

CHAPTER 17

Electromagnetic Interference

CHAPTER 17: ELECTROMAGNETIC INTERFERENCE

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Executive Summary

Investment in astronomy is part of a concerted strategy by the Department of Science and Technology (DST) to establish South Africa as an international hub for astronomy. Investments have not only targeted local projects, but also international projects that have been located in South Africa, such as the Southern African Large Telescope (SALT) and the Square Kilometre Array (SKA).

In order to protect these multi-billion Rand investments from increased levels of interference (and thereby reducing the scientific performance of the facilities), protection of the observing environment is critical. Such increased levels are expected with an increase in industrial and telecommunications activity.

The potential increase in interference resulting from activities associated with shale gas development (SGD) has been assessed, and separation distances, or buffers, derived to ensure no detrimental impact on the SKA. Buffers are classified in terms of risk classes, where any activities that are proposed to be undertaken within specific buffers will be required to implement appropriate and effective mitigation measures before proceeding with such activities. The identification of these measures will be subject to further detailed, site specific assessments.

Calculated separation distances can reach up to 40 km for the most sensitive parts of the SKA. There is an opportunity to reduce these distances, should further detailed studies be undertaken to provide site specific detail.

CHAPTER 17: ELECTROMAGNETIC INTERFERENCE

17.1 Introduction and scope

17.1.1 Relevance of electromagnetic interference (EMI) for radio astronomy developments

Southern Africa has a rich history in astronomy, dating back to 1820 and the establishment of the Cape of Good Hope Royal Observatory. More recently, however, the development of astronomy in South Africa has been part of a considered strategy that has its origins in a white paper on Science & Technology, drafted in 1996. The white paper identified the need for a basic competence in flagship sciences such as astronomy. This strategic position was carried forward into the National Research Development Strategy, published in 2002 by the Department of Science and Technology (DST), in which astronomy, together with human palaeontology and indigenous knowledge, is identified as an area in which South Africa is most likely to succeed because of an inherent natural geographic advantage. This led to the DST adopting a vision that South Africa should become the preferred destination for major astronomy projects and associated international investment in construction and operations of astronomical facilities (DST 10 Year Plan 2008-2018). This commitment is repeated in the DST's Strategic Plan for the fiscal years 2011-2016:

“In growing its knowledge base, South Africa also needs to build on its niche strengths, especially those in which it has a geographic or natural advantage, such as astronomy, biodiversity, Antarctic research, minerals processing and palaeontology.”

As a result of this strategy, the South African government has undertaken multi-billion Rand investments into world class astronomical facilities: firstly, the multinational 10 metre (m) Southern African Large Telescope (SALT) in Sutherland – at the time of writing, the largest optical telescope in the southern hemisphere; and secondly, the successful African¹ bid to host the international Square Kilometre Array (SKA)² project. This includes the establishment of the South African funded and designed MeerKAT³ radio telescope, which will be the premier centimetre (cm)-wavelength radio astronomy facility in the world until the SKA is built. Investments in both facilities are supported by a wide range of human capital development programs. These are meant to increase the capacity of South African scientists and engineers who are able to participate in the scientific programs of these facilities. South Africa's bid was supported by the Heads of States and Government of the African Union in a Declaration at their 2010 Assembly. This Declaration expressed unequivocal support for

¹ South Africa's bid to host the SKA was on behalf of eight other African Partner Countries, including: Namibia, Botswana, Zambia, Mozambique, Madagascar, Mauritius, Kenya and Ghana.

² For further information, go to: www.skatelescope.org.

³ For further information, go to: www.ska.ac.za.

South Africa to lead the bid to locate the SKA in Africa, and committed Africa to participate in the global SKA project. The SKA was also recognised as a flagship project by the African Ministerial Council on Science and Technology.

Once fully constructed, the SKA will extend over 3 000 kilometres (km), representing a multi-billion Euro investment by the global scientific community in one of the premier technological developments in the world. A radio astronomy facility, such as the SKA, is an extremely sensitive radio receiver with more than 15 orders of magnitude greater sensitivity when compared to a typical cellular phone. It is designed to receive extremely weak radio signals that are emitted naturally from cosmic sources. Its scientific performance is highly dependent on the technical scope of the facility, as well as the scientific properties of the environment in which it is located. Such properties would include tropospheric and ionospheric disturbances and precipitable water vapour, as well as various geo-hydrological and meteorological dependencies. These would all be cost drivers for the establishment of such a project. However, the principle risk to the scientific performance of a radio astronomy facility is the presence of radio frequency interference (RFI), which, for radio astronomy; are radio signals not of cosmic origin. RFI is generated from a variety of terrestrial sources that include intended radiators such as television broadcasters, global system for mobile communications (GSM) transmissions and wireless networks, but also unintended radiators that include the operations of most commercial electronic devices. Even microwave ovens and the spark plugs of petrol vehicles are unintended sources of RFI. For this reason, the identification of sites for the establishment of new radio astronomy areas is a highly scientific and technical process.

The Northern Cape Province of South Africa, and in particular the Great Karoo, has been shown, through an international SKA site selection process, to be one of the best locations in the world to establish a cm-wavelength radio astronomy site. This was confirmed following the recommendation by an independent panel of experts that South Africa, along with the SKA African Partner Countries, be awarded the right to host the SKA. To protect the region for astronomy, the South African government promulgated the Astronomy Geographic Advantage (AGA) Act, Act No. 21 of 2007. This Act empowers the Minister of Science and Technology to declare Astronomy Advantage Areas, and protect these areas through regulations. The Northern Cape Province has been declared as an Astronomy Advantage Area.

In a report by the Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (Department of Mineral Resources (DMR), 2012), an impact analysis of shale gas development (SGD) on the SKA is undertaken (Digital Addenda 17A and 17B). In it, the author provides a concrete assessment framework to determine the impact of RFI on the SKA. The framework is based

on internationally accepted principles for protection of the radio astronomy services, as described by the International Telecommunications Union (ITU). Required protection threshold levels for the radio astronomy service are described in ITU Recommendation ITU-R RA.769-2 (Digital Addendum 17C). The basic principles upon which this recommendation is developed has been used in the derivation of the South African Radio Astronomy Service (SARAS) protection level (DST, 2011). This protection level has been promulgated in terms of the AGA Act (Appendix D - Government Gazette Notice No. 35007, 10 February 2012), and adopted in South Africa to provide a clear and objective decision making process in the assessment of RFI on the SKA and other radio astronomy facilities. This process is sufficiently robust to be applied to an extensive range of scenarios that may be the cause of RFI, including television broadcasting, public communications, household and industrial activities, and renewable energy. A literature survey suggests that, other than the report prepared for the South African Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (DMR, 2012), there is no other published national or international impact assessment conducted on the risk of RFI from hydraulic fracturing (“fracking”) activities on radio astronomy facilities.

Figure 17.1 describes, at a high level, typical uses of the electromagnetic spectrum across which the SKA will be operating (the SKA will operate between 100 MHz and 25 GHz at its fullest extent). Low level electromagnetic interference, produced by the use of electrical and industrial equipment, would typically fill a large part of the radio frequency spectrum below 1 GHz (not shown). The risks posed by these sources are typically dependent on the distance from an SKA receiver that they are used, the transmitter power of the relevant device, and any relaxation of the protection levels. This figure is only illustrative, and should not be used in isolation to determine potential risk to the SKA.

