Procedure		Document No.	2790
Document Title	**Monitoring Program – Environmental Radiation**		
Area	Olympic Dam Shared Services	**Issue Date**	27 July 2018
Major Process	Environment	**Sub Process**	Environment
Authoriser	Laura Tyler – Asset President Olympic Dam	**Version Number**	16

1 SCOPE

This Monitoring Program (MP) describes the environmental radiation monitoring requirements for the existing Olympic Dam operations (MC 2.8.2(e)). Some environmental radiation monitoring at Olympic Dam is integrated within other non-radiation specific environmental monitoring programs (see section 2.1).

The purpose of this MP is to:

- Provide sufficient data to determine compliance with the statutory requirements for radiation doses to the public and to assess radiological impacts on non-human biota (NHB);
- Monitor, identify and quantify changes in environmental radiation levels;
- Determine the impacts of any changes;
- Monitor the effectiveness of control measures.

This MP addresses a number of distinct elements of radiation emissions monitoring. For each element, the MP sets out some background information, the purpose of the monitoring and the deliverables which are produced as a result of the monitoring. The MP also includes a description of the methods for measuring achievement of **compliance criteria** and the movement of trends towards **leading indicators** (where applicable).

This MP also provides detailed methodology for the calculations involved in determining the total effective dose to **members of the public** above the natural background from inhalation of radionuclides in dust and inhalation of radon decay products.

1.1 Responsible ODC personnel

The Olympic Dam Asset President is responsible for ensuring that all legal and other requirements described in this MP are met.

ODC employs a Statutory Radiation Safety Officer acceptable to the Radiation Protection Division of the Environment Protection Authority (EPA), to establish, maintain and fulfil the requirements of this MP, thereby fulfilling its obligation with respect to clause 2.10.1(d) of the Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005) (MC 2.10.1d, MC 2.10.1f).

1.2 Review and modification

This MP is reviewed annually. Major changes or amendments following the review are documented in the Annual EM Program Targets, Actions and Major Changes document.

It should be noted that as a result of operational activities or through optimisation of sample design some existing monitoring sites may be lost and others added (where possible) to maintain the integrity of the sampling program. Access restrictions can result in some sites occasionally being unable to be monitored.

1.3 Radiological considerations

The generic pathways of exposure (i.e. the mechanisms by which radiation or radioactive materials can be transported from the operation to people) are described in International Commission on Radiological Protection (ICRP) Publication 29 (ICRP 1979). The primary exposure pathways for **members of the public** from the operations at Olympic Dam are the inhalation of radon decay products and the inhalation of radionuclides in dust (ODC 1996a). Doses to **members of the public** are based on these radiation exposure pathways (MC 2.8.2(d)).

Ingestion of radionuclides from the consumption of local fauna and flora is another pathway but it has not been included in public dose assessments because it has been verified as negligible (ODC 1996b). Similarly, direct gamma radiation from the operation has also not been included because it reduces by many orders of magnitude over a distance of one kilometre and therefore results in negligible public exposure.

In assessing doses to **members of the public**, it is usual to identify a group of people (known as the 'critical group') who are most likely to be the most exposed individuals and calculate their doses (**Mining Code** 2005). To date, the residents of Roxby Downs and Olympic Village have been identified as critical groups.

While the residents of Andamooka could also be identified as a critical group, the Olympic Dam Expansion Draft Environmental Impact Statement (DEIS, 2009) shows that doses will be less than those received at Olympic Village. It is important to note that the atmosphere contains a naturally occurring background concentration of radon decay products and radionuclides in dust. It is therefore necessary to determine the local background concentrations and to subtract these from the total measured concentration in order to identify the contribution directly attributable to the operation.

Doses are directly calculated from the results of the environmental monitoring using standard methods which are outlined in this document.

2 DETAILED PROCEDURE

2.1 Context

Environmental radiation monitoring is integrated into ODC's **Environmental Management System**, with some radiological parameters being measured as part of other monitoring programs as seen in Table 2.1.

Table 2-1: Related documents

Environmental Monitoring Program	Radiological parameter
Airborne Emissions, Document No. 2788	Radionuclide emissions monitoring. Performance of systems to control emissions.
Groundwater, Document No. 2791	Monitoring of radionuclide concentrations in groundwater. Monitoring of radionuclides in water for dust suppression.
Waste, Document No. 2792	Radioactive waste production. Performance of systems to control waste.

