18 APPENDICES

Appendix 1 – Literature Reviewed to Identify Valued Ecosystem Components (VECs)

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Appendix 2 – NORI-D Megafauna Samples

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C5E	CTA	ROV_025	8954	2021-11-18	4275	ROV Net	Echinodermata	
C5E	CTA	ROV_025	8957	2021-11-18	4275	ROV Scoop	Cnidaria	Actiniaria
C5E	CTA	ROV_025	8960	2021-11-18	4275	ROV Scoop	Porifera	
C5E	CTA	ROV_025	8963	2021-11-18	4274	ROV Net	Echinodermata	Asteroidea
C5E	CTA	ROV_025	8951	2021-11-18	4273	ROV Scoop	Echinodermata	Holothuroidea
C5E	CTA	ROV_026	8982	2021-11-19	4292	ROV Scoop	Cnidaria	Octocorallia
C5E	CTA	ROV_026	8985	2021-11-19	4291	ROV Scoop	Porifera	
C5E	CTA	ROV_030	9089	2021-11-28	4284	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_031	9114	2021-11-30	4309	ROV Slurp gun	Porifera	
C5E	CTA	ROV_031	9123	2021-11-30	4309	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_031	9126	2021-11-30	4310	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_031	9117	2021-11-30	4309	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_031	9129	2021-11-30	4309	ROV Slurp gun	Cnidaria	Octocorallia
C5E	CTA	ROV_031	9120	2021-11-30	4309	ROV Slurp gun	Echinodermata	Asteroidea
C5E	CTA	ROV_032	9176	2021-12-01	4284	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_032	9169	2021-12-01	4283	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_032	9152	2021-12-01	4283	ROV Scoop	Porifera	Hexactinellida
C5E	CTA	ROV_032	9179	2021-12-01	4283	ROV Scoop	Cnidaria	Octocorallia
C5E	CTA	ROV_032	9158	2021-12-01	4283	ROV Scoop	Porifera	Hexactinellida
C5E	CTA	ROV_032	9142	2021-12-01	4283	ROV Push core	Porifera	Hexactinellida
C5E	CTA	ROV_032	9161	2021-12-01	4283	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_032	9148	2021-12-01	4284	ROV Scoop	Cnidaria	Actiniaria
C5E	CTA	ROV_032	9135	2021-12-01	4282	ROV Scoop	Porifera	Hexactinellida
C5E	CTA	ROV_032	9132	2021-12-01	4282	ROV Scoop	Cnidaria	Hexacorallia
C5E	CTA	ROV_032	9164	2021-12-01	4282	ROV Scoop	Arthropoda	
C5E	CTA	ROV_032	9175	2021-12-01	4282	ROV Scoop	Echinodermata	Asteroidea
C5E	CTA	ROV_032	9172	2021-12-01	4286	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	CTA	ROV_032	9155	2021-12-01	4286	ROV Slurp gun	Echinodermata	Holothuroidea

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C5E	CTA	ROV_032	9135	2021-12-01	4288	ROV Scoop	Porifera	Hexactinellida
C5E	CTA	ROV_032	9167	2021-12-01	4290	ROV Slurp gun	Echinodermata	Holothuroidea
C5E	PRZ	ROV_037	9228	2021-12-12	4192	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_037	9234	2021-12-12	4190	ROV Push core	Porifera	Demospongiae
C5E	PRZ	ROV_037	9233	2021-12-12	4185	ROV Push core	Porifera	Hexactinellida
C5E	PRZ	ROV_037	9240	2021-12-12	4185	ROV Push core	Echinodermata	Asteroidea
C5E	PRZ	ROV_037	9237	2021-12-12	4184	ROV Manipulator	Echinodermata	Asteroidea
C5E	PRZ	ROV_037	9243	2021-12-12	4189	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_038	9259	2021-12-14	4232	ROV Manipulator	Porifera	Hexactinellida
C5E	PRZ	ROV_038	9262	2021-12-14	4226	ROV Manipulator	Arthropoda	Cirripedia
C5E	PRZ	ROV_038	9250	2021-12-14	4226	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_038	9269	2021-12-14	4225	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_038	9276	2021-12-14	4223	ROV Manipulator	Cnidaria	Octocorallia
C5E	PRZ	ROV_038	9253	2021-12-14	4222	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_038	9256	2021-12-14	4219	ROV Manipulator	Porifera	Hexactinellida
C5E	PRZ	ROV_038	9266	2021-12-14	4215	ROV Manipulator	Echinodermata	Holothuroidea
C5E	PRZ	ROV_038	9272	2021-12-14	4213	ROV Manipulator	Echinodermata	Holothuroidea
C6A	NORI-D	BC_046	BC_046.L1.bio.mgf.B0002	2019-08-28	4158.01	Box Core	Echinodermata	Holothuroidea
C6A	NORI-D	BC_048	BC_048.L1.bio.mgf.B0066	2019-08-30	4167.3	Box Core	Porifera	
C6A	NORI-D	BC_050	BC_050.L1.bio.mgf.B0159	2019-08-30	4110.71	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_050	BC_050.L1.bio.mgf.B0160	2019-08-30	4110.71	Box Core	Porifera	
C6A	NORI-D	BC_050	BC_050.L1.bio.mgf.B0164	2019-08-30	4110.71	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_052	BC_052.L1.bio.mgf.B0230	2019-08-31	4182.96	Box Core	Echinodermata	Asteroidea
C6A	NORI-D	BC_052	BC_052.L1.bio.mgf.B0235	2019-08-31	4182.96	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_053	BC_053.L1.bio.mgf.B0270	2019-08-31	4095.3	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_054	BC_054.L1.bio.mgf.B0295	2019-08-31	4090.31	Box Core	Cnidaria	Hexacorallia
C6A	NORI-D	BC_055	BC_055.L1.bio.mgf.B0328	2019-08-31	4195.52	Box Core	Brachiopoda	
C6A	NORI-D	BC_055	BC_055.L1.bio.mgf.B0334	2019-08-31	4195.52	Box Core	Mollusca	Bivalvia

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C6A	NORI-D	BC_056	BC_056.L1.bio.mgf.B0369	2019-08-31	4145.33	Box Core	Mollusca	Bivalvia
C6A	NORI-D	BC_060	BC_060.L1.bio.mgf.B0516	2019-09-01	4160.19	Box Core	Porifera	
C6A	NORI-D	BC_062	BC_062.L1.bio.mgf.B0595	2019-09-03	4149.19	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_063	BC_063.L1.bio.mgf.B0624	2019-09-04	4196.62	Box Core	Echinodermata	Holothuroidea
C6A	NORI-D	BC_063	BC_063.L1.bio.mgf.B0627	2019-09-04	4196.62	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_063	BC_063.L1.bio.mgf.B0628	2019-09-04	4196.62	Box Core	Cnidaria	Hexacorallia
C6A	NORI-D	BC_064	BC_064.L1.bio.mgf.B0667	2019-09-04	4309.41	Box Core	Porifera	
C6A	NORI-D	BC_064	BC_064.L1.bio.mgf.B0669	2019-09-04	4309.41	Box Core		
C6A	NORI-D	BC_066	BC_066.L1.bio.mgf.B0738	2019-09-05	4185.24	Box Core	Porifera	
C6A	NORI-D	BC_066	BC_066.L1.bio.mgf.B0739	2019-09-05	4185.24	Box Core	Bryozoa	
C6A	NORI-D	BC_068	BC_068.L1.bio.mgf.B0782	2019-09-05	4196.41	Box Core	Cnidaria	
C6A	NORI-D	BC_068	BC_068.L1.bio.mgf.B0783	2019-09-05	4196.41	Box Core	Porifera	
C6A	NORI-D	BC_068	BC_068.L1.bio.mgf.B0786	2019-09-05	4196.41	Box Core	Mollusca	Bivalvia
C6A	NORI-D	BC_070	BC_070.L1.bio.mgf.B0853	2019-09-06	4174.48	Box Core	Porifera	
C6A	NORI-D	BC_070	BC_070.L1.bio.mgf.B0857	2019-09-06	4174.48	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_070	BC_070.L1.bio.mgf.B0858	2019-09-06	4174.48	Box Core	Porifera	
C6A	NORI-D	BC_072	BC_072.L1.bio.mgf.B0919	2019-09-06	4252.63	Box Core	Echinodermata	Ophiuroidea
C6A	NORI-D	BC_074	BC_074.L1.bio.mgf.B0992	2019-09-06	4181.77	Box Core	Porifera	
C6A	NORI-D	BC_077	BC_077.L1.bio.mgf.B1085	2019-09-07	4261.74	Box Core	Porifera	
C6A	NORI-D	BC_078	BC_078.L1.bio.mgf.B1121	2019-09-07	4279.95	Box Core	Cnidaria	Hexacorallia
C6A	NORI-D	BC_078	BC_078.L1.bio.mgf.B1124	2019-09-07	4279.95	Box Core	Cnidaria	
C6A	NORI-D	BC_078	BC_078.L1.bio.mgf.B1129	2019-09-07	4279.95	Box Core	Arthropoda	Isopoda
C6A	NORI-D	BC_079	BC_079.L1.bio.mgf.B1162	2019-09-08	4303.38	Box Core	Echinodermata	Crinoidea
C6A	NORI-D	BC_081	BC_081.L1.bio.mgf.B1228	2019-09-08	4322.54	Box Core	Porifera	
C6A	NORI-D	BC_082	BC_082.L1.bio.mgf.B1262	2019-09-08	4225.62	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_084	BC_084.L1.bio.mgf.B1332	2019-09-09	4291.18	Box Core	Annelida?	
C6A	NORI-D	BC_085	BC_085.L1.bio.mgf.B1360	2019-09-09	4213.85	Box Core	Annelida?	
C6A	NORI-D	BC_087	BC_087.L1.bio.mgf.B1426	2019-09-09	4221.33	Box Core	Cnidaria	Hexacorallia

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C6A	NORI-D	BC_087	BC_087.L1.bio.mgf.B1430	2019-09-09	4221.33	Box Core	Porifera	
C6A	NORI-D	BC_088	BC_088.L1.bio.mgf.B1465	2019-09-09	4319.96	Box Core	Cnidaria	
C6A	NORI-D	BC_088	BC_088.L1.bio.mgf.B1471	2019-09-09	4319.96	Box Core	Porifera	
C6A	NORI-D	BC_089	BC_089.L1.bio.mgf.B1502	2019-09-10	4250.54	Box Core	Porifera	
C6A	NORI-D	BC_090	BC_090.L1.bio.mgf.B1528	2019-09-12	4258.17	Box Core	Porifera	
C6A	NORI-D	BC_091	BC_091.L1.bio.mgf.B1571	2019-09-13	4279.55	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_092	BC_092.L1.bio.mgf.B1602	2019-09-13	4223.88	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_094	BC_094.L1.bio.mgf.B1641	2019-09-13	4326.33	Box Core	Porifera	
C6A	NORI-D	BC_100	BC_100.L1.bio.mgf.B1835	2019-09-14	4285.09	Box Core	Arthropoda	Scalpelliforme
C6A	NORI-D	BC_100	BC_100.L1.bio.mgf.B1845	2019-09-14	4285.09	Box Core	Porifera	
C6A	NORI-D	BC_100	BC_100.L1.bio.mgf.B1854	2019-09-14	4285.09	Box Core	Porifera	
C6A	NORI-D	BC_102	BC_102.L1.bio.mgf.B1912	2019-09-15	4307.24	Box Core	Porifera	
C6A	NORI-D	BC_103	BC_103.L1.bio.mgf.B1944	2019-09-15	4318.57	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_103	BC_103.L1.bio.mgf.B1981	2019-09-15	4318.57	Box Core	Cnidaria	Octocorallia
C6A	NORI-D	BC_104	BC_104.L1.bio.mgf.B1994	2019-09-15	4341.13	Box Core	Bryozoa	
C6A	NORI-D	BC_104	BC_104.L1.bio.mgf.B1995	2019-09-15	4341.13	Box Core	Porifera	
C6A	NORI-D	BC_106	BC_106.L1.bio.mgf.B2058	2019-09-15	4195.89	Box Core	Porifera	
C6A	NORI-D	BC_106	BC_106.L1.bio.mgf.B2060	2019-09-15	4195.89	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_107	BC_107.L1.bio.mgf.B2094	2019-09-16	4396.93	Box Core	Porifera	
C6A	NORI-D	BC_108	BC_108.L1.bio.mgf.B2100	2019-09-16	4320.64	Box Core	Porifera	
C6A	NORI-D	BC_117	BC_117.L1.bio.mgf.B2405	2019-09-19	4359.29	Box Core	Porifera	
C6A	NORI-D	BC_118	BC_118.L1.bio.mgf.B2439	2019-09-19	4376.62	Box Core	Echinodermata	Holothuroidea
C6A	NORI-D	BC_118	BC_118.L1.bio.mgf.B2445	2019-09-19	4376.62	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_119	BC_119.L1.bio.mgf.B2476	2019-09-19	4303.5	Box Core	Porifera?	
C6A	NORI-D	BC_122	BC_122.L1.bio.mgf.B2582	2019-09-20	4305.39	Box Core	Porifera	
C6A	NORI-D	BC_130	BC_130.L1.bio.mgf.B2799	2019-09-21	4332.88	Box Core	Cnidaria	
C6A	NORI-D	BC_131	BC_131.L1.bio.mgf.B2824	2019-09-21	4312.92	Box Core	Bryozoa	
C6A	NORI-D	BC_132	BC_132.L1.bio.mgf.B2837	2019-09-21	4349.15	Box Core	Cnidaria	Octocorallia

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C6A	NORI-D	BC_133	BC_133.L1.bio.mgf.B2874	2019-09-21	4242.82	Box Core	Porifera	
C6A	NORI-D	BC_137	BC_137.L1.bio.mgf.B2985	2019-09-22	4283.21	Box Core	Porifera	
C6A	NORI-D	BC_137	BC_137.L1.bio.mgf.B2989	2019-09-22	4283.21	Box Core		
C6A	NORI-D	BC_140	BC_140.L1.bio.mgf.B3080	2019-09-23	4257.95	Box Core	Porifera?	
C6A	NORI-D	BC_140	BC_140.L1.bio.mgf.B3082	2019-09-23	4257.95	Box Core	Porifera	
C6A	NORI-D	BC_141	BC_141.L1.bio.mgf.B3114	2019-09-23	4311.62	Box Core	Annelida	Polychaeta
C6A	NORI-D	BC_145	BC_145.L1.bio.mgf.B3237	2019-09-24	4240.48	Box Core	Echinodermata	Crinoidea
C6A	NORI-D	BC_149	BC_149.L1.bio.mgf.B3352	2019-09-24	4219.02	Box Core	Arthropoda	Amphipoda
C6A	NORI-D	BC_150	BC_150.L1.bio.mgf.B3384	2019-09-24	4238.01	Box Core	Porifera	
C6A	NORI-D	BC_151	BC_151.L1.bio.mgf.B3410	2019-09-25	4249.92	Box Core	Porifera	
C6B	NORI-D	BC_176	BC_176.L1.bio.mgf.B0001	2019-11-23	4234	Box Core	Echinodermata	Holothuroidea
C6B	NORI-D	BC_177	BC_177.L1.bio.mgf.B0061	2019-11-24	4193	Box Core	Mollusca	Bivalvia
C6B	NORI-D	BC_179	BC_179.L1.bio.mgf.B0175	2019-11-24	4148	Box Core	Porifera	
C6B	NORI-D	BC_183	BC_183.L1.bio.mgf.B0350	2019-11-25	4332	Box Core	Arthropoda	Amphipoda
C6B	NORI-D	BC_185	BC_185.L1.bio.mgf.B0461	2019-11-25	4253	Box Core	Bryozoa	
C6B	NORI-D	BC_191	BC_191.L1.bio.mgf.B0816	2019-11-27	4170	Box Core	Mollusca	Bivalvia
C6B	NORI-D	BC_192	BC_192.L1.bio.mgf.B0829	2019-11-27	4240	Box Core	Arthropoda	Amphipoda
C6B	NORI-D	BC_193	BC_193.L1.bio.mgf.B0884	2019-11-28	4215	Box Core		
C6B	NORI-D	BC_195	BC_195.L1.bio.mgf.B1009	2019-11-28	4180	Box Core	Arthropoda	Isopoda?
C6B	NORI-D	BC_196	BC_196.L1.bio.mgf.B1059	2019-11-28	4221	Box Core	Arthropoda	Isopoda
C6B	NORI-D	BC_198	BC_198.L1.bio.mgf.B1175	2019-11-29	4139	Box Core	Bryozoa	
C6B	NORI-D	BC_198	BC_198.L1.bio.mgf.B1180	2019-11-29	4139	Box Core	Arthropoda	Amphipoda
C6B	NORI-D	BC_199	BC_199.L1.bio.mgf.B1238	2019-11-29	4173	Box Core	Annelida	Polychaeta
C6B	NORI-D	BC_199	BC_199.L1.bio.mgf.B1241	2019-11-29	4173	Box Core	Bryozoa	
C6B	NORI-D	BC_200	BC_200.L1.bio.mgf.B1291	2019-11-29	4180	Box Core	Mollusca	Gastropoda
C6B	NORI-D	BC_200	BC_200.L1.bio.mgf.B1293	2019-11-29	4180	Box Core	Bryozoa	
C6B	NORI-D	BC_203	BC_203.L1.bio.mgf.B1435	2019-11-29	4199	Box Core	Annelida	Polychaeta
C6B	NORI-D	BC_205	BC_205.L1.bio.mgf.B1551	2019-11-30	4172	Box Core	Porifera	

CAMPAIGN #	TARGET SITE	DEPLOYMENT ID	SAMPLE ID	DATE	DEPTH (M)	SAMPLING INSTRUMENT	PHYLUM	ORDER / CLASS
C6B	NORI-D	BC_205	BC_205.L1.bio.mgf.B1557	2019-11-30	4172	Box Core	Brachiopoda	
C6B	NORI-D	BC_208	BC_208.L1.bio.mgf.B1703	2019-11-30	4208	Box Core	Brachiopoda	
C6B	NORI-D	BC_209	BC_209.L1.bio.mgf.B1749	2019-11-30	4174	Box Core	Arthropoda	Isopoda
C6B	NORI-D	BC_209	BC_209.L1.bio.mgf.B1755	2019-11-30	4174	Box Core	Porifera	
C6B	NORI-D	BC_210	BC_210.L1.bio.mgf.B1794	2019-12-01	4172	Box Core	Porifera	Hexactinellida
C6B	NORI-D	BC_210	BC_210.L1.bio.mgf.B1795	2019-12-01	4172	Box Core	Porifera	
C6B	NORI-D	BC_212	BC_212.L1.bio.mgf.B1894	2019-12-01	4174	Box Core	Mollusca	Bivalvia
C6B	NORI-D	BC_214	BC_214.L1.bio.mgf.B1996	2019-12-02	4193	Box Core	Porifera	
C6B	NORI-D	BC_214	BC_214.L1.bio.mgf.B2001	2019-12-02	4193	Box Core	Porifera	
C6B	NORI-D	BC_215	BC_215.L1.bio.mgf.B2050	2019-12-02	4187	Box Core	Mollusca	Gastropoda
C6B	NORI-D	BC_219	BC_219.L1.bio.mgf.B2199	2019-12-02	4236	Box Core	Porifera or Cnidaria	
C6B	NORI-D	BC_223	BC_223.L1.bio.mgf.B2397	2019-12-03	4169	Box Core	Cnidaria	Octocorallia
C6B	PRZ	BC_226	BC_226.L1.bio.mgf.B2527	2019-12-04	4140	Box Core	Echinodermata	Holothuroidea
C6B	PRZ	BC_227	BC_227.L1.bio.mgf.B2587	43803	4297	Box Core	Bryozoa	

Appendix 3 – GHG Emissions Calculations

SUMMARY

	Air Travel CO$_2$e (tonnes)	Vessel CO$_2$e (tonnes)	Collector Equipment CO$_2$e (tonnes)	Total equipment shipping emissions CO2e (tonnes)	Total collector test emissions CO2e (tonnes)
Estimated Total GHG Emissions Collector Test	334.84	17,159.67	2,969.60	1.81	20,465.93

BREAKDOWN

1. Flights

Assuming 100 people flight to San Francisco coming from Europe

Rough Average flight distance from Europe to San Francisco (km) - 10,000

Number of people on board	Air passenger distance travelled to get to/from ship (km)	Air Travel CO$_2$e (tonnes)	Air Travel CO2 (tonnes)	Air Travel CH$_4$ (tonnes)	Air Travel N$_2$O (tonnes)
100	2,000,000	334.84	332	0.01	10.60

EF source: GHG protocol https://ghgprotocol.org/calculation-tools

Transport	CO2 Factor (kg / passenger mile)	CH4 Factor (kg / passenger mile)	N2O Factor (kg / passenger mile)	AR5 (kgCO2e)
Air Travel - Long Haul (>= 2300 miles)	0.166	0.0006	0.0053	0.1674213

2. Vessels

There will be 3 vessels during the collector test. The Hidden Gem, a support vessel and a science vessel.

Fuel usage is the source of GHG emissions and vessels usage occurs in two ways: transportation to/from the CCZ and while in the CCZ.

Routes to get to CCZ:

Hidden Gem (40,000 hp)	Rotterdam to Teneriffe test area	Test area to Tenerife's port	Tenerife to Punta arenas	Punta arenas to Manzanillo	Manzanillo to CCZ	CCZ to San Diego	Return to Rotterdam	Roundtrip total
nautical miles	1,500	246	5,674	4,778	900	1,350	13,548	27,996

Allseas support vessel (1/4 of the size of hidden gem, 10,000 hp)	Rotterdam to Manzanillo	Manzanillo to CCZ	CCZ to Hawaii	Roundtrip total
nautical miles	6,565	900	2,000	9,465

Science vessel (Assuming it comes from the gulf coast, 10,000 hp)	Gulf of Mexico to manzanillo	Manzanillo to CCZ	Go back to manzanillo	then gulf of Mexico	Resupply in SD roundtrip	Resupply in SD roundtrip
nautical miles	2,000	900	900	2,000	2,700	8,500

1 nautical mile = 1.15078 miles

Vessels	Distance travel vessel (Nautical Miles)	Distance travel vessel (Miles)	Marine Gas Oil Usage during transport (gal (US))	Marine Gas Oil Usage while on site for 60 days (gal (US))	Total fuel usage (gal (US))	Vessel CO_2e (tonnes)	Vessel CO_2 (tonnes)	Vessel CH_4 (tonnes)	Vessel N_2O (tonnes)
Hidden Gem (40,000hp)	27,996	32,217	682,000	475000	1,157,000	11,952.89	11,813	0.0694	0.5207
Allseas support vessel (10,000hp)	9,465	10,892	159,000	75000	234,000	2,417.44	2,389	0.0140	0.1053
Science vessel (10,000hp)	8,500	9,782	159,000	111000	270,000	2,789.35	2,757	0.0162	0.1215

Total Vessel emissions CO2e (tonnes) 17,159.67

EF source: GHG protocol https://ghgprotocol.org/calculation-tools

Mobile Combustion	CO2 Factor (kg / gal (US))	CH4 Factor (kg / gal (US))	N2O Factor (kg / gal (US))	AR5 (kgCO2e)
Diesel Fuel - Diesel Ships and Boats	10.21	0.00006	0.00045	10.33093

3. Collector Equipment

No. 2 oil gallons to MMBtu 0.138 EF source: GHG protocol https://ghgprotocol.org/calculation-tools

Collector test equipment	Distillate Fuel Oil No. 2 during test (gal (US))	Distillate Fuel Oil No. 2 during test (mmbtu)	Collector Equipment CO_2e (tonnes)	Collector Equipment CO_2 (tonnes)	Collector Equipment CH_4 (tonnes)	Collector Equipment N_2O (tonnes)
Compressor	290,000	40,020	2,969.60	2,959.88	0.12	0.02

Collector equipment will be running 34 days out of 60.

EF source: GHG protocol https://ghgprotocol.org/calculation-tools

Stationary Combustion	CO2 Factor (kg / mmbtu)	CH4 Factor (g / mmbtu)	N2O Factor (g / mmbtu)	AR5 (kgCO2e)
Distillate Fuel Oil No. 2	73.96	3	0.6	74.203

4. Shipment of containers with equipment via sea

10 containers from Rotterdam to San Diego by Sea. Assuming they are full.
Assuming the largest shipping container (40") carrying maximum allowed weight (19,958kg)

	Number of 40" shipping containers	Max Gross allowed weight of container (kg)*	Maximum weight shipped (Tonnes)	Estimated distance shipped (km)	Total shipping emissions CO2e (tonnes)**
Emissions of shipping equipment	10	20,185	202	15,013	1.81114

* Source: https://www.technogroupusa.com/size-and-weight-limit-laws/
**via CarbonCare calculator: https://www.carboncare.org/en/co2-emissions-calculator.html

Appendix 4 – Preliminary Underwater Noise & Vibration Impact Assessment

The Metals Company

the metals company

TECHNICAL MEMORANDUM

DRAFT

NORI-D Contract Area EIS
Clarion-Clipperton Zone (CCZ)

Preliminary Underwater Noise and Vibration Impact Assessment Study

TM 220
23 February 2022

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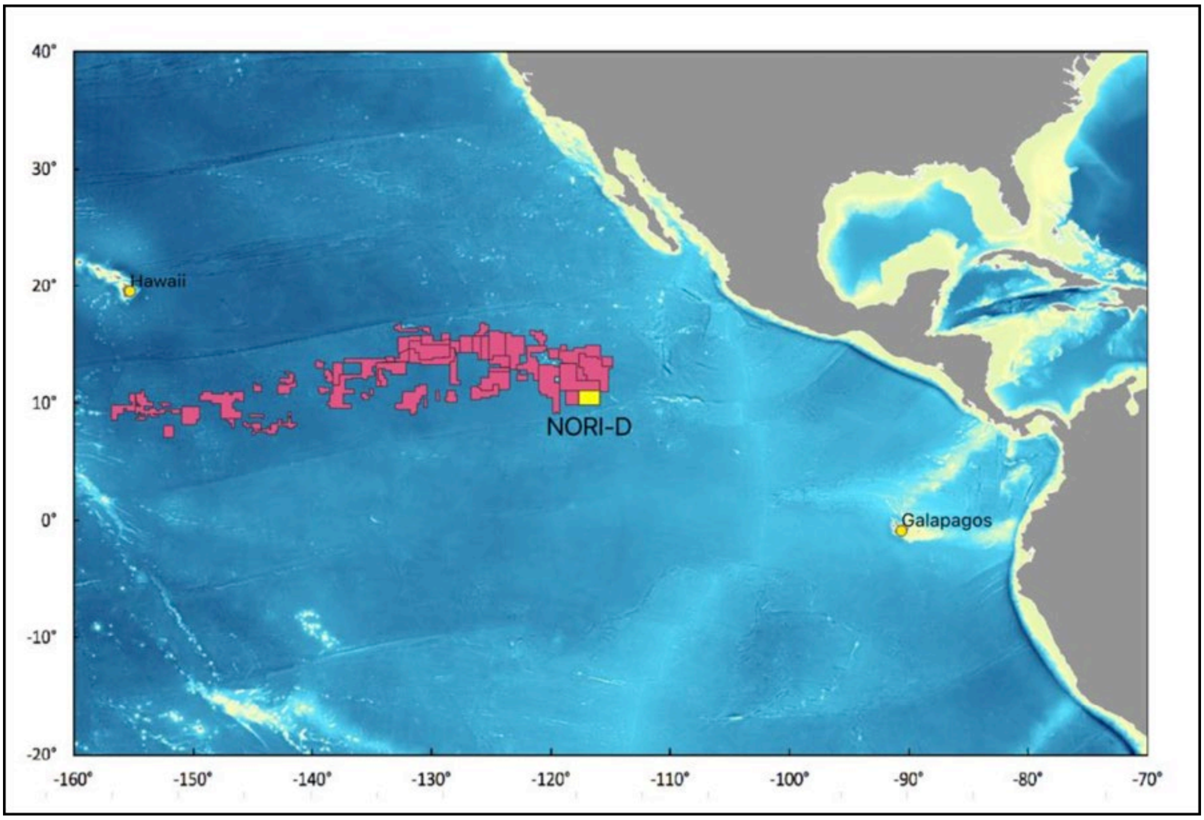
ES1 Introduction

Nauru Ocean Resources, Inc. (NORI) plans to carry out testing of a polymetallic nodule collector system (the Collector Test) in the NORI-D lease area of the eastern Clarion-Clipperton Zone (CCZ), eastern tropical Pacific Ocean. Figure 1 shows a location map of NORI-D lease area.

NORI will prepare an Environmental and Social Impact Assessment (ESIA) in support of an application to the International Seabed Authority (ISA) for a contract to commercially collect deep ocean polymetallic nodules. Testing of a prototype collector vehicle (PCV) and riser system is a mandatory sub-task of the overarching operational ESIA. The ISA requires a dedicated assessment of the technical and environmental performance of the prototype system, which is one fifth of the proposed commercial scale. To date, NORI (2021) has prepared a Draft Collector Test Environmental Impact Statement (EIS).



Source: Flynn & Donnelly (2021a). Red blocks represent other ISA lease areas within the CCZ.

Figure 1 NORI-D lease area location map.

The Metals Company, Inc. (TMC) engaged EnviroGulf Consulting to undertake a desktop preliminary study to characterise underwater noise and vibrations generated by the pilot Collector Test system (the 'Project') and to assess likely consequential impacts to marine fauna. This information will be used to update the underwater noise and vibration aspects of the Draft Collector Test EIS.

ES1.1 Objectives

The key objectives of the present desktop study are to:

- Identify the key louder sources of underwater noise and vibration sources, assess their source levels based on literature reviews and using relevant information from comparative analogues.
- Assess the extent to which Project-generated sound fields propagate and/or attenuate to levels within the range of ambient background noise, using simple geometric spreading laws.
- Calculate distances from Project-generated noise sources to isopleths (lines of equal sound levels) at which acoustic threshold criteria for selected noise-sensitive marine fauna occur, using Project-generated noise source levels.
- Identify and assess potential Project underwater noise and vibration impacts on marine fauna, propose appropriate mitigation and management measures to reduce potential adverse impacts, and assess the residual impacts after implementation of the mitigation and management measures.
- Provide information and data from this underwater noise and vibration assessment to assist TMC and NORI in preparing the ESIA for commercial nodule collecting and processing operations, as well as preparing an environmental management and monitoring plan (EMMP) and, specifically, its underwater noise and vibration management sub-plan.
- Address reviewer comments and queries on the adequacy of the underwater noise and vibration assessment provided in the Draft Collector Test EIS (NORI, 2021).

Realisation of the of the above objectives may assist government regulatory authorities – in particular, the Nauru Government and the ISA – to make an informed decision on the residual underwater noise and vibration impacts of the pilot Collector Test Project on key marine fauna observed or expected to be present in CCZ and the eastern central Pacific Ocean.

ES1.3 Potential Issues

Potential issues in relation to Project-generated underwater noise and vibrations are:

- Potential physical noise issues:
  - Underwater noise and vibrations at the sea surface due to the presence and operation of the Surface Support Vessel (SSV) and occasional presence of an Offshore Supply Vessel (OSV).
  - Mid-water underwater noise and vibration generated by the Vertical Transport System (VTS in the water column occupied by VTS such as the flexible jumper hose from the Prototype Collector Vehicle (PCV) to the base of a rigid steel pipe (riser) and thence to the moon pool of the SSV. The depth of the water column affected by the VTS is about 4,300 m, including the epipelagic (0-200 m), mesopelagic (200–1,000 m) and bathypelagic (1,000–4,300 m).

  - Near surface and mid-water underwater noise and vibration generated by the flow of process wastewaters (returned seawater, fine sediments, fine nodule fragments) through return pipe from the SSV to its outlet at 1,200 m below biological more productive zones. The depth of the water column affected directly by acoustic noise and vibration from the wastewater return pipe includes the epipelagic zone (0–200 m), mesopelagic zone (200–1,00 m) and a 200-m-long sections of the upper bathypelagic zone (i.e., 1,000–1,200 m).
  - Underwater noise and vibrations generated at the ocean floor and benthic environment by the PCV undertaking nodule collection, and by PCV-onboard noise sources such as water jet pumps, suction pumps, nodule separation units, electric-driven tracks, etc.
  - High-frequency underwater noise produced by underwater navigation and positioning systems or geophysical instruments such as Multibeam Echosounders (MBES), Acoustic Doppler Current Profilers (ADCP), Ultra-short Baseline (USBL), Long Baseline (LBL), etc.
- Marine ecology issues:
  - Acoustic damage to, or acoustic disturbance of, offshore marine mammals (e.g., whales and dolphins) at the sea surface or in deeper water during dives.
  - Acoustic damage to, or acoustic disturbance of, epipelagic, mesopelagic and bathypelagic fish and other nekton (e.g., cephalopods).
  - Acoustic damage to, or acoustic disturbance of, benthic and epibenthic fish and macroinvertebrates (e.g., decapod crustaceans) within and adjacent to the seafloor footprint of seafloor mining operations.
- Marine resource use issues:
  - Potential acoustic disturbance of offshore pelagic fish species targeted by commercial fisheries, such as tuna.

In addition to the above potential effects of underwater noise and vibrations that are addressed in the present desktop study, various reviewers of the underwater noise component of the Draft Collector Test EIS raised similar potential effects as outlined above. However, the following additional potential effects raised by the reviewers have been included:

- Potential for underwater noise to be disruptive in the SOFAR (Sound Fixing and Ranging) channel, where introduced noise (e.g., from the riser that passes through the SOFOR channel) may travel for very long distances from hundreds to thousands of kilometres.
- Potential for high intensity, low- and mid-frequency sonar impacted cetaceans, which may result in fatal strandings.

ES1.4 Exclusions

This report has excluded the following:

- Underwater water noise generated during transits of Project-related vessels (e.g., the SSV and OSV) between their home ports and outside the NORI-D lease area.

- Airborne noise assessments are excluded since the focus of this report is on the generation of underwater noise and vibration at the offshore location of the NORI-D lease area. While airborne noise from vessels may penetrate surface waters, the resulting in-water sound field will be masked by the much louder thruster-generated underwater noise while the SSV and OSV maintain station by dynamic positioning (DP).

- Oceanic birds such as albatrosses, petrels and storm-petrels, shearwaters are assessed not to be vulnerable to the Project-generated underwater noise as those species capable of diving would only be transiently exposed to underwater noise and lack sufficient cumulative exposure for acoustic impacts to occur.

- Detailed acoustic modelling has not been performed for this desktop assessment study as this will be undertaken by specialist acoustic consultants with up-to-date computer-based modelling techniques. The present report uses geometric spreading law equations to calculate distances at which acoustic threshold criteria for selected noise-sensitive species are exceeded or distances to ambient background levels. In combination with adopting conservative under water noise source levels for Collector Test components, this approach gives reasonable estimates of distances to where Collector Test component underwater noise levels exceed acoustic damage or acoustic disturbance threshold criteria.

ES2 Key Collector Test Components

The pilot Collector Test system has three main components, which follow the general mining sequence from seafloor nodule harvesting through nodule lifting via the vertical transport system (i.e., the riser) to the surface support vessel:

- Seafloor: Nodule harvesting using a Prototype Collector Vehicle (PSV).

- Water column: Vertical Transfer System (VTS) - riser and airlift system

- Surface: Surface Support Vessel (SSV) and offshore supply vessel (OSV).

Table 1 lists the proposed Collector Test components and durations.

Table 1 Proposed Collector Test components and duration

Seq.	**Code**	**Test component**	**Duration (hours)**		
1	**FIP**	**Field Inspection and Preparation**			**20**
2	**HTR**	**Harvester Test Runs (manoeuvring and pick-up tests)**			**223**
2.1	HTR.1	Manoeuvrability test runs (no production):		97	
2.1.1	HTR.1a	Straight-line test	24		
2.1.2	HTR.1b	Turning (radius) test	26		
2.1.3	HTR.1c	Obstacle avoidance test	25		
2.1.4	HTR.1d	Lane tracking test	22		
2.2	HTR.2	Pick-up test runs (with production):		126	
2.2.1	HTR.2a	First pick-up test	28		
2.2.2	HTR.2b	Pick-up test during turning	37		

Seq.	**Code**	**Test component**	**Duration (hours)**		
2.2.3	HTR.2c	Pick-up efficiency test	41		
2.2.4	HTR.2d	Pick-up performance test with turning	37		
3	**RIC**	**Riser Installation and Commissioning (circulation tests)**			**186**
4	**SIT**	**System Integration Test (functional testing)**			**24**
5	**STR**	**System Test Runs (commissioning & performance tests)**			**319**
5.1	STR.1	Commissioning test runs:		155	
5.1.1	STR.1a	Manoeuvrability test (no production)	60		
5.1.2	STR.1b	Production ramp-up test with 180'-turning	95		
5.2	STR.2	Nominal performance test runs:*		102	
5.2.1	STR.2a	Straight-line performance test with 180e-turning	41		
5.2.2	STR.2b	Contour mining (small-scale field test)	61		
5.3	STR.3	Advanced test runs (outside test field No 6):		62	
5.3.1	STR.3a	Capacity stress test runs	29		
5.3.2	STR.3b	Slope ability test runs (>3 degrees)	33		
6	**EST**	**Emergency Shutdown Test**			**24**
7	**DSC**	**Decommissioning and Site Closure**			**63**
				Total duration	**859**

Source: Draft Collector Test EIS (NORI, 2021). *Test runs to demonstrate target production rates and efficiencies.

ES3 Existing Marine Environment

ES3.1 Marine Physical Environment

ES3.1.1 Oceanography

The NORI-D lease area in the eastern CCZ region is influenced primarily by three latitudinally demarcated currents, from north to south:

- The westerly flowing North Equatorial Current (NEC) that is sourced from the California Current.
- The easterly flowing North Equatorial Countercurrent (NECC).
- The westerly flowing South Equatorial Current (SEC).

During boreal winter and spring (January–April) period, oceanography around NORI-D is more influenced by the NEC and California Current. However, during the boreal mid-summer (July) to early winter (December) period, the oceanography around NORI-D is more influenced by the NECC, which translates to warmer surface waters but there is also generally greater surface mixing during this period and a deepening of the thermocline. Ocean current magnitude decreases with increasing depth, with current speeds at the seafloor being only a few cm/s.

These current systems are dynamic and can be considered a series of flow fields and eddies as opposed to consistent jets. The frontal zones at the borders of these current systems are dynamic and form mixing areas that have seasonal latitudinal shifts.

The Mixed Layer Depth (MLD), defined as the depth where the temperature is 0.5 °C cooler than the surface temperature and accounts for changes in salinity (Monterey and Levitus, 1997), is generally between about 20–70 m across the length of the CCZ. Temporally stable MLD and thermoclines in the CCZ and can lead to concentrated nutrients at the base of the MLD, which are often associated with enhanced phytoplankton and zooplankton abundance and productive marine vertebrate foraging habitat. This nutrient enhancement at the base of the MLD appears to be present at NORI-D (CSA, 2020)

The pelagic environment of the CCZ is typical of the open ocean conditions of the eastern central Pacific. The upper water column is strongly stratified both in terms of temperature and salinity, with a shallow thermocline and halocline, with a well-developed and thick oxygen minimum layer located below the thermocline.

Water quality is addressed in detail in the Draft Collector Test EIS (NORI, 2021) and by Flynn and Connelly (2021a) and is not summarised here.

ES3.1.2 Ocean Floor and Benthic Environment

The benthic environment of the CCZ is characteristic of abyssal plains. The ocean floor is dominated by soft substrata including unconsolidated fine-grained sediments, deeper clayey sediments, and organic material. The homogeneity of these soft sediment abyssal plains is punctuated by areas of hard substrata, including polymetallic nodules and the occasional seamount.

ES3.1.3 Ambient Background Noise

There are a number of natural physical and marine biological sound sources, as well as existing anthropogenic sources of underwater sound that may be expected to be present at the NORI-D lease area in the CCZ, which include:

- Sea surface sound sources:
    - surface wind is a major contributor.
    - breaking waves, bubbles and sea spray.
    - rainfall noise at the sea surface.
- Lightning and thunder sources.
- Earthquake and tremor sound sources.
- Marine biological sound sources such as:
    - Cetacean calls and echolocation sounds.
    - Snapping shrimp.
    - Sound-producing (soniferous) fishes.
- Existing anthropogenic noise sources mainly from distant shipping and transiting ships.

Based on the sound recordings of deep-sea hydrophone deployments in shallow water (538 m depth) between December 2019 to June 2020 and in deep water (4,297 m depth) between October 2019 to April 2020), Table 2 presents a snapshot of measured ambient noise levels.

Table 2 Ambient noise measured in shallow and deep water at NORI-D

Location	Depth (m)	Broadband Sound Pressure Level (SPL) (dB re 1 μPa rms)				
		Average	**Range**	**10%**	**50%**	**90%**
Shallow water	538 m	105.0	97–118	100.0	104.8	110.7
Deep water	4,257 m	95.0	91–104	94.0	97.8	100.6

Source: NORI-D Collector Test EIS (NORI, 2021). rms is root mean square.

The recorded received sound levels in Table 2 indicate that the background range of ambient noise was lower at the deep-water recorder (91–104 dB re 1 μPa rms) compared to that of the shallow-water recorder (97–118 dB re 1 μPa rms).

ES3.2 Marine Biological Environment

The existing marine biological environment is presented in the Collector Test EIS (NORI, 2021) and in Flynn and Connelly (2021a, 2021b). This section summarises the hearing frequencies and communication or echolocation frequencies, and source levels when available, of key underwater noise-sensitive marine fauna. This allows Project-generated underwater noise fields to be compared with marine biological sound sources frequencies and especially if they overlap, which indicates the potential for interference of or masking of biologically relevant signals.

ES3.2.1 Baleen Whales

Baleen whales (Mysticeti) are classified within the low-frequency functional hearing group with a hearing frequency range from 7 Hz and 35 kHz (NMFS, 2018).

Table 3 presents hearing frequency ranges for selected baleen whales that have been observed or likely to be found in the eastern CCZ (Flynn and Donnelly, 2021a).

Table 3 Hearing frequency ranges for selected baleen whales

Common name	Scientific name	Best sensitivity frequency range#	Total frequency range*
Humpback whale	*Megaptera novaeangliae*	20 Hz to 8 kHz	20 Hz to 10 kHz
Bryde's whale	*Balaenoptera brydei*	70 to 900 Hz	70 Hz to 950 Hz
Minke whale	*Balaenoptera acutorostrata*	100 to 200 Hz	10 Hz to 22 kHz
Sei whale	*Balaenoptera borealis*	1.5 to 3.5 kHz	1.5 kHz to 3.5 kHz
Fin whale	*Balaenoptera physalus*	20 to 150 Hz	14 Hz to 28 kHz
Blue whale	*Balaenoptera musculus*	20 to 200 Hz	12 Hz to 31 kHz

Source: *Multiple reference sources form literature review. # Erbe (2002).

ES3.2.2 Toothed Whales and Dolphins

Most of the toothed whales (Odontoceti) occurring in the CCZ (e.g., dolphins, the larger toothed whales, beaked whales and bottlenose dolphins) are classified within the mid-frequency functional hearing group with a hearing frequency range from 150 Hz and 160 kHz (NMFS, 2018).

Some of the above hearing, vocalisation and communication frequency ranges in Table 3 may be referred to in subsequent assessments of acoustic impacts to marine fauna.

Table 4 presents hearing frequency ranges for selected toothed whales and dolphins that have been observed or likely to be found in the eastern CCZ (Flynn and Donnelly, 2021a).

