	6.5
FRBH03a	Nil	Nil
FRBH04	18.2	6.77
FRBH04a	4.0	Nil
FRBH05	Nil	Nil

Although no groundwater was encountered in FRBH05 and FRBH05a, on completion of the drilling substantial amount of warm air was being expelled from the 30 m deep FRBH05 borehole. During the groundwater sampling program, some eleven weeks after the well installation, it was noted that air was still being expelled from the dry monitoring well. The source and mechanism for the air expulsion from the borehole has not been investigated.

8.1.7 Geotechnical issues

In accordance with AS2870-1996 ‘Residential Slabs and Footings’, all four sites are classified as Class S (less than 20 mm movement) due to the sandy and clayey sand sites underlain by calcrete or laterite to 4 m depth and weathered rock below. Sites with rocky outcrops would be classified as Class A.

Conventional excavation machinery may encounter difficulties at relatively shallow depth (<1.5 m) at Fishers Ridge due to the laterite formations. It is considered likely that larger machinery and hydraulic rock breakers would be required if excavations are to extend below 1.5 m depth.

8.1.8 Earthquake and liquefaction

The Site Hazard Factor for Fishers Ridge is 0.7 based on a 1 in 500 year annual probability of exceedance for areas within Northern Territory. As the facilities will be designed for long periods (300 years), additional seismic studies may be required to further define the above hazard factors for the long design life of the structures. The liquefaction potential is low (due to the unsaturated underlying soils and the depth to groundwater).

8.1.9 Construction materials

Limited construction materials are available at Fishers Ridge and are restricted to the laterite and thin clay horizons.

8.1.10 Sub-surface migration

Falling head permeability tests carried out at the four sites indicate that up to a depth of 10 m below existing surface levels migration of fluids would be greatly impeded by the very low permeability of the existing soil and rock profiles.

At depth, recovered rock core had a high clay content, which is considered to be a result of in-situ weathering resulting in a reduction of the porosity and therefore overall permeability of the profile.

However, highly fractured zones with occasional mineral infilling were noted, indicating some potential fluid flow may occur along these fractures.

8.1.11 Hydrogeology

Groundwater was measured at between 4.0 and 27.2 m below ground surface.

At Fishers Ridge, groundwater generally flows to the east on the east side of the ridge and to the west on the west side of the ridge. Local hydraulic gradients are estimated to be approximately 1–2%.

Fishers Ridge is in a tropical wet-dry area where groundwater characteristics are typically quite different to the arid zone southern sites. Shallow, seasonal ‘perched’ water tables are common, and water table variations in the shallow permanent aquifers may be over 5 m annually (e.g. Hutton et al. 1997 illustrate a well in tropical woodland near Darwin with annual variation of up to 10 m some years). However, seasonal variations in Tindall Limestone bores near the site are not pronounced.

Water level fluctuations in the Cretaceous sediments at Fishers Ridge are significant as shown by the drying up of two wells between August and October 2006. Water level logger data obtained to date is not useable as one was installed in a well that dried up and the other logger malfunctioned.

8.1.12 Surface hydrology

The Fishers Ridge site is located in the Wet-Dry tropics with an average rainfall of nearly 1,000 mm/yr, with active streams that flow each Wet Season.

A loop of the King River briefly enters and leaves the western boundary of the site near the south-western corner, whilst Roper Creek flows enters the site on the eastern boundary and exits the southern boundary near the south-eastern corner. The drainage divide runs approximately north-south just to the east of the centre of the site. Local drainages (not as distinct streams) occur over parts of the site.

If investigations are taken further at this site the floodplains of both King River and Roper Creek would require further study to check the expected extent of flooding, although based on site observations the higher parts of site are likely to be out of flood reach for credible floods. Anecdotally King River has been known to at least reach the road bridge at the Stuart Highway.

8.1.13 Meteorology

Fishers Ridge will experience the highest annual rainfall of all four sites, and has the highest predicted 1:1000 year ARI of 33.4 mm (5 minute) and 573.3 mm (72 hour).

8.2 Biological issues

8.2.1 Vegetation – regional setting

The vegetation of the region is dominated by Eucalypt woodlands over savannah grasslands with small areas of a number of riparian vegetation communities (DIPE 2003). The communities described for the region in the Northern Territory Parks and Conservation Masterplan-Daly Basin Region 2004 (NRETA 2005) include *Corymbia dichromophloia* and *Eucalyptus tetrodonta* woodland with grassland understorey.

Detailed assessment of both the region and the local area vegetation has been described in Kinhill Stearns (1983) with more recent assessments northeast of the site in Maud Creek South Station, Maude Creek (Dames and Moore 1998), which is about 55 km north of Fishers Ridge.

Kinhill Stearns (1983) described the following vegetation communities as common in the area:

- open forest-woodland of *E. tetrodonta, E. miniata, Corymbia terminalis* over mixed spinifex-annual sorghum and tropical tall-grass (*Themeda, Sehima*)
- low open woodland or low woodland with *Corymbia dichromophloia, C. terminalis* over spinifex and annual grasses
- mixed open woodlands of *Eucalyptus foelscheana, E. tectifica-Corymbia confertiflora* and other species with perennial tall grasses.

The dominant vegetation communities recorded in the region by Dames and Moore (1998) were:

- *Corymbia dichromophloia* and *Erythrophleum chlorostachys* woodland
- *Eucalyptus tetrodonta* open woodland to woodland
- *E. foelscheana/ E. tectifica* woodland to open woodland
- *Lophostemon grandiflorus* open woodland
- *E. tectifica/Erythrophleum chlorostachys* low open woodland
- *Eucalyptus pruinosa* low open woodland.

8.2.2 Conservation status of vegetation species and communities

A search of the EPBC Act Protected Matters Database indicates that there are no known plant species of national significance in the area.

In the Daly Basin Bioregion, two plant species regarded as vulnerable under the Territory Parks and Wildlife Conservation Act, have been recorded. *Nervilia plicata*, *Hibiscus vitifolius* are known to occur to the northwest of Katherine (DIPE 2003). Neither species is likely to occur at Fishers Ridge, due to differences in soils and habitat characteristics. Four species regarded as data deficient have been identified as requiring more research to confirm their status, namely *Nervilia cordata, N. peltata,* *N. uniflora* and *Didymoplexis pallens* (DIPE 2003). None of these species was recorded during the dry season survey and based on their habitat requirements, none would be expected to occur at the site.

A small riparian strip of flood terrace vegetation occurs along the King River adjacent to the site. The vegetation is generally in good condition and represents significant fauna habitat to the area. The Draft Conservation Plan for the Daly Basin Bioregion 2003 identifies riparian strips as significant ecosystems for the Daly Basin.

8.2.3 Introduced plants

Assessing the weed diversity and populations was difficult given the recent fuel reduction burn. Observations of weed species along the Stuart Highway and surrounding access tracks provided some indication of the species expected to occur on site.

Hyptis was reasonably widespread throughout the site, with a higher density in the riparian habitat and along the access track. Dames and Moore (1998) also noted that this was the most abundant weed on the creek banks and levees of the Maud Creek region. *Passiflora foetida* was also present in these floodplain habitats.

Sida acuta was recorded in the heavily grazed areas of the site (quadrats 1 and 5) and is potentially as abundant as Hyptis in the drier regions of the site. Dames and Moore (1998) recorded significant infestations of both *Sida acuta* and *Sida cordifolia*. Both species are likely to occur throughout the site especially given the presence of feral animals such as pigs, which readily disperse seeds.

No Weeds of National Significance (WONS) or Schedule Class A/C, B/C, or C species as listed under the *Weed Management Act 2001* (NT) were observed in the site.

8.2.4 Fauna

8.2.4.1 Ground mammals

No species was recorded in the site, although three species were seen adjacent to the site and 24 species have been recorded in the wider region. Short-beaked echidna, Agile wallaby and Antilopine kangaroo were seen along the King River or the main access road to the site. Water rat and Grassland Melomys would be predicted to occur at the site, while Northern quoll could use the site as part of a wider territory.

8.2.4.2 Bats

Twenty one species have been recorded in the wider region, including the threatened species, Ghost bat and Orange horseshoe (leaf-nosed) bat. A number of small insectivorous bat species would be expected to roost in hollow trees and to use the surface water for drinking. However, the absence of large areas of rock outcrop, caves and sink holes will exclude the presence of many species. No field assessment was undertaken of this group. Even so, the site does not provide critical habitat for any bat species.