The data generated by these monitoring programs, combined with the monitoring outlined in the following sections, is used to:

- Determine public doses;
- Assess the radiological impacts on NHB;
- Monitor the concentrations of radionuclides in the environment.

The following sections provide detail on the radiation specific monitoring that is undertaken (MC 2.8.2(e)).

2.2 Member of the public doses

2.2.1 Background

Environmental radiation monitoring data is used to determine public doses.

Monitoring and assessment for over 25 years has shown that the primary source of environmental radiation exposure from Olympic Dam is radon, resulting in project originated concentrations of radon decay products. Radon is emitted from both point and fugitive sources. Point sources include ventilation shafts (raise bores) and some process stacks. Fugitive releases of radon may occur from mineral processing and materials handling activities as well as from stockpiled ore and the tailings storage facility.

Airborne dust containing radionuclides is also emitted from the operation, however this constitutes a small portion of the overall dose.

ODC has consistently operated in a manner that limits annual radiation dose to **members of the public** from the operational activities at Olympic Dam to less than a small fraction of the 1 mSv/y limit.

The methods for determining inhalation dose from monitoring results can be found in Appendix A and B.

2.2.2 Purpose

- Provide data to calculate public radiation doses in order to meet the **environmental outcomes**.
- Ensure annual doses are less than the **compliance criteria** (or statutory limit) of 1 mSv/y.

- Alert management when levels approach the **leading indicator**.

2.2.3 Deliverable(s)

Data leading to calculated estimates of annual radiation doses to **members of the public** in the critical groups identified in section 1.3 of this MP.

2.2.4 Method

Monitoring to calculate radiation doses is based on the exposure pathways which are summarised as follows:

Inhalation of radon decay products (RnDP);

- Radon is emitted from the operational activities and decays to the RnDP with time. RnDP monitoring is currently being conducted using real time monitors situated at compliance monitoring stations at Roxby Downs and Olympic Village.
- The methodology for assessment of dose from the RnDP monitoring is outlined in Appendix A.

Inhalation of radioactive dust;

- Dust emitted from the operation may be radioactive and may be inhaled leading to internal doses. Radionuclide concentrations in dust will be monitored at compliance monitoring stations, Roxby Downs and Olympic Village with high volume sampler filters sent for radionuclide analysis to determine the long-lived radionuclide concentrations in air.
- The methodology for assessment of dose from radionuclide concentrations in dust monitoring is outlined in Appendix B.

Gamma radiation;

- Gamma radiation reduces significantly with distance from the radiation source. Gamma radiation monitoring to date has confirmed this, and it is predicted that gamma exposure for the identified critical groups will remain negligible due to the distance of the locations from the radiation sources.

Ingestion of radioactive material that has accumulated in flora and fauna;

- Radionuclides in dust from the operation may deposit on plants or onto the soil where plants grow and could be ingested by people. Similarly, plant material could be ingested by animals which are then consumed by people. Previous monitoring and estimates made in the **EIS** have indicated that exposure from this pathway is negligible.

Ingestion of radioactive material that has accumulated in potable water;

- The potable water supply for the critical groups comes from desalination and consequently there are no mechanisms for contamination of this water by radioactive material from the operations.

By totalling the effective radiation doses from radon decay products (ED_{Rn}) and radionuclides in dust (ED_D) the total effective dose (ED) (in units of mSv/y) for the critical groups is obtained (as noted, ingestion of radionuclides (ED_I) and irradiation by gamma (ED_G),are negligible and are not totalled in the ED).

Calculation of doses based on radiation exposure monitoring is conducted in accordance with the recognised methodology outlined by the ICRP and the **Mining Code** (as shown in Appendix A and B).

Raw monitoring data will be collated and reviewed regularly with doses assessed annually.

2.3 Non-human biota (NHB) dose assessment

2.3.1 Background

Radiological impacts to plants and animals can result from deposition of particulates that contain radionuclides into the environment. The protection of non-human species (plants and animals) from radiation has previously been assumed to have occurred as a result of the systems used for the protection of humans. This approach has changed in recent years, and the ICRP has recommended a dedicated system for assessing the protection of non-human species, which is outlined in ICRP 108 (ICRP 2008).

The new approach is based on an assessment of relative risk to species of plants or animals, using the software tool ERICA (ERICA, 2007). The tool makes use of a database of biological data from a set of standard species of NHB. Standard terrestrial species are defined, for the purposes of an ERICA assessment, as species broadly representing the majority of species found in nature. ODC uses ERICA to assess the potential impacts to NHB.