Table 4 Hearing frequency ranges for selected larger toothed whales and dolphins

Common name	**Scientific name**	**Hearing frequency range**
Larger toothed whales:		
Killer whale	Orcinus orca	500 Hz to 120 kHz
False killer whale	Pseudorca crassidens	1.1 kHz to 130 kHz
Sperm whale	Physeter macrocephalus	100 Hz to 30 kHz*
Short-finned pilot whale	Globicephala macrorhynchus	20 kHz to 40 kHz[§]
Long-finned pilot whale	Globicephala melas	4 kHz to 100 kHz[#]
Smaller toothed whales (dolphins):		
Bottlenose dolphin	Tursiops truncatus	40 Hz to 150 kHz
Spotted dolphin	Stenella attenuata	3.1 kHz to 21.4 kHz
Spinner dolphin	Stenella longirostris	1 kHz to 65 kHz
Risso's dolphin	Grampus griseus	80 Hz to 100 kHz
Dusky dolphin	Lagenorhynchus obscurus	75 Hz to 175 kHz[a]

Source: Howorth (2003).* Wartzok and Ketten (1999) and Madsen et al. (2006). [#] Pacini et al. (2010); [§] Greenhow et al. (2014); [a] Yin (1999) and Tremel et al. (1998).

There was insufficient time available in the present study to undertake a literature search to collate hearing frequency ranges for the plethora of other toothed whales that have been observed or likely to occur in the NORI-D contact area and eastern CCZ.

ES3.2.3 Sea Turtles

The acoustic sensitivity of sea turtles relates mainly to their hearing ability and to some temporary underwater vocalisations limited to sea turtle hatchlings. There is limited information on underwater hearing in sea turtles. Notwithstanding, Table 5 presents a summary from the scientific literature of sea turtles that may occur in the CCZ and NORI-D lease area.

Table 5 Underwater hearing frequency ranges for sea turtles

Species	**Hearing range (Hz)**	**Most sensitive hearing range (Hz)**	**Reference**
Green turtle (*Chelonia mydas*)	100 – 800 (sub-adult)	200 – 400 sub-adult)	Bartol and Ketten (2006)
	50 – 1,600 (juvenile)	600 – 700 (juvenile)	Dow Piniak et al. (2016)

Species	Hearing range (Hz)	Most sensitive hearing range (Hz)	Reference
	50 – 1,600 (juvenile)	200 – 400 (juvenile)	Dow Piniak et al. (2012)
	100 – 800 (juvenile)	600 – 700 (juvenile)	Yudhana et al. (2010)
Loggerhead turtle (*Caretta caretta*)	25 – 1,000	100 – 400	Bartol et al. (1999); O'Hara and Wilcox (1990); Martin et al. (2012)
	50 – 1,000 (juvenile)	100 – 400 (juvenile)	Lavender et al. (2014)
	110 – 1,131 (adult)	200 – 400 (adult)	Martin et al. (2012)
Kemp's ridley turtle (*Lepidochelys kempi*)	100 – 500	100 – 200	Bartol and Ketten (2006)
Leatherback turtle (*Dermochelys coriacea*)	50 – 1,200 (hatchling)	100 – 400 (hatchling)	Cook and Forrest, 2005; Dow Piniak et al. (2012)

Lenhardt et al. (1983) proposed that the sea turtle ear is adapted for hearing via bone conduction in water, but bone conduction is a poor receptor in air, suggesting that the whole body serves as a receptor while the turtle is underwater. However, the range of bone-conducted sounds detected by sea turtles (except leatherback turtles) are limited to only low frequencies (Tonndorf, 1972).

ES3.2.4 Fishes

The hearing abilities and sensitivities of fish vary depending on whether they are bony fish (Osteichthyes) or cartilaginous fish (Chondrichthyes), which are described below.

Bony fishes (Osteichthyes)

Popper (2012) divided fish into four groups based on hearing abilities and morphology:

Group 1: Fish that do not have a swim bladder:

- Group 1 fish include species that are likely to use only particle motion for sound detection. The highest frequency of hearing is likely to be no greater than 400 Hz, with poor sensitivity compared to fish with a swim bladder. Fish within this group would include flatfish, some gobies, some species of tuna, and all elasmobranchs (i.e., sharks, skates and rays).

Group 2: Fish that detect sounds from below 50 Hz and up to perhaps 800–1,000 Hz (though several probably only detect sounds to 600–800 Hz).

- Group 2 fish include species that have a swim bladder but no known structures in the auditory system that would enhance hearing, and sensitivity (lowest sound detectable at any frequency) is therefore considered to be poor. Sounds would have to be more intense to be detected when compared to fishes in Group 3 (described below).

- Group 2 fish species detect both particle motion and pressure, and the differences between species are related to how well the species can use the pressure signal. A wide range of species falls into this category, including tuna with swim bladders (e.g., yellowfin tuna).

Group 3: Fish that have some type of structure that mechanically couples the inner ear to the swim bladder (or other gas bubble), thereby resulting in detection of a wider bandwidth of sounds and lower intensities than fish in other groups.

- Group 3 fish species detect sounds to 3,000 Hz or more, and their hearing sensitivity, which is pressure driven, is better than in fish of Groups 1 and 2. There are not many marine species known to fit within Group 3, but this group may include some species of sciaenids (drummers and croakers). It is also possible that a number of deep-sea species fall within this category, but that is only based on morphology of the auditory system. Other members of this group would include all Otophysi fish (mostly freshwater fishes), though few of these species other than catfishes are found in marine waters.

Group 4: All Group 4 fish species are members of the herring family and relatives (Clupeiformes).

- Group 4 fish hear sounds below 1,000 Hz in a similar manner to fish in Group 1, but their hearing range extends up to at least 4,000 Hz (e.g., sardines), and some species (e.g., American shad) can detect sounds over 180 kHz (Mann et al., 2001).

Cartilaginous fishes (Chondrichthyes)

Cartilaginous fish (Chondrichthyes) have no accessory organs of hearing often found in bony fishes, such as a swim bladder (Amundsen and Landrø, 2011) and as such, they are incapable of detecting sound pressure (Casper and Mann, 2012). Cartilaginous fish such as sharks, skates and rays, only possess inner ear labyrinths, which allows them to detect particle motion (Myrberg, 2001).

The hearing bandwidth for cartilaginous fish is from about 20 Hz up to 1 kHz, with similar thresholds in all species above 100 Hz (Casper and Mann, 2009). Studies of the hearing abilities of sharks have demonstrated highest sensitivity to low frequency sound between 40 Hz and 800 Hz, which is sensed solely through the particle-motion component of an acoustical field (Myrberg, 2001).

Casper et al. (2003) showed that the hearing sensitivities of four species of skate (Rajidae) were between 200 Hz and 800 Hz, with the most sensitive hearing between 200 Hz and 300 Hz.

Vocalisation and Sound Production in Fishes

In general, sounds produced by sound-producing (soniferous) fishes are used for communication are generally associated with reproductive activities (e.g., courtship or spawning) and territorial or aggressive behaviour (Hawkins and Amorim, 2000).

General fish sound and choruses have a source level range of between 120 and 160 dB re 1 µPa at 1 m with a frequency range of between 100 Hz and 5 kHz (Mann, 2012).

ES3.2.5 Marine Invertebrates

Most marine invertebrates are thought to be most sensitive to low-frequency particle motion as they lack gas-filled organs such as swim bladders (Edmonds et al., 2016). Table 6 lists frequency ranges detected by selected marine invertebrates.

Table 6 Frequency ranges detected by selected marine invertebrates

Species	Hearing range (Hz)	Most sensitive hearing range (Hz)	Reference
American lobster (*Homarus americanus*)	10 – 150	18 – 75	Offutt (1967)
Common prawn (*Palaemon serratus*)	100 – 3,000	N/R	Lovell et al. (2005)
Ocellated octopus (*Amphioctopus fangsiao*)*	50 – 200	50 – 150	Kaifu et al. (2007)
Longfin inshore squid (*Loligo pealeii*)	80 – 1,000	200 – 400	Mooney et al. (2016)
Common cuttlefish (*Sepia officianalis*)	85 – 1,000	100 – 300	Samson et al. (2014)
Pacific oyster (*Crassostrea gigas*)	10 – 1,000	10 – 200	Charifi et al. (2017)

A list of pelagic invertebrates in the midwater environment and deep water and abyssopelagic environment were not available to undertake searches on the hearing ranges of those species that may sense sound pressure as opposed to those sensing particle motion only.

ES4 Project Noise Source Levels

It is not possible to include all underwater noise sources likely to be generated by the Collector Test runs and system tests as they may be novel (i.e., prototypes or few analogues available) or their respective noise signatures may be unknown and are likely to vary widely depending on their operational state. Moreover, it would be an onerous task to accurately predict the underwater noise fields of more than a few sources. Therefore, the key louder noise sources (single or combined) have been selected as a first step for assessing their impacts on marine fauna. If the assessed impacts on marine fauna do not show negative or significant adverse impacts on marine fauna, then the second step to assess the Collector Test's quieter noise and vibration sources is not required nor warranted.

When multiple noise sources generating sounds at different sound pressure levels are present in the same general area, the sound with the highest decibel (dB) value will essentially "mask" the sounds with lower dB values. Under the rules of addition (i.e., combining noise levels as per the U.S. Navy, 1999; WSDOT, 2015), if there is a difference of more than a few dB between the received levels that each source produces at a given location, then the combined received level at that location will be determined by the loudest source. Where both sources produce similar sound levels, then the combined received level will be up to 3 dB higher than the received level due to an individual source.

ES4.1 Adopted Project Noise Source Levels

Based on the findings of the present report, Table 7 presents the key louder underwater noise source levels that were used to calculate distances to nominal isopleths of interest or to isopleths that represent acoustic threshold criteria for selected noise-sensitive marine fauna.

Table 7 Adopted underwater noise source levels for Collector Test components

Code	Collector Test Component	Source Level (dB re 1μPa at 1m)	Peak Frequency Range (Hz or kHz)
Surface waters (epipelagic zone):			
SSV	Surface Support Vessel (SSV) in DP mode	190	20 Hz to 2 kHz
OSV	Offshore Support Vessel (OSV) in DP mode	189	20 Hz to 2 kHz
SSV+OSV	Combined SSV + OSV in DP mode	**193**	20 Hz to 2 kHz
Midwater (epipelagic, mesopelagic and bathypelagic) zone:			
VTS	Upper rigid steel-pipe riser (with production)*	155	12–20 Hz
VTS	Lower rigid steel-pipe riser (with production)#	150	12–20 Hz
WRP	Wastewater return pipe	145	12-20 Hz
Benthic and deepwater environment (bathypelagic) zone:			
HTR.2	PCV pick-up test (with production)	**175**	20 Hz – 1kHz

Notes: DP mode means that a vessel is maintaining station by dynamic positioning using its thrusters. The blue shaded rows denote the predicted noise source levels that have been selected for assessing acoustic impacts to marine fauna. * upper section of the riser above the air injection point. # lower section of the riser below the air injection point.

Based on Table 7, the following underwater noise source levels (SLs) have been used and which represent the dominant Project noise in the ISA-recognised three depth zones of interest (ISA, 2020):

- Surface waters and epipelagic zone:
  Combined noise SL of the SSV and OSV in DP mode of **193 dB re 1 μPa at 1 m**.
- Mid-water (epipelagic, mesopelagic, and bathypelagic) zone:
  Noise SL of the VTS (upper riser with air injection) of **155 dB re 1 μPa at 1 m**.
  Noise SL of the VTS (upper riser with no air injection) of **150 dB re 1 μPa at 1 m**.
- Benthic boundary layer and deep-water (abyssopelagic) zone:
  Noise SL of the nodule collector system (PCV with production) of **175 dB re 1 μPa at 1 m**.

ES4.1.1 Acoustic Positioning and Geophysical Instrument Noise Sources

The Collector Test components include navigational positioning, acoustic underwater positioning systems and the use of geophysical instruments that generate mainly non-impulsive continuous or intermittent narrowband underwater noise of varying high frequencies. Currently envisaged instruments that are proposed to be used in the Collector Test program include:

- Multibeam echosounder (MBES)

- Acoustic Doppler Current Profilers (ADCP).
- Ultra-short baseline (USBL) acoustic positioning system
- Long baseline (LBL) acoustic positioning system.
- Inertial Measurement Units (IMU)
- Doppler Velocity Log (DVL)

Table 8 presents the adopted noise source levels and frequencies of some key systems and geophysical instruments.

Table 8 Adopted sound source levels of representative geophysical sensors

Geophysical source	Source Level* (dB re 1µPa at 1m)			Pulse frequency (kHz)	Pulse duration (ms)	Pulses per second (pps)
	Pk–Pk	RMS	SEL*			
Multi-beam echosounder [b]	226	218	182	200	0.25	50
USBL acoustic navigation [a]	211	202	177	25	8	4
LBL transponder	196[#]	188	154[#]	8–16	12	1
Single-beam echosounder [a]	221	213	177	200	0.10	5
Single-beam echosounder [b]	202	193	159	200	0.36	20
Side scan sonar [b]	232	220	179	200	0.084	N/R

Source: [a] EGS (2017); b *Sound pressure source level units are dB re 1 µPa at 1 m for peak-peak and RMS sound pressure levels, and sound exposure levels (SEL) source level units are dB re 1 µPa^2.s at 1 m. [#] Estimated values.

Table 9 presents additional operating frequencies, source levels, pulse frequency and repetition rates, and where available, the beamwidth in degrees (°) for a range of USBLs, transceivers and transponders.

Table 9 Summary of underwater noise characteristics of positioning systems

Equipment	Operating frequency (kHz)	Source level* (dB*)	Pulse duration (ms)	Repetition rate (Hz)	Beamwidth (°)
Sonardyne Ranger 2 Transponder	19 – 34	194	5	1	Omni.
Sonardyne Ranger 2 USBL HPT 3000/5/7000 Transceiver	19 – 34	194	5	1	NR
IxSea GAPS Beacon System	8 – 16	188	12	1	Omni.
Easytrak Nexus 2 USBL Transceiver	18 – 32	192	5	2	Omni.
Kongsberg HiPAP 501/502 USBL Transceiver	27 – 30.5	190	2	1	15
Kongsberg HiPAP USBL	25	202	1	4	NR

Source: NMFS (2019). *Source level units are dB re 1 µPa at 1 m root-mean-squared (rms). NR is not Reported. Ms denotes milliseconds. Omni. Denotes omnidirectional.

ES4.2 Calculated Distances to Selected Isopleths

Based on simple geometric spreading laws, the distances to nominal isopleths of interest including isopleths representing acoustic damage or acoustic disturbance threshold criteria for selected noise-sensitive marine fauna (e.g., whales and dolphins, sea turtles and fishes). Subsequent acoustic impact assessments for selected marine fauna will refer to the following tables.

ES4.2.1 Surface Vessel Noise Source Level and Isopleth Distances

Table 10 present estimates of distances to isopleths of the combined broadband continuous noise generated by the Project’s surface vessels (i.e., the SSV and OSV) as they maintain station by dynamic positioning using their thrusters. The source level of 193 dB re 1 µPa at 1 m is based on the combination of the individual vessel noise source levels using the rules of addition described above.

Table 10 Surface vessels in DP mode and distances to selected isopleths

Component	**Isopleth (dB re 1µPa rms, received level)**						
SL of 193 dB re 1 µPa at 1m	180	170	160	150	140	130	120
Distance to isopleth (m)	4.5	14.1	44.7	141.3	446.7	1,412	4,466

Notes: Vessel noise is a point source generating non-impulsive continuous broadband noise that is omnidirectional or hemispherical. A spherical spreading law ($20\text{Log}_{10}R$, where R is range in metres) was used for isopleth distance calculations, which is appropriate for a point source in deep water.

ES4.2.2 Riser Noise Source Levels and Isopleth Distances

Table 11 present estimates of distances to isopleths of broadband continuous noise generated by the flow slurry ascending the riser. Riser noise arises from the vertical transport of seawater, fine sediments and nodules, the flow of which generate non-impulsive, continuous broadband noise, with occasional knocking noise as nodules collide with each other and impact the steel pipe wall of the riser.

Note that there are two sections of the riser within the water column that need to be considered, as they have different line noise sources:

- The upper riser is a 2,500-m long riser section (with air lift) generating a line source of underwater noise within the epipelagic and mesopelagic zone.
- The lower riser is an approximately 1,800-m long section (without air lift) generating a line source of underwater noise within the mesopelagic and bathypelagic zones.
- In the upper riser section ,the line noise source level is estimated to be 155 dB re 1 µPa at 1 m, whereas the lower riser section noise source level is estimated to be 150 dB re 1 µPa at 1 m.

Table 11 Upper and lower risers and distances to selected isopleths

Component	**Isopleth (dB re 1µPa rms, received level)**						
Upper riser (with air lift):							
SL of 155 dB re 1 µPa at 1m	180	170	160	150	140	130	120
Distance to isopleth (m)	–	–	–	3.2	31.6	316.2	3,162
Lower riser (without air lift):							
SL of 150 dB re 1 µPa at 1m	180	170	160	150	140	130	120
Distance to isopleth (m)	–	–	–	–	10.0	100.0	1,000.0

Notes: The riser is a line source generating non-impulsive continuous broadband noise that is spreads laterally. A cylindrical spreading law ($10Log_{10}R$, where R is range in metres) was used for isopleth distance calculations, which is appropriate for a line source.

The anticipated louder noise generated by the upper riser section (155 dB re 1 µPa at 1 m) is due to the injection of air into the vertically rising slurry of seawater, fine sediments and nodules, which is more turbulent and results in a bubble and froth flow and an expected higher frequency of nodules and nodule fragments contacting with the wall of the rigid riser steel pipe, which generates non-impulsive, broadband intermittent noise in addition to slurry flow noise (scraping the inner wall of the riser). In addition, isothermal expansion of air decreases the water content of the slurry in the upper portion of the riser (Verichev et al., 2012). In the lower riser section, the slurry is comprised only of seawater, fine sediments and nodules with the absence of air (due to high pressure in the deep ocean) and, as such, there is less turbulence and vertical transport is more of a slug flow.

In addition, there will be a point source of noise generated by the air lift injector nozzles, which will be at around 2,500 m deep for the commercial operation.

ES4.2.3 Collector Vehicle Source Level and Isopleth Distances

Table 12 presents estimates of distances to isopleths of broadband continuous noise generated by the PCV nodule harvester (with production). The Collector Test run with production for the PCV is not connected by the flexible jumper hose to the base of the riser, as the collected nodules will be returned and deposited in a line on the seabed behind the PCV. Under a full PCV production test run, the underwater noise generated by the PCV would mask any noise within the flexible jumper hose, which will likely be a standard marine grade rubber hose, and which would be expected to produce less noise than the steel pipe of the rigid riser.

Table 12 Seabed nodule collector (PCV) and distances to selected isopleths

Component	**Isopleth (dB re 1µPa rms)**						
SL of 175 dB re 1 µPa at 1m	180	170	160	150	140	130	120
Distance to isopleth (m)	–	1.8	5.6	17.8	56.2	177.8	562.0

Notes: Underwater noise from the operating PCV is a point source generating non-impulsive continuous broadband noise that is omnidirectional and hemispherical. A spherical spreading law ($20Log_{10}R$, where R is range in metres) was used for isopleth distance calculations, which is appropriate for a point source in deep water.

ES4.2.4 Visualisation of Key Project Sound Fields

A visualisation of Project-generated underwater sound fields is shown in Figure 2, which presents a diagram of the extent of the sound fields generated by the louder noise sources resulting from Project activities.

In Figure 2, both the horizontal and vertical distances to isopleths of interest including isopleths that represent acoustic threshold criteria for selected marine fauna. For example, distances to the 140 dB re 1 μPa rms above which disruptive behavioural effects on baleen whales may be expected encompasses an area of 0.62 km^2 of the ocean around the Project's surface vessels (i.e., SSV and OSV in DP mode). Similarly, the 130 and 120 dB re 1 μPa rms isopleths, encompass areas of 19.5 km^2 and 62.7 km^2, respectively. The apparent large area of 62.7 km^2 encompassing the 120 dB re 1 μPa rms isopleth would be equivalent to that produced by a large Panamax tanker at cruising speed with a source level of about 190 dB re 1 μPa at 1m.

In Figure 2 the 140 and 150 dB re 1 μPa rms isopleths are not shown around the riser, as they are close to the rise and are masked by in its upper and lower sections by the non-impulsive continuous broadband noise fields emanating downwards and upwards from the Project's surface vessels in DP mode and the nodule collector (PCV), respectively.

ES4.2.5 Positioning and Geophysical Instrument Noise Sources

Table 13 lists the noise source levels and operating frequencies of underwater navigation and acoustic positioning systems, as well as geophysical sensing instruments (e.g., transceivers, transponders, beacons).

Table 13 Summary of underwater noise characteristics of positioning systems

Equipment	**Operating frequency (kHz)**	**Source level* (dB*)**	**Pulse duration (ms)**	**Repetition rate (Hz)**	**Beamwidth (°)**
Sonardyne Ranger 2 Transponder	19 – 34	194	5	1	Omni.
Sonardyne Ranger 2 USBL HPT 3000/5/7000 Transceiver	19 – 34	194	5	1	NR
IxSea GAPS Beacon System	8 – 16	188	12	1	Omni.
Easytrak Nexus 2 USBL Transceiver	18 – 32	192	5	2	Omni.
Kongsberg HiPAP 501/502 USBL Transceiver	27 – 30.5	190	2	1	15
Kongsberg HiPAP USBL	25	202	1	4	NR

Source: NMFS (2019). *Source level units are dB re 1 μPa at 1 m root-mean-squared (rms). NR is not reported.

ES5 Mitigation and Management Measures

Given the nature and short duration of the Collector Test program, there are limited avoidance, mitigation and management measures that can be implemented to avoid or minimise potential impacts to noise-sensitive marine fauna.

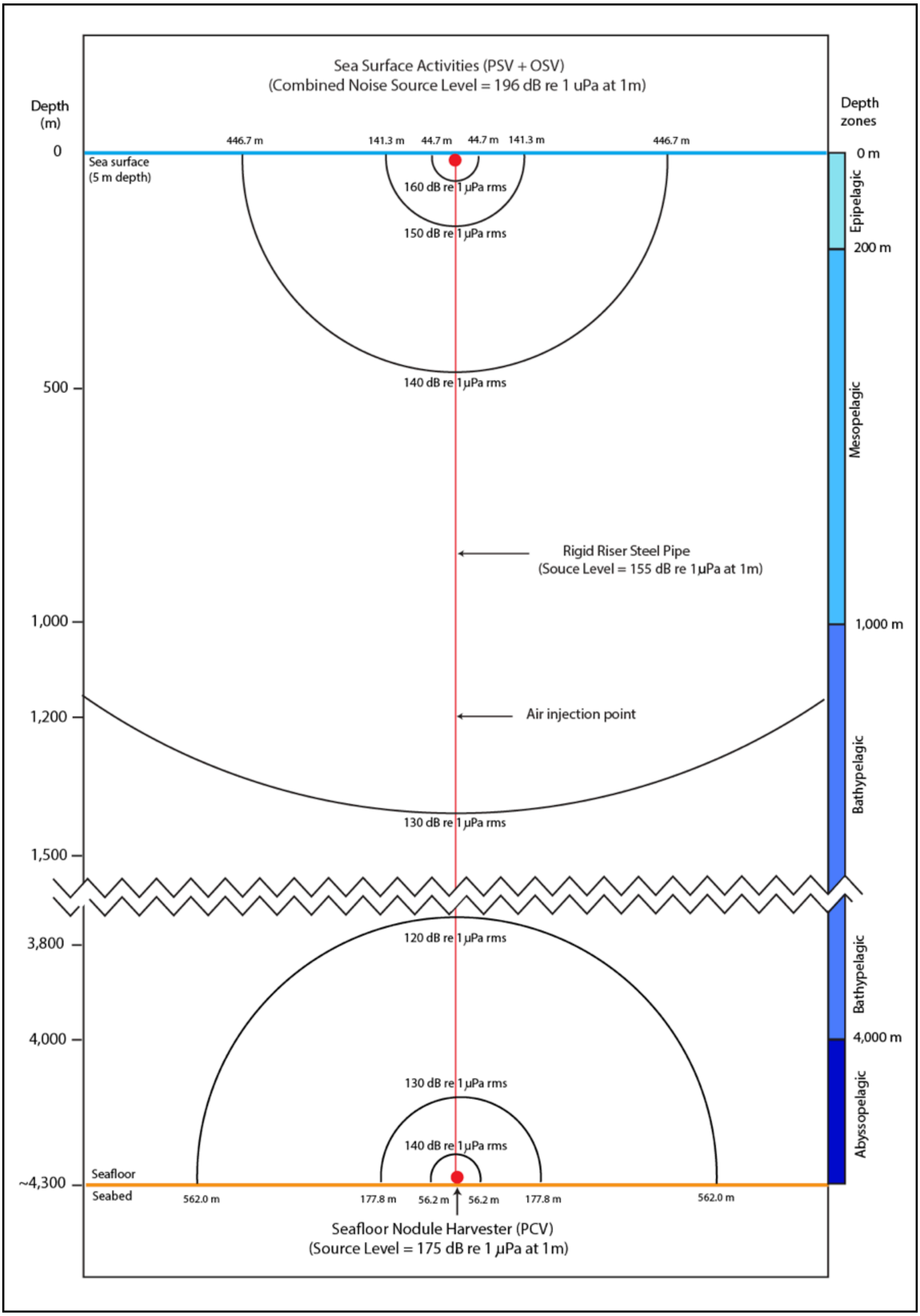


Figure 2 Predicted sound fields from key Collector Test components

ES5.1 Mitigation by Design

Some underwater noise mitigation measures by design include underwater noise reduction or minimisation measures that are incorporated in the Collector Test program components such as:

- Use of modern ships and offshore supply vessels that comply with IMO (2014) guidelines, though this will apply more to the proposed commercial production Surface Support Vessel (SSV) than the modified DS *Hidden Gem* selected for the Collect Test program.
- Use of modern and efficient thruster systems and dynamic positioning systems (e.g., DP II in preference to DP I, or DP III in preference to DP II).
- The of Vertical Transport System (VTS) using airlift riser technology rather than noisier technologies such as risers fitted with multiple slurry pumps (typically ~1,000 m apart) or risers fitted with a large single subsea slurry lift pump (SSLP) with individual positive displacement pump modules and located at the base of the riser.
- The outlet of the return process wastewater pipe will be located at 1,200 m depth, which is below the biologically productive epipelagic zone 90–200 m depth and upper mesopelagic zone (200–1,000 m depth), as well as minimising activities in the sound-fixing-and-ranging (SOFAR) channel (typically at a depth of 900 to 1000 m in the CCZ) within which low-frequency sound is transmitted over very long distances (hundreds to thousands of kilometres).

Additional mitigation by design measures may be identified during the Collector Test program, which can then be developed further and incorporated into the design of the full-scale commercial operation, which will be addressed in the ESIA.

ES5.2 Mitigation by Regulations

The NORI–D lease area is in international waters and not under the jurisdiction of any one state. However, there are number mitigation by regulations that reduce interaction with whales, for example regulations to reduce collision risks (IMO, 2009).

As an example of regulations for maintaining safe distances from cetaceans when the Collector Test SSV and OSV are manoeuvring around the NORI-D test site are those of the Commonwealth of Australia (DOEE, 2017):

Vessel no-go zones:

- Whale adult – no approach within 100 m
- Whale calf – no approach within 200 m
- Dolphin adult – no approach within 50 m
- Dolphin calf no approach within 150 m

In addition, there are stricter rules for vessel approaches in front of or behind whales:

- Whale adult – no approach within 300 m
- Whale calf – no approach within 300 m
- Dolphin adult – no approach within 150 m
- Dolphin calf no approach within 150 m

While manoeuvring in the vicinity of whales or dolphins at the Test Area, vessel masters or skippers would generally reduce vessel speed, for example to 8 knots or 'no wake'; however, this would not apply during dynamic positioning as the vessels are essentially stationary or moving very slowly (e.g., 0.5 m/s or 0.97 knots).

The above types of regulations would mainly apply during the setting up of the Collector Test program when the vessels first arrive at site. Thereafter, when the surface vessels are maintaining station using dynamic positioning thrusters (i.e., in DP mode), the above approach distance limitations do not apply. If a whale or dolphin voluntary approaches the vessels (though unlikely when the vessels are generating underwater noise in DP mode), no alteration of course or change in dynamic positioning is required.

ES5.2 Operational Mitigation Measures

There is potential for some navigational or positioning system transponders and geophysical instruments to be ramped up (i.e., emissions gradually increased to full power). up rather than being started with full-on emissions. Such ramp-up operational mitigation measures can serve to alert and allow time for noise-sensitive fauna (e.g., cetaceans) to leave the immediate area and avoid exposure to potential harmful sound levels. However, there are no data to support the contention that this is effective for other marine fauna such as fishes, invertebrates, or sea turtles (Amaral et al., 2020).

ES6 Acoustic Impacts to Marine Fauna

The following residual impact assessment of the proposed Collector Test runs and system tests to selected noise-sensitive marine fauna representative of the in the following three key ISQ-recognised depth zones (ISA, 2020):

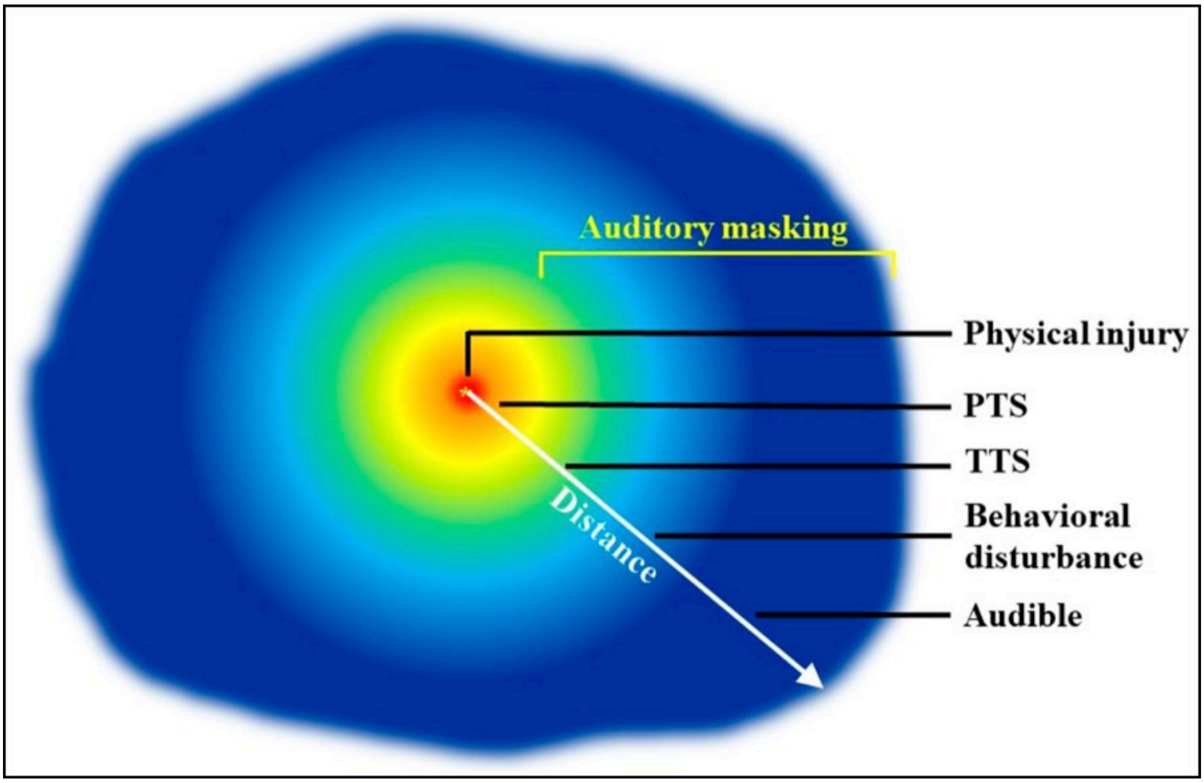
- Surface and epipelagic zone – combined noise of the SSV and OSV.
- Midwater (epipelagic, mesopelagic and bathypelagic) zone – Riser noise.
- Benthic and deepwater bathypelagic and abyssopelagic zone – seabed nodule harvester (PCV) noise.

ES6.1 Acoustic Zones of Influence

One approach of attempting to assess the effects of noise on marine pelagic fauna (e.g., cetaceans, sea turtles and fishes) is the concept of acoustic zones of influence (Richardson and Malme, 1995). Figure 3 shows a simple acoustic impact model based on the distance of the noise source from the receiver (receptor) such as a whale.

In Figure 3, the physical injury and permanent hearing loss (onset of Permanent Threshold Shift or PTS) zones represent acoustic damage impacts to marine fauna whereas the zones of temporary hearing loss (on set of Temporary Threshold Shift or TTS) and behavioural changes represent acoustic disturbance impacts. The zone of audibility is taken as the maximum potential radius of influence and is limited either by the hearing threshold of the marine animal under consideration or by the intensity of the sound related to ambient noise in that frequency range.

Acoustic masking may occur when Project-generated underwater noise impedes the ability of a marine animal to perceive a biologically relevant signal (Erbe et al., 2017). For this to occur the noise must be loud enough and have similar frequency content to the signal, as well as occurring at the same time.



Source: Guan and Brookens (2021) based on the original concept by Richardson and Malme (1995). PTS is Permanent Threshold Shift. TTS is Temporary Threshold Shift.

Figure 3 Conceptual acoustic zones of influence

The audibility or detectability (i.e., above background ambient levels) of Project-generated noise by a receptor (marine animal) is generally not considered an adverse impact, as long as acoustic damage or acoustic disturbance effects are not evident. It is also evident that the ambient noise varies over a wide range of levels (as much as 27 dB as measured at the NORI-D lease area) as conditions vary. Such variation is frequent and common. This has significant effects since the range (distance) of audibility of a source will depend on the noise level.

The following assessments of acoustic impacts relate principally to known noise sensitive marine fauna or groups. Oceanic birds such as albatrosses, petrels and storm-petrels, shearwaters are assessed not to be vulnerable to the Project-generated underwater noise as those species capable of diving are only transiently exposed to underwater noise resulting in insufficient cumulative exposure for acoustic impacts to occur.

ES6.2 Acoustic Impacts to Cetaceans

ES6.2.1 Acoustic Threshold Criteria for Cetaceans

A review of the literature revealed the following threshold levels of non-impulsive broadband noise at which acoustic damage and behavioural effects have been observed.

Many studies have defined a received sound level of 180 dB re 1 μPa rms as "harassment" and that a 160 dB re 1 μPa rms is the level likely to cause "behavioral response" (e.g., avoidance) (NMFS, 2014). Based on a literature search, the following acoustic threshold criteria have been adopted as a starting point to estimate the size of the area affected by Project-generated underwater noise, which is dominated by non-impulsive, continuous broad band noise. Therefore, the acoustic threshold of **180 dB re 1 μPa rms** has been adopted as threshold above which acoustic damage to a cetacean may be expected.

Acoustic Disturbance Threshold Criteria:

- Upper acoustic disruptive behavioural threshold of **160 dB re 1 μPa$_{rms}$** :
  - Threshold for onset of disruptive behavioural responses and significant avoidance of non-impulsive noise source, (NMFS, 2014)
- Lower acoustic behavioural threshold of **120 dB re 1 μPa$_{rms}$** :
  - Threshold for onset of more subtle behavioural responses such as increased presence at the surface and less frequent diving, but avoidance not expected.

The application of the 120 dB re 1 μPa$_{rms}$ threshold can sometimes be problematic because this threshold level can overlap with ambient background noise.

Permanent and Temporary Hearing Loss Threshold Criteria:

Table 14 presents non-impulsive sound PTS and TTS threshold criteria for cetacean functional hearing groups based on NOAA (2016) and Finneran (2016).

Table 14 Non-impulsive noise PTS and TSS threshold criteria for cetaceans

Cetacean functional hearing group (Southall et al., 2007)	**Hearing range**	**Non-impulsive Sound Exposure Level ($SEL_{24\text{-}h}$) (dB re 1 μPa^2·s)**	
		PTS threshold	**TTS threshold**
Low-frequency (LF) cetaceans	7 Hz to 35 kHz	199	179
Mid-frequency (MF) cetaceans	150 Hz to 160 kHz	198	178
High-frequency (HF) cetaceans	227 Hz to 160 kHz	173	153

Source: NOAA (2016) and Finneran (2016). The SEL assumes that a cetacean would remain in the area for 24 hours, which is an unlikely scenario; therefore, threshold levels would be larger for shorter duration periods.

Table 15 presents impulsive noise PTS and TSS threshold criteria for cetacean functional hearing groups.

Table 15 Impulsive noise PTS and TSS threshold criteria for cetaceans

Hearing Group	NMFS (2014)	NMFS (2018)			
	Behaviour	PTS onset Thresholds*		TTS onset Thresholds*	
	SPL_{rms}	SEL_{24h}	SPL_{pk}	SEL	SPL_{pk}
	dB re 1μPa	dB re 1μPa2·s	dB re 1μPa	dB re 1μPa2·s	dB re 1μPa
LF	160	183	219	168	213
MF		185	230	170	224
HF		155	202	140	196

Source: NMFS (2014, 2018). * Dual metric acoustic thresholds for impulsive sounds; whichever threshold results in the largest isopleth for calculating PTS onset is to be used. The threshold criteria are unweighted. LF, MF, and HF denotes low-frequency, mid-frequency and high-frequency cetacean functional hearing groups, respectively.

ES6.2.2 Impacts to Baleen Whales (Mysticeti)

Six species of baleen whales may be expected to occur in the CCZ including humpback, minke, Bryde's, sei, fin and blue whales. The humpback whale (*Megaptera novaeangliae*) has been selected as a representative for baleen whales as this species has been the most heavily researched in relation to its reactions and behaviour to both impulsive underwater noise (e.g., marine seismic surveying using airgun arrays) and non-impulsive underwater noise (e.g., shipping traffic, drilling and dredging).

As most of the underwater noise generated by the Collector Test components and activities are non-impulsive, continuous broadband noise, received levels in SPL rms have been selected to assess impacts on the humpback whale as a surrogate for all baleen whales. Since baleen whales are associated primarily with the sea surface and epipelagic zone, the principal Project-generated noise within this zone is associated with the spread of surface vessels (SSV and OSV) in DP mode at the Collector Test Area.

Acoustic Damage Impacts to Baleen Whales

Acoustic damage impacts to baleen relate to potential injury, tissue damage or permanent hearing loss (as measured by Permanent Threshold Shift (PTS) onset). The findings of the present study are as follows:

- The adopted published threshold criterion for acoustic damage to cetaceans (180 dB re 1 μPa rms) is limited to a zone within 4.5 m of the combined SSV and OSVs, which represents an extremely small area and volume of water, and a baleen whale is unlikely to approach or remain in this small impact zone.
- In the case of diving baleen whales, the acoustic damage isopleth of 180 dB re 1 μPa rms is not exceeded in epipelagic or mesopelagic waters in the vicinity of upper half of the rigid riser, which has a line source level of 155 dB re 1 μPa a 1m.

- The non-impulsive cumulative Sound Exposure Level ($SEL_{24\ hr}$) PTS threshold criterion of 199 dB re 1 $\mu Pa^2 \cdot s$ (Table 14) is not predicted to be exceeded given that a baleen whale is most unlikely to remain in direct proximity of the SSV/OSV thrusters for a period of 24 hours. Therefore, no tissue damage or permanent hearing loss (PTS onset) of baleen whales is predicted.

High-frequency instrument Impacts

Most baleen whales have hearing sensitivities below that of the high frequency echosounders or other geophysical instruments, for example the humpback whale (range 20 Hz to 8 kHz). Baleen whales are unlikely to detect any frequency used by high-frequency acoustic positioning systems and geophysical instruments, except the lowest frequencies (i.e., 8 to 10 kHz) of an LBL transponder (8–16 kHz range) .Therefore, no acoustic injuries or auditory damage (PTS onset) to baleen whales are predicted from the operation of high-frequency transducers used in acoustic navigation or positioning systems or multibeam echosounders (MBES), as they would have to pass transducers at close range and remain there to be subjected to sound levels that can cause these effects.

Overall, no acoustic damage impacts to baleen whales at the surface or diving within the epipelagic or mesopelagic zones are predicted from underwater noise generated by Project's surface vessel activities.

Acoustic Disturbance Impacts to Baleen Whales

Two acoustic behavioural disturbance threshold criteria for baleen whales are considered: a) 160 dB re 1 µPa rms above which baleens whales elicit disruptive behaviour (e.g., deviating around a noise source or vacating an area to avoid of a noise source), and b) 120 dB re 1 µPa rms above which baleen whales show more subtle behavioural responses or reactions may occur (e.g., brief orientation responses or minor changes in locomotion speed, direction, or diving). The findings of the present study are as follows:

- The acoustic threshold criterion of 160 dB re 1 μPa_{rms} for disruptive behavioural impacts (e.g., whales deviating or vacating an area) is only exceeded within 45 m of the Project's surface vessels in DP mode, which represents a small area or volume of seawater within which a baleen whale is unlikely to approach or remain in such close proximity to the vessels.

- The non-impulsive cumulative Sound Exposure Level ($SEL_{24\ hr}$) TTS threshold criterion of 179 dB re 1 $\mu Pa^2 \cdot s$ (Table 14) and the impulsive cumulative SEL of 168 of dB re 1 $\mu Pa^2 \cdot s$ (Table 15) are not predicted to be exceeded given that a baleen whale is most unlikely to remain in direct proximity of the SSV/OSV thrusters for a period of 24 hours. Therefore, no temporary hearing loss (TTS onset) to baleen whales is predicted.

- The acoustic threshold criterion of 120 dB re 1 μPa_{rms} for low level or subtle behavioural impacts to cetaceans is exceeded within 4.4 km radius of the Project's surface vessels in DP mode. Baleen whales within this zone will be exposed to non-impulsive continuous broadband noise above 120 dB re 1 µPa rms, which will readily be audible as it will be above ambient background noise (range 97 to 118 dB re 1 μPa_{rms}). The radius of the 120 dB re 1 µPa$_{rms}$ sound field will reduce during periods of rainfall or higher sea states, which increase ambient levels near the ocean surface.

- Given that free-ranging, approaching baleen whales should be able to sense the Project-generated noise gradient and may initiate a range of responses, such as moving towards or away from the Surface vessel sin DP mode, or not reacting at all. In addition, the Project's Test Area and its predicted ensonified zone is not within the known migratory routes of baleen whales.

This report has assessed that Project activities are not expected to cause any adverse impacts on baleen whales. The equivalent underwater noise field out the 120 dB re 1 µPa$_{rms}$ isopleth would be a Panamax tanker at its normal cruising speed (~13 knots) with a noise source level of 190 dB re 1 µPa at 1 m. The radial distance of 4.4 km to the 120 dB re 1 µPa$_{rms}$ isopleth is within the range of behavioural impact zones (3.5 to 4.5 km radius) determined for marine rock dumping and medium-sized cutter suction dredgers (CSD) and small sized trailing suction hopper dredgers (THSD) vessels and dredging activities (Li, 2019).

Since the Project's surface vessel activities are highly localised to a specific offshore site (i.e., the Test Area within the NORI-D lease area), the noise source may be considered as a relatively 'fixed' or stationary location, and to which some cetaceans show less aversion or avoidance behaviour. For example, Richardson et al. (1995) state that "*stationary industrial activities producing continuous noise result in less dramatic reactions by cetaceans than do moving sound sources, particularly ships*".

Overall, acoustic disturbance impacts to baleen whales from Project activities are assessed to be negligible and not significant given the small area of ocean affected compared to the surrounding large expanse of ocean. The radial distance of 4.4 km to the 120 dB re 1 µPa rms isopleth is within the range (3.5 to 4.5 km) of behavioural impact zones determined for marine rock dumping and medium-sized cutter suction dredgers (CSD) and small sized trailing suction hopper dredgers (THSD) vessels and dredging activities.

