Flowback Fluid 6 Month Report

Purpose

Santos QNT Pty Ltd was granted approval for the McArthur Basin 2019-2020 Hydraulic Fracturing Program Exploration permit 161 Environmental Management Plan (EMP) on 23 October 2019.

In accordance with Regulation 37A of the Petroleum (environment) Regulations 2016 (the Regulations), Santos is required to give the minister 'a report about flowback fluid' within 6 months of flowback occurring. Since flowback commenced on 25th November 2019. This report is due 25th May 2020.

Scope

This report is required to contain the following information:

a) the identity of any chemical or NORM found in the flowback fluid; (refer to attached reports 1 and 2)

b) the concentration of any chemical or NORM found in the flowback fluid; (refer to attached reports 1 and 2)

c) details regarding how any chemical or NORM has been or will be managed; (refer to EMP Appendix G: Wastewater Management Plan, and also report 4 which assess the risk to avian receptors that may come into contact with fluids contained in open-top tanks)

d) details regarding how any chemical or NORM has been or will be transported; (not applicable - no transport is currently proposed)

e) details regarding how any chemical or NORM has been or will be treated; (refer to EMP Appendix G: Wastewater Management Plan)

f) details regarding any action proposed to be taken to prevent any chemical or NORM spill; (refer to the mitigation and management measures within Table 6-1 of EMP, Section 2.4.1.1 of EMP Appendix G: Wastewater Management Plan, and also Report 3 which assesses the potential risk to terrestrial environmental receptors exposed to soils under a hypothetical fluid release scenario)

g) details of the emergency contingency plan included in the environment management plan to which the activity relates; (refer to EMP Appendix K: Emergency Response Plan and Section 4.1.2 of EMP Appendix H: Spill Management Plan)

h) the requirements in relation to the management of any chemical or NORM of the prescribed chemical legislation. (refer to Attachment C of EMP Appendix A: Chemical Risk Assessment)

Inclusions

A summary of the appended reports comprises:

1) Monitoring results (TAN1FBCT)

   - An excel spreadsheet of monitored water quality results (6 samples) for fluid sampled from enclosed storage tanks currently storing flowback and produced water from Tanumbirini-1 well.

   - Assessment of testing requirements

2) An evaluation of the hydraulic fracturing chemical additives used for their potential to generate degradants that may require analytical testing in addition to that specified in the CoP (Section C.8)

   - The assessment concluded that additive chemicals used in the hydraulic fracturing process are degradable or ionizable to specific chemical analytes included in the CoP analytical suite or are not degradable.

   - The assessment concluded that no additional analytes need to be added to the suite of analytes listed in Section C.8 of the CoP.

3) Terrestrial soil exposure risk assessment

   - An assessment to determine the potential risk to terrestrial receptors exposed to soils based on a hypothetical release scenario

   - The assessment concluded that no chemicals detected in the wastewater at their maximum concentration, and under a hypothetical maximum release scenario, would result in soil levels above conservative screening criteria protective of terrestrial receptors.

4) Avian risk assessment

   - Quantitative assessment of risk to avian receptors that may come into contact with fluids contained in open-top tanks, the only potentially complete exposure pathway identified in the EMP

   - The assessment concluded that there is no unacceptable risk to potential avian receptors should they be exposed to the waste water currently stored in the enclosed tanks

Inclusion 1

Monitoring results (TAN1FBCT)

					FACILITY	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN
					LOCATION	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE
					DESCRIPTION	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP
					SAMPLE_DATE	15/01/2020	15/01/2020	12/02/2020	12/02/2020	4/03/2020	4/03/2020
					WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972	EB2006500	EB2006500
					START_DEPTH	0.2	4	0.2	4	4	0.2
					SAMPLE TYPE	N	N	N	N	N	N
METHOD	**PARAMETER-CHEMICAL**	**FRACTIO**	**LOR**	**UNIT**		**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**
APHA 3125 B	Boron	D	100	µg/L				15400	16700		
APHA 3125 B	Boron	D	5	µg/L	11000	10600					
APHA 3125 B	Boron	D	500	µg/L						15900	16500
APHA 3125 B	Boron	T	105	µg/L				15800	17000		
APHA 3125 B	Boron	T	5	µg/L	15800	15400					
APHA 3125 B	Boron	T	525	µg/L						19200	18200
APHA 3125 B	Selenium	D	0.2	µg/L	1.8	1.6					
APHA 3125 B	Selenium	D	2	µg/L				2	2	3	2
APHA 3125 B	Selenium	T	0.5	µg/L	1.3	1.8					
APHA 3125 B	Selenium	T	2	µg/L				2	3	4	2
APHA 3125 B	Zinc	D	1	µg/L	226	2					
APHA 3125 B	Zinc	D	5	µg/L				5	5	425	10
APHA 3125 B	Zinc	T	5	µg/L	1610	33		10	105	6590	12
APHA_1030F	Ionic Balance	N	0.01	%	3.52	0.17		3.31	7.64	3.02	4.31
APHA_1030F	Total Anions	N	0.01	meq/L	157	134		146	182	184	160
APHA_1030F	Total Cations	N	0.01	meq/L	146	134		156	212	174	147
APHA_2320_B	Bicarbonate Alkalinity as CaCO3	N	1	mg/L	908	596		836	817	735	909
APHA_2320_B	Carbonate Alkalinity as CaCO3	N	1	mg/L	1	1		1	1	1	1
APHA_2320_B	Hydroxide Alkalinity as CaCO3	N	1	mg/L	1	1		1	1	1	1
APHA_2320_B	Total Alkalinity as CaCO3	N	1	mg/L	908	596		836	817	735	909
APHA_2510_B	Electrical Conductivity @ 25°C	N	1	µS/cm	15100	13200		14100	18100	17400	14600
APHA_2540_C	Total Dissolved Solids @180°C	T	10	mg/L	9920	8650		8610	11000	10300	9050
APHA_2540_D	Suspended Solids	N	5	mg/L	24	528		6	5	41	15
APHA_3112_CV_FIMS	Mercury	D	0.0001	mg/L		0.0001					0.0001
APHA_3112_CV_FIMS	Mercury	D	0.0005	mg/L	0.0005			0.0005	0.0005		
APHA_3112_CV_FIMS	Mercury	D	0.0050	mg/L						0.0050	
APHA_3112_CV_FIMS	Mercury	T	0.0001	mg/L		0.0001		0.0001	0.0001		0.0001
APHA_3112_CV_FIMS	Mercury	T	0.0005	mg/L	0.0005						
APHA_3112_CV_FIMS	Mercury	T	0.0050	mg/L						0.0050	
APHA_3120	Calcium	D	1	mg/L	122	49		123	179	122	124
APHA_3120	Magnesium	D	1	mg/L	58	57		67	86	69	60
APHA_3120	Potassium	D	1	mg/L	32	31		35	44	37	34
APHA_3120	Sodium	D	1	mg/L	3100	2890		3300	4490	3700	3100
APHA_4110	Bromide	N	1.00	mg/L	59.6	51.3		56.3	77.7	70.1	53.8
APHA_4500_Cl	Chloride	N	1	mg/L	4930	4330		4570	5880	6010	5000
APHA_4500_Cl_G	Free Chlorine	N	0.02	mg/L	0.02	0.02		0.02		0.02	0.02
APHA_4500_Cl_G	Free Chlorine	N	0.10	mg/L					0.10		
APHA_4500_Cl_G	Total Residual Chlorine	N	0.02	mg/L	0.02	0.02		0.02		0.02	0.02
APHA_4500_Cl_G	Total Residual Chlorine	N	0.10	mg/L					0.10		
APHA_4500_CN_O	Total Cyanide	T	0.004	mg/L	0.004	0.004		0.004	0.004	0.004	0.004
APHA_4500_F_C	Fluoride	N	0.1	mg/L	1.8	1.8		1.6	1.6	0.8	1.7
APHA_4500_H_B	pH - Lab	N	0.01	pH Unit	8.01	6.70		7.87	7.88	8.10	7.84
APHA_4500_NH3_G	Ammonia as N	N	0.01	mg/L	34.8	29.3		28.9	33.6	36.1	33.6
APHA_4500_NO2_B	Nitrite as N	N	0.01	mg/L	0.01	0.06		0.01	0.01	0.01	0.01
APHA_4500_NO3_F	Nitrate as N	N	0.01	mg/L	0.01	0.01		0.01	0.01	0.01	0.04
APHA_4500_NORG_D	Total Kjeldahl Nitrogen as N	N	0.5	mg/L	41.8	42.8		45.0	46.2		
APHA_4500_NORG_D	Total Kjeldahl Nitrogen as N	N	1.0	mg/L						39.7	41.2
APHA_4500_NORG+NO3	Total Nitrogen as N	N	0.5	mg/L	41.8	42.8		45.0	46.2		
APHA_4500_NORG+NO3	Total Nitrogen as N	N	1	mg/L						39.7	41.2
APHA_4500_P_E	Reactive Phosphorus as P	T	0.01	mg/L	0.69	0.31		0.62	0.74	0.01	0.35
APHA_4500_P_H	Total Phosphorus as P	T	0.05	mg/L	0.94	1.03		0.99	1.06		
APHA_4500_P_H	Total Phosphorus as P	T	0.10	mg/L						0.98	1.82
APHA_4500_SIO2	Reactive Silica	N	0.05	mg/L	127	125		120	125		

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				SAMPLE_DATE	15/01/2020	15/01/2020	12/02/2020	12/02/2020	4/03/2020	4/03/2020
				WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972	EB2006500	EB2006500
				START_DEPTH	0.2	4	0.2	4	4	0.2
				SAMPLE TYPE	N	N	N	N	N	N
METHOD	**PARAMETER-CHEMICAL**	**FRACTIO**	**LOR**	**UNIT**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**
APHA_4500_SIO2	Reactive Silica	N	1.00	mg/L					45.9	123
APHA_4500_SO4_E	Sulfate as SO4 2-	D	1	mg/L	1	2	22	4	12	42
APHA_5310_B_DOC	Dissolved Organic Carbon	N	5	mg/L	112	234	84	71	47	79
APHA_5310_B_TOC	Total Organic Carbon	N	2	mg/L		247				
APHA_5310_B_TOC	Total Organic Carbon	N	5	mg/L	108		89	83	52	85
ASTM_D_6303-98	Formaldehyde	N	0.1	mg/L	1.0	0.3	0.1	0.6	0.1	0.1
CSN_75_7611_75_7612	Gross alpha	N	0.23	Bq/L		0.26				
CSN_75_7611_75_7612	Gross alpha	N	0.24	Bq/L			0.24			
CSN_75_7611_75_7612	Gross alpha	N	0.26	Bq/L	0.62					0.68
CSN_75_7611_75_7612	Gross alpha	N	0.30	Bq/L				1.06	0.39	
CSN_75_7611_75_7612	Gross beta activity - 40K	N	0.46	Bq/L		0.46				
CSN_75_7611_75_7612	Gross beta activity - 40K	N	0.49	Bq/L			0.49			
CSN_75_7611_75_7612	Gross beta activity - 40K	N	0.52	Bq/L	0.52					0.56
CSN_75_7611_75_7612	Gross beta activity - 40K	N	0.61	Bq/L				0.61	0.61	
Field Measure	Clarity - Field	N		No Unit	Hi Tb	Hi Tb			M Tb	M Tb
Field Measure	Colour - Field	N		No Unit	BLACK	BLACK			BLACK	BLACK
Field Measure	Electrical Conductivity - Field	N		µS/cm			15302	18584	17223	14583
Field Measure	Field Ambient Temperature	N		°C	28.1	30.9	32.1	29.8	24.3	30.3
Field Measure	Odour - Field	N		No Unit	HYDR	HYDR			SEWAGE	SEWAGE
Field Measure	pH - Field	N		pH Unit	7.04	7.13	7.2	7.4	8.02	7.96
IN_HOUSE_LC-MSMS_EDC	2,4-Dinitrophenol	N	0.01	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
IN_HOUSE_LC-MSMS_EDC	2-Methyl-4,6-dinitrophenol	N	0.05	µg/L	0.05	0.05	0.05	0.05	0.05	0.05
IN_HOUSE_LC-MSMS_EDC	4-Chloro-3-Methylphenol	N	0.10	µg/L	0.10	0.10	0.10	0.10	0.10	0.10
IN_HOUSE_LC-MSMS_EDC	4-Nitrophenol	N	0.10	µg/L	0.10	0.10	0.10	0.10	0.10	0.10
IN_HOUSE_LC-MSMS_EDC	Dinoseb	N	0.10	µg/L	0.10	0.10	0.10	0.10	0.10	0.10
IN_HOUSE_LC-MSMS_EDC	Hexachlorophene	N	0.10	µg/L	0.10	0.10	0.10	0.10	0.10	0.10
USEPA_6020	Aluminium	D	0.01	mg/L					0.01	0.01
USEPA_6020	Aluminium	D	0.05	mg/L	0.05	0.05	0.05	0.05		
USEPA_6020	Aluminium	T	0.01	mg/L					0.28	0.07
USEPA_6020	Aluminium	T	0.05	mg/L	0.08	0.20	0.12	0.15		
USEPA_6020	Antimony	D	0.001	mg/L					0.001	0.002
USEPA_6020	Antimony	D	0.005	mg/L	0.005	0.005	0.005	0.005		
USEPA_6020	Antimony	T	0.001	mg/L					0.001	0.002
USEPA_6020	Antimony	T	0.005	mg/L	0.005	0.005	0.005	0.005		
USEPA_6020	Arsenic	D	0.001	mg/L					0.002	0.009
USEPA_6020	Arsenic	D	0.005	mg/L	0.006	0.015	0.012	0.012		
USEPA_6020	Arsenic	T	0.001	mg/L					0.004	0.010
USEPA_6020	Arsenic	T	0.005	mg/L	0.011	0.017	0.014	0.011		
USEPA_6020	Barium	D	0.001	mg/L					4.70	5.41
USEPA_6020	Barium	D	0.005	mg/L	5.17	0.969	4.63	8.89		
USEPA_6020	Barium	T	0.001	mg/L					5.39	4.97
USEPA_6020	Barium	T	0.005	mg/L	5.18	2.33	4.92	8.16		
USEPA_6020	Beryllium	D	0.001	mg/L					0.001	0.001
USEPA_6020	Beryllium	D	0.005	mg/L	0.005	0.005	0.005	0.005		
USEPA_6020	Beryllium	T	0.001	mg/L					0.001	0.001
USEPA_6020	Beryllium	T	0.005	mg/L	0.005	0.005	0.005	0.005		
USEPA_6020	Cadmium	D	0.0001	mg/L					0.0001	0.0001
USEPA_6020	Cadmium	D	0.0005	mg/L	0.0005	0.0005	0.0005	0.0005		
USEPA_6020	Cadmium	T	0.0001	mg/L					0.0001	0.0001
USEPA_6020	Cadmium	T	0.0005	mg/L	0.0005	0.0005	0.0005	0.0005		
USEPA_6020	Chromium	D	0.001	mg/L					0.005	0.039
USEPA_6020	Chromium	D	0.005	mg/L	0.037	0.035	0.042	0.049		
USEPA_6020	Chromium	T	0.001	mg/L					0.007	0.042