In practice, the assessment is based on the operational contribution to radionuclide concentrations in soils (measured with dust deposition gauges). The NHB assessment is based on the modelled risk to species (rather than individual plants or animals). Therefore, the radionuclide concentrations of individual plants and animals are not used to determine impact, however this concentration information is useful when determining potential human doses from direct or indirect ingestion of the plant.

2.3.2 Purpose

To provide data for the consideration of radiological risks to NHB in the region of the mine and to alert management if levels are found to approach the **leading indicator** value for non-human biota.

2.3.3 Deliverable(s)

Records from passive dust deposition monitoring sites and comparison with the annual compliance rate of 25 Bq/m^2/y at the NHB monitoring sites.

Assessment of the impacts to **reference plants and animals** (ARPANSA 2010) for the appropriate ERICA Tier level, including as necessary comparison of the results with the reference level of 10 µGy/h.

2.3.4 Method

The method for assessing doses to NHB is in accordance with the recognised approach outlined in ICRP 2008. BHP has established a compliance criterion of 25 Bq/m^2/y at the SML boundary. It is noted that it is highly unlikely that any exceedances of the compliance radionuclide deposition rate would lead to any harm to flora and fauna due to radiation. However, this level has been established as a precautionary level and could change as more information on NHB becomes available and the national standards are developed.

The method is based on determining the quantity of radionuclides from the operation that deposit into the environment and using this data and the ERICA software to determine whether the screening level has been exceeded and if so, to undertake further ERICA assessments at the appropriate Tier level.

To assess the impacts to NHB, the quantity of long-lived radionuclides in the ^{238}U decay chain that have deposited into the environment must be determined. Five passive dust deposition monitoring sites are located around the site (see Appendix C, Figure 7-1). Samples are collected every month and analysed for the total mass of particulates. To achieve sufficient sample mass to measure the radionuclide concentrations, the deposition samples are composited for 12 months prior to final radionuclide analysis. Annual composite samples are analysed for ^{238}U; ^{230}Th ^{226}Ra ^{210}Po ^{210}Pb activity. From these values deposition rates are calculated and compared annually to previous monitoring results to assess trends and the long-lived radionuclides in the ^{238}U decay chain and are utilised for ERICA assessments. Radionuclide analysis is done using standard analytical techniques at the Olympic Dam laboratory (or at a recognised external laboratory). The laboratory will report results as 'total dust deposited' (in grams) and 'radionuclides deposited' (in Bq for each of the long-lived radionuclides). The deposition rate is then determined by dividing the quantity deposited by the collection area of the gauge and the sampling time, to give a final deposition rate in units of g/m^2/year or Bq/m^2/year.

Appendix C shows the deposition monitoring sites for NHB. Monitoring sites PD 1, PD 4, PD 8 and PD 13 will be used for the assessment.

Based on the increase in soil radionuclide concentrations and a standard database of radiation effects to plants and animals, the software calculates a nominal exposure rate for the standard plants and animals. The exposure rate is then compared to the 'reference level' (which is set at a default level of 10 µGy/h). If the reference level is exceeded for a particular species, then a more detailed assessment (called tier 2 or tier 3 assessments) is conducted, in which more realistic exposure parameters are entered into the ERICA software, rather than the default parameters. If the reference level is exceeded following a tier 3 assessment the radionuclide deposition data are used to develop a contour plot showing the operational contribution of radionuclides into the environment. The approximate contour at the project boundary is determined and used to calculate the change in soil radionuclide concentration which is used as input data to the ERICA software then flora and fauna distribution maps are used to determine if the species are actually present within the risk contour, and whether the species diversity or abundance is affected. Such a situation is not anticipated at Olympic Dam.

2.4 Combined environmental radiation monitoring

2.4.1 Background

A requirement of the **Mining Code** is that a program be established for monitoring the concentration of radionuclides in the environment, with the general aim of identifying any long-term changes in radionuclide concentrations in the environment as a result of operations. If any changes in concentration have been detected, the impact of those changes can be determined.

The monitoring data also provides information on the effectiveness of management controls for environmental radiation and verification of the public dose estimates.

As noted in section 2.1, some environmental radiation monitoring is conducted as part of other environmental monitoring. For example, when groundwater is monitored, various parameters, including radionuclide content are analysed. This section collates all the environmental radiation monitoring from this MP and other MP's into one table for clarity.

2.4.2 Purpose

To identify long-term radiological trends in the environment as a result of operations.

2.4.3 Deliverable(s)

A database of radionuclide concentrations in the environment over the long-term.