Auditory Masking Impacts to Baleen Whale Calls

There are no peer-reviewed threshold criteria for assessing masking effects on baleen whales when exposed intermittently or continuously to low sound pressure levels within the range of ambient background levels. Notwithstanding, the findings of this report are:

- Potential masking impacts to cetacean vocalisation or communications are predicted to be low, given the low source sound pressure levels generated by the Project's surface vessels in DP mode, which reduce rapidly with distance from the source.
- Potential masking may be countered by baleen whales such as humpback and northern right whales, by increasing the intensity or altering the frequencies of their calls when present in an area where noise is above ambient levels.
- Communications between baleen whale mother and calf pairs (should they be present on the CCZ) are least likely to be affected by masking, given their natural protective close proximity to each other.

ES6.2.3 Impacts to Toothed Whales (Odontoceti)

Acoustic impacts to toothed whales are expected to be less than those predicted for baleen whales above and, as mid-frequency cetaceans, they are sensitive to higher sound frequencies ranging from 150 Hz to 160 kHz which, although there is some overlap at the lower frequencies, are generally above those generated by the Project (20 Hz to 2 kHz).

Acoustic Damage Impacts to Toothed Whales

- The adopted published threshold criterion for acoustic damage to cetaceans (180 dB re 1 µPa rms) is limited to a zone within 4.5 m of the combined SSV and OSVs, which represents an extremely small area and volume of water unlikely to be approached by a toothed whales or dolphins.
- In the case of diving toothed whales (which dive deeper than baleen whales), the acoustic damage isopleth of 180 dB re 1 µPa rms is not exceeded in epipelagic or mesopelagic waters in the vicinity upper half of the rigid riser, which has a line source level of 155 dB re 1 µPa a 1m.
- The non-impulsive cumulative Sound Exposure Level ($SEL_{24\ hr}$) PTS threshold criterion of 198 dB re 1 $\mu Pa^2 \cdot s$ (Table 14) and impulsive sound SEL of 185 dB re 1 $\mu Pa^2 \cdot s$ (Table 15) are not predicted to be exceeded given that a toothed or dolphin whale is most unlikely to remain in direct proximity of the SSV/OSV thrusters for a period of 24 hours. Therefore, no tissue damage or permanent hearing loss (PTS onset) to toothed whales is predicted.
- The non-impulsive cumulative Sound Exposure Level ($SEL_{24\ hr}$) TTS threshold criterion of 178 dB re 1 $\mu Pa^2 \cdot s$ (see Table 14) and impulsive sound SEL of 170 dB re 1 $\mu Pa^2 \cdot s$ (Table 15) are not predicted to be exceeded given that a toothed whale or dolphin is most unlikely to remain in direct proximity of the SSV/OSV thrusters for a period of 24 hours. Therefore, no temporary hearing loss (TTS onset) to toothed whales or dolphins is predicted.
- No acoustic injuries or auditory damage (e.g., PTS and TTS) to toothed whales or dolphins are predicted from the operation of high-frequency transducers used in acoustic navigation or positioning systems or multibeam echosounders (MBES), as they would have to pass transducers at close range and remain there to be subjected to sound levels that can cause these effects.
- While most toothed whales and dolphins have hearing sensitivities that overlap that of the high-frequency instruments, they will readily detect the Project’s high frequency signals. However, toothed whales or dolphins approaching the Test Area will detect the sound gradients of the high-frequency instruments sound signals may be attracted to sound beams, avoid them or show little interaction

No acoustic damage impacts to toothed whales are predicted from the low-frequency noise (20 Hz to 2 kHz) generated by the Project’s surface vessels (SSV and OSV) in DP mode, which will generate non-impulsive, continuous broadband noise with frequency between 20 Hz and 2 kHz. In addition, no acoustic damage impacts from the Projects’ high-frequency transponders or geophysical instrument sources to toothed whales or dolphins are predicted. In some cases, dolphin species may be attracted to the Project’s high-frequency signals as is commonly observed for some dolphin species (e.g., bottlenose dolphins) that are inquisitive and regularly approach vessels that are actively using side scan sonars or multibeam echosounders (NSR, 2001).

Acoustic Disturbance of Toothed Whales

- The acoustic threshold criterion of 160 dB re 1 μPa_{rms} for disruptive behavioural impacts (e.g., whales deviating or vacating an area) is only exceeded within 45 m of the Project's surface vessels in DP mode, which represents a small area or volume of seawater within which a toothed whale or dolphin is unlikely to approach or remain in such close proximity to the vessels.
- The acoustic threshold criterion of 120 dB re 1 μPa_{rms} for low level or subtle behavioural impacts to cetaceans is exceeded within 4.4 km radius of the Project's surface vessels in DP mode. Toothed whales and dolphins within this zone will be exposed to non-impulsive continuous broadband noise above 120 dB re 1 μPa rms, which will readily be audible as it will be above ambient background noise (range 97 to 118 dB re 1 μPa_{rms}). The radius of the 120 dB re 1 μPa_{rms} sound field will reduce during periods of rainfall or higher sea states, which increase ambient levels near the ocean surface. However, unlike baleen whales, toothed whales and dolphins are unlikely to be deterred by such low levels of continuous broadband noise containing low frequencies.

Overall, acoustic disturbance impacts to toothed whales and dolphins are predicted to be negligible for the principle non-impulsive continuous broadband noise generated by Collector Test components and activities.

Auditory Masking Impacts to Toothed Whales

The sound emissions from underwater acoustic positioning systems and geophysical instruments comprise brief, high frequency pulses (in the order of a few milliseconds), occurring several seconds apart. Masking effects in toothed whales caused by the high-frequency emissions from underwater acoustic positioning systems and geophysical instruments would be temporary and negligible because the bandwidths are limited to various narrow beam frequencies (e.g., 12 kHz for MBES) compared to the broader spectrum of toothed whale communication calls and echolocation. In addition, sound levels drop very rapidly within a short distance outside the beams.

ES6.3 Impacts to Sea Turtles

ES6.3.1 Acoustic Threshold Criteria for Sea Turtles

Sea turtle hearing sensitivity is not well studied and there are no published noise level criteria unconstrained, free-ranging sea turtles at sea. Avoidance reactions to seismic sources have been documented in caged turtles at levels between 166 and 179 dB re 1 μPa rms (McCauley et al., 2000; Moein-Bartol et al., 1995). The lower threshold level of 166 dB re 1 μPa rms is based on research by McCauley et al. (2000) who exposed caged turtles to the impulsive noise of a single airgun (Bolt 600B, 20-cubic inch chamber), increased swimming speed was noted above 166 dB re 1 μPa rms and more erratic behaviour above 175 dB re 1μPa rms. Therefore, for the purposes of the present report, a conservative acoustic behavioural disturbance threshold of **175 dB re 1 μPa rms** has been adopted in this report as applicable to free-ranging sea turtles that may be exposed to non-impulsive, continuous broadband noise typical of the proposed Collector Test activities at the ocean surface (e.g., the SSV).

Popper et al. (2014) proposed that dual injury threshold levels of a cumulative SEL of 210 dB re 1 μPa^2·s and a peak SPL of 207 dB re 1 μPa$_{pk}$ applicable to fish should apply to sea turtles. However, Table 16 lists more recent physiological threshold criteria that have been proposed by Hulton et al. (2020) for TTS onset, PTS onset and gastrointestinal tract injury onset in sea turtles.

Table 16 Recent acoustic threshold criteria for sea turtles

Behavioural criteria	**Physiological criteria**		
	TTS onset	**PTS onset**	**GI onset injury ***
175 dB re 1 μPa rms	189 dB re 1 μPa^2·s *	204 dB re 1 μPa^2·s *	243 dB re 1 μPa$_{pk}$
	226 dB re 1 μPa$_{rms}$	232 dB re 1 μPa$_{rms}$	

Notes: * Units are for Sound Exposure Level (SEL) all other values are in units for Sound Pressure Level (SPL). # GI onset injury denotes a gastrointestinal tract injury SPL of 50% (Hutton et al, 2020).

ES6.3.2 Acoustic Damage Impacts to Sea Turtles

The range hearing sensitivities (25 to 1,600 Hz) overlaps the frequency range of Project-generated noise (20 Hz to 2 kHz). The following summarises acoustic damage impacts to sea turtles from Project-generated noise sources:

- The 232 dB re 1 μPa$_{rms}$ for TTS onset is not exceeded by any Project-generated noise source; therefore, permanent hearing loss in sea turtles is not predicted.
- The 226 dB re 1 μPa$_{rms}$ for PTS onset is not exceeded by any Project-generated noise source; therefore, temporary hearing loss in sea turtles is not predicted.

Overall, acoustic damage impacts to sea turtles are assessed to be negligible given the absence of loud Project noise sources.

ES6.3.3 Acoustic Disturbance Impacts to Sea Turtles

The following summarises acoustic damage impacts to sea turtles from Project-generated noise sources:

- The disruptive behavioural threshold criterion of 175 dB re 1 μPa rms is exceeded within 7.5 m of the point source (vessel draft of 5 m below the sea surface) of surface vessels in DP mode. This represents a minor impact zone for sea turtles, which are unlikely to approach the surface vessels at lower levels within the sound gradient.
- The disruptive behavioural threshold criterion of 175 dB re 1 μPa rms is not exceeded by riser noise, which has a source level of 155 dB re μPa at 1 m. Therefore, acoustic disruptive disturbance of diving sea turtles from low-level riser noise is not predicted.

- Seabed noise from the nodule harvester (PCV) will have no impact on sea turtle behaviour, given that diving turtles do not dive to the deep ocean environment (i.e., abyssopelagic zone).

Overall, no acoustic disturbance impacts to free-ranging sea turtles in the Nori-D Test Area are predicted.

ES6.3.4 Auditory Masking Impacts to Sea Turtles

Adult sea turtles do not vocalise underwater, therefore, there is no capacity for masking impacts

ES6.4 Impacts to Fishes

ES6.4.1 Acoustic Threshold Criteria for Fishes

Table 17 presents acoustic damage (injury and PTS onset) and acoustic disturbance threshold criteria for fishes exposed to impulsive and non-impulsive noise.

Table 17 Acoustic threshold criteria for fish functional hearing groups

Fish Functional Hearing Group	**Acoustic injury and PTS onset**	**Impairment/Acoustic Disturbance**	
		Recoverable Injury	**TTS onset**
Thresholds for impulsive noise:			
Group 1 fish: No swim bladder (particle motion detection)	219 dB SEL or 213 dB SPL$_{pk}$	216 dB SEL or 213 dB SPL$_{pk}$	>219 dB SEL
Group 2 fish: Swim bladder not involved in hearing (particle motion detection)	210 dB SEL24h or 207 dB SPL$_{pk}$	203 dB SEL or 207 dB SPL $_{pk}$	>186 dB SEL
Group 3 fish: Swim bladder involved in hearing (primarily sound pressure detection or 'hearing')	207 dB SEL or 207 dB SPL$_{pk}$	203 dB SEL or 207 dB SPL$_{pk}$	186 dB SEL
Thresholds for non-impulsive continuous noise:			
Group 3 fish: Swim bladder involved in hearing (primarily sound pressure detection or 'hearing')	–	170 dB SPL$_{rms}$	158 dB SPL$_{rms}$

Source: Based on Xodus (2016) and Popper et al. (2014); Peak sound pressure level (SPL) in units of dB re 1 μPa; sound exposure level (SEL) in units of dB re 1 μPa^{2}·s.

In Table 17 there are no acoustic injury and PTS onset for non-impulsive, continuous broadband noise.

ES6.4.2 Acoustic Damage Impacts to Fishes

No acoustic damage impacts to fishes are predicted, given the absence threshold criteria for permanent acoustic injury or PTS onset to non-impulsive, continuous broadband noise (see Table 17). This agrees with Popper et al. (2014) who state there is no direct evidence of mortality or potential mortal injury to fishes from ship noise which, in the case of the current Project, would also apply to non-impulsive, continuous broadband noise associated with the riser and seabed PCV activities.

ES6.4.3 Acoustic Disturbance Impacts to Fishes

The following summarises acoustic disturbance impacts to fishes from Project-generated noise sources:

- The behavioural threshold criterion of 150 dB re 1 μPa$_{rms}$ is exceeded within 141.3 m of the point source (vessel draft of 5 m below the sea surface) of surface vessels in DP mode. This represents a minor impact zone for fishes, which are unlikely to approach the vessels at lower levels within the sound gradient.

- The behavioural threshold criterion of 150 dB re 1 μPa$_{rms}$ is exceeded within 3.2 m of the riser, which has a line source level 155 dB re 1μPa at 1m. Fish behavioural disturbance and avoidance within this very small impact zone is assessed as negligible.

- The TSS onset threshold of 158 dB re 1 μPa$_{rms}$ is exceeded within 56.2 m of the point source (vessel draft of 5 m below the sea surface) of surface vessels in DP mode. This represents a small impact zone for fishes to experience temporary hearing loss. Fishes are unlikely to remain in proximity of the surface vessels owing to underwater noise and turbulent flows generated by the thrusters and, therefore unlikely to be exposed to TSS onset.

- The acoustic recoverable injury threshold of 170 dB re 1 μPa$_{rms}$ is exceeded within 14.1 m of the point source (vessel draft of 5 m below the sea surface) of surface vessels in DP mode. This represents a small impact zone for fishes, which are also unlikely to remain in proximity of the surface vessels owing to underwater noise and turbulent flows generated by the thrusters and, therefore unlikely to succumb to recoverable injuries.

- The acoustic recoverable injury threshold of 170 dB re 1 μPa$_{rms}$ is not exceeded in the vicinity of the riser and only within 1.8 m of the seabed PCV (with production). Overall, no recoverable injuries to midwater or deepwater fishes are predicted for the riser and PCV operation.

- The TSS onset threshold of 158 dB re 1 μPa$_{rms}$ is exceeded within 56.2 m of the point source (vessel draft of 5 m below the sea surface) of surface vessels in DP mode. This represents a small impact zone for fishes to experience temporary hearing loss. Fishes are unlikely to remain in proximity of the surface vessels owing to underwater noise and turbulent flows generated by the thrusters and, therefore unlikely to be exposed to TSS onset.

- The TSS onset threshold of 158 dB re 1 μPa$_{rms}$ is not exceeded in the midwater environment surrounding the riser, which has a line source level of 155 dB re 1 μPa at 1 m, which is of similar in magnitude to the TSS onset threshold. Therefore, temporary hearing loss in midwater fishes is not predicted.

- The TSS onset threshold of 158 dB re 1 μPa$_{rms}$ is exceeded within 7.1 m the seabed PCV (with production), which as has source level of dB re 1 μPa at 1 m. This represents a very small impact zone for deepwater and abyssopelagic fishes and, therefore, temporary hearing loss is not predicted.

Overall, acoustic disturbance impacts to shallow water, midwater environment and deepwater fishes are assessed to be negligible, given the relatively low to moderate source levels of non-impulsive continuous broadband noise and the fact that the sound fields attenuate rapidly with distance. In addition, fishes are expected to acclimate ('habituate') or at least desensitise to the sound fields emanating from the Project's point or line noise sources to some degree.

ES6.4.4 Auditory Masking Impacts to Fishes

Since the vocalisation and communication frequency ranges of some fish species overlaps the frequency range of the Project's proposed activities (20 Hz–2 kHz), there is a potential for the masking of fish vocalisations and communication calls, especially benthic soniferous species.

At the seabed, the source level of the Collector Test of the PCV (with production) is predicted to be 175 dB re 1 μPa at 1m, which 140, 130 and 120 dB re 1 μPa rms isopleths at distances of 56.2, 177.8 and 562 m, respectively. These zones within which potential masking of fish vocalisation and communications are assessed to be small, thus masking impacts to seabed fish vocalisations and other communication calls would be highly localised and not significant in the wider population of benthic soniferous fish in adjoining seabed areas.

A limitation for assessing masking impacts is the absence of a species list of deepwater, epibenthic and benthic fish species for the NORI-D Test Area or adjoining CCZ areas.

ES6.5 Acoustic Impacts to Invertebrates

The assessment of impacts to marine invertebrates Is performed separately for those species or groups that live in the water column (i.e., pelagic invertebrates) and those that live on or in the seabed (i.e., epibenthic and infauna, respectively)

In general, marine invertebrates lack a gas-filled bladder or other gas-filled organs and are thus unable to detect the pressure changes associated with sound pressure waves emanating from the Project's noise sources.

ES6.5.1 Acoustic Threshold Criteria for Marine Invertebrates

In the absence of any peer reviewed acoustic threshold criteria for marine invertebrates, the accepted practice is to use the acoustic threshold criteria for the Group 2 fish functional hearing group (i.e., fishes without a mechanically coupled gas bladder to the inner ear). However, in Table 17, there are only threshold criteria for the Group 3 fish functional hearing group fishes (i.e., swim bladder involved in hearing); therefore, the threshold criteria for non-impulsive noise for the Group 3 fish functional hearing group have been conservatively adopted for those marine invertebrates capable of sensing sound pressure.

While it is generally accepted that most marine invertebrates have sensory organs or systems that sense particle motion (e.g., vibrations), there are no peer-reviewed marine invertebrates threshold criteria for particle motion. In the absence of vibration threshold criteria, particle motion has been considered qualitatively in the present report and especially those cases where a Project Collector Test component is likely to generate vibrations in the ocean floor.

Acoustic Damage to Invertebrates

Most marine invertebrates in the water column (e.g., squid and jellyfishes) and benthic environment (e.g., decapod crustaceans and molluscs) do not have any gas-filled chambers (Lovell et al., 2005), there is no possibility for amplification of sound pressure waves from Project-generated noise sources.

Given that the Collector Test components and activities generate non-impulsive continuous broadband noise, acoustic damage impacts are not expected in those marine invertebrates of the upper ocean, midwater environment and deepwater and benthic environment.

Acoustic Disturbance Impacts to Invertebrates

Most macroinvertebrate species within the NORI-D contact area are benthic sedentary forms, which are unable to evade PCV-generated underwater noise and vibration. Vibration impacts at the seabed from operation of the PCV are predicted to be highly localised to the immediate area of nodule harvesting, therefore behavioural disturbance of benthic macroinvertebrates is assessed to be negligible. Many benthic macroinvertebrates will be physically disturbed by nodule harvest test runs, which is addressed separately in the Draft Collector Test EIS.

In terms of acoustic disturbance to cephalopods in the water column, which are a major prey item for deep diving whales, Kaifu et al. (2007) have shown that the common squid (*Loligo vulgaris*) responds by jetting and moving away from a noise source. This behavioural response may be expected to occur in those cephalopod species within the in the Collector Test Area. area.

- The adopted acoustic threshold criterion of 150 dB re 1 μPa rms for water column cephalopods above which behaviour effects may be expected is exceeded at 141.3 m (Table 10) from the underwater noise generated by the Project's surface vessels (SSV and OSV in DP mode). This potential behavioural impact zone represents a very small area or volume of seawater within which cephalopods may occur. This Project-generated noise is not predicted to adversely disturb water column cephalopods, owing to their high mobility and behavioural avoidance of the Project's louder noise sources

Overall, the Project's acoustic noise and/or vibration sources within the water column or near the seabed are not predicted to result in significant behavioural disturbance of marine invertebrates, owing to the relatively small areas or volumes of seawater within which the acoustic behavioural threshold criterion of 150 dB re 1 μPa$_{rms}$ is exceeded or the highly located area of vibrations within the seabed and immediate overlying water.

ES7 Limitations and Uncertainties

ES7.1 Limitations

The present report presents the results and findings of a high-level desktop assessment study. Underwater noise and vibration measurements and detailed acoustic modelling were not undertaken, as this will be undertaken separately by a consultancy specialising in underwater acoustics.

The use of simple geometric propagation and transmission loss equations to calculate distances to isopleths of acoustic threshold criteria for selected noise-sensitive marine fauna is a simplification. However, conservative values have been used so that a reasonable idea of potential impact zones of Project-generated underwater noise could be determined and allow impacts on marine fauna to be assessed.

ES7.2 Uncertainties

An assessment of cumulative underwater noise impact assessment was not possible for the purposes of the present report. Such an exercise requires more detailed quantitative acoustic modelling, which would be carried out by an acoustic consultancy.

Notwithstanding, the present report has assessed that the noise sources of the Collector Test components and activities occur within different but distinct zones, as exemplified in Figure 2, through riser noise spans most of the water column. Surface vessels in DP more dominate the Project-generated sound field in the upper ocean as does the nodule harvester (PCV) on and near the seabed. While the riser-generated noise spans most of the water column (~4,250 m), the riser noise field is masked in its upper and lower sections in the vicinity of surface vessel noise and seabed nodule harvester noise, respectively.

ES8 Conclusions

This report concludes that the underwater noise generated in the shallow-water environment (surface support vessels in DP mode), midwater environment (riser tests), and deep ocean environment (seabed nodule harvesting test runs) are unlikely to trigger any long-term, persistent, deleterious impacts upon marine fauna within these three environmental compartments recognised by the ISA (2020).

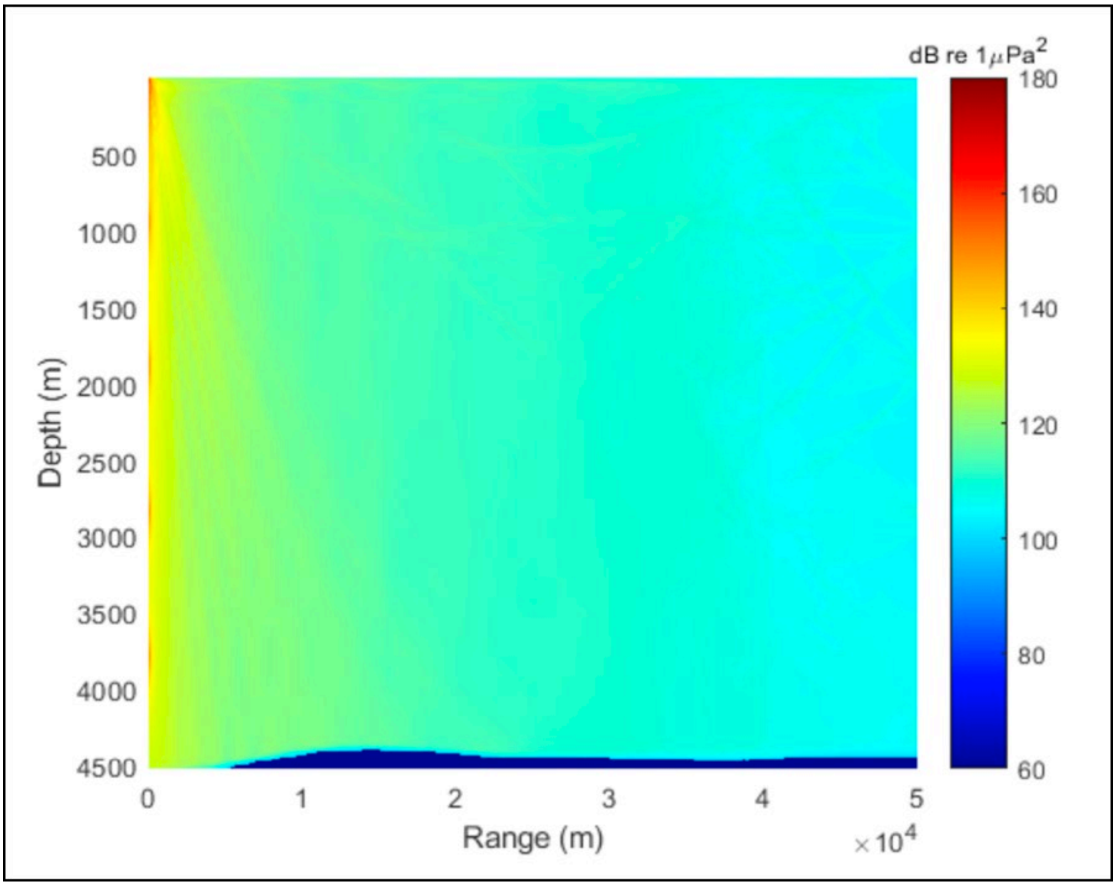
The apparent low levels of acoustic impacts to marine fauna assessed in the present report are partly due to the following:

- The pilot Collector Test program is a scaled down version camped to a full commercial operation. For example, the nodule harvester (PCV) will be 50% of the dimensions (size) of the commercial PCV and the commercial collector system will comprise five of the larger PCVs operating simultaneously feeding via flexible jumper hoses into a single rigid riser steel pipe.
- The vertical transport system rigid steel riser will be of a larger diameter.
- Collector Test runs and system tests are of short duration.
- The main type of underwater noise generated by the Collector Test components is non-impulsive, continuous broadband or intermitted broadband or narrowband noise.
- The generally low to moderate sound pressure levels of the modelled three loudest noise sources:
  - surface vessels in DP mode– 193 dB re 1 μPa at 1m.

  - vertical transport system (riser) – 150 – 155 dB re 1 µPa at 1m.
  - seabed nodule harvesting (with production) – 175 dB re 1 µPa at 1m.
- The general absence of loud impulsive noise sources, only occasional impulse noise from thruster cavitation during surface vessels maintaining station by dynamic positioning (DP).

The findings of the present report need to be confirmed by conducting more extensive modelling of the sound sources and sound fields generated by the main Collector Test runs and system tests. It is understood that TMC is in the process of selecting suitable acoustic consultancy to perform this task.

Finally, the findings of this report with regards to the extent of Project-generated sound fields is in general agreement with one other acoustic study of a similar nodule collector test system that has been published by van der Schaar et al. (2020) for the Blue Nodules Global Sea Mineral Resources (GSR) contract area in the CCZ. Figure 4 shows a sound pressure level map of the mining scenario based on propagation loss computed with Bellhop acoustic software and source levels estimated from field measurements and literature.



Source: Adapted from van der Schaar et al. (2020) with annotations added.

Figure 4 Sound pressure map for the Blue Nodule Project (van der Schaar et al. (2020)

In Figure 4, at the surface and epipelagic zone, the surface support vessels source is visible as are the and in the vertical water column the slurry lift pumps at 944 m, 1,889 m, 2,883 m and

3,778 m depths. However, the sound source of the GSR nodule collector vehicle is not visible, as the sound emitted by the vehicle on the sea floor is dominated by the sound contributions of the other sources (van der Schaar et al., 2020). In the case of the present Collector Test study, the vertical transport system (riser) will not have multiple and noisy vertical slurry pumps but have a single airlift system with air injection around 2,500 m depth.

ES9 References

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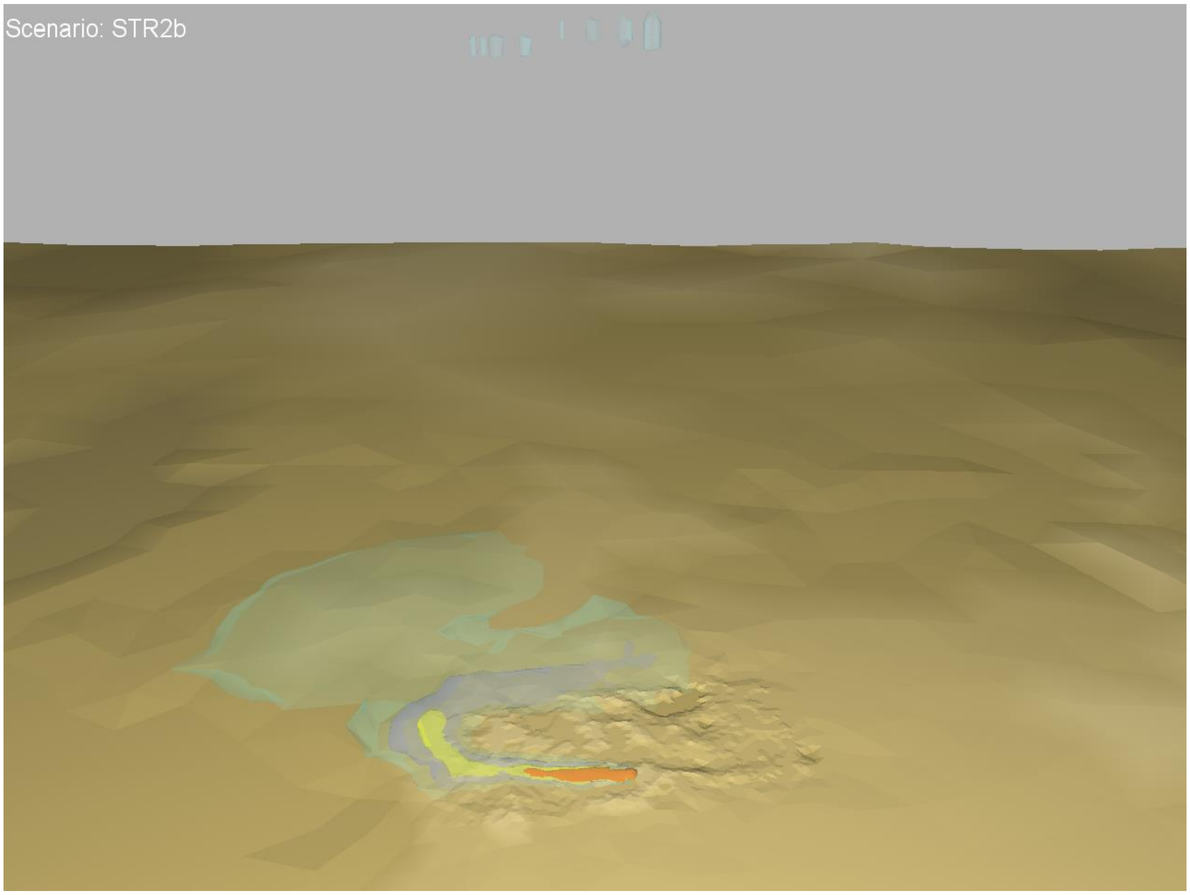
Appendix 5 – NORI-D Pilot Collector Test Sediment Plume Modelling (DHI, 2021)

NORI-D Pilot Collector Test Sediment Plume Modelling

Draft Report



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April 2021

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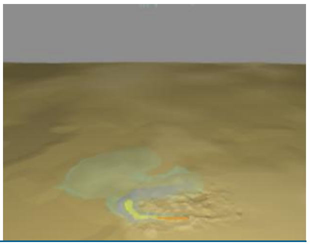
Approved by
Tom Foster President

NORI-D Pilot Collector Test Sediment Plume Modelling

Draft Report



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1 Introduction

DHI Water & Environment, Inc. (DHI) has been commissioned by CSA Ocean Sciences Inc. (CSA) to carry out hydrodynamic and sediment plume modelling studies for The Metals Company (TMC) deep sea mining Block D concession area held by Nauru Ocean Resources Inc. (NORI) in the Clarion-Clipperton Zone (CCZ).

The present report provides the results of the sediment plume modelling carried out for the Pilot Nodule Collector Test (PNCT) scheduled for January 2022.

2 Modelling Methodology

The modeling focuses on the transport and dispersion of sediments from the spill sources at the pilot nodule collector and pilot sediment return-water discharge (also referred to as the mid-water column discharge). While the modelling approach allows a differentiation between the near-field (where the momentum and buoyancy of the discharge is controlling) and the far-field (where advection and dispersion is controlling, often referred to as the passive plume phase), sediment discharge volumes for the PNCT are relatively small. Consequently, only the far field processes are considered in the PNCT sediment plume assessment (i.e. the effects of momentum and buoyancy are assumed to affect less than one model computational cell (ca. 50m), an assumption in line with the findings from field experiments by Muñoz Royo et al. (2021)).

2.1 Modelling Software

The numerical modeling carried out to assess the potential sediment plume impact from the PNCT involved a range of MIKE by DHI models that capture, reproduce and evaluate the deep ocean hydrodynamic processes and mid-water column and near-seabed sediment plume dynamics within the study area. This necessitated coupling between a hydrodynamic and sediment transport model.

The MIKE modules applied in this study are briefly described below:

- **MIKE 3 FM HD:** MIKE 3 FM HD is a 3-dimensional hydrodynamic model based on a flexible mesh approach that has been developed by DHI for applications within oceanographic, coastal and estuarine environments. The model is based on the numerical solution of the three-dimensional (3D) incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and of hydrostatic pressure. The spatial discretization of the equations is performed using a cell centered finite volume method. The horizontal discretization can combine triangular and quadrilateral elements, while the vertical discretization is based on a combined sigma-z discretization. Together with the inclusion of the Flather boundary conditions, the model is ideal for downscaling regional scale oceanographic models such as the HYbrid Coordinate Ocean Model (HYCOM) for high resolution applications. The regional scale resolution and bathymetry of the oceanographic models can be matched at the boundaries minimizing boundary error, then gradually imposing the higher resolution through the flexible mesh approach in the specific area of interest. MIKE 3 FM HD has been used to simulate the water levels, current, salinity and temperature in the area of interest over a typical January production period matching the likely seasonal processes anticipated during the pilot collector test, scheduled for January 2022 at the time of simulation.

- **MIKE 3 FM MT:** MIKE 21 FM MT is a 3-dimensional model for multi-fraction cohesive sediment transport that describes the processes of settling, erosion, transport and deposition of sediment under the influence of currents and waves. The model can be directly coupled with the hydrodynamic model to be able to include sediment plume density effects etc. in the hydrodynamics. The model includes routines for flocculation, hindered settling and fluid mud and can incorporate both cohesive and non-cohesive material in the same simulation. Overall, the MIKE 3 FM MT model calculates the resulting transport, dispersion, settling, deposition and re-suspension of sediments (cohesive and non-cohesive) brought into suspension by the pilot collector works.

2.2 Hydrodynamic Model Setup

2.2.1 Bathymetry, Mesh and Layers

The model bathymetry within the concession area has been established from the survey point cloud of depth soundings provided by The Metals Company as listed below:

- Multibeam Survey Data, 50m resolution

Outside the survey area bathymetry data is taken from the General Bathymetric Chart of the Oceans (GEBCO_2020) grid. The GEBCO_2020 Grid is the latest global bathymetric product released and developed through the Nippon Foundation-GEBCO Seabed 2030 Project. Agreement between the multibeam survey data and the GEBCO data at the boundary of the concession area is found to be good.

For the assessment of the short-term PNCT operation, the developed mesh for the HD model of the NORI-D area has been cropped in size to focus on the pilot nodule extraction work area. This is scheduled to occur in NORI-D sub-Area 6 based on information provided by The Metals Company and Allseas. For the pilot collector test model design, a nominal 50m mesh resolution covering Area 6 has been found to provide a reasonable balance between resolution of bed features and the sediment plume against computational time. This resolution is decreased progressively towards the model boundaries, with a nominal mesh resolution of 2000m at the model boundary (approximately 30km from the work area).

The resulting mesh, after completion of the various development sensitivity tests, is shown in Figure 2.1. The full model domain bathymetry is shown in Figure 2.2, with detail of the Area 6 pilot collector test area, where the sediment plume is anticipated, shown in Figure 2.3.

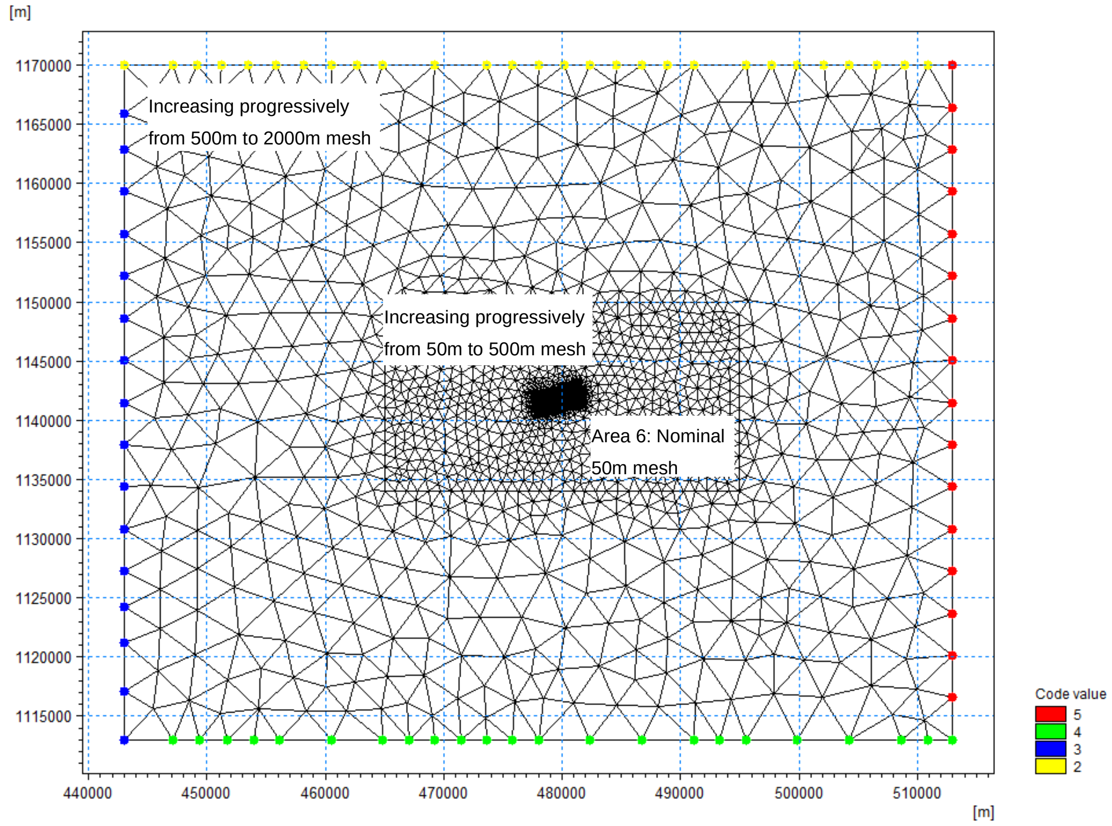

Figure 2.1 Collector test model mesh.

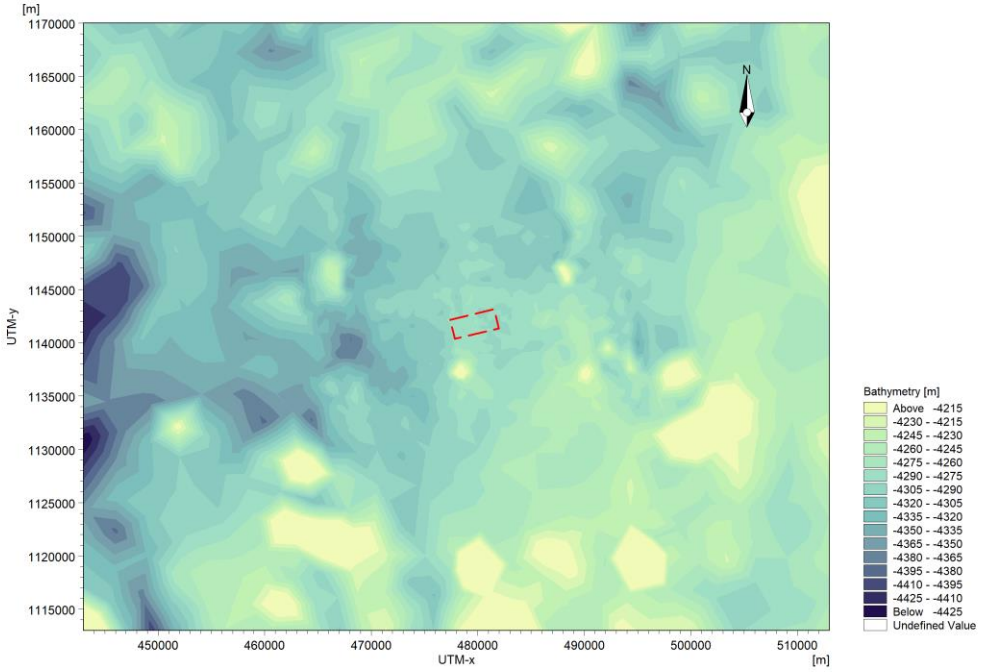

Figure 2.2 NORI-D Pilot collector test sediment plume model bathymetry with the pilot collector test area (Area 6) highlighted

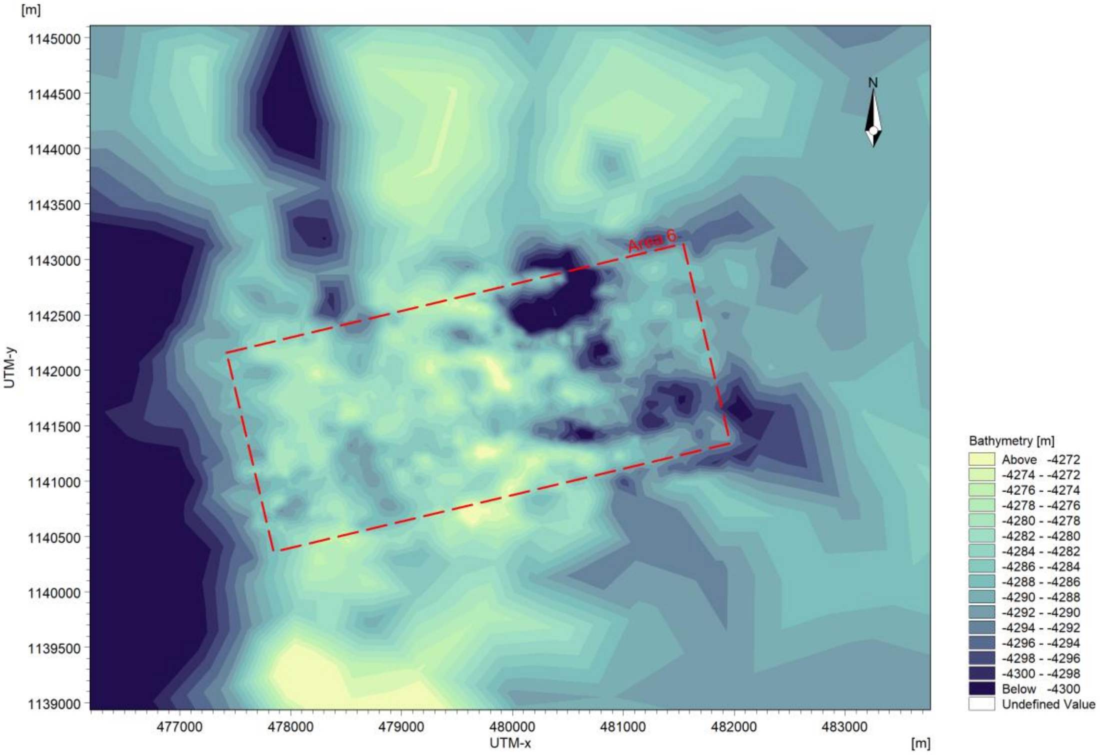

Figure 2.3 Detail of the Area 6 pilot collector test sediment plume model bathymetry

Testing of various vertical layer schemes has been undertaken during the development of the pilot collector test sediment plume model. Focus has been placed on achieving a near-bed layer and mid-water column resolution that will provide adequate resolution of the sediment plume.

The vertical layer thickness in MIKE 3 FM can be defined either as a fraction of the water depth (adaptive layering, termed σ layers) and/or at fixed water depths (z layer). For computational efficiency, a σ layer arrangement appears appealing. However, due to the deep ocean depths of NORI-D and the relatively large local variations in depth in Area 6, a combined σ-z grid was found to provide superior performance in terms of salinity, temperature and near-bottom currents. Consequently, as the ultimate purpose of the modelling is to resolve the sediment plume transport and dispersion near the seabed and near the mid-water column discharge, a combination of an adaptive layering scheme and fixed water depths has been adopted for the pilot collector model as defined in Table 2.1 and Table 2.2. Using this mixed σ-z distribution, the model includes 51 layers over the water depth, see Figure 2.4.

