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REPORT

VAPOUR MITIGATION STRATEGY

Beverley Assessment Area

Submitted to:
Environment Protection Authority
GPO Box 2607
Adelaide, South Australia

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1.0 INTRODUCTION

The South Australian Environment Protection Authority (SA EPA) engaged Golder Associates Pty Ltd. (Golder) to prepare a vapour mitigation strategy (VMS) for the Assessment Area in Beverley, South Australia. The Assessment Area is identified in Appendix A and contains a variety of residential and industrial properties.

The need for this VMS has been triggered by the identification of concentrations of trichloroethylene (TCE) within shallow soil and sub-slab vapour samples, as reported by Golder in the *Groundwater and Soil Vapour Data Report - Beverley Assessment Area, South Australia,* report no. 1418522-003-R-Rev 1, dated 27 May 2015. This VMS has been prepared for use in the event that mitigation is required based on future sampling events and risk assessment.

The SA EPA has previously identified potential groundwater contamination within a zone incorporating approximately 3000 properties in Beverley, Woodville South, Woodville West, Findon and Allenby Gardens. In conjunction with South Australia Health and the Department of Environment, Water and Natural Resources, in 2008 the SA EPA provided advice to residents that groundwater should not be extracted within this zone. Review of previous investigation reports obtained for the Assessment Area identified concentrations of chlorinated hydrocarbons in groundwater which warranted further assessment to clarify the potential for risks to human health through vapour intrusion into houses. These previous investigation reports were utilised by SA EPA to assist in developing the recent targeted investigations detailed in the above referenced report.

2.0 OBJECTIVES

The primary objective of this VMS is to provide a framework for mitigation of potential health risks to residents due to possible intrusion of TCE (and related breakdown products) into residential properties within the Assessment Area.

The assessment and mitigation of potential vapour intrusion into non-residential properties within the Assessment Area is not included within this VMS. The potential for risks to occupiers of commercial and industrial properties within the Assessment Area are considered likely to be lower than potential risks to occupants of residential properties and will therefore be assessed and managed on a case by case basis.

This VMS focuses on rapid mitigation of vapour intrusion into residential structures to reduce the potential for impacts to human health. The recommended mitigation strategy should be considered as an interim action to provide effective human health protection and should form part of a final long-term remediation plan. The preferred long term response is to eliminate or substantially reduce the sub-surface source of vapours (e.g. groundwater, sub-surface soil, service lines) to permanently eliminate the vapour intrusion risk. It is acknowledged that due to the number of potential contaminant source areas and the significant complexities of achieving comprehensive clean up (remediation) in the subsurface, the proposed interim vapour mitigation measures may need to operate for the life of each building.

3.0 DECISION PROCESS

To allow robust, transparent and consistent decisions to be made regarding the assessment and mitigation of potential vapour intrusion at individual properties, a decision process has been designed for the Assessment Area.

The decision process is based on TCE thresholds previously established by SA EPA and SA Health for other vapour intrusion assessments in South Australia and are based around a threshold indoor air concentration of 2 $\mu g/m^3$ (micrograms per cubic metre), above which further investigation is required (Government of South Australia 2014). Additional decision thresholds are also defined above 2 $\mu g/m^3$, requiring increasing levels of action or mitigation at 20 $\mu g/m^3$ and 200 $\mu g/m^3$. The adopted TCE response concentrations for indoor air are provided in Figure 1 below.

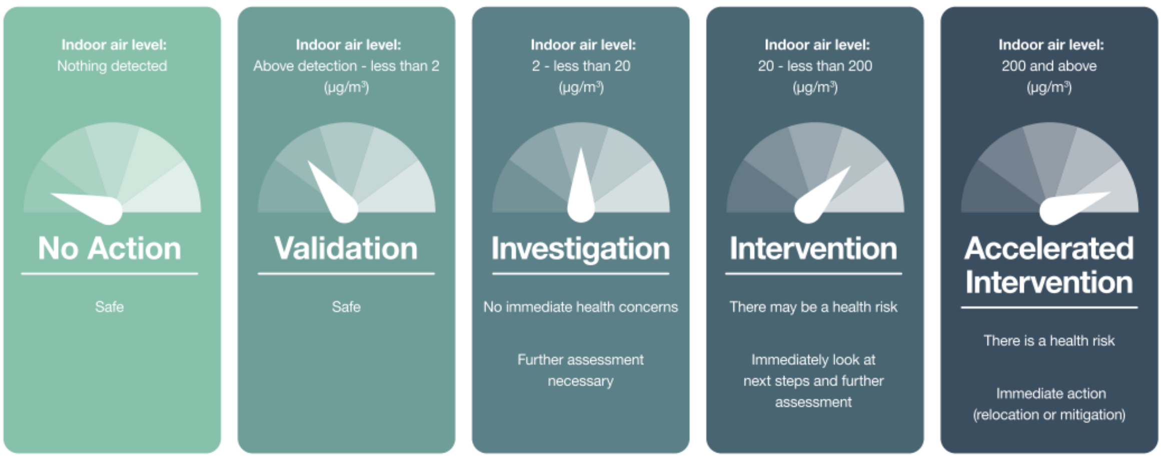


Figure 1: TCE Indoor Air Concentration Response Ranges (Government of South Australia, 2014)

The screening level assessment of potential risks associated with intrusion of TCE vapour within the Assessment Area is currently underway. The initial screening assessment will estimate TCE concentrations in indoor air based on concentrations of TCE measured in soil gas at various locations across the Assessment Area. Based on the theoretical TCE concentrations estimated (with vapour intrusion modelling) for each portion of the Assessment Area, decisions will be made regarding further investigation or mitigation requirements.

Where estimated theoretical TCE concentrations in indoor air exceed 2 $\mu g/m^3$, property specific investigations are recommended to clarify the potential for vapour intrusion. A property specific risk assessment will then be completed to assess what further actions are necessary. With all property specific data at least two rounds of monitoring are proposed prior to implementing further actions in order to provide confidence that the results of monitoring are representative of actual property conditions.

Should the theoretical TCE concentration in indoor air fall between 2 and 20 $\mu g/m^3$ it is recommended that monitoring of crawl space and sub-slab vapour be carried out on at least a quarterly basis for 12 months to assess variability in the data, followed by a re-assessment of potential health risk.

In the event that theoretical TCE concentrations in indoor air exceed 20 $\mu g/m^3$ it is recommended that further testing of the specific property be completed, including the assessment of potential preferential pathways for vapour intrusion, indoor air sampling under controlled conditions, and measurements of differential pressure and air flow in sub floor areas. This property specific assessment is discussed further in Section 4. Based on this data the potential for health risks to residents can be clarified. In the event that risks are indicated to be unacceptable, it is recommended that a suitable vapour mitigation system be installed. The system design will be based on the concepts presented in Section 6, adapted based on property specific factors, as discussed in Section 8.

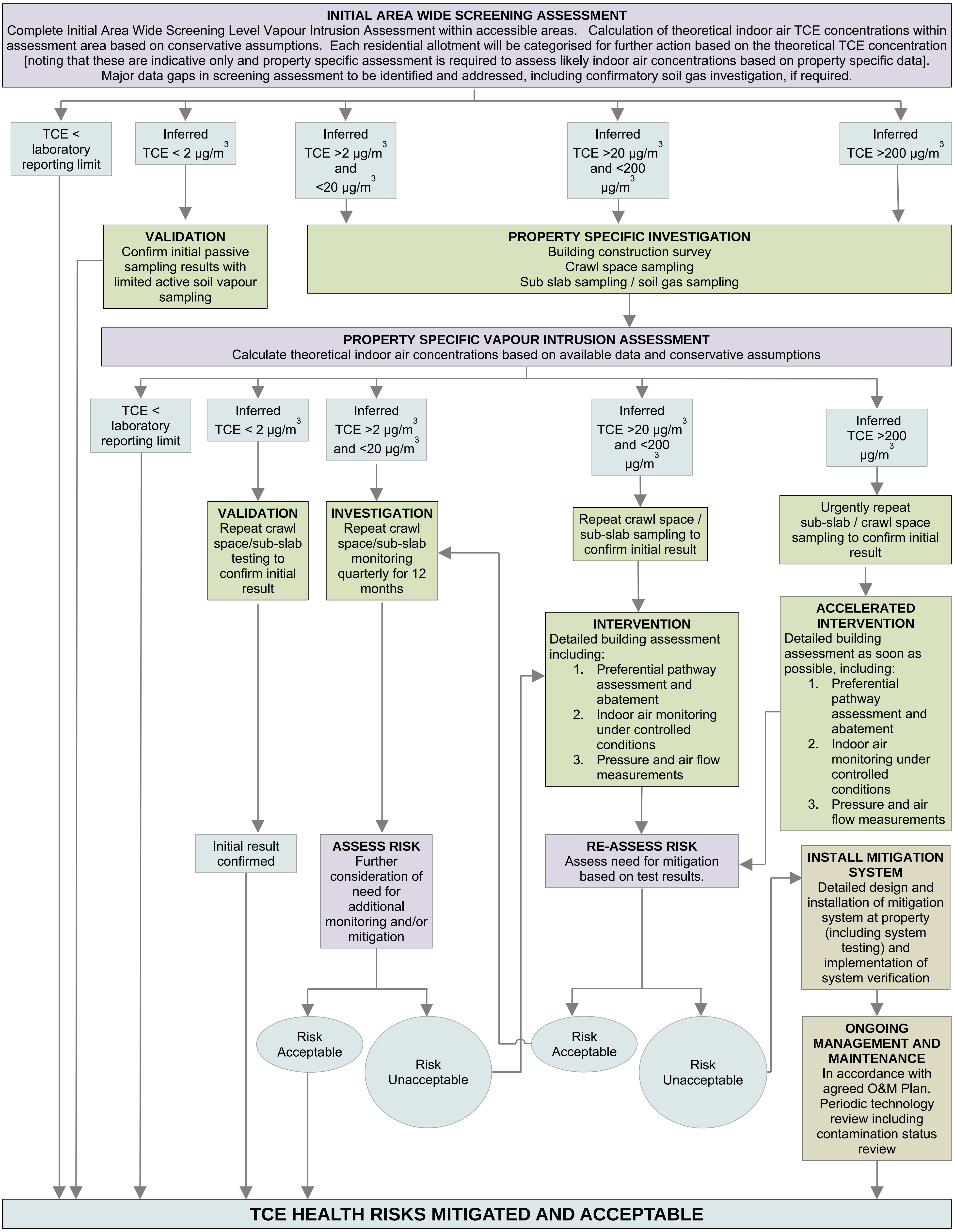
In the event that installation of a mitigation system is required, it shall be subject to verification of effective performance and ongoing management and maintenance, with remote monitoring. The system will be required to operate until such a time that the vapour impacts are remediated, or for the lifetime of the existing building structure.

