Water resource management plan

Stimulation impact monitoring program

AE-D

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Santos
GLNG Project

Gas Field Development Project
Environmental Impact Statement

Appendix AE-D: Stimulation impact monitoring program

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1 Stimulation impact monitoring program

1.1 Purpose and scope

This Stimulation impact monitoring program has been prepared for the Santos GLNG Gas Field Development Project (the GFD Project) to meet relevant requirements of Schedule J (Well Construction, Maintenance and Stimulation Activities) of Santos GLNG's upstream environmental authorities (EAs). Table 1–1 provides these EA requirements and reference to the relevant section of this Stimulation impact monitoring program.

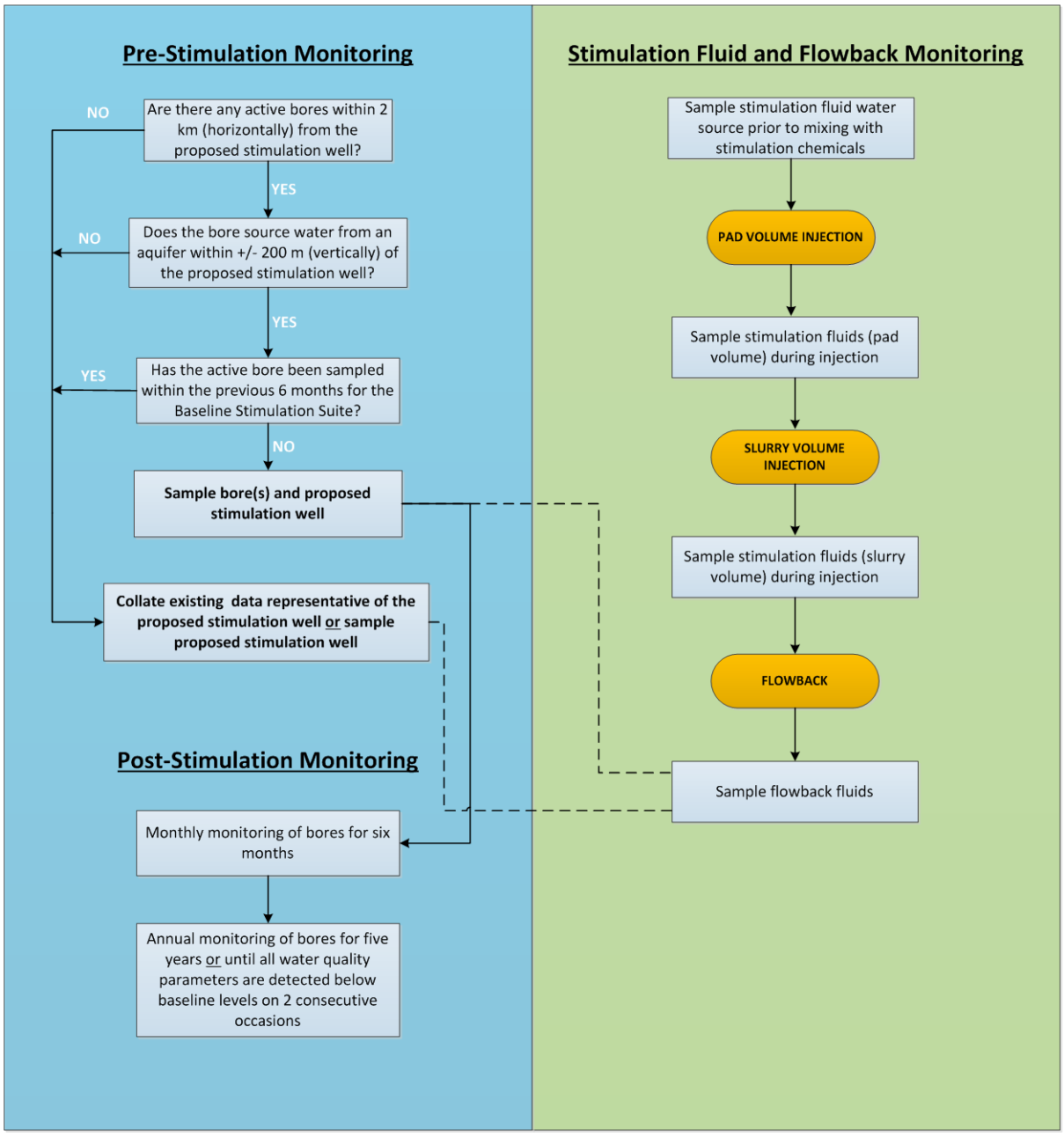
Table 1–1 Stimulation impact monitoring program requirements

Upstream EA condition	Section
Water Quality Baseline Monitoring (J11) Prior to undertaking any stimulation activity, the holder of this environmental authority must undertake a baseline bore assessment of the quality of: a) all landholders' active groundwater bores (subject to access being permitted by the landholder) that are spatially within a two (2) kilometre horizontal radius from the location of the stimulation initiation point within the target gas producing formation; and	Section 2.1
b) all active landholders' groundwater bores (subject to access being permitted by the landholder) in any aquifer that is within 200 metres above or below the target gas producing formation and is spatially located with a two (2) kilometre radius from the location of the stimulation initiation point; and	Section 2.1
c) any other bore that could potentially be adversely impacted by the stimulation activity(ies) in accordance with the findings of the risk assessment required by conditions (J9) and (J10).	Section 2.1
(J12) Prior to undertaking stimulation activities at a well, the holder of this environmental authority must have sufficient water quality data to accurately represent the water quality in the well to be stimulated. The data must include as a minimum the results of analyses for the parameters in condition (J13).	Section 2.2
(J13) Stimulation baseline bore assessments required in Condition (J11) must include the minimum water quality analytes and physico-chemical parameters identified in the Baseline Assessment Guideline (EHP) and any restricted stimulation fluids as defined in the Environmental Protection Act 1994, as amended from time to time, in order to establish baseline water quality.	Section 5
Stimulation Impact Monitoring Program (J14) A Stimulation Impact Monitoring Program must be developed prior to the carrying out of stimulation activities which must be able to detect adverse impacts to water quality from stimulation activities and must consider the findings of the risk assessment required by conditions (J9) and (J10) that relate to stimulation activities and must include, as a minimum, monitoring of: a) the stimulation fluids to be used in stimulation activities at sufficient frequency and which sufficiently represents the quantity and quality of the fluids used; and	Section 3.1-3.3
b) flow back waters from stimulation activities at sufficient frequency and which sufficiently represents the quality of that flow back water; and	Section 3.4
c) flow back waters from stimulation activities at sufficient frequency and accuracy to demonstrate that 150 % of the volume used in stimulation activities has been extracted from the stimulated well; and	Section 3.4
d) all bores in accordance with condition (J11) at the following minimum frequency: i. monthly for the first six (6) months subsequent to the stimulation activities being undertaken; then ii. annually for the first five (5) years subsequent to the stimulation activities being undertaken or until analytes and physico-chemical parameters listed in condition (J13) are not detected in concentrations above baseline bore monitoring data on two (2) consecutive monitoring occasions.	Section 4

Upstream EA condition	Section
(J15) The Stimulation Impact Monitoring Program must provide for monitoring of: a) analytes and physico-chemical parameters relevant to baseline bore and well assessments to enable data referencing and comparison including, but not necessarily being limited to the analytes and physico-chemical parameters in condition (J13); and	Section 5
a) any other analyte or physico-chemical parameters that will enable detection of adverse water quality impacts and the inter-connection with a non-target aquifer as a result of stimulation activities including chemical compounds that are actually or potentially formed by chemical reactions with each other or coal seam materials during stimulation activities.	Section 5

Figure 1-1 provides an overview of the monitoring described in this Stimulation impact monitoring program, including pre-stimulation monitoring, monitoring of stimulation fluid and flowback, and post-stimulation monitoring.

Figure 1-1 Stimulation monitoring overview



2 Pre-stimulation monitoring

2.1 Baseline groundwater bore assessment/sampling

2.1.1 Location and timing

Prior to undertaking stimulation activities, an assessment of existing water quality data, including existing monitoring information and analytical results, will be completed to determine if baseline sampling is required. This assessment will consider:

- Existing groundwater bore information obtained during regional monitoring assessments;
- Existing groundwater bore information obtained during previous stimulation baseline monitoring;

If existing baseline water quality data is not available, groundwater samples will be collected from:

- All landholders' active groundwater bores that are spatially located within a two (2) km horizontal radius from the location of the stimulation initiation point with the target gas producing formation; and
- All active landholders' groundwater bores in any aquifer that is within 200 m above or below the target gas producing formation and is spatially located within a two (2) km radius from the location of the stimulation initiation point; and
- Any other bore that could potentially be adversely impacted by the stimulation activities in accordance with the findings of the risk assessment.

It is important to note that restriction to sampling such as land access, equipment present at the bore (such as pumps) may occur. When sampling cannot be undertaken due to land access or physical restrictions, baseline water quality will be extrapolated from relevant surrounding bores.

2.2 Baseline stimulation well sampling

2.2.1 Location and timing

Prior to the stimulation activities, Santos GLNG will ensure there is sufficient water quality data to accurately represent the water quality in the well to be stimulated. Given the process of well perforation and stimulation (as identified in the risk assessment) it is not considered viable or practical to collect a representative water sample from the well to be stimulated prior to stimulation. Therefore, as a general practice, Santos GLNG will assess existing data (including analytical results) collected from other unstimulated wells located within a similar coal sequence and provide representative water quality data for the well to be stimulated (such as completed in the same target formation and within a 2 km radius). If there is no water quality information available that provides representative water quality data for the well to be stimulated, then a water sample is to be collected from an unstimulated production well located within a similar coal sequence prior to stimulation.

3 Stimulation fluid and flowback monitoring

3.1 Stimulation water source sampling

3.2 Location and timing

Source water that will be used for stimulation activities will be sampled prior to the commencement of the stimulation operations to confirm that water quality is suitable for use in stimulation activities. This water will typically be sourced from produced water from a gas wells or from other available sources and will be stored in the storage located on the well lease prior to the commencement of stimulation activities.

3.3 Stimulation fluid sampling – pad volume

3.3.1 Location and timing

The pad volume comprises a mix of water and sand (typically 99% by volume) drawn from the on lease water storage (whose source has already been characterised) and dry blended guar gum (dry mixed on site) together with a number of additives, such as borate, clay stabilisers and buffering agents. Following mixing, the viscose stimulation fluid (pad volume) is injected to stimulate the coal seam. This viscose stimulation fluid (pad volume) will be sampled at least once during the injection process.

Additional samples will be taken in response to changes to stimulation fluid mixtures (i.e. if different stimulation water sources or additional chemical additives are used during a stimulation event).

3.4 Stimulation fluid sampling – slurry volume

3.4.1 Location and timing

Immediately after the coal seam has been stimulated and the pad volume injection ceases, stimulation immediately proceeds to injection of the slurry volume including the addition of specifically graded sands, referred to as the 'proppant'. Breaker compounds are added at progressively increasing concentrations throughout the slurry volume injection to reduce the viscosity of the pad volume.

Similar to pad volume sampling, the slurry volume fluid will be sampled at least once, when the maximum concentration of breaker compounds has been added (i.e. towards the end of the slurry volume injection). Additional samples will be taken in response to changes to stimulation fluid mixtures (i.e. if different stimulation water sources or additional chemical additives are used during a stimulation event).

3.5 Flowback sampling

3.5.1 Location and timing

Following the completion of injection, stimulation fluids are brought back to the surface. This fluid is referred to as the flowback volume (or 'flowback') and is largely comprised of water and the degraded additives left after the slurry and pad volumes have been mixed with the breaker compounds. Flowback flow monitoring will be undertaken to demonstrate that the volume of flowback will as a minimum be equal to or greater than 150% of the total volume of stimulation fluids injected into the well.

4 Post-stimulation monitoring

4.1 Baseline groundwater bore sampling

4.1.1 Location and timing

Following stimulation, water quality samples will be taken from relevant baseline groundwater bores (Section 2.1). This would include all active groundwater bores that are spatially located within a two (2) km horizontal radius from the location of the stimulation initiation point with the target gas producing formation, and draw groundwater from an aquifer that is within 200 m above or below the target gas producing formation. These baseline bores would be monitored:

- Monthly for the first 6 months subsequent to the stimulation activities being undertaken; then
- Annually for the first 5 years subsequent to the stimulation activities being undertaken or until analytes and physico-chemical parameters are not detected in concentrations above baseline bore monitoring data on 2 consecutive monitoring occasions.

5 Analytical testing

Water/stimulation fluid sampling parameters are provided below in Table 5–1 in accordance with the *Baseline Assessment Guideline* (DEHP, 2014).

Table 5–1 Water/stimulation fluid sampling parameters

Physical parameters	Ions	Metals (dissolved & total)	Alkalinity	Dissolved gases and other
pH (field and laboratory)	*Calcium*	*Aluminium*	*Total alkalinity as $CaCO_3$*	*Carbon dioxide (field)*
Temperature (field only)	*Chloride*	*Arsenic*	*Bicarbonate as $CaCO_3$*	*Methane*
Electrical conductivity (field and laboratory)	*Fluoride*	*Barium*	*Carbonate as $CaCO_3$*	*Hydrogen sulphide*
Total dissolved solids (laboratory only)	*Magnesium*	*Beryllium*	*Hydroxide as $CaCO_3$*	*Volatile organic compounds (VOC)*
	Potassium	*Boron*	*Total hardness*	*Semi-volatile organic compounds (SVOC)*
	Sodium	*Cadmium*		*Total petroleum hydrocarbons (TPH) or total recoverable hydrocarbons (TRH)*
	Sulphate	*Chromium*		*Benzene*
		Cobalt		*Toluene*
		Copper		*Ethyl-benzene*
		Iron		*Xylene (total)*
		Lead		*Naphthalene*
		Manganese		*Phenanthrene*
		Mercury		*Benzo(a)pyrene*
		Molybdenum		*Sodium hypochlorate**
		Nickel		*Sodium hydroxide**
		Selenium		*Formaldehyde**
		Uranium		*Ethanol**
		Vanadium		
		Zinc		

***** Sampling only when biocides are added to stimulation fluids