Table 2.1 Preliminary model vertical sigma layering from 0 – 100 m water depth

Adaptive Layer elevation as % of water depth (height below water surface)	**Nominal Layer height (m) below water surface for cell center with 100 m water depth**	**Nominal layer thickness (m) for cell with 100 m water depth**
50%	50	50
50%	100	50

Table 2.2 Preliminary z-level vertical layers from 100-4440 m water depth

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	**Nominal layer thickness (m) for cell with 4642 m water depth**
400	300
600	200
800	200
900	100
950	50
1000	50
1050	50
1100	50
1150	50
1200	50
1250	50
1300	50
1350	50
1400	50
1450	50
1550	100
1650	100
1750	100
1850	100

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	Nominal layer thickness (m) for cell with 4642 m water depth
2050	100
2250	200
2450	200
2650	200
2850	200
3050	200
3250	200
3450	200
3650	200
3850	200
4050	200
4150	100
4200	50
4230	30
4250	20
4260	10
4264	4
4268	4
4272	4
4276	4
4280	4
4284	4
4288	4
4292	4
4296	4

Nominal Layer height (m) above seabed for cell center with 4642 m water depth	Nominal layer thickness (m) for cell with 4642 m water depth
4300	4
4310	10
4330	20
4360	30
4440	80

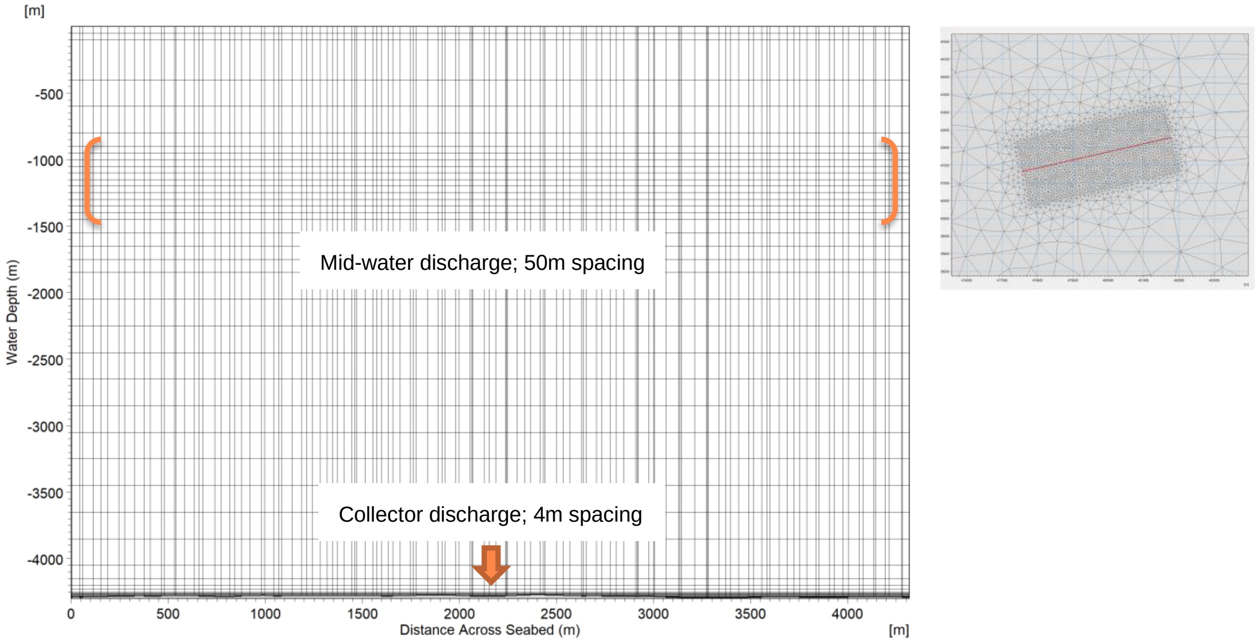

Figure 2.4 Longitudinal slice through Area 6 vertical resolution increases around the mid-water column discharge (-1000m) and near the seabed.

Due to the suspended sediment modelling requirements in the MT module, the hydrodynamic timestep has to be greatly reduced from that required for hydrodynamic model stability (i.e. higher resolution) to 300s. This is found to meet the Courant–Friedrichs–Lewy stability requirement for robust advection-dispersion modelling (due to the prevailing low currents). After much sensitivity testing, the duration of the model production period for each collector test scenario was set at 11 days (55 days in total over the entire PNCT operation). This proved adequate for model warm-up and coverage of the collector test operation and subsequent transport, dispersion and settling of the plume to a level where all concentrations had reduced to a level approximately two orders of magnitude below anticipated background level in the model domain (See Appendix A).

2.2.2 Model Boundary Conditions

The hydrodynamic model utilizes boundary conditions from the HYCOM oceanographic model (HYCOM 2021). Validation of the suitability of the HYCOM model for provision of boundary conditions to the NORI-D model area has been undertaken against measurements in the central Pacific collected as part of the Global Tropical Moored Buoy array maintained by the National Oceanographic and Atmospheric Administration (NOAA 2021) and against satellite derived current measurements maintained by the European Union Copernicus Marine Science program (Copernicus 2021). Example of HYCOM performance against the NOAA measurement in the general area of NORI-D is provided in Figure 2.5 and against the Copernicus measurements extracted at the NORI-D long mooring location in Figure 2.6. Overall, the comparison between HYCOM and the available regional current monitoring data is found to be adequate from a model boundary generation perspective.

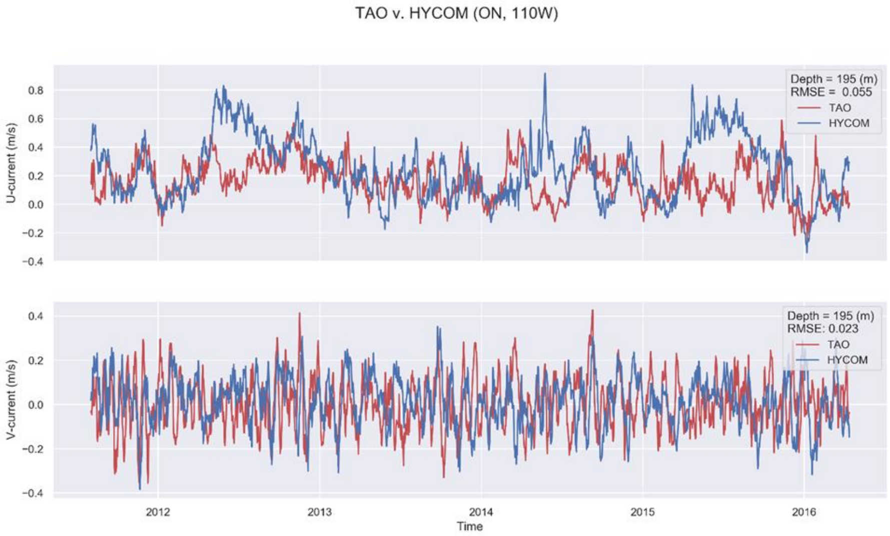

Figure 2.5 Example of HYCOM performance against NOAA Tropical Ocean Atmosphere (TAO) buoy measurements (NOAA 2021) at 0ºN, 110ºW

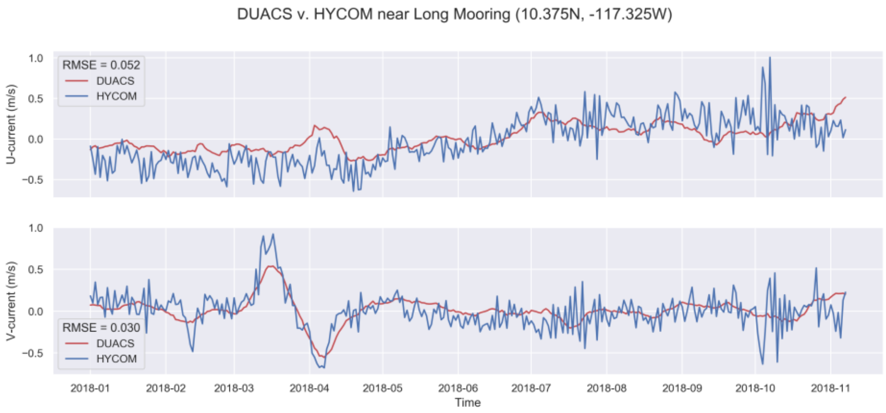

Figure 2.6 Example of HYCOM performance against Data Unification and Altimeter Combination System (DUACS) measurements (Copernicus 2021) near NORI-D long mooring (10.375ºN, 117.325ºW). Note satellite measurements are daily and as such do not capture shorter term variability

2.2.3 Hydrodynamic Model Validation

Since 2019, DHI has progressively developed the hydrodynamic (HD) model for the NORI-D area. At the time of the present report, model validation has been performed against the first set of current measurements from the NORI-D area (CSA 2020). A summary of the near-bed current data is provided in Figure 2.7, showing a dominant north-north-west / south-east flow direction for the approximately 8 months of data available at the time of writing.

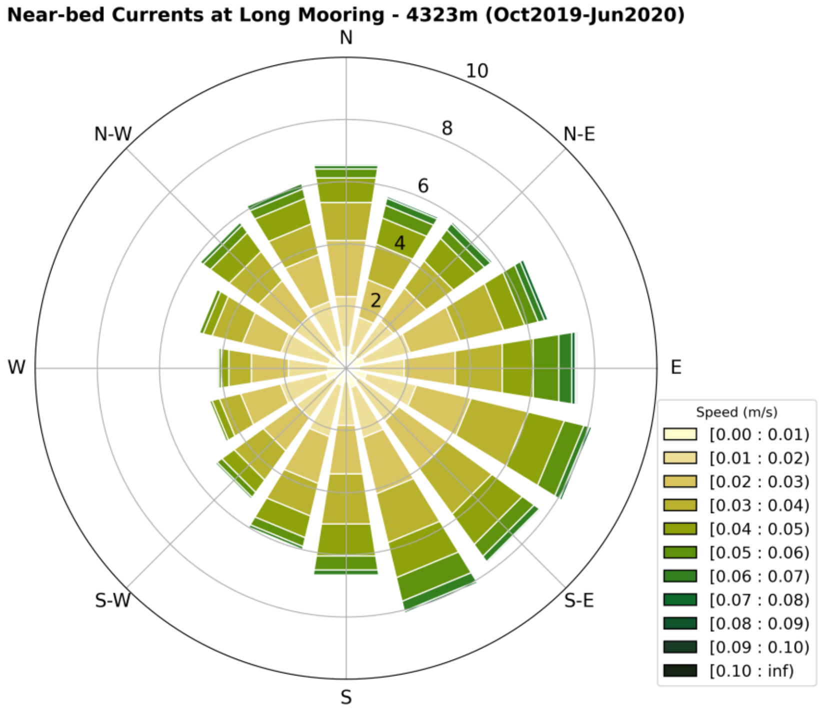

Figure 2.7 Summary of measured near bed current data from NORI-D long mooring (current flowing to) 14 October 2019 to 26 June 2020

Example, model performance against a sub-set of this site-specific measurement data is provided in Figure 2.8. This shows generally good performance in terms of modelled vs. measured current speed through the water column. The hydrodynamic model will continue to be progressively improved as more data becomes available (from subsequent field campaigns). However, based on the validation results presented in Figure 2.8 the hydrodynamic model is considered fit for purpose for the assessment of the relatively small scale (from a sediment spill perspective) PNCT.

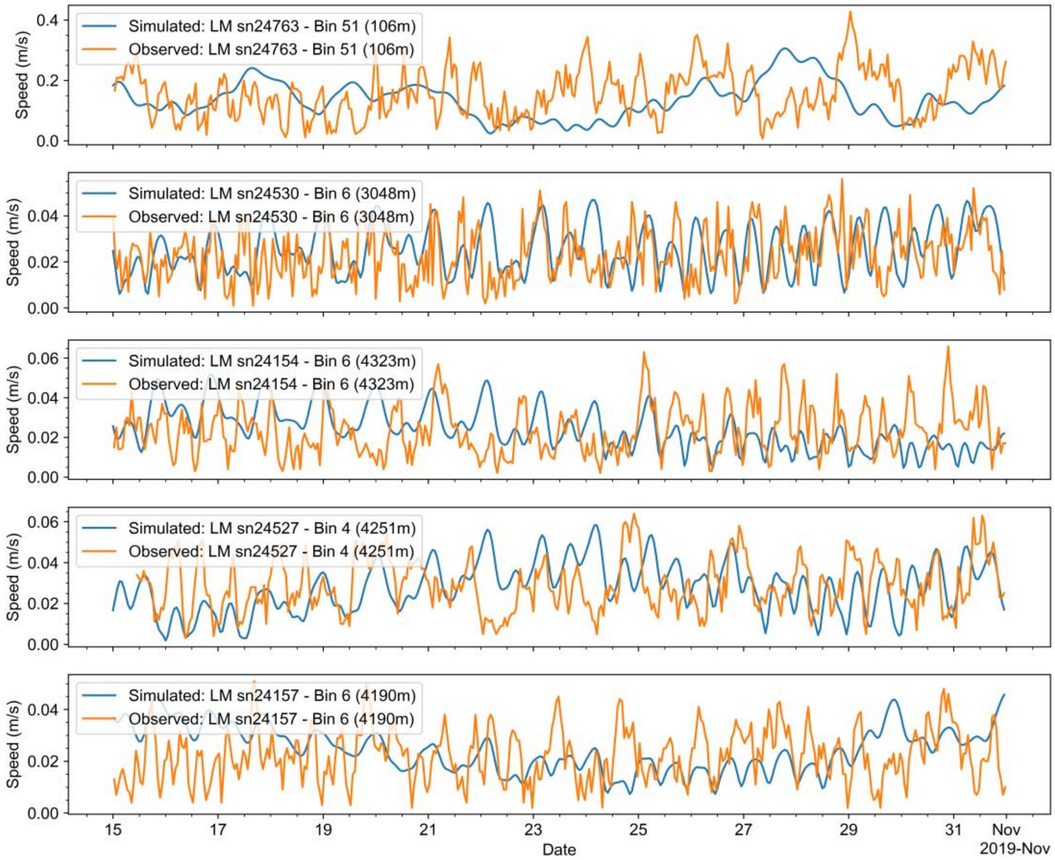

Figure 2.8 Validation of the preliminary HD model against the measured ADCP data (CSA 2020) from the NORI-D long-mooring.

2.3 Suspended Plume Modelling Setup

2.3.1 Sediment Settling Characteristics

The sediment settling characteristics of the seabed material, that will be introduced into the water column as a result of the pilot collector operation, have been determined based on detailed laboratory tests of seabed sediment from the NORI-D concession area undertaken by iSeaMC (iSeaMC 2020). From a modelling perspective, the results of these laboratory experiments can be summarised by a set of sediment settling velocities as a function of sediment concentration. Two test sequences were carried out, one with a starting concentration of 1g/l and a second with a starting concentration of 10g/l, which are considered representative of anticipated discharge concentrations. Results in terms of settling velocities as a function of concentration, provided by iSeaMC, are summarised in Table 2.3 and Table 2.4.

Table 2.3 Bottom sediment settling characteristics (particle size and settling rate) as a function of ambient concentration (iSeaMC 2020). NORI-D Sediment: Starting concentration 1g/l

Starting concentration 1g/l	Time	T=10 min.	T=30 min.	T=60 min.	T=120 min.	T=180 min.	T=240 min.	T= 24 hr.
Characteristic	Particle Concentration [g/l]	0.911	0.427	0.14	0.072	0.053	0.046	0.008
d_{25}	µm	294	465	279	199	161	154	282
d_{50}		448	681	386	278	228	218	326
d_{75}		671	933	506	370	313	289	375
$W_{s\,25}$	m/d	81.8	125.9	78.7	63.9	57.8	56.7	79.3
$W_{s\,50}$		120.7	209.2	103.4	78.5	68.9	67.2	88.8
$W_{s\,75}$		204.6	350.9	139.1	99.3	85.9	80.8	100.6

Table 2.4 Bottom sediment settling characteristics (particle size and settling rate) as a function of ambient concentration (iSeaMC 2020). NORI-D Sediment: Starting concentration 10g/l

Starting concentration 10g/l	Time	T=10 min.	T=30 min.	T=60 min.	T=120 min.	T=180 min.	T=240 min.	T= 24 hr.
Characteristic	Particle Concentration [g/l]	9.368	6.559	0.767	0.079	0.058	0.052	0.007
d_{25}	µm	863	1292	430	213	157	122	318
d_{50}		1378	1902	641	296	206	161	371
d_{75}		2085	2395	830	412	268	208	437
$W_{s\,25}$	m/d	204.5	377.8	99.9	68.2	61.7	58	82.2
$W_{s\,50}$		420.6	704.6	142.9	79	67.4	62.2	90.2
$W_{s\,75}$		797.5	929	194.2	96.8	75.2	67.6	101.1

As intermediate concentrations are established by letting the tests continue for a period of time, with the lower concentrations being achieved as sediment falls out of suspension, the assumption must be made that the material remaining in suspension remains representative of the starting material grading distribution. This is a reasonable assumption given the fact that the tests are undertaken at a constant rate of shear. Further, the derived settling characteristics also demonstrate consistent flocculation characteristics across the range of test concentrations. This would not be the case if there was a significant change in the underlying non-flocculated sediment characteristics. Consequently, while it is recognised that additional testing of intermediate starting concentrations would be beneficial to confirm the validity of the underlying assumption of no change in base sediment characteristics, all indications are that it is an appropriate assumption for the assessment of the sediment plume characteristics resulting from the PNCT program.

The sediment settling velocity formulation in MIKE 3 FM MT divides the concentration regime into three zones as shown in Figure 2.9. For the purpose of the PNCT sediment plume model, the assumption is made that the concentration in the passive plume will not exceed the passive plume hindered settling limit, which is expected to be in the order of 10g/l.

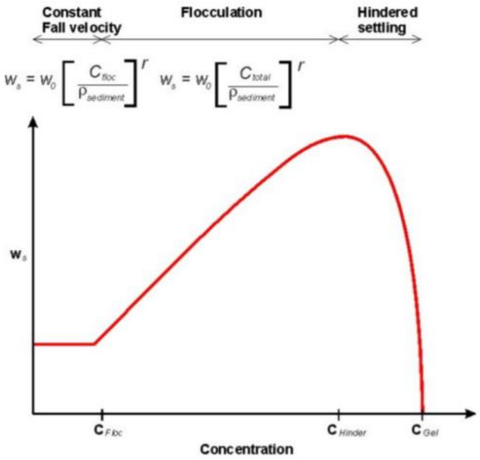

Figure 2.9 Sediment settling velocity formulation in MIKE 3 MT (outside the hinder settling regime)

Based on the iSeaMC laboratory data, flocculation is assumed not to occur at concentrations below 0.03g/l (30mg/l). Sensitivity tests to this assumption have been performed as documented in Appendix B.

Between 0.03g/l and 10g/l flocculation is assumed to occur as a function of the total concentration of floc generating material. This is consistent with the iSeaMC laboratory results for NORI-D bottom sediments at shear rates representative of the boundary of the active plume (iSeaMC 2020). Discussion relating to the validity of this assumption against other published data is provided in Appendix B. The flocculation formulation used in MIKE3 MT is shown in Figure 2.9. For a known sediment solid density, curve fitting is used to determine W_0 (the setting velocity coefficient) and r (the settling velocity power). The resulting settling velocity coefficients and settling velocity powers for the three sediment fractions identified by iSeaMC are documented in Table 2.5, calculated for a solid density of 2400kg/m^3 based on communication from iSeaMC.

Table 2.5 Flocculation parameters determined from the laboratory results presented in Table 2.3 and Table 2.4

Sediment Fraction	Parameter	Based on solid density of 2400kg/m^3
D_{25}	W_o	0.02851
	r	0.35
D_{50}	Wo	0.14277
	r	0.49
D_{75}	Wo	0.20221
	r	0.5

The resulting comparison between model and measured settling velocity for the three sediment fractions is shown in Figure 2.10. Overall, it should be stressed that this is a very high level of agreement between measured and modelled settling velocity. This is only possible due to the high-quality settling velocity measurements provided by iSeaMC (i.e. the average absolute % error between measured and predicted settling velocities is generally found to be higher than the 15% as seen Figure 2.10).

The three sediment factions are introduced into the plume model, with the working assumption for the PNCT assessment, of equal distribution by mass in the three settling velocity fractions.

These data were introduced into the model with the following concentration limits:

Table 2.6 Other key settling parameters

Parameter	**Value**	**Unit**
Lower limit concentration for hindered settling	10,000	mg/l
Lower limit concentration for flocculation	30	mg/l

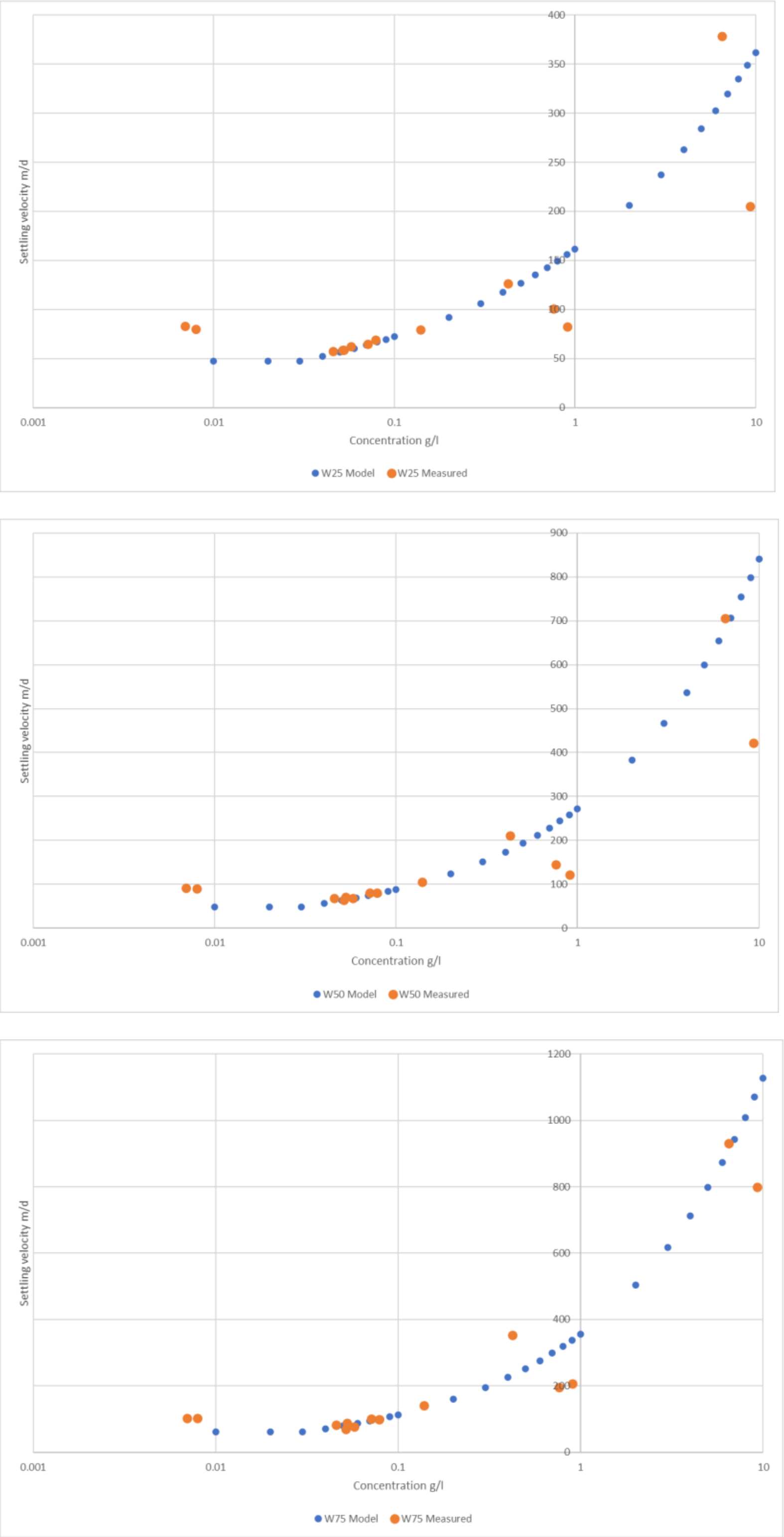

Figure 2.10 MIKE 3 MT sediment settling velocity for NORI-D bottom sediment as a function of concentration compared to iSeaMC measurements (iSeaMC 2020) for the 3 sediment fractions identified by the laboratory experiments [Average absolute % error between measured and modelled = 15%]

In addition to the bed sediment, residual nodule material was included in the model with the following key settling characteristics.

Table 2.7 Modelled residual nodule sediment settling characteristics

Fraction	**Mean Grain Size, d (mm)**	**Settling Velocity, Ws (m/s)**
Residual Nodule (D75)	0.8	0.102
Residual Nodule (D25)	6	5.735

2.3.2 Sediment Deposition and Resuspension Characteristics

The sediment deposition and resuspension characteristics are also important model parameters. Key parameters are presented in Table 2.8.

Table 2.8 Modelled sediment deposition and resuspension characteristics

Parameter	**Value**
Critical Shear Stress for Deposition	0.07N/m^2 (DHI 2017)
Deposition Density	180kg/m^3 (iSeaMC 2020, DHI 2017)
Critical Shear Stress for re-suspension	0.1N/m^2 (iSeaMC 2020)

Short term measurements of blanketing (iSeaMC 2020) indicate an initial deposition density in the order of 100kg/m^3 to 160kg/m^3 This is typical for freshly deposited fine material (DHI 2017). However, this will tend to consolidate with time and a longer-term deposition density in the order of 180kg/m^3, which is considered more appropriate (DHI 2017) for quantification of the net sedimentation at the end of the pilot collector test program. This difference between initial and longer-term deposition density should be taken into account in the interpretation of the sedimentation results, in that, initial deposition thicknesses may be up to a factor of 2 higher than those presented, dropping to the presented figures over a period of weeks after the completion of the pilot collector test program as a result of consolidation. Further, it is noted that data from iSeaMC indicates considerable micro scale variability in sedimentation thickness as a result of the presence of the nodules. This is expected to (at the micro scale) increase sedimentation thickness by between 30% and 100% in the depressions between nodules compared to the area average and decrease deposition over the nodules by a corresponding amount, at least until an average blanketing deposition depth of 11mm is achieved (iSeaMC 2020), after which deposition would become more uniform.

The critical shear stress for re-suspension is based on the results of re-suspension laboratory experiments carried out by iSeaMC in the presence of nodules (iSeaMC 2020), converted from limiting current speed to bottom shear stress.

2.3.3 Pilot Collector Test Discharge Characteristics

The PNCT scenario plan has been established based on review of information provided from The Metals Company and Allseas. At the time of simulation, the pilot collector test is scheduled for January 2022. Hydrodynamic forcing for the sediment plume model simulation is thus selected from a typical January period, with January 2017 being selected as typical.

Mid-Water Column Return Flow

The mid-water column return flow discharge is set at 1000m below surface based upon communication from Allseas and The Metals Company. Table 2.8 provides a summary of the key mid-water column discharge characteristics for the base PNCT operation. These data are scaled by the production for each scenario.

Table 2.9 Pilot Nodule Collector Test mid-water column discharge characteristics

Parameter	Value
Residual Nodule Sediment Load	1.17kg/s (0.0006 m^3/s)
Residual seabed sediment load	1.17kg/s (0.0005 m^3/s)
Water Discharge	0.097m^3/s (99/51kg/s)
Total Discharge including sediment	0.0981m^3/s
Discharge Temperature	7.5°C
Discharge Salinity	34.67PSU
Discharge Configuration	Single 0.2m ø
Discharge velocity	3.12m/s
Discharge orientation	Vertically down
Discharge Depth	1000m
Mid-water column discharge offset	330m in advance of collector.
Riser movement	Same speed as collector

Collector Discharge Port Information

Key discharge characteristics for the PNCT discharge have been provided by Allseas and The Metals Company. Sediment and water discharge characteristics are provided for the base pilot collector operation in Table 2.9. These data are scaled by the production for each scenario.

Table 2.10 Pilot Nodule Collector Test discharge characteristics

Parameter	Value
Discharge Port Vertical Orientation	0º
Number of nozzles	4
Height above seabed	4m
Discharge port velocity	0.7m/s
Discharge port area	1m^2
Residual nodule sediment Load	Base 0.38kg/s (0.0002m^3/s)
Residual seabed sediment load	Base 16.72kg/s (0.007m^3/s)
Water Discharge	Base 2.186m^3/s (2241kg/s)
Total Discharge including sediment	Base 2.1932m^3/s
Discharge Temperature	Ambient at bed
Discharge Salinity	Ambient at bed
Collector speed	Varies depending on scenario
Collector track	Varies depending on scenario
Spill from tracks and track cleaning system	Not included for collector test sediment plume assessment as no data on spill rates, but expected to be small
Spill from collector head	Disturbance allowance of 2% of fine sediment flux = 0.02 * 17.10 kg/s = 0.342kg/s released at seabed with no discharge velocity. This is in line with data from hydraulic suction dredging techniques.

2.3.4 Pilot Collector Test Operations

System Test Runs (STR) are the only portion of the pilot test program put forward by Allseas that will generate any significant volume of sediment spill, with five (5) cases identified as dominating. Table 2.10 to Table 2.14 summarize the key data relevant from the sediment plume modelling for these 5 sediment plume generating cases. The total PNCT operational duration generating significant spill is 61.5hrs over an expected operational period of 259hrs. The total sediment spill over this operational period is approximately 259T from the mid water discharge and 4015T from the pilot collector on the seabed.

Table 2.11 STR1b

Parameter	Value
Duration on seabed	26hrs
Run length	12.4km (4x3.1km run lines)
Average harvester speed	0.14m/s
Turn Distance	377m (4 turns)
Lane spacing	50m
Run duration (at 0.14m/s)	Production 24.6hrs
	Turning 0.75hrs
Delays	26 - 24.6-0.75 = 0.65hrs insert at turning
Net turning and delay time per turn (no production)	0.35hrs/turn
Production rate	686.9T in 12.4km = 55.3T/km
Mid-Water discharge	Present

Table 2.12 STR2a

Parameter	Value
Duration on seabed	9hrs
Run length	9.3km (3x3.1km run lines)
Average Harvester Speed	0.3m/s
Turn Distance	377m (2 turns)?
Run duration (at 0.3m/s)	Production 8.6hrs
	Turning 0.35hrs
Lane spacing	38m
Delay	9.0-8.6-0.35= 0.05hrs insert at turning
Net turning and delay time per turn (no production)	0.2hours
Production rate	750T in 9.3km = 80.6T/km
Mid-Water discharge	Present

Table 2.13 STR 2b

Parameter	Value
Duration on seabed	21hrs
Run length	22.32km (Contours)
Average Harvester Speed	0.3m/s
Turn Distance	Radius 20-200m (Production does not stop)
Run duration (at 0.3m/s)	Production 20.6hrs
	Turning N/A (Production does not stop)
Lane spacing	N/A
Delay	N/A (ignoring the 0.4hr discrepancy)
Production rate	1780T in 22.3km = 79.75T/km
Mid-Water discharge	Present

Table 2.14 STR 3a

Parameter	Value
Duration on seabed	4.5hrs
Run length	6.2km (2x3.1km run lines)
Average harvester speed	0.4m/s (Average of 2 lanes)
Turn Distance	188m (1 turn)
Lane spacing	10m
Run duration (at 0.4m/s)	Production 4.3hrs
	Turning 0.1hrs
Delays	4.5 - 4.3-0.1 = 0.1hrs insert at turning
Net turning and delay time per turn (no production)	0.2hrs/turn
Production rate	515T in 6.2km = 83.0T/km
Mid-Water discharge	Present

Table 2.15 STR 3b

Parameter	Value
Duration on seabed	8hrs
Run length	6.2km (2x3.1km run lines) but only mining on lane 2
Average harvester speed	0.25m/s (Average of 2 lanes)
Turn Distance	188m (1 turn)
Lane spacing	50m
Run duration (at 0.25m/s)	Production 3.4hrs
	Turning. N/A (as only one production pass)
Delays	Not relevant (as only one production pass)
Net turning and delay time per turn (no production)	Not relevant (as only one production pass)
Production rate	283.3T in 3.1km = 91.4T/km
Mid-Water discharge	Present

2.3.5 Pilot Collector Tracks

The pilot nodule extraction operations have been strategically placed within an Area 6 in a manner that avoids the locations with the largest elevation variance, i.e. the Eastern sector of Area 6. The nodule collector tracks for each scenario follow the Allseas execution plan. Run length, the speed at which the nodule collector would travel and production rate follows the parameters listed in Section 2.3.4. The nodule collector track for each operational scenario can be viewed in Figure 2.11 to Figure 2.15. Where, each blue point represents the location of the nodule collector each minute. After one pass (3.1 km) has been completed (excluding scenario STR2b), the nodule collector makes a turn and begins the next pass 50m south of its last location. The turning is not simulated in the model as it does not produce significant spill of sediment; however, the time delay for each turning event is considered before the start of the next pass.

It is important to note, that the mid-water column discharge occurring at 1000m below the surface follows the same track as the nodule collector. However, the assumption is made that, rather than moving constantly at the speed of the collector, the surface vessel (and thereby the mid-water column discharge) moves in 600m steps, moving from 300m behind to 300m in front of the collector with each step. This is worst case from a sediment plume perspective as it avoids dilution as a result of the constant movement of the source.

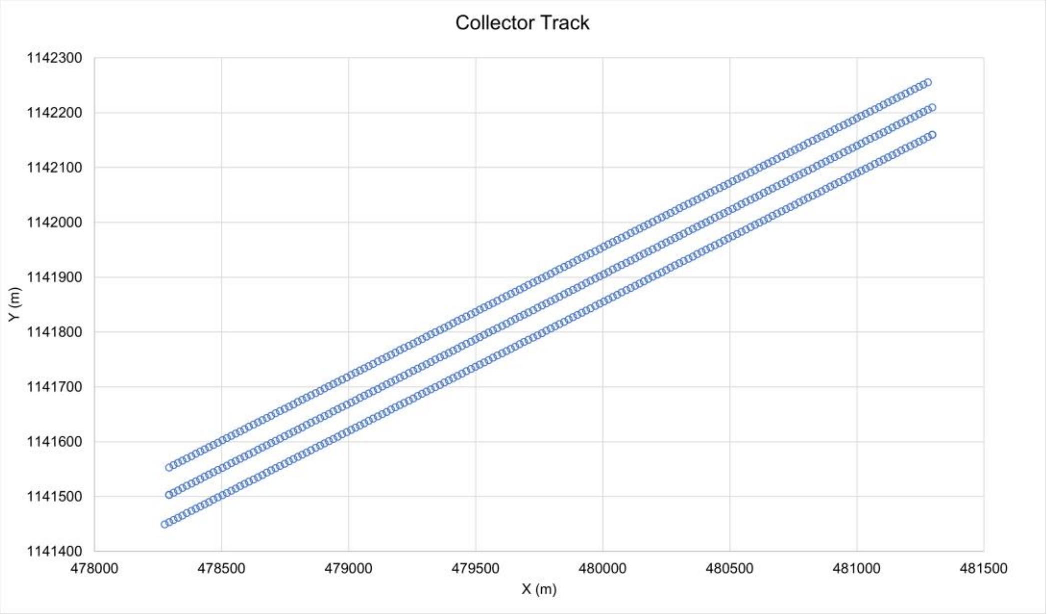

Figure 2.11 Scenario STR2a: Nodule collector track

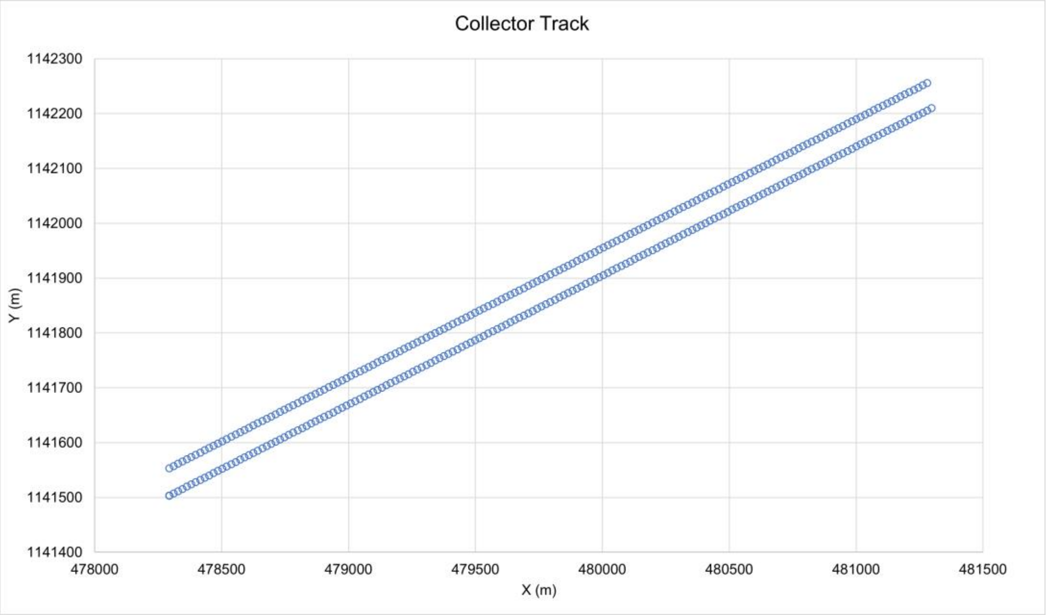

Figure 2.12 Scenario STR3a: Nodule collector track

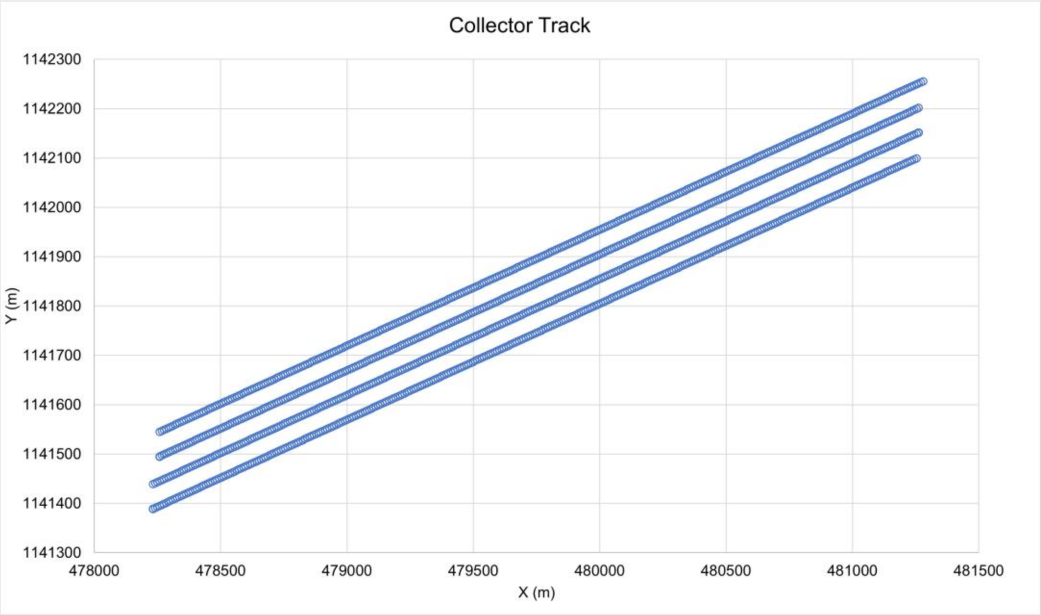

Figure 2.13 Scenario STR1b: Nodule collector track

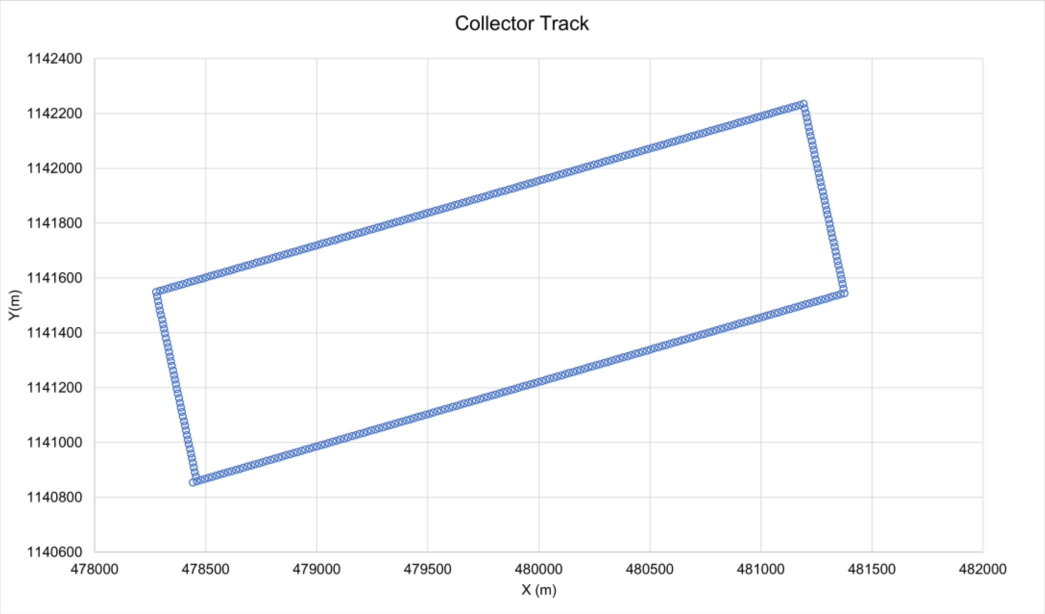

Figure 2.14 Scenario STR2b: Nodule collector track

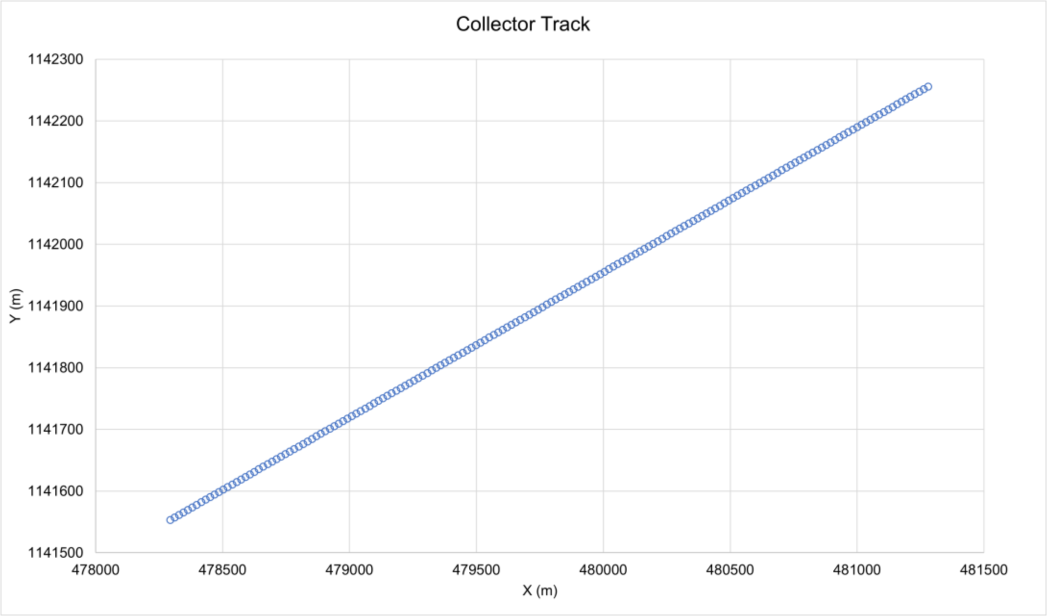

Figure 2.15 Scenario STR3b: Nodule collector track

3 Pilot Collector Test Sediment Plume Results

The sediment plume model results for the PNCT are presented in terms of incremental (above background) sedimentation and incremental (above background) Total Suspended Sediment (TSS) concentration, rather than absolute sedimentation and suspended sediment concentration. This is considered normal practice for sediment plume modelling (e.g. PIANC 2010, Marnane et al. 2017) for cases where:

- The background sedimentation and suspended sediment concentration varies weakly in space and time. In these cases it can be assumed that the environmental receptors are adapted to this weakly varying background and will thus respond to incremental stress above this background.
- Background concentrations are sufficiently low as to not influence the settling properties of the incremental material brought into suspension by the activities

Background suspended sediment and sedimentation data are presented and discussed in Appendix C. Although the field program is ongoing at the time of writing, adequate field data is now available to confirm that it is a reasonable assumption, due to the slowly varying current conditions in the area and deep oceanic nature of the environment, that these two fundamental assumptions supporting the use of an incremental rather than absolute approach to the sediment plume modelling, are valid. Further, the available field data allows a preliminary definition of background suspended sediment concentrations and sedimentation rates for the NORI-D area to be made (Appendix C), at least at a level of reliability suitable for assessment of the PNCT sediment plume results. These estimates will be updated as additional field data is recovered and prior to the assessment of the full scall extraction operation.