Inside the radio wave spectrum

Almost every wireless technology – from cell phones to garage door openers – uses radio waves to communicate. Some services, such as TV and radio broadcasts, have exclusive use of their frequency within a geographic area. But many devices share frequencies, which can cause interference. Examples of radio waves used by everyday devices:

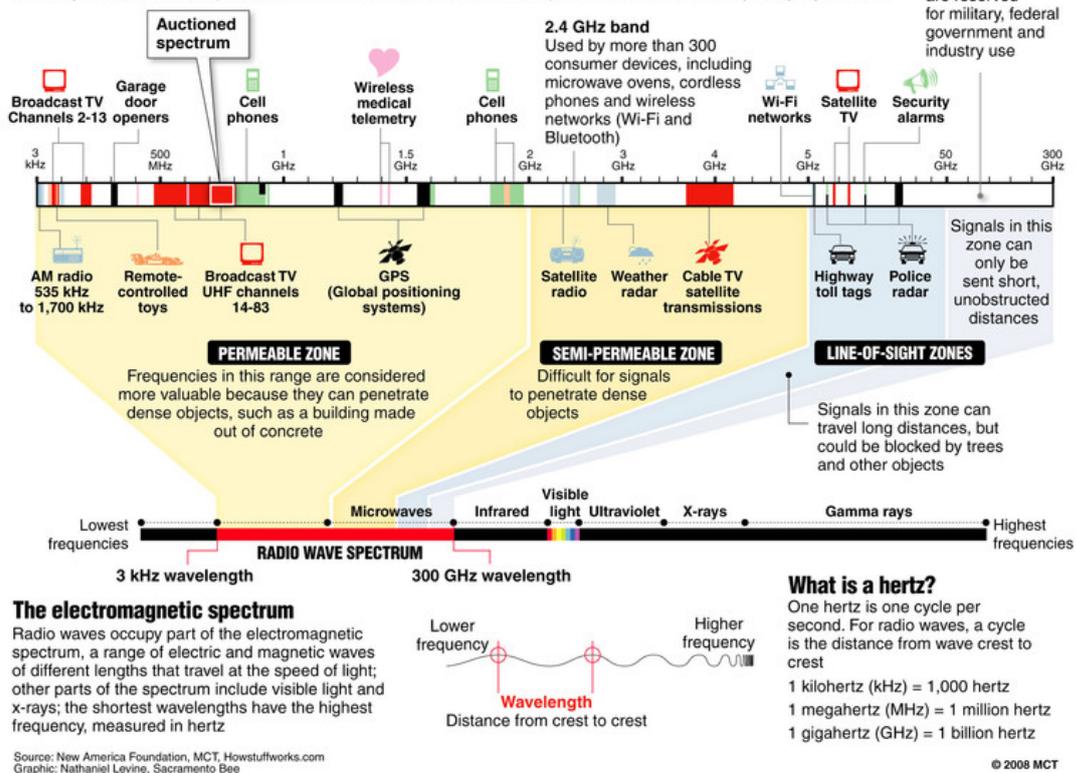


Figure 17.1: Everyday uses of the radio frequency spectrum (image credit:

<http://theconversation.com/wireless-spectrum-is-for-sale-but-what-is-it-11794> [Online: 19-09-2016])

17.2 Scope of main strategic issues

The scientific return of a radio telescope relies on an environment that is as free as possible from RFI within the radio frequency band of interest. Historically, radio telescopes have operated within narrow parts of the radio frequency spectrum (approximately 1% of the radio frequency spectrum is allocated for use of the radio astronomy service by the ITU). Modern and next-generation radio astronomy facilities, such as the SKA, aim to operate across very wide frequency ranges. The component of the SKA in South Africa, at its fullest extent, will operate from 100 megahertz (MHz) to 25.5 gigahertz (GHz). As a result, it is dependent on domestic legislation to ensure protection of the international community's investment into South Africa.

For the first phase of the SKA, capital investment amounts to approximately R5 billion, whilst phase two of the SKA could be at least five times this. Operational costs are expected to be anywhere between 8% - 10% of the total capital cost per annum, for 50 years. However, it is the indirect socio-economic benefits resulting from participating in the SKA project that are of greatest value, and include:

- Skills development, and spin-off products, in next-generation engineering and computing technologies as well as ‘big data’ processing;
- Establishment of knowledge generation capacity, and hence contribution towards the growth of a knowledge-based economy in South Africa;
- The promotion of South Africa as a viable destination for international investment in high-tech infrastructure and scientific projects; and
- Attracting youth into careers of science, technology, engineering and mathematics.

17.3 Key potential impacts

17.3.1 Nature of impact

The SKA is sensitive to two classes of RFI. The first class includes relatively high power, narrow band radio signals commonly associated with a variety of telecommunication services such as GSM, Wi-Fi and Bluetooth. These narrowband signals tend to be strong, and can have one of three potential detrimental impact (in increasing order of RFI signal strength):

- i. The RFI signal pollutes a narrow part of the radio frequency spectrum of interest. The radio telescope continues to operate, but the polluted part of the spectrum must be filtered out. The cosmic information in the filtered band cannot be recovered, resulting in decreased scientific performance due to reduced access to the radio frequency spectrum;
- ii. The RFI signal is strong enough to cause saturation in the radio astronomy receiver equipment. Saturation causes non-linear artefacts across the entire observing band that cannot be removed. No observations can be made by the equipment;
- iii. The RFI signal is sufficiently strong to cause permanent damage to radio astronomy receiver equipment.

In recent years, the demand for higher data throughput has seen an increase in availability of consumer devices using ultra-wideband protocols. These devices are typically used for short distance communication (such as spread spectrum technologies), or in radar technologies (such as vehicle parking assist).

The second class of RFI includes relatively low power broadband emissions that are generated as a by-product from the use of electrical equipment. This is commonly referred to as EMI, and examples include welding activities and the sparking on electrical power lines. Although typically low power, EMI can potentially cover a large part of the frequency spectrum relevant to the SKA, making it unusable for radio astronomy observations. In this case the spectral occupancy of the interference

makes it equally destructive as saturation or permanent damage to the receivers. The result is a significant loss in scientific performance.

The assessment of interference also considers its transient nature as a result of its operational use or physical movement of the interference source (e.g. satellites or vehicles). More recently, detailed studies have been undertaken into short duration transient events that are typical of the permanent operation of an interference source. Sufficiently complex to be classified as a separate sub-class of EMI, this interference often requires more sophisticated equipment to measure and the source is usually more difficult to identify. They tend to exist for only a short period, but can occupy a large part of the spectrum. Significant peak interference levels, for example mechanical relays used for switching of electric motors, could lead to short duration saturation of a sensitive receiver. This again produces non-linear artefacts in the observable band, making it unsuitable for astronomy observations.

This assessment of the impact of EMI takes into account the uncertainty presented by the limited information on the nature of potential sources associated with SGD activities. It also treats EMI as the primary source of detrimental risk. Whilst the use of radio communication equipment does represent a significant risk of detrimental impact, this risk is technology dependent. Through the adoption of key guidelines and principles this risk can be addressed and reduced. Furthermore, the use of such equipment will be subject to relevant regulations promulgated in terms of the AGA Act where relevant.

17.3.2 Methodologies and assumptions

17.3.2.1 Decision-making framework

A framework to assess the impact of EMI, and RFI, on or around the SKA site is provided in Digital Addendum 17E. To ensure no detrimental impact on SKA stations, in the generalised case for each frequency f_i we require the following condition to be true:

$$\text{Compliance} \rightarrow \text{Loss}_{det} \geq \text{Loss}_{required}$$

where:

$$\text{Loss}_{required} = \text{ProtectLevel} - \text{EmissionLevel}$$

Each variable ($\text{Loss}_{required}$) is described as follows:

- $\text{Loss}_{required}$ = the required attenuation of an EMI/RFI signal [dB]

- *EmissionLevel* = characteristic profile of radio emission of the EMI/ RFI source, and can be expressed in units of spectral power density [dB(W/Hz)]
- *ProtectLevel* = required protection threshold level. Unless otherwise prescribed, the default level is defined by SARAS as:

$$\begin{aligned} \text{SARAS}[\text{dBm/Hz}] &= -17.2708\log_{10}(f) - 192.0714 \quad \text{for } f < 2\text{GHz}, \\ &= -0.065676\log_{10}(f) - 248.8661 \quad \text{for } f > 2\text{GHz} \end{aligned}$$

Where; f is in MHz, and where:

$$Loss_{det} = PathLoss + Shielding$$

Each variable ($Loss_{det}$) is described as follows:

- $Loss_{det}$ = predicted/measured attenuation of EMI/ RFI signal [dB]
- $PathLoss$ = attenuation resulting from radio propagation, including the free space loss between the EMI/ RFI source and radio astronomy receiver, and diffraction losses [dB]. These losses may be determined via the following methods, in order from most conservative to least conservative:
 - Free space loss;
 - Free space loss + diffraction model;
 - Measurement.
- $Shielding$ = attenuation resulting from additional physical shielding [dB]

17.3.2.2 Methodology

To ensure compliance with protection levels, the principle adopted in the assessment methodology is to assume that the required attenuation ($Loss_{Required}$) is equal or less than the predicted attenuation ($Loss_{Det}$) between EMI/ RFI sources and radio astronomy receivers. Determination of $Loss_{Required}$ relies on, as input; the protection threshold levels (SARAS) and the characteristic emission profile of the potential EMI/ RFI source. Determination of the predicted attenuation ($Loss_{Det}$) relies either on site specific path loss measurements, which would be impractical to implement on a large scale, or on propagation models. In the case of propagation modelling both free space loss and loss as a result of topographical diffraction over a fixed separation distance are calculated. Additional shielding may be considered in situations where free space loss and topographical diffraction is insufficient. However, this should only be considered as part of site specific mitigation measures.