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					SAMPLE_DATE	15/01/2020	15/01/2020	12/02/2020	12/02/2020	4/03/2020	4/03/2020
					WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972	EB2006500	EB2006500
					START_DEPTH	0.2	4	0.2	4	4	0.2
					SAMPLE TYPE	N	N	N	N	N	N
METHOD	**PARAMETER-CHEMICAL**	**FRACTIO**	**LOR**	**UNIT**		**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**
USEPA_6020	Chromium	T	0.005	mg/L		0.045	0.045	0.044	0.047		
USEPA_6020	Cobalt	D	0.001	mg/L						0.001	0.001
USEPA_6020	Cobalt	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Cobalt	T	0.001	mg/L						0.002	0.001
USEPA_6020	Cobalt	T	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Copper	D	0.001	mg/L						0.001	0.002
USEPA_6020	Copper	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Copper	T	0.001	mg/L						0.009	0.002
USEPA_6020	Copper	T	0.005	mg/L		0.016	0.007	0.005	0.010		
USEPA_6020	Iron	D	0.05	mg/L		0.92	0.20	0.07	0.23	0.14	0.30
USEPA_6020	Iron	T	0.05	mg/L		9.97	14.0	2.10	4.00	6.45	0.78
USEPA_6020	Lead	D	0.001	mg/L						0.001	0.001
USEPA_6020	Lead	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Lead	T	0.001	mg/L						0.005	0.001
USEPA_6020	Lead	T	0.005	mg/L		0.007	0.005	0.005	0.005		
USEPA_6020	Manganese	D	0.001	mg/L						0.233	0.488
USEPA_6020	Manganese	D	0.005	mg/L		0.654	0.252	0.466	0.688		
USEPA_6020	Manganese	T	0.001	mg/L						0.276	0.466
USEPA_6020	Manganese	T	0.005	mg/L		0.701	0.459	0.462	0.593		
USEPA_6020	Molybdenum	D	0.001	mg/L						0.004	0.003
USEPA_6020	Molybdenum	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Molybdenum	T	0.001	mg/L						0.006	0.005
USEPA_6020	Molybdenum	T	0.005	mg/L		0.029	0.059	0.012	0.011		
USEPA_6020	Nickel	D	0.001	mg/L						0.017	0.008
USEPA_6020	Nickel	D	0.005	mg/L		0.040	0.010	0.012	0.015		
USEPA_6020	Nickel	T	0.001	mg/L						0.019	0.009
USEPA_6020	Nickel	T	0.005	mg/L		0.090	0.028	0.010	0.026		
USEPA_6020	Silver	D	0.001	mg/L						0.001	0.001
USEPA_6020	Silver	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Silver	T	0.001	mg/L						0.001	0.001
USEPA_6020	Silver	T	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Strontium	D	0.001	mg/L						16.9	13.5
USEPA_6020	Strontium	D	0.005	mg/L		12.1	6.52	11.9	21.8		
USEPA_6020	Strontium	T	0.001	mg/L						17.3	12.0
USEPA_6020	Strontium	T	0.005	mg/L		12.0	9.10	13.6	21.5		
USEPA_6020	Thorium	D	0.001	mg/L						0.001	0.001
USEPA_6020	Thorium	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Thorium	T	0.001	mg/L						0.001	0.001
USEPA_6020	Thorium	T	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Tin	D	0.001	mg/L						0.001	0.001
USEPA_6020	Tin	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Tin	T	0.001	mg/L						0.001	0.001
USEPA_6020	Tin	T	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Uranium	D	0.001	mg/L						0.001	0.001
USEPA_6020	Uranium	D	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Uranium	T	0.001	mg/L						0.001	0.001
USEPA_6020	Uranium	T	0.005	mg/L		0.005	0.005	0.005	0.005		
USEPA_6020	Vanadium	D	0.01	mg/L						0.01	0.01
USEPA_6020	Vanadium	D	0.05	mg/L		0.05	0.05	0.05	0.05		
USEPA_6020	Vanadium	T	0.01	mg/L						0.01	0.01
USEPA_6020	Vanadium	T	0.05	mg/L		0.05	0.05	0.05	0.05		
USEPA_8015	>C10 - C16 Fraction	N	100	µg/L		2860		1550	1840	950	1130
USEPA_8015	>C10 - C16 Fraction	N	570	µg/L			6930				

				FACILITY	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN
				LOCATION	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE
				DESCRIPTION	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP
				SAMPLE_DATE	15/01/2020	15/01/2020	12/02/2020	12/02/2020	4/03/2020	4/03/2020
				WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972	EB2006500	EB2006500
				START_DEPTH	0.2	4	0.2	4	4	0.2
				SAMPLE TYPE	N	N	N	N	N	N
METHOD	**PARAMETER-CHEMICAL**	**FRACTIO**	**LOR**	**UNIT**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**
USEPA_8015	>C10 - C16 Fraction minus Naphthalene (F2)	N	100	µg/L	2860		1550	1840	950	1130
USEPA_8015	>C10 - C16 Fraction minus Naphthalene (F2)	N	570	µg/L		6930				
USEPA_8015	>C10 - C40 Fraction (sum)	N	100	µg/L	6840		4000	3370	3000	3780
USEPA_8015	>C10 - C40 Fraction (sum)	N	570	µg/L		140000				
USEPA_8015	>C16 - C34 Fraction	N	100	µg/L	3980		2450	1530	2050	2650
USEPA_8015	>C16 - C34 Fraction	N	570	µg/L		128000				
USEPA_8015	>C34 - C40 Fraction	N	100	µg/L	100		100	100	100	100
USEPA_8015	>C34 - C40 Fraction	N	570	µg/L		5340				
USEPA_8015	C6 - C36 Fraction (Sum)	N	20	µg/L	7020		4120	3480	3090	3880
USEPA_8015	C6 - C36 Fraction (Sum)	N	230	µg/L		136000				
USEPA_8260	Benzene	N	1	µg/L	1	1	1	1	1	1
USEPA_8260	C6 - C10 Fraction	N	20	µg/L	30	180	20	20	20	20
USEPA_8260	C6 - C10 Fraction minus BTEX (F1)	N	20	µg/L	30	180	20	20	20	20
USEPA_8260	Ethylbenzene	N	2	µg/L	2	2	2	2	2	2
USEPA_8260	meta- & para-Xylene	N	2	µg/L	2	2	2	2	2	2
USEPA_8260	ortho-Xylene	N	2	µg/L	2	2	2	2	2	2
USEPA_8260	Toluene	N	2	µg/L	2	2	2	2	2	2
USEPA_8260	Total Xylenes	N	2	µg/L	2	2	2	2	2	2
USEPA_8270_UT	2-Nitrophenol	N	0.1	µg/L					0.1	
USEPA_8270_UT	2-Nitrophenol	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	3-Methylcholanthrene	N	0.1	µg/L					0.1	
USEPA_8270_UT	3-Methylcholanthrene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	7.12-Dimethylbenz(a)anthracene	N	0.1	µg/L					0.1	
USEPA_8270_UT	7.12-Dimethylbenz(a)anthracene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Acenaphthene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Acenaphthene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Acenaphthylene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Acenaphthylene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Anthracene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Anthracene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Benz(a)anthracene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Benz(a)anthracene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Benzo(a)pyrene	N	0.05	µg/L					0.05	
USEPA_8270_UT	Benzo(a)pyrene	N	0.19	µg/L	0.19	0.19				0.19
USEPA_8270_UT	Benzo(a)pyrene	N	0.22	µg/L			0.22	0.22		
USEPA_8270_UT	Benzo(a)pyrene TEQ (zero)	N	0.1	µg/L					0.1	
USEPA_8270_UT	Benzo(a)pyrene TEQ (zero)	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Benzo(b+j)fluoranthene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Benzo(b+j)fluoranthene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Benzo(g.h.i)perylene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Benzo(g.h.i)perylene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Benzo(k)fluoranthene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Benzo(k)fluoranthene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Chrysene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Chrysene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Dibenz(a.h)anthracene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Dibenz(a.h)anthracene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Fluoranthene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Fluoranthene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Fluorene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Fluorene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Indeno(1.2.3.cd)pyrene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Indeno(1.2.3.cd)pyrene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2

				FACILITY	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN
				LOCATION	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE	TAN1FBCT1 TANUMBIRINI 1 WELL FLOWBACK STORAGE
				DESCRIPTION	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP
				SAMPLE_DATE	15/01/2020	15/01/2020	12/02/2020	12/02/2020	4/03/2020	4/03/2020
				WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972	EB2006500	EB2006500
				START_DEPTH	0.2	4	0.2	4	4	0.2
				SAMPLE TYPE	N	N	N	N	N	N
METHOD	**PARAMETER-CHEMICAL**	**FRACTIO**	**LOR**	**UNIT**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**	**RESULTS**
USEPA_8270_UT	m-Cresol	N	0.1	µg/L					0.8	
USEPA_8270_UT	m-Cresol	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Naphthalene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Naphthalene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	p-Cresol	N	0.1	µg/L					8.7	
USEPA_8270_UT	p-Cresol	N	0.2	µg/L	184	108	141	279		123
USEPA_8270_UT	Phenanthrene	N	0.1	µg/L					0.8	
USEPA_8270_UT	Phenanthrene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Pyrene	N	0.1	µg/L					0.1	
USEPA_8270_UT	Pyrene	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270_UT	Sum of polycyclic aromatic hydrocarbons (PAHs)	N	0.1	µg/L					0.8	
USEPA_8270_UT	Sum of polycyclic aromatic hydrocarbons (PAHs)	N	0.2	µg/L	0.2	0.2	0.2	0.2		0.2
USEPA_8270B_PAH	2.3.4.6-Tetrachlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2.4.5-Trichlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2.4.6-Trichlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2.4-Dichlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2.4-Dimethylphenol	N	1.0	µg/L	1.1	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2.6-Dichlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	2-Chlorophenol	N	1.0	µg/L	1.0	1.0	1.0	1.0	1.0	1.0
USEPA_8270B_PAH	Pentachlorophenol	N	2.0	µg/L	2.0	2.0	2.0	2.0	2.0	2.0
USEPA_8270B_PAH	Phenol	N	1.0	µg/L			5.9	7.7		
USEPA_8270B_PAH	Phenol	N	1.3	µg/L					1.3	
USEPA_8270B_PAH	Phenol	N	4.7	µg/L		8.6				
USEPA_8270B_PAH	Phenol	N	4.8	µg/L	37.1					10.7

Notes	
BLANK CELL	Information not available
FRACTION	T - Total
	D - Dissolved
	N - Null
SAMPLE TYPE	N - Normal Grab Sample
	TB - Trip Blank
	NST - No Sample Taken
	FD - Field Duplicate
WORKORDER (Empty)	Field measurement only

Inclusion 2

An evaluation of hydraulic fracturing chemical additives

To: Santos Ltd.

From: Bill Frez

CC: Nigel Goulding, Tom Biksey

Date: 24 March 2020

Re: Tanumbirini Wastewater Flowback EP161, McArthur Basin – Assessment of Chemistry and Testing Requirements

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Summary

Santos Ltd. ("Santos") is conducting an exploration and appraisal program within Exploration Permit (EP) 161, which is located in the Beetaloo Sub-basin of the broader McArthur Basin. The McArthur Basin is located southeast of Katherine, Northern Territory, and covers approximately 180,000 square kilometres. Santos has undertaken exploration activities in EP 161 since 2013 including drilling of two exploration wells Tanumbirini-1 and Marmbulligan-1, and the development of a water bore drilling and monitoring program in 2018. Santos has prepared an Environment Management Plan (EMP) for McArthur Basin 2019 – 2020 Hydraulic Fracturing Program in the Northern Territory EP 161. The EMP proposed Hydraulic Fracture Stimulation (HFS) to be conducted through 2019-2020 at the Tanumbirini 1, Tanumbirini 2H and Inacumba 1/1H well locations. Pursuant to the approval conditions of the EMP, a risk assessment of the hydraulic fracturing wastewater at the well locations is required.

To support a risk assessment, water samples were collected from the Tanumbirini 1 well enclosed storage tank (EB2001149, EB2001149, EB2003972, and EB2003972) on 15 January 2020 and 12 February 2020. Laboratory analyses of these samples for inorganic, organic and radionuclide analytes have been completed pursuant to the monitoring wastewater chemistry analytes specified in Section C.3 of the Code of Practice: Onshore Petroleum Activities in the Northern Territory (CoP). The Tanumbirini 1 well wastewater flowback storage tank/pond 1 results are provided in **Attachment 1**.

This Technical Memo assessed the vendor chemicals used in HFS to evaluate potential degradants that may be present in the wastewater flowback. The potential degradants identified were compared to the monitoring wastewater chemistry analytes specified in the CoP. The objective of this comparison was to determine if the CoP-required wastewater chemistry analytes include the potential degradants identified in this assessment as follows:

- If the degradation data indicated that the formation of degradants was possible and the degradants formed were not included in the chemistry analytes specified in the CoP, then additional analytical testing is recommended.
- If the degradation data indicated that no degradant formation was possible or that limited or no degradants with specific chemical identity (i.e., a chemistry analyte specified in the CoP) were formed, then additional testing would not be recommended.

If the degradants are not included in the wastewater chemistry analytes in the CoP, then additional analytical testing would be required to determine the concentration and identity of the degradants for the required risk assessment of the HFS wastewater at the enclosed storage tank under the EMP.

Risk Assessment

The HFS fluid systems assessed in this evaluation include those proposed by Halliburton as part of their Coil Tubing Hydraulic Fracturing System and Standard Hydraulic Fracturing System used within EP161, a combined total of 63 chemicals (Halliburton Chemicals). These Halliburton Chemicals were previously assessed in a chemical risk assessment (CRA)[1]. To determine if potential degradants from each of the Halliburton Chemicals required further laboratory analysis (i.e., in addition to analyses specified in the CoP), the degradation data contained in the risk dossiers from the previous CRA were compiled and evaluated.

Degradants

The results of the assessment of potential degradants from the Halliburton Chemicals that may be present in the Tanumbirini well wastewater flowback are shown in **Table 1** and are discussed below.

Inorganic Chemicals

The inorganic Halliburton Chemicals can be grouped into three general categories:

- Chemicals that are typically inert under environmental conditions (e.g., Ulexite, quartz, silica dioxide and bismuth oxide).
- Chemicals that dissociate into cations and anions (e.g., hydrochloric acid, sodium chloride and sodium hydroxide).
- Chemicals that have the potential to release substances that may be biologically active and might require additional analytical testing.

None of the chemicals that are inert and chemically stable under standard environmental conditions will generate degradants that would require additional testing (**Table 1**). Similarly, those inorganic chemicals that will dissociate into respective ion pairs will not require additional testing because their ions are included in the chemistry analytes specified in the CoP. It must be noted that the two borated chemicals (i.e., disodium octaborate tetrahydrate and sodium perborate tetrahydrate) may release boron in the form of boric acid or other boronated substances. However, in these instances, further analysis of boron is not needed because it is included in the chemistry analytes specified in the CoP. Therefore, no further additional analysis of potential degradants is required for inorganic chemicals because all potential degradants are included in the chemistry analytes specified in the CoP.