In assuming the validity of these assumptions, it is noted that the absolute concentration can be calculated from the presented model results by adding the spatially and temporally averaged background concentration presented in Appendix C to the incremental concentrations determined from the sediment plume model.

Sections 3.1 through Section 3.5 present the sedimentation and incremental TSS concentration for the individual STR scenarios for reference purposes. Results for the cumulative PNCT operations (i.e. the integral of the 5 STR scenarios) are presented in Section 4.

The incremental sedimentation is expressed in mm based upon an assumed medium term deposition density of 180kg/m^3 (See Section 2.3.2 for more details on deposition density).

In order to take into account both the magnitude and duration of the incremental TSS, the incremental TSS is expressed as the percentage exceedance of 0.1mg/l, 1mg/l, 5mg/l and 10mg/l above background concentration. These limits have been provided by The Metals Company, with the lower threshold of 0.1mg/l being representative of 10% of background concentration (Appendix C).

It is noted that the presentation of sediment plume results as exceedance of threshold limits is the standard and most informative approach for providing information on the characteristics of a dynamic sediment plume and its potential impacts on biological receptors. This is because biological receptors tend to respond to a function of both magnitude and duration of exposure, not just the magnitude of exposure. Unfortunately, much of the academic literature on deep sea mining plumes presents the characteristics of a plume by a dilution factor, instantaneous concentration or a statistical descriptor of the concentration which are poor descriptors for impact assessment purposes. Unfortunately, this difference in results presentation method makes direct comparison with the present results to literature difficult. To address this a comparison of the present PNCT sediment plume results and literature values is provided in Appendix D. Compensating for, amongst other factors, results presentation method, Appendix D demonstrates that there is a good correlation between the plume characteristics documented in the present report for the NORI-D PNCT and plume extent found in literature.

It is relevant to describe how Exceedance of a threshold is calculated by considering the following examples:

- A concentration of 2mg/l present at a specific location for 2hrs over a 10hr analysis period would result in an exceedance of 0.1mg/l of 20%, 1mg/l of 20% and an exceedance of 5mg/l of 0%
- A concentration of 6mg/l present for 2hrs over the same 10hr analysis period would result in the same exceedance of 0.1mg/l and 1mg/l of 20%, but also an exceedance of 5mg/l of 20%

As exceedance is influenced by the duration over which the statistics are calculated, results are presented for a statistical period starting from when production commences, finishing 24hrs and 48hrs after production stops for all concentration thresholds, plus 96hrs after production stops for the lower threshold limit of 0.1mg/l. The suitability of these statistical analysis periods is discussed in Appendix A. In assessing the TSS exceedance results as a function of time, it is beneficial to consider exceedance probability as a measure of the exposure of a specific location to a specific concertation threshold (e.g. 0.1mg/l). When the concentration falls below that threshold (either by the plume moving away from that location or due to dispersion and settling) the exceedance probability at that specific location will start to decline. i.e. a 2hr exposure in the first 10 hours is 20%, but a 2hr exposure in the first 10 hours over a 20hr assessment period is only 10%. Providing exposure information over different assessment periods is critical to the assessment of potential consequence of the plume as it allows a short-term concentrated exposure to be differentiated from a long-term low level persistent exposure. These situations would otherwise not be captured by basic statistical descriptors such as max concentration.

It is also relevant to highlight that, once the loading has been removed (i.e. at the end of the specific PNCT operation) and once the plume concentration has fallen below the threshold being assessed (Appendix A indicate that this is less than 24 hrs after completion of the operation for a 0.1mg/l threshold for the present PNCT operation), the extent of the plume expressed as exceedance probability will not change in location or size. Only the exceedance proabability will change as the assessment duration increases. This may seem counter intuitive, but by adopting in the present PNCT case a statistical analysis period ending 24hours (or longer) after the end of the operation the exceedance proabability is presenting exposure information for the maximum plume extent at the specific threshold concentration being assessed. As the statistical analysis period extends, the percentage of the total time that a specific exposure events represents will reduce as there are no new exposure events once that initial 24hour period post operation is passed.

For each results figure, the boundary of the Area 6 pilot test is shown, with Universal Transverse Mactator (UTM) co-ordinates overlaid, to provide scale.

Incremental TSS results are presented at fixed heights above the seabed (5m and 20m) for the collector and at a fixed water depth (1050m) for the mid-water column discharge (i.e. 50m below the discharge port).

3.1 Scenario STR1b Results

Sedimentation results for Scenario STR1b are presented in Section 3.3.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.3.2, 20m above the seabed in Section 3.3.3 and at 1050m for the mid-water column discharge in Section 3.3.4.

3.1.1 Sedimentation

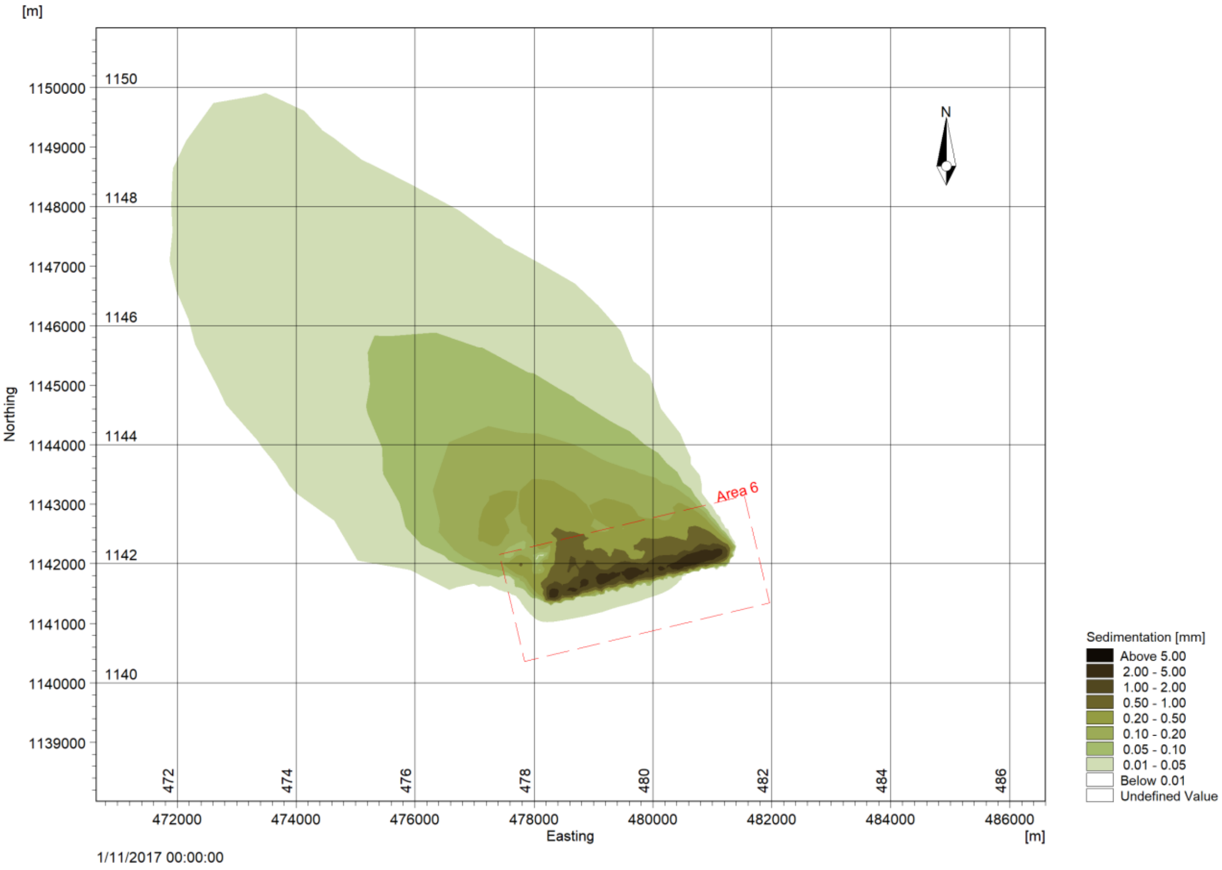

Figure 3.1 Scenario STR1b: Sedimentation (mm) ca. 10 days after completion of operation

3.1.2 TSS 5m Above Seabed

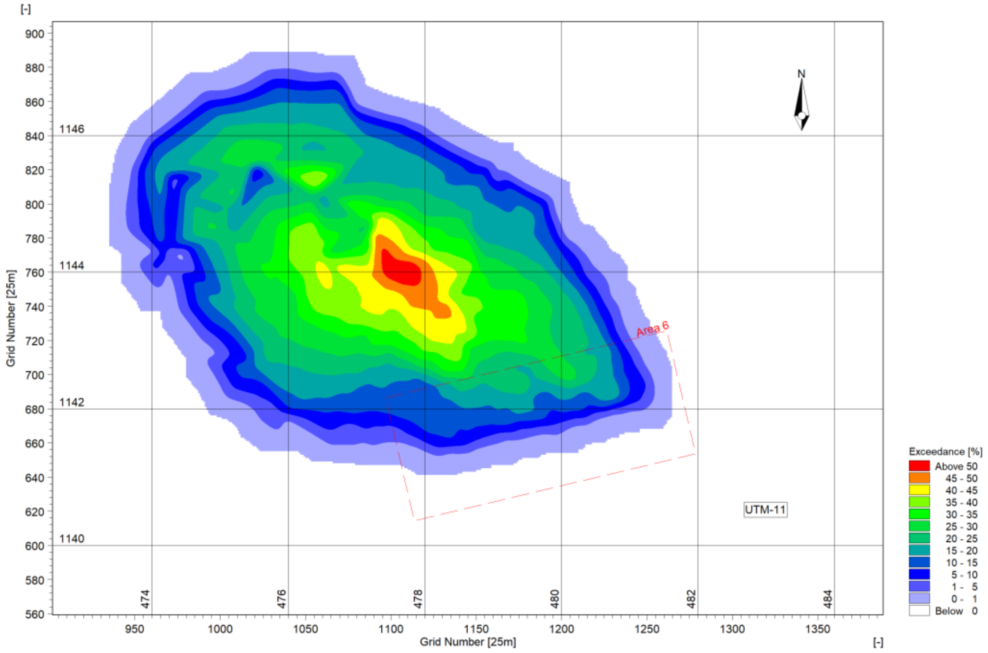

Figure 3.2 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

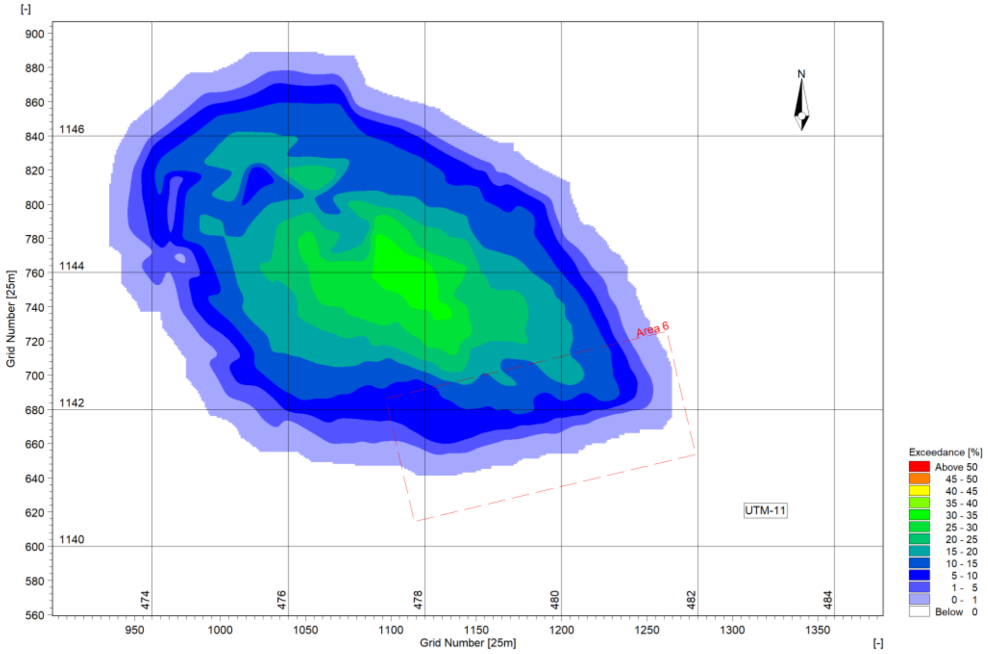

Figure 3.3 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

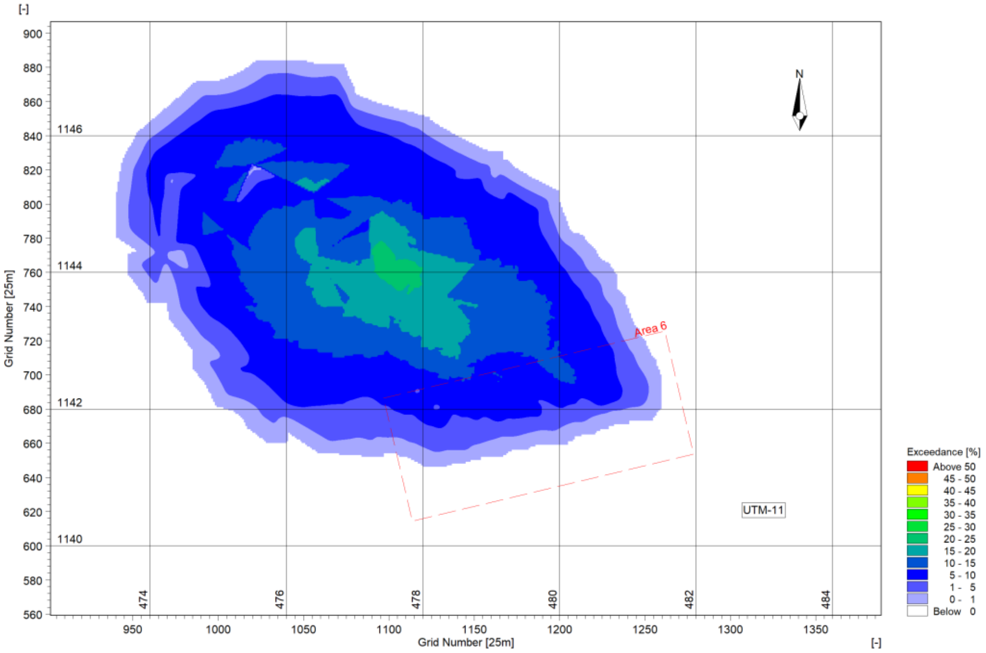

Figure 3.4 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 5m above the seabed

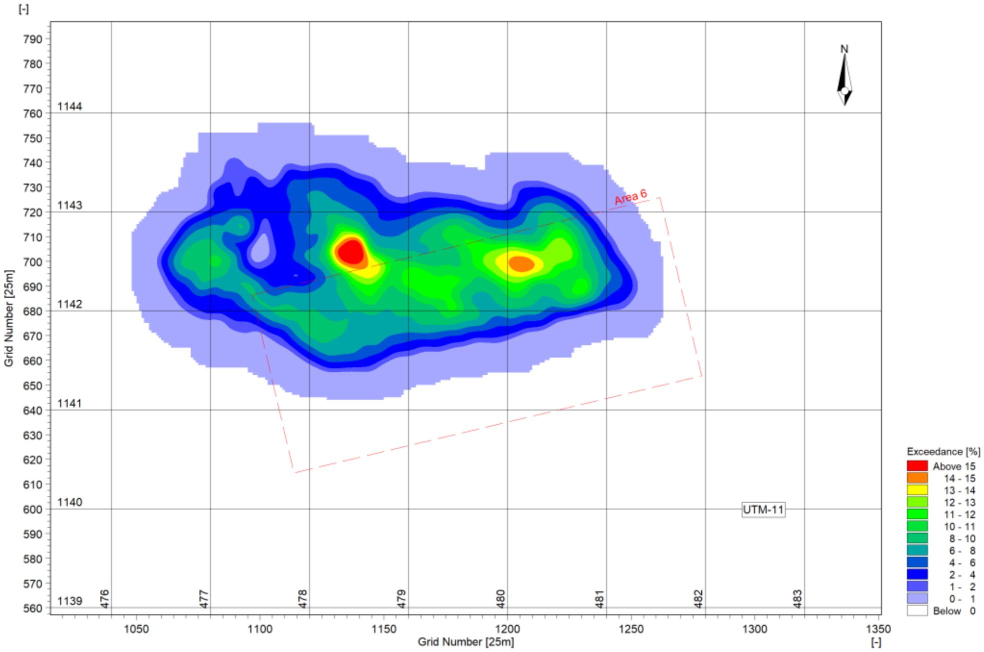

Figure 3.5 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

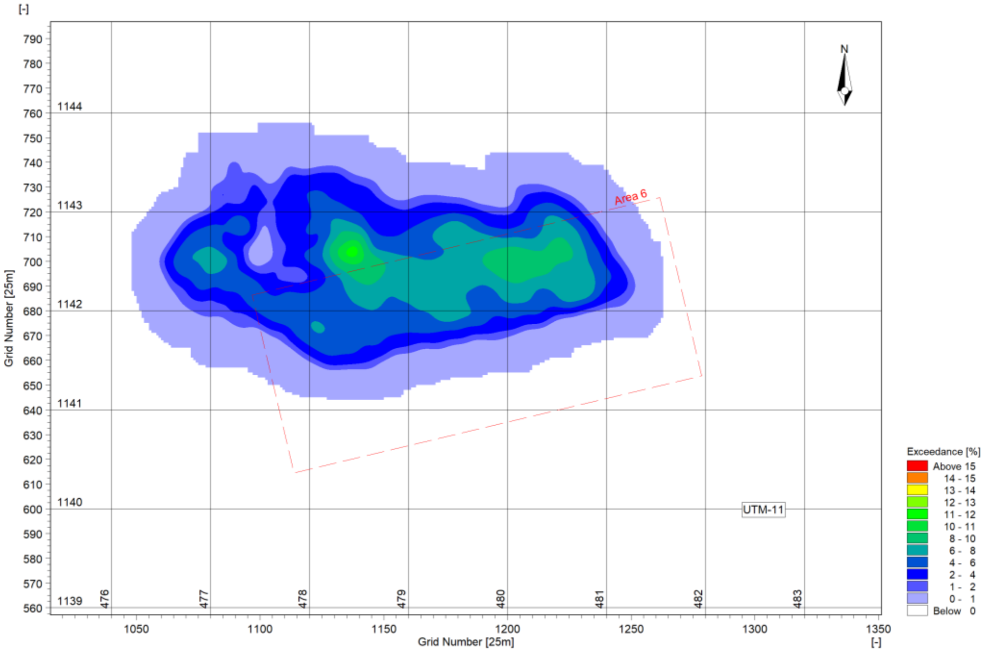

Figure 3.6 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

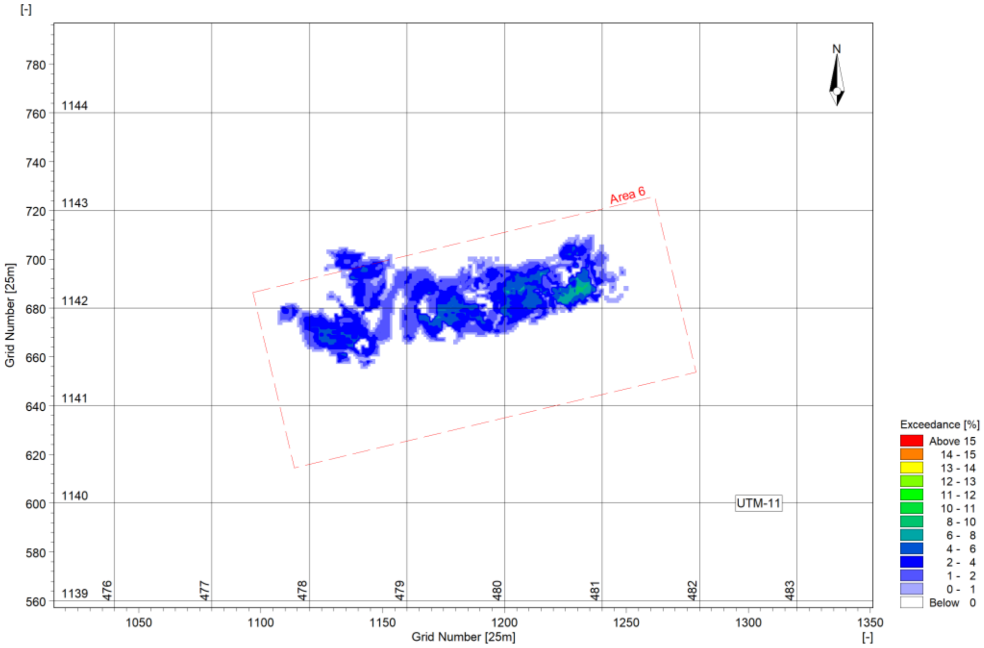

Figure 3.7 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

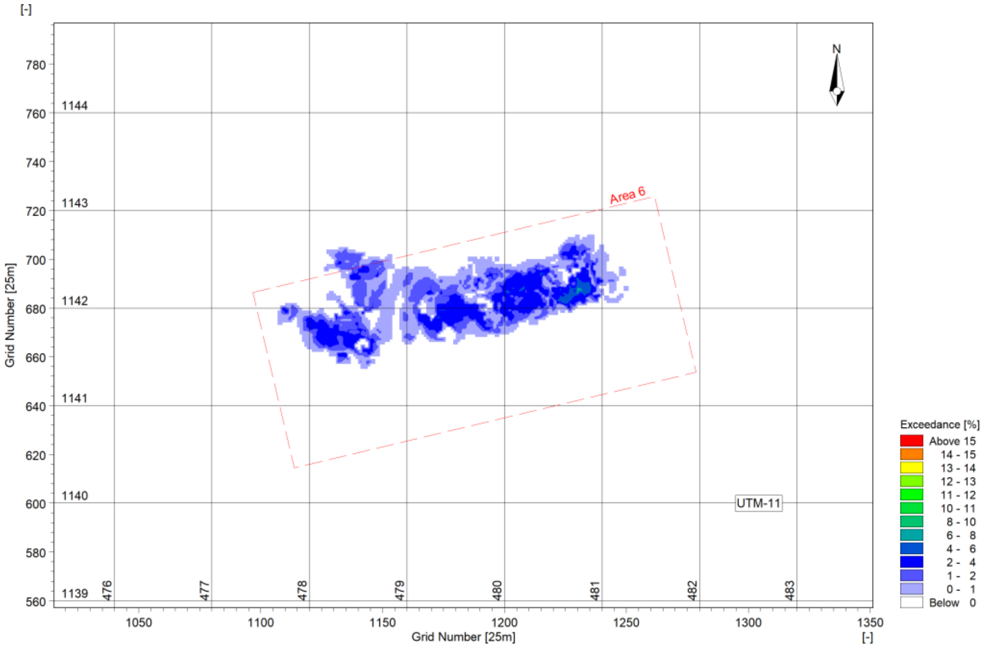

Figure 3.8 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

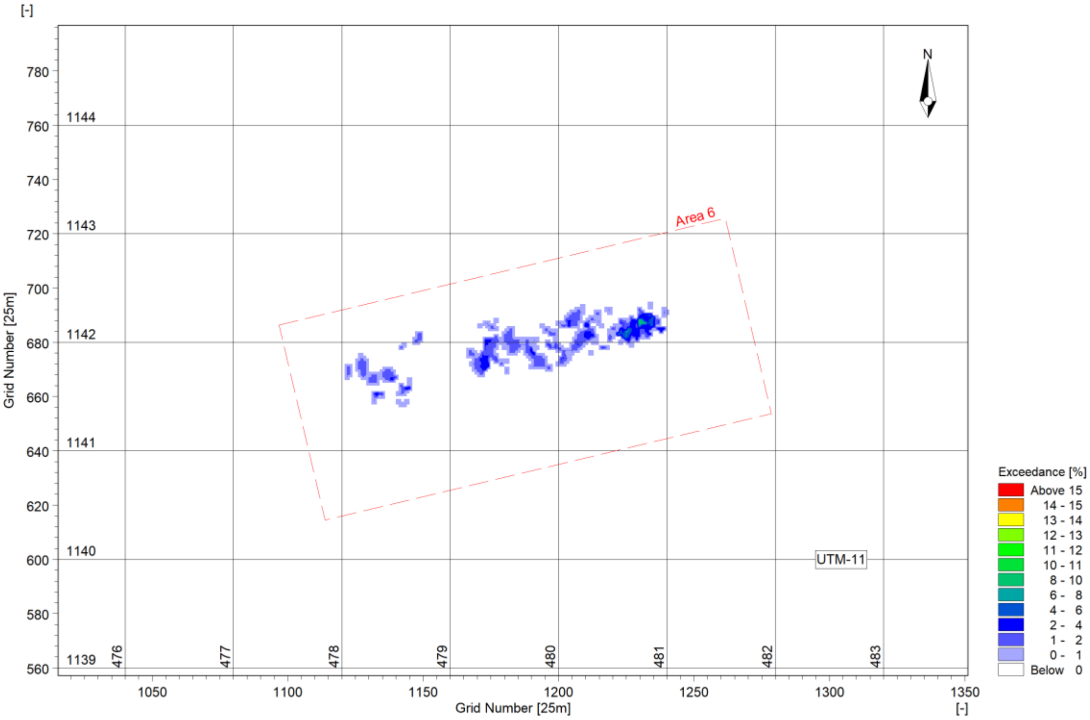

Figure 3.9 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

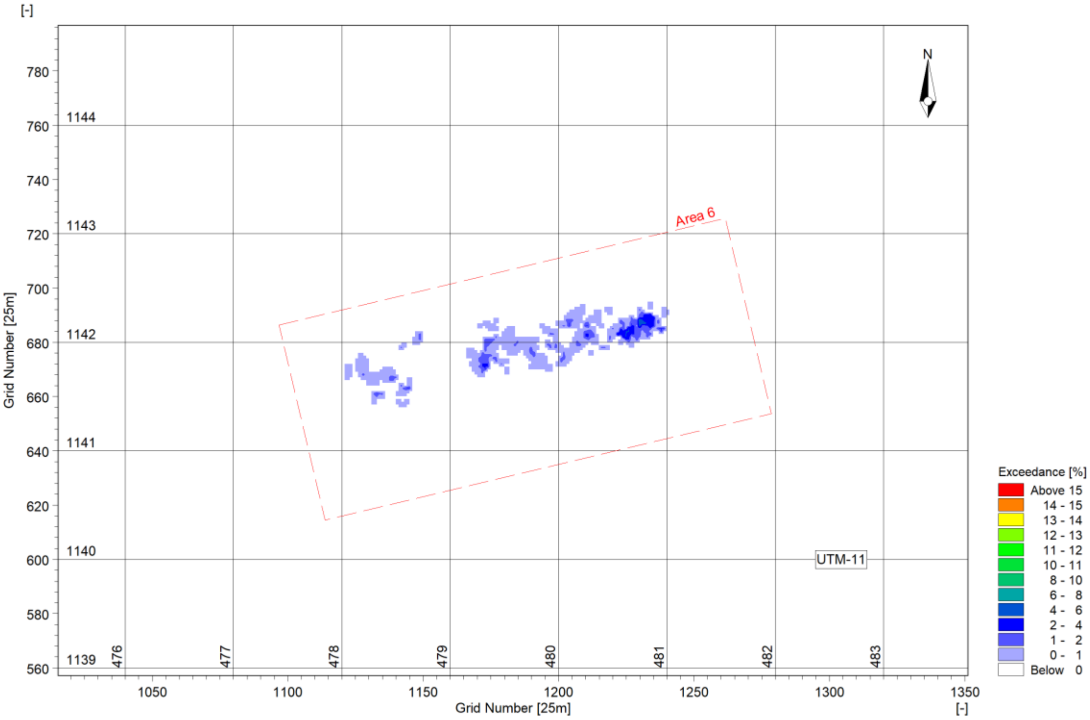

Figure 3.10 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.1.3 TSS 20m Above Seabed

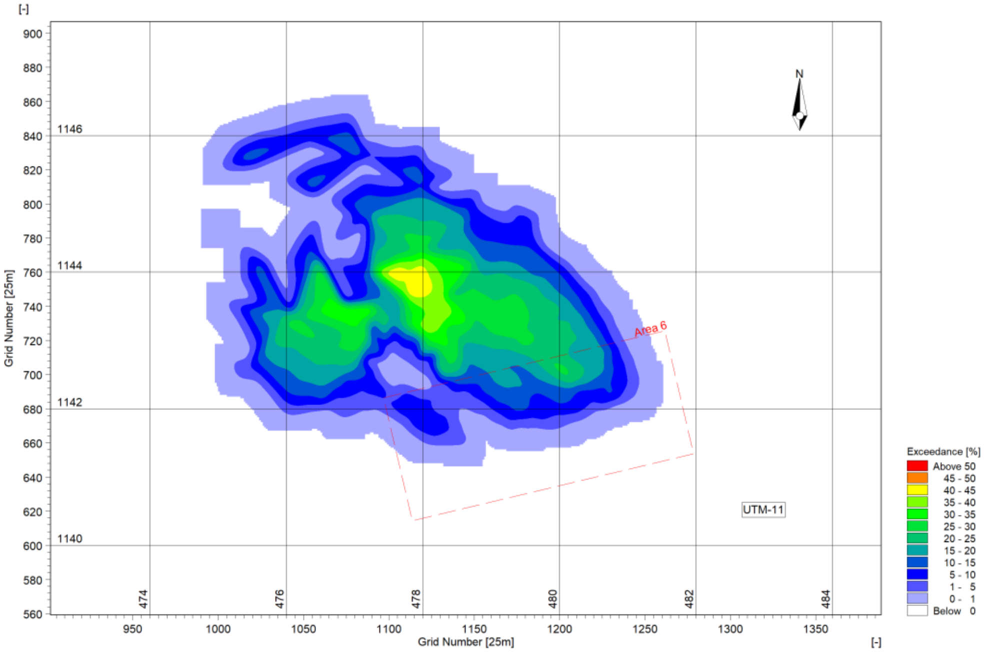

Figure 3.11 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

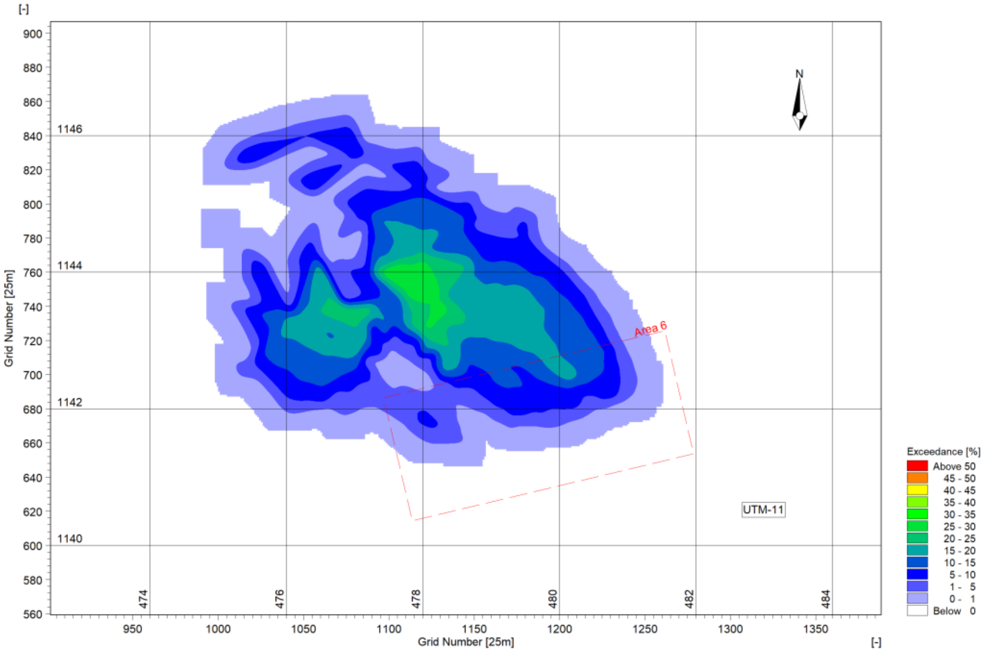

Figure 3.12 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

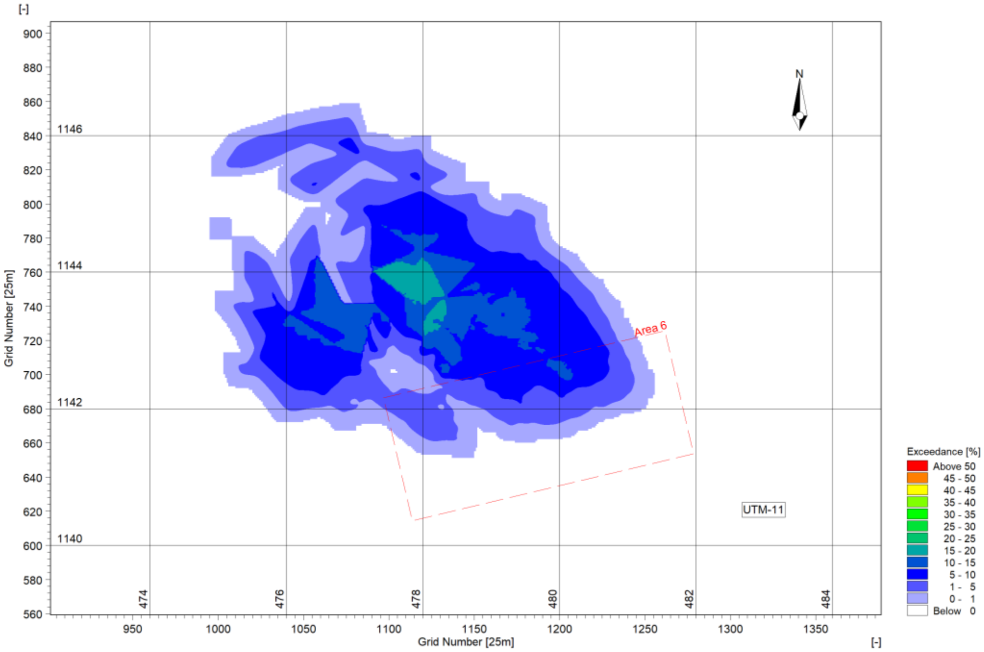

Figure 3.13 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 20m above the seabed

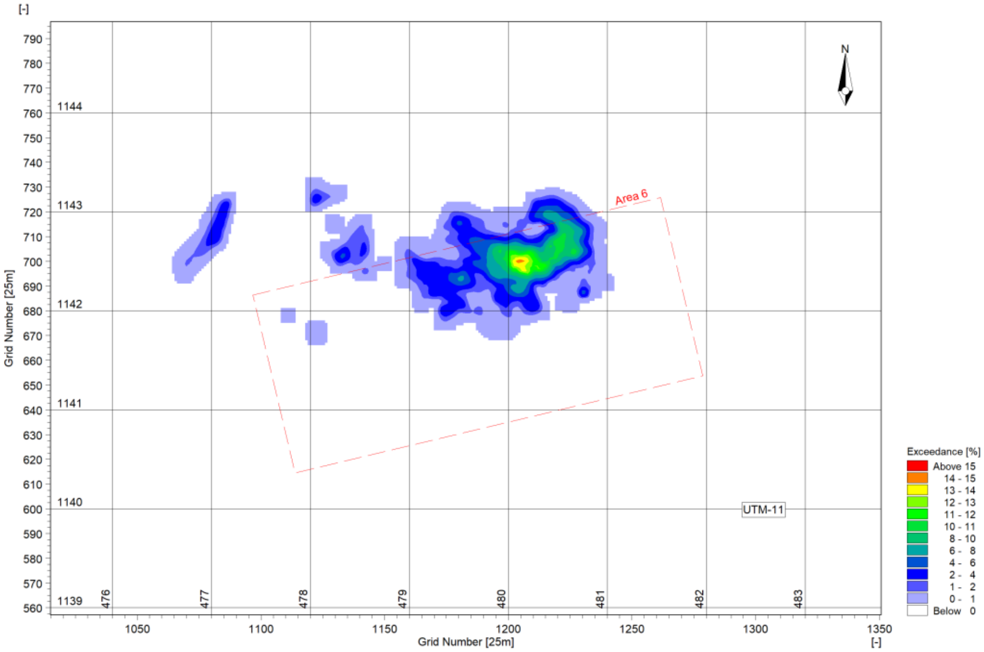

Figure 3.14 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

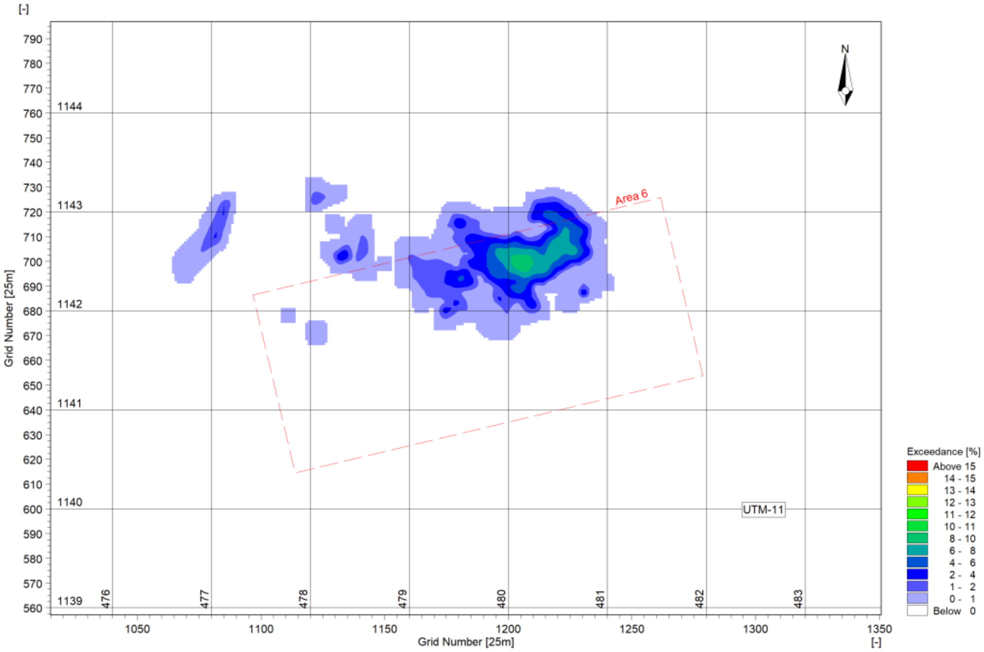

Figure 3.15 Scenario STR1b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

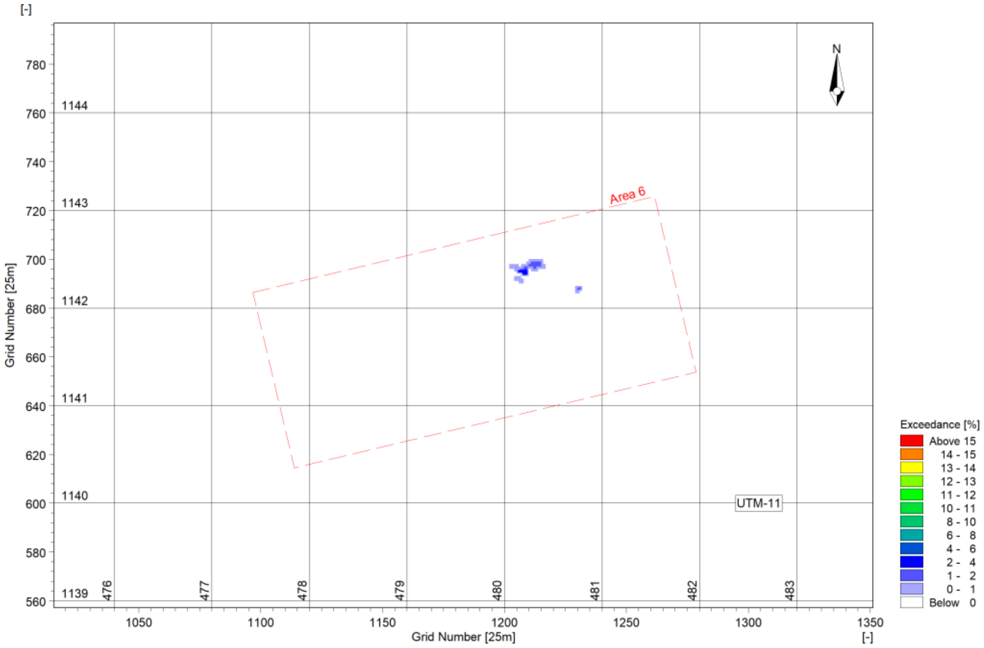

Figure 3.16 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

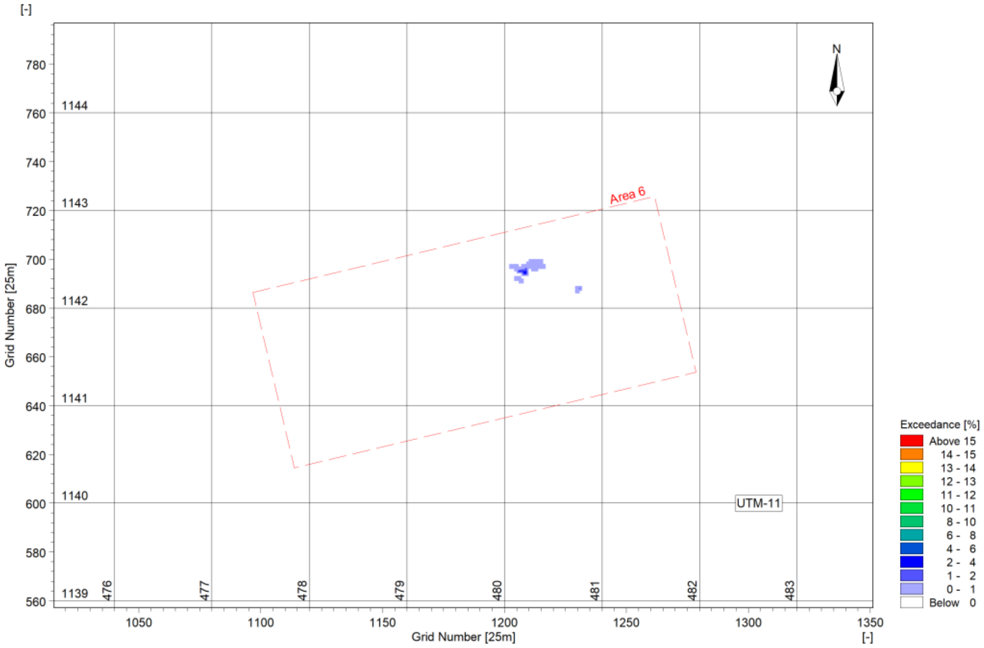

Figure 3.17 Scenario STR1b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

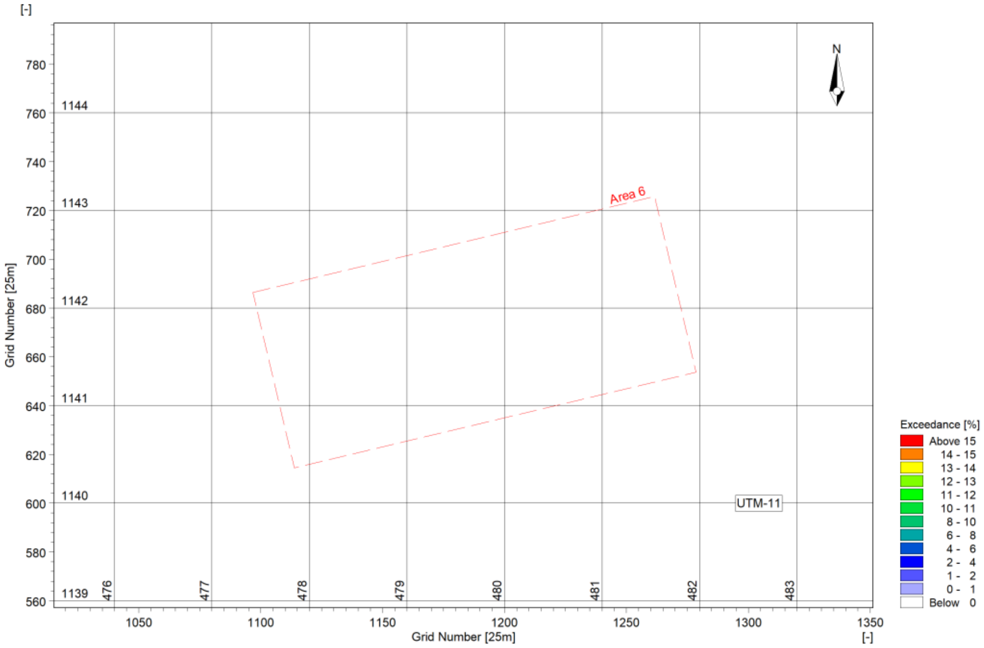

Figure 3.18 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

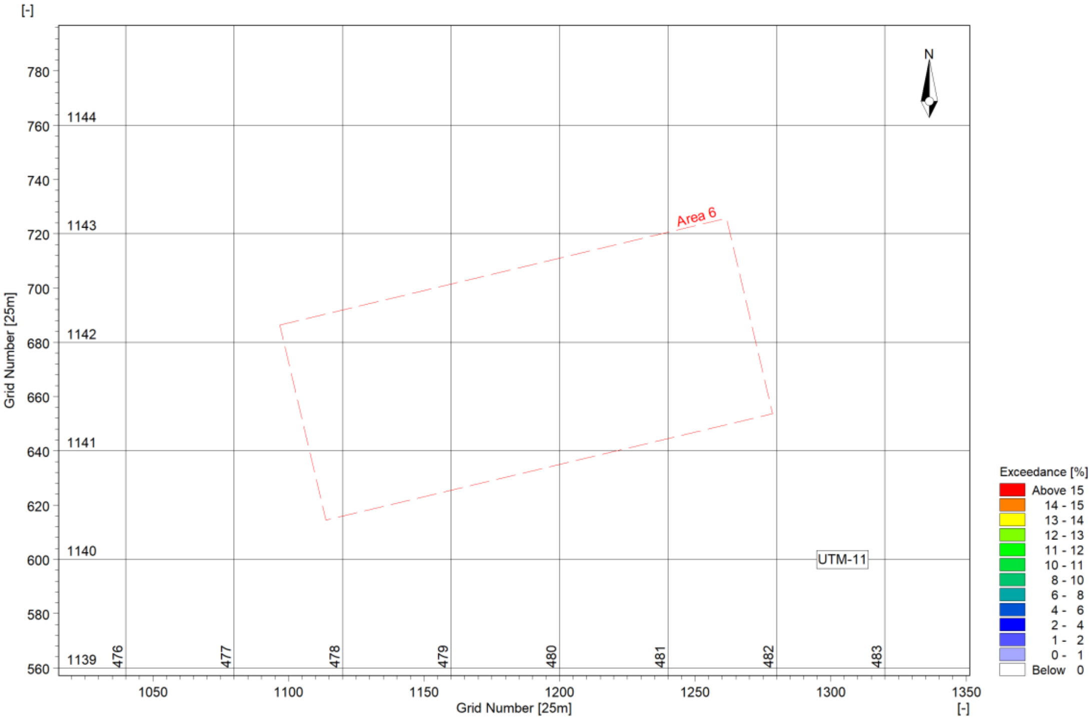

Figure 3.19 Scenario STR1b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.1.4 TSS at Mid-Water Column Discharge