Should the property specific assessment identify estimated TCE concentrations in indoor air below 2 µg/m^3, but above the laboratory reporting limit, vapour intrusion risks shall be considered to be acceptable subject to the results of repeat sampling and analysis of soil vapour, and/or crawl space vapour confirming this conclusion.

The decision process is summarised in the flow chart presented on the following page.

The timing of further assessment and mitigation works should be prioritised based on the inferred level of risk identified across the Assessment Area, with those properties considered to be most at risk of vapour intrusion addressed as early as practicable within the assessment/mitigation program.

BEVERLEY ASSESSMENT AREA
VAPOUR MITIGATION STRATEGY – DECISION FLOW CHART



4.0 PROPERTY SPECIFIC ASSESSMENT

As described in the decision process outlined in Section 3, if theoretical TCE concentrations modelled in indoor air potentially exceed 20 µg/m^3 based on repeat crawl space and/or sub-slab testing, intervention activities incorporating a detailed building assessment are recommended. The recommended process for implementing the detailed building assessment/preliminary intervention activities is as follows:

1) Consult with property owner and property occupier
2) Undertake a building construction/condition survey
3) Remove potential volatile organic compound (VOC) sources inside the house (where possible) – to reduce background sources of VOCS
4) Conduct field screening with a gas chromatograph-mass spectrometer (GC-MS) to identify potential significant preferential pathways for vapour intrusion
5) Seal identified significant preferential pathways (i.e. identified major cracks and/or gaps around service penetrations) if possible and readily achievable in short term, and assess outcomes of sealing using GC-MS
6) Conduct 24hr sampling of indoor air under close to normal conditions
7) Conduct 24hr sampling of indoor air under closed conditions (limited ventilation)
8) Conduct 7 day passive indoor air sampling
9) Measure differential pressures between sub-floor and indoor air

Preferably, the majority of the works above will be undertaken whilst the house is unoccupied, so that the environment can be controlled and inconvenience to residents associated with multiple access visits minimised.

The outcomes of the property specific assessment outlined above will be used to re-assess potential vapour intrusion risks at the specific property and the need for further investigation or the installation of mitigation systems.

5.0 REVIEW OF MITIGATION OPTIONS

The need for installation of mitigation systems within the Assessment Area has not been determined. However to minimise any delays in the selection of appropriate systems, in the event that system installation is required, a review of vapour mitigation options has been completed. The review considers typical residential constructions types in the area.

5.1 Residential Construction Types

Residential property construction in the area is typically single storey residences ranging from relatively recent construction to around 90 years old, with the majority of structures estimated to be between 30 and 80 years old.

Based on limited inspection of three properties (Nos. 34, 36 and 46 William St) and viewing of residential property types from the road corridor, it is considered that the following three major construction types are likely to exist within the Assessment Area:

Conceptual House 1 - Vented Crawl space: Solid brick buildings with timber floors (tongue and groove on joists without subfloor) supported on a system of strip footings and dwarf walls, with unlined sub-floor (crawl space) area. The sub-floor area is typically between 0.3 and 1.0 m in height (average around 0.5 m) and is passively vented by a series of vents located around the base of the walls. The wall cavities are vented on most properties and there are also vents at the top of walls in some of the older properties.

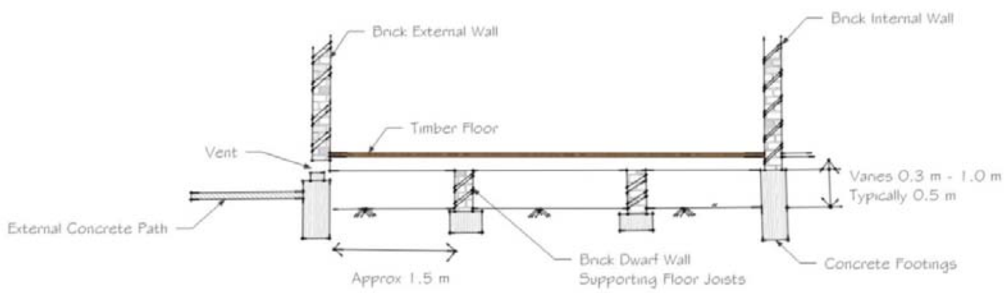


Figure 2: Conceptual House 1 – Vented Crawlspace.

Conceptual House 2 - Unvented Crawl space: Solid brick buildings with timber floors (tongue and groove on joists without subfloor) supported on strip footings with shallow unvented and unlined sub-floor area. Most of the details for this building type are similar to Conceptual House 1, with the exception of the potential lack of venting of the sub-floor area. This construction has been identified within a more recent extension to one property and therefore is considered to potentially exist within other parts of the Assessment Area.

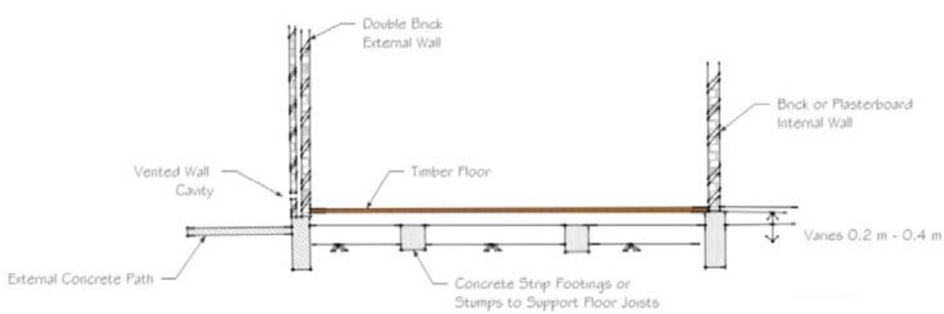


Figure 3: Conceptual House 2 - Unvented Crawlspace

Conceptual House 3 – Concrete Raft Slab: Brick buildings (either double brick or brick veneer) with concrete floor slab. The typical design of concrete floor slabs constructed in Adelaide since the late1970's is a concrete raft slab which consists of a reinforced concrete slab with integrated beams, both around the edges of the slab and also internally. The internal beam depth varies based on geotechnical design considerations, but is typically expected to be around 0.5 m deep, with a 0.15 m thick slab. Internal beams are typically located on approximately at 3 or 4 m centres (likely at interior load-bearing walls).