Organic Chemicals

The organic substances on the Halliburton Chemical list consist of alcohols, amines, aldehydes, fatty acids, ethoxylated alcohols, glycols, biocides and large molecular weight polymers. As noted in **Table 1**, essentially all the alcohols, amines, aldehydes, fatty acids, ethoxylated alcohols and glycols undergo biodegradation. While the specific chemical nature of the degradants cannot be readily determined at this time, it is likely that breakdown of these substances results in lower molecular weight hydrocarbons and other hydrolytic products that are not readily detected via conventional analysis nor would they be of greater environmental concern than the parent chemicals. Ultimately these chemicals (which have short biodegradation half-lives) would degrade to carbon dioxide and methane.

[1] Beetaloo McArthur Basin Hydraulic Fracturing Fluid System - Chemical Risk Assessment (EHS Support 2019)

The biocides, glutaraldehyde and tributyl tetradecyl phosphonium chloride (TTPC) undergo biodegradation. Under aerobic conditions, glutaraldehyde is metabolized to CO2 via a glutaric acid intermediate. Under anaerobic conditions, glutaraldehyde is metabolized to 1,5-pentanediol[2] which is readily biodegradable according to Organization of Organization for Economic Cooperation and Development (OECD) criteria[3]. Therefore, degradants glutaraldehyde does not warrant further analysis. Although TTPC was not determined to degrade under conditions of OECD 301 testing, after 24- and 168-hours degradation was noted to be substantial (i.e., greater than 81% and greater than 98%, respectively). No data is available on the TTPC degradants. However, it is likely that degradation results in short chain aliphatics and hydrolysis products that are not amenable to standard regulatory analytical methods.

Polymer Chemicals

The polymers are a diverse chemical group in the Halliburton Chemicals. The acrylate polymers include several large molecular weight polymers (e.g., sodium acrylate acrylamide, sodium polyacrylate, acrylamide acrylate copolymer) that do not degrade readily under environmental conditions based on standard degradation testing. The polylactide (PLA) polymer does not have available degradation testing according to standard methods. Two additional polymers (gaur gum and hydroxypropyl guar) undergo environmental degradation to lower molecular hydrocarbon fragments and hydrolysis products of little environmental concern.

Therefore, neither the acrylate polymers, PLA, or guar are likely to generate degradants that would require further testing.

Conclusions and Recommendations

Sixty-three chemicals on the Northern Territory Chemical listing were evaluated for their potential to generate degradants that would require additional analytical testing beyond that conducted on the Tanumbirini 1 wastewater flowback water. The assessment determined if potential degradants are included in the chemistry analytes specified in the CoP or required further analytical testing as follows:

- If the degradation data indicated that the formation of degradants was possible and the degradants formed were not included in the chemistry analytes specified in the CoP, then additional analytical testing is recommended.
- If the degradation data indicated that no degradant formation was possible or that limited or no degradants with specific chemical identity (i.e., a chemistry analyte specified in the CoP) were formed, then additional testing would not be recommended.

The 63 Halliburton Chemicals assessed either were degradable or ionizable to specific chemical identities included in the CoP or were not degradable. Based on this assessment, there are no degradants of the Halliburton Chemicals that would require additional analytical testing beyond the chemistry analyte specified in the CoP.

[2] Leung 2001. Ecotoxicology of Glutaraldehyde: Review of Environmental Fate and Effects Studies Ecotoxicology and Environmental Safety. 49 (1): 26-39

[3] ECHA 2020. https://echa.europa.eu/registration-dossier/-/registered-dossier/14818/5/3/1

Tables

Table 1
Degradant Assessment of Halliburton Chemicals
Tanumbirini Water Quality Tiered Assessment
Santos

CAS Number	Chemical Name	Evidence of Degradation[a]	Analysis for Degradants Recommended
7647-01-0	Hydrochloric acid	Dissociates completely to hydrogen (H+) and chloride (Cl-) ions. Both ions are ubiquitous in the environment.	No
7647-14-5	Sodium Chloride	Dissociates completely to hydrogen (Na+) and chloride (Cl-) ions. Both ions are ubiquitous in the environment.	No
1319-33-1	Ulexite	A borated naturally-occurring mineral not expected to degrade substantially.	No
1310-73-2	Sodium hydroxide	Dissociates completely to sodium (Na+) and hydroxyl (OH-) ions. Both ions are ubiquitous in the environment.	No
14808-60-7	Crystalline silica, quartz	A naturally-occurring mineral not expected to degrade.	No
12008-41-2	Disodium octaborate tetrahydrate	In natural waters, boron forms stable species and exists primarily as un-dissociated boric acid [B(OH)3] and complex polyanions (e.g., [B(OH)4]-).	Yes, Boron
10486-00-7	Sodium perborate tetrahydrate	In natural waters, boron forms stable species and exists primarily as un-dissociated boric acid [B(OH)3] and complex polyanions (e.g., [B(OH)4]-).	Yes, Boron
112926-00-8	Silica dioxide	A naturally-occurring material not expected to degrade .	No
68937-66-6	Alcohols, C6-12, ethoxylated propoxylated	C6-8 alkyl-(even, linear), ethoxylated (<2.5 EO) [CAS No. 1426148-68-6) was 63% in 28 days. C9-11, branched (2.5 EO) [CAS No. 169107-21-5] 72% in 28 days in an ultimate aerobic biodegradability (CO2 headspace) ISO 14593 water quality test (ECHA) [Kl. score = 2]. C9-11, branched (3 EO) [CAS No. 169107-21-5] 101% in 28 days.	No
7631-90-5	Sodium bisulfite	At environmental pHs, sodium bisulfite dissociates in water to form sodium (Na+) ions, bisulfite ions (HSO3-), sulfite (SO23-) ions, and sulfur dioxide (SO2) which is a gas.	No
81741-28-8	Tributyl tetradecyl phosphonium chloride (TTPC)	Not readily biodegradable in an OECD 301 test however, after 24- and 168-hours, degradation was >81% and >98%, respectively. In activated sludge, there was >40% degradation after 30 days and >30% after 7 days.	No
9005-65-6	Sorbitan monooleate polyoxyethylene derivative	In an ISO Standard 14593 ready biodegradation test, degradation of Tween 81 (CAS No. 9005-65-6) was 61% after 28 days, indicating ready biodegradability.	No
78330-21-9	Ethoxylated branched C13 alcohol	In an OECD 301B test, degradation was 75% in 28 days.	No
7775-27-1	Sodium persulfate	Dissociates in aqueous media to the sodium cation (Na+) and persulfate anion (S2O82-).	No
68131-39-5	Alcohols, C12-15, ethoxylated	In an OECD 301B test, degradation was 72% in 28 days.	No
61791-00-2	Fatty acids, tall-oil, ethoxylated	Based on the results for the read-across substance, Fatty acids, tall oil, ethoxylated (EO > 1 < 2.5) (CAS 61791-00-2) is considered to be readily biodegradable.	No
7681-82-5	Sodium iodide	Dissociates in water to (Na+) and (I-) ions.	No
7772-98-7	Sodium thiosulfate	Dissociates in aqueous media to sodium (Na+) and thiosulfate (S2O32-) ions. The thiosulfate anion is stable in neutral or alkaline media, but not in acidic media (USEPA, 2007). In aqueous media, thiosulfate irreversibly disproportionates to sulfide and sulfate.	No

Table 1
Degradant Assessment of Halliburton Chemicals
Tanumbirini Water Quality Tiered Assessment
Santos

CAS Number	Chemical Name	Evidence of Degradation[a]	Analysis for Degradants Recommended
25322-69-4	Polypropylene glycol	OECD 301F test, polypropylene glycol (identified as Polyol PD 230, MW 260) was degraded 2.1% after 7 days; 60.6% after 14 days; and 86.6% after 28 days.	No
1304-76-3	Bismuth Oxide	An inorganic mineral that is slightly soluble in water and not expected to disassociate readily.	No
7757-83-7	Sodium Sulfite	Sodium sulphite dissociates in water to form sodium (Na+) ions, sulphite (SO23-) ions, and bisulphite ions (HSO3-).	No
9000-30-0	Guar gum	Guar gum is a carbohydrate polymer consisting of D-mannose and D-galactose sugars from the guar plant or cluster bean. It is expected to be readily biodegradable and not bioaccumulate.	No
25987-30-8	Acrylamide, sodium acrylate polymer	The acrylamide/sodium acrylate copolymer is not expected to be readily biodegradable. The physico-chemical properties of the copolymer would preclude it from undergoing significant biodegradation (Guiney et al., 1997). Biodegradation is limited due to the very high molecular weight and the low water solubility of the copolymer.	No
9003-04-7	Sodium polyacrylate	Sodium polyacrylates are not readily biodegradable, but are partly accessible to ultimate biodegradation particularly under long incubation conditions.	No
9003-06-9	Acrylamide acrylate copolymer	The acrylamide/sodium acrylate copolymer is not expected to be readily biodegradable. The physico-chemical properties of the copolymer would preclude it from undergoing significant biodegradation (Guiney et al., 1997). Biodegradation is limited due to the very high molecular weight and the low water solubility of the copolymer.	No
9051-89-2	1,4-Dioxane-2,5-dione, 3,6-dimethyl-, (3R,6R)-, polymer with rel-(3R,6S)-3,6-dimethyl-1,4-dioxane-2,5-dione and (3S,6S)-3,6-dimethyl-1,4-dioxane-2,5-dione	The lactide polymer (PLA) is not expected to be readily biodegradable as biodegradation is limited due to the very high molecular weight and the low water solubility of the copolymer. However, data from degradation testing according to standard methods are not available. However, there is evidence that PLA can undergo degradation via isolated and variable bacterial populations.	No
39421-75-5	Hydroxylpropyl guar	Hydroxypropyl guar is the propylene glycol derivative of a carbohydrate polymer consisting of D-mannose and D-galactose sugars from the guar bean. It is expected to be readily biodegradable.	No
67-48-1	Choline Chloride	Choline chloride is readily biodegradable. Distribution modelling using Mackay Level 1 shows choline to be distributed completely into water.	No
107-21-1	Ethylene glycol	Ethylene glycol was readily biodegradable in an OECD 301A test. After 10 days, degradation was 90-100%.	No
102-71-6	Triethanolamine	Triethanolamine is readily biodegradable and is predicted as such via USEPA EpiSuite.	No
69227-22-1	Alcohols, C10-16, ethoxylated propoxylated	C9-11, branched (2.5 EO) [CAS No. 169107-21-5] was readily biodegradable, as indicated by degradation of 72% in 28 days in an ultimate aerobic biodegradability.	No
64-19-7	Acetic acid	Readily biodegradable in a non-acclimated freshwater study. After 20 days, degradation was 96%.	No
111-42-2	Diethanolamine	Diethanolamine is readily biodegradable and is predicted as such via USEPA EpiSuite.	No
7758-19-2	Chlorous acid, sodium salt	Chlorous acid, sodium salt readily dissociates in aqueous solutions to the sodium (Na+) and chlorite (ClO2-) ion. The chlorite (ClO2-) ion is in equilibrium with chlorous acid (HClO2) in water.	No

Table 1
Degradant Assessment of Halliburton Chemicals
Tanumbirini Water Quality Tiered Assessment
Santos

CAS Number	Chemical Name	Evidence of Degradation[a]	Analysis for Degradants Recommended
25322-68-3	Polyethylene glycol	Data are available on tetraEG and pentaEG, both being major constituents of PEG 200 (Bailey and Koleste, 1966; OECD, 2004). Both tetraEG and pentaEG are inherently biodegradable. For tetraEG, there was 22% degradation after 20 days in a BOD test and 40% degradation after 28 days in an OECD 301D test. For pentaEG, there was 34% degradation after 20 days in a BOD test (OECD, 2004).	No
104-55-2	Cinnamaldehyde	Cinnamaldehyde is readily biodegradable. In an OECD 301B test, degradation of cinnamaldehyde was 89% after 7 days, 94% after 14 days, and 100% after 28 days, indicating ready biodegradation.	No
111-46-6	Diethylene glycol	Diethylene glycol is readily biodegradable. In an OECD 301B test, there was 70-80% and 90-100% degradation after 28 days.	No
1338-43-8	Sorbitan, mono-9-octadecenoate, (Z)	In an ISO Standard 14593 ready biodegradation test, degradation of Tween 81 (CAS No. 9005-65-6) was 61% after 28 days, indicating ready biodegradability.	No
126-96-5	Sodium diacetate	No studies are available on sodium diacetate. Sodium acetate is readily biodegradable. In a DOC Die-Away test, degradation for sodium acetate was 86% after 7 days and 99% after 28 days.	No
7447-40-7	Potassium chloride	Potassium chloride (KCl) dissociates completely in aqueous solutions to potassium (K+) and chloride (Cl-) ions. Potassium chloride and its dissociated ions are ubiquitous in the environment.	No
135800-37-2	Fatty acids, C8-C16, ethylhexyl ester	Fatty acids, C8-C16, 2-ethylhexyl esters are readily biodegradable and is predicted as such via USEPA EpiSuite.	No
77-92-9	Citric acid	Citric acid is readily biodegradable and is predicted as such via USEPA EpiSuite.	No
67-56-1	Methanol	In a closed bottle test using seawater, there was 84% and 95% degradation after 10 and 20 days, respectively.	No
61788-90-7	Amine oxides, cocoalkyldimethyl	In an OECD 301 D test, degradation was 89% after 14 days and 93% after 28 days.	No
61789-40-0	Cocobetaine	In an OECD 301 D test, degradation was 84% after 30 days (ECHA) [Kl. score = 2]. In an OECD 301 E test, degradation was 90% and 100% after 14 and 28 days, respectively (ECHA) [Kl. score = 2]. In an OECD 301 B test, degradation was 84% an 99% after 7 and 28 days, respectively (ECHA).	No
299-29-6	Iron gluconate	Although no biodegradation studies are available on iron gluconate involving freshwater organisms the substance was considered readily biodegradable based on testing in seawater. In an OECD 306 test involving seawater, degradation of iron gluconate after 28 days was 79% and 78% at concentrations of 6.0 and 7.5 mg/L, respectively.	No

Table 1
Degradant Assessment of Halliburton Chemicals
Tanumbirini Water Quality Tiered Assessment
Santos