The radio frequency propagation model ITU Recommendation ITU-R P.526 is used to determine separation distances required between sources of EMI/ RFI and SKA receivers to ensure compliance. The model is highly dependent on the following:

- i. Relative heights of receiver and transmitter;
- ii. Receiver technologies, and characteristic emission profile of transmitters;
- iii. Local topographical features.

To determine the characteristic profile of EMI, a variety of methods can be adopted. The most accurate is to undertake a series of measurements under all potential operational conditions, using accepted measurement methodologies. One approach would be to do individual measurements for a wide range of equipment typically used in SGD to derive an average characteristic profile during operation. A second approach would be to do emission characterisation of an entire fracturing site during various stages of development. In the absence of such measurements, national or international standards can be adopted. Whilst a SGD site can be considered a fixed installation, International Special Committee on Radio Interference (CISPR) standards can be adopted to provide EMI limitations of general classes of equipment to be used in SGD activities. The South African National Standards Authority adopts CISPR standards for use in South Africa. Digital Addendum 17A describes a wide range of CISPR standards. Given the frequency dependency of the SARAS protection levels (DST, 2011) and the nature of radio frequency propagation; Digital Addendum 17A shows that the lowest frequency limit of each receiver technology (see Section 7, Digital Addendum 17A) determines the largest required separation distance. This aspect will be used to determine the required separation distance in this assessment.

17.3.2.2.1 Transient assessments

The assessment of transient sources of interference is guided by ITU Recommendation ITU-R RA.1513-1, which considers the acceptable loss of data for a radio astronomy facility as a result of interference. This is expressed as a percentage of time, where no single network of interference can result in greater than 2% data loss, whilst a total data loss of no more than 5% for all sources can be tolerated. This requirement is considered in the assessment of various operational use profiles, such as the treatment of moving sources of interference (see Digital Addendum 17A).

In the case of regular use, or mixed use of multiple pieces of equipment, or large density of transient sources of interference are treated as permanent sources.

17.3.3 Impact systems

17.3.3.1 Radio astronomy systems

The only radio astronomy system that may be impacted by SGD activities in the study area is the SKA⁴. At its fullest extent, the SKA in Africa will consist up to 3 000 dishes, each of which is similar to a MeerKAT⁵ dish as shown in Figure 17.2, and specialised aperture arrays⁶. The configuration will be split into three different components: a highly concentrated core, measuring up to 5 km in diameter and consisting of 50% of the antennas; a set of spiral arms stretching out to 180 km and including a further 30% of the antennas; and final, up to 25 SKA remote stations distributed across South Africa and the African Partner Countries. Each dish will be approximately 15 m high, and operate over a frequency range from 350 MHz up to 25.5 GHz. Co-located with the dishes, within the core and spiral arms, will be aperture arrays that operate below 350 MHz at a height of 1 m. Consistent with international recommendations, and for the purposes of this assessment, the gain of each of these antennae is assumed to be 0 dB in the direction of the EMI/ RFI source. Current timelines for the construction of the SKA are as follows:

- i. SKA Phase 1**
 - a. Construction: 2018 – 2023
 - b. Operations: 2023 onwards
- ii. SKA Phase 2**
 - a. Design: 2021 - 2023
 - b. Construction: 2023 - 2030
 - c. Operations: 2030 onwards

⁴ See www.skatelescope.org for further details.

⁵ MeerKAT is a South African funded and designed pre-cursor facility, and will consist of 64 dishes when completed in 2017. It will be one of the world's premier cm-wavelength radio astronomy facilities when completed, and is designed as a Strategic Infrastructure Project (SIP) by the Presidential Infrastructure Coordinating Commission (PICC). See www.ska.ac.za for more details.

⁶ See www.skatelescope.org/aperture-arrays/ for further details.



Figure 17.2: Photograph of MeerKAT dish (image credit: SKA South Africa)

Figure 17.3 indicates the study area, with superimposed SKA Phase 1 and SKA Phase 2 configuration. Corridors for the core and spiral arms have been pre-identified, inside which the density of SKA stations will increase over time. Individual points identify the locations of SKA Remote Stations. The black polygon identifies the Karoo Central Astronomy Advantage Area (KCAAA), declared in terms of the AGA Act. Any activities, and use of radio communication equipment, located within this area, is subject to compliance with regulations for the protection of radio astronomy, as promulgated by the Minister of Science and Technology. These regulations will impose conditions and restrictions on use, subject to a prescribed impact assessment.

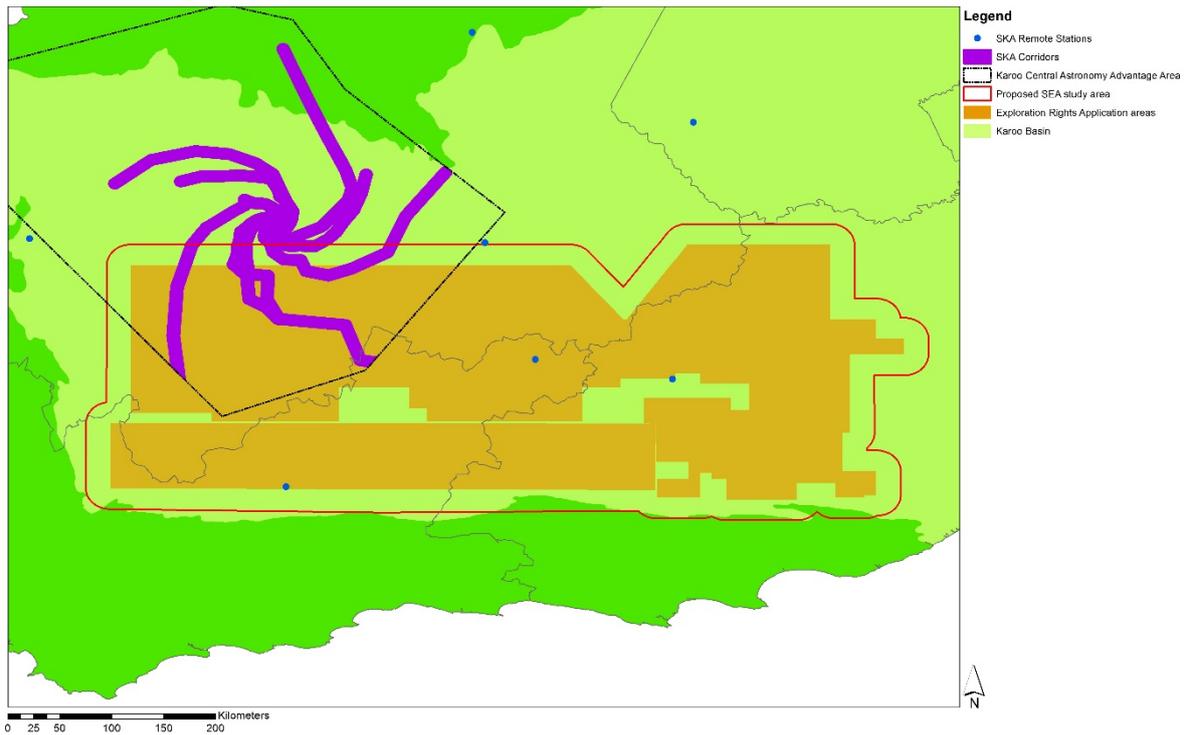


Figure 17.3: Study area with SKA Phase 1 and Phase 2 configuration.