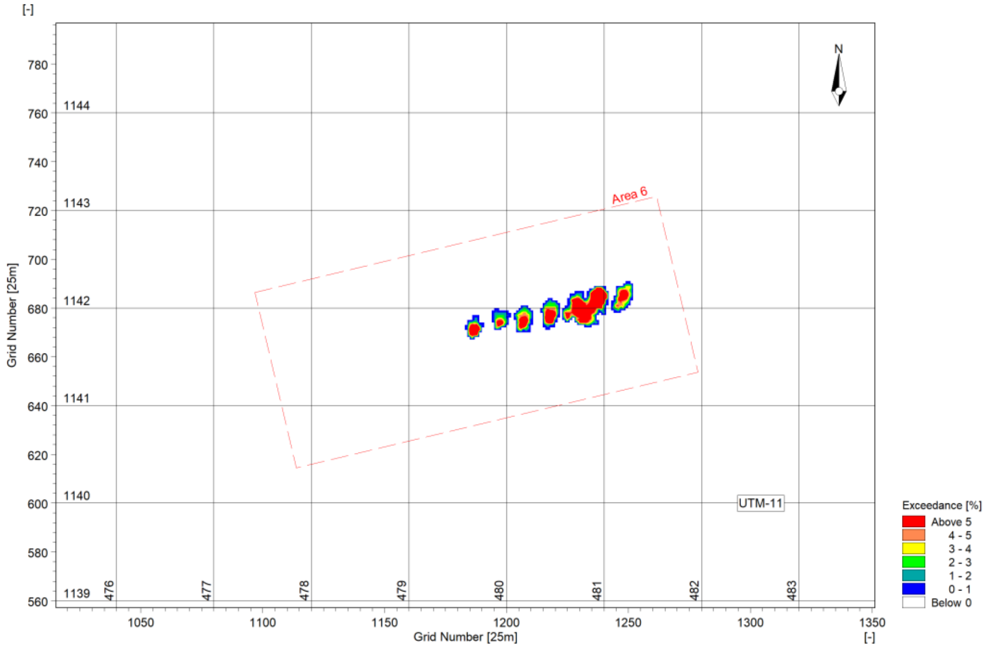

Figure 3.20 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

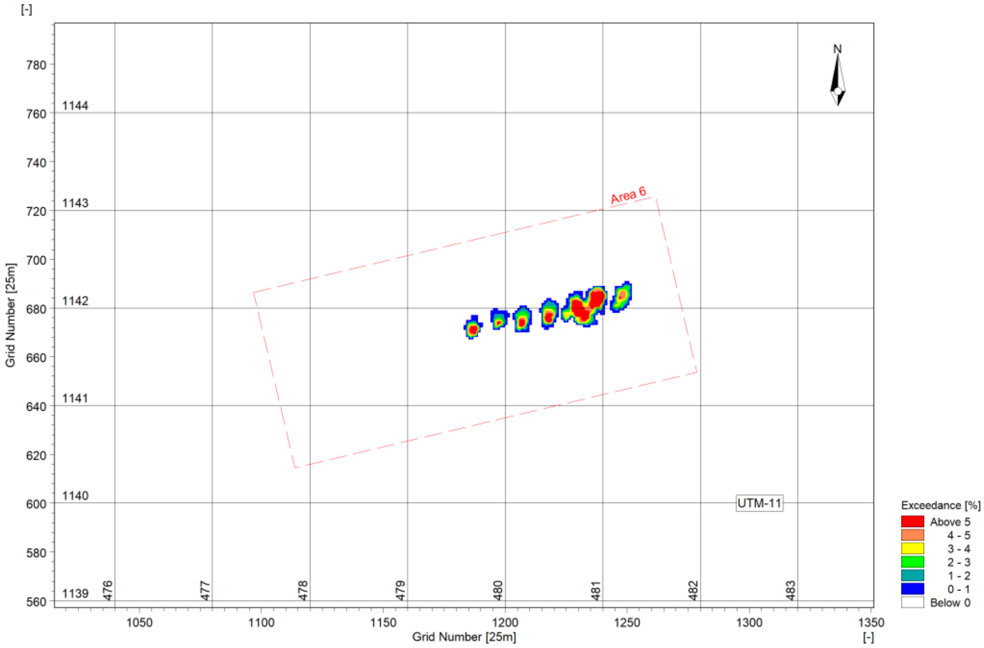

Figure 3.21 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

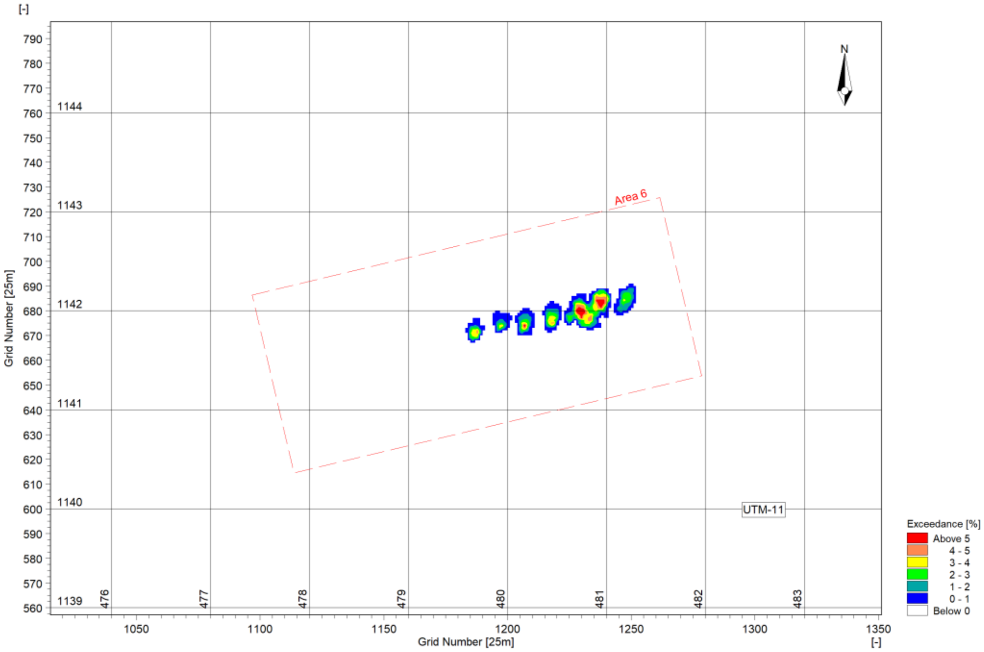

Figure 3.22 Scenario STR1b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.2 Scenario STR2a Results

Sedimentation results for Scenario STR2a are presented in Section 3.1.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.1.2, 20m above the seabed in Section 3.1.3 and at 1050m for the mid-water column discharge in Section 3.1.4.

3.2.1 Sedimentation

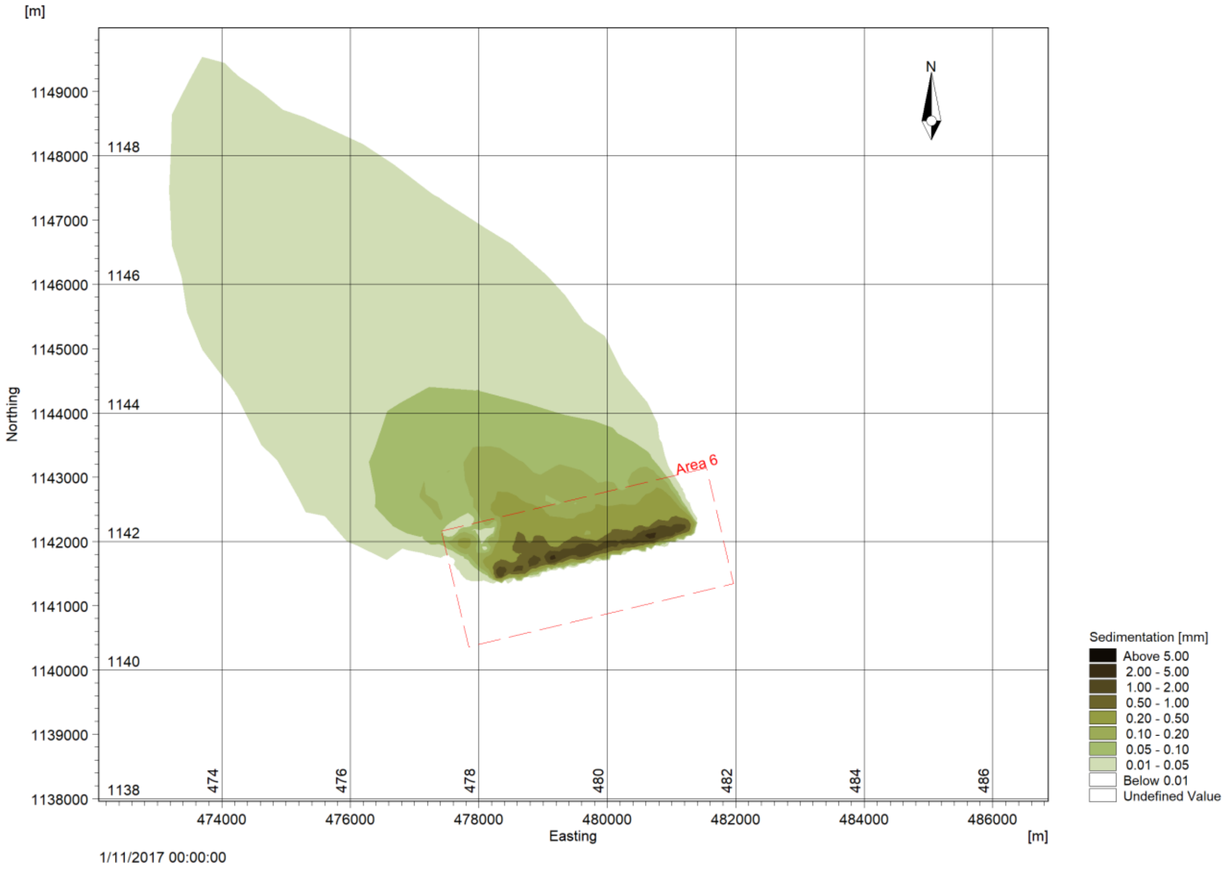

Figure 3.23 Scenario STR2a: Sedimentation (mm) ca. 10.5 days after completion of operation

3.2.2 TSS 5m Above Seabed

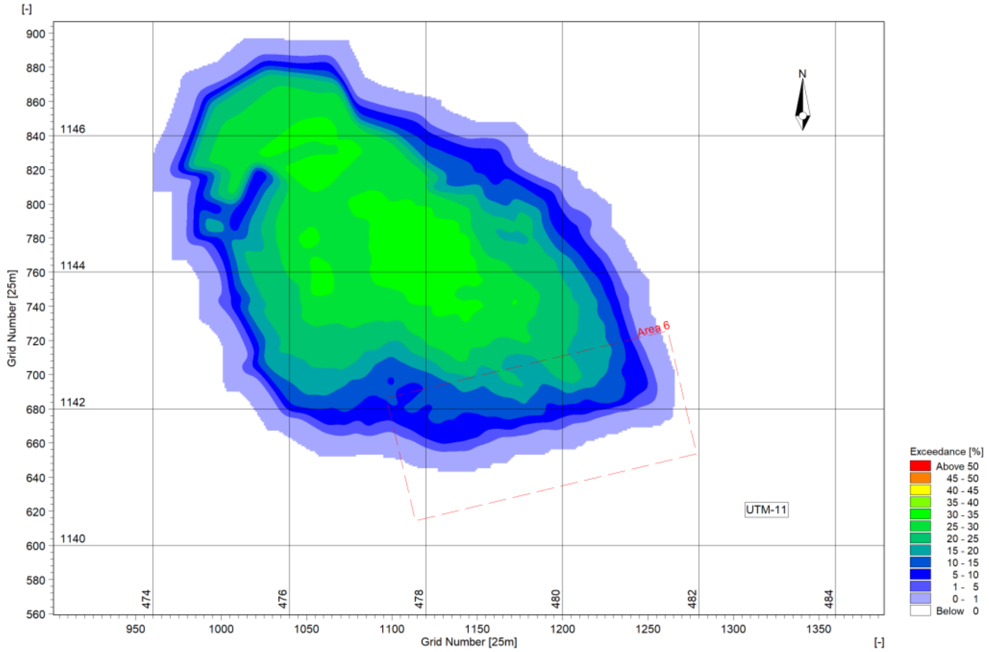

Figure 3.24 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

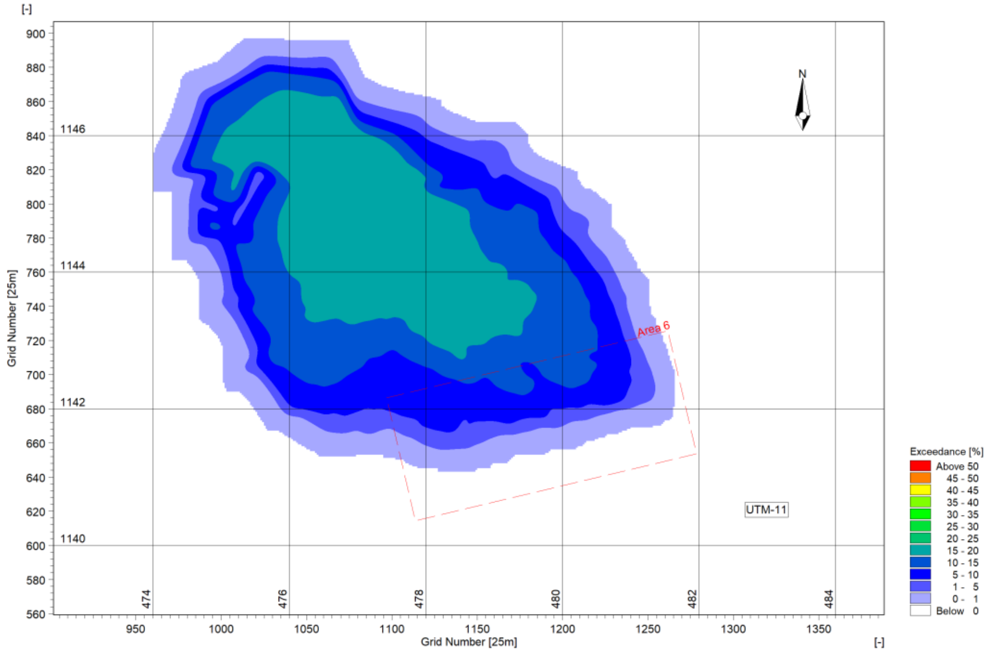

Figure 3.25 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

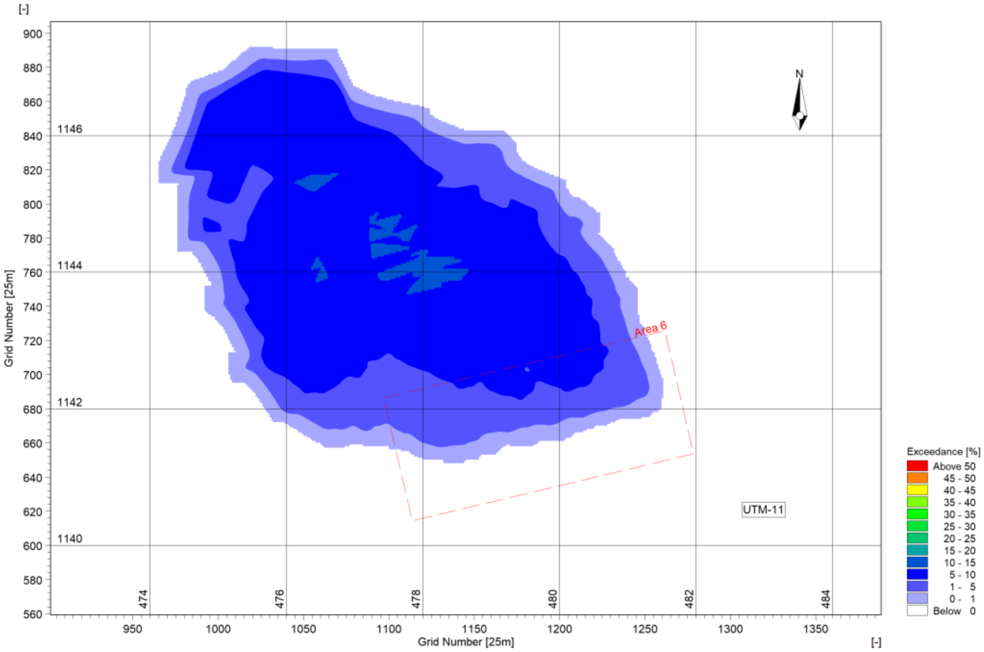

Figure 3.26 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 5m above the seabed

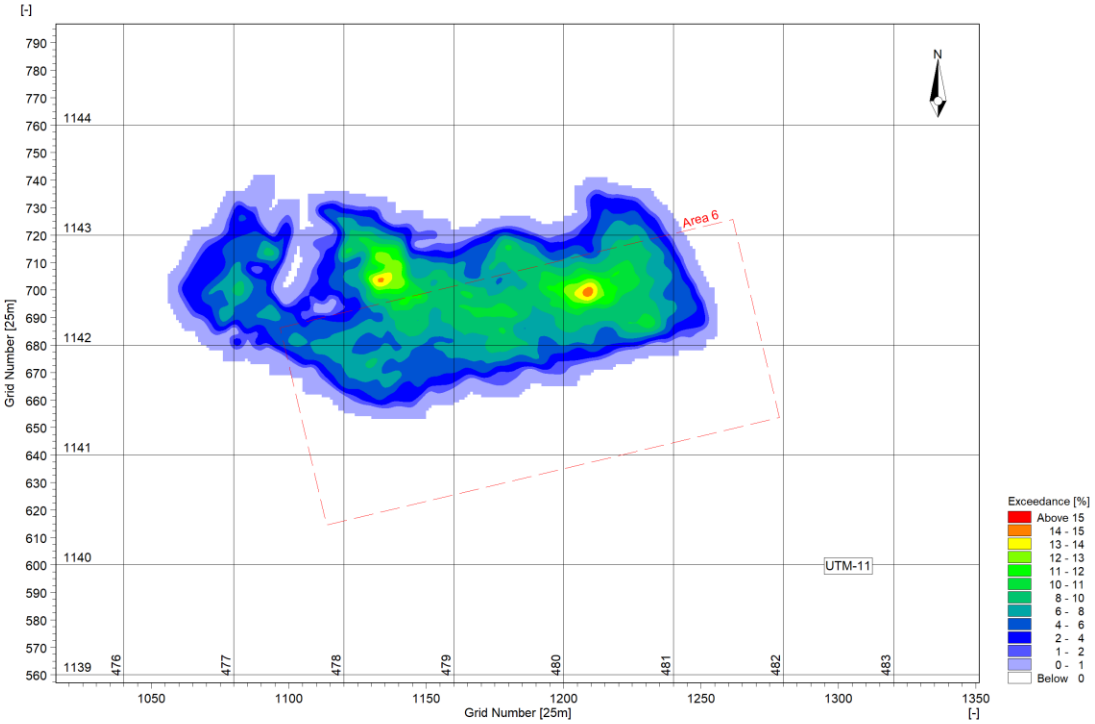

Figure 3.27 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

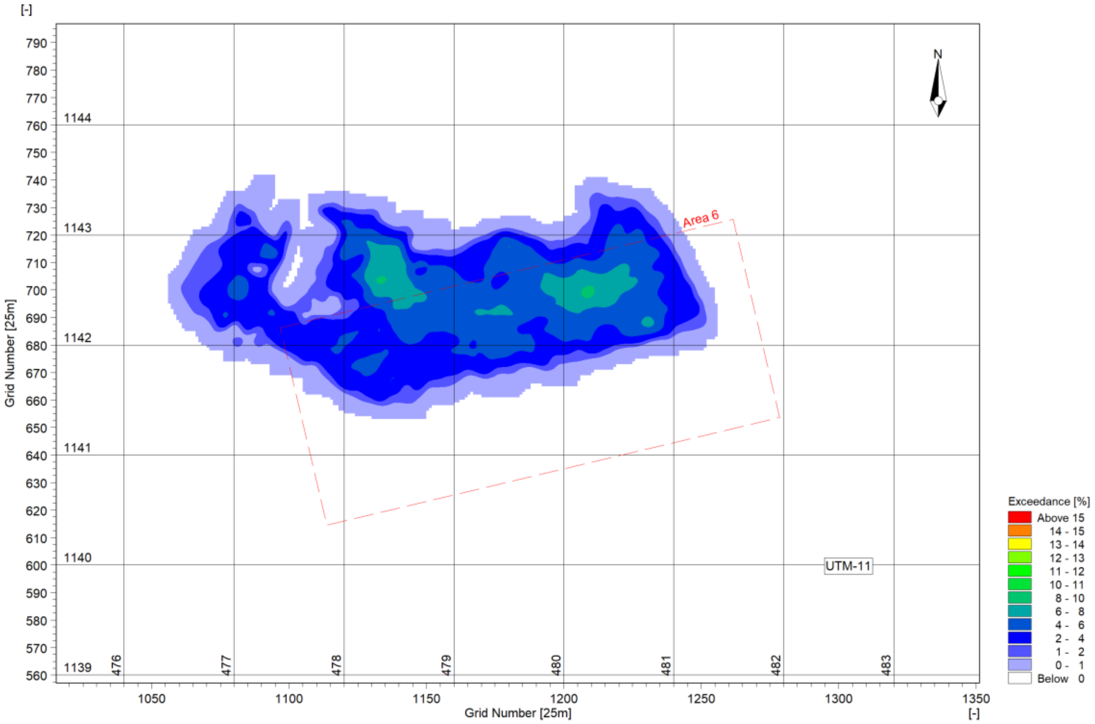

Figure 3.28 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

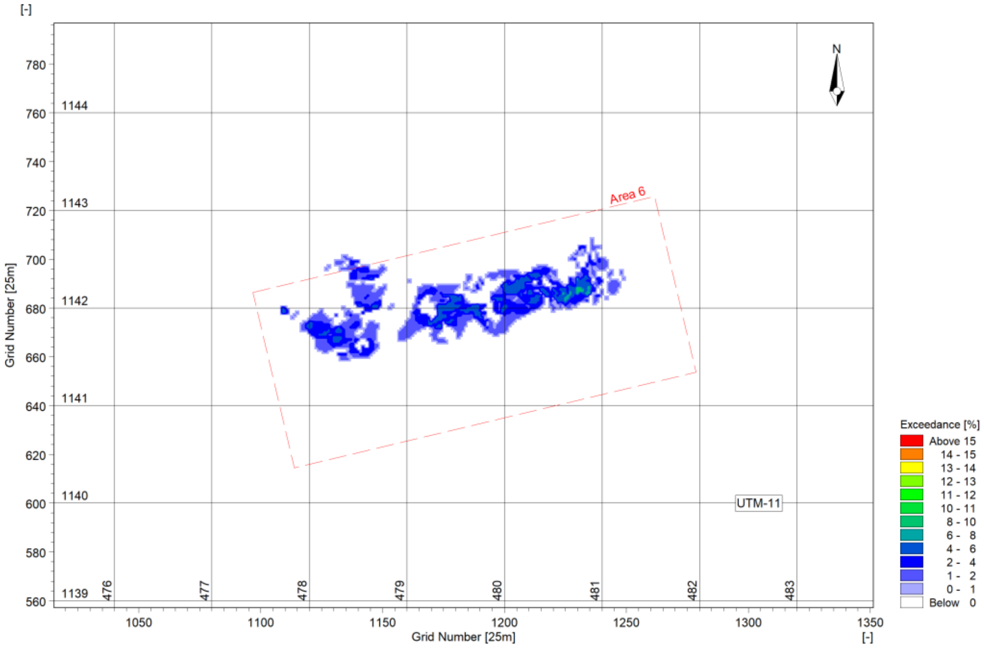

Figure 3.29 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

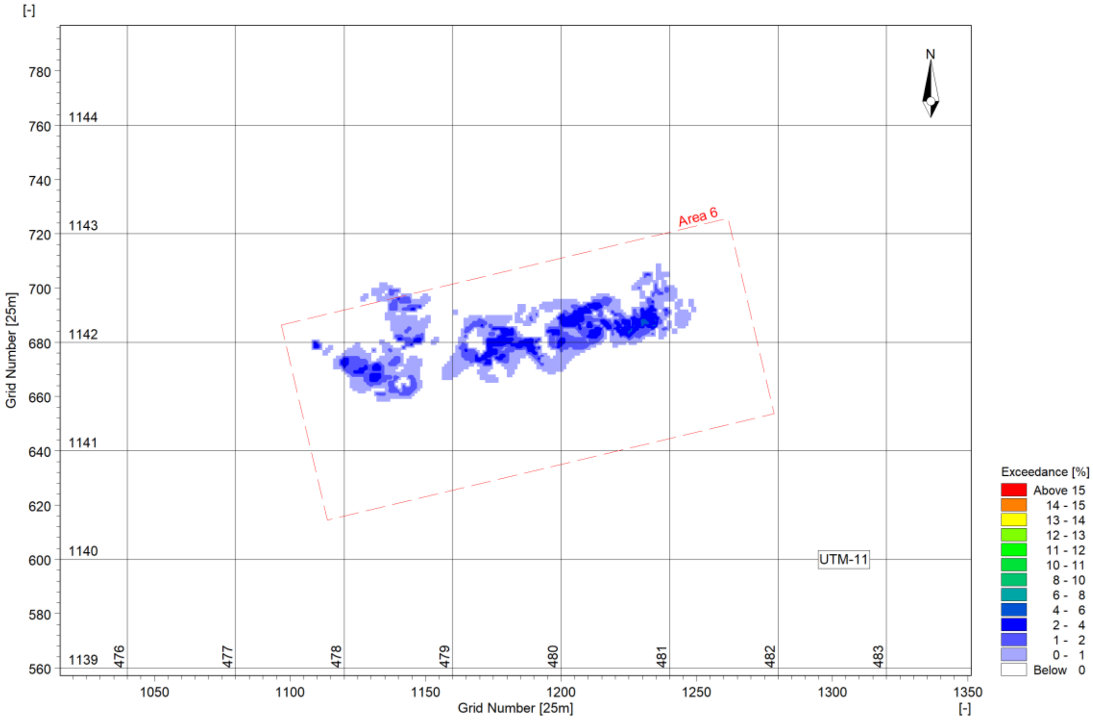

Figure 3.30 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

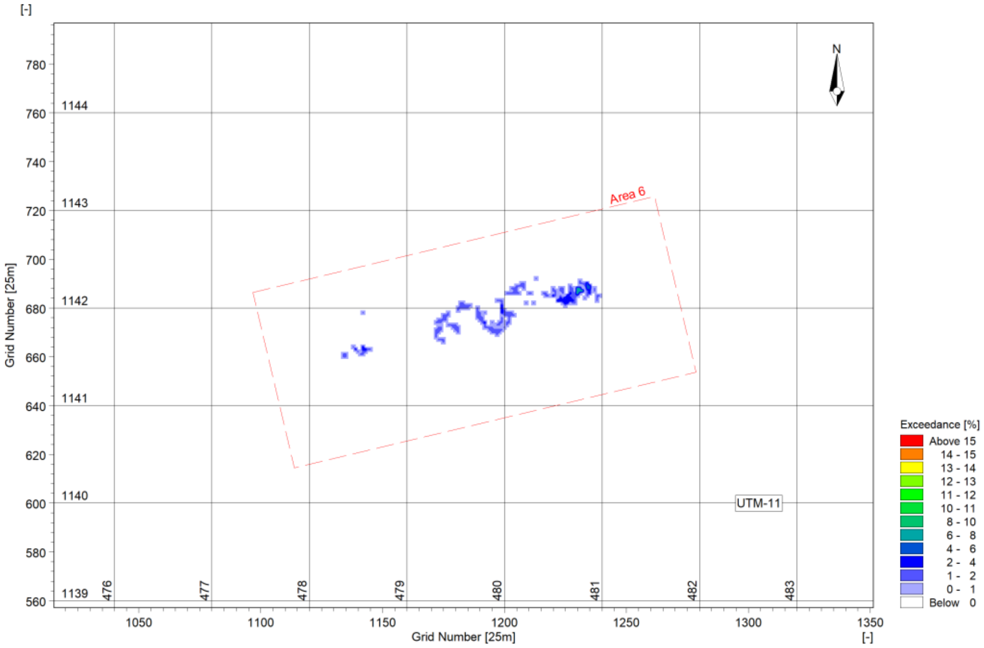

Figure 3.31 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

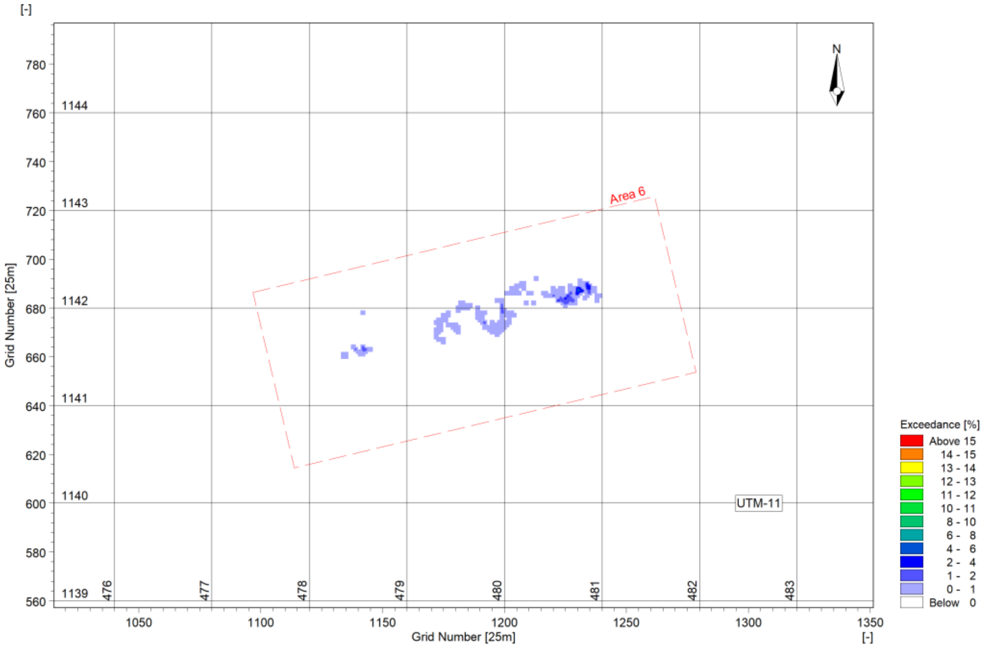

Figure 3.32 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.2.3 TSS 20m Above Seabed

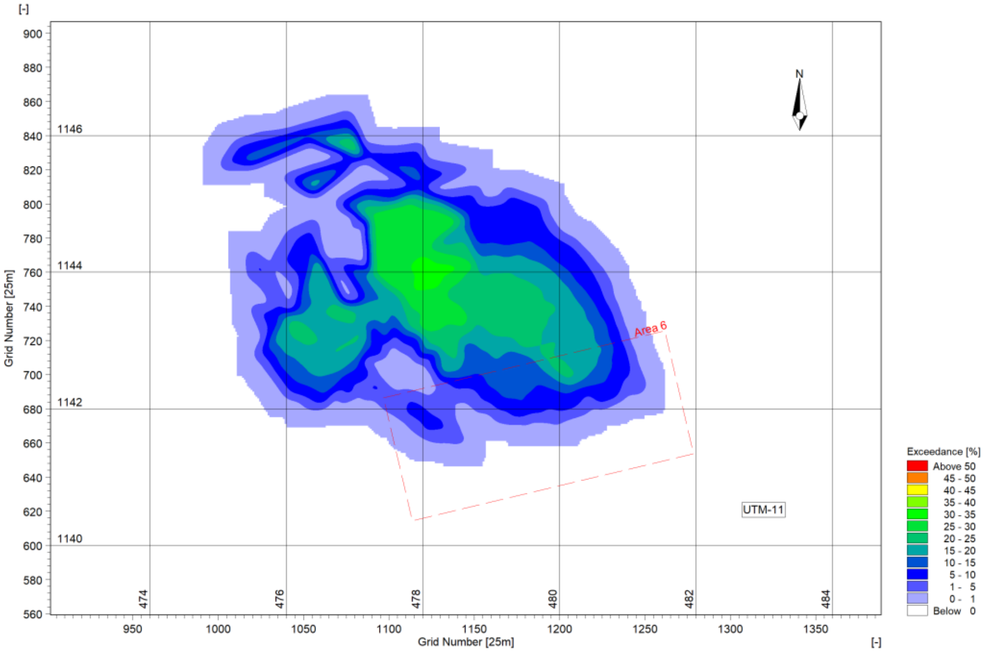

Figure 3.33 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

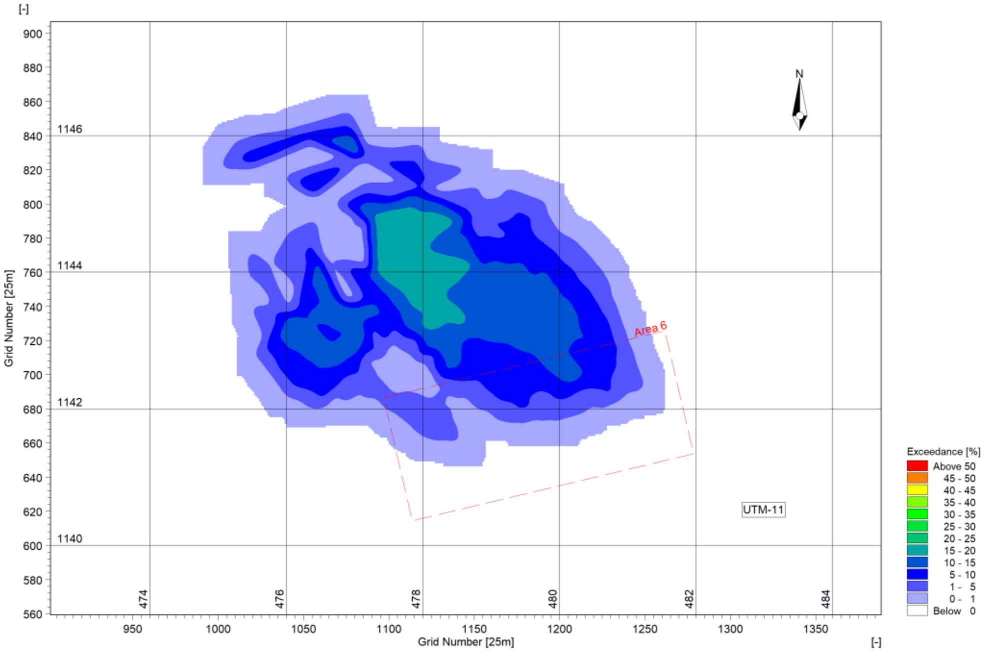

Figure 3.34 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

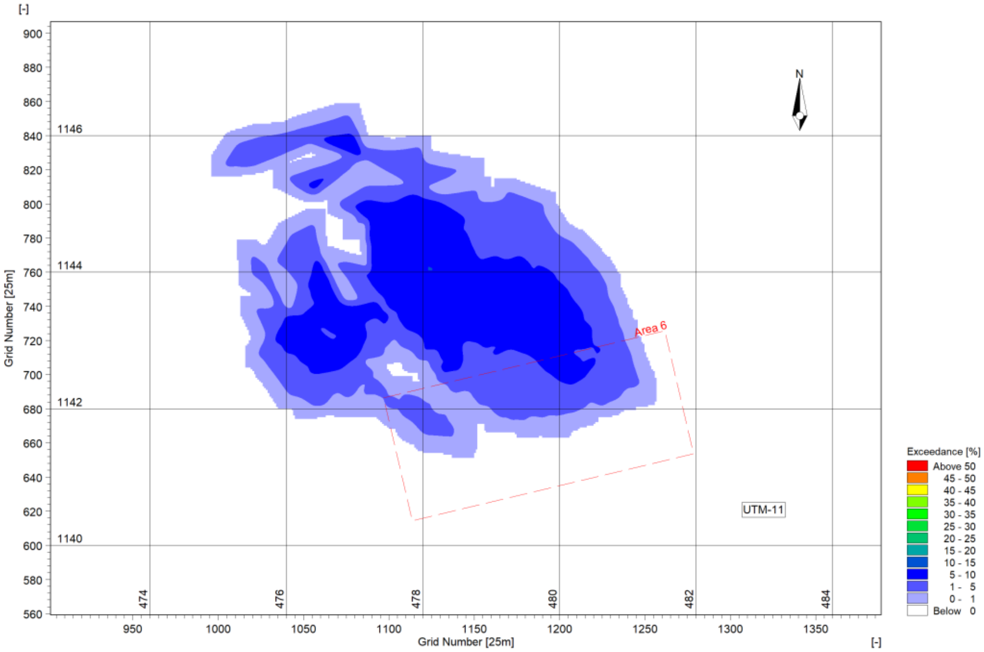

Figure 3.35 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 20m above the seabed