CAS Number	Chemical Name	Evidence of Degradation[a]	Analysis for Degradants Recommended
100-52-7	Benzaldehyde	In an activate sludge test, degradation was approximately 100% after 19 days as measured by DOC removal (ECHA) [Kl. score = 2].In a BOD test, degradation was >60% after 28 days as measured by O2 consumption (ECHA) [Kl. score = 2].In a CO2 evolution test, degradation was about 60% in 7 days and 100% in 28 days (ECHA).	No
144-55-8	Sodium bicarbonate	Sodium bicarbonate will be found predominantly in the aquatic environment where it dissociates completely to sodium (Na+) and bicarbonate (HCO3-) ions.	No
107-89-1	Aldol	No experimental data are available but per EpiSuite, the substance is expected to degrade.	No
68551-12-2	Alcohols, C12-16, ethoxylated	No studies are available on alcohol, C12-16, ethoxylated. Alcohols, C12-15, ethoxylated is readily biodegradable. In an OECD 301B test, degradation was 72% in 28 days. An alcohol, C12-15, ethoxylated (7 EO) degraded 80 to 88% in 28 days when tested using a shake-flask CO2-evolution test method (ECHA).	No
68155-28-4	Amides, tall-oil fatty, N,N-bis(hydroxyethyl)	Amides, C18-unsatd, N,N-bis(hydroxyethyl) is readily biodegradable. In an OECD 301 D test, degradation was 70% after 28 days. In an OECD 301 B test, degradation was 79% after 14 days and 86% after 28 days.	No
71-36-3	Butyl alcohol	1-Butanol is readily biodegradable. In a BOD test, degradation was 87% after 10 days and 92% after 20 days.	No
64-17-5	Ethanol	Ethanol is readily biodegradable. The degradation of ethanol was approximately 74% and 84% (O2 consumption) within 10 and 20 days, respectively, in a biodegradation test using a non-adapted domestic inoculum in a freshwater medium.	No
64742-47-8	Hydrotreated light petroleum distillate	In the supporting OECD 301 study, naphtha solvents were readily biodegraded in 28 days but not within the 10-day window. The mean of three samples was 61% theoretical biological oxygen demand on Day 28 (Shell, 1997). In a valid OECD 301F supporting study Kerosene Mid-Blend was not considered readily biodegradable in 28 days, with less than 60% degradation on day 28 (58.6%). However, according to USEPA guidance for biodegradability, it is considered inherently biodegradable because significant degradation occurred (Mobil, 1999). On the basis of this and the known properties of hydrocarbons in the range C9 to C16, in their environmental classification report CONCAWE considered that kerosenes are not readily biodegradable; but as they can be degraded by microorganisms, they are regarded as being inherently biodegradable (CONCAWE, 2001).	No
1569-01-3	Propylene glycol n-propyl ether	Propylene glycol n-propyl ether is readily biodegradable. In an OECD 301 A test, degradation was 91.5% after 28 days.	No
56-81-5	Glycerine	Glycerine was readily biodegradable in an OECD 301D test. Degradation was 57% after 5 days, 84% after 15 days and 92% after 30 days.	No
123-73-9	Crotonaldehyde	In an inherent biodegradation test, degradation was 78% after 5 days, 83% after 10 days and 94% after 15 days. In an OECD 301 C (MITI-I) test, degradation was >80% with or without adjustment of the pH to 7.0 at Day 1 of culturing.	No

Table 1
Degradant Assessment of Halliburton Chemicals
Tanumbirini Water Quality Tiered Assessment
Santos

CAS Number	Chemical Name	Evidence of Degradation[a]	Analysis for Degradants Recommended
107-13-1	Acrylonitrile	In OECD 302C 61% degraded after 14 days (determined by BOD [NO2]); 96% degraded after 14 days (determined by BOD [NH3]); 100% degraded after 14 days (determined by TOC removal); and 100% after 28 days. In OECD 301C 15% degraded after 28 days (determined by BOD [NO2]); 23% after 28 days (determined by BOD [NH3]); 38% after 28 days (determined by TOC removal); and 44% after 28 days.	No
104-76-7	2-Ethyl hexanol	In OECD TG 302B, >95% degradation within five days.	No
75-07-0	Acetaldehyde	In OECD 301 C (MITI-I), 80% (BOD demand) and 93% (TOC removal) after 14 days.	No
7757-82-6	Sodium Sulfate	Sodium sulfate dissociates in aqueous media to sodium (Na+) and sulfate (SO42-) ions.	No
497-19-8	Sodium carbonate	Sodium carbonate will be found predominantly in the aquatic environment where it dissociates completely to sodium (Na+) and carbonate (CO32-) ions.	No
111-30-8	Glutaraldehyde	Glutaraldehyde was considered readily biodegradable in an OECD 301A (DOC die away test). Degradation was 90-100% in 28 days.	No

Notes:
BOD = Biological oxygen demand
Concawe = European Oil Company Organisation for Environment, Health and Safety (Belgium)
DOC = Dissolved Organic Carbon
ECHA = European Chemicals Agency
mg/L = milligram per litter
ISO - International Standards Organization
MITI-I = Ministry of International Trade and Industry
OECD = Organisation for Economic Co-operation and Development
PLA = polylactide polymer
TOC = total organic carbon
TTPC = glutaraldehyde and tributyl tetradecyl phosphonium chloride
USEPA = United Sates Environmental Protection Agency

[a] = Taken from Toxicological Dossiers Feb 2020

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Mobil, 1999. as cited in ECHA Information on Chemicals. https://echa.europa.eu/information-on-chemicals

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Attachment 1 - Tanumbirini 1 Well Wastewater Flowback Analytical Results

Attachment 1
Tanumbirini 1 Well Wastewater Flowback Analytical Results
Tanumbirini Water Quality Tiered Assessment
Santos

					Field Sample ID	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1
					Description	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP
					Sample Date	15/01/2020	15/01/2020	12/02/2020	12/02/2020
					WorkOrder	EB2001149	EB2001149	EB2003972	EB2003972
					Sample Type	N	N	N	N
					Depth	0.2	4	0.2	4
Method	Chemical	Cas No	Fraction	Result Unit	Limit of Detection	Result	Result	Result	Result
APHA 3125 B	Boron	7440-42-8	D	µg/L	100	--	--	15400	16700
APHA 3125 B	Boron	7440-42-8	T	µg/L	105	--	--	15800	17000
APHA 3125 B	Selenium	7782-49-2	T	µg/L	0.2	--	--	2 U	3
APHA 3125 B	Zinc	7440-66-6	T	µg/L	5	1610	33	10	105
APHA_3120	Calcium	7440-70-2	D	mg/L	1	122	49	123	179
APHA_3120	Magnesium	7439-95-4	D	mg/L	1	58	57	67	86
APHA_3120	Potassium	7440-09-7	D	mg/L	1	32	31	35	44
APHA_3120	Sodium	7440-23-5	D	mg/L	1	3100	2890	3300	4490
APHA_4110	Bromide	24959-67-9	N	mg/L	1	59.6	51.3	56.3	77.7
APHA_4500_Cl	Chloride	16887-00-6	N	mg/L	1	4930	4330	4570	5880
APHA_4500_F_C	Fluoride	16984-48-8	N	mg/L	0.1	1.8	1.8	1.6	1.6
APHA_4500_NH3_G	Ammonia as N	NA	N	mg/L	0.01	34.8	29.3	28.9	33.6
APHA_4500_NORG_D	Total Kjeldahl Nitrogen as N	TKN	N	mg/L	0.5	41.8	42.8	45	46.2
APHA_4500_NORG+NO3	Total Nitrogen as N	NA	N	mg/L	0.5	41.8	42.8	45	46.2
APHA_4500_P_E	Reactive Phosphorus as P	7723-14-0	T	mg/L	0.01	0.69	0.31	0.62	0.74
APHA_4500_P_H	Total Phosphorus as P	NA	T	mg/L	0.05	0.94	1.03	0.99	1.06
APHA_4500_SIO2	Reactive Silica	NA	N	mg/L	0.05	127	125	120	125

Attachment 1
Tanumbirini 1 Well Wastewater Flowback Analytical Results
Tanumbirini Water Quality Tiered Assessment
Santos

					Field Sample ID	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1	McArthur Basin TAN1FBCT1
					Description	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP
					Sample Date	15/01/2020	15/01/2020	12/02/2020	12/02/2020
					WorkOrder	EB2001149	EB2001149	EB2003972	EB2003972
					Sample Type	N	N	N	N
					Depth	0.2	4	0.2	4
Method	Chemical	Cas No	Fraction	Result Unit	Limit of Detection	Result	Result	Result	Result
APHA_4500_SO4_E	Sulfate as SO4 2-	NA	D	mg/L	1	1 U	2	22	4
ASTM_D_6303-98	Formaldehyde	50-00-0	N	mg/L	0.1	1	0.3	0.1	0.6
CSN_75_7611_75_7612	Gross alpha	12587-46-1	N	Bq/L	0.3	--	--	--	1.06
USEPA_6020	Barium	7440-39-3	D	mg/L	0.005	5.17	0.969	4.63	8.89
USEPA_6020	Barium	7440-39-3	T	mg/L	0.005	5.18	2.33	4.92	8.16
USEPA_6020	Molybdenum	7439-98-7	T	mg/L	0.005	0.029	0.059	0.012	0.011
USEPA_8015	>C10 - C16 Fraction	NA	N	µg/L	100	2860	6930	1550	1840
USEPA_8015	>C10 - C16 Fraction minus Naphthalene (F2)	NA	N	µg/L	100	2860	6930	1550	1840
USEPA_8015	>C10 - C40 Fraction (sum)	NA	N	µg/L	100	6840	140000	4000	3370
USEPA_8015	>C16 - C34 Fraction F3	NA	N	µg/L	100	3980	128000	2450	1530
USEPA_8015	>C34 - C40 Fraction F4	NA	N	µg/L	570	--	5340	--	--
USEPA_8015	C6 - C36 Fraction (Sum)	NA	N	µg/L	20	7020	--	4120	3480
USEPA_8270_UT	p-Cresol	106-44-5	N	µg/L	0.2	184	108	141	279

Notes:
Grey text = detection limit value, not detected
Blank Cell = Information not available
-- = not analysed
µg/L = micrograms per litre
Bq/L = becquerel per litre
m = meter
mg/L = milligrams per litre
NA = CAS not applicable
TKN = Total Kjeldahl nitrogen
U = less than detection limit
FRACTION T = Total
D = Dissolved
N = Null
SAMPLE TYPE N = Normal Grab Sample
WORKORDER (Empty) = Field measurement only

Inclusion 3

Terrestrial soil exposure risk assessment

MEMO

To: Santos Ltd.

From: Bill Frez, EHS Support

CC: Nigel Goulding, EHS Support
Tom Biksey, EHS Support

Date: 3 April 2020

Re: Tanumbirini Wastewater - Terrestrial Soil Exposure Risk Assessment, EP-161, McArthur Basin

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Summary

Santos Ltd. ("Santos") is conducting an exploration and appraisal program within Exploration Permit (EP)-161, which is located in the Beetaloo Sub-basin of the broader McArthur Basin. The McArthur Basin is located southeast of Katherine, Northern Territory (NT), and covers approximately 180,000 square kilometres. Santos has undertaken exploration activities in EP-161 since 2013 including drilling of two exploration wells (Tanumbirini-1 and Marmbulligan-1) and the development of a water bore drilling and monitoring program in 2018. Santos has prepared an Environment Management Plan (EMP) for McArthur Basin 2019 – 2020 Hydraulic Fracturing Program in the NT EP-161. The EMP proposed Hydraulic Fracture Stimulation (HFS) to be conducted through 2019-2020 at the Tanumbirini 1, Tanumbirini 2H and Inacumba 1/1H well locations.

As part of the EMP, a chemical risk assessment was completed for the chemicals potentially occurring in wastewater after hydraulic fracturing (EHS Support 2019). This risk assessment (EHS Support 2019) evaluated the chemistry of the hydraulic fracturing fluid systems, estimated the probable concentration of these chemicals in wastewater and completed a quantitative evaluation of potential risks. Based on the assessment completed for the hydraulic fracturing fluid chemicals, it was determined that the only potentially complete exposure pathway (considering the program of works and associated management controls) was to avian receptors that may come in contact with wastewater contained in open-top tanks during treatment. The quantitative risk assessment evaluated potential risks to avian receptors and determined that there would be no unacceptable risks from direct contact and ingestion of wastewater.

The operational philosophy and management controls discussed in the EMP have been effectively implemented at the Site; therefore, the conceptual exposure model (CEM) is unchanged with potential exposures limited to avian receptors. Pursuant to the approval conditions of the EMP, laboratory sampling and analysis of wastewater is required to be routinely conducted and the risks associated with wastewater were reassessed. As part of the EMP, the reassessment was conducted to evaluate the risk to avian receptors contacting chemicals detected in wastewater (EHS Support 2020), confirming there was no unacceptable risk to this receptor group.

As a follow on to the above noted wastewater risk assessment (EHS Support 2020), the Northern Territory Government asked Santos to assess the potential ecological risks from a hypothetical

release of liquids to soil within the containment area. The following report utilises screening methodologies documented in the EMP submitted by Santos to evaluate the potential risks associated with a hypothetical release of wastewater to land. The approach calculated concentrations of chemicals in soils that would result from a release of wastewater to soils within the bunded area and compared those concentrations, where possible, to ecological soil screening criteria found in appropriate regulatory guidance documents.

Screening Level Risk Assessment

This risk assessment is focused on potential exposure of terrestrial receptors to chemicals detected in the four water samples (EB2001149, EB2001149, EB2003972 and EB2003972) collected from the Tanumbirini 1 well HFS wastewater enclosed storage tank on 15 January 2020 and 12 February 2020. Laboratory analyses of these wastewater samples for inorganic, organic, and radionuclide analytes has been completed pursuant to the monitoring wastewater chemistry analytes specified in Section C.3 of the Code of Practice: Onshore Petroleum Activities in the Northern Territory (Northern Territory Government, 2019).

The risk assessment was conducted assuming chemicals in wastewater samples would ultimately be incorporated into soils within the bund that could pose an exposure risk to terrestrial receptors. The following steps were conducted.

Calculation of Chemical Concentrations in Soils

Calculation of Chemical Concentrations in Soils – The previous Chemical Risk Assessment (CRA) (EHS Support 2019) evaluated the potential for a release of the contents of the large storage to soil and the vertical depth of associated infiltration (estimated as 1 meter based on modelling). Using this information, the area of the compound and the depth of infiltration the volume of affected soil was calculated at 20,000 cubic meters (m^3). The maximum concentrations of chemicals in wastewater from the sampled wastewater samples were used to determine their maximum concentrations in soils (C_{soil}) according to Equation 1 below.

$$C_{soil} = C_{wat} \times V_{tank} / M_{Soil} / D_{soil} \qquad \text{Eq. 1}$$

where

C_{wat} = maximum detected concentration of chemical in wastewater from four wells

V_{tank} = volume of the largest enclosed storage tank in the event of a complete release (8×10^6 Litres)

M_{soil} = mass of soil ($2 \times 10^4 m^3$)

D_{soil} = bulk density of soil (1,350 kilograms per cubic meter [kg/m^3])

The maximum concentration of chemical in soil (C_{soil}) was, where possible, compared to Australian National Environment Protection Measures (NEPM) standards protective of ecological resources. In certain instances, where NEPM values were not available, other data available from the European Union, the United States Environmental Protection Agency, or background threshold values (BTVs) for the McArther Basin surficial soils were used as screening criteria.

As noted above the screening risk evaluation methods utilised are consistent with those used for the hydraulic fracturing fluid risk assessment conducted prior to approval of the activities at the Tanumbirini 1 well (EHS Support 2019). Consistent with the results of the previous risk assessment conducted prior to approval of the activities at the Tanumbirini 1 well (EHS Support 2019) the risk assessment conducted for avian receptors potentially exposed to wastewater concluded there is no unacceptable risk to these receptors potentially exposed to chemicals in the Tanumbirini wastewater samples (EHS Support 2020).