8.2.4.3 Birds

Over 200 bird species have been recorded in Nitmiluk National Park, with 77 species from the Cutta Cutta Caves Nature Park and about 70 species from RAAF Base Tindal. Twenty one species were recorded in and adjacent to the site during the survey, with most species present along the King River. All were species common in the Top End, although several species were of particular conservation significance.

8.2.4.4 Reptiles and amphibians

Seventy eight reptile species and 25 frog species have been recorded in all of Nitmiluk National Park. Twenty nine reptile species and 12 species of amphibians have been recorded at Cutta Cutta Caves, with similar species diversity from RAAF Base Tindal. Eleven reptile species and one frog species were recorded during field assessments. All were common species with a wide range in the Top End.

8.2.4.5 Fish

Thirty eight species have been recorded in the watercourses in the region. Red-tailed rainbow fish was the only species seen during the assessment in the King River adjacent to the site.

8.2.4.6 Introduced species

The Cane toad (*Bufo marinus*) was recorded along the floodplain and adjacent areas west of the site. Cane toads were trapped and were also observed occupying burrows within termite mounds, soil holes, and low tree hollows. It is likely that the species will occur across the site during the wet season.

Cattle and pigs were present across the site, with the latter common along the King River, Roper Creek and the edge of Leech Lagoon.

Six other introduced vertebrates have been recorded in the region.

8.2.5 Conservation status of fauna species

A search of the EPBC Act Protected Matters Database showed that a number of threatened bird and mammal species and/or species habitat may occur in the area. These species are as follows:

- Red goshawk (*Erythrotriorchis radiatus*) – Vulnerable

  The Red goshawk is known to occupy a range of habitats in northern and eastern Australia. This species prefers coastal and subcoastal tall open forests and woodlands. Habitats required by Red goshawk for breeding are very specific. They will only nest in trees taller than 20 m, and these are usually within 1 km of water. The species has a large home range and is often a coastal woodland species (Birds Australia 2006).

  The Fishers Ridge site contains very few trees over 20 m high, but it is in close proximity to Leech Lagoon and the King River, where trees of this stature are present. It is also likely that there are small areas of tall trees on more fertile or better watered sites elsewhere in the area. Nonetheless, the species is present in

Nitmiluk National Park. While it has not been recorded for the region in the NT fauna database, it could occur as a vagrant over the site.

- Gouldian finch (*Erythrura gouldiae*) – Endangered

  The species is listed as endangered and migratory under the EPBC Act and endangered under the TPWC Act. Occasional records for the Gouldian finch (*Erythrura gouldiae*) occur across much of the northern NT, including a record 15 km north east of the site (DPI 2006). No records have been found to show that the species occurs within the Fishers Ridge area. The species prefers open tropical woodland with grassy understorey habitat within or close to areas of rocky hills containing *Eucalyptus tintinnans*, which is an important small tree used for nesting by the species (Garnett and Crowley 2002). *Eucalyptus tintinnans* does not occur at the site or adjacent region and the grasslands within the site are unlikely to provide enough suitable habitat to support Gouldian finches. It was not recorded for the site in Kinhill Stearns (1983) or at Cutta Cutta Caves (PWCNT 2000).

- Crested shrike-tit (northern) (*Falcunculus frontatus whitei*) – Vulnerable

  A single record of Crested shrike-tit (northern form) is available 9 km to the south east of Fishers Ridge. Crested shrike-tit prefer eucalypt woodlands and forests. Populations are generally strongly associated with river red gum open woodland. In this region, the Crested shrike-tit appears to be reliant on extensive stands of this species. In southern Australia, the species can more easily glean prey from the loose ribbon-like bark of species such as *E. camaldulensis* than from the deeply furrowed bark of some other Eucalypt species (Joseph and Reid 1981).

  The King River floodplain adjacent to the site has scattered river red gums within the tall open riparian woodlands. These trees are sparse, however they may provide the habitat required for Crested shrike-tit. A number of the large trees within the riparian zone were also noted as being hollow, thereby providing further habitat for this species.

- Australian painted snipe (*Rostratula australis*) – Vulnerable

  The Australian painted snipe is usually found in shallow inland wetlands, either freshwater or brackish, that are either permanently or temporarily filled. Usually only single birds are seen, though larger groups of up to 30 have been recorded. It nests on the ground amongst tall reed-like vegetation near water, and feeds near the water's edge and on mudflats, taking invertebrates, such as insects and worms, and seeds (DEH now DEWHA 2003).

  The species has a scattered distribution throughout many parts of Australia. Though some individuals are apparently resident in some areas, other individuals appear to be nomadic, temporarily occupying areas where suitable habitat exists (DEH 2003).

  A search of the NT Parks & Wildlife Commission's Biological Records Scheme (BRS) database, 2006 showed no records of Australian painted snipe occurring in the Fishers Ridge area, although Leech Lagoon provides suitable habitat for the species.

- Bare-rumped sheath tail bat (*Saccolaimus saccolaimus nudicluniatus*) – Critically endangered

  This species or species habitat was noted as potentially occurring in the Fishers Ridge area during a search of the EPBC Protected Matters Database. A search of the Territory BRS indicated that the species has not been recorded in this area or its surrounds.

Other species of particular conservation significance which could occur in the region include a group of bird species, such as Hooded parrot, Rainbow bee-eater, Azure kingfisher, Black falcon, Square-tailed kite, Grey falcon, Masked owl, Australian bustard and Bush stone-curlew. Brush-tailed phascogale is a mammal that could be present, if not in the site, then at least in the region. Most of these species are declining in distribution and population number in the NT and Australia.

Hooded parrot (*Psephotus dissimilis*) occurs north of the site and has been reported as occurring in the district. It nests in large termite mounds. All termite mounds greater than 1.5 m high in the site were inspected but nest holes were not recorded.

Rainbow bee-eater (*Merops ornatus*) was present in the riparian vegetation of the King River and Roper Creek adjacent to the site. It was abundant at the former location. This species is a listed migratory marine species under the EPBC Act and JAMBA. The presence of a permanent watercourse provides important nesting and feeding habitat for this species which uses slopes and riverbanks for establishing nests. It is highly likely that this species uses the area for nesting and breeding and the site for feeding. The species is common across all of the Top End and some birds are regional migrants, while others are transcontinental migrants.

Azure kingfisher (*Alcedo azurea)* is a species confined to riparian corridors and it is likely to occur along the King River and possibly at Leech Lagoon. It is too dry for the species in the site and it would not occur there.

The other bird species could occur in the region, but the site does not offer any area of habitat that is preferred or of critical importance to any of the species.

Very little is known of the Brush-tailed phascogale (*Phascogale tapoatafa pirata*) in the NT, let alone the region. It is likely that the northern form of the species will be recognised as a new species. Typical of the species, it has a large home range and low capture rates occur. It appears to have been relatively common in the past and there has been a decline in its population recently, with all of the recent records of the species north of Katherine. Nonetheless there is sufficient suitable habitat for the species in the region and site.

8.3 Land use and demography

8.3.1 Site tenure and use

The site is the property of the Commonwealth and is not subject to Northern Territory planning schemes. It also lies some 40 km away from the Katherine Municipal boundary and is not subject to local planning schemes.

The site is currently used for grazing by arrangement between the local pastoralist and Defence. Anecdotal evidence suggests that recreational anglers access the local waterways via the site.

8.3.2 Surrounding land use

The site is surrounded by perpetual pastoral leases, freehold land and Crown land lease for future development. There is also nearby Aboriginal Community Land.

8.3.3 Heritage sites

Two recorded sacred sites exist within the boundary off the Fishers Ridge site, although not close to the target area identified as the potential location of a CRWMF.

Cutta Cutta Caves lie some 14 km west of the site, and Leech Lagoon lies some 2 km south of the site. The caves are listed on the Register of the National Estate and a decision on Leech Lagoon is pending.

8.3.4 Proximity to occupied places

8.3.4.1 Aboriginal

Five kilometres north of the site lies Aboriginal Freehold Land, and 2.5 km to the east lies Aboriginal Trust Land. The closest Aboriginal family outstation is between 5 and 10 km away.