The key outcome of this assessment is to ensure protection of the SKA stations within these geographic locations, through the determination of masks that identify areas of high detrimental impact.

17.3.4 Production of EMI resulting from SGD

17.3.4.1 Key sources of risk

Given the unavailability of measurements, the characteristic emission profile of EMI sources is described by CISPR recommendations, which are adopted by the South African Bureau of Standards (SABS) as a national standard. These standards prescribe an upper limit on allowable levels of emission.

A description of the expected characteristic EMI profile for a single SGD site and supporting activities is provided in Table 17.1. This profile is based on a proposed inventory of equipment⁷ for each potential phase of construction, operations and decommissioning. It is assumed that the equipment will be operated at an average height of 2 m.

⁷ The authors engaged with technical staff within the petroleum industry to acquire further technical information. However, this information is preliminary and may vary from site to site. It is recommended that this table is updated following more detailed planning by the developers.

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Table 17.1: Description of expected EMI profile of SGD sites and supporting activities during construction and operation. The decommissioning state is expected to be similar to construction state.

| EMI Source | Characteristic Profile | Use Profile [% Time] | Use Profile [Location] | Level at 350 MHz [dB(uV/m) @ 10m] | No. per Site | Integrated Level at 350 MHz [dB(uV/m) @ 10m] |
|---|---|----------------------|------------------------|-----------------------------------|--------------|--|
| Site Preparation [one month] | | | | | | |
| Diesel Vehicles | CISPR 12:2009 - 20dB | 40% | On-Site, Road | 17 | 5 | 24 |
| Petrol Vehicles | CISPR 12:2009 | 40% | On-Site, Road | 37 | 5 | 44 |
| Pumps/ Compressors/ Generators | CISPR 12:2009 | 100% | On-Site | 37 | 5 | 44 |
| Local Wireless Communication Systems (ISM) at 464 MHz | ICASA Radio Regulations: Short Range Devices (Non-Specific SRD) | 100% | On-Site | 115 ⁸ | 1 | 115 ⁹ |
| Computer Systems | CISPR 22:2009 (Class B) | 100% | On-Site | 37 | 3 | 42 |
| Bulldozers/ Concrete Mixers/ Forklifts/ Crane | CISPR 12:2009 | 40% | On-Site | 37 | 5 | 44 |
| Electrical Appliances (Domestic) | CISPR 14-1:2009 | 100% | On-Site | 37 | 10 | 47 |
| Electrical Appliances ISM (Industrial) | CISPR 11:2009 (Class A) | 10% | On-Site | 47 | 5 | 54 |
| Data Testing Systems | CISPR 11:2009 (Class A) | 10% | On-Site | 47 | 1 | 47 |
| Total On-Site: | | | | | | 115 |
| Total On Road: | | | | | | 44 |
| Total On-Site (Excl. Communication Systems): | | | | | | 54 |
| Drilling/Securing [three months] | | | | | | |
| Drilling Rig | CISPR 12:2009 | 50% | On-Site | 37 | 1 | 37 |
| Drilling Services (Trucks) | CISPR 12:2009 | 40% | On-Site, Road | 37 | 3 | 42 |
| Local Wireless Communication Systems (ISM) | ICASA Radio Regulations: Short Range Devices (Non-Specific SRD) | 100% | On-Site | 115 | 1 | 115 |
| Computer Systems | CISPR 22:2009 (Class B) | 100% | On-Site | 37 | 3 | 42 |
| Electrical Appliances (Domestic) | CISPR 14-1:2009 | 100% | On-Site | 37 | 5 | 44 |
| Electrical Appliances ISM (Industrial) | CISPR 11:2009 (Class A) | 10% | On-Site | 47 | 3 | 52 |
| Total On-Site: | | | | | | 115 |
| Total On Road: | | | | | | 42 |

⁸ This level is prescribed at a frequency of 464 MHz. For the purposes of calculating the impact, it is assumed that this maximum emission level is at 350 MHz as opposed to 464 MHz. The impact on the results due to this change in frequency is negligible.

⁹ See footnote 8.

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| EMI Source | Characteristic Profile | Use Profile [% Time] | Use Profile [Location] | Level at 350 MHz [dB(uV/m) @ 10m] | No. per Site | Integrated Level at 350 MHz [dB(uV/m) @ 10m] |
|---|---|----------------------|------------------------|-----------------------------------|--------------|--|
| Total On-Site (Excl. Communication Systems): | | | | | | 52 |
| Stimulation and Well Test [12 months] | | | | | | |
| Drilling Services (Trucks) | CISPR 12:2009 | 40% | On-Site, Road | 37 | 3 | 42 |
| Well testing equipment | CISPR 11:2009 | 10% | On-Site | 47 | 1 | 47 |
| Local Wireless Communication Systems (ISM) | ICASA Radio Regulations: Short Range Devices (Non-Specific SRD) | 100% | On-Site | 115 | 1 | 115 |
| Computer Systems | CISPR 22:2009 (Class B) | 100% | On-Site | 37 | 2 | 40 |
| Electrical Appliances (Domestic) | CISPR 14-1:2009 | 100% | On-Site | 37 | 5 | 44 |
| Total On-Site: | | | | | | 115 |
| Total On Road: | | | | | | 42 |
| Total On-Site (Excl. Communication Systems): | | | | | | 48 |

Key points for consideration:

- i. The profile addresses both on-site and supporting activities on roads;
- ii. Expected EMI levels are prescribed in relevant CISPR standards as average levels. In the case of CISPR 22 (Class B), and CISPR 11 (Class A), quasi-peak levels are prescribed;
- iii. The profile addresses the nature of use of the equipment. However, given the mix of equipment and the commonality in the CISPR descriptions, the overall EMI profile will remain constant and should be treated as a permanent source of EMI;
- iv. The inventory of equipment includes local communication devices, such items as Wi-Fi, Bluetooth and any other proprietary communication equipment that could be used by the developer (either separately, or built into the equipment). The use of such equipment can potentially be mitigated should appropriate guidelines and principles be adopted; and
- v. Cumulative impact may be considered in the various scenarios, dependent on the relative location of each of the potential sites to an SKA station. For n sites that are equidistant to an SKA station, the cumulative impact will scale as $10\log_{10}(n)$.

Based on a single site, and following the prescribed methodology as per Section 17.3.2, the required attenuation is determined and described in Table 17.2 (detailed calculations provided in Digital Addendum 17F) for each phase of the development (construction, operations, decommissioning). The table covers the following situations:

- i. On-Site (excl. Communication Service) – attenuation required to ensure that EMI resulting from the use of electrical and industrial equipment poses no risk of detrimental impact to SKA stations;
- ii. On-Site – this is the same as per On-Site (excl. Communication Service), but includes the use of short range wireless devices for short range communication as part of the assessment. Additional shielding would be required as part of a more detailed and site specific mitigation strategy. This is dependent on the technology and mode of communication to be used;
- iii. On Road – supporting transport activities;

Table 17.2: Required attenuation for each phase, on a site-per-site basis.

| Phase | | Required Attenuation [dB @ 350MHz] | Additional Shielding [dB] |
|--|-------------------------|------------------------------------|---------------------------|
| On-Site (excl. Communication Service) | | | |
| Construction | Site Preparations | 155 | 0 |
| | Drilling Securing | 153 | 0 |
| Operations | Stimulation & Well Test | 149 | 0 |
| Decommissioning | Site Preparations | 155 | 0 |
| On-Site | | | |
| Construction | Site Preparations | 155 | 61 |
| | Drilling Securing | 155 | 61 |
| Operations | Stimulation & Well Test | 155 | 61 |
| Decommissioning | Site Preparations | 155 | 61 |
| On Road | | | |
| Construction | Site Preparations | 145 | 0 |
| | Drilling Securing | 143 | 0 |
| Operations | Stimulation & Well Test | 143 | 0 |
| Decommissioning | Site Preparations | 145 | 0 |

The required attenuation is used as the primary input in determining required separation distances, or buffers (see Section 17.3.5). Activities located within these buffers will not have achieved the required attenuation, and would therefore produce detrimental impact on SKA stations. In the case of stations located in the spiral arms, these buffers will assume average topographical terrain. Any additional shielding required, or mitigation measures, should be determined on a site specific basis as and when required. In the case of SKA remote stations, site specific topography will be considered.