Screening Assessment

The screening assessment consisted of a focused evaluation of the risks to terrestrial receptors potentially exposed to wastewater associated chemicals (**Attachment A**)and calculated to occur in soils adjacent to the enclosed storage tanks. These data were used to calculate maximum concentrations of chemicals in soils based on Equation 1 above.

Table 1 identifies maximum concentrations of chemicals detected in wastewater, the maximum concentration of chemicals potentially expected in the one meter stratum of soil adjacent to the enclosed storage tanks, the ecological soil screening level defined by NEPM or alternative criteria set forth by other regulatory agencies and the ratio of calculated concentration in soil to screening criteria.

Conclusions and Recommendations

A screening assessment was performed to determine the potential risk to terrestrial receptors exposed to soils affected by Tanumbirini 1 wastewater based on a hypothetical release scenario. The assessment consisted of a screening level evaluation to determine if further quantitative risk assessment would be required to assess potential risk to terrestrial receptors.

The screening level risk assessment concluded that no chemicals detected in the wastewater at their maximum concentration, under a hypothetical maximum release scenario, would result in soil levels above screening criteria protective of terrestrial receptors.

Therefore, these findings are in agreement with the chemical risk assessment that was developed and submitted with the EMP (EHS Support 2019) and the assessment to evaluate exposure to avian receptors (EHS Support 2020), which both concluded that there were no unacceptable risks to terrestrial receptors from wastewater in enclosed storage tanks at the site.

References

EHS Support. 2020. Tanumbirini Flowback Wastewater- Avian Risk Assessment, EP-161, McArthur Basin.

EHS Support. 2019. Beetaloo McArthur Basin Hydraulic Fracturing Fluid System - Chemical Risk Assessment. 03 July.

Northern Territory Government. 2019. Code of Practice: Onshore Petroleum Activities in the Northern Territory. 31 May.

Tables

Table 1.
Screening Assessment of Avian Exposure to Soils Potentially Impacted by Tanumbirini Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Chemical	Water Fraction	Maximum Detected Concentration in Water (mg/L)	Maximum Calculated Concentration in Soil(mg/kg)	Soil Screening Level (mg/kg)	Note	Maximum Concentration/Soil Screening Level (HQ)
C6 - C10 Fraction minus BTEX (F1)	N	1.80E-01	5.33E-02	1.25E+02	1	4.27E-04
>C10 - C16 Fraction minus Naphthalene (F2)	N	6.93E+00	2.05E+00	2.50E+01	1	8.21E-02
>C16 - C34 Fraction (F3)	N	1.28E+02	3.79E+01	3.00E+02	2	1.26E-01
>C34 - C40 Fraction (F4)	N	5.34E+00	1.58E+00	2.80E+03	2	5.65E-04
p-Cresol	N	2.79E-01	8.27E-02	1.63E+02	3	5.07E-04
2.4-Dimethylphenol	N	1.10E-03	3.26E-04	4.00E-02	4	8.15E-03
Formaldehyde	N	1.00E+00	2.96E-01	NV		NV
Phenol	N	3.71E-02	1.10E-02	3.70E+01	5	2.97E-04
Arsenic	T	1.70E-02	5.04E-03	4.00E+01	6	1.26E-04
Barium	D	8.89E+00	2.63E+00	8.20E+02	7	3.21E-03
Boron	T	1.70E+01	5.04E+00	5.70E+00	8	8.84E-01
Bromide	N	7.77E+01	2.30E+01	5.00E+01	9	4.60E-01
Chromium	D	4.90E-02	1.45E-02	1.00E+02	10	1.45E-04
Copper	T	1.60E-02	4.74E-03	2.00E+01	11	2.37E-04
Fluoride	N	1.80E+00	5.33E-01	2.16E+02	12	2.47E-03
Iron	T	1.40E+01	4.15E+00	1.96E+04	12	2.12E-04
Magnesium	D	8.60E+01	2.55E+01	1.47E+03	12	1.73E-02
Manganese	T	7.01E-01	2.08E-01	4.30E+03	13	4.83E-05
Molybdenum	T	5.90E-02	1.75E-02	9.90E+00	14	1.77E-03
Nickel	T	9.00E-02	2.67E-02	5.00E+00	15	5.33E-03
Selenium	D	1.80E-03	5.33E-04	2.00E+02	16	2.67E-06
Strontium	D	2.18E+01	6.46E+00	1.38E+01	12	4.68E-01
Zinc	T	1.60E+00	4.74E-01	1.50E+01	17	3.16E-02

Table 1.
Screening Assessment of Avian Exposure to Soils Potentially Impacted by Tanumbirini Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Notes:
ACL = Added contaminant limits
As = Arsenic
BTEX = Benzene, Toluene, Ethylbenzene, and Xylene
CEC = Cation Exchange Capacity
Cu = Copper
D = dissolved
DDT = dichlorodiphenyltrichloroethane
ECHA = European Chemical Agency
EIL = Ecological Investigation Level
ESL = Ecological Screening Level
HQ = hazard quotient
mg/kg = milligrams per kilogram
mg/L = milligrams per litre
N = null
NEPM = National Environment Protection Measures
NOAEL = no-observed-adverse=effect-level
NV = No readily available screening criterion
PNEC = predicted no effect concentration
T = total
TPH = total petroleum hydrocarbons
UCL = upper confidence limit
USEPA = United States Environmental Protection Agency

1 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination)Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure. Table 1B(6) ESLs for TPH fractions F1 – F4, BTEX and benzo(a)pyrene in soil. Areas of ecological significance.

2 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination)Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure Table 1B(6) Schedule B (1) - ESLs for TPH fractions F1 – F4, BTEX and benzo(a)pyrene in soil Urban residential and public open spaces.

3 = USEPA 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. Table 3 Region 4 Soil Screening Values for Hazardous Waste Sites Value for mammalian species.

4 = USEPA 2011. Region 4 Ecological Risk Assessment Supplemental Guidance 2017. Value for soil invertebrates species.

5 = USEPA 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. Table 3. Value for mammalian species.

6 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination)Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure Table 1B(5)Table 1B(6) Schedule B (1) - Generic EILs for aged As, fresh DDT and fresh naphthalene in soils irrespective of their physicochemical properties.

7 = USEPA 2018. Region 4 Ecological Risk Assessment Supplemental Guidance. Table 3 Region 4 Soil Screening Values for Hazardous Waste Sites Value for avian species.

8 = ECHA 2020. Boron Predicted no effect concentration (PNEC) in soil for terrestrial species. https://echa.europa.eu/brief-profile/-/briefprofile/100.028.319

9 = ECHA 2020. NOAEL as concentration in food source for Wistar Han rat.

10 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure Table 1B(3) Schedule B (1) Soil-specific added contaminant limits for aged chromium III and nickel in soil. Areas of ecological significance.

11 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure. Schedule B (1) Table 1B(2) ACL for aged Cu at pH 4.5 and CEC 5.

12 = Background threshold value based on 95 percent UCL of mean for McArther Basin surficial soils.

13 = USEPA 2007. Ecological Soil Screening Levels for Manganese Interim Final OSWER Directive 9285.7-71. Table 2.1-Avian Wildlife Manganese Eco-SSLs (mg/kg dry weight in soil).

14 = ECHA 2020. Molybdenum predicted no effect concentration (PNEC) in soil for terrestrial species. Hazard for Terrestrial Organism.

15 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure Table 1B(3) Soil-specific added contaminant limits for aged chromium III and nickel in soil. Areas of ecological significance Schedule B (1).

16 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure. Schedule B (1), Table 1B(3) Soil-specific added contaminant limits for aged chromium III and nickel in soil. Areas of ecological significance.

17 = NEPM 2011. Guideline on Investigation Levels for Soil and Groundwater. National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure. Schedule B (1), Table 1B(1) Soil-specific added contaminant limits for aged zinc in soil at pH 4 and CEC 5.

Attachment A Screening Assessment – Tanumbirini Well 1 Storage Tank Water

Attachment A
Avian Risk Screening Assessment
Tanumbirini Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

										Freshwater Trigger Value (FTV, µg/L)					
					FIELD	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	FTVs by Protection Level (% Species)					
					SAMPLE ID	TAN1FBCT1	TAN1FBCT1	TAN1FBCT1	TAN1FBCT1						
					DESCRIPTION	TANUMBIRINI 1 WELL WASTEWATER STORAGE CONCEPT TANK - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL WASTEWATER STORAGE CONCEPT TANK - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL WASTEWATER STORAGE CONCEPT TANK - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL WASTEWATER STORAGE CONCEPT TANK - COVERED - 4m BOTTOM - 0.2m TOP	99%	95%	90%	80%	Alternative SW Screening Criteria (µg/L)	Reference
					SAMPLE DATE	1/15/2020	1/15/2020	2/12/2020	2/12/2020						
					WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972						
					SAMPLE TYPE	N	N	N	N						
					DEPTH	0.2	4	0.2	4						
METHOD	CHEMICAL	CAS No	FRACTION	RESULT UNIT	LIMIT OF DETECTION	Result	Result	Result	Result						
APHA 3125 B	Boron	7440-42-8	D	µg/L	100	--	--	*15400*	*16700*	90	370	680	1300		
APHA 3125 B	Boron	7440-42-8	T	µg/L	105	--	--	*15800*	*17000*	90	370	680	1300		
APHA 3125 B	Selenium	7782-49-2	T	µg/L	0.2	--	--	2 U	3	5	11	18	34		
APHA 3125 B	Zinc	7440-66-6	T	µg/L	5	1610	*33*	**10**	105	2.4	8	15	31		
APHA_3120	Calcium	7440-70-2	D	mg/L	1	122	49	123	179	NC	NC	NC	NC	NC	
APHA_3120	Magnesium	7439-95-4	D	mg/L	1	58	57	67	86	NC	NC	NC	NC	2.00E+06	a
APHA_3120	Potassium	7440-09-7	D	mg/L	1	32	31	35	44	NC	NC	NC	NC	NC	
APHA_3120	Sodium	7440-23-5	D	mg/L	1	3100	2890	3300	4490	NC	NC	NC	NC	NC	
APHA_4110	Bromide	24959-67-9	N	mg/L	1	59.6	51.3	56.3	77.7	NC	NC	NC	NC	NC	
APHA_4500_Cl	Chloride	16887-00-6	N	mg/L	1	4930	4330	4570	5880	NC	NC	NC	NC	NC	
APHA_4500_F_C	Fluoride	16984-48-8	N	mg/L	0.1	1.8	1.8	1.6	1.6	1300	3100	4800	8200		
APHA_4500_NH3_G	Ammonia as N	NA	N	mg/L	0.01	**34.8**	**29.3**	**28.9**	**33.6**	NC	NC	NC	NC	10	b
APHA_4500_NORG_D	Total Kjeldahl Nitrogen as N	TKN	N	mg/L	0.5	*41.8*	*42.8*	*45*	*46.2*	350	350	350	350		
APHA_4500_NORG+NO3	Total Nitrogen as N	NA	N	mg/L	0.5	**41.8**	**42.8**	**45**	**46.2**	NC	NC	NC	NC	350	b
APHA_4500_P_E	Reactive Phosphorus as P	7723-14-0	T	mg/L	0.01	0.69	0.31	0.62	0.74	NC	NC	NC	NC	NC	
APHA_4500_P_H	Total Phosphorus as P	NA	T	mg/L	0.05	**0.94**	**1.03**	**0.99**	**1.06**	NC	NC	NC	NC	10	b
APHA_4500_SIO2	Reactive Silica	NA	N	mg/L	0.05	127	125	120	125	NC	NC	NC	NC	NC	
APHA_4500_SO4_E	Sulfate as SO4 2-	NA	D	mg/L	1	1 U	2	22	4	NC	NC	NC	NC	2.00E+06	a
ASTM_D_6303-98	Formaldehyde	50-00-0	N	mg/L	0.1	1	0.3	0.1	0.6	NC	NC	NC	NC	1610	c
CSN_75_7611_75_7612	Gross alpha	12587-46-1	N	Bq/L	0.3	--	--	--	**1.06**	NC	NC	NC	NC	0.5	d
USEPA_6020	Barium	7440-39-3	D	mg/L	0.005	5.17	*0.969*	*4.63*	8.89	4	4	4	4		
USEPA_6020	Barium	7440-39-3	T	mg/L	0.005	5.18	*2.33*	*4.92*	8.16	4	4	4	4		
USEPA_6020	Molybdenum	7439-98-7	T	mg/L	0.005	**0.029**	**0.059**	**0.012**	**0.011**	NC	NC	NC	NC	0.034	e
USEPA_8015	>C10 - C16 Fraction	NA	N	µg/L	100	2860	**6930**	**1550**	**1840**	NC	NC	NC	NC	500	f
USEPA_8015	>C10 - C16 Fraction minus Naphthalene	NA	N	µg/L	100	2860	**6930**	**1550**	**1840**	NC	NC	NC	NC	500	f
USEPA_8015	>C10 - C40 Fraction (sum)	NA	N	µg/L	100	**6840**	**140000**	**4000**	**3370**	NC	NC	NC	NC	500	f
USEPA_8015	>C16 - C34 Fraction	NA	N	µg/L	100	3980	**128000**	**2450**	**1530**	NC	NC	NC	NC	500	f
USEPA_8015	C6 - C36 Fraction (Sum)	NA	N	µg/L	20	**7020**	--	**4120**	**3480**	NC	NC	NC	NC	500	f
USEPA_8270_UT	p-Cresol	106-44-5	N	µg/L	0.2	**184**	**108**	**141**	**279**	NC	NC	NC	NC	100	g

Attachment A
Avian Risk Screening Assessment
Tanumbirini Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Yellow Fill = Constituent concentration exceeds screening criterion	
SAMPLE NOTES	
--	Information not available
FRACTION	T - Total
	D - Dissolved
	N - Null
SAMPLE TYPE	N - Normal Grab Sample
	TB - Trip Blank
	NST - No Sample Taken
	FD - Field Duplicate
	Field measurement only
NA	CAS not applicable

WATER QUALIY SCREENING CRITERIA EXCEEDANCE KEY

Results underlined exceeds Freshwater Trigger Value 80%
Results in italic exceeds Freshwater Trigger Value 90%
Results shaded exceeds Freshwater Trigger Value 95%
Results in bold red exceeds Freshwater Trigger Value 99%
Bold Green exceeds alternative screening criterion

ALTERNATIVE WATER SCREENING CRITERIA NOTES

NC - No appropriate screening criterion
1 - API Publication 4709 September 2001. Frequently Asked Questions About TPH Analytical Methods for Crude Oil
a - Major ions of concern for livestock drinking water quality - https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
b - Default trigger values for physical and chemical stressors for southeast Australia for slightly disturbed ecosystems. FW Lakes and Reservoirs. https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
c - Chronic aquatic life water quality criterion from Hohreiter DW1, Rigg DK.Derivation of ambient water quality criteria for formaldehyde. Chemosphere. 2001. Chemosphere. Nov;45(4-5):471-86. https://www.ncbi.nlm.nih.gov/pubmed/11680743
d - Trigger values for radioactive contaminants for irrigation water. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
e -Australian and New Zealand Guidelines for Fresh and Marine Water Quality Screening Benchmarks (October 2000) from (From Oak Ridge National Laboratory - Risk Assessment Information System) https://rais.ornl.gov/tools/eco_search.php
f - CRWQCB . 2007. Screening For Environmental Concerns at Siteswith Contaminated Soil and Groundwater. California Regional Water Quality Control Board. INTERIM FINAL - November 2007. Table F4-b, Freshwater Criterion Region 2 Basin Plan
g - Guidelines for chemical compounds in water found to cause tainting of fish flesh and other aquatic organisms - https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf

Definitions
CAS = Chemical Abstracts Service
NA = not applicable
SO4 2- = sulfate

Qualifiers
U = less than detection limit

Units
µg/L = micrograms per litre
Bq/L = becquerel per litre
mg/L = milligrams per litre

Inclusion 4

Avian risk assessment

MEMO

To: Santos Ltd.