There are a further nine Aboriginal communities within 50 km of the site, ranging from minor outstations to major town camps in Katherine.

8.3.4.2 European

Apart from the Tindal airbase and Katherine, the area is characterised by homesteads at pastoral properties.

8.3.5 Population density and potential for growth

The principal population centres are Katherine and Tindal. Katherine is the Northern Territories' fourth largest town with a population of approximately 10,000 people.

In the relevant census district, the population is sparse, with approximately 20 km^2 per person.

No clear pattern emerges for consistent population growth in the area, although a change in statistical boundaries prior to the 2006 census makes it difficult to compare that year with the previous time series.

8.4 Transport issues

8.4.1 National networks

The site is accessed from the Stuart Highway, which is a National road constructed to high standards. The Adelaide to Darwin railway line passes through Katherine.

8.4.2 Site access and interior roads

There is an unsealed but formed road that passes from the Highway, through the site and onwards towards an Aboriginal outstation. This road appears to perform well, even though the area is in a high rainfall zone (some erosion was observed at water crossing places). This road, and any road leading from it to a potential site for the CRWMF would need upgrading.

9. Site summary – Muckaty Station

This section summarises the findings of the site characterisation process for the Gazetted and Regional sites at Muckaty Station. Additional details can be found in the accompanying reports.

9.1 Physical issues

9.1.1 Regional geological setting

The Muckaty Station site comprises mainly of fine to very coarse grained Lower Proterozoic Quartz Sandstone and Pebbly Sandstone with interbedded Claystone and Siltstone of the Tomkinson Group.

Around Muckaty Station homestead are the Cambrian Helen Springs Volcanics. Much of the west part of the sheet consists of a surface covering of Quaternary aeolian sand and silty sand with some minor outcrops of Laterite.

The Tomkinson Group consists of thick siliciclastic units that alternate with six mixed siliciclastic-carbonate intervals. This Group is a succession of shallow marine and continental sedimentary rocks, which the Hayward Creek Formation is the lower part of the sequence.

The Hayward Creek Formation is described as a thinly to very thickly bedded medium to very coarse sandstone and pebbly sandstone with minor pebble to cobble conglomerate (clasts of white vein quartz and white to pinkish cream quartz arenite), minor thinly bedded fine to medium sandstone, siltstone, mudstone and intraformational conglomerates, and basaltic lava. The depositional environment is fluvial to shallow marine, intertidal with periodic subaerial exposures.

Surface exposures of the Helen Springs Volcanics basaltic lava or flood basalt is limited but airborne magnetic imagery suggests the basalt may extend under the north-eastern corner of the nominated site and below the alluvial and aeolian sand plains which were targeted by several boreholes.

9.1.2 Site geology

Two distinct subsurface provinces have been identified within the Muckaty site. Province 1 predominantly consists of a sand valley with sandy soils and some laterite surrounded by low rocky ridges while Province 2 is a sand plain with slightly deeper sands occurring on the north-eastern corner of the nominated site. Both these provinces encountered up to five to six metres of sand (SP) and silty sand (SM) overlying bedrock material. The remainder of the site is covered by low rocky outcrops of the Hayward Creek Formation fine to coarse sandstones to conglomerates.

The regional investigation site consisted of weathered and fractured Hayward Creek Formation sandstones and quartzite rock from the surface.

Table 9.1 summarises the subsurface conditions at the Muckaty site.

Table 9.1 Summary of soil and geology at Muckaty Station

Average depth (m)	Province	Material description	Age/formation
0 – 5	1/2	Sand (SP), Silty Sand (SM), fine to medium grained, loose to dense, dry. Laterite, fine to very coarse, sub rounded to angular	Quaternary
5 – 11 MSBH01	2	Siltstone/Sandstone, light grey to white, fine grained, claystone, white, highly to extremely weathered.	Gum Ridge Formation? Cambrian
5 – >35 MSBH01/02	2	Basalt, white to grey-green (some purple bands) low to very high strength, highly weathered to fresh, variable fracture spacing but becoming more intact below ~20m. abundant Augite throughout.	Helen Springs Volcanics. Cambrian
5 – >48 MSBH03/06	1	Pebbly Sandstone, fine to very coarse grained, sub angular to rounded, quartz rich, highly to slightly weathered, low to high strength.	
	1	Sandstone, fine to coarse grained, angular to sub angular grains, extremely to highly weathered	Hayward Formation. Lower Proterozoic
5 – >48 MSBH04/05	1	Predominantly Siltstone, extremely to highly weathered, very low to medium strength, with some interbedded mudstone and sandstone	

9.1.2.1 Province 1

Rock outcrops of Hayward Formation sediments in low lying ridges surround Province 1. The shallow valley is mainly covered by loose, dry sands and silty sands with some basal gravels above bedrock at shallow depths (<5 m). The bedrock in Province 1 is comprised of pebbly sandstone, sandstone, quartz sandstone, mudstones and siltstone of the Hayward Formation

9.1.2.2 Province 2

Province 2 is a very prominent sand plain that runs WNW-ESE of the site which is bound by low lying mud plains to the north and the Hayward Creek Formation rocky ridges to the south.

Boreholes encountered up to 4.5 m of sand and silty sand overlying bedrock. A thin layer of sandstone and siltstones, which have been interpreted as being from the Cambrian Gum Ridge Formation, overly highly weathered to fresh basalt of the Helen Springs Volcanics. Interception of the basalt in the boreholes confirmed the interpretation from the airborne magnetic survey of basalt underlying the sand plains.

The basal section of these sediments is clay rich and highly to extremely weathered and this may have resulted from in situ weathering of the sediments by ground water moving above the basalt layer.

9.1.2.3 Regional studies area

The regional studies area is a prominent rocky ridgeline that extends west of the Stuart Highway for a distance of about 3 km which is covered by extensive quartzite outcrop. A deep gully bisects the ridgeline at its western end and boreholes were located in each of the western ridgelines to provide information for regional geology and groundwater studies. Boreholes encountered quartz sandstone over quartzite to a investigation depth of approximately 50 m.

9.1.3 Permeability

Falling head tests provided results in the range 1.2 x 10^{-6} to 6.3 x 10^{-8} m/s. The permeability of the underlying soils at Muckaty Station may be classified as medium for the upper sands and very low for the bedrock materials in accordance with Terzaghi & Peck (1967). Laboratory permeability test results on compacted sands from Muckaty Station recorded K = 6.3 x 10^{-8}, classified as low to very low.

9.1.4 Mineralogy and petrology

Mineralogical and petrographic of the basalt intercepted in MSBH01 at 28 m depth identified calcium-plagioclase (with some sericitic alteration) and clinopyroxene as the dominant minerals with minor olivine, magnetite, carbonate and silica minerals, all typical of a slightly weathered to fresh basalt.

Above the basalt was a clay rich unit, identified within the borehole logs as highly weathered siltstone (MSBH01 9.9–11.85 m) which was identified as being a kaolinitic claystone with minor muscovite.

The highly weathered quartz sandstones intercepted in MSBH03 (20.3 m depth) were confirmed by the dominance of fine grained quartz in a kaolinitic matrix.

The highly weathered siltstones intercepted in MSBH05 (17.65 m depth) were confirmed by the dominance of ultrafine kaolinite with muscovite (altered to sericite) and a trace of fine quartz.

The highly weathered quartz sandstone intercepted in GHBH02 (46.9 m depth) were confirmed by the dominance of medium grained quartz grains with claysericite throughout (weathered feldspar/lithic fragments).

9.1.5 Mineral prospectivity

There are no known economic mineral deposits within the Muckaty site. The Muckaty area contains significant manganese deposits and is prospective for base metals, diamonds, copper and hydrocarbons. OM Manganese operates the Bootu Creek Manganese Mine, which is located 25 km to the east of the site. Amorphous and massive cryptomelane manganese oxides are mined.

Two exploration licence applications (EL24951 & EL26553) cover the Muckaty site which have been applied for by Neil Henry Scriven (research has been unable to find any information on the applicant or mineral exploration targets).

9.1.6 Groundwater

Table 9.2 shows recorded groundwater depths at Muckaty Station.