17.3.4.2 Scenarios

- i. *Scenario 0: Reference Case*

Detailed studies have previously been undertaken on the existing radio frequency environment to determine suitability of hosting the SKA. Inputs such as population density (used as a proxy for general presence of EMI), transport routes and location of licensed transmitters were used. The background EMI currently presents an acceptable level of interference for the SKA stations. Any change in this EMI background in the vicinity of SKA stations could result in a detrimental impact on the SKA.

ii. Scenario 1: Exploration Only

It is expected that a limited number of sites will be tested during the exploration phase. It is also assumed that, given the description in Table 17.1, the EMI profile for each fracturing site will not change substantially for the three phases of construction, operation and decommissioning.

Given the low density of exploration activities, the cumulative impact of activities will not significantly increase the required attenuation beyond current levels on a per site basis. It is also unlikely that more than one or two exploration activities will take place within the vicinity of an SKA station¹⁰. The increase in vehicle volume is expected to be negligible¹¹, and SKA remote stations would not have been established prior to the commencement of exploration activities.

iii. Scenario 2: Small Gas

It is assumed that 55 wellpads within one production block, located somewhere in the Central Karoo will be established, with the characteristic EMI emissions described as per Table 17.1. The cumulative impact of the Small Gas activities¹² will not increase the required attenuation beyond what would be required for a single SKA site, since it is assumed that no more than one production block would be established within the vicinity of an SKA station (see footnote 10). It is likely that the increase in vehicular would be insignificant (see footnote 11).

iv. Scenario 3: Big Gas

The Big Gas scenario will result in the establishment of four production blocks with around 410 well pads in total. This will result in an increased cumulative impact. It is likely that many SGD activities may be established fairly close to each other, and will be operating within the vicinity of an SKA station (see footnote 10). Such cumulative impact will scale with the number of wellpads and their location, raising the required attenuation by one class level (see Section 17.3.5). A significant increase in vehicular activity may see roads becoming permanent sources of EMI.

¹⁰ More specifically, sites that are equidistant to an SKA station, and within or adjacent to a pre-determined buffer.

¹¹ Subject to a detailed operational plan for exploration and development activities by the relevant developers.

¹² For the purposes of this chapter, an activity is interpreted to mean the full scope of relevant construction, or operation, activities at a single well pad.

17.3.4.3 Mitigation options

Various mitigation options exist to address EMI and RFI sources, which can be separated into two different categories. The first category deals with mitigation options that are technology dependent, as well as being dependent on the use profile of the relevant equipment. These options include the following:

- i. Wireless communication equipment – the use of any wireless communication equipment, including consumer devices such as Bluetooth, Wi-Fi, as well as wireless local area networks (WLAN), may pose an unacceptably high risk and should be replaced by fixed communication services only. In the case of use within the declared KCAAA, the proposed infrastructure and any subsequent replacement these will be subject to the appropriate impact assessment process, as and when required;
- ii. Vehicles –petrol vehicles generate excessive levels of interference due to sparking events associated with the spark plugs. An alternative will be to change to diesel vehicles, which may mitigate the impact but not completely due to the subsidiary electronic equipment located in vehicles. Vehicle use in buffer zones will have to be monitored and reduced if required;
- iii. Pumps and Generators - tend to generate interference below the lowest frequency of interest to the SKA, assuming that in the case of pumps or electric motors, brush fewer units are used. However, typically the control hardware used to switch on/off pumps or generators make use of noisy switching electronics. Mechanical contactors used for switching larger currents produce sparking interference each time they operate. The effect of this interference can reliably be reduced by placing all associated hardware in shielded enclosures;
- iv. Micro controllers and monitoring hardware - typically have well defined clock frequencies and interference associated with communication protocols. Placing all such hardware inside shielded enclosures that make use of proper cable interfaces will help to reduce generated interference;
- v. All electrical/electronic cabling - can contribute to interference generated by the plant. Depending on the type of cable, conducted interference in the form of common mode current will flow on the outside of the cable. This conducted interference can radiate into the environment at frequencies where the cable becomes a resonant structure. Mitigation of such interference can be reduced by either improving the EMI performance of the cables used through the use of filters at interfaces to shielded enclosures, the use of shielded cables with appropriate grounding, or by placing them directly in soil. Sleeving should not be used as this prevents close capacitive contact between the cables and the

soil around it. This approach can, however, have significant cost implications and would have to be evaluated based on the site location and stage of operation.

The second category of options is dependent on site specific information. In principle, site specific topographical features may be taken advantage of to increase the predetermined attenuation to an SKA station. This helps to reduce the effective separation distance of that specific proposed SGD site. However, this mitigation strategy may only be undertaken on an individual site by site basis, and cannot be implemented generally.

17.3.5 Risk assessment

A map of sensitivity zones, derived from Table 17.2, is shown in Figure 17.4. The sensitivity zones are relevant for all construction and decommissioning phases, and are calculated assuming a generic, flat Karoo landscape¹³. A second map of sensitivity zones, relevant for all operational phases, is shown in Figure 17.5. The separate locations beyond the spiral arms, pertaining to the SKA remote stations, should only be considered for activities to be proposed beyond the year 2023. Both maps have been calculated with the exclusion of short range radio communication devices, which would require an additional 61 dB of attenuation or the adoption of alternative technologies that can provide the same level of service in a more ‘radio astronomy friendly’ manner (i.e. the use of wired, as opposed to wireless, technologies). It is unlikely that the use of these short range devices can be mitigated entirely through the implementation of a separation distance, and other measures would have to be considered – particularly within the declared KCAAA.

The sensitivity zones are categorised into various classes from 1 – 5, where each sensitivity class is informed by a specific separation distance. SGD activities beyond the pre-identified sensitivity zones do not represent a risk of detrimental impact on the SKA as a result of EMI (assuming that general guidelines concerning the use of communication equipment is followed). Should an activity be proposed to take place within a defined sensitivity area, additional attenuation would be required in order to comply with the protection level requirement of the SKA. The additional attenuation required per sensitivity class and the phase specific separation distance is described in Table 17.3. Should numerous SGD activities be undertaken within the same sensitivity class (this may be the case during the Big Gas scenario), the effective impact would increase, requiring additional attenuation to mitigate (the effective sensitive of the area increases). This is due to the cumulative effect of SGD activities (e.g. four well pads under construction in the same vicinity near an SKA station would result in an

¹³ It would not make sense to calculate sensitivity zones taking into account site specific topography, as individual sources of RFI would have varying impact depending on the exact location of SKA stations within the spiral arms. Such calculations would be undertaken in cases where site specific information is required to reduce the potential of RFI sources.

increase in additional mitigation of up to 6dB). Using the sensitivity class descriptions described in Table 17.3, the assessment of risk for each of the scenarios, with and without mitigation, is set out.

Figure 17.6 presents a risk map of electromagnetic interference impacts to radio astronomy (SKA) across four SGD scenarios, with- and without mitigation.

The generic case for n activities located within the same sensitivity class is described by Figure 17.7, which determines the additional mitigation required (in addition to that determined by the specific sensitivity class) as a function of the number of activities. For example, eight wellpads located within sensitivity class 2 would require an additional 19 dB of attenuation and effectively increase the risk to that described by sensitivity class 5. It is likely that such a situation would only arise during the Big Gas scenario.