From: Bill Frez, EHS Support

CC: Nigel Goulding, EHS Support
Tom Biksey, EHS Support

Date: 27 March 2020

Re: Tanumbirini Flowback Wastewater - Avian Risk Assessment, EP-161, McArthur Basin

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Summary

Santos Ltd. ("Santos") is conducting an exploration and appraisal program within Exploration Permit (EP)-161, which is located in the Beetaloo Sub-basin of the broader McArthur Basin. The McArthur Basin is located southeast of Katherine, Northern Territory (NT), and covers approximately 180,000 square kilometres. Santos has undertaken exploration activities in EP-161 since 2013 including drilling of two exploration wells (Tanumbirini-1 and Marmbulligan-1) and the development of a water bore drilling and monitoring program in 2018. Santos has prepared an Environment Management Plan (EMP) for McArthur Basin 2019 – 2020 Hydraulic Fracturing Program in the NT EP-161. The EMP proposed Hydraulic Fracture Stimulation (HFS) to be conducted through 2019-2020 at the Tanumbirini 1, Tanumbirini 2H and Inacumba 1/1H well locations.

As part of the EMP, a chemical risk assessment was completed for the flowback/produced water after hydraulic fracturing. This risk assessment evaluated the chemistry of the hydraulic fracturing fluid systems, estimated the probable concentration of these chemicals in flowback and completed a quantitative evaluation of risks. Based on the assessment completed it was determined that the only potentially complete exposure pathway (considering the program of works and associated management controls) was to avian receptors that may come in contact with fluids contained in open-top tanks recognising that wastewater was stored in enclosed tanks. Based on avian receptors coming in contact with flowback/produced water containing these chemicals, the quantitative risk assessment determined that there would be no unacceptable risks to avian receptors.

Pursuant to the approval conditions of the EMP, sampling and analysis of flowback/produced water is required to be routinely conducted and the risks associated with flowback/produced water reassessed. The operational philosophy and management controls discussed in the EMP have been effectively implemented at the Site; therefore, the conceptual exposure model is unchanged with potential exposures limited to avian receptors. The following report utilises the risk assessment methodologies documented in the EMP submitted by Santos and the analytical data for flowback/produced water to update the quantitative evaluation of risks to avian receptors.

Risk Assessment

This risk assessment is focused on potential exposure of avian receptors to chemicals detected above screening criteria in the four water samples (EB2001149, EB2001149, EB2003972 and EB2003972) collected from Tanumbirini 1 well HFS flowback enclosed storage tank water (wastewater) on 15 January 2020 and 12 February 2020. Laboratory analyses of these wastewater samples for inorganic, organic, and radionuclide analytes has been completed pursuant to the monitoring wastewater chemistry analytes specified in Section C.3 of the Code of Practice: Onshore Petroleum Activities in the Northern Territory (Northern Territory Government, 2019).

The risk assessment conducted on the four wastewater samples included the following two steps:

1. Screening Assessment – Identify chemicals of low ecological concern that do not require additional evaluation in the risk assessment process based on a comparison to the Australian and New Zealand Environment and Conservation Council (ANZECC) (2000) trigger values or, absent such values, alternative screening criteria as noted in **Attachment A**.
2. Quantitative Risk Evaluation – Identify chemicals that are a concern for avian receptors, and therefore require additional evaluation to characterise potential risks. Potential exposure was assessed using a quantitative evaluation of the potential complete avian exposure pathway and the screening assessment.

As noted above the Quantitative Risk Evaluation methods utilised below are identical to those used for the hydraulic fracturing risk assessment conducted prior to approval and the undertaking of the activities at the Tanumbirini 1 well (EHS Support, 2019). Consistent with the results of the previous risk assessment conduced prior to approval of the activities at the Tanumbirini 1 well, this risk assessment concluded there is no unacceptable risk to avian receptors.

Screening Assessment

The screening assessment consisted of a focused evaluation of the potential risks to avian receptors if exposed to chemicals detected in wastewater samples (**Attachment A**). The objective of the screening assessment was to identify chemicals of low concern to avian receptors that do not require additional evaluation in the risk assessment process.

The screening assessment used aquatic trigger values set forth in ANZECC (2000) which are deemed to be protective of aquatic species such as fish, invertebrates and algae assuming chronic, continual and prolonged contact with surface water. In instances where no trigger values were available, alternative screening criteria were employed and are noted as such in **Attachment A**. Inherently this approach is considered highly conservative as:

- In toxicological testing, aquatic species are more sensitive than terrestrial species to chemicals due to their emersion within the fluid, additional modes of action (for example impacts on gill function etc) and the potential for secondary stressors to impact on health.
- Even if exposed, Avian receptors will have limited periods of duration in contact with the fluids. Roosting, breeding and continuous access will not occur on the water body; therefore, contact will be episodic in nature and possibly only involve ingestion during dry periods.

Chemicals detected in the wastewater samples with concentrations exceeding the conservatively adopted water quality criteria were carried through the quantitative risk evaluation.

The detected chemicals analysed in the wastewater samples that had concentrations exceeding the conservatively adopted water quality criteria and that may pose a potential risk to avian receptors include:

- Boron
- Zinc
- Barium
- Molybdenum
- Ammonia
- p-Cresol
- >C10 - C16 Fraction
- >C10 - C16 Fraction minus Naphthalene (F2)
- >C10 - C40 Fraction (sum)
- >C16 - C34 Fraction F3
- >C34 - C40 Fraction
- >C34 - C40 Fraction F4
- C6 - C36 Fraction (Sum)
- Gross alpha

It should be noted that the gross alpha screening criteria is only a generic screening value and, consistent with the ADWG (2017), triggers a more detailed assessment. As outlined in the detailed assessment framework, an order-of-magnitude higher radiological exposure are acceptable as the natural background is higher than the screening level and thresholds for active intervention have been established at corresponding doses 10 to 50 times higher than the corresponding screening value. Thus, gross alpha detected at a level of 1.06 becquerel per litre (Bq/L) requires no further evaluation.

Attachment A presents the results of the screening level assessment.

Quantitative Risk Assessment

Potential exposure of avian receptors to the chemicals of concern in the wastewater samples was quantitatively assessed for representative avian species that were previously evaluated in the chemical risk assessment (EHS Support, 2019). The potential avian exposure pathway was assessed based on the potential ingestion of wastewater by avian receptors using standard methods and in accordance with the methodologies used in the EHS Support (2019). Potential dietary intake of water containing these chemicals was compared to toxicity reference values (TRVs) developed specifically for avian wildlife. Potential risks were estimated using a chemical specific hazard quotient and a combined hazard index. A potential hazard quotient threshold level less than 1 indicates there are no unacceptable exposures to the avian species; the hazard index is the sum of the hazard quotients on an avian species-specific basis.

Table 1 summarises the results of the quantitative risk evaluation and includes a short term (21-day) and long term (1 year) scenario of fluid exposure which aligns with the current approach of off-site transportation and management of fluids and a possible future scenario with possible longer term storage on-site. The hazard index for all the assessed avian species was orders of magnitude less than the threshold hazard index of 1 for both exposure scenarios. Therefore, there were no unacceptable exposures to the avian species from potential ingestion of chemicals in flowback wastewater.

Table 1 Hazard indices for target avian species exposed to wastewater

Avian Species	Hazard Index for 21 days of Storage	Hazard Index for 1 year of Storage
Crested Pigeon	8.0E-03	1.4E-01
Willie Wagtail	4.4E-02	7.7E-01
Peaceful Dove	9.0E-03	1.6E-01
Cattle Egret	7.7E-03	1.3E-01
Brown Honeyeater	1.0E-02	1.8E-01

Attachment B presents the detailed calculations and outcomes of the quantitative risk evaluation for the target avian species in **Table 1**.

Conclusions and Recommendations

An assessment was performed to determine the potential risk to avian receptors exposed to Tanumbirini 1 well flowback. The assessment consisted of a screening level evaluation to identify chemicals of concern in the wastewater that require further assessment using avian ingestion intake models in a quantitative risk evaluation.

The risk assessment concluded that no chemicals detected in the wastewater above water quality criteria pose an unacceptable risk to avian receptors, assuming the wastewater is used as a drinking water source. Therefore, with respect to avian use of the Tanumbirini 1 well flowback and the approved site activities and associated management controls, no further action is recommended. These findings are consistent with the chemical risk assessment that was developed and submitted with the EMP (EHS Support, 2019), which also concluded that there were no unacceptable risks to avian receptors.

References

ANZECC. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation. Agriculture and Resource Management Council of Australia and New Zealand Council.

EHS Support. 2019. Beetaloo McArthur Basin Hydraulic Fracturing Fluid System - Chemical Risk Assessment. 03 July.

NHMRC, NRMMC. 2011. Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra. Updated August 2018.

Northern Territory Government. 2019. Code of Practice: Onshore Petroleum Activities in the Northern Territory. 31 May.

Attachment A Screening Assessment – Tanumbirini Well 1 Tank Water

Attachment A
Avian Risk Screening Assessment
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

										Freshwater Trigger Value (FTV, µg/L)					
					FIELD	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN	MCARTHUR BASIN						
					SAMPLE ID	TAN1FBCT1	TAN1FBCT1	TAN1FBCT1	TAN1FBCT1	FTVs by Protection Level (% Species)					
					DESCRIPTION	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	TANUMBIRINI 1 WELL FLOWBACK STORAGE CONCEPT TANK/POND 1 - COVERED - 4m BOTTOM - 0.2m TOP	99%	95%	90%	80%	Alternative SW Screening Criteria (µg/L)	Reference
					SAMPLE DATE	1/15/2020	1/15/2020	2/12/2020	2/12/2020						
					WORK ORDER	EB2001149	EB2001149	EB2003972	EB2003972						
					SAMPLE TYPE	N	N	N	N						
					DEPTH	0.2	4	0.2	4						
METHOD	CHEMICAL	CAS No	FRACTION	RESULT UNIT	LIMIT OF DETECTION	Result	Result	Result	Result						
APHA 3125 B	Boron	7440-42-8	D	µg/L	100	--	--	15400	16700	90	370	680	1300		
APHA 3125 B	Boron	7440-42-8	T	µg/L	105	--	--	15800	17000	90	370	680	1300		
APHA 3125 B	Selenium	7782-49-2	T	µg/L	0.2	--	--	2 U	3	5	11	18	34		
APHA 3125 B	Zinc	7440-66-6	T	µg/L	5	1610	33	10	105	2.4	8	15	31		
APHA_3120	Calcium	7440-70-2	D	mg/L	1	122	49	123	179	NC	NC	NC	NC	NC	
APHA_3120	Magnesium	7439-95-4	D	mg/L	1	58	57	67	86	NC	NC	NC	NC	2.00E+06	a
APHA_3120	Potassium	7440-09-7	D	mg/L	1	32	31	35	44	NC	NC	NC	NC	NC	
APHA_3120	Sodium	7440-23-5	D	mg/L	1	3100	2890	3300	4490	NC	NC	NC	NC	NC	
APHA_4110	Bromide	24959-67-9	N	mg/L	1	59.6	51.3	56.3	77.7	NC	NC	NC	NC	NC	
APHA_4500_Cl	Chloride	16887-00-6	N	mg/L	1	4930	4330	4570	5880	NC	NC	NC	NC	NC	
APHA_4500_F_C	Fluoride	16984-48-8	N	mg/L	0.1	1.8	1.8	1.6	1.6	1300	3100	4800	8200		
APHA_4500_NH3_G	Ammonia as N	NA	N	mg/L	0.01	34.8	29.3	28.9	33.6	NC	NC	NC	NC	10	b
APHA_4500_NORG_D	Total Kjeldahl Nitrogen as N	TKN	N	mg/L	0.5	41.8	42.8	45	46.2	350	350	350	350		
APHA_4500_NORG+NO3	Total Nitrogen as N	NA	N	mg/L	0.5	41.8	42.8	45	46.2	NC	NC	NC	NC	350	b
APHA_4500_P_E	Reactive Phosphorus as P	7723-14-0	T	mg/L	0.01	0.69	0.31	0.62	0.74	NC	NC	NC	NC	NC	
APHA_4500_P_H	Total Phosphorus as P	NA	T	mg/L	0.05	0.94	1.03	0.99	1.06	NC	NC	NC	NC	10	b
APHA_4500_SIO2	Reactive Silica	NA	N	mg/L	0.05	127	125	120	125	NC	NC	NC	NC	NC	
APHA_4500_SO4_E	Sulfate as SO4 2-	NA	D	mg/L	1	1 U	2	22	4	NC	NC	NC	NC	2.00E+06	a
ASTM_D_6303-98	Formaldehyde	50-00-0	N	mg/L	0.1	1	0.3	0.1	0.6	NC	NC	NC	NC	1610	c
CSN_75_7611_75_7612	Gross alpha	12587-46-1	N	Bq/L	0.3	--	--	--	1.06	NC	NC	NC	NC	0.5	d
USEPA_6020	Barium	7440-39-3	D	mg/L	0.005	5.17	0.969	4.63	8.89	4	4	4	4		
USEPA_6020	Barium	7440-39-3	T	mg/L	0.005	5.18	2.33	4.92	8.16	4	4	4	4		
USEPA_6020	Molybdenum	7439-98-7	T	mg/L	0.005	0.029	0.059	0.012	0.011	NC	NC	NC	NC	0.034	e
USEPA_8015	>C10 - C16 Fraction	NA	N	µg/L	100	2860	6930	1550	1840	NC	NC	NC	NC	500	f
USEPA_8015	>C10 - C16 Fraction minus Naphthalene	NA	N	µg/L	100	2860	6930	1550	1840	NC	NC	NC	NC	500	f
USEPA_8015	>C10 - C40 Fraction (sum)	NA	N	µg/L	100	6840	140000	4000	3370	NC	NC	NC	NC	500	f
USEPA_8015	>C16 - C34 Fraction	NA	N	µg/L	100	3980	128000	2450	1530	NC	NC	NC	NC	500	f
USEPA_8015	C6 - C36 Fraction (Sum)	NA	N	µg/L	20	7020	--	4120	3480	NC	NC	NC	NC	500	f
USEPA_8270_UT	p-Cresol	106-44-5	N	µg/L	0.2	184	108	141	279	NC	NC	NC	NC	100	g