2.4.4 Method

The methods of radiological monitoring are summarised in Table 2.2.

Table 2-2: Radiological monitoring methods

Environmental radiation parameter	Monitoring method	Where results are used
Radionuclides in airborne dust	Active sampling using high volume samplers located at the air quality monitoring sites (see Appendix C for locations). Filter papers are changed monthly and collected as per the existing method for dust monitoring and analysed for long-lived radionuclides in the ^{238}U decay chain.	Public dose assessment. Reporting changes in atmospheric conditions.
Radionuclide deposition	Deposition gauges are used to collect samples which are composited and analysed yearly for the long-lived radionuclides in the ^{238}U decay chain.	NHB assessment.
Radon decay product concentration	Active sampling using dedicated equipment located at the air quality monitoring sites. Equipment samples air every 10 minutes and results are downloaded on a regular basis to a central database. (see section 2.2.4 and Appendix A of this MP)	Public dose assessment. Reporting changes in atmospheric conditions.
Radionuclides in groundwater	Water samples taken as part of the groundwater sampling program are analysed for the long-lived radionuclides of the ^{238}U decay chain. (see section 2.3.4 of the Groundwater MP)	Investigative monitoring. Reporting changes in radionuclide concentrations in groundwater.
Radioactive process material spills	Record of time, location and magnitude of spill, and spill receptor. (see EM Program ID 2.2)	Used to compare spill and radiological monitoring results.

3 COMMITMENTS

3.1 Reporting

Results in the form of public doses, NHB assessments and environmental radionuclide concentrations are reported in the annual EPMP report and Licence to Mine and Mill Radioactive Ores (**Licence LM1**, 1988) annual report following the sampling program, with comparisons to previous year's information (MC 2.8.2(g)).

A copy of the ERICA report will be provided in the annual EPMP report as part of the NHB impact assessment. This is a standard report generated by the ERICA software itself.

Dose assessment and a discussion of the results are also reported in the Annual Radiation Report, submitted to the Radiation Protection Division of the EPA.

3.2 Summary of commitments

Table 3-1: Summary of commitments

Action	Parameter	Frequency
Monitor	Number and Extent of Radioactive Process Material Spills	Ongoing
Monitor	RnDP and radionuclide in dust data from particulate monitoring program (HiVolume filters and Real time RnDP monitors)	Monthly
Monitor	Fugitive particulate emissions – dust deposition	Monthly
Monitor	Fugitive particulate emissions — ^{238}U ^{230}Th ^{226}Ra ^{210}Po ^{210}Pb activity	Annually
Assess	Conduct NHB assessment (using ERICA program if required)	Annually
Calculate	RnDP and dust doses for critical groups	Annually
Report	Critical group doses and NHB impact assessment in Annual Radiation and Occupational Hygiene Report to the Radiation Protection Division of the EPA	Annually
Report	Monitoring results in the annual EPMP report to the Indenture Minister	Annually
Review	The Environmental Radiation MP and modify as appropriate	Annually

4 DEFINITIONS AND REFERENCES

4.1 Definitions

Throughout the EPMP some terms are taken to have specific meaning. These are indicated in bold text in the documentation and are defined in the glossary in section 5 of the EMM. Defined terms have the same meaning wherever they appear in bold text. Some other terms and acronyms are also defined in the glossary, but do not appear in bold text.

4.2 References

ARPANSA 2010, Environmental protection: Development of an Australian Approach for Assessing Effects of Ionising Radiation on Non-human Species, Che Doering, Technical report No.154.

ERICA 2007, Environmental Risk from Ionising Contaminants: Assessment and Management, ERICA Program 2007 (http://www.facilia.se/projects/erica.asp).

ICRP 1979, Publication 29, (ICRP 29). 'Radionuclide Release into the Environment: Assessment of Doses to Man'.

ICRP 1996a, Publication 71, (ICRP 71). 'Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4 Inhalation Dose Coefficients'.

ICRP 1996b, Publication 72, (ICRP 72). 'Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients'.

ICRP 2008, Environmental Protection: the Concept and Use of Reference Animals and Plants, ICRP Publication 108, Annals of the ICRP 38 (4–6).

Licence to Mine and Mill Radioactive Ores (**Licence LM1**), 1988.

Mining Code 2005, Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (ARPANSA 2005).

ODC 1996a (Olympic Dam Corporation) Pty Ltd 1996a, 'Environmental Management and Monitoring Plan, 1996'.