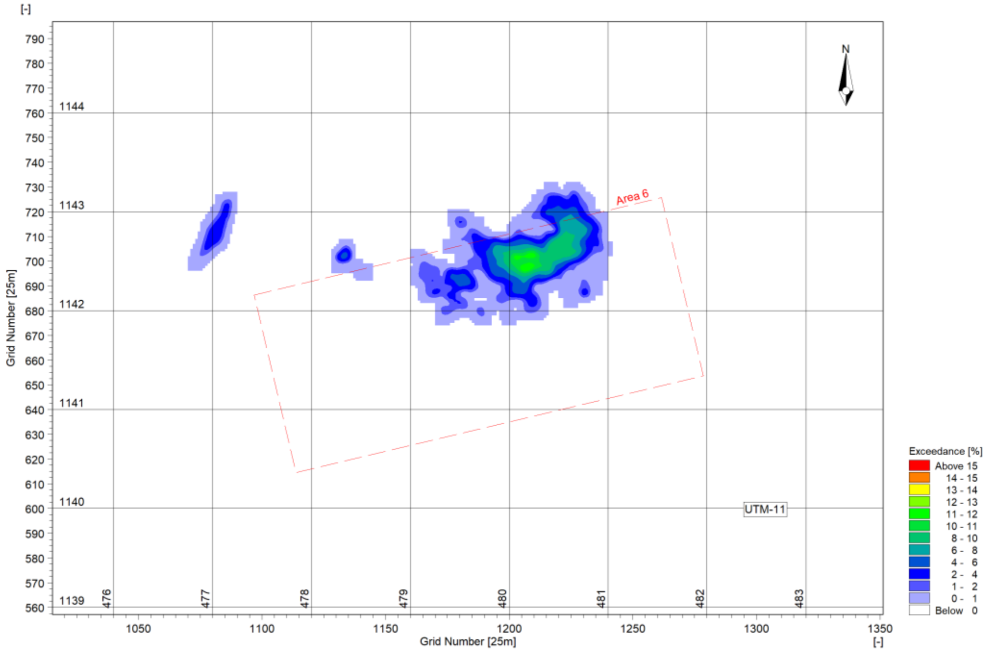

Figure 3.36 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

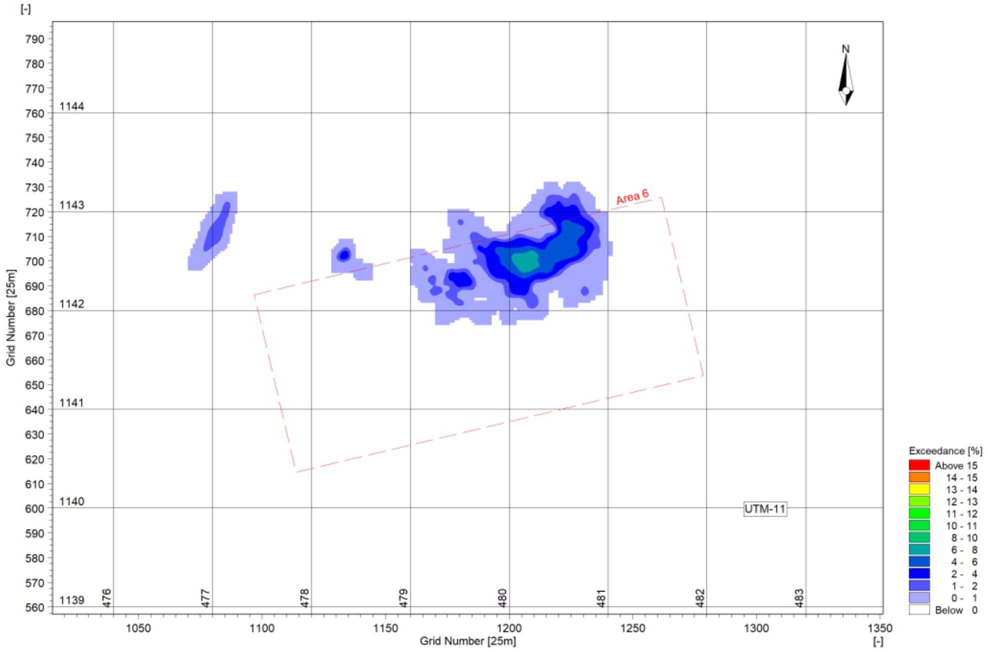

Figure 3.37 Scenario STR2a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

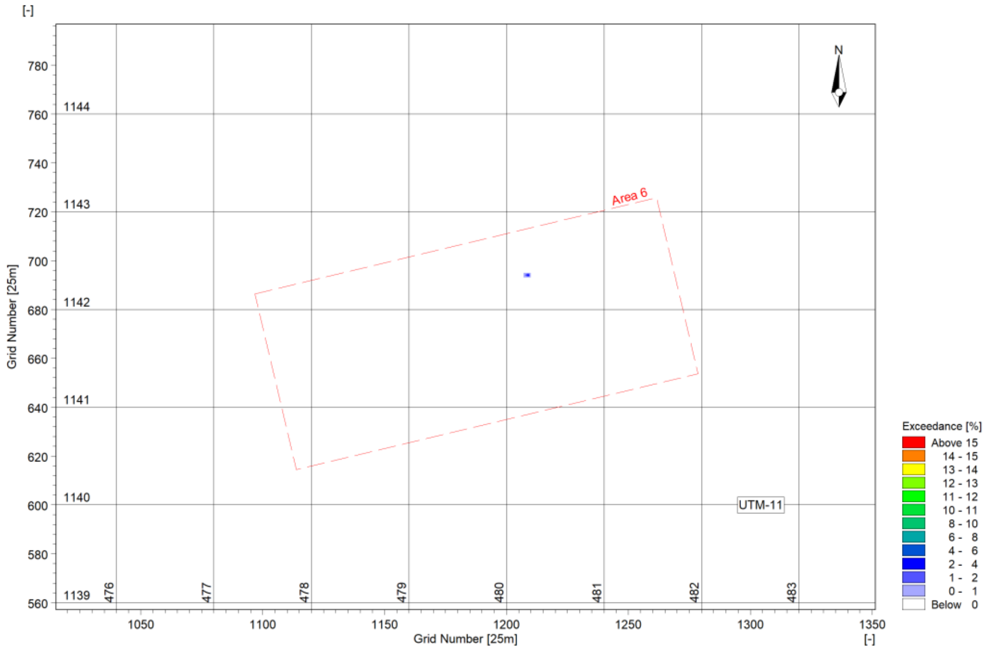

Figure 3.38 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

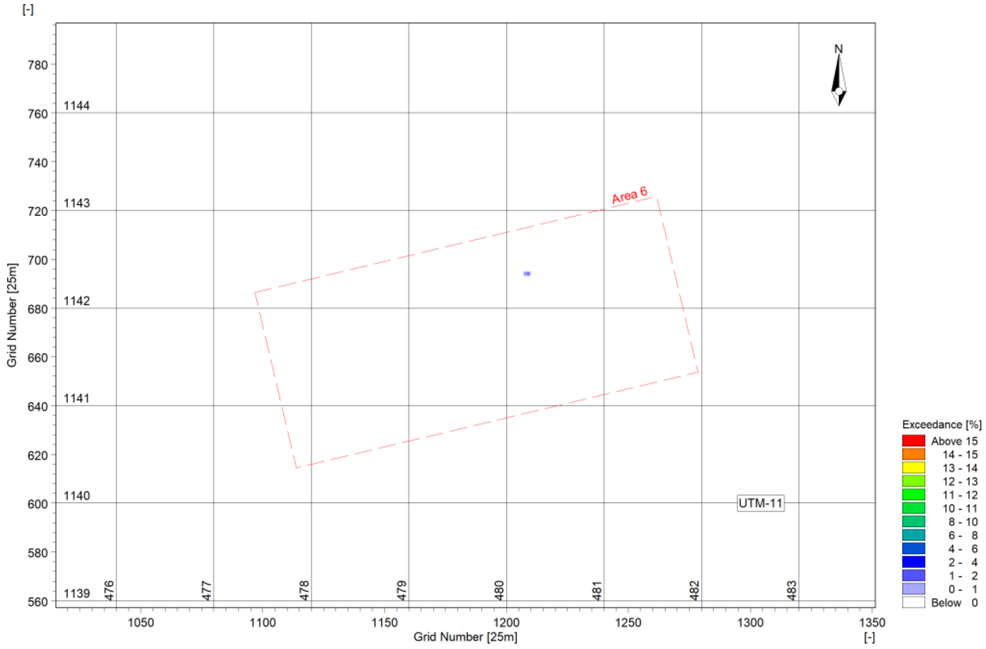

Figure 3.39 Scenario STR2a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

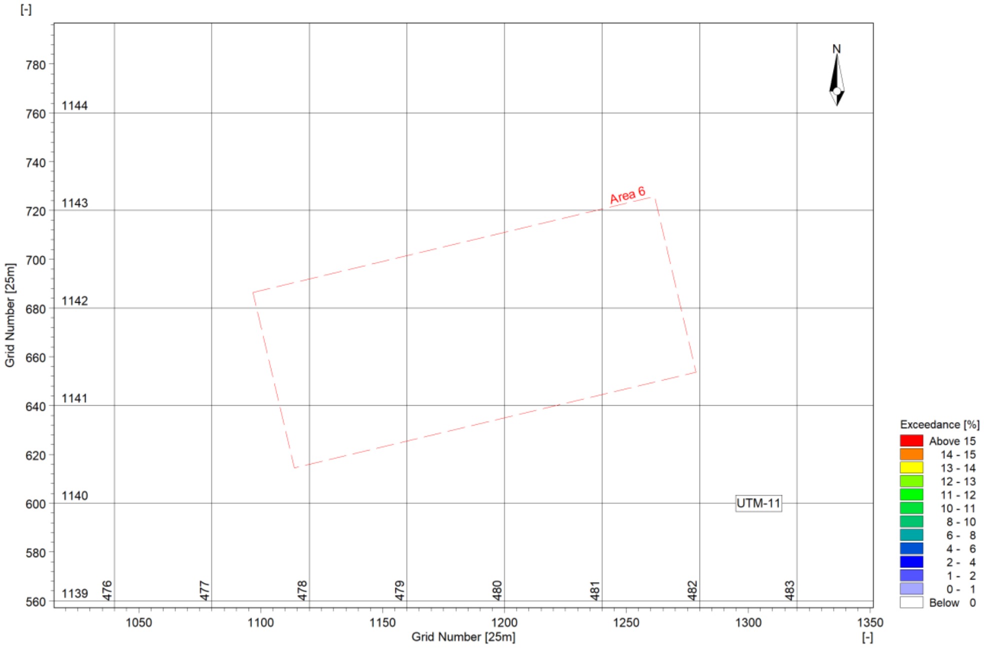

Figure 3.40 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

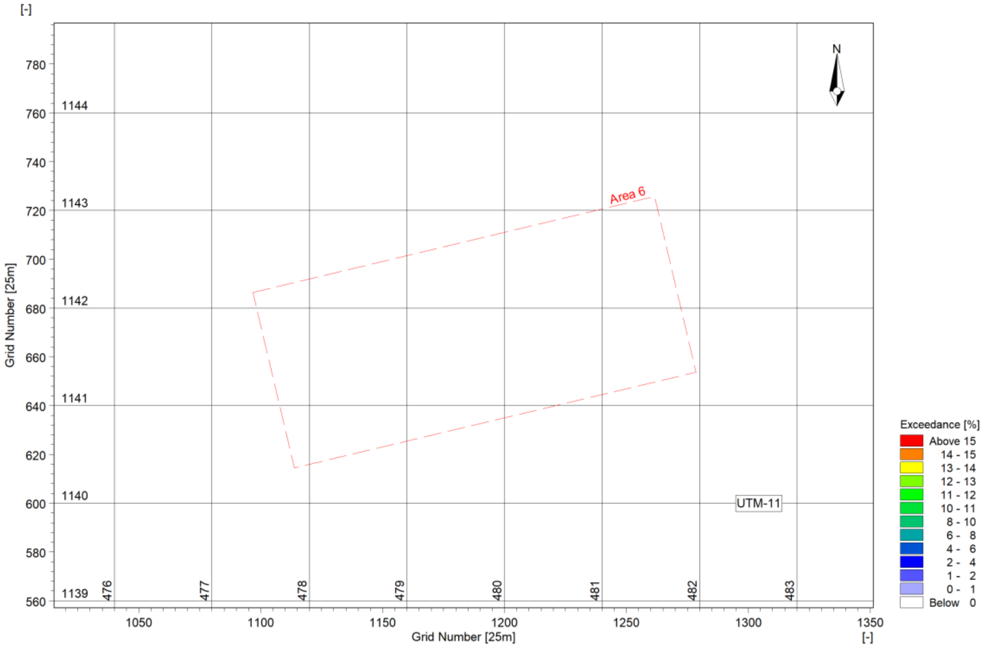

Figure 3.41 Scenario STR2a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.2.4 TSS at Mid-Water Column Discharge

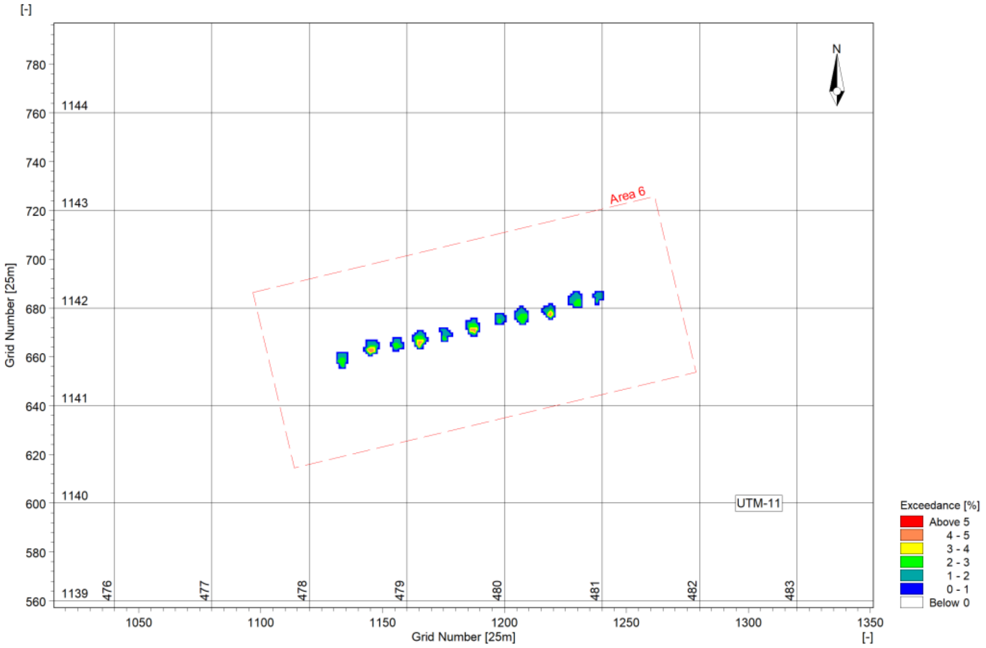

Figure 3.42 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

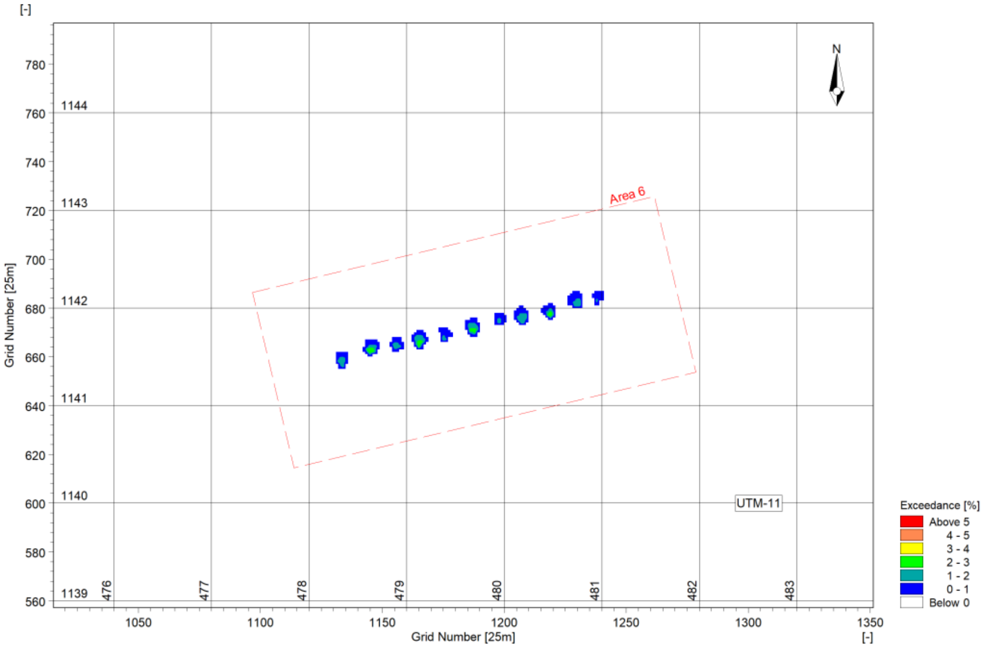

Figure 3.43 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

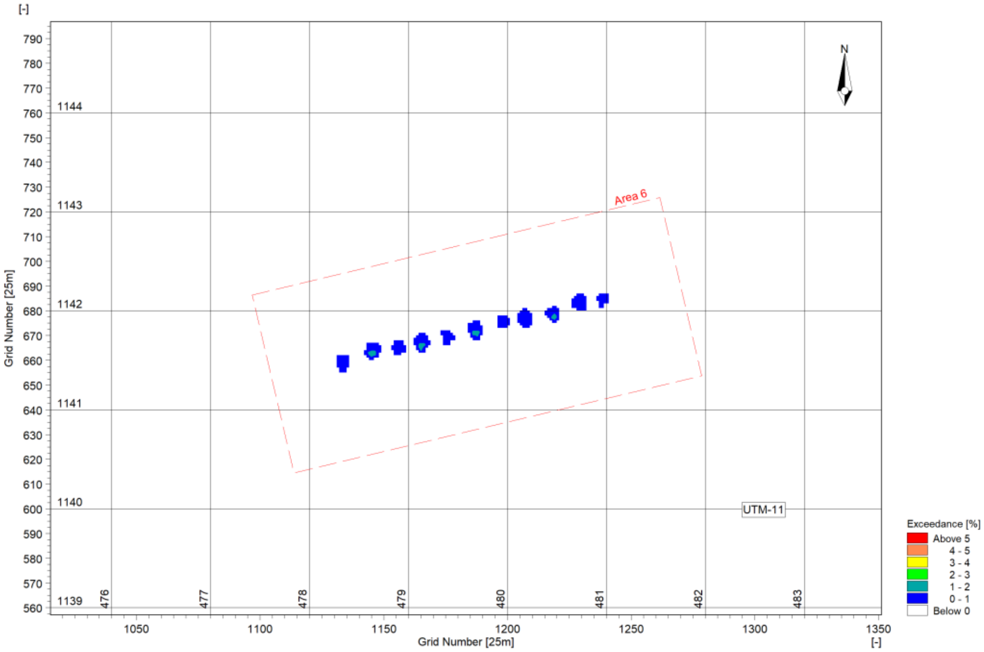

Figure 3.44 Scenario STR2a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.3 Scenario STR2b Results

Sedimentation results for Scenario STR2b are presented in Section 3.4.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.3.2, 20m above the seabed in Section 3.4.3 and at 1050m for the mid-water column discharge in Section 3.4.4.

3.3.1 Sedimentation

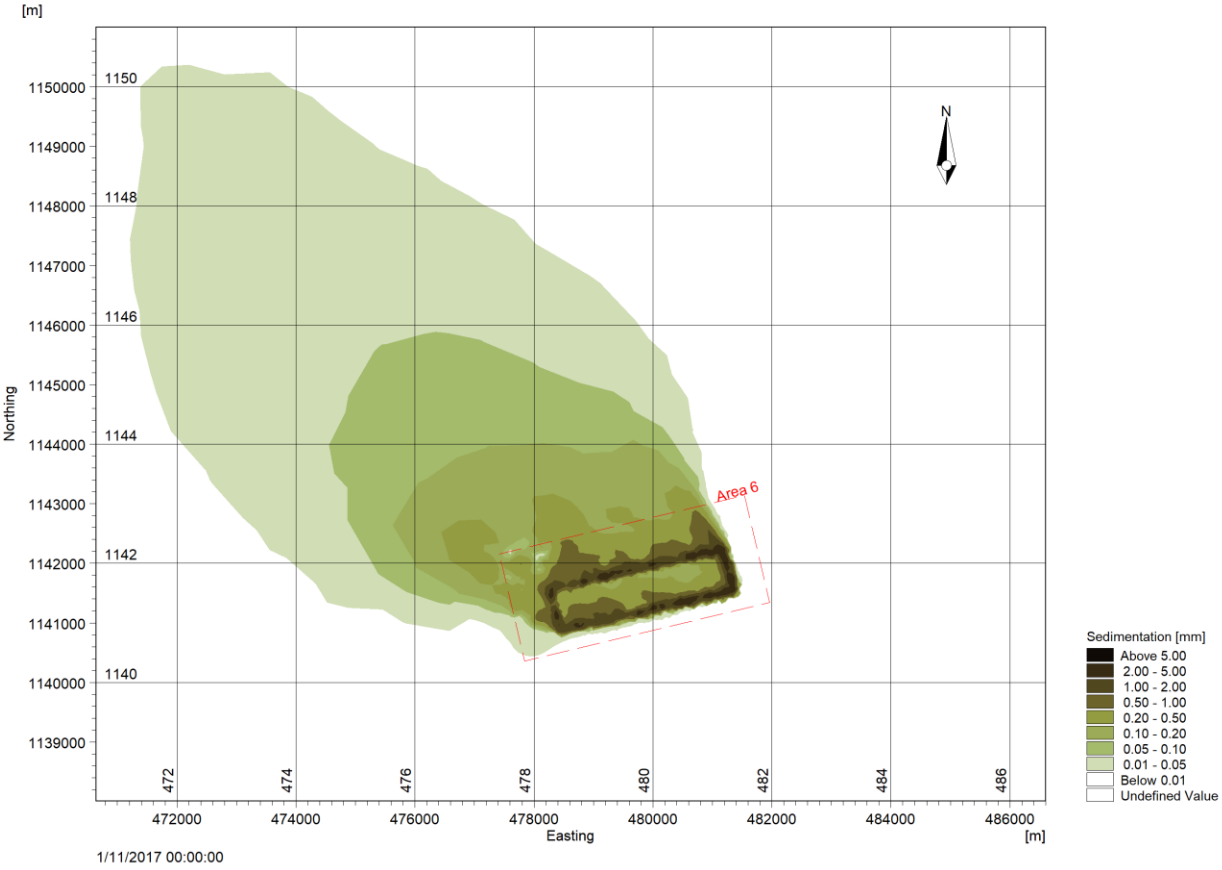

Figure 3.45 Scenario STR2b: Sedimentation (mm) ca. 10 days after completion of operation

3.3.2 TSS 5m Above Seabed

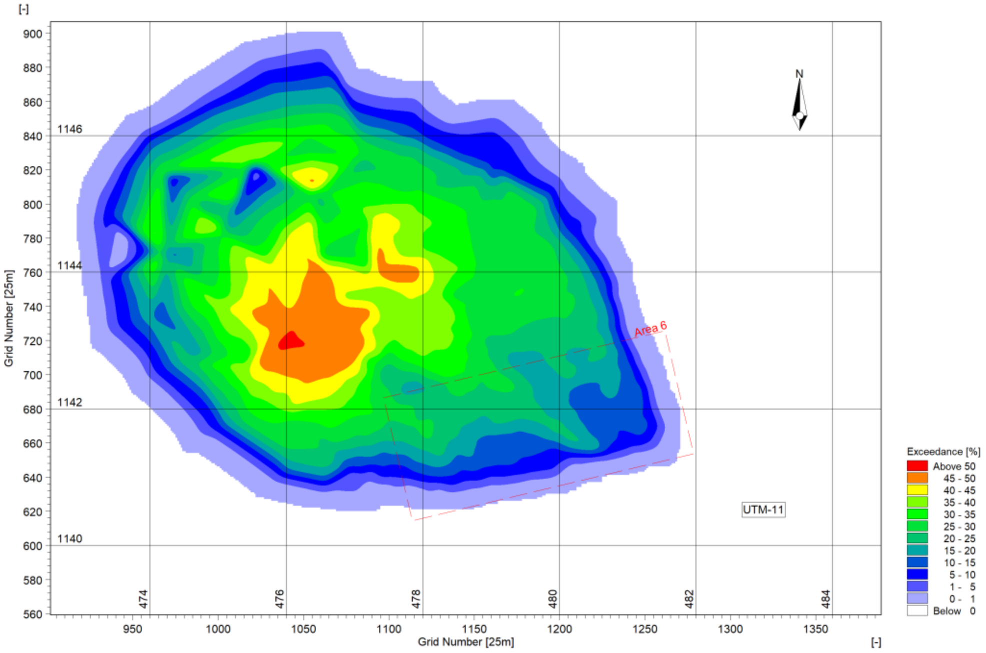

Figure 3.46 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

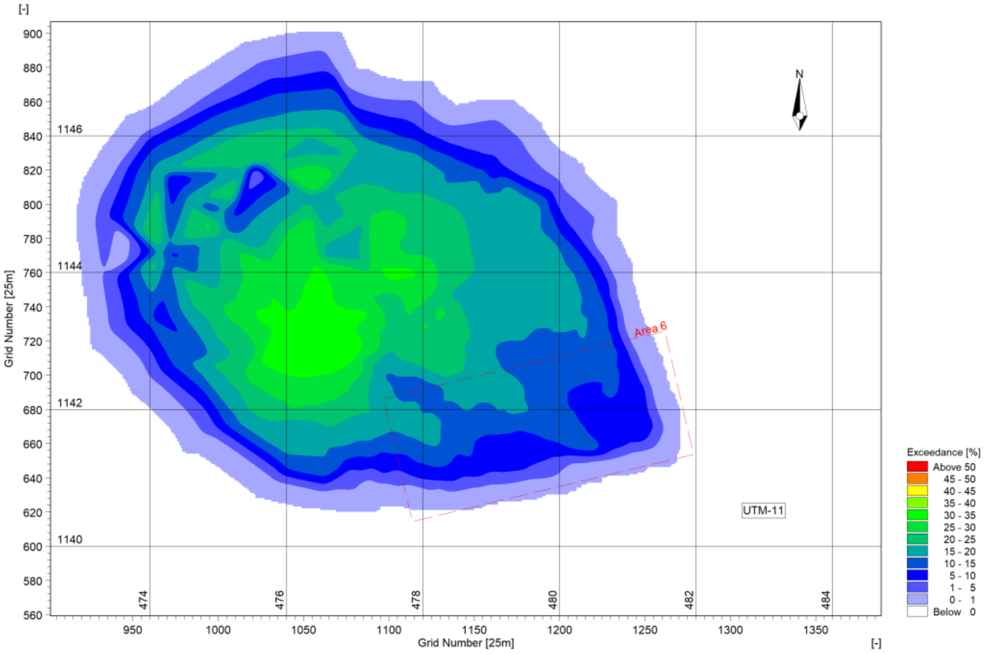

Figure 3.47 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

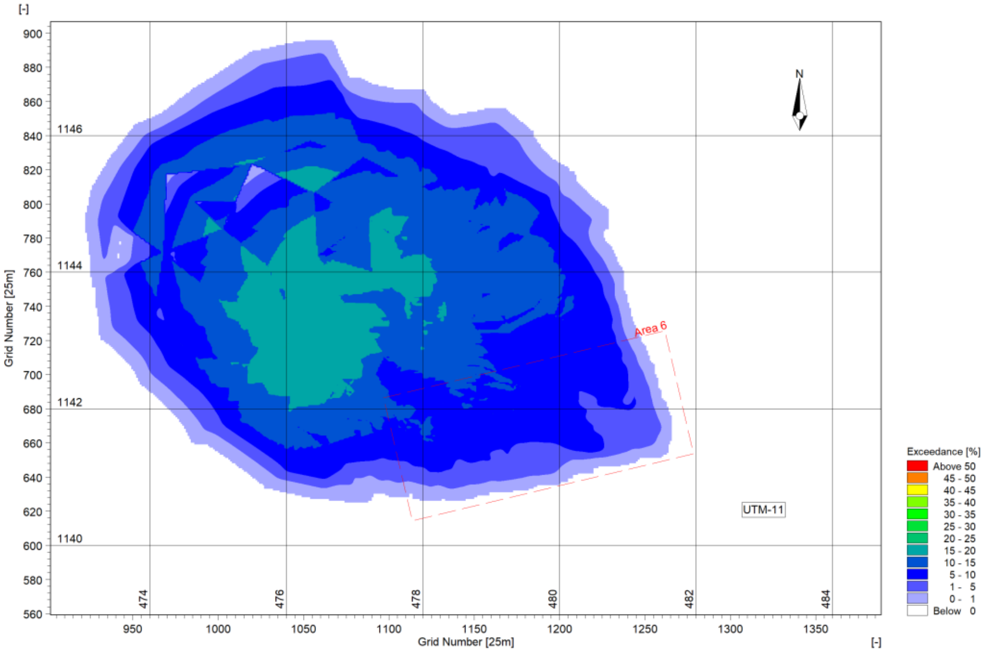

Figure 3.48 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 5m above the seabed

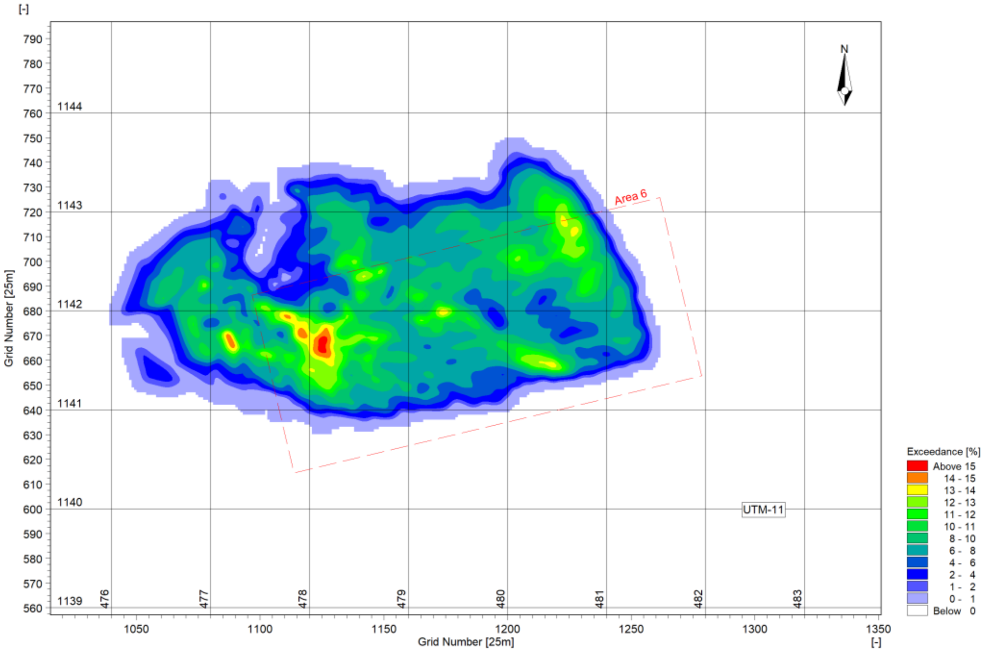

Figure 3.49 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

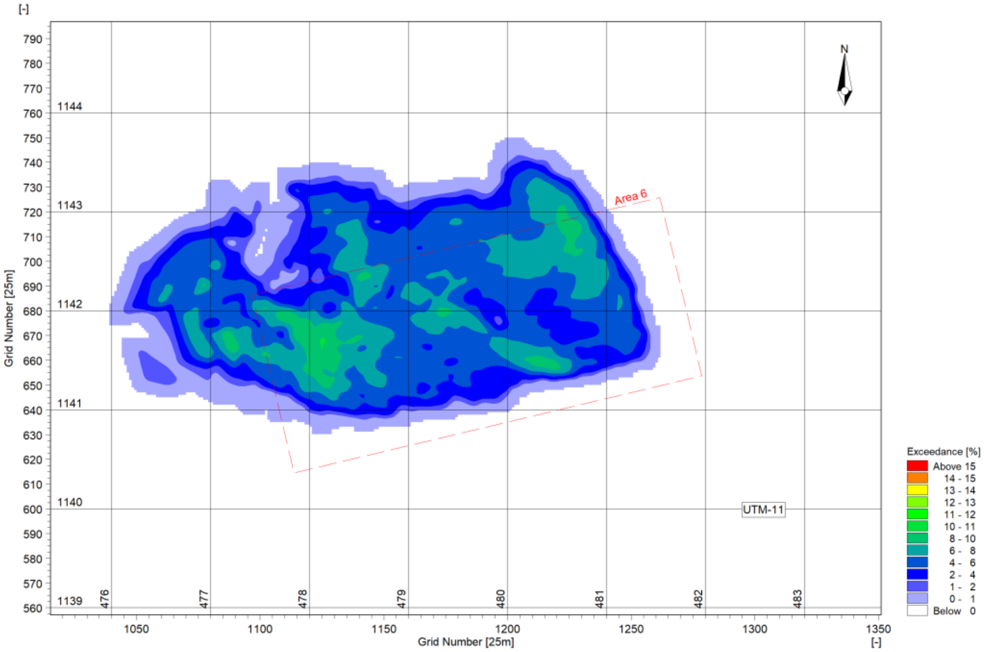

Figure 3.50 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

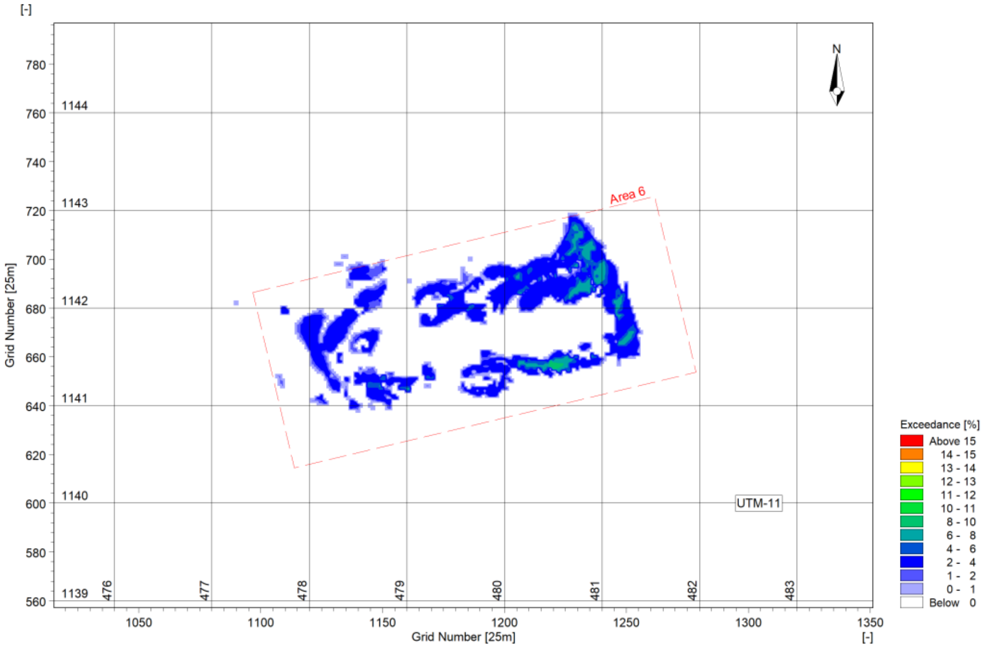

Figure 3.51 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

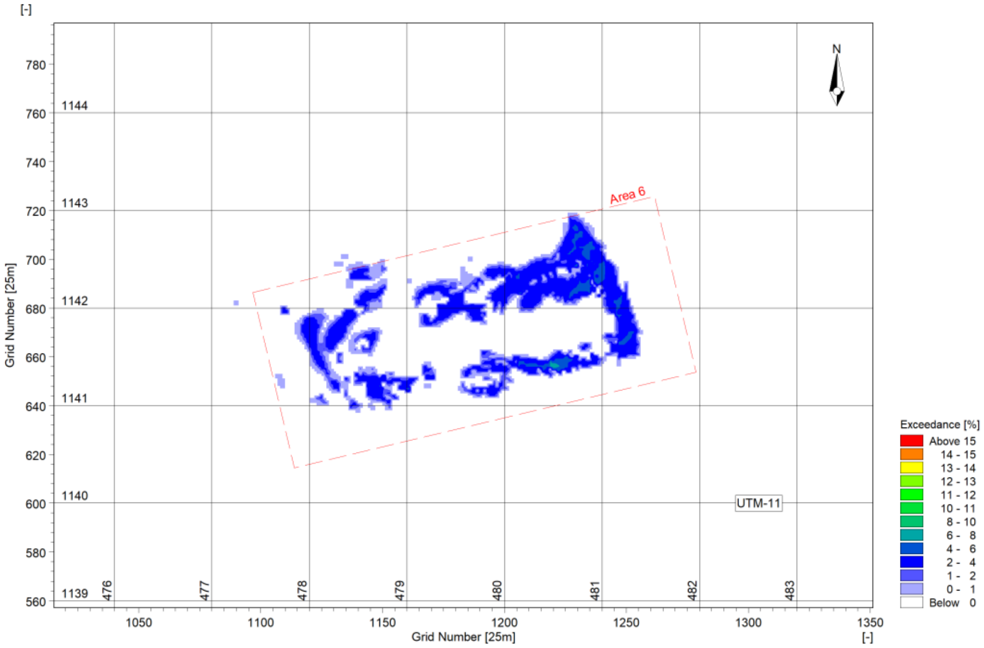

Figure 3.52 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

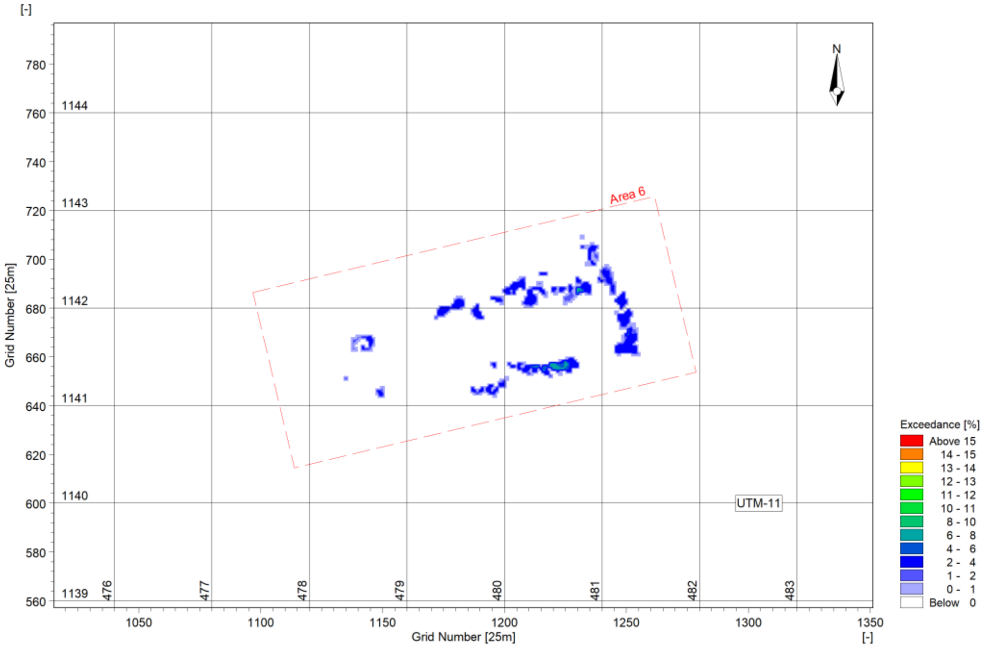

Figure 3.53 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

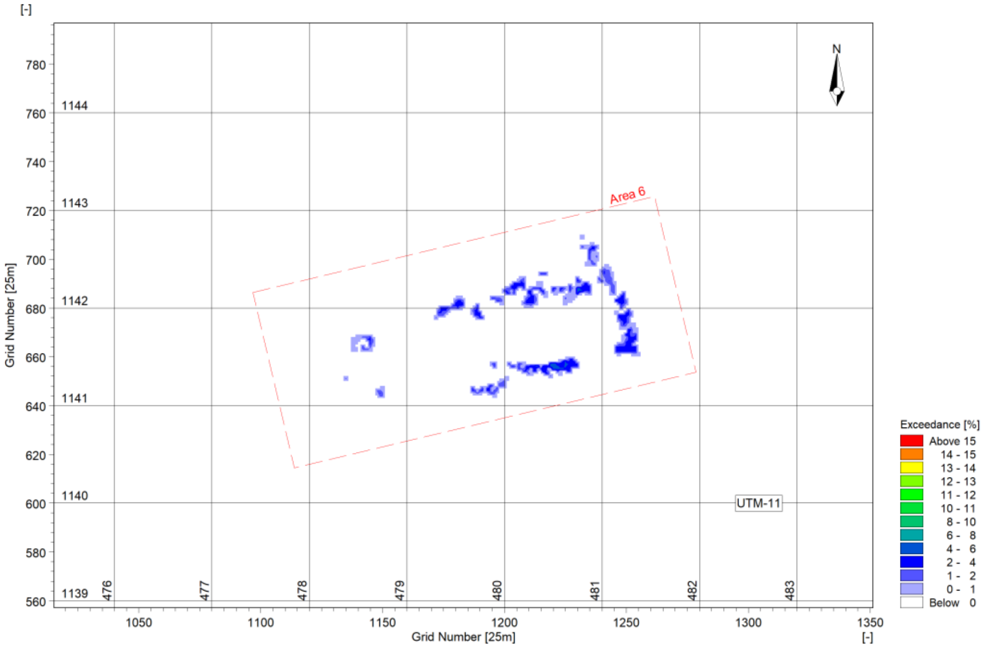

Figure 3.54 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.3.3 TSS 20m Above Seabed

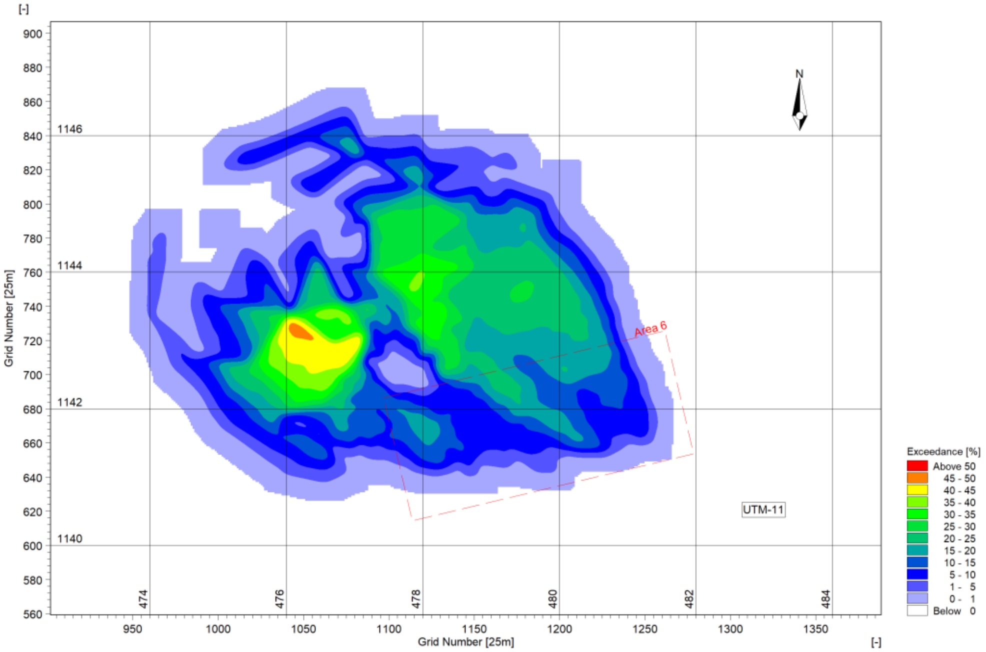

Figure 3.55 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

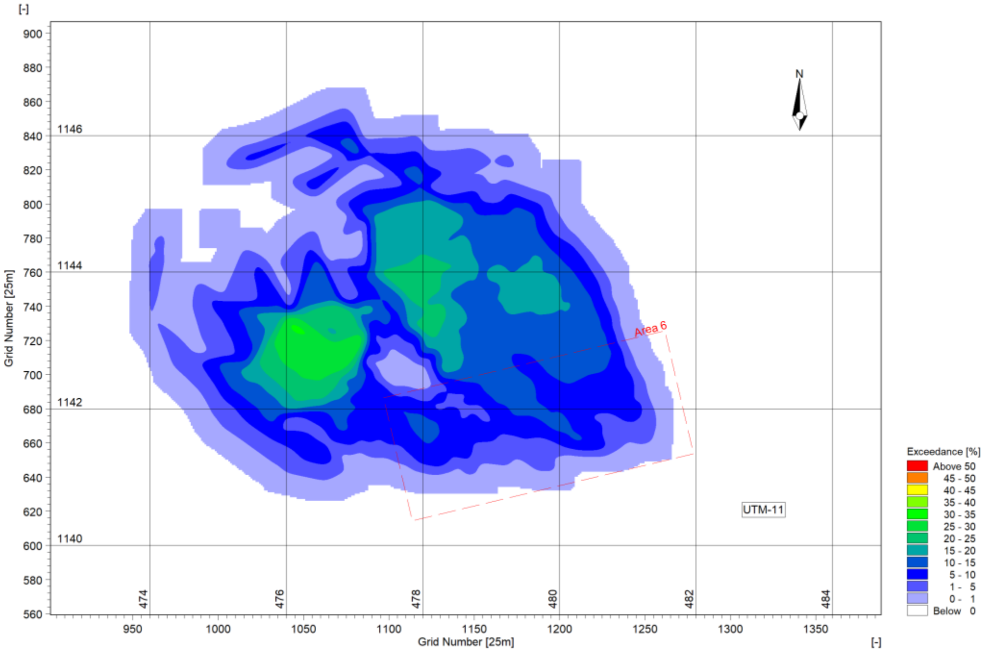

Figure 3.56 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

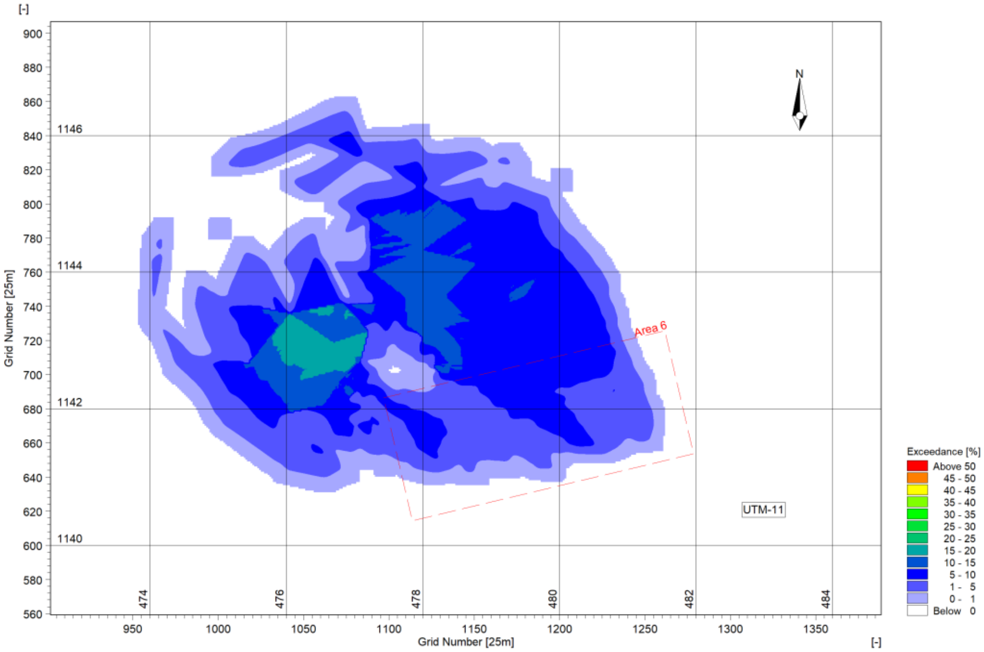

Figure 3.57 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 20m above the seabed