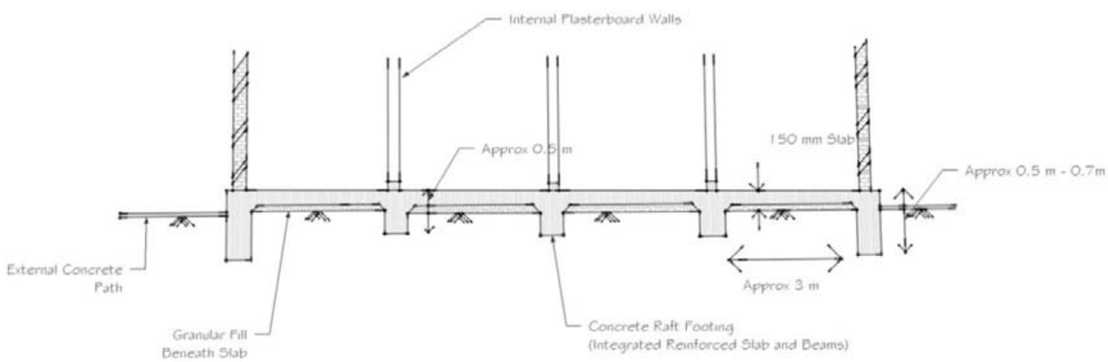


Figure 4: Conceptual House 3 - Concrete Raft Slab on Ground

All houses will have floor penetrations for water and sewer connections, and may also have floor penetrations for other services (e.g. gas, electrical, telephone).

The presence of basements has not been considered. In the event that basements are identified to exist within properties of interest, further consideration of potential vapour intrusion risks and mitigation options will be required.

5.2 Vapour Mitigation Options

5.2.1 Review of Options

A review of vapour intrusion mitigation options has been completed for each of the conceptual house types detailed in Section 4.1. Conceptual Houses 1 and 2 are similar (the difference is Type 2 is not vented) and therefore these types are combined for purposes of the evaluation below. A summary of the mitigation options considered and a qualitative assessment of each option is presented in Tables 1 and 2.

The scope of vapour mitigation presented in this VMS is designed to address property specific exposure considerations, and does not address remediation of the vapour source itself. It is recommended that separate investigations be implemented to identify the source and extent of the soil vapour source including TCE and implementation of an appropriate remediation strategy in accordance with SA EPA guidelines.

The proposed performance objective for vapour mitigation systems is to reduce TCE concentrations in indoor air within residential properties to below 2 µg/m^3, or as low as reasonably practicable.

The selection of appropriate vapour mitigation systems is dependent on a range of factors, including the following:

- Expected indoor air concentrations prior to mitigation;
- Property construction details and property layout;
- Potential for preferential pathways for vapour entry to the building;
- Soil type beneath the building;

- Property owner considerations (aesthetics, disruption, etc);
- Effect of mitigation on indoor air quality (e.g. humidity);
- Robustness;
- Operations and maintenance considerations;
- Expected duration of operation;
- Energy consumption; and
- Construction and O&M costs.

5.2.2 Conceptual House Types 1 and 2 – Crawl Space House

The potential mitigation options considered for Conceptual House Types 1 and 2 are:

1) Sub-membrane depressurisation using small purpose built fans[1].
2) Crawl space depressurisation using small purpose built fans.
3) Crawl space ventilation using small purpose built fans.
4) Crawl space/house ventilation using energy recovery ventilator (ERV).
5) Indoor air treatment using carbon (or other media) filtration unit.
6) Soil vapour extraction on the building exterior.
7) Crawl space pressurisation using small purpose built fans.
8) Whole-house pressurisation using fans.
9) Passive ventilation

A description and advantages and disadvantages of each option are provided in Table 1. Further discussion of each option is presented below.

[1] Suitable fans must be moisture resistant, quiet running and inexpensive to operate. Fans utilised in Canada and the US for mitigation of radon gas in houses are suitable for this purpose.

Table 1: Vapour Mitigation Option Assessment - Crawl Space Houses

Technology	Description	Advantages	Disadvantages	Comments
1. Sub-membrane depressurisation	Fan used to depressurise soil below membrane on floor of crawl space	Soil vapours intercepted before entering crawl space; can be implemented using small fans, floor leakage not an issue	Requires effective sealing of membrane around utilities and to foundation walls Not feasible in low crawl spaces	Not likely to be practically feasible in houses within the Assessment Area
2. Crawl space depressurisation	Small fan is used to depressurise crawl space and increase ventilation, often sealing of openings in floor also required	Typically can be achieved using relatively small fan	Air leakage downward through house floor, may be difficult to achieve consistent depressurisation Over depressurisation should be avoided to reduce increased flux of deep vapours to house and prevent backdrafting of combustion appliances	Recommended as the currently preferred option
3. Crawl space ventilation	Small fan is used to increase ventilation through the crawl space, with sealing of openings in floor; requires passive vents to allow air to enter into the crawl space	Typically can be achieved using relatively small fan	Air leakage downward through house floor May be difficult to achieve neutral pressures	Retained as possible secondary option
4. Crawl space/house ventilation using an Energy Recovery Ventilator (ERV)	HVAC type equipment that is primarily used to increase ventilation and condition air, can also be used to depressurise smaller air spaces	Air can be conditioned and controlled, ventilation can be provided, if depressurised, potential similar effectiveness to crawl space depressurisation	Relatively extensive duct work, multiple penetrations of floor and wall of house Higher cost for units compared to radon-type fans	Retained as possible secondary option

Technology	Description	Advantages	Disadvantages	Comments
5. Indoor air treatment using carbon units	Portable air cleaning unit	Relatively unobtrusive, could be deployed relatively quickly	Experience suggests that effectiveness may be limited Requires maintenance (carbon replacement)	Retained as possible temporary option
6. Soil vapour extraction	Installation of vertical or horizontal wells and extraction of vapours using blowers	Potentially could be effective as longer-term solution to intercept vapours, avoids potential disturbance associated with works in house	Requires larger blowers The radius of influence in fine-grained soils present at Site is uncertain Likely to require air treatment of exhaust Larger footprint area for remediation works	Retained as possible secondary option
7. Crawl space pressurisation using fans.	Small fan is used to pressurise crawl space and increase ventilation, often sealing of openings in floor also required	Typically can be achieved using relatively small fan	Air from crawl space may be pushed up through floor, consistent pressurisation may be difficult to achieve Limited control over vapour migration pathways	Not recommended
8. Whole-house pressurisation using fans	Larger fan is used to pressurise house	Limited advantages	Requires larger fans and possible conditioning of outdoor air (cooling, moisture removal) Consistent pressurisation likely difficult to achieve given house construction May result in discomfort to occupants and/or interfere with building operation	Not recommended

Technology	Description	Advantages	Disadvantages	Comments
9. Passive ventilation	Sealing major preferential entry routes for vapours from the crawl space and increasing passive ventilation by strategically removing bricks and adding grated vents, or coring holes at base of external walls to increase airflow in crawl space.	Potentially low operational and maintenance requirements.	Only potentially suitable where very low concentration reductions in indoor air are required. Lack of certainty in outcome (vapour intrusion often occurs through small, difficult to seal cracks and openings and subfloor ventilation will vary with climatic conditions) Repeated verification testing under different climatic conditions required. Need to manage/mitigate the potential for future cracking/floor penetrations Only achievable where the floor is sufficiently elevated above surrounding ground level such that suitable ventilation can be readily achieved.	Retained as possible secondary option where only very small reductions in indoor air concentrations required and house construction is suitable.

Option 1, submembrane depressurisation, is the typical preferred approach for mitigation of soil vapour intrusion at houses with tall crawl spaces. This technology involves construction of an impermeable liner on the dirt floor of a crawl space that is sealed to foundation walls, and piping below the membrane (ASTM E2121 -13). The piping is connected to a small fan to depressurise the soil below the membrane. This technology is likely not feasible because of the limited accessibility of crawl spaces for homes in the Assessment Area.

Option 2, crawl space depressurisation using small purpose built fan(s), would require construction of one or more small holes in the building wall near ground surface and installation of piping from the crawl space to fan(s), likely mounted on the wall of the house (ASTM E2121-13). Air inlets, possibly with valves to control inflow of air, would be constructed on the opposite side of the house from the exit pipes and fan. For Conceptual House 2, this option would involve construction of new vents. Several fans of different size with variable speed controls would be tested in a trial and flow and pressure in the crawl space would be measured.

For crawl space depressurisation it will be important to not over depressurise the void space to avoid backdrafting of combustion appliances. Backdrafting can potentially occur if the crawl space depressurisation is sufficiently high such that areas of the house with combustion appliances are also depressurised. This potentially prevents flue gases from venting causing a hazardous environment in the house. The floors are tongue and groove wood panels on joists (without subfloor) and therefore sealing of the wood floor may be required (e.g., through application of coating material). Partial sealing of the crawl space dirt floor or addition of an amendment to surface soil to reduce soil-air permeability could also be considered, but is expected to be relatively ineffective because of limited access to the crawl space. If implemented appropriately (with low vacuums and flow), crawl space depressurisation may not require air treatment of exhaust.

Option 3, crawl space ventilation using small purpose built fan(s), uses similar equipment to Option 2, but the goal is increased ventilation, while keeping pressure neutral through use of passive vents. Ventilation is not as effective as depressurisation in reducing vapour intrusion and therefore is not recommended as the primary mitigation measure.

Option 4, crawl space/house ventilation using an energy recovery ventilator (ERV)[2], is a feasible option. A potential advantage is that air entering the crawl space or house can be conditioned (e.g., humidity removed and pre-cooled, if this were to be important) and ventilation rate increased. In addition, by adjusting the dampers in an ERV, it may be possible to create a slight depressurisation in the air space.

There are several disadvantages with an ERV based on the construction and configuration of the houses. First, these units must be housed indoors or possibly in a purpose-built enclosure beside the house that is weather-proof. Second, these units require four ducts or pipes, two of which would lead from the unit to the crawl space, and two of which would be situated outside. In both cases, the air inlet and exit points must be at least 3m apart to avoid short-circuiting and entrainment of exhaust into fresh air entering the crawl space. This would require two penetrations of the house floor at least 3m apart and construction of ducts inside the house. Given that the space inside the house is limited (i.e., efficiently used for living space), this is unlikely to be a desirable option for home owners or occupants of the house (this option is better suited for an unfinished basement with space).

Option 5, air treatment using carbon units, can be used to remove chemical vapours from air. This is a potential short-term option that could be relatively quickly implemented to reduce indoor vapour concentrations. There is limited experience and published data on the use of this technology for mitigation of exposures from vapour intrusion. Based on communication with other practitioners, experience suggests that air cleaning units have resulted in approximately 50% reduction in concentrations at some sites.

[2] **Energy recovery ventilator** (**ERV**) is process equipment that exchanges the energy contained in normally exhausted building or space air and using it to treat (precondition) the incoming outdoor air in a HVAC system. During the warmer seasons, the system pre-cools and dehumidifies air while humidifying and pre-heating air in the cooler seasons. A heat recovery ventilator recovers heat from exhausted air.

Option 6, soil vapour extraction, is a potentially feasible technology but given the low to moderate permeability soil deposits may require multiple soil vapour extraction points, possibly drilled horizontally or sub-horizontally below houses. Vertical wells would be simpler to construct but the radius of influence may be limited. Compared to other options, the size of equipment is larger and consequently the footprint for infrastructure and disturbance is also larger. The yards surrounding houses are relatively small and there appears to be limited space next to houses or on public property beside roads to implement this option. In addition, soil vapour extraction would result in greater volatile emissions due to higher vacuums in the subsurface and mostly likely would require treatment of air emissions.

Option 7, crawl space pressurisation, is not recommended for further assessment at this time. Crawl space pressurisation is feasible and equipment would be similar to crawl space depressurisation. However, the disadvantage with crawl space pressurisation is that air containing soil vapours would not be collected and pathways for soil vapour migration and emissions to surface would not be controlled.

Option 8, house pressurisation, is not recommended for further assessment at this time. House pressurisation would require larger fans and conditioning of outdoor air (i.e., cooling, moisture removal). It is anticipated that it would be difficult to effectively pressurise the houses in the Assessment Area using this technology. Experience with radon mitigation indicates house pressurisation is typically not an effective technology.

Option 9, passive ventilation, is a potentially feasible option where are only small reductions in indoor air concentrations is required and building construction is amenable to this method. By sealing major entry points for vapour and providing increased passive ventilation of the crawl space there is likely to be small reductions in indoor vapour concentrations, which may or may not be sufficient to mitigate the vapour concern depending on site specific conditions for the house being evaluated. Whilst sealing obvious large entry points can be effective, our experience is that vapour intrusion often occurs through small, difficult to seal cracks and openings, which are expected to be present based on our understanding of house construction in the Assessment Area. The permanence of sealing of openings should also be considered as well as possible future cracks and openings that may be created in the floor.

Increased ventilation of crawl spaces will reduce indoor vapour concentrations but ventilation may be dependent on weather conditions and season. For added certainty, the constant ventilation and depressurisation afforded by a small fan may be warranted (Option 3). Passive ventilation, although not preferred, is retained for possible further consideration in specific circumstances (i.e. minor mitigation required, suitable house construction).

5.2.3 Conceptual House Type 3 – Slab on Grade House

The potential mitigation options considered for Conceptual House Type 3 are:

1) Sub-slab depressurisation using interior sumps.
2) Sub-slab depressurisation using exterior sumps and horizontally drilled penetration through exterior foundation wall.
3) Indoor air treatment using carbon (or other media) filtration unit.
4) Soil vapour extraction on the building exterior.
5) Whole house pressurisation.

A description and advantages and disadvantages of each option are provided in Table 2. Further discussion of each option is presented below.

Table 2: Vapour Mitigation Option Assessment - Slab On Grade Houses

Technology	Description	Advantages	Disadvantages	Comments
1. Sub-slab depressurisation – interior sumps	Fans connected to small sump(s) below the floor slab; goal is to depressurise sub-slab soil, often sealing of openings in floor also required	Proven technology for mitigation of vapour intrusion	Because of interior grade beams may require multiple sumps and pipe runs; relatively disruptive, may not be aesthetically desirable Effectiveness difficult to predict	Retained as possible option
2. Sub-slab depressurisation – exterior sumps	Core holes and horizontal pipes installed through perimeter foundation wall from beside building pits are connected to header and small fan(s); goal is to depressurise sub-slab soil, often sealing of openings in floor also required	Proven technology but less effective configuration than below house sumps, avoids construction indoors	May not be effective for interior portion of house because deployed from house perimeter Disruptive in outdoor areas	Retained as possible option
3. Indoor air treatment using carbon units	Portable air cleaning unit	Relatively unobtrusive, could be deployed relatively quickly	Experience suggests that effectiveness may be limited Requires maintenance (carbon replacement)	Retained as possible temporary option
4. Soil vapour extraction	Installation of vertical or horizontal wells and extraction of vapours using blowers	Potentially could be effective as longer-term solution to intercept vapours, avoids potential disturbance associated with works in house	Requires larger blowers The radius of influence in fine-grained soils present at Site is uncertain Likely to require air treatment Requires larger footprint area for remediation works	Retained as possible option
5. Whole house pressurisation using fans	Larger fan is used to pressurise house	Limited advantages	Requires larger fans and possible conditioning of outdoor air (cooling, moisture removal) Consistent pressurisation likely difficult to achieve given house construction May result in discomfort to occupants and/or interfere with building operation	Not recommended

Technology	Description	Advantages	Disadvantages	Comments
6. Sealing of cracks/penetrations	This option is to identify preferential pathways and seal these to minimise further vapour migration through these pathways.	Potentially low operational and maintenance requirements.	Lack of certainty in outcome (vapour intrusion often occurs through small, difficult to seal cracks and openings and subfloor ventilation will vary with climatic conditions) Need to manage/mitigate the potential for future cracking/floor penetrations Repeated verification testing under different climatic conditions required.	Not recommended as a stand-alone option

Option 1, sub-slab depressurisation using interior sump(s), would require coring hole(s) in the floor slab and excavation of small sumps (up to 0.5 m), which in turn would be connecting to pipe runs that would potentially lead to the attic or roof where piping would be connected to small fan(s). Typically sealing of floor penetrations such as cracks and openings (e.g., drains) in the floor would also be required. Typically, this technology is effective for buildings with continuous slabs without interior grade beams, when constructed on relatively permeable soils. The Assessment Area houses are likely to generally have interior grade beams that extend to up to 0.5 m depth below ground surface making air flow less efficient and soil-air permeability is inferred to be low to moderate. This technology is considered likely feasible but may require multiple sumps and larger fans. Multiple sumps and pipe runs inside the house may be undesirable with respect to aesthetics. This technology is retained as a possible option.

Option 2, sub-slab depressurisation using exterior sumps, is similar to Option 1 except that multiple small pits would be excavated adjacent to the house, and core holes would be drilled through the foundation walls that would connect to subsoils below the raft foundation slab. Typically sealing of floor penetrations such as cracks and openings (e.g., drains) in the floor would also be required. The pits would be connected through a header that would extend along a portion or the entire house perimeter, either above ground or within a trench. This option would result in significant disturbance to outdoor areas but it avoids indoor sumps and pipe runs. It may be less effective than Option 1 with respect extent of depressurisation because it is deployed from the house perimeter. This technology is retained as a possible option.

Options 3, 4 and 5 were described above for Conceptual House Types 1 and 2.

Option 6, sealing of preferential pathways, is not considered viable as a stand –alone option, however should be conducted in conjunction with the recommended options.

5.2.4 Preferred Options

For properties with crawl spaces the preferred option is crawl space depressurisation with sealing of accessible floor penetrations.

For properties constructed on concrete slabs, a range of options have been retained for further site specific evaluation. These options, in order of preference, are as follows:

1) Sub-slab depressurisation – depending on building design, suctions pits may be located on the building exterior and/or interior (Options 1 or 2).

2) Reduction of soil vapour beneath the structure using a soil vapour extraction system immediately adjacent to the structure (subject to pilot trials successfully demonstrating that an appropriate radius of influence can be achieved) (Option 4).

6.0 CONCEPTUAL MITIGATION SYSTEM DESIGN

For each of the preferred options, a conceptual mitigation system design has been prepared. It is noted that the actual option selected for a specific property is subject to further detailed design and pilot trials as discussed in Section 8.0.

6.1 Conceptual House Types 1 and 2 – Crawl Space House

The performance requirements and conceptual design for the preferred option, crawl space depressurisation, are described below.

6.1.1 Performance Requirements

The primary design criterion is to create a slight depressurisation in the crawl space. A secondary design criterion is to provide for ventilation to dilute soil vapours that may enter the crawl space. While a higher ventilation rate is beneficial with respect to dilution of vapours, operating costs are higher for larger fans and the noise is typically greater. Therefore, the design criteria for ventilation rate should balance these considerations.

Under ASTM E2121 - 13 "*Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings*" (ASTM E2121), the minimum depressurisation recommended for sub-slab depressurisation systems is 6 to 9 Pascals or 0.024 to 0.036 inches water column (W.C.) Industry practice is to achieve this depressurisation below greater than 90% of the building footprint. This depressurisation criterion should be met during different seasons, but would not necessarily apply during short-duration extreme weather events.

While ASTM E2121 does not specifically provide a threshold criterion for crawl space depressurisation, a similar threshold for minimum depressurisation for sub-slab depressurisation systems is considered reasonable. For this project, the target crawl space depressurisation is 10 to 50 Pascals or 0.04 to 0.20 inches W.C.

The target crawl space ventilation rate is 2 air changes per hour. This will provide for some dilution of vapours in the crawl space and based on the air volumes of crawl spaces at houses in the assessment area will be achievable for most houses using a relatively small purpose built fan (e.g. approximately 90 Watt).

Crawl space depressurisation systems typically do not require air treatment because only low depressurisation is applied, therefore the mass flux of contaminants from soil into the air is not significantly different to the mass flux prior to installing the system. Consequently, emission rates are typically low. Because of dispersion and dilution of vapours that occurs when air is discharged from vent stacks (which are above the roof), there is rapid reduction to negligible concentrations. Sampling and analysis of ambient air could be conducted to verify acceptable air concentrations, as warranted.

6.1.2 Conceptual Design

The conceptual design for crawl space depressurisation is as follows:

- Core 125 mm diameter hole in house wall;
- Install pipe in core hole to connect to crawl space;
- Seal pipe in wall with non-VOC containing caulk;
- Connect piping to external fan mounted on building exterior wall;
- Piping will consist of 100 mm diameter PVC;
- Fan will consist of a relatively small, low noise, weatherproof fan (expected to be an 80-150 Watt fan, connect to a single phase exterior power outlet, see equipment specification in Section 7;
- Install condensate trap downstream of fan, if fan does not have an integrated condensate trap; and

- Vent stack will be completed with a rain cap located a minimum of 300 mm above the roof eave and a minimum of 3 m from doors or windows.

The flow rate and pressure in the crawl space will be controlled through air intakes on the opposite side of the crawl space from the fan intake. A valve will be located on the suction side of the fan to allow bleed-in of atmospheric air to control the vacuum in the crawl space. It is anticipated that one to two fans will be sufficient to mitigate houses at the site, if required.

A pressure sensor will be installed upstream of the fan to enable monitoring of vacuum in the pipe. If the pressure drops below a threshold (i.e., indicating malfunction of equipment or major leak in the system), the pressure sensor will trigger a visual alarm and remote call-out to maintenance staff. A pressure gauge will also be installed on the suction side of the riser to enable visual monitoring of vacuum.

Sealing of tongue and groove wood floors and other potential openings (e.g., drains if present) may be required to prevent excessive leakage of indoor air into the crawl space. It may be possible to seal floors through application of a coating material.

A sketch of a typical pump and pipework detail, together with photographs of typical installations are presented below

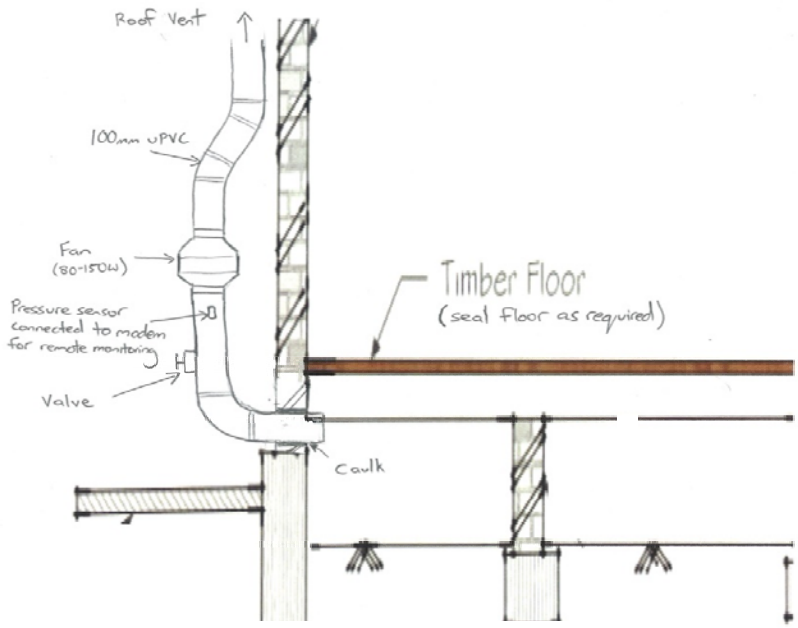


Figure 4: Typical crawlspace depressurisation detail

Figure 5: Typical fan for sub-slab or crawl space depressurisation

Figure 6: Typical fan and pipework configuration for depressurisation system

6.1.3 Implementation Strategy

The proposed implementation strategy is as follows:

1) Seal major accessible floor openings and penetrations such as drains, if present.
2) Install temporary fan and conduct step-test trial of flow versus vacuum for crawl space depressurisation for two to three different fans.
3) Install desired fan and monitor system parameters over a longer time period and analyse samples of crawl space air and indoor air to confirm acceptable system performance.
4) Adjust and optimise system through control of air flow rates and additional sealing of floor, as warranted.
5) Implement other provisional measures described in Section 5.2.2, if required.

6.2 Conceptual House Type 3 – Slab on Grade House

The performance requirements and conceptual design for the preferred mitigation option, sub-slab depressurisation, are described below.

6.2.1 Performance Requirements

Under ASTM E2121 - 13 "*Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings*", the minimum depressurisation recommended for sub-slab depressurisation systems is 6 to 9 Pascals or 0.024 to 0.036 inches water column (W.C.) Industry practice in Canada and the United States is to achieve this depressurisation below greater than 90% of the building footprint (there is currently no specific Australian industry practice). This depressurisation criterion should be met during different seasons, but would not necessarily apply during short-duration extreme weather events.

As detailed in Section 6.1.1, sub-slab depressurisation systems typically do not require air treatment. Sampling and analysis of ambient air could be conducted to verify acceptable air concentrations, as warranted.

6.2.2 Conceptual Design

6.2.2.1 Sub-slab Depressurisation – Internal Sumps

The conceptual design for sub-slab depressurisation using interior sump(s) is as follows:

- Core 125 mm diameter hole in house concrete floor;
- Create 300 mm by 300 mm wide by 500 mm deep sump in the soil beneath the slab;
- Suspend pipe 20 mm below bottom of floor slab;
- Seal pipe in floor slab with non-VOC containing caulk;
- Connect piping to external fan mounted on building exterior wall;
- Pipe will consist of 100 mm diameter PVC;
- Fan will consist of a small, low noise, weatherproof fan (expected to be an 80-150 Watt fan, see equipment specification below);
- Install condensate trap downstream of fan, if fan does not have an integrated condensate trap; and
- Vent stack will be completed with a rain cap located a minimum of 300 mm above the roof eave and a minimum of 3 m from doors or windows.

Because of the interior grade beams, multiple sumps may be required to effectively depressurise the sub-slab soils.

A pressure sensor will be installed upstream of the fan to enable monitoring of vacuum in the pipe. If the pressure drops below a threshold (i.e., indicating malfunction of equipment or major leak in the system), the pressure sensor will trigger a visual alarm and remote call-out to maintenance and/or other designated staff. A pressure gauge will also be installed on the suction side of the riser to enable visual monitoring of vacuum.

Sealing of floors and other potential openings (e.g., drains if present) may be required to prevent excessive leakage of indoor air into the sub-slab soils.

6.2.2.2 Sub Slab Depressurisation – Perimeter penetrations

The conceptual design for sub-slab depressurisation using perimeter penetrations is as follows:

- Excavate multiple pits beside house;
- Core horizontal 125 mm diameter hole in house foundation wall such that top of the core hole is a few millimetres below the concrete floor slab;
- Create 300 mm by 300 mm wide by 500 mm deep sump (note because of horizontal orientation and proximity to wall and foundation it may not be possible to create a sump of this size);
- Suspend pipe 20 mm past interior building wall;
- Seal pipe in floor slab with non-VOC containing caulk.
- Connect piping to external fan mounted on building exterior wall;
- Pipe will consist of 100 mm diameter PVC;
- Fan will consist of a small, low noise, weatherproof radon fan (expected to be an 80-150 Watt fan, see equipment specification below);
- Install condensate trap downstream of fan, if fan does not have an integrated condensate trap; and

- Vent stack will be completed with a rain cap located a minimum of 300 mm above the roof eave and a minimum of 3 m from doors or windows.

Because of the interior grade beams and non-optimal location of sumps along the building perimeter multiple exterior pits will likely be required to effectively depressurise the sub-slab soils.

There are similar requirements for pressure monitoring and sealing of floors as for sub-slab depressurisation using interior sumps.

A sketch of a typical sub-slab depressurisation detail for a perimeter sump is presented below, together with photographs of the typical installation process. Note that for internal sumps the detail is similar to the perimeter sump, however the pipework from the sump must pass through the inside of the building to reach the roof or an external wall.

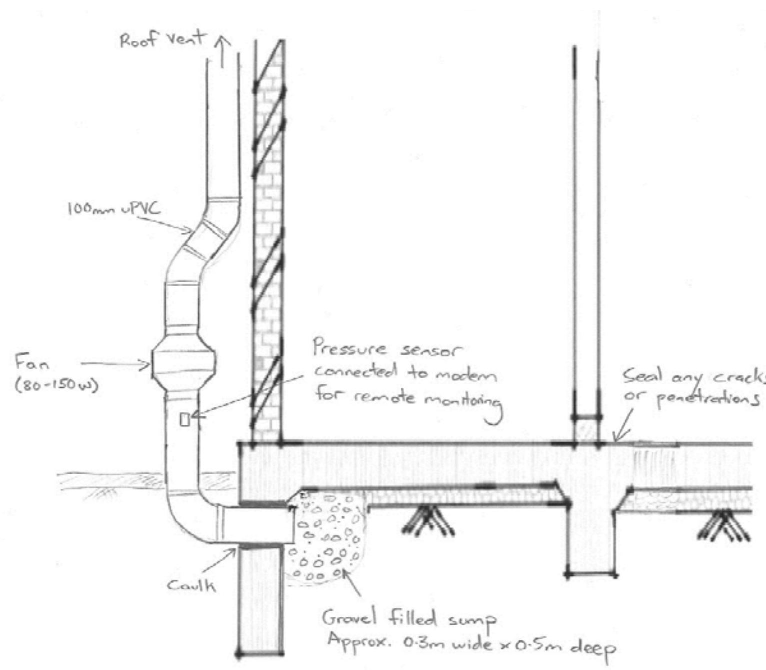


Figure 7: Typical sub-slab depressurisation perimeter sump detail

Figure 8: Construction of internal sump

Figure 9: Construction of external wall penetration

6.2.2.3 Soil Vapour Extraction

The conceptual design for soil vapour extraction is as follows:

- Install vertical wells near to house or sub-horizontal wells drilled below house;
- Vertical wells will extend close to water table; horizontal wells will extend at least several metres below the house foundation, with alignment to depend on access for drill rig (see below) and utilities;
- Wells will likely consist of 100 mm diameter PVC pipe;
- Wells will be connected to header pipe, which in turn will connect to moisture knock-out, blower and air treatment unit;
- Install valves on wells and header upstream of blower;
- Install sampling ports on wells and upstream and downstream of air treatment units;
- Install other controls for monitoring system operation, as warranted; and
- Equipment will be housed in small secure, shed-like structure.

Drilling of sub-horizontal wells would require consideration of access and space for the drill rig. Unless a pit is excavated and horizontal pipe-jacking is used, the well alignment is constrained with respect to the achievable radius of curvature for drilling sub-horizontal wells from surface. Practically this means drilling from a point some distance from the house targeted for mitigation to achieve the desired well alignment. There are likely significant constraints to installation of sub-horizontal wells in the Assessment Area. While drilling of vertical wells would also require access for a drill rig, there would be greater flexibility with respect to locating the drill rig. Vertical wells may be less effective than horizontal wells with respect to radius of influence for soil vapour capture below houses.

As part of design and implementation, a pilot test would be conducted where a short-term soil gas pumping test would be performed. Through monitoring of pressures at the well and nearby soil vapour probes and wells, the radius of influence for soil gas flow would be determined. Modelling may also be performed to predict soil vapour plume capture.

6.2.3 Implementation Strategy

The proposed implementation strategy for sub-slab depressurisation technology for both the internal sump and external pit/sump options is as follows:

1) Seal major accessible floor openings and penetrations such as drains, if present.
2) Install sump(s) and sub-slab vapour probes at varying distances from the sump(s).
3) Install temporary fan and conduct trial of flow versus vacuum for sub-slab depressurisation using a trial fan. Conduct pressure field extension tests where differential pressures between the house and sub-slab soils are measured using a manometer at multiple sub-slab probe locations at varying distances from the sump.
4) Install desired fan and monitor system parameters over a longer time period and analyse samples of sub-slab air and indoor air to confirm acceptable system performance.
5) Adjust and optimise system through control of air flow rates and additional sealing of floor, as warranted.
6) Implement other provisional measures described in Section 5.2.3, if required.

The implementation strategy for sub-slab depressurisation systems will, in part, depend on the degree to which staged implementation is acceptable to stakeholders. Because of the interior grade beams, the pressure extension created by a single sump may be relatively limited. One strategy would nevertheless be to install only a minimal number of sumps (e.g., one or two) and then test performance to determine whether acceptable, and to continue a process of adding to the system as warranted.

The implementation strategy for soil vapour extraction will require consideration of additional factors because of added complexity and scale of mitigation compared to sub-slab depressurisation including mobilisation of equipment and materials, access and site constraints, permitting, air treatment, longer time frames for system pilot testing and full scale construction and testing.

7.0 EQUIPMENT REQUIREMENTS

7.1 Preliminary Equipment

A preliminary list of most equipment components for crawl space depressurisation is provided below. Reference to specific products is provided for example only and equivalent products are acceptable.

7.1.1 Fan Specification

Given the uncertainty in factors affecting flow and pressure (soil permeability, floor leakage and crawl space volume), a range of fans are recommended, as indicated below. It is recommended that the first three fans below, or similar fans, be procured for pilot-scale crawl space depressurisation trials. These fans will also likely be suitable for sub-slab depressurisation of slab at grade foundations. Conversion of fans for 240V power supply will be required.

Fan #1: Fantech HP190SL (Slimline)

- 87 Watt
- Single-phase, 120V
- Maximum air flow rate of 4.5 m^3/min
- Five-year limited warranty
- Air stream temperatures up to 60 °C
- Certifications: cULus

This fan is UL (USA) listed for mounting in wet outdoor conditions, is quiet and has an integrated condensate control system. Confirmation of Australian certification is required. The housing of the fan is high impact UV resistant polycarbonate. It is visually attractive and electrical controls are protected from moisture. The fan is attached to uPVC pipe using flexible coupling. For 100mm uPVC pipe use Indiana Seals #156-44, Pipeconx PCX 56-44 or Australian equivalent.

http://www.amazon.ca/Fantech-HP190SL-Slimline-Radon-Fan/dp/B005J8BJ62

Model	Rated power	Voltage / phase	Max. amps	0.0" P_s	0.5" P_s	0.75" P_s	1.0" P_s	1.25" P_s	1.5" P_s	1.75" P_s	2.0" P_s	Max P_s	Shipping weight	Item #
	W	V / ~	A	cfm								in.wg	lbs	
HP 175	65	120 / 1	0.57	151	112	91	70	40	12	-	-	1.66	1	45047
HP 190	85	120 / 1	0.78	157	123	106	89	67	45	18	1	2.01	7	411297
HP 220	152	120 / 1	1.30	344	260	226	193	166	137	102	58	2.46	8	411349
HP 2133	20	120 / 1	0.17	134	68	19	-	-	-	-	-	0.84	1	45044
HP 2190	85	120 / 1	0.78	163	126	104	81	58	35	15	-	1.93	3	45048

Fan #2: Fantech FR110

- 80 Watt
- Single-phase, 120 V
- Maximum air flow rate of 167 cfm
- Five-year limited warranty
- Fan 100% Speed-controllable (WC 15 speed control accessory)
- Prewired and supplied with a mounting bracket
- Can be installed in any orientation
- Approved for residential and commercial applications and for wet locations
- Air stream temperatures up to 140 °F
- Certifications: HVI, cULus, cCSAus

Fan #3: Fantech FR160

- 130 Watt
- Single-phase, 120 V
- Maximum air flow rate of 299 cfm
- Five-year limited warranty
- Fan 100% Speed-controllable (WC 15 speed control accessory)
- Prewired and supplied with a mounting bracket
- Can be installed in any orientation
- Approved for residential and commercial applications and for wet locations
- Air stream temperatures up to 140 °F
- Certifications: HVI, cULus, cCSAus

Fan Model	Energy Star	RPM	Voltage	Rated Watts	Wattage Range	Max. Amps	Static Pressure in Inches W.G.							Max. Ps	Duct Dia.
							0″	.2″	.4″	.6″	.8″	1.0″	1.5″		
FR 100	✔	2950	120	21.2	13 – 22	0.18	137	110	83	60	21	—	—	0.9″	4″
FR 110	—	2900	115	80	62 – 80	0.72	167	150	133	113	88	63	4	1.60″	4″
FR 125	✔	2950	115	18	15 – 18	0.18	148	120	88	47	—	—	—	0.79″	5″
FR 140	✔	2850	115	61	47 – 62	0.53	214	190	162	132	99	46	—	1.15″	6″
FR 150	✔	2750	120	71	54 – 72	0.67	263	230	198	167	136	106	17	1.58″	6″
FR 160	—	2750	115	129	103 – 130	1.14	289	260	233	206	179	154	89	2.32″	6″
FR 200	✔	2750	115	122	106 – 128	1.11	408	360	308	259	213	173	72	2.14″	8″
FR 225	✔	3100	115	137	111 – 152	1.35	429	400	366	332	297	260	168	2.48″	8″
FR 250	—	2850	115	241	146 – 248	2.40	649	600	553	506	454	403	294	2.58″	10″

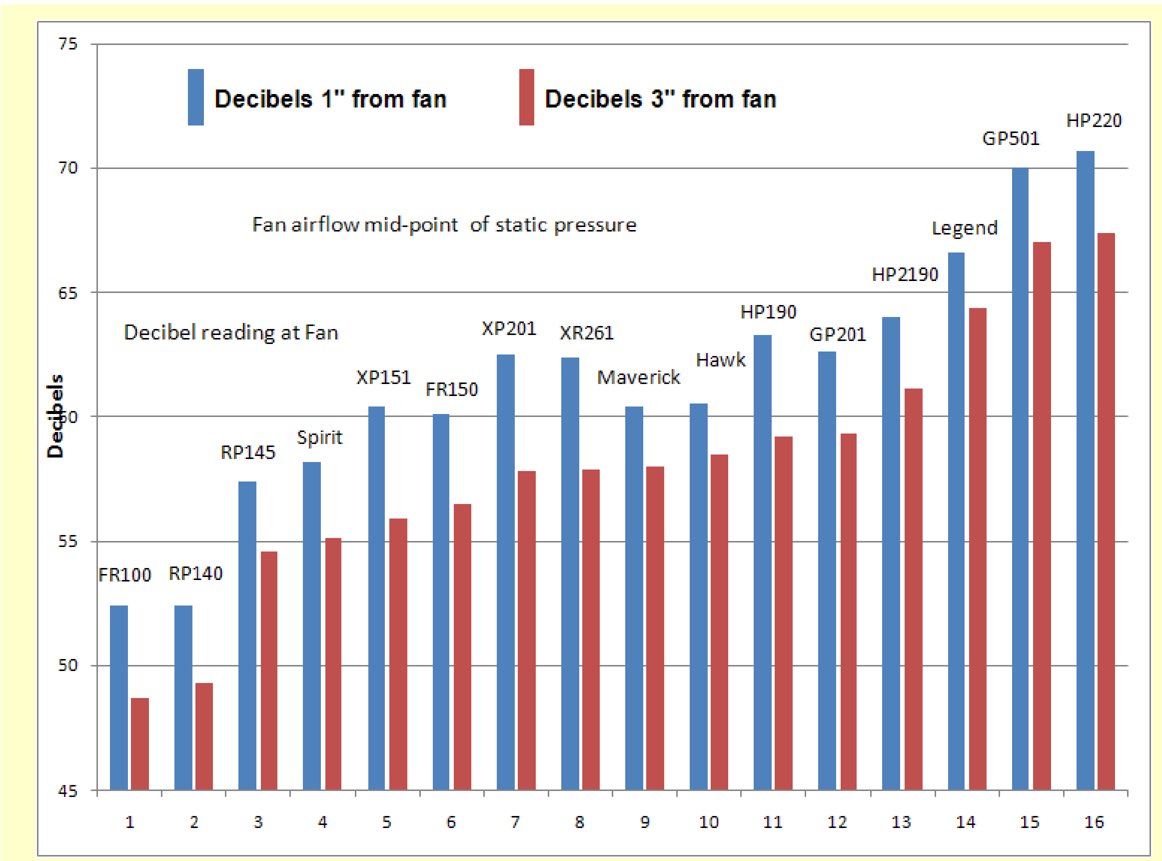
Performance shown is for installation type D - Ducted inlet, Ducted outlet. Speed (RPM) shown is nominal. Perfomance is based on actual speed of test. Performance ratings do not include the effects of appurtenances in the airstream.

Fan #4: FR 200 (Provisional)

This fan has similar wattage to FR160 but is designed to provide for more air flow at low vacuum. This fan is provisionally recommended if higher air change rate of larger crawl space is required.

Fan Noise

Fans are fairly quiet but noise generally increases with fan size and wattage. A target noise rating is 55 decibels. Noise can be mitigated to some extent through exhaust mufflers or foamcore pipe. Fans should also be located away from bedroom windows to the extent possible. Excessive vibration may cause noise. This may be a result of mounting supports for the fan, which can be adjusted or cushioned with materials such as neoprene or other material. Occasionally the fan blades accumulate dirt or bugs, and may need to be cleaned.



http://www.wpb-radon.com/Radon_fan_noise.html

7.1.2 Piping and Attachments

The recommended piping and attachments are listed below, however locally available equivalent products may be used:

- 100 mm diameter Schedule 40 uPVC pipe.
- 100 mm valves. Ball valves are inexpensive and provide basic control. Gate valves generally provide for greater air flow control.
- Vent Cap for 4" Schedule 40 Item # 76002
  http://radon.radonaway.com/inventoryD.asp?item_no=76002&CatId={3DB74209-9496-4B1F-9A1B-5D494AF7106A}#sthash.HiO3pKe2.dpuf

- Flexible rubber couplings with metal clamps on both ends. https://www.fernco.ca/
- Fan Guard Kit 4" Schedule 40 Item # 76040-2 condensate trap needed for FR series of fans http://radon.radonaway.com/inventoryD.asp?item_no=76040-2&CatId={689D508D-89C8-4B81-96D8-43F6BB2A969E}#sthash.Btm2mSgU.dpuf
- Compact ball valves https://my.misumi-ec.com/asia/CategorySearchView/103_27000000_27020000_27020700_27020707.html
- System labels

7.1.3 Floor Sealing

The recommended floor sealing products are listed below, however locally available equivalent products may be used:

- Vulkem Self-Leveling Sealant Item # 28032 Description - Polyurethane, well-suited for concrete slabs. - See more at: http://radon.radonaway.com/inventoryD.asp?item_no=28032&CatId={42E6019E-8BCF-4A77-A782-056E1A6E5DBC}#sthash.NTHYdUJx.dpuf

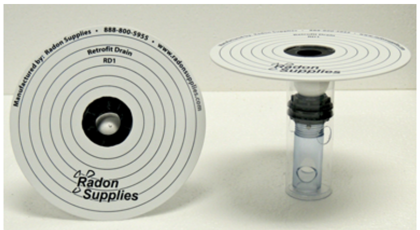
  or

  SikaFlex® Self Levelling Sealant http://aus.sika.com/en/solutions_products/02/02a024/02a024sa08/02a024sa08100/02a024sa08101.html Note that the this product contains some xylene and this should be taken into account during air monitoring
- Pecora Dynatrol Sealant Item # 68036 Description - Polyurethane non-sag elastomeric sealant. 30-year life expectancy. - See more at: http://radon.radonaway.com/inventoryD.asp?item_no=68036&CatId={42E6019E-8BCF-4A77-A782-056E1A6E5DBC}#sthash.I5tZJCRV.dpuf\

  or

  SikaFlex® -11FC elastic joint sealant http://aus.sika.com/en/solutions_products/02/02a024/02a024sa08/02a024sa08100/02a024sa08101.html Note that the this product contains some xylene and this should be taken into account during air monitoring.
- F-S2 Dranjer® - Retrofit sump seal - brass valve Item # 28010 http://radon.radonaway.com/inventoryD.asp?item_no=28010&CatId={37420FF0-DCA4-490D-8582-635719736648}
- F-R2 Dranjer® - Retrofit floor drain seal - flexible flange, brass valve Item # 28009 http://radon.radonaway.com/inventoryD.asp?item_no=28009&CatId={37420FF0-DCA4-490D-8582-635719736648}#sthash.cOxMnB8m.dpuf

- Radon Supplies Retrofit drain – Small 5 1/4" top dia. x 1 1/4" bottom dia., 4" length. Retrofit model has rigid flange, which can be cut to size (with scissors, snips or shears) allowing installation into virtually all existing floor drains. Includes ball-valve.
  http://www.radonsupplies.com/merchant2/merchant.mvc?Screen=PROD&Store_Code=R&Product_Code=RD1&Category_Code=DR



- Radon Supplies Retrofit drain – Large 7 1/2" top dia. x 2 1/2" bottom dia.
  6 1/2" length, Retrofit model has rigid flange, which can be cut to size (with scissors, snips or shears) allowing installation into virtually all existing floor drains. Includes ball-valve.
  http://www.radonsupplies.com/merchant2/merchant.mvc?Screen=PROD&Store_Code=R&Product_Code=RD2&Category_Code=DR

7.1.4 Monitoring and Controls

As a minimum, a visible alarm should be installed just upstream of the fan. The alarm is triggered based on vacuum in pipe dropping to less than a vacuum set-point. The standard pressure switches available from radon suppliers (see two units below) is activated when the vacuum drops below 0.25 inch W.C. This vacuum set-point is acceptable for a sub-slab depressurisation system, but may be too high for a crawl space depressurisation system. For crawl space depressurisation, the recommended minimum vacuum is 10 Pascals or 0.04 inch W.C. There will be some pressure loss in the pipe and therefore a slightly higher vacuum set-point is reasonable. The preliminary specification for crawl space, a set-point of 13 Pascals or 0.05 inch W.C. is recommended on a preliminary basis.

The recommended pressure switch for sub-slab depressurisation system is (either unit below):

- Checkpoint IIA Mitigation System Alarm Item # 28001-2 Description - Audible alarm; green and red LED lights; factory preset to activate at .25" WC vacuum pressure; low voltage
  http://radon.radonaway.com/inventoryD.asp?item_no=28001-2&CatId={95C1E825-15C9-4960-AEF6-92B0308C4319}#techspecs

- System Alarm Factory preset to activate at .25"WC vacuum pressure, audible alarm, green and red light readout, low voltage http://www.radondetect.ca/system-alarm.html

The recommended pressure switch for crawl space depressurisation system is (either unit below):

- Dwyer manufactures low pressure switch to 0.07 inch W.C.
  http://www.dwyer-inst.com/Product/Pressure/DifferentialPressure/Switches/Series1900

- AnTune Controls manufactures low pressure switch to 0.05 inch W.C.
  http://www.ajantunes.com/LowPressureSwitches/tabid/235/ProdID/495/CatID/282/language/en-US/Default.asp

An autodialer that is connected to the pressure switch is recommended. Golder has successfully used the Omega OMA-VM606 autodialer on other projects but a simpler unit with fewer channels would also be suitable:

- Omega OMA-VM606 autodialer
  http://www.omega.com/pptst/OMA-VM606.html

A pressure gauge or manometer should be installed upstream of the fan for sub-slab depressurisation systems to provide for a quick, visual read-out of the approximate vacuum. While the vacuum is often on the order of 1 or 2 inches W.C. for small- to moderate-sized houses with moderate to higher permeability subsoils, higher vacuums are anticipated for the houses within the Assessment Area because the raft foundation and interior grade beams will likely result in a reduction in the air flow rate.

The recommended manometer for sub-slab depressurisation systems is:

- Magnahelic® Manometer Series 2000 – 2010. 0 to 10 inch W.C. For exterior use. High accuracy (within 2%)
  https://www.dwyer-inst.com/Product/Pressure/DifferentialPressure/Gages/Series2000

The recommended manometer for crawl space depressurisation system is:

- Magnahelic® Manometer Series 2000 – 2000-00. 0 to 0.25 inch W.C. For exterior use. High accuracy (within 2%)
  https://www.dwyer-inst.com/Product/Pressure/DifferentialPressure/Gages/Series2000

7.1.5 Temporary Monitoring Equipment

Differential pressure monitoring is recommended on a temporary basis during pilot scale trials and commissioning. It is recommended that four transducers and a data logger be procured:

- Pace Scientific Inc. model P300-0.4 ∆P transducers (range of approximately +/- 0.4 inch W.C. (100 Pascals) with maximum resolution of 0.00024 inch W.C. (0.06 Pascals). Pace Scientific Inc. model XR440 data logger set to the maximum 12-bit resolution.
  https://www.pace-sci.com/

- Digital Micromanometer with full-scale minimum +/- 2,000 Pa with 0.5 Pa resolution, e.g., GrayWolf's DP-702LH differential pressure sensor, when installed in an AdvancedSense (or WolfPack®) meter
  http://www.wolfsense.com/differential-pressure-meters-micromanometer.html

- Anemometer – hot wire anemometer for measurement of air speed, with data logging capability

- Regin Smoke Pen Product# S221 Smoke Pen Refill
  http://www.radonsupplies.com/merchant2/merchant.mvc?Screen=PROD&Store_Code=R&Product_Code=S220&Category_Code=DA

8.0 DETAILED DESIGN PROCESS

Should the implementation of mitigation measures be triggered by the decision process outlined in Section 3, detailed design will be required based on property specific factors. The detailed design process will incorporate the following primary elements:

1) Property specific inspection and review of system installation constraints
2) Property owner consultation to determine optimal design features, aesthetic and other considerations for system installation.
3) Application for permits or authorisations that may be required
4) Adapting the most appropriate conceptual mitigation system designs based on information obtained from elements 1 and 2 above to derive a preferred property specific design
5) Trialling of system design to confirm property specific system parameters
6) Review and sign off on the design by the property owner and government appointed risk manager.

9.0 VERIFICATION AND LONG TERM MANAGEMENT

Following installation of the system verification of effectiveness will be required. The system verification shall incorporate the following, as appropriate to each design:

- Measurement of crawl space air flows and TCE concentrations
- Measurement of pressure differences between indoor air and sub slab and crawl spaces
- Measurement of indoor air concentrations

Based on the outcomes of verification testing it may be necessary to adjust the system to ensure its effectiveness.

Long term management and maintenance requirements will be documented in property specific management and maintenance plans to be developed at the conclusion of system installation. Active systems will be remotely monitored such that appropriate notifications will be automatically provided to the risk manager should system operation fail to achieve pre-established performance targets (e.g. crawl space pressure exceeds a set value or fan failure occurs).

10.0 REFERENCES

ASTM E2121 - 13 *Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings.*

Golder, *Groundwater and Soil Vapour Data Report - Beverley Assessment Area, South Australia,* report no. 1418522-003-R-Rev 1, dated 27 May 2015.

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Report Signature Page

GOLDER ASSOCIATES PTY LTD

Ian Hers
Principal Specialist Engineer

James Corbett
Principal Environmental Engineer

IH/JCC/sjm

A.B.N. 64 006 107 857

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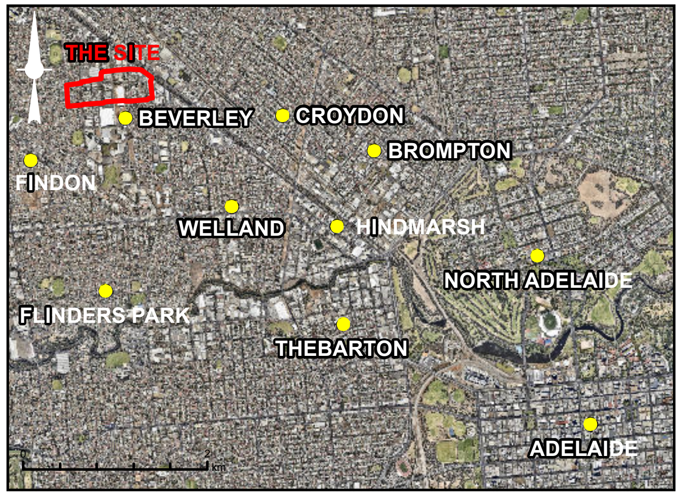
APPENDIX A

Assessment Area

LOCATION MAP



LEGEND

Assessment Area

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1. Aerial image sourced from Nearmap Pty. Ltd, aerial dated 11.03.2015, sourced 18.05.2015.
2. Roads data sourced from DPTI, Department for Transport Energy and Infrastructure, South Australian Government, sourced http://www.dptiapps.com.au/dataportal/Roads.zip, sourced 19.06.2014.

0 50 100 150 200 METRES

REFERENCE SCALE: 1:5,000 (at A3)

PROJECTION: GDA 1994 MGA Zone 54

CLIENT
ENVIRONMENT PROTECTION AUTHORITY

PROJECT
GROUNDWATER AND SOIL VAPOUR DATA REPORT - BEVERLEY ASSESSMENT AREA, SOUTH AUSTRALIA

TITLE
ASSESSMENT AREA LOCATION PLAN

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-27
PREPARED	KB
DESIGN	-
REVIEW	MP
APPROVED	JCC

PROJECT No.	CONTROL	Rev.	FIGURE
1418522	003-R	1	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: 25mm 0

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Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Pty Ltd
118 Franklin Street
Adelaide, South Australia 5000
Australia
T: +61 8 8213 2100

Golder Associates