Attachment A
Avian Risk Screening Assessment
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Yellow Fill = Constituent concentration exceeds screening criterion	
SAMPLE NOTES	
--	Information not available
FRACTION	T - Total
	D - Dissolved
	N - Null
SAMPLE TYPE	N - Normal Grab Sample
	TB - Trip Blank
	NST - No Sample Taken
	FD - Field Duplicate
	Field measurement only
NA	CAS not applicable

WATER QUALIY SCREENING CRITERIA EXCEEDANCE KEY

Results underlined exceeds Freshwater Trigger Value 80%
Results in italic exceeds Freshwater Trigger Value 90%
Results shaded exceeds Freshwater Trigger Value 95%
Results in bold red exceeds Freshwater Trigger Value 99%
Bold Green exceeds alternative screening criterion

ALTERNATIVE WATER SCREENING CRITERIA NOTES

NC - No appropriate screening criterion
1 - API Publication 4709 September 2001. Frequently Asked Questions About TPH Analytical Methods for Crude Oil
a - Major ions of concern for livestock drinking water quality - https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
b - Default trigger values for physical and chemical stressors for southeast Australia for slightly disturbed ecosystems. FW Lakes and Reservoirs. https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
c - Chronic aquatic life water quality criterion from Hohreiter DW1, Rigg DK.Derivation of ambient water quality criteria for formaldehyde. Chemosphere. 2001. Chemosphere. Nov;45(4-5):471-86. https://www.ncbi.nlm.nih.gov/pubmed/11680743
d - Trigger values for radioactive contaminants for irrigation water. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf
e -Australian and New Zealand Guidelines for Fresh and Marine Water Quality Screening Benchmarks (October 2000) from (From Oak Ridge National Laboratory - Risk Assessment Information System) https://rais.ornl.gov/tools/eco_search.php
f - CRWQCB . 2007. Screening For Environmental Concerns at Sites With Contaminated Soil and Groundwater. California Regional Water Quality Control Board. INTERIM FINAL - November 2007. Table F4-b, Freshwater Criterion Region 2 Basin Plan
g - Guidelines for chemical compounds in water found to cause tainting of fish flesh and other aquatic organisms - https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf

Definitions
CAS = Chemical Abstracts Service
NA = not applicable
SO4 2- = sulfate

Qualifiers
U = less than detection limit

Units
µg/L = micrograms per liter
Bq/L = becquerel per liter
mg/L = milligrams per liter

Attachment B Quantitative Risk Assessment – Avian Receptors – Tanumbirini Well 1 Tank Water

Attachment B - Table B-1
Tier 2 Assessment - Summary
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Common Name	Scientific Name	Body Mass (Kg)								Drinking WIR (L/day)[3,4]
		Sex[1]	N	Mean	Standard Deviation	Min	Max	Location	Source ID[2]	Mean
Crested Pigeon	*Ocyphaps lophotes*	B	21	0.204	---	0.142	0.26	Australia	515a	0.020
Willie Wagtail	*Rhipidura leucophrys picata*	B	13	0.0201	---	0.0145	0.0255	Australia	518a	0.004
Peaceful Dove	*Geopelia placida*	B	38	0.0478	---	0.035	0.065	Australia	515a	0.008
Cattle Egret	*Bubulcus ibis*	M	27	0.372	---	0.296	0.46	FL, USA	1207	0.0304
Cattle Egret	*Bubulcus ibis*	F	59	0.36	---	0.27	0.512	FL, USA	1207	0.0298
Brown Honeyeater	*Lichmera indistincta*	M	37	0.0118	0.0015	0.009	0.015	Australia	517	0.0030
Brown Honeyeater	*Lichmera indistincta*	F	15	0.0106	0.0021	0.008	0.014	Australia	517	0.0028

Notes:

1, Sex: M, Male; F, Female; B, Both

2, Body mass statistics compiled in Dunning (2008); Original source documents based on Source ID in Dunning (2008) include: CRC Handbook of Avian Body Masses 2nd Edition. CRC Press; 2 edition Boca Raton : CRC Press, [2008].

515a, *Higgins, P J and S J J F Davies 1996 Handbook of Australian, New Zealand and Antarctic birds Oxford University Press, Mel-bourne, Australia Volume 3*

518a, *Higgins, P J , J M Peter, and S J Cowling 2006 Handbook of Australian, New Zealand and Antarctic birds Oxford University Press, Melbourne, Australia Volume 7*

1207, *Telfair, R C 1994 Cattle Egret (Bubulcus ibis) In The Birds of North America, A Poole and F Gill (editors) The Birds of North America, Inc , Philadelphia, PA,* and The American Ornithologists' Union, Washington, DC Number 113

517, *Higgins, P J , J M Peter, and W K Steele 2001 Handbook of Australian, New Zealand and Antarctic birds Oxford University Press, Melbourne, Australia Volume 5*

3, Drinking water ingestion rate (WIR) based on the allometric relationship developed by Calder and Braun (1983) *Scaling of osmotic regulation in mammals and birds. Am J Physiol. 1983 May;244(5): R601-6.*, , where WIR (L/day) = 0.059 x BW $(Kg)^{0.67}$

4, Proposed WIR shown in bold, estimated based on the arithmetic mean of female or combined body mass; WIR may be estimated based on other body mass statistics depending on the appropriate exposure scenario.

BW = body weight
kg = kilogram
L = litre
--- no data

Attachment B - Table B-2
Crested Pigeon
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Constituent Name	CAS No.		Mammal NOAELt	Mammal NOAEL Test Animal		Avian NOAELt [1]	Avian NOAEL Test Animal			Avian Receptor Crested Pigeon	
				Animal	Body Weight (kg)		Animal	Body Weight (kg)		Body Weight (kg)	Derived TRV
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4		10.3	Rat	0.35	28.8	Mallard Duck	1.58	a	0.204	4.8E+01
Zinc (as ZnSO4 - ECHA)	7733-02-0		13	Rat	0.35	15	White Leghorn Hen	1.766	a	0.204	2.5E+01
Barium (BaSO4 - ECHA)	7727-43-7		101.4	Rat	0.35	20.800	Day old chicks	0.121	a	0.204	1.8E+01
Molybdenum Mo - ECHA	7439-98-7		17	Rat	0.35	4	Chicken	1.5	a	0.204	5.8E+00
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7		250	Rat	0.35	NA	NA	NA		0.204	2.9E+02
p-Cresol (ECHA)	106-44-5		50	Rat	0.35	NA	NA	NA		0.204	5.7E+01
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0		750	Rat	0.35	NA	Bobwhite Quail	0.178		0.204	8.6E+02
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0		750	Rat	0.35	NA	Bobwhite Quail	0.178		0.204	8.6E+02
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7		50	Rat	0.35	125	Bobwhite Quail	0.178		0.204	1.2E+02
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7		50	Rat	0.35	125	Bobwhite Quail	0.178		0.204	1.2E+02
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2		150	Rat	0.35	NA	Bobwhite Quail	0.178		0.204	1.7E+02
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5		2984	Rat	0.35	NA	Bobwhite Quail	0.178		0.204	3.4E+03

Notes:
a -Oak Ridge National Laboratory. 1996. Toxicological Benchmarks for Wildlife: 1996 Revision. Risk Assessment Program Health Sciences Research Division Oak Ridge, Tennessee 37831
CAS = Chemical Abstracts Service
ECHA = European Chemical Agency
kg = kilogram
mg = milligram
NA = not applicable
NOAELt = No observed adverse effect level test animal - mg/kg/day
TRV = toxicity reference value
1 - If an avian NOAEL was not available, the mammal NOAEL was used to derive the TRV for the avian receptor.
ND = no data available

$$Derived\ TRV = NOAEL_{test} * \left(\frac{Body\ Weight test}{Body\ Weight Avian}\right)^{(1/4)}$$

Exposure Route	Parameter Code		Parameter Definition	Units (a)	Parameter Value	Source (b)
Ingestion	IR		Ingestion rate	l/day	0.020	Table B-1
	EF		Exposure frequency	day/yr	21	BPJ
	ED		Exposure duration	yr	1	BPJ
	BW		Body weight	kg	0.204	Table B-1
	AT-NC		Averaging time - noncancer	days	365	BPJ

Notes:
a/ Units:
l/day = litres per day
day/yr = days per year
yr = year
kg = kilogram
b/ References:
BPJ - Best Professional Judgement

Constituent Name	CAS No.		EPC [1]	Toxicity	Total Intake (mg/kg/day)	Hazard Quotient
			Average CW (mg/l)	TRVs		Ingestion
Boron (from disodium octaborate tetrahydrate)	12280-03-4		16.4	4.8E+01	9.4E-02	2.0E-03
Zinc	7733-02-0		0.44	2.5E+01	2.5E-03	1.0E-04
Barium	7727-43-7		5.15	1.8E+01	3.0E-02	1.6E-03
Molybdenum	7439-98-7		0.028	5.8E+00	1.6E-04	2.8E-05
Ammonia	7664-41-7		31.650	2.9E+02	1.8E-01	6.3E-04
p-Cresol	106-44-5		0.178	5.7E+01	1.0E-03	1.8E-05
>C10 - C16 Fraction	93763-35-0	2	3.295	8.6E+02	1.9E-02	2.2E-05
>C10 - C16 Fraction minus Naphthalene (F2)	93763-35-0	2	3.295	8.6E+02	1.9E-02	2.2E-05
>C10 - C40 Fraction (sum)	EC 940-734-7	2	38.553	1.2E+02	2.2E-01	1.8E-03
>C16 - C34 Fraction F3	EC 940-734-7	2	33.990	1.2E+02	1.9E-01	1.6E-03
>C34 - C40 Fraction	8002-74-2	2	5.340	1.7E+02	3.1E-02	1.8E-04
C6 - C36 Fraction (Sum)(Hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	2	4.873	3.4E+03	2.8E-02	8.2E-06
					Cumulative:	**8.0E-03**

Notes:
CAS = Chemical Abstracts Service
CW = concentration in water
EPC = exposure point concentration
mg/kg/day = milligrams per kilograms per day
mg/l = milligrams per litre
NA = not available/applicable
TRV = toxicity reference value
1 - EPC is detected concentration presented on Table 1.
2 - Surrogates evaluated as per CAS No. or EC No. from data provided on ECHA

$$Total\ Intake = \frac{EPC\ \times IR\ \times EF\ \times ED}{BW\ \times ED\ x\ 365\ ^{days}/_{year}}$$

$$Hazard\ Quotient = \frac{Total\ Intake\ \left(\frac{mg}{kg-day}\right)}{TRV\ \left(\frac{mg}{kg-day}\right)}$$

Attachment B - Table B-3
Willie Wagtail
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Constituent Name	CAS No.	Mammal NOAELt	Mammal NOAEL Test Animal		Avian NOAELt [1]	Avian NOAEL Test Animal		Avian Receptor Willie Wagtail	
			Animal	Body Weight (kg)		Animal	Body Weight (kg)	Body Weight (kg)	Derived TRV
Amine oxides, cocoalkyldimethyl	61788-90-7	42	Rat	0.35	NA	NA	NA	0.0201	8.6E+01
Chlorous acid, sodium salt	7758-19-2	4	Rat	0.35	NA	NA	NA	0.0201	8.2E+00
Crontonaldehyde	123-73-9	2.5	Rat	0.35	NA	NA	NA	0.0201	5.1E+00
Glutaraldehyde	111-30-8	4	Rat	0.35	206	Mallard Duck	1.58	0.0201	6.1E+02
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	10.3	Rat	0.35	28.8	Mallard Duck	1.58	0.0201	8.6E+01
Zinc (as ZnSO4 - ECHA)	7733-02-0	13	Rat	0.35	15	White Leghorn Hen	1.766	0.0201	4.4E+01
Barium (BaSO4 - ECHA)	7727-43-7	101.4	Rat	0.35	20.800	Day old chicks	0.121	0.0201	3.3E+01
Molybdenum Mo - ECHA	7439-98-7	17	Rat	0.35	4	Chicken	1.5	0.0201	1.0E+01
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	250	Rat	0.35	NA	NA	NA	0.0201	5.1E+02
p-Cresol (ECHA)	106-44-5	50	Rat	0.35	NA	NA	NA	0.0201	1.0E+02
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0201	1.5E+03
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0201	1.5E+03
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0201	2.2E+02
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0201	2.2E+02
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	150	Rat	0.35	NA	Bobwhite Quail	0.178	0.0201	3.1E+02
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	2984	Rat	0.35	NA	Bobwhite Quail	0.178	0.0201	6.1E+03

Notes:
CAS = Chemical Abstracts Service
ECHA = European Chemical Agency
kg = kilogram
NA = not applicable
NOAELt = No observed adverse effect level test animal
TRV = toxicity reference value
1/ If an avian NOAEL was not available, the mammal NOAEL was used to derive the TRV for the avian receptor.

$$Derived\ TRV = NOAEL_{test} * \left(\frac{Body\ Weight test}{Body\ Weight Avian}\right)^{(1/4)}$$

Exposure Route	Parameter Code	Parameter Definition	Units (a)	Parameter Value	Source (b)
Ingestion	IR	Ingestion rate	l/day	0.004	Table B-1
	EF	Exposure frequency	day/yr	21	BPJ
	ED	Exposure duration	yr	1	BPJ
	BW	Body weight	kg	0.0201	Table B-1
	AT-NC	Averaging time - noncancer	days	365	BPJ

Notes:
a/ Units:
l/day = litres per day
day/yr = days per year
yr = year
kg = kilogram
b/ References:
BPJ - Best Professional Judgement

Constituent Name	CAS No.	EPC [1]	Toxicity	Total Intake (mg/kg/day)	Hazard Quotient
		CW (mg/l)	TRVs		Ingestion
Boron (from disodium octaborate tetrahydrate)	7733-02-0	16.4	8.2E+00	2.0E-01	2.5E-02
Zinc	7727-43-7	0.44	5.1E+00	5.4E-03	1.1E-03
Barium	7439-98-7	5.15	6.1E+02	6.3E-02	1.0E-04
Molybdenum	7664-41-7	0.028	8.6E+01	3.4E-04	4.0E-06
Ammonia	106-44-5	31.650	4.4E+01	3.9E-01	8.8E-03
p-Cresol	93763-35-0	0.178	3.3E+01	2.2E-03	6.7E-05
>C10 - C16 Fraction	93763-35-0	3.295	1.0E+01	4.1E-02	3.9E-03
>C10 - C16 Fraction minus Naphthalene (F2)	93763-35-0	3.295	5.1E+02	4.1E-02	8.0E-05
>C10 - C40 Fraction (sum)	EC 940-734-7	38.553	1.0E+02	4.8E-01	4.7E-03
>C16 - C34 Fraction F3	EC 940-734-7	33.990	1.5E+03	4.2E-01	2.7E-04
>C34 - C40 Fraction	8002-74-2	5.340	1.5E+03	6.6E-02	4.3E-05
C6 - C36 Fraction (Sum)(Hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	4.873	2.2E+02	6.0E-02	2.8E-04
				Cumulative:	**4.4E-02**