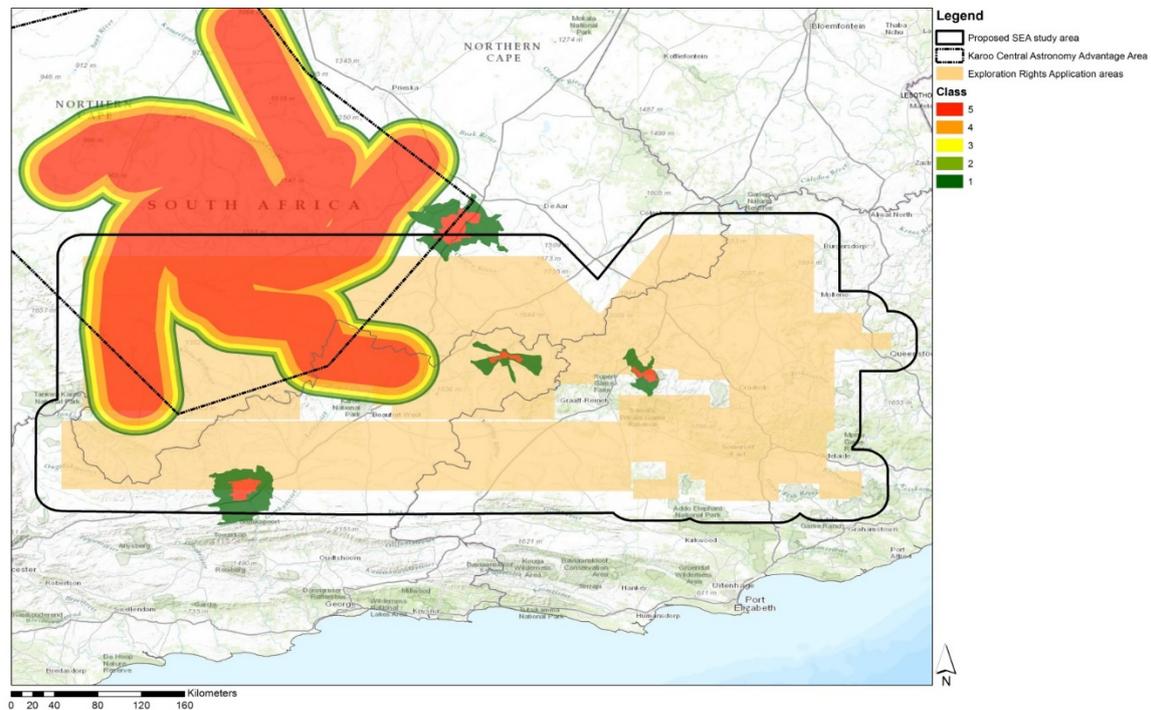


Figure 17.4: Map of sensitivity areas for the construction and decommissioning phase. In this phase up to 155 dB of attenuation is required in total.

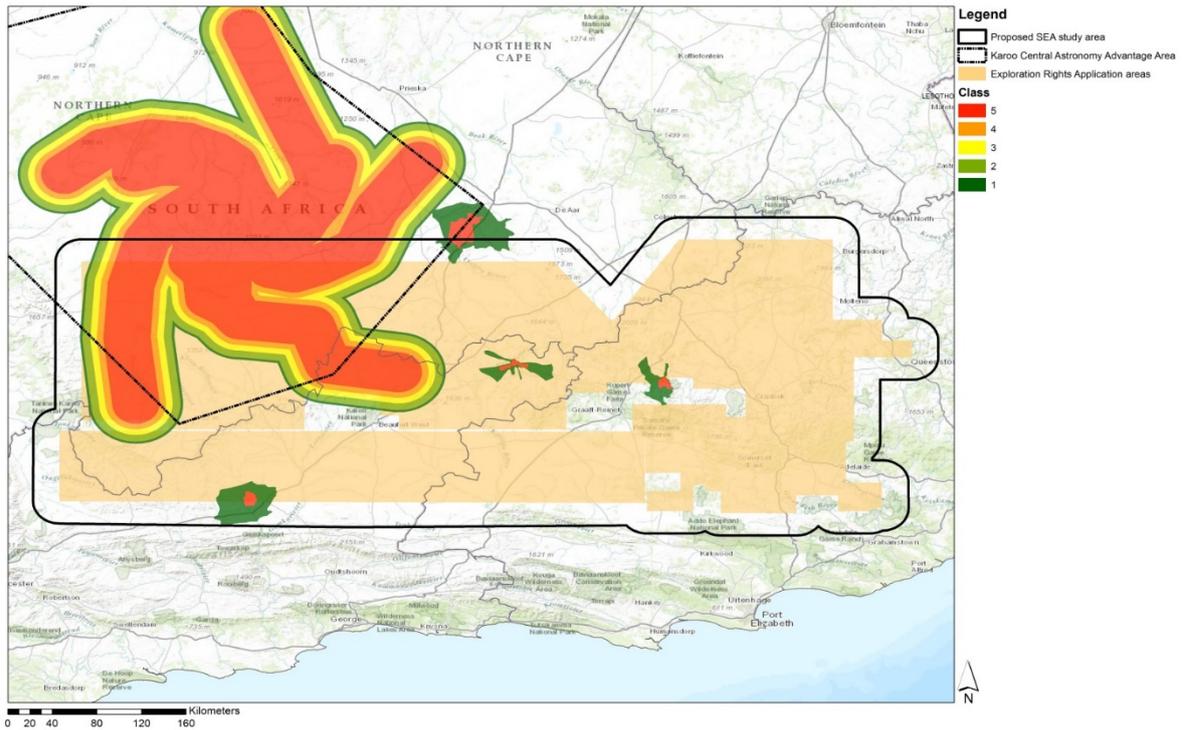


Figure 17.5: Map of sensitivity areas - operations phase. In this phase, up to 149 dB of attenuation is required in total.

Table 17.3: Sensitivity class description

| Sensitivity Class Description | | | | | |
|---|-------|-------|-------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 |
| Separation Distance (Construction and Decommissioning) | 38 km | 36 km | 33 km | 29 km | 22 km |
| Separation Distance (Operations) | 36 km | 34 km | 28 km | 23 km | 18 km |

Table 17.4: Consequence terms defined for the risk assessment.

| Consequence term | Description |
|--------------------|---|
| Slight | Limited pollution (20%) of radio spectrum, limited radio observations can be undertaken at an SKA station |
| Moderate | Moderate pollution (40%) of the radio spectrum, limited radio observations can be undertaken at one or more SKA stations |
| Substantial | High pollution (60%) of the radio spectrum, very limited radio observations can be undertaken at one or more SKA stations |
| Severe | Very high pollution (100%) of radio spectrum, no radio observation can be undertaken at an SKA station or limited observations at multiple SKA stations |
| Extreme | Very high pollution (100%) of radio spectrum, no radio observations can be undertaken at multiple SKA stations |

Table 17.5: Risk assessment table sets out the assessment of risk for each of the scenarios, with and without mitigation. No SGD takes place in the Reference Case, and limited shale gas production takes place in Small Gas, and extensive SGD takes place in Big Gas.

| Impact | Scenario | Location | Without mitigation | | | With mitigation (identified and carried out in accordance with Table 17.5) ¹⁴ | | |
|--|-----------------------|-------------------------|--------------------|--------------------|-----------|--|--------------------|----------|
| | | | Consequence | Likelihood | Risk | Consequence | Likelihood | Risk |
| Electromagnetic interference impact on radio astronomy (SKA) | Reference Case | SKA Sensitivity Class 5 | Slight | Very Unlikely | Very low | Slight | Very Unlikely | Very low |
| | Exploration Only | | Extreme | Very Likely | Very high | Moderate | Likely | Moderate |
| | Small Gas | | Extreme | Very Likely | Very high | Moderate | Likely | Moderate |
| | Big Gas ¹⁵ | | Extreme | Very Likely | Very high | Moderate | Likely | Moderate |
| | Reference Case | SKA Sensitivity Class 4 | Slight | Extremely Unlikely | Very low | Slight | Extremely Unlikely | Very low |
| | Exploration Only | | Severe | Very Likely | High | Slight | Very Unlikely | Very low |
| | Small Gas | | Severe | Very Likely | High | Moderate | Very Unlikely | Low |
| | Big Gas ¹⁶ | | Extreme | Very Likely | Very High | Moderate | Very Unlikely | Moderate |
| | Reference Case | SKA Sensitivity Class 3 | Slight | Extremely Unlikely | Very low | Slight | Extremely Unlikely | Very low |
| | Exploration Only | | Substantial | Very Likely | Moderate | Slight | Very Unlikely | Very low |

¹⁴ The success of mitigation methods is not guaranteed, and subject to further analysis and detailed assessment. The consequence and likelihood can therefore be amended accordingly. **Mitigation includes prohibition of all SGD activities within sensitivity class 5 and the KCAAA.**

¹⁵ The risk identified in this table assumes vicinity Big Gas scenario where 410 wellpads are developed across 4 different production blocks, and should be amended in accordance with the method described in Section 17.3.5 for the cumulative impact of multiple activities.