Table 9.2 Recorded groundwater levels at Muckaty Station

Borehole	Gazetted/Regional	Recorded depth (mbgl)	
		Installation	Sampling
MSBH01	G	24.7	24.9
MSBH02	G	24.0	24.1
MSBH03	G	14.6	14.8
MSBH04	G	5.3	5.4
MSBH05	G	7.0	25.6
MSBH06	G	24.0	25.0

Sampling took place approximately seven weeks after installation.

9.1.7 Geotechnical issues

In accordance with AS2870-1996 'Residential Slabs and Footings', all four sites are classified as Class S (less than 20 mm movement) due to the sandy and clayey sand sites underlain by calcrete or laterite to 4 m depth and weathered rock below. Sites with rocky outcrops would be classified as Class A.

Conventional excavation machinery is considered suitable for excavations to approximately 1.0 to 2.5 m depth below existing surface levels within the two Provinces on Muckaty Station. Below these depths, on the rocky ridges surrounding the two Provinces and at the regional site larger machinery, hydraulic rock breakers and drill and blast methods may be required to aid excavation of medium to high strength rock materials The stability of the excavations is unlikely to cause problems and it is considered that they would remain open without support..

9.1.8 Earthquake and liquefaction

The site hazard factor for Muckaty Station is 0.9 based on a 1 in 500 year annual probability of exceedance for areas within Northern Territory. As the facilities will be designed for long periods (300 years), additional seismic studies may be required to further define the above hazard factors for the long design life of the structures.

The liquefaction potential is low due to the very shallow to outcropping bedrock and deep groundwater levels.

9.1.9 Construction materials

Muckaty Station has limited construction materials available on-site, restricted to the upper sands and gravels from within the sand valleys and plains. Rock excavated from the bedrock and ridges may be crushed to produce some construction materials such as general fill and pavement materials.

Muckaty Station has a road construction borrow source located in the south eastern corner of the gazetted area which was used in the construction of the Bootu Creek mine haul road.

9.1.10 Sub-surface migration

Falling head permeability tests carried out at the four sites indicate that up to a depth of 10 m below existing surface levels migration of fluids would be greatly impeded by the very low permeability of the existing soil and rock profiles.

At depth, recovered rock core had a high clay content, which is considered to be a result of in-situ weathering resulting in a reduction of the porosity and therefore overall permeability of the profile.

However, highly fractured zones with occasional mineral infilling were noted, indicating some potential fluid flow may occur along these fractures.

9.1.11 Hydrogeology

Muckaty Station has several wells, some of which are not in use, but almost all of which are capable of producing potable quality water at usable rates. The name ‘Ngapa’ means desert rains. The groundwater derived from the episodic desert rains sustains the ranching operation at Muckaty Station. The generally good groundwater quality in existing wells the Muckaty station area is evidence that the groundwater is mostly relatively young and derived from local precipitation.

Recharge to the water table is likely to be episodic and associated predominantly with major precipitation events, when surface water runoff takes place. Therefore, considerable temporal variation in groundwater levels is likely. Average recharge rates, as a percentage of total rainfall, could be quite high. Perched water tables are possible at the base of alluvial deposits immediately following major precipitation events. These would dissipate with time as the newly recharged groundwater infiltrated into the fractures of the bedrock.

The depth to water at the Bootu mine haul road bore near the southeast corner of the Muckaty site is reported to be 22 m. The local direction of groundwater flow at the Muckaty site was not discernible from existing water well data as there were no wells located on site prior to this study. However it can be expected that the regional water table surface is a subdued form of the topography such that the regional groundwater flow direction to the west of the Stuart Highway is towards the low lying sandy desert plains to the west, and local flow systems can be expected to be controlled by local topography also.

The loose alluvial sediments that drape much of the bedrock would be expected to have a high permeability due to their coarse grainsize whereas the bedrock beneath the alluvial sediments would be expected to have a relatively low permeability, controlled primarily by fractures.

9.1.12 Surface hydrology

The local catchments in the Muckaty area are generally well defined due to the local relief which is on the order of tens of metres. Tomkinson Creek, the primary surface water course in the area, close to Muckaty Station, is relatively well defined, although ephemeral. There are no permanent streams in the area.

The Muckaty site is part of the Tomkinson Creek catchment, which is part of the Wiso regional catchment area.

A local surface water drainage divide crosses the northern part of the Muckaty site, separating the South Tomkinson Creek Catchment to the north from another tributary of the Tomkinson Creek to the south.

Over most of the Muckaty site, surface water drains from the site to the southwest. It then enters a northwest-trending valley, the axis of which passes approximately 3 km from the south-western corner of the site. The drainage along this valley then joins Tomkinson Creek approximately 25 km west of the regional site, which then drains north-westwards, ultimately into the northern Tanami Desert.

9.1.13 Meteorology

The Muckaty region has a sub-tropical climate with distinct wet and dry seasons. The wet season is from January to early March, with an average of 44 rain-days per year. On average in the wet season between 50 and 125 mm of rain fall each month, whereas in the dry season less than 10 mm fall per month.

The 1:1000 ARI is 25.4 mm (5 minutes) and 495.9 mm (72 hour).

9.2 Biological issues

9.2.1 Vegetation – regional setting

Muckaty Station is on the edge of two bioregions, Tanami and Sturt Plateau (NRETA 2006). It shares a range of characteristics and similarities with both bioregions. While there is a strong monsoonal influence on climate and water availability, many of the flora and fauna species, especially ground fauna, are more typical of a desert environment than the Top End. Christian et al. (1952) indicates that the Ashburton (hilly, rocky country) and Elliot (plains) land systems are present in the region.

The Muckaty site forms part of the Tanami bioregion with the regional site forming part of the Sturt Plateau bioregion.

The Tanami bioregion comprises mainly red Quaternary sandplains overlying Permian and Proterozoic strata which are exposed locally as hills and ranges. The sandplains support mixed shrub steppes of *Hakea suberea*, desert bloodwoods, acacias and grevilleas over *Triodia pungens* hummock grasslands. Acacia shrublands over hummock grass communities occur on the ranges. Alluvial and lacustrine calcareous deposits occur throughout.

The Sturt Plateau bioregion mostly comprises a gently undulating plain on lateritised Cretaceous sandstones. Soils are predominantly neutral sandy red and yellow earths. The most extensive vegetation is eucalypt woodland (dominated by variable-barked bloodwood, *Corymbia dichromophloia*) with spinifex understorey.

Most of the bioregion is generally in moderate to good condition, due at least in part to the lack of intensive development. There are pervasive, but generally minor impacts associated with weeds, feral animals, pastoralism and changed fire regimes.

A conservation plan for the Sturt Plateau bioregion is currently being prepared. This included a comprehensive survey of the bioregion's fauna and flora, and an assessment of conservation values. The conservation plan was not available at the time of survey.

9.2.2 Conservation status of vegetation species and communities

No flora species of conservation significance were recorded at the time of the survey. Based on regional data from NRETA, it is considered unlikely that species of conservation significance occur at the site in the areas of interest.

9.2.3 Introduced plants

Of particular note was the lack of weed species throughout the Muckaty site. All weed species recorded were primarily associated with the more fertile red earths and black soil areas of the Muckaty Station and adjacent to more heavily used tracks and sites.

No weed species were recorded at the regional site even though the area is considered more disturbed and is relatively close to the Stuart Highway.

9.2.4 Fauna

9.2.4.1 Ground mammals

Mammals were not recorded at the regional studies area, while four species were recorded at the Muckaty site. Red kangaroo (*Macropus rufus*) and Euro (*Macropus robustus*) were seen in the general vicinity of the gazetted site and would be expected to occur here. The Northern nailtail wallaby (*Onychogalea unguifera*) was recorded once within the denser shrubland vegetation of the gazetted site. Spinifex hopping mouse (*Notomys alexis*) was found across the Muckaty site in the sandy areas with hummock grassland habitats. Being a colonial species, it is likely that a relatively large population of this species occurs on site.

The Short-beaked echidna (*Tachyglossus aculeatus*), Forrest's mouse (*Leggadina forresti*), Greater bilby (*Macrotis lagotis*), Sandy inland mouse (*Pseudomys hermannsburgensis*) and Desert mouse (*P. desertor*) are predicted to occur (echidna, desert mouse and Forrest's mouse) or may be present (other species). The Echidna would likely inhabit both areas. Forrest's mouse, Desert mouse, Sandy inland mouse and Greater bilby would more likely use the sandy slopes and plains with shrublands and hummock grasslands at the Muckaty site.