ODC 1996b (Olympic Dam Corporation) Pty Ltd 1996b, 'Justification for Changes to the Environmental Management and Waste Management Programmes 1996'.

ODC 1998, WMC (Olympic Dam Corporation) Pty Ltd 1998, 'Olympic Dam Operations: Environmental Management and Monitoring Plan Annual Report, 01/03/97 – 28/02/98'.

5 APPENDIX A: RADON DECAY PRODUCT DOSE ASSESSMENT METHOD

The method for assessing RnDP dose has been developed at Olympic Dam and involves monitoring RnDP data and meteorological information to determine project originated impact above natural background.

RnDP concentrations are measured and recorded on a ten minute basis at powered monitoring sites located at Roxby Downs's township (RDS) and Olympic Dam Village (ODV).

The RnDP concentration measurements are captured by data loggers and regularly downloaded to the computer network for storage in a database.

Meteorological data is acquired from the Bureau of Meteorology weather station equipped with wind speed and direction sensors. This is located in the vicinity of the ODV monitoring station at the Olympic Dam Airport and is representative of meteorological conditions in the operational area.

The natural background concentrations of RnDP at ODV and RDS and the concentrations attributable to the operation are calculated using wind direction to differentiate the location of the sources. The concentration of RnDP measured at ODV and RDS when the wind is blowing from within their respective operational sectors (i.e. comes from the vicinity of the operation) is deemed to be comprised of background plus operationally-related radon decay products. Alternately, when the wind is blowing from directions other than the operational sectors, it is designated as coming from the background sectors, and the measured concentration of radon decay products is deemed to be entirely due to natural background sources. Central to this method is the assumption that background concentrations are independent of wind direction. The assumption is conservative because wind from the north-east of the operation has naturally higher concentrations of radon decay products than wind from the south-west, thus leading to an overestimate of the operation's contribution.

The annual RnDP concentration attributable to the operation is calculated at ODV and RDS by:

- Subtracting the monitoring site's mean background sector concentration from the site's mean operational sector concentration;
- Multiplying the residual by the fraction of time that wind direction was within the monitoring site's operational sector.

A threshold wind speed (1 m/s) is used to exclude data from the above calculation because concentrations measured at RDS and ODV below this wind speed are unlikely to be influenced by RnDP originating from the operation, and the wind direction sensor nears the limit of its ability to accurately determine direction at wind speeds below this value. The effect of using different wind speed criteria when filtering the data is presented in ODC (1998).

ODC estimates the effective dose from radon decay products ED_{Rn} (in mSv/y) using the following equation:

$ED_{Rn} = R \times t \times DCF$

where R is the residual radon decay product concentration (mJ/m^3), t is the total number of hours per year (8,760 h/y) and DCF is the dose conversion factor applicable for **members of the public** with full-time occupancy at ODV or RDS and is equivalent to 1.1 mSv per mJ.h.m^{-3} (ICRP 1996b).

6 APPENDIX B: RADIONUCLIDES IN DUST DOSE ASSESSMENT METHOD

The method for assessing the radioactive dust contribution to total dose involves analysing radionuclides in dust concentration data and meteorological information to derive an operational impact above natural background.

The dust concentration in air monitoring (using high volume samplers) provides monthly PM10 concentration in ambient air for each monitoring site at RD and ODV.

The background radionuclide concentrations are based on measurements from a high volume air sampler at the Roxby Downs Homestead (RDH) located on Roxby Downs Station, approximately 30 km SSW of the operation. The background measurements were taken in 2006/2007 and are displayed in table 6.1 below.

Analysis of long-lived radionuclide concentrations in dust is undertaken on samples collected from each of the two sites, RV and ODV. The calculation of dose to **members of the public** related to the operation involves subtracting the derived background concentrations measured at RDH from the measured RDS and ODV results.

The dose estimation methods used are provided in ICRP 71 (ICRP 1996a), and the dose conversion factors (DCFs) used for each uranium series radionuclide are specified in ICRP 72 (ICRP 1996b).

The mean concentration of each long-lived radionuclide in dust attributable to the operation is multiplied by the number of hours of exposure per year, the standard persons breathing rate, and a DCF that converts the concentration of inhaled radionuclide in dust into effective dose for that radionuclide ED_R (in mSv/y). The formula used is:

$ED_R = C \times t \times B \times DCF$

where C is the mean annual concentration (Bq/m^3),), t is the total number of hours per year (8,760 h/y), B is the breathing rate (m^3/h) and DCF is the dose conversion factor (in mSv/Bq) for the specific radionuclide.