¹⁶ See Footnote 14.

| Impact | Scenario | Location | Without mitigation | | | With mitigation (identified and carried out in accordance with Table 17.5) ¹⁴ | | |
|--------|-----------------------|-------------------------|--------------------|--------------------|----------|--|--------------------|----------|
| | | | Consequence | Likelihood | Risk | Consequence | Likelihood | Risk |
| | Small Gas | | Substantial | Very Likely | Moderate | Slight | Very Unlikely | Very low |
| | Big Gas ¹⁷ | | Severe | Very Likely | High | Moderate | Very Unlikely | Low |
| | Reference Case | SKA Sensitivity Class 2 | Slight | Extremely Unlikely | Very low | Slight | Extremely Unlikely | Very low |
| | Exploration Only | | Moderate | Very Likely | Low | Slight | Extremely Unlikely | Very low |
| | Small Gas | | Moderate | Very Likely | Low | Slight | Extremely Unlikely | Very low |
| | Big Gas ¹⁸ | | Substantial | Very Likely | Moderate | Moderate | Extremely Unlikely | Very low |
| | Reference Case | | Slight | Extremely Unlikely | Very low | Slight | Extremely Unlikely | Very low |
| | Exploration Only | SKA Sensitivity Class 1 | Slight | Very Likely | Very low | Slight | Extremely Unlikely | Very low |
| | Small Gas | | Slight | Very Likely | Very low | Slight | Extremely Unlikely | Very low |
| | Big Gas ¹⁹ | | Moderate | Very Likely | Low | Moderate | Extremely Unlikely | Very low |

¹⁷ See Footnote 14.

¹⁸ See Footnote 14.

¹⁹ See Footnote 14.

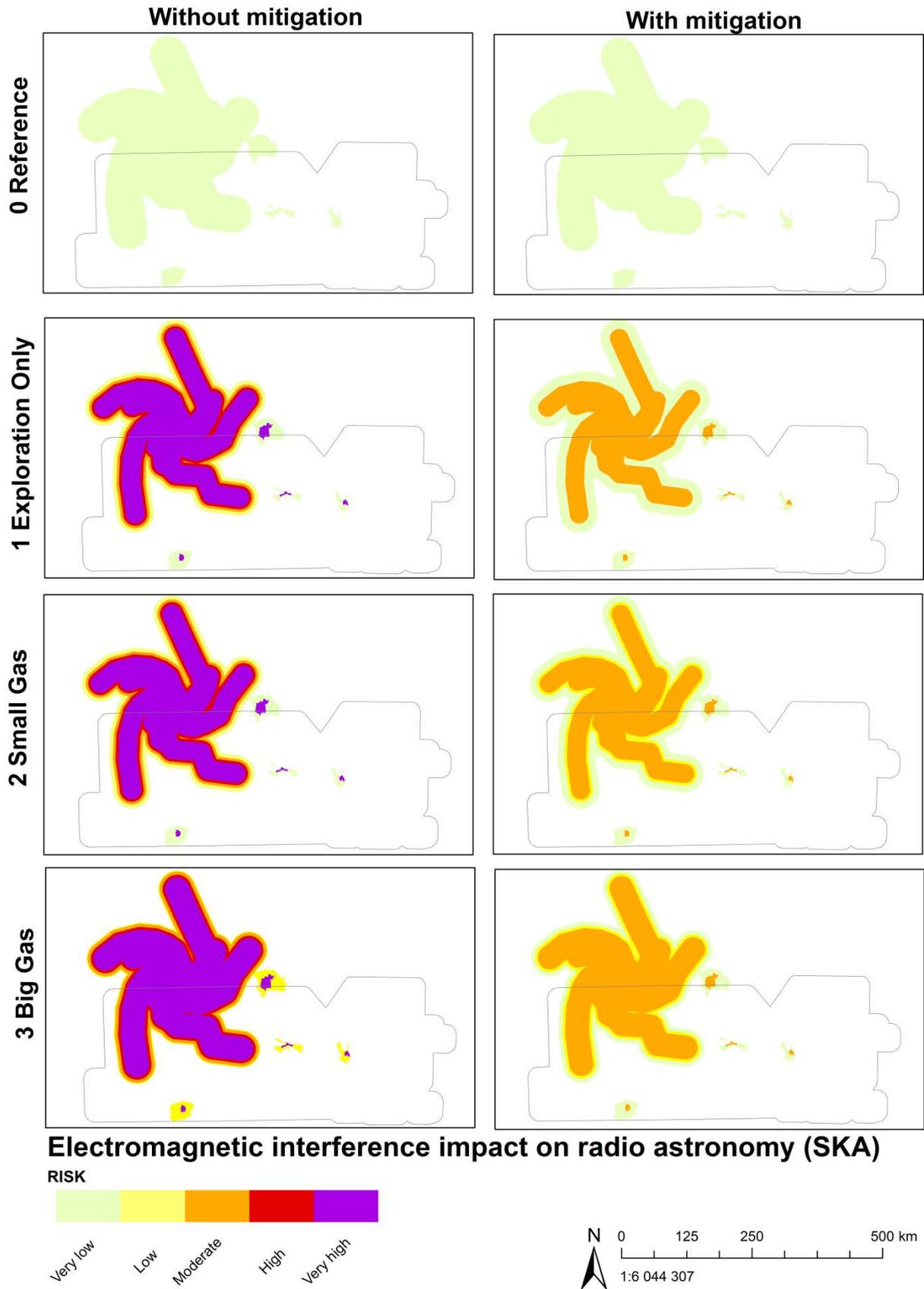


Figure 17.6: Map indicating the risk of electromagnetic interference on radio astronomy across four SGD scenarios, with- and without mitigation.