The Centralian pebble-mound mouse (*Pseudomys johnsoni*), has been recorded within the region. It has a preference for gravely slopes in hummock grasslands (as found in both areas, but more especially the larger areas of this habitat in the Muckaty site).

9.2.4.2 Birds

Forty one (41) native bird species were recorded in and adjacent to Muckaty Station, of which twenty five species were recorded. Most species were associated with the Muckaty site due to the presence of more diverse overstorey and understorey habitats that were largely absent from the regional studies area. The most numerous species at both sites were Zebra finch and Spinifex pigeon, both of which are typical desert species widespread in the arid zone.

9.2.4.3 Reptiles and amphibians

As predicted, reptile diversity and abundance was highest and yielded the greatest result for the trapping effort across both areas. Two species were numerically dominant at Site 1 of the Muckaty site, *Ctenophorus isolepis gularis* (Sand dragon, Military dragon) and *Varanus gouldii flavirufus* (Sand goanna (monitor)).

Ctenotus grandis, *Strophurus ciliaris* and *Varanus tristis* were also recorded at the Muckaty site.

Centralian blind snake, a data deficient species for the NT, has been reported for the region and could occur at the site. Blind snake tracks were evident through Site 1 and deep, sandy soil is preferred habitat by this group.

Tiliqua multifasciata (Centralian bluetongue) and *Varanus acanthurus* (Spiny-tailed monitor) were the only captures at the regional studies area. A *Ctenophorus* sp. and *Ctenotus saxatilis* were seen, but not captured, at this site and *Ctenophorus nuchalis* was recorded as road kill on the Stuart Highway. This species is, therefore, expected to be present.

An additional 14 species of reptiles and at least four amphibian species are predicted to occur in the sites (NRETA database).

9.2.4.4 Introduced species

House mouse (*Mus musculus*) was the only introduced species captured (in the burned shrubland and tussock grassland of the gazetted site).

Cattle (*Bos indica* and *Bos taurus*), goats and horses were present across the site and associated with the pastoral activities of Muckaty Station. While not observed by the survey team, anecdotal evidence from the station owner and managers of the Bootu Creek mine indicated that donkeys were also present.

Feral cat has been recorded recently at Bootu Creek mine and on Muckaty Station. Cat tracks were observed adjacent to the denser vegetation of the Muckaty site, although none was captured during the survey. This observation was confirmed by the Parsons Brinckerhoff hydrogeological assessment team, which observed a cat on the southern area of the gazetted site. European red fox is also likely to be present in small numbers across the region and site and European rabbit has been reported to occur here in the past.

Asian house gecko (dtella) is present around habitation areas. Cane toad has not been recorded in the region.

9.2.5 Conservation status of fauna species

No mammal species of conservation significance were recorded during the survey. Suitable habitat is present for Greater bilby and Centralian pebble-mound mouse. Both species are predicted to have been present at the site in the past and may still be present, especially following above average seasonal conditions. Further investigations would be required to confirm their occurrence.

Nearly all bird species recorded were common in central Australia, with the exception of the Australian bustard, which is listed as vulnerable at the Territory level. This species was recorded as one bird along the main access road into the Station.

9.3 Land use and demography

9.3.1 Site tenure and use

Muckaty Station is an Aboriginal Land Trust area and is held under inalienable community rights.

9.3.2 Surrounding land use

To the north of the Station are the two small towns of Renner Springs and Helen Springs. To the south lie Banka Banka Pastoral Station and the Aboriginal Land Trust Karlantijpa. To the east there are two pastoral Stations, Banka Banka and Helen Springs, and to the west is the Karlantijpa North Aboriginal Land Trust.

9.3.3 Heritage sites

There are four places listed on the Australian Heritage Places Inventory, all are within or near Tennant Creek, which is some 110 km south of Muckaty.

The Ngapa people assisted the field teams when choosing routes for the drill rig access tracks. Several places on Muckaty Station have significance to the local Aboriginal population, although these have not been marked on maps.

9.3.4 Zoning

No zoning or planning schemes pertain to Muckaty Station.

9.3.5 Proximity to occupied places

9.3.5.1 Aboriginal

Between 10 and 50 km from Muckaty Station there are five Aboriginal Family Outstations.

Muckaty itself has a Family Outstation located approximately 5 km from the Muckaty site.

9.3.5.2 European

The nearest major population centre is Tennant Creek, some 110 km to the south of Muckaty. Renner Springs is a roadhouse some 40 km north of Muckaty.

9.3.6 Population density and potential for growth

Muckaty lies in the Tablelands Statistical Local Area (SLA). This has a total population of 1,250 and an area of 240,000 km^2 (i.e. 192 km^2 per person). The statistics show a slight decline in total population, however the 2006 census data cannot be directly compared to earlier years since the boundaries change.

Growth is predicted for the Northern Territory as a whole, however this growth is likely to occur in Darwin and Alice Springs, with smaller increases in Katherine and Tennant Creek. It is unlikely that any significant growth will take place in rural and remote areas such as Muckaty.

9.4 Transport issues

9.4.1 National networks

The Muckaty site lies close to the Stuart Highway between Alice Springs and Darwin. A rail-head exists to the west of the Muckaty site, which is accessed by the Bootu Creek mine haul road.

9.4.2 Site access and interior roads

The Muckaty site lies close to a private, single-lane sealed haul road used to transport manganese ore to the rail head west of Muckaty. If this road were to be considered, an arrangement with OM Manganese (the operator of Bootu Creek Mine) would need to be agreed.

There are station tracks that traverse Muckaty Station, however these are not formed and are subject to periodic closure following rain.

The regional studies area is accessed by an unformed track from the Stuart Highway.

10. Project outcomes

The initial task was to record the site characteristics in terms of their natural ability to provide barriers between the radioactive wastes and the biosphere, in other words, without engineered enhancements to the conceptual designs or natural barriers. Subsequently, the conceptual designs were subjected to a detailed analysis of the potential to engineer enhanced barriers between the wastes and the biosphere.

This section presents the outcome of the two analyses.

10.1 Un-enhanced site suitability

The 'un-enhanced' site suitability matrix (Table 10.1) is a summary of each site set against the criteria (themes) adopted for this Stage One report (see Section 2.9).

The greater the score, the less suitable the site is for the specific concept for each site (i.e. store, repository or warehouse).

Table 10.1 Un-enhanced site suitability matrix

Source	Guideline	Detail	Mount Everard			Harts Range			Fishers Ridge			Muckaty Station		
			Store	Repository	Warehouse	Store	Repository	Warehouse	Store	Repository	Warehouse	Store	Repository	Warehouse
Code of practice for near-surface burial of radioactive waste in Australia	Rainfall	Low rainfall	1	1	1	1	1	1	4	4	4	2	2	2
		Flood potential	1	1	1	3	3	3	2	2	2	1	1	1
		Surface drainage	1	1	1	1	1	1	1	1	1	2	2	2
	Water table	Depth (>5m)	1	1	1	1	2	1	1	3	1	1	2	1
		Small rise and fall	1	1	1	1	2	1	1	4	1	*	*	*
	Modelling	Geological complexity	1	1	1	1	1	1	3	3	3	2	3	1
		Hydrogeology	1	1	1	1	2	1	2	4	1	1	2	1
	Stability	Seismicity	1	1	1	1	1	1	1	1	1	2	2	2
		Tectonics	1	1	1	1	1	1	1	1	1	1	1	1
		Volcanic activity	1	1	1	1	1	1	2	2	2	1	1	1
	Population	Density	1	1	1	2	2	2	1	1	1	1	1	1
		Projected population growth	1	1	1	1	1	1	3	3	3	1	1	1
		Future development potential	1	1	1	1	1	1	3	3	3	2	2	2
	Groundwater use	Human consumption	1	1	1	3	3	3	2	2	2	2	2	2
		Pastoral use	1	1	1	2	2	2	3	3	3	3	3	3
		Agricultural use	1	1	1	1	1	1	2	2	2	1	1	1
	Migration of nuclides	Geochemistry	1	1	1	1	1	1	2	2	2	1	1	1
		Geotechnical properties	1	1	1	1	1	1	1	2	1	1	3	1
International Atomic Energy Agency	Geology	Isolation of waste	1	1	1	1	1	1	1	1	1	1	1	1
		Limitation of releases	1	1	1	1	1	1	1	2	1	1	1	1
		Sufficient volume	1	1	1	1	1	1	1	2	1	1	1	1
		Uniformity	1	1	1	1	1	1	1	3	1	1	2	1
		Modellability	1	1	1	1	1	1	1	3	1	1	2	1
	Hydrogeology	Flow	1	1	1	1	1	1	1	3	1	1	2	1
		Flow path	1	1	1	1	2	1	1	3	1	1	2	1
		Potential gradient changes	1	1	1	1	1	1	1	3	1	1	2	1
		Simplicity of setting	1	1	1	1	1	1	1	3	1	1	2	1
		Dispersion characteristics	1	1	1	1	1	1	1	2	1	1	2	1