The effective dose from radioactive dust ED_D (in mSv/y) is then the sum of the effective dose for each of the long-lived radionuclides.

Table 6.1 background levels form Roxby Downs Homestead

Background Data from RDH					
uBq/m^3	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po
Average	0.55	0.74	1.50	318.30	36.32
Standard Deviation	0.60	0.74	2.31	83.02	21.23
Standard Error	0.17	0.21	0.67	23.96	6.13

7 APPENDIX C: DEPOSITION MONITORING LOCATIONS

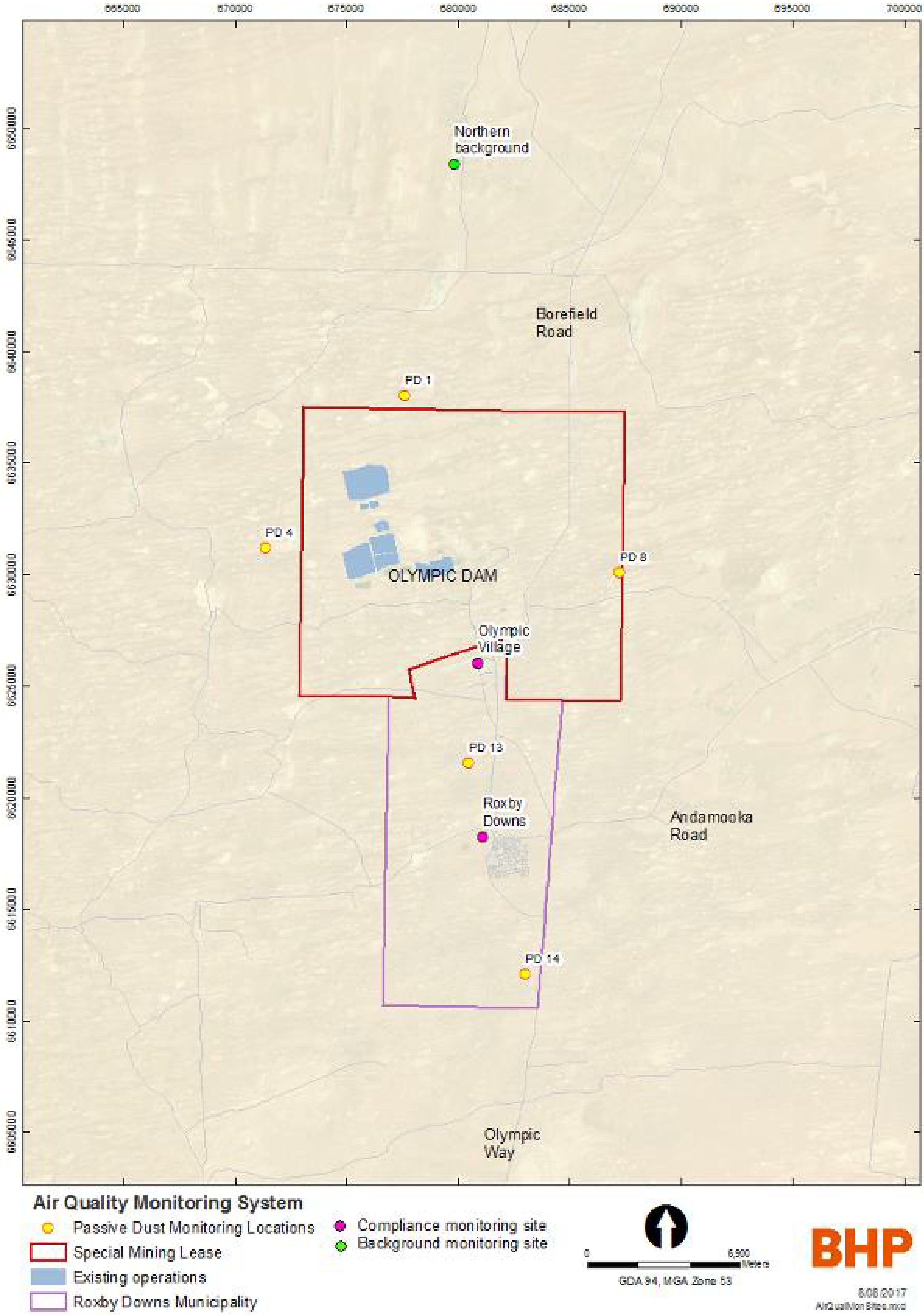

Figure 7-1: Air Quality Monitoring Sites