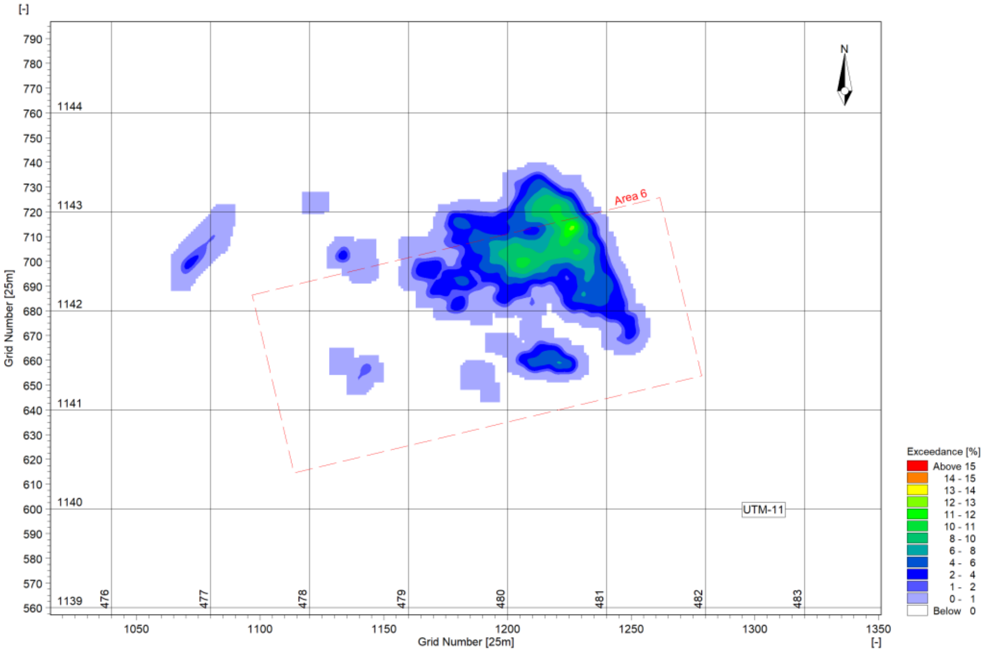

Figure 3.58 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

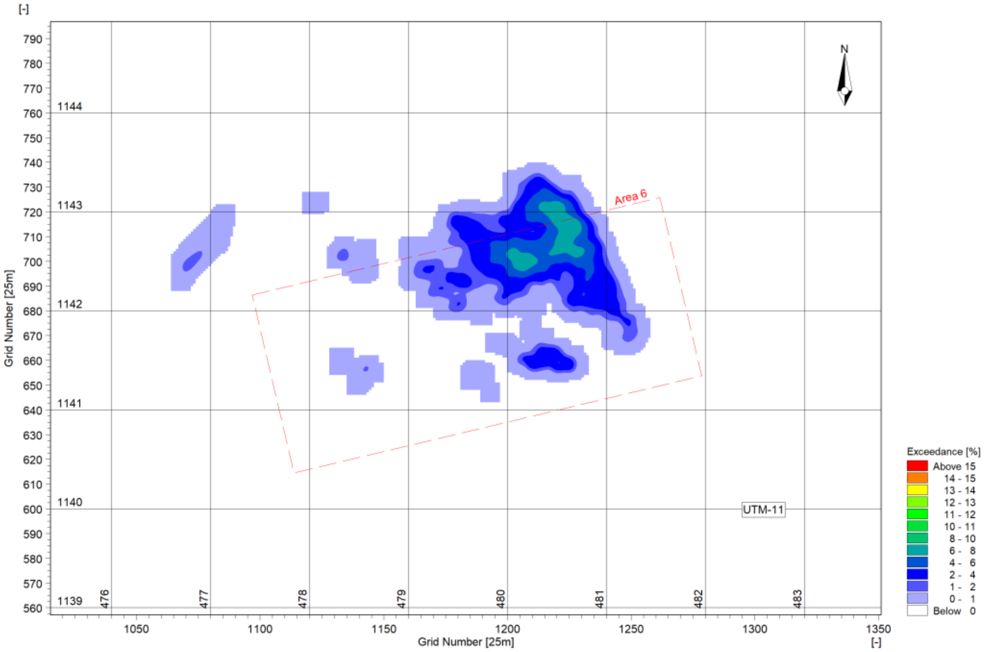

Figure 3.59 Scenario STR2b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

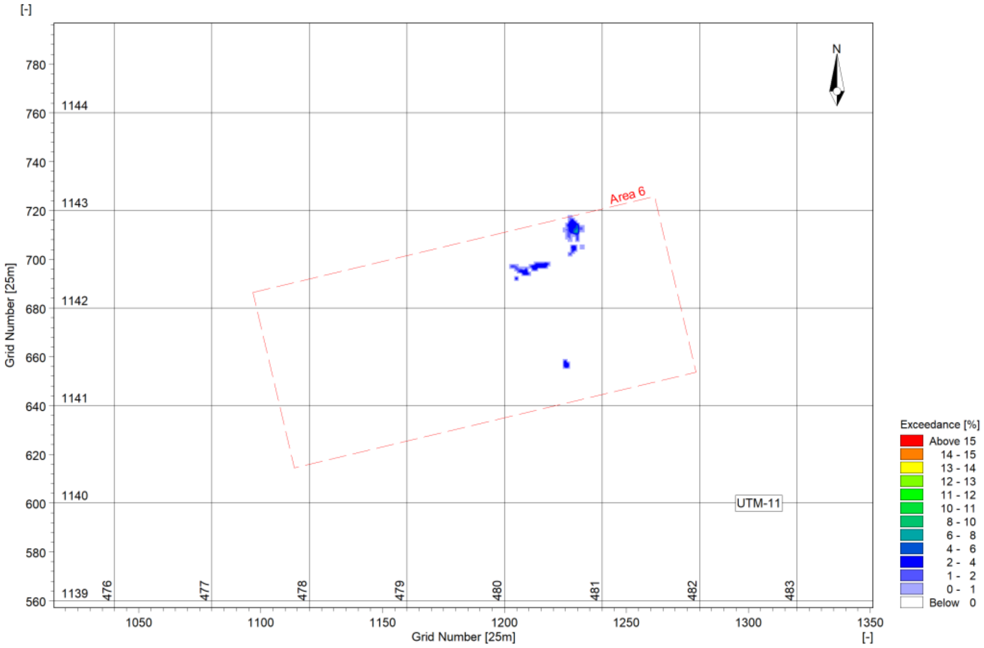

Figure 3.60 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

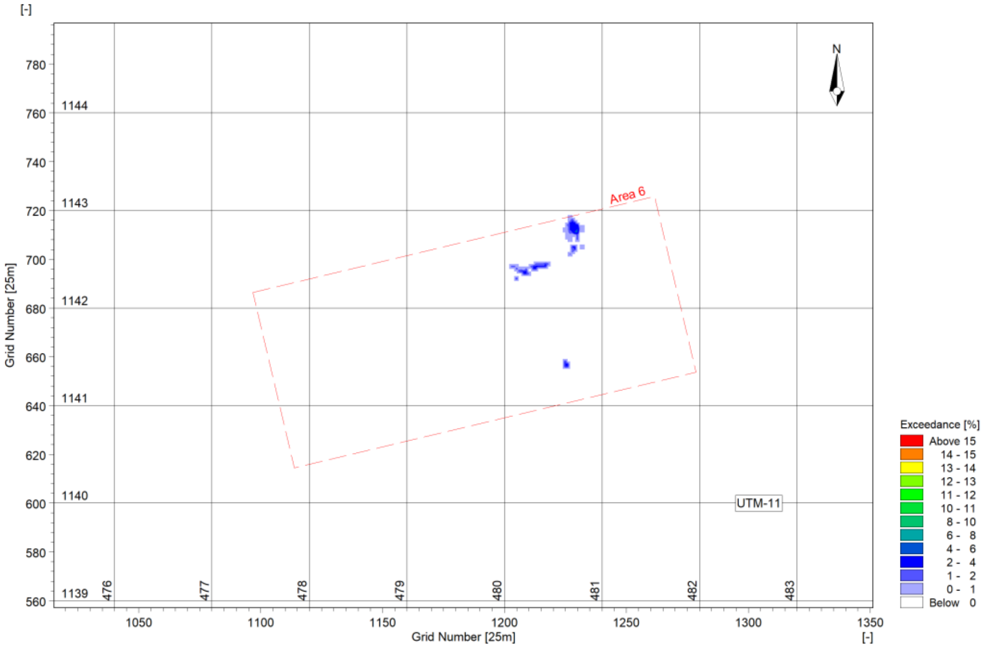

Figure 3.61 Scenario STR2b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

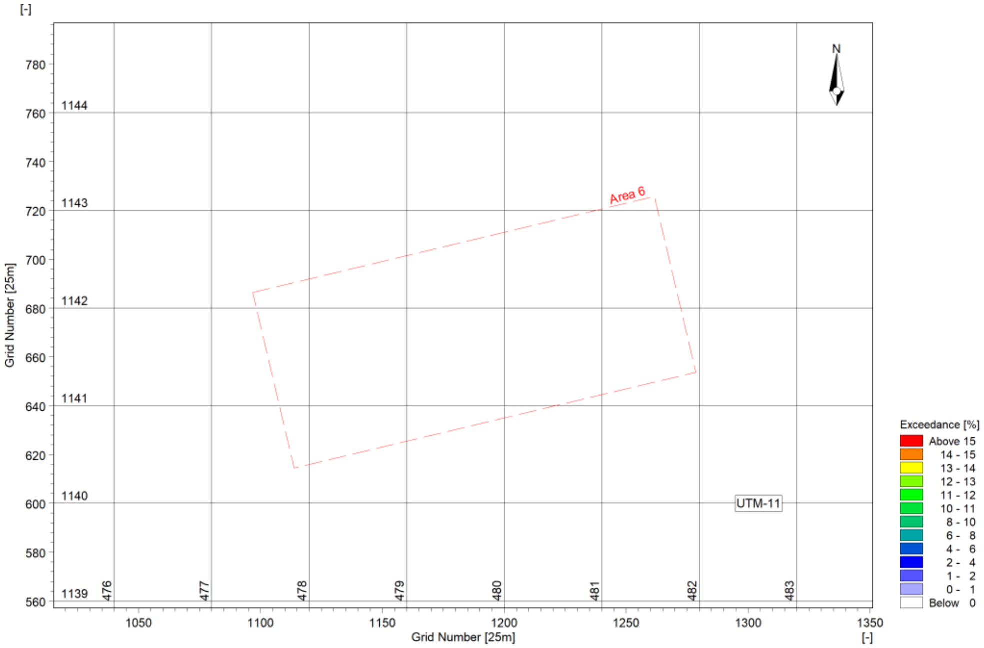

Figure 3.62 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

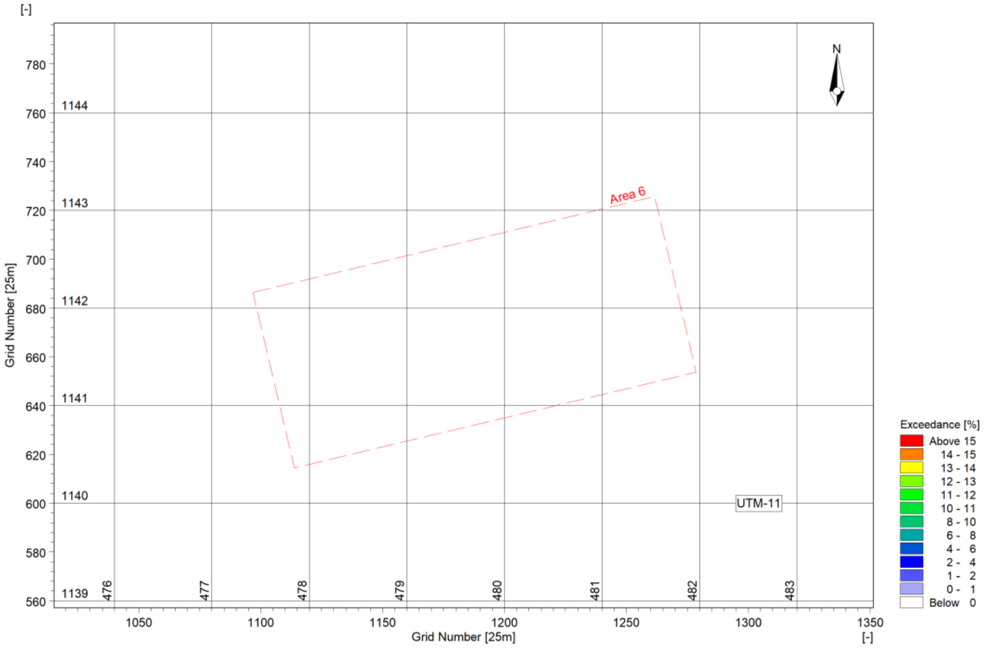

Figure 3.63 Scenario STR2b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.3.4 TSS at Mid-Water Column Discharge

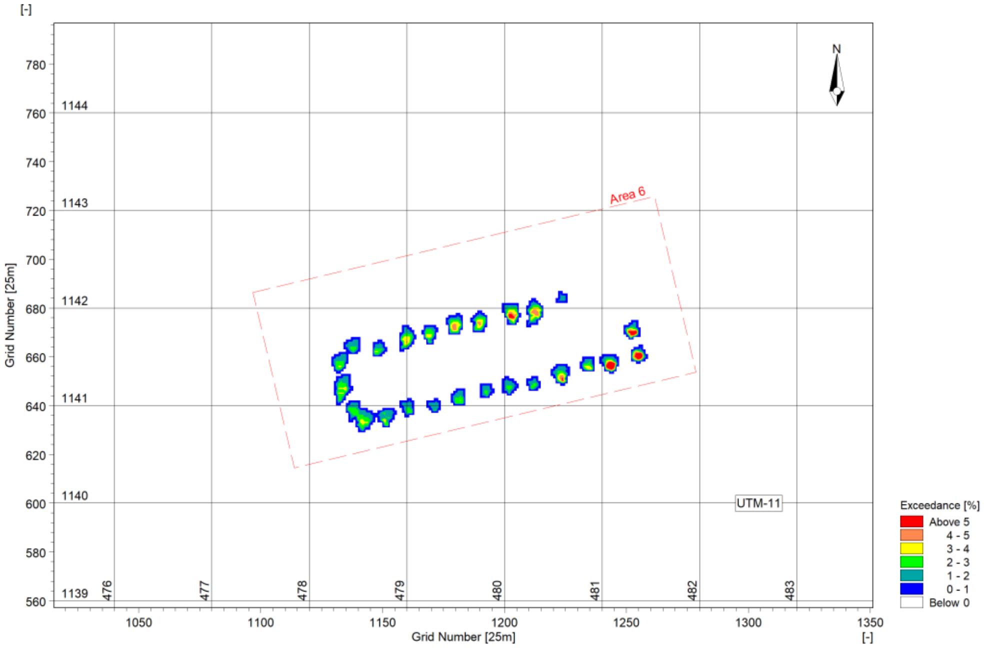

Figure 3.64 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

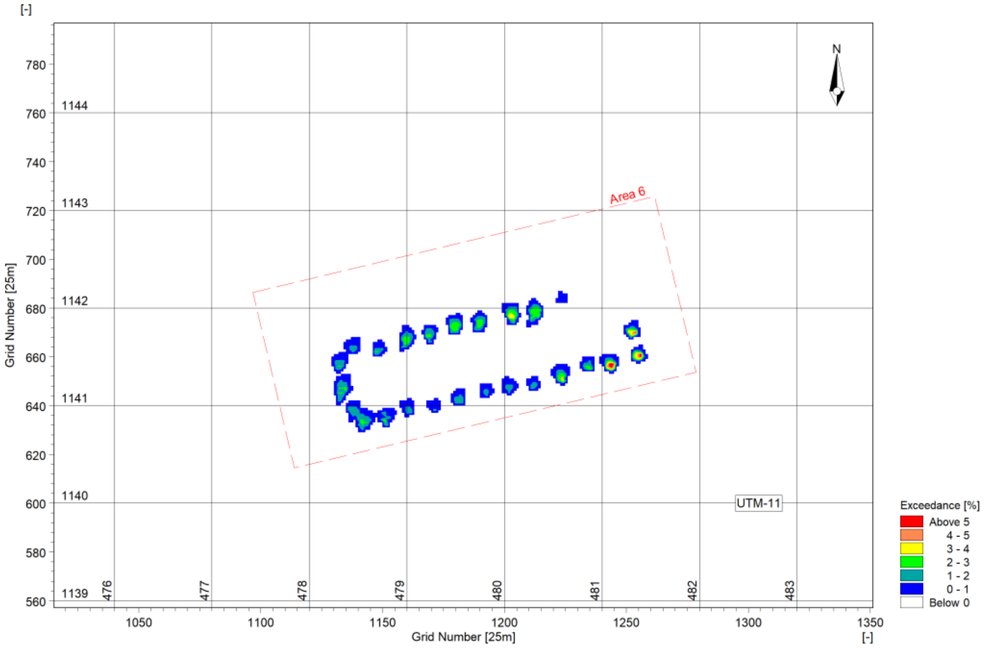

Figure 3.65 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

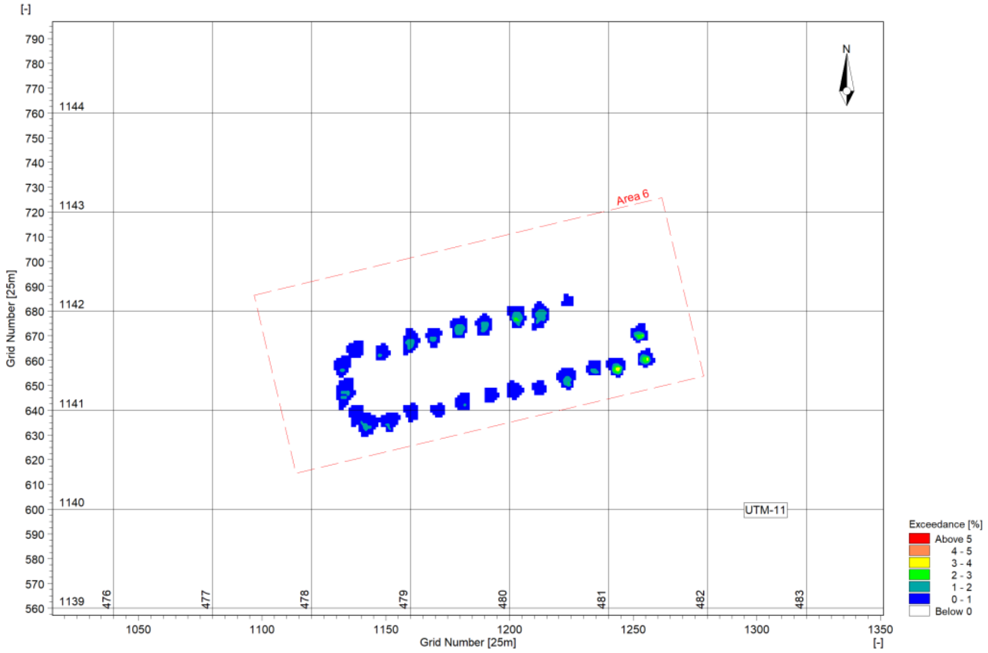

Figure 3.66 Scenario STR2b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.4 Scenario STR3a Results

Sedimentation results for Scenario STR3a are presented in Section 3.2.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.2.2, 20m above the seabed in Section 3.2.3 and at 1050m for the mid-water column discharge in Section 3.2.4.

3.4.1 Sedimentation

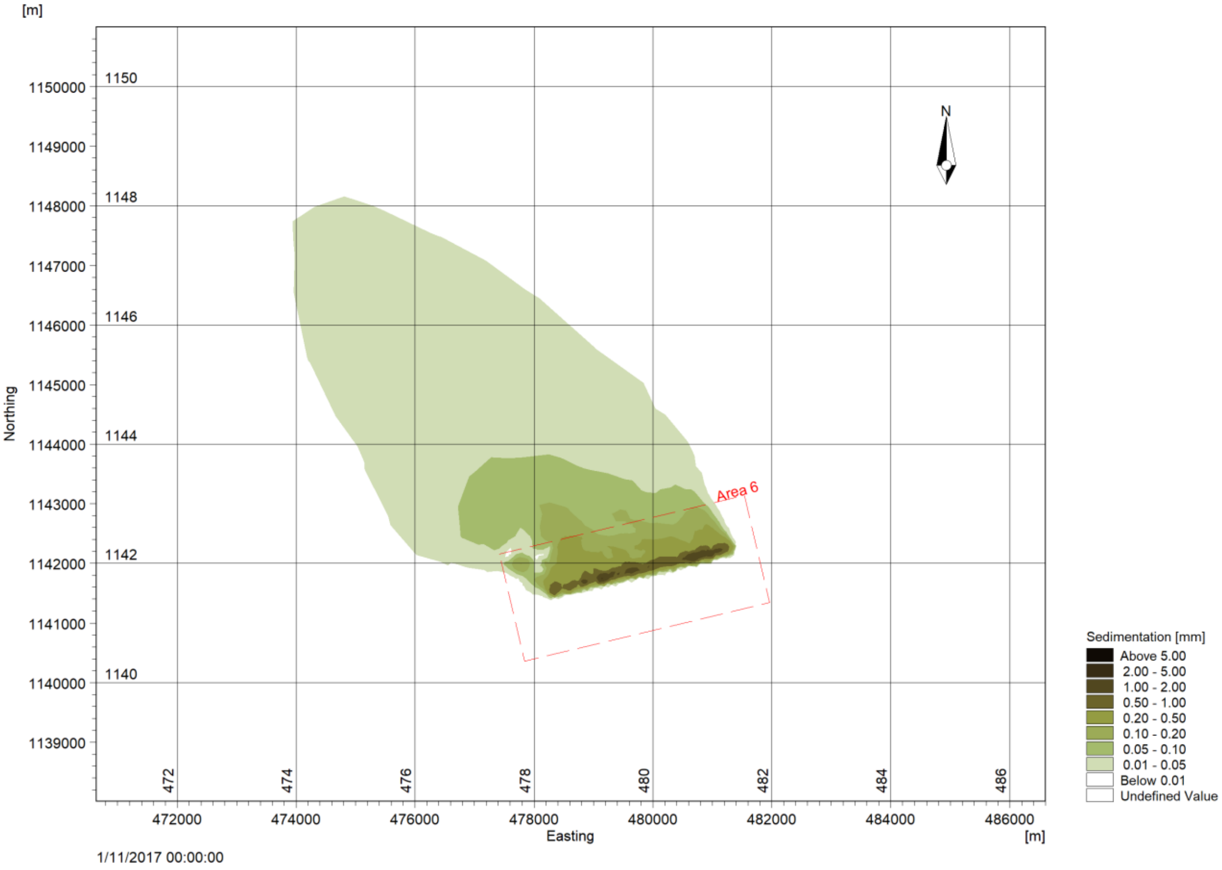

Figure 3.67 Scenario STR3a: Sedimentation (mm) ca. 10.5 days after completion of operation

3.4.2 TSS 5m Above Seabed

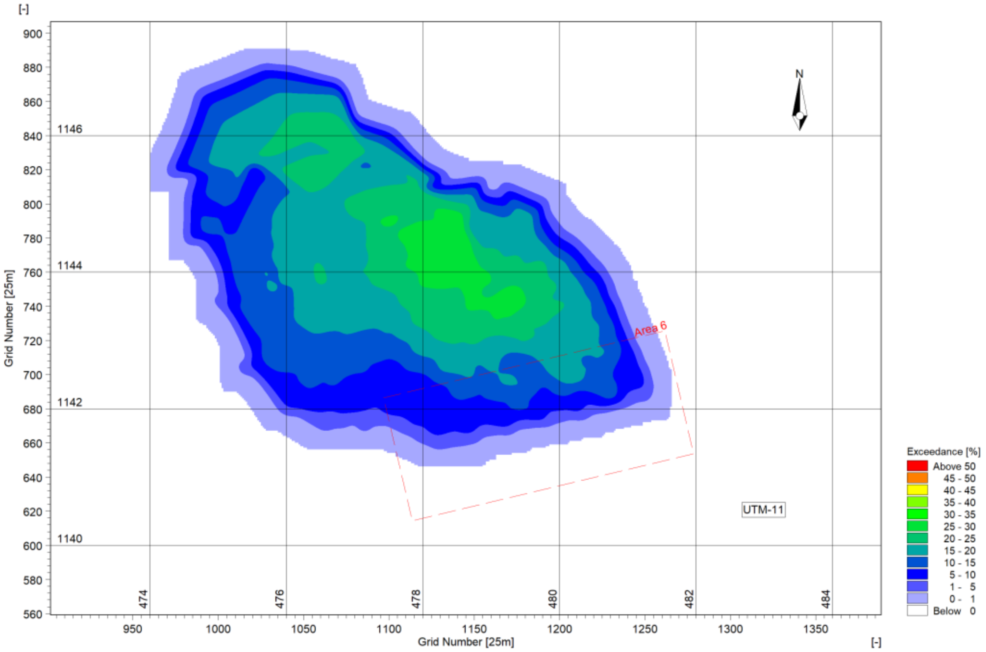

Figure 3.68 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

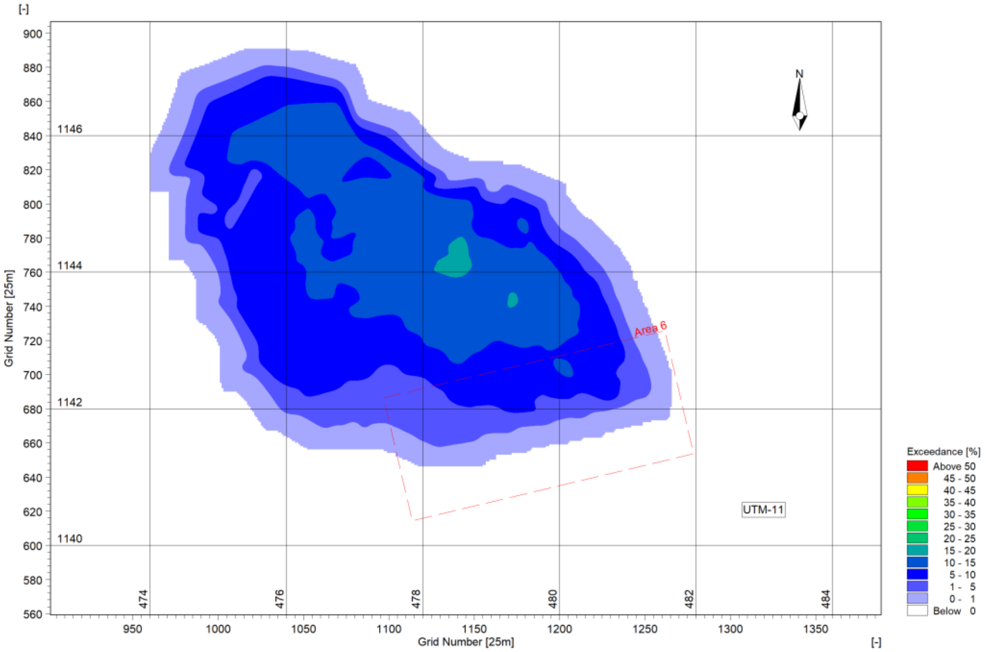

Figure 3.69 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

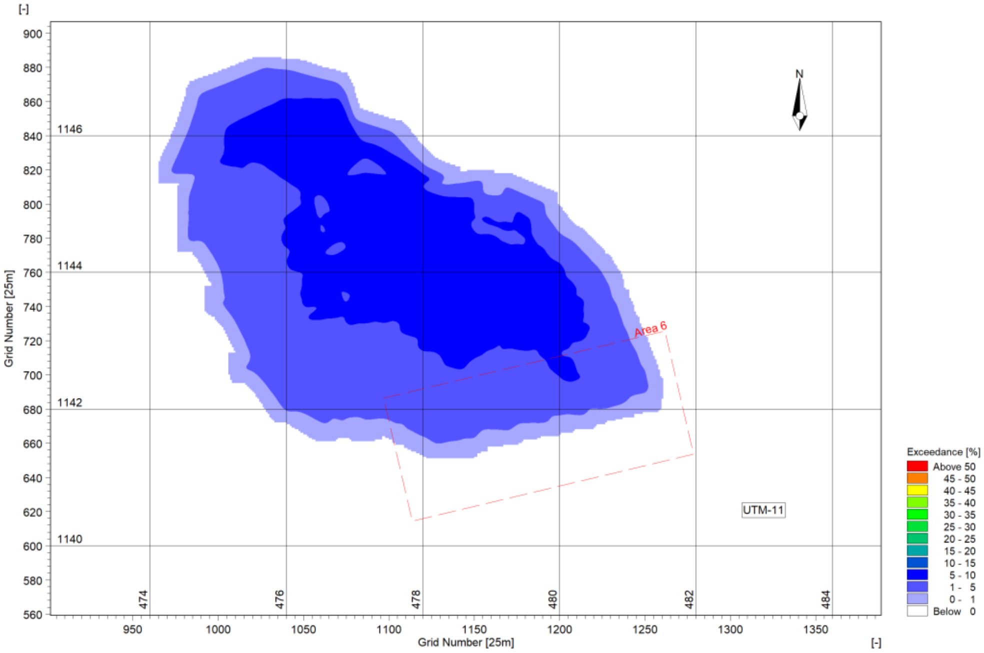

Figure 3.70 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 5m above the seabed

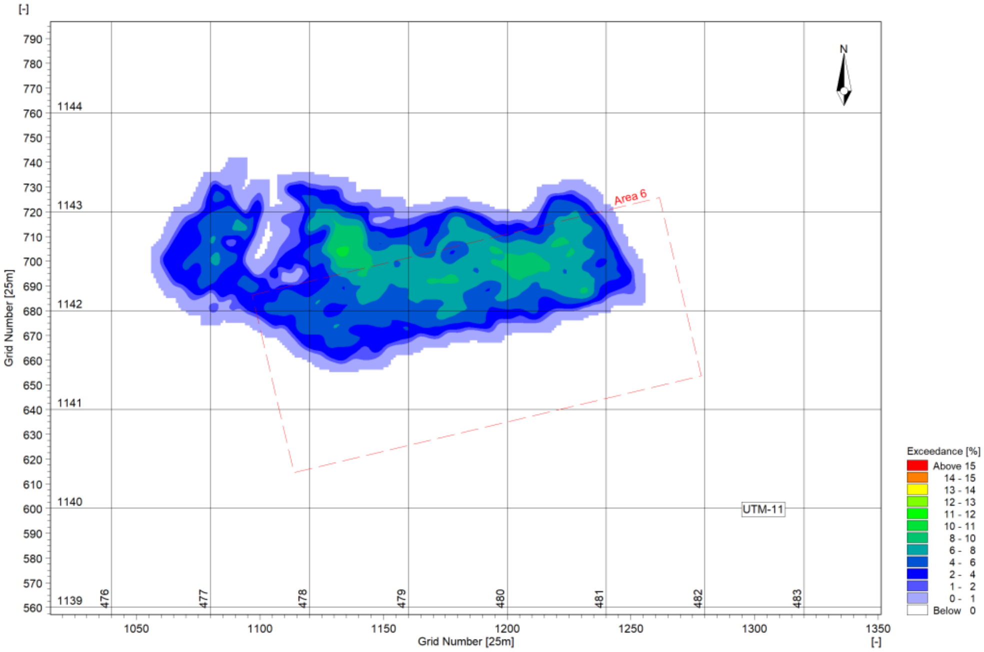

Figure 3.71 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

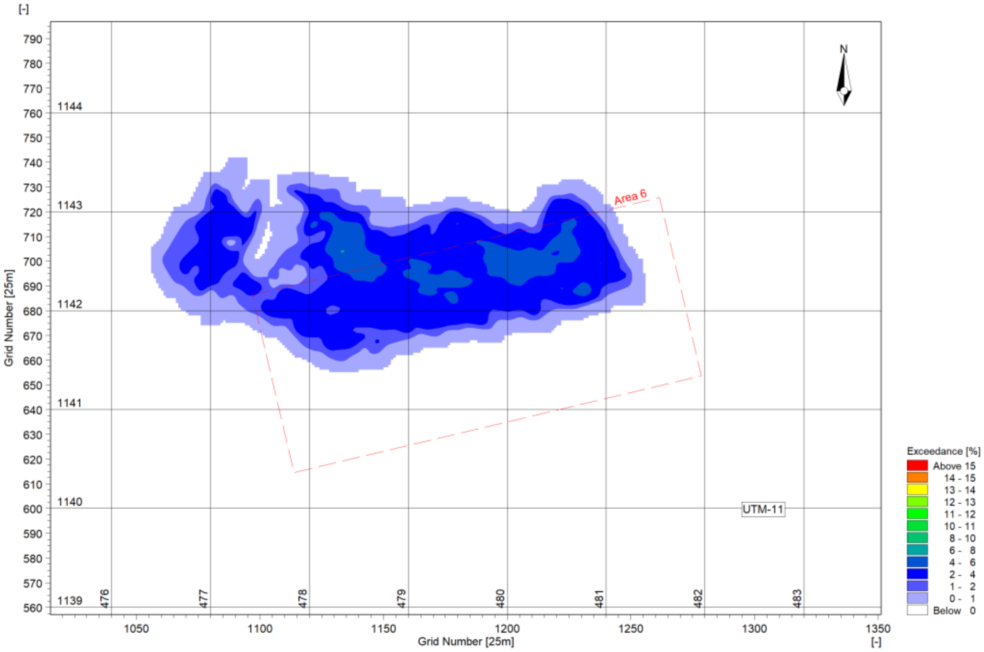

Figure 3.72 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

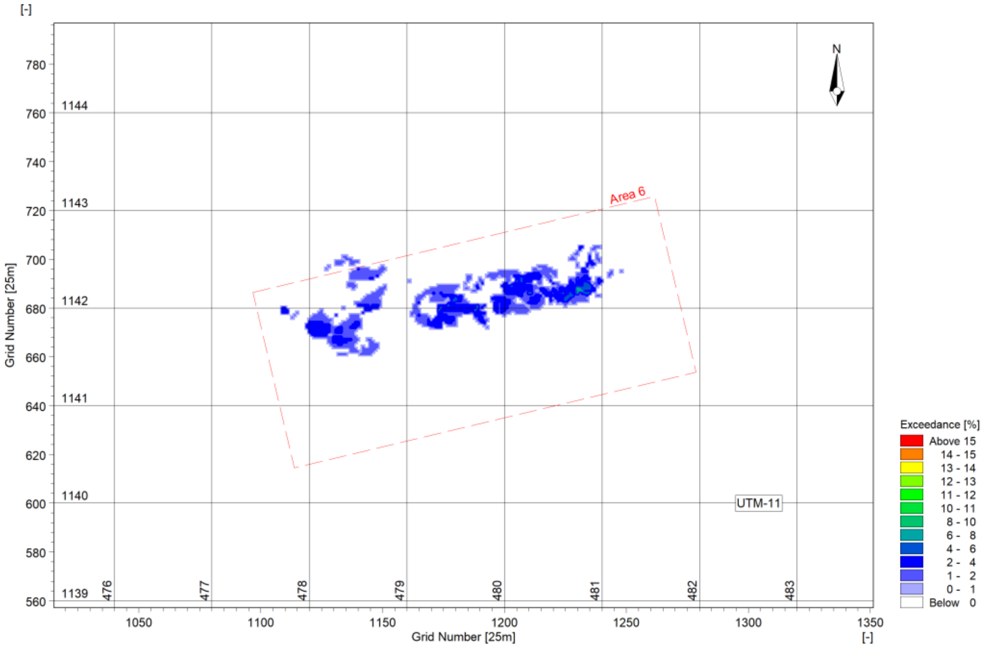

Figure 3.73 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

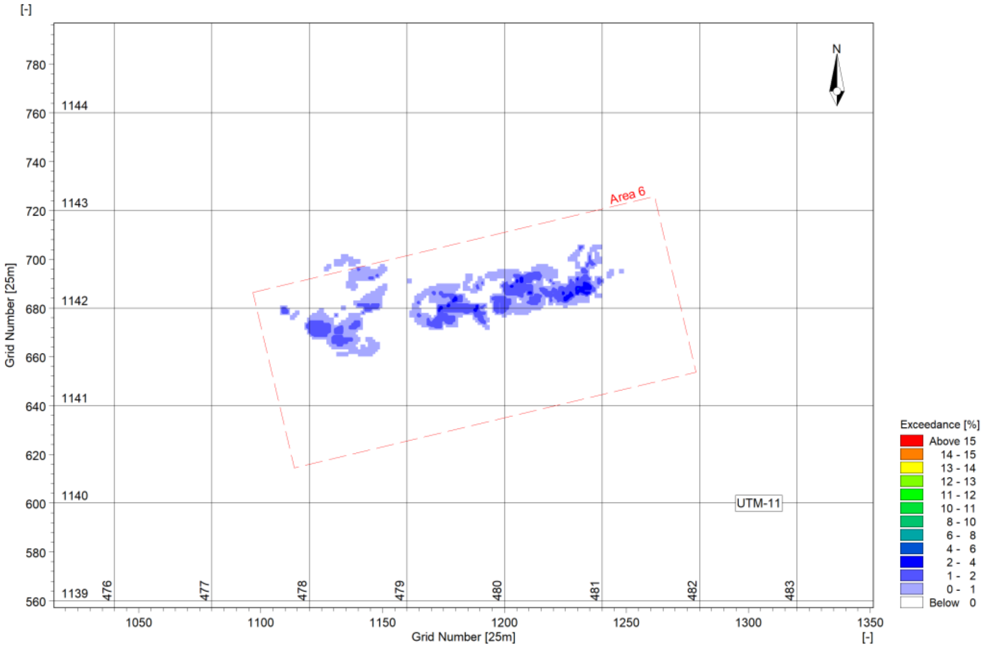

Figure 3.74 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

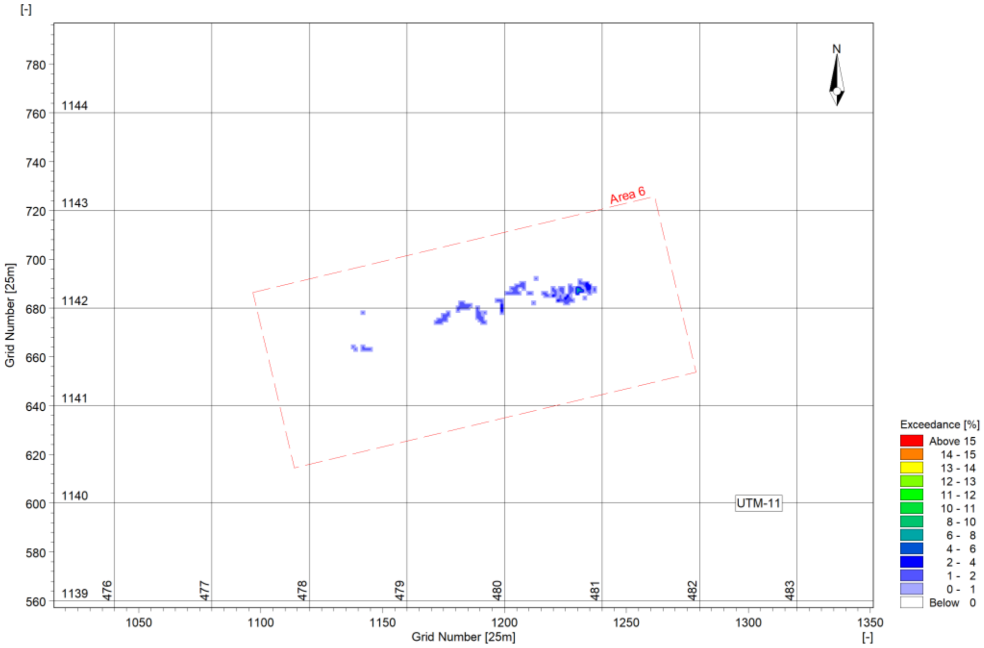

Figure 3.75 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

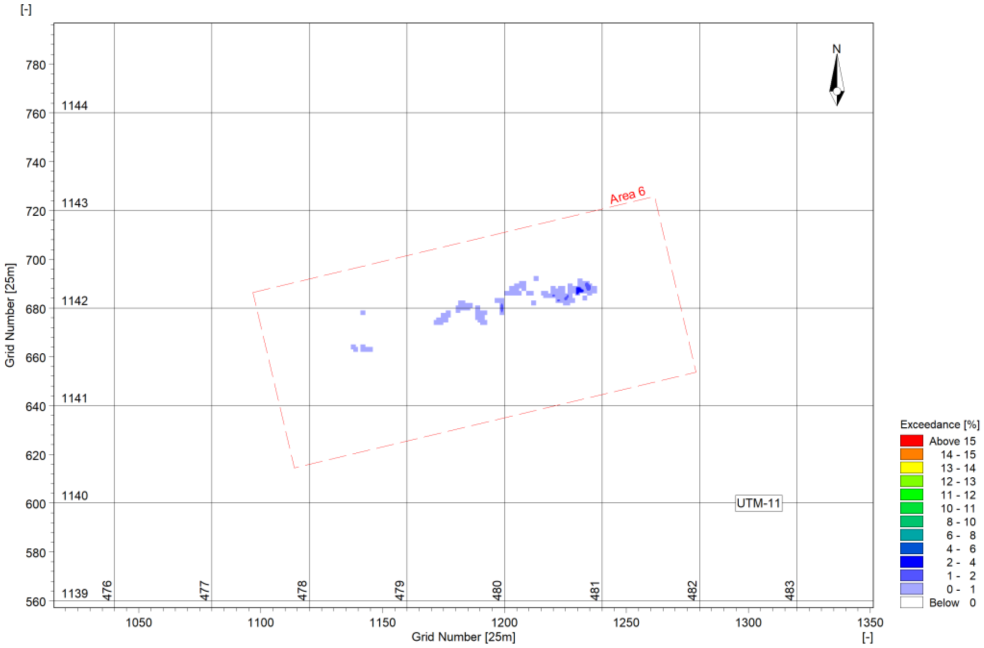

Figure 3.76 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.4.3 TSS 20m Above Seabed