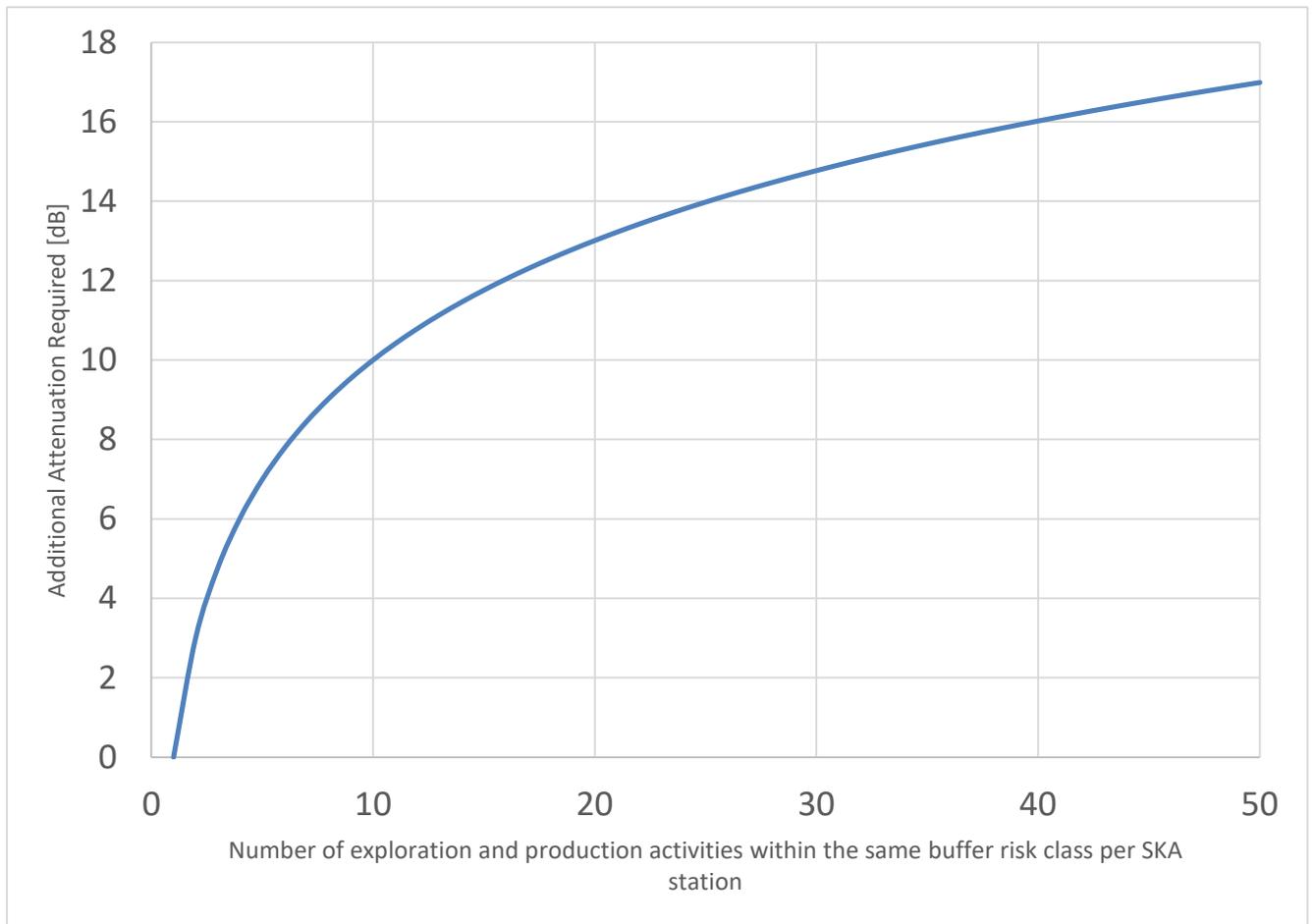


Figure 17.7: Additional attenuation required as a result of cumulative effect of multiple wellpads.

17.3.6 Limits of acceptable change

17.3.6.1 EMI

The acceptable threshold level of interference is determined by the SARAS protection level (DST, 2011). Any received signal that is in excess of this protection level is deemed to be an interference source. No increase in the background EMI environment is acceptable at each of the SKA stations if it is to increase the level of EMI (as detected by an SKA station) above the SARAS protection level (DST, 2011).

17.3.7 Best practice guidelines for minimisation of risk impact

Best practice guidelines are applicable to all phases of construction, operations and decommissioning. These guidelines take into account the current state of information regarding inventory of equipment and use profiles during construction, operations and decommissioning, and should be reconsidered

once further information can be made available for site specific assessments. Table 17.6 presents a series of guidelines to be adopted in the event that a SGD activity is proposed to be located within a specific sensitivity class.

Table 17.6: Best practice guidelines for the mitigation of EMI and RFI.

| | | Guidelines | | | | |
|--------------------------------------|---|---|---|---|---|--|
| Sensitivity Class | 1 | 2 | 3 | 4 | 5 | |
| Mitigation Required | 5 dB | 10 dB | 15 dB | 20 dB | >25 dB | |
| Guideline | High level site specific EMI assessment, to be undertaken by electromagnetic compatibility (EMC) specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements. | Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements. | Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements. | Detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements. | No SGD activity to be undertaken if located within sensitivity class 5 or the KCAAA. If located beyond the KCAAA, detailed site specific EMI assessment to be undertaken by EMC specialists to identify key sources of risk. SGD made subject to complying with mitigation requirements. | |
| Potential Level of Mitigation | Highest sources of interference identified and mitigated through modest shielding implementation. | Highest sources of interference identified and mitigated through proper shielding implementation. Cable routing evaluated; depending on level of interference identified (cables below ground if possible). | Sources of interference across a wider frequency range anticipated. More extensive mitigation through proper shielding of higher number of equipment likely. Cable routing below ground if possible. Improved earthing to reduce interference current distribution. | Detailed implementation of shielding measures required. This includes more extensive shielding of every aperture from which interference can be generated. Greater attention to cabling and earthing required to ensure minimal contribution. | No SGD activity to be undertaken if located within sensitivity class 5 or the KCAAA. | |

17.3.7.1 Monitoring and evaluation

The following is proposed to ensure compliance with the protection requirements of the SKA stations:

- i. Should any SGD activities be proposed within any buffer areas during the relevant phase of construction, operations or decommissioning, the developers will be required to engage

with the Astronomy Management Authority, a unit of the DST, prior to the commencement of any such activities. The developers will be required to undertake detailed impact assessments to identify risk and adopt mitigation strategies. The successful implementation of the specified mitigation strategies that ensure attenuation requirements are complied with, have to be demonstrated to the satisfaction of the Astronomy Management Authority, in consultation with the National Research Foundation (NRF);

- ii. Ongoing radio frequency measurements to be undertaken, according to a methodology determined by the Astronomy Management Authority in consultation with the NRF, at relevant sites once activities are commenced;
- iii. SKA stations to undertake continuous monitoring of the radio frequency environment during all construction, operation and decommissioning activities.

17.4 Gaps in knowledge

The following areas have insufficient information, requiring the authors to make assumptions in the impact analysis process:

- i. EMI characteristic profiles – the lack of radio frequency measurement information meant that internationally accepted standards had to be adopted to characterise the expected emission profiles. This does represent a minimum risk approach, as CISPR standards do prescribe an upper limit on the expected emissions. Actual measurements will provide more accurate EMI characteristic profiles, and will lead to a better representative risk/impact assessment;
- ii. Use profile – the use profile, primarily time but also location, is assumed. It is likely that some equipment will not be used 100% of the time. However, the variety of equipment operating at different times means that the emission levels were considered to be the overall characteristic EMI profile on a per site basis. Further information on this may impact this assumption;
- iii. Equipment inventory – an approximate inventory of equipment was obtained from technical staff. However, the use of specific equipment that has not been captured could produce large uncertainty. As a result, improved site specific information would need to be confirmed;
- iv. Supporting activities – more detailed information on supporting activities that would provide greater level of understanding on increased vehicular volumes.

It is recommended that:

- i. EMI characterisation measurements²⁰ of a representative installation that incorporates the majority of equipment to be used should be done. This will be more accurate than evaluation of individual components, which does not fully take into account the combined effect of interconnecting devices;
- ii. Developers provide detailed inventory of equipment to be used during the various phases of SGD, and relevant characteristic profiles of EMI emissions (either measurement data, or standard);
- iii. Developers provide detailed schedule of site construction, operations and decommissioning, to enable a greater level of understanding of the use profile of equipment;
- iv. Developers provide a detailed list of communication requirements to enable the identification of mitigation options for radio communication services.

Should the further information described in items i.-iv. above be available, a review of the defined risk areas, guidelines and mitigation measures could be undertaken.

17.5 References

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- International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 14-1: Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission. International Electrotechnical Commission (IEC), Geneva

²⁰ EMI measurements should be conducted using peak detector equipment, from which average levels can be derived if required.

- International Special Committee on Radio Interference (CISPR). 2009. CISPR Product Standards 22 Class B: Information technology equipment, Radio disturbance characteristics, Limits and methods of measurement. International Electrotechnical Commission (IEC), Geneva
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17.6 Digital Addenda 17A - 17F

SEPARATE DIGITAL DOCUMENT

Digital Addenda 17A - 17F