			Mount Everard			Harts Range			Fishers Ridge			Muckaty Station		
Source	Guideline	Detail	Store	Repository	Warehouse	Store	Repository	Warehouse	Store	Repository	Warehouse	Store	Repository	Warehouse
		Geochemistry of groundwater	1	1	1	1	2	1	1	3	1	1	1	1
		Effects on engineered barriers	1	1	1	1	1	1	1	2	1	1	1	1
		Precipitation/co-precipitation	1	1	1	1	1	1	1	2	1	1	1	1
		Formation of transportable compounds	*	*	*	*	*	*	*	*	*	*	*	*
		Tectonic activity	1	1	1	1	1	1	1	1	1	1	1	1
		Seismic activity	1	1	1	1	1	1	1	1	1	1	2	1
		Flooding	1	1	1	3	3	3	2	2	2	1	1	1
		Landslide	1	1	1	1	1	1	2	2	2	1	1	1
		Erosion	1	1	1	1	2	1	2	2	2	1	1	1
		Drainage	1	2	1	1	3	1	1	1	1	1	2	1
		Ponding	1	2	1	1	2	1	1	1	1	1	2	1
		Upstream catchment	2	2	2	2	2	2	1	1	1	1	1	1
		Extreme events	1	1	1	1	1	1	1	3	1	1	2	1
		Major hazardous facilities	1	1	1	1	1	1	1	1	1	1	1	1
		Airports	1	1	1	1	1	1	2	2	2	1	1	1
		Hazardous transport loads	2	1	2	1	1	1	1	1	1	1	1	1
		Prospectivity	1	1	1	1	1	1	1	1	1	*	*	*
		Use of groundwater	1	1	1	1	1	1	1	3	1	1	2	1
		Principal access routes	1	1	1	1	1	1	1	1	1	2	2	2
		Ownership	1	1	1	1	1	1	1	1	1	2	2	2
		Neighbouring uses	2	2	2	2	2	2	3	3	3	2	2	2
		Future land use potential	1	1	1	1	1	1	2	2	2	1	1	1
	Population	Density	1	1	1	1	1	1	1	1	1	1	1	1
		Growth	1	1	1	1	1	1	2	2	2	1	1	1
		'Raw score'	54	55	54	61	70	61	76	107	75	60	77	59
		Weighted score[L]	55	56	55	62	71	62	77	109	76	64	82	63

* *No or not enough information*

L *The weighted score takes into account the lack of information at some locations and for some issues*

10.2 Site suitability discussion

The site suitability workshop outcome is summarised in Table 10.2.

Table 10.2 Summary of site suitability workshop

Facility element	Mount Everard	Harts Range	Fishers Ridge	Muckaty Station
Store (ILW)	55	62	77	64
Repository (LLW)	56	71	109	82
Warehouse (LLW)	55	62	76	63

Therefore, while a Store, Repository and Warehouse are all possible at any of the four sites, the analysis suggests that the Fishers Ridge site has less inherently attractive features overall, particularly for a below-grade burial of low and intermediate (short-lived) level waste. This is primarily because the site lies in a higher rainfall area than the other three sites, and the geology and hydrogeology is more complex than the other sites.

One issue that the analysis did not identify was the degree of difficulty of excavating a repository, although it can be seen that the score for a repository at Muckaty Station is higher than at all sites except Fishers Ridge. This is because there is bedrock close the surface at the Muckaty Station site which might require blasting if a repository were to be established on this site. Since the precise location of a facility was not determined in this stage of the study, it is possible that a location on the Muckaty site at Muckaty Station could be found with sufficient cover over the bedrock to avoid having to blast.

Overall the analysis indicates that the Mount Everard and Harts Range sites rate above the other sites in terms of inherent suitability. Note that this analysis did not consider operational issues such as have been outlined above (e.g. radio quiet at Mount Everard).

10.3 Concept design modifications

Having described the inherent natural characteristics of each site in broad terms, and compared them to the National and International siting Guidelines, the next task was to examine the concept design and identify any modifications that could be made that would in part overcome the deficiencies in natural characteristics.

Tables 10.3 and 10.4 show the results of a Workshop held to identify and document potential modifications.

Rows shaded in violet are those that influence subsequent cost analysis the greatest.

The issues shown in Tables 10.3 and 10.4 were provided to a cost engineer.

Table 10.3 Concept modification workshop (Mount Everard and Harts Range)

Aspect	Issues	Mount Everard				Harts Range				Comments
		Buried LLW	Warehouse LLW	Below-ground ILW	Above-ground ILW	Buried LLW	Warehouse LLW	Below-ground ILW	Above-ground ILW	
Groundwater	Depth to water	Depth to water below design depth	Not material	Depth to water below design depth	Not material	Same as Mount Everard				If shallow has implications for compaction
	Variability in level	As above	As above	As above	As above					
	Water quality	Fresh to brackish	Fresh to brackish	Fresh to brackish	Fresh to brackish					Has implications for concrete manufacture
	Perched aquifers	None	None	None	None					
Surface water	Soils (infiltration)	Sandier than Harts Range, some pooling				Higher clay content, slow infiltration				Seal potential spill areas
	Flood protection	Diversion of sheet flow				Flooding from Creek				
	Erosion	Little top soil				Little top soil				Affects cap design for burial
Rainfall	Infiltration & water collection	Low rainfall				Same as Mount Everard				Capacity of stormwater pond
Subsoils & rocks	Foundations	No issues				Same as Mount Everard				Building foundations and consideration of any special requirements for heavy-lift cranes
	Depth to bedrock	> 100 m				Same as Mount Everard				Ease of excavation for buried wastes of below ground ILW store
	Excavation properties	Easy				Same as Mount Everard				Ease of excavation for buried wastes of below ground ILW store
Construction materials	Clay	No suitable clays		No suitable clays		Same as Mount Everard				Construction of cap and liners (burial)
	Gravels	Quarry				Same as Mount Everard				Concrete manufacture
	Concrete batch plant	Yes	Yes	Yes	Yes	Same as Mount Everard				Will a batch plant be necessary (i.e. is there an existing facility near by?).
Seismicity	Earthquake protection	No	No	No	No	Same as Mount Everard				Will buildings require specific earthquake protection (Codes)?
Security	Proximity to publicly accessible areas	Need for barrier to screen from Tanami H'way. Possible ASIO buffer distance requirements				No additional barriers (other than double fencing)				Concept has double security fencing. Is any other (additional) security measure needed?
Natural hazards	Bushfire and lightning strikes	Site is burnt regularly to control fuel loads				Site has not been burnt for several years				Has the potential to affect depth of buffer zones and vegetation clearance. Quantity of fire-suppression water held on site. Sprinkler system on roofs.
Constraints	Electromagnetic noise	Radio quiet (Faraday protection)				Not an issue				
	Construction timing	Possible need to construct/operate in array down-time				Not an issue				
	Access (for construction)	See above				Not an issue				
	Proximity to construction materials	Not enough known				Further from Alice than Mount Everard				Affects cost of construction
	Proximity to labour force	Reasonably near Alice Springs				Further from Alice than Mount Everard				Affects cost of construction
Communications	Proximity to networks	Has a landline				Wireless link to Alice Springs				Probably have to allow for satellite comms. at every site
Power	Proximity to established grid & reliability of supply	Mains power to site (buried cables for radio quiet)				No mains power - on-site generation				Probably have to allow for back-up power at every site
Water	Supply for construction & operation	Water available on-site				Water available on-site, but of potentially contaminated quality				
Road	Proximity to major roads	3-400 m new road construction				2 km new road construction				
Rail	Assume rail not an option at this stage									
Buildings		Not an issue				Not an issue				Any special treatment to protect against corrosion of cyclone

Table 10.4 Concept modification workshop (Fishers Ridge and Muckaty Station)

Aspect	Issues	Fishers Ridge: Buried LLW / Warehouse LLW / Below-ground ILW / Above-ground ILW	Muckaty Station: Buried LLW / Warehouse LLW / Below-ground ILW / Above-ground ILW	Comments
Groundwater	Depth to water Variability in level	Water-proofing all round. De-watering prior to construction	Depends largely on exact location, but there is deep groundwater.	If shallow has implications for compaction and excavations
	Water quality	Fresh	Fresh at the Muckaty site ranging to brackish outside site	Has implications for concrete manufacture
	Perched aquifers	Yes	No	
Surface water	Soils (infiltration)	Cap rock and topography are favourable	Valleys and sand plains at the Muckaty site are porous. Bedrock at the surface surrounding the valleys	Seal potential spill areas
	Flood protection	Small up-stream catchment, good drainage	Diversion of local flows necessary	Affects cap design for burial
	Erosion	Not an issue	Not an issue	
Rainfall	Infiltration & water collection	Highest rainfall site	Not an issue	Capacity of stormwater pond
Subsoils & rocks	Foundations	Possibly greater cost than at any other site	Depends on specific location, but mostly shallow bedrock	Building foundations and consideration of any special requirements for heavy-lift cranes
	Depth to bedrock	Not an issue (> 70 m)	0-5 m at Muckaty site	Ease of excavation for buried wastes of below ground ILW store
	Excavation properties	Cap rock over clays	Probable need for blasting	Ease of excavation for buried wastes of below ground ILW store
Construction materials	Clay	No suitable sources on site. Possible need for an artificial liner as well as clay	No suitable sources of clay on site	Construction of cap and liners (burial)
	Gravels	Quarry	Same as Fisher Ridge	Concrete manufacture
	Concrete batch plant	Quarry	Same as Fisher Ridge	Will a batch plant be necessary (i.e. is there an existing facility near by?).
Seismicity	Earthquake protection	Similar potential at all sites (i.e. not a cost differentiator)	Shallow bedrock is generally beneficial	Will buildings require specific earthquake protection (Codes)?
Security	Proximity to publicly accessible areas	Not an issue	Not an issue	Concept has double security fencing. Is any other (additional) security measure needed?
Natural hazards	Bushfire and lightning strikes	Probable need for extra fire-fighting measures and greater water-holding. Probable need to greater width fire-breaks and buffer zones	Lower fuel loads than other sites, but greater grass plains	Has the potential to affect depth of buffer zones and vegetation clearance. Quantity of fire-suppression water held on site. Sprinkler system on roofs.
Constraints	Electromagnetic noise	Not an issue	Not an issue	
	Construction timing	Not an issue	Not an issue	
	Access (for construction)	Good access	Need good temporary (construction) roads	
	Proximity to construction materials	Unknown at this time	Probably the most remote site	Affects cost of construction
	Proximity to labour force	Close to Katherine	Probably the most remote site	Affects cost of construction
Communications	Proximity to networks	No existing comms.	Land line to homestead, but needs new comms.	Probably have to allow for satellite comms. at every site
Power	Proximity to established grid & reliability of supply	4-5 km from main line on Stuart H'Way	On-site generation with back-up	Probably have to allow for back-up power at every site
Water	Supply for construction & operation	New well construction or truck in water for construction	Need to truck water in for construction, although there are some stock-watering points (good quality water)	
Road	Proximity to major roads	4-5 km off Stuart H'Way	15 km from Stuart H'Way	
Rail	Assume rail not an option at this stage			
Buildings		Cyclone Code area	Not an issue	Any special treatment to protect against corrosion of cyclone

10.4 Differential cost analysis

The estimate for the project was prepared in two stages.

In the first instance, square metre rates ($\$/m^2$) were used to establish the base building cost for buildings common to all sites and above/below ground options for Low and Intermediate level waste. Added to this were the specifics for each area, e.g. cranes, laboratory areas, shielded areas, etc. These were combined to form an overall square metre rate for each different area within the overall facility.

To this, we then added the site specific items, e.g. access roads, electrical supply requirements, etc.

These two practises provided a basic construction cost using 'Adelaide' rates. With any construction project, there will be costs on top of the base construction for Contractor Preliminaries (site establishment, supervision, etc.) and for profit margin, which were added to the construction cost as percentage driven add-ons.

Due to the remote siting of the proposed facility, a locality factor was added to the 'Adelaide' cost. These were percentage-based and were:

- 10% for Mount Everard
- 20% for Harts Range and Fishers Ridge
- 40% for Muckaty.

Understanding that this is a very early concept design estimate, contingencies for both Design and Construction purposes were added. Again, these are percentage add-ons, totalling 15% combined.

Escalation/rise and fall has not been accommodated in the current estimate as no programme was available.

Given the nature of the current design, the estimate should be rated, at best, as +/- 50% accuracy for the current identified scope and should be used as a benchmarking guide between the options rather than a definitive cost estimate.

10.5 Common buildings (base cost)

The costs associated with the building elements in the 'base case' are shown in Table 10.5.

Table 10.5 Building costs common to every site

Item	Cost ($)
Preliminaries	1,645,320
Functional area	9,845,000
Site preparation	370,000
Roads, footpaths & paved areas	1,009,680
Boundary walls, fencing & gates	287,000
External electrical services	550,000
External communications	1,000,000
Special provisions	2,186,000
Total	16,893,000

10.6 Cost differentials (site-specific)

Table 10.6 shows site-specific costs (which include the Base Case Costs).

Table 10.6 Site-specific costs (±50%)

Site	LLW above ground ILW above ground	LLW below ground ILW below ground	LLW above ground ILW below ground	LLW below ground ILW above ground
Mount Everard	$40,861,000	$46,105,000	$42,847,000	$44,119,000
Harts Range	$47,287,000	$53,007,000	$49,453,000	$50,840,000
Fishers Ridge	$58,641,000	$64,361,000	$60,807,000	$62,194,000
Muckaty Station	$55,164,000	$61,838,000	$57,692,000	$59,310,000

It can be seen that the least expensive option is to store low-level, short-lived intermediate level, and intermediate long-lived waste above ground at Mount Everard. The most expensive is to bury LLW, and store ILW below ground at Fishers Ridge.

It must be emphasised that this does not make any one site the ‘preferred site’.

By spending money on modifications to the concept design at each site, all sites are rendered comparable in terms of performance.

The range of costs for all potential solutions is $23,500,000 (between the lowest cost and the highest), with the average cost being $54,531,150.

11. Discussion

This section contains a discussion of the similarities and differences between the sites characterised in this phase of the project. It represents a summary of the preceding sections.

11.1 Geology

The geology of the two southern sites (Mount Everard and Harts Range) is such that it is relatively easy to model, and meets siting guidelines in terms of volume.

Fishers Ridge is a more complex geological environment, which will require a greater investigation by drilling and a more complex modelling effort.

Muckaty Station is in a complex geological environment, however this is somewhat off-set by the large areas available (i.e. the location of any facility can be chosen to avoid more complex sub-strata). Outcropping bed rock over much of the Muckaty site would have to be blasted if shallow-ground burial is contemplated, however there are transition zones between bed rock outcrops and alluvial plains that could accommodate below-ground storage with less aggressive construction methods.

All sites have low to very low permeability due to the clay content of sub-strata, although there may be cracks and fissures at Fishers Ridge and Muckaty that would need further investigation.

Limited construction materials are available on-site, for all sites. This factor is highlighted in the cost analyses that see suitable materials being imported to all sites.

11.2 Hydrogeology

Mount Everard and Harts Range have deep groundwater that does not appear to vary greatly in depth.

Fishers Ridge appears to have perched aquifers and relatively close surface expressions of groundwater. Of all the sites, Fishers Ridge may be closest to groundwater abstraction wells and large-scale beneficial use of groundwater.

Muckaty Station has groundwater levels that vary in depth with local re-charge events, although the depth to groundwater will depend on the exact location of any facility.

11.3 Surface hydrology and meteorology

Mount Everard and Harts Range are in arid zones with low annual rainfall. They are relatively flat with ill-defined drainage paths. Harts Range is close to a creek and will require flood-modelling to refine an understanding of surface water management options.

Fishers Ridge is in an area of relatively high rainfall, being close to the monsoon zone. This is off-set to some extent by the topography of the site, which lies on a dome, thus having relatively good drainage characteristics (with a small up-stream catchment area). The site is close to a creek and a river.

Muckaty Station is in a climate transition zone between the arid zone to the south and the sub-tropics to the north. Annual rainfall is low but it is understood that storms can close station roads for several days each year.

11.4 Remoteness

All sites are located in areas characterised by sparse local population densities. With the exception of operational personnel at Mount Everard and Harts Range, and the Station Manager of Muckaty the sites lie more than 5 km from places inhabited continuously or occasionally.

Mount Everard is the closest site to a major population centre, being approximately 25 km from Alice Springs as the crow flies.

11.5 Access and road/rail infrastructure

All sites are close to major road and rail networks, and each site will need upgrading of existing on-site roads or the construction of new roads.

11.6 Operational constraints

Mount Everard is a radar receiver station and Defence has indicated that it requires radio-quiet conditions. While shielding electronic equipment is relatively straightforward, it adds to the construction cost. The area available at Mount Everard is also the smallest of the four sites, thus limiting the choice of location for a CRWMF.

Defence and Contractor personnel and their families currently live at Harts Range, although Defence is in the process of deciding whether or not to close the accommodation facilities and re-locate personnel to Alice Springs. The investigations carried out for this study were unable to determine the extent of the RADHAZ zone in front of the transmitter array, and thus were confined to an area behind the zone.

Fishers Ridge is currently used for grazing by arrangement between Defence and local pastoralists. Anecdotal information suggests that recreational anglers transit the site to reach the King River. The road that transits the site is used to access an Aboriginal community to the west.

Muckaty Station is an operating cattle property although the Muckaty site is fenced off from grazing areas. The Bootu Creek manganese mine operators have constructed a haul road to access a rail head to the west of the gazetted site. If access to the Muckaty site were to be along this road, an arrangement would need to be reached with OM Manganese.

11.7 Ecology

Fishers Ridge is the most biologically prospective site, although at the time of the flora and fauna investigations a recent bush fire had reduced the ability of the field team to fully characterise the ecology of the site. The site has been subjected to grazing, but at a low density.

Mount Everard and Harts Range are fenced to exclude grazing animals. Both sites have been subject to fuel-reduction burns in recent years.

Muckaty Station is an operational cattle station, although the Muckaty site appears to be fenced off from grazing pastures.

None of the sites hosts species that would be threatened by a CRWMF.

11.8 Statutory planning considerations

Mount Everard, Harts Range and Fishers Ridge are all Commonwealth-owned and are thus not subject to Northern Territory planning schemes.

Mount Everard is close to the Tanami Road. Northern Territory planning requirements suggest that the design of facilities within 500 m of designated roads should take into account safety and aesthetic considerations, such as screening.

All sites are remote from municipal planning zones.

11.9 Conformity with national and international siting guidelines

None of the four candidate sites is incompatible with national or international siting guidelines. Previous site-selection processes in Australia took a very broad-scale approach to constraint mapping (i.e. a ‘coarse grid’). This study, although preliminary in nature, took a site-specific approach (i.e. a ‘fine grid’).

Each of the four sites will require modifications to the conceptual designs provided for this project. Such modifications will enhance the sites’ natural abilities to contain radioactive wastes.

The Mount Everard and Harts Range sites can accommodate shallow-ground burial of low and intermediate level (short lived) wastes. It would also be possible to sink the intermediate level vault below ground level to increase gamma shielding.

Perched water tables and higher rainfall at Fishers Ridge may require additional waterproofing, both for infiltration through a cap on a buried repository and for exclusion of shallow groundwater in perched aquifers, however the site can accommodate shallow ground burial of low level and intermediate (short-lived) waste. It can also accommodate a below ground level intermediate vault.

At Muckaty, options depend very much on the choice of location for the facility. Since some areas contain outcropping bed rock, burial may be either difficult (due to the need to blast) or inadvisable, since the underlying rock may require extensive grouting after blasting. These areas could accommodate a warehouse for low and intermediate (short-lived) waste, and it may not be practical to sink an intermediate level waste store below ground level. The alluvial valleys of Muckaty may be subject to periodic inundation, mitigating against sub-surface choices, however the transition zones (i.e. the shoulders of loose agglomerates between bed rock outcrops and alluvial plains) offer potential for waste burial.

11.10 Next steps in the process

This study represents the first stage in the process of selecting a candidate site for the CRWMF.

Once the Commonwealth has nominated its choice of site (or sites), extensive additional studies will be needed to provide the detailed data that will enable a 'Safety Case' to be developed.

An Environmental Impact Statement (EIS) under the terms of the Environment Protection and Biodiversity Conservation Act will be required, together with stakeholder consultation. Should approval be granted following the assessment of the EIS, Licences for Siting and Operation will be required from the granting authority, the Australian Radiation Protection and Nuclear Safety Agency.

Arrangements for the collection, conditioning and packaging of wastes, and the chain-of-custody record-keeping system that that implies will need to be formalised.

Recruitment and training of personnel for the operation of the CRWMF will be required.

12. Study team

The work described in this report and the technical papers that accompany it was originally commissioned and managed by the Commonwealth Department for Education, Science and Training (DEST). Following the Federal election in 2007, the work was managed by the Department of Resources, Energy and Tourism (DRET).

Table 12.1 shows the make-up of the study team.

Table 12.1 Study team

Name	Function	Affiliation
David Howard	Project Director	Parsons Brinckerhoff
Tim Harrington	Project Manager, Radioactive Waste Management	Kellogg Brown & Root
Julieanne Goode	Deputy Project Manager, Environmental Science	Parsons Brinckerhoff
Dr Peter Woods Alan Wade Allan Puhalovic Dr Ed Oldmeadow Sandra Struck Andrew Tuffs	Hydrogeology, Hydrology and Geochemistry	Parsons Brinckerhoff
Mark Drechsler Neil Hannaway Chad Parken	Geology, Geotechnical and Mineral Prospectivity	Parsons Brinckerhoff
Scott Haynes Nicole Smit Kristy Finch	Planning and Demography	Parsons Brinckerhoff
Dr Bob Anderson Sarah Reachill Katie Fels Anthony Wright Jason Wadsworth	Ecology, Flora and Fauna	Kellogg Brown & Root
Scott Haynes Nicole Smit Kristy Finch	Meteorology	Parsons Brinckerhoff
Gordon Benham	Road, Rail, Traffic and Logistics	Parsons Brinckerhoff
Mason Robb	Differential Cost Analyses	Currie and Brown
Bronwen Bowskill Justin Nottage Rachel Potts Jason Wadsworth	Geographic Information Systems and Remote Sensing	Parsons Brinckerhoff and Kellogg Brown & Root

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- Northern Territory Government (maps, plans, spatial data, NT Strike, aerial photographs and permits)
- Geosciences Australia (maps, plans and spatial data)
- Australian Nuclear Science and Technology Organisation (Concept designs and waste conditioning)
- Northern Land Council (Muckaty Station)
- representatives of the Ngapa Clan (Muckaty Station)
- Mr Ray Aylett (Muckaty Station Manager)
- GHD Alice Springs (survey of drill collars and profiles, Mount Everard and Harts Range)
- Alsurv Darwin (survey of drill collars and profiles, Muckaty Station)
- Coffey Geosciences (laboratory test work)
- Spatial Solutions (Geographic Information Systems and Visualisation)
- OM Manganese (Safety induction for use of the haul road at Muckaty Station)
- Defence and RAAF (Mount Everard, Harts Range and Fishers Ridge)
- BAE Systems (Mount Everard and Harts Range)
- Drilling Solutions (Contract Drilling)
- Phillips Earthmoving (access track and test pit works at Muckaty Station)
- Support staff from Parsons Brinckerhoff and Kellogg Brown & Root.