Notes:
CAS = Chemical Abstracts Service
CW = concentration in water
EPC = exposure point concentration
mg/kg/day = milligrams per kilograms per day
mg/l = milligrams per liter
TRV = toxicity reference value
1/ EPC is average detected concentration

$$Total\ Intake = \frac{EPC\ \times IR\ \times EF\ \times ED}{BW\ \times ED\ x\ 365\ ^{days}/_{year}}$$

$$Hazard\ Quotient = \frac{Total\ Intake\ \left(\frac{mg}{kg-day}\right)}{TRV\ \left(\frac{mg}{kg-day}\right)}$$

Attachment B - Table B-4
Peaceful Dove
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Constituent Name	CAS No.	Mammal NOAELt	Mammal NOAEL Test Animal		Avian NOAELt [1]	Avian NOAEL Test Animal		Avian Receptor Peaceful Dove	
			Animal	Body Weight (kg)		Animal	Body Weight (kg)	Body Weight (kg)	Derived TRV
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	10.3	Rat	0.35	28.8	Mallard Duck	1.58	0.0478	6.9E+01
Zinc (as ZnSO4 - ECHA)	7733-02-0	13	Rat	0.35	15	White Leghorn Hen	1.766	0.0478	3.6E+01
Barium (BaSO4 - ECHA)	7727-43-7	101.4	Rat	0.35	20.800	Day old chicks	0.121	0.0478	2.6E+01
Molybdenum Mo - ECHA	7439-98-7	17	Rat	0.35	4	Chicken	1.5	0.0478	8.3E+00
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	250	Rat	0.35	NA	NA	NA	0.0478	4.1E+02
p-Cresol (ECHA)	106-44-5	50	Rat	0.35	NA	NA	NA	0.0478	8.2E+01
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0478	1.2E+03
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0478	1.2E+03
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0478	1.7E+02
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0478	1.7E+02
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	150	Rat	0.35	NA	Bobwhite Quail	0.178	0.0478	2.5E+02
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	2984	Rat	0.35	NA	Bobwhite Quail	0.178	0.0478	4.9E+03

Notes:
CAS = Chemical Abstracts Service
ECHA = European Chemical Agency
kg = kilogram
NA = not applicable
NOAELt = No observed adverse effect level test animal
TRV = toxicity reference value
1/ If an avian NOAEL was not available, the mammal NOAEL was used to derive the TRV for the avian receptor.

$$Derived\ TRV = NOAEL_{test} * \left(\frac{Body\ Weighttest}{Body\ WeightAvian}\right)^{(1/4)}$$

Exposure Route	Parameter Code	Parameter Definition	Units (a)	Parameter Value	Source (b)
Ingestion	IR	Ingestion rate	l/day	0.008	Table B-1
	EF	Exposure frequency	day/yr	21	BPJ
	ED	Exposure duration	yr	1	BPJ
	BW	Body weight	kg	0.0478	Table B-1
	AT-NC	Averaging time - noncancer	days	365	BPJ

Notes:
a/ Units:
l/day = litres per day
day/yr = days per year
yr = year
kg = kilogram
b/ References:
BPJ - Best Professional Judgement

Constituent Name	CAS No.	EPC [1]	Toxicity	Total Intake (mg/kg/day)	Hazard Quotient
		CW (mg/l)	TRVs		Ingestion
Boron (from disodium octaborate tetrahydrate)	7727-43-7	16.4	6.9E+01	1.5E-01	2.2E-03
Zinc	7439-98-7	0.44	3.6E+01	4.1E-03	1.1E-04
Barium	7664-41-7	5.15	2.6E+01	4.8E-02	1.8E-03
Molybdenum	106-44-5	0.028	8.3E+00	2.6E-04	3.1E-05
Ammonia	93763-35-0	31.650	4.1E+02	2.9E-01	7.1E-04
p-Cresol	93763-35-0	0.178	8.2E+01	1.6E-03	2.0E-05
>C10 - C16 Fraction	93763-35-0	3.295	1.2E+03	3.1E-02	2.5E-05
>C10 - C16 Fraction minus Naphthalene (F2)	93763-35-0	3.295	1.2E+03	3.1E-02	2.5E-05
>C10 - C40 Fraction (sum)	EC 940-734-7	38.553	1.7E+02	3.6E-01	2.1E-03
>C16 - C34 Fraction F3	EC 940-734-7	33.990	1.7E+02	3.1E-01	1.8E-03
>C34 - C40 Fraction	8002-74-2	5.340	2.5E+02	4.9E-02	2.0E-04
C6 - C36 Fraction (Sum)(Hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	4.873	4.9E+03	4.5E-02	9.2E-06
				Cumulative:	**9.0E-03**

Notes:
CAS = Chemical Abstracts Service
CW = concentration in water
EPC = exposure point concentration
mg/kg/day = milligrams per kilograms per day
mg/l = milligrams per liter
NA = not available/applicable
TRV = toxicity reference value
1/ EPC is average detected concentration

$$Total\ Intake = \frac{EPC\ \times IR\ \times EF\ \times ED}{BW\ \times ED\ x\ 365^{\ days}/_{year}}$$

$$Hazard\ Quotient = \frac{Total\ Intake\ \left(\frac{mg}{kg-day}\right)}{TRV\ \left(\frac{mg}{kg-day}\right)}$$

Attachment B - Table B-5
Cattle Egret
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Constituent Name	CAS No.	Mammal NOAELt	Mammal NOAEL		Avian NOAELt [1]	Avian NOAEL		Avian Receptor	
			Test Animal			Test Animal		Cattle Egret	
			Animal	Body Weight (kg)		Animal	Body Weight (kg)	Body Weight (kg)	Derived TRV
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	10.3	Rat	0.35	28.8	Mallard Duck	1.58	0.36	4.2E+01
Zinc (as ZnSO4 - ECHA)	7733-02-0	13	Rat	0.35	15	White Leghorn Her	1.766	0.36	2.2E+01
Barium (BaSO4 - ECHA)	7727-43-7	101.4	Rat	0.35	20.800	Day old chicks	0.121	0.36	1.6E+01
Molybdenum Mo - ECHA	7439-98-7	17	Rat	0.35	4	Chicken	1.5	0.36	5.0E+00
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	250	Rat	0.35	NA	NA	NA	0.36	2.5E+02
p-Cresol (ECHA)	106-44-5	50	Rat	0.35	NA	NA	NA	0.36	5.0E+01
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.36	7.4E+02
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.36	7.4E+02
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.36	1.0E+02
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.36	1.0E+02
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	150	Rat	0.35	NA	Bobwhite Quail	0.178	0.36	1.5E+02
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	2984	Rat	0.35	NA	Bobwhite Quail	0.178	0.36	3.0E+03

Notes:
CAS = Chemical Abstracts Service
ECHA = European Chemical Agency
kg = kilogram
NA = not applicable
NOAELt = No observed adverse effect level test animal
TRV = toxicity reference value
1/ If an avian NOAEL was not available, the mammal NOAEL was used to derive the TRV for the avian receptor.

$$Derived\ TRV = NOAEL_{test} * \left(\frac{Body\ Weighttest}{Body\ WeightAvian}\right)^{(1/4)}$$

Exposure Route	Parameter Code	Parameter Definition	Units (a)	Parameter Value	Source (b)
Ingestion	IR	Ingestion rate	l/day	0.030	Table B-1
	EF	Exposure frequency	day/yr	21	BPJ
	ED	Exposure duration	yr	1	BPJ
	BW	Body weight	kg	0.36	Table B-1
	AT-NC	Averaging time - noncancer	days	365	BPJ

Notes:
a/ Units:
l/day = litres per day
day/yr = days per year
yr = year
kg = kilogram
b/ References:
BPJ - Best Professional Judgement

Constituent Name	CAS No.	EPC [1]	Toxicity	Total Intake (mg/kg/day)	Hazard Quotient
		CW (mg/l)	TRVs		Ingestion
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	16.4	4.2E+01	7.8E-02	1.9E-03
Zinc (as ZnSO4 - ECHA)	7733-02-0	0.44	2.2E+01	2.1E-03	9.7E-05
Barium (BaSO4 - ECHA)	7727-43-7	5.15	1.6E+01	2.4E-02	1.5E-03
Molybdenum Mo - ECHA	7439-98-7	0.028	5.0E+00	1.3E-04	2.6E-05
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	31.650	2.5E+02	1.5E-01	6.1E-04
p-Cresol (ECHA)	106-44-5	0.178	5.0E+01	8.5E-04	1.7E-05
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	3.295	7.4E+02	1.6E-02	2.1E-05
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	3.295	7.4E+02	1.6E-02	2.1E-05
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	38.553	1.0E+02	1.8E-01	1.7E-03
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	33.990	1.0E+02	1.6E-01	1.5E-03
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	5.340	1.5E+02	2.5E-02	1.7E-04
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	4.873	3.0E+03	2.3E-02	7.8E-06
				Cumulative:	**7.7E-03**

Notes:
CAS = Chemical Abstracts Service
CW = concentration in water
ECHA = European Chemical Agency
EPC = exposure point concentration
mg/kg/day = milligrams per kilograms per day
mg/l = milligrams per liter
NA = not available/applicable
TRV = toxicity reference value
1/ EPC is average detected concentration

$$Total\ Intake = \frac{EPC\ \times IR\ \times EF\ \times ED}{BW\ \times ED\ x\ 365\ ^{days}/_{year}}$$

$$Hazard\ Quotient = \frac{Total\ Intake\ \left(\frac{mg}{kg-day}\right)}{TRV\ \left(\frac{mg}{kg-day}\right)}$$

Attachment B - Table B-6
Brown Honeyeater
Tanumbirini Flowback Pond Wastewater - Avian Risk Assessment
McArthur Basin
Santos Ltd.

Constituent Name	CAS No.	Mammal NOAELt	Mammal NOAEL Test Animal		Avian NOAELt [1]	Avian NOAEL Test Animal		Avian Receptor Brown Honeyeater	
			Animal	Body Weight (kg)		Animal	Body Weight (kg)	Body Weight (kg)	Derived TRV
Amine oxides, cocoalkyldimethyl	61788-90-7	42	Rat	0.35	NA	NA	NA	0.0106	1.0E+02
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	10.3	Rat	0.35	28.8	Mallard Duck	1.58	0.0106	1.0E+02
Zinc (as ZnSO4 - ECHA)	7733-02-0	13	Rat	0.35	15	White Leghorn Hen	1.766	0.0106	5.2E+01
Barium (BaSO4 - ECHA)	7727-43-7	101.4	Rat	0.35	20.800	Day old chicks	0.121	0.0106	3.8E+01
Molybdenum Mo - ECHA	7439-98-7	17	Rat	0.35	4	Chicken	1.5	0.0106	1.2E+01
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	250	Rat	0.35	NA	NA	NA	0.0106	6.0E+02
p-Cresol (ECHA)	106-44-5	50	Rat	0.35	NA	NA	NA	0.0106	1.2E+02
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0106	1.8E+03
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized))	93763-35-0	750	Rat	0.35	NA	Bobwhite Quail	0.178	0.0106	1.8E+03
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0106	2.5E+02
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	50	Rat	0.35	125	Bobwhite Quail	0.178	0.0106	2.5E+02
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	150	Rat	0.35	NA	Bobwhite Quail	0.178	0.0106	3.6E+02
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	2984	Rat	0.35	NA	Bobwhite Quail	0.178	0.0106	7.2E+03

Notes:
CAS = Chemical Abstracts Service
ECHA = European Chemical Agency
kg = kilogram
NA = not applicable
NOAELt = No observed adverse effect level test animal
TRV = toxicity reference value
1/ If an avian NOAEL was not available, the mammal NOAEL was used to derive the TRV for the avian receptor.

$$Derived\ TRV = NOAEL_{test} * \left(\frac{Body\ Weighttest}{Body\ WeightAvian}\right)^{(1/4)}$$

Exposure Route	Parameter Code	Parameter Definition	Units (a)	Parameter Value	Source (b)
Ingestion	IR	Ingestion rate	l/day	0.0028	Table B-1
	EF	Exposure frequency	day/yr	21	BPJ
	ED	Exposure duration	yr	1	BPJ
	BW	Body weight	kg	0.0106	Table B-1
	AT-NC	Averaging time - noncancer	days	365	BPJ

Notes:
a/ Units:
l/day = litres per day
day/yr = days per year
yr = year
kg = kilogram
b/ References:
BPJ - Best Professional Judgement

Constituent Name	CAS No.	EPC [1]	Toxicity	Total Intake (mg/kg/day)	Hazard Quotient
		CW (mg/l)	TRVs		Ingestion
Boron (Released from disodium octaborate tetrahydrate)	12280-03-4	16.4	1.0E+02	2.5E-01	2.5E-03
Zinc (as ZnSO4 - ECHA)	7733-02-0	0.44	5.2E+01	6.7E-03	1.3E-04
Barium (BaSO4 - ECHA)	7727-43-7	5.15	3.8E+01	7.8E-02	2.0E-03
Molybdenum Mo - ECHA	7439-98-7	0.028	1.2E+01	4.2E-04	3.5E-05
Ammonia (ECHA - Ammonia, anhydrous)	7664-41-7	31.650	6.0E+02	4.8E-01	8.0E-04
p-Cresol (ECHA)	106-44-5	0.178	1.2E+02	2.7E-03	2.3E-05
>C10 - C16 Fraction (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized)	93763-35-0	3.295	1.8E+03	5.0E-02	2.8E-05
>C10 - C16 Fraction minus Naphthalene (ECHA: Surrogate as hydrocarbons, C9-16, hydrotreated, dearomatized))	93763-35-0	3.295	1.8E+03	5.0E-02	2.8E-05
>C10 - C40 Fraction (sum) (ECHA: Surrogate as hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	38.553	2.5E+02	5.9E-01	2.3E-03
>C16 - C34 Fraction F3 (ECHA: Surrogate hydrocarbons, C18-C24, iso-alkanes <2% aromatics)	EC 940-734-7	33.990	2.5E+02	5.2E-01	2.0E-03
>C34 - C40 Fraction (ECHA: Surrogate as paraffin waxes and Hydrocarbon waxes)	8002-74-2	5.340	3.6E+02	8.1E-02	2.3E-04
C6 - C36 Fraction (Sum)(ECHA: Surrogate as hydrocarbons, C6, n-alkanes, iso-alkanes, cyclics, n-hexane rich)	EC 925-292-5	4.873	7.2E+03	7.4E-02	1.0E-05
				Cumulative:	**1.0E-02**

Notes:
CAS = Chemical Abstracts Service
CW = concentration in water
ECHA = European Chemical Agency
EPC = exposure point concentration
mg/kg/day = milligrams per kilograms per day
mg/l = milligrams per liter
NA = not available/applicable
TRV = toxicity reference value
1/ EPC is average detected concentration

$$Total\ Intake = \frac{EPC\ \times IR\ \times EF\ \times ED}{BW\ \times ED\ x\ 365\ ^{days}/_{year}}$$

$$Hazard\ Quotient = \frac{Total\ Intake\ \left(\frac{mg}{kg-day}\right)}{TRV\ \left(\frac{mg}{kg-day}\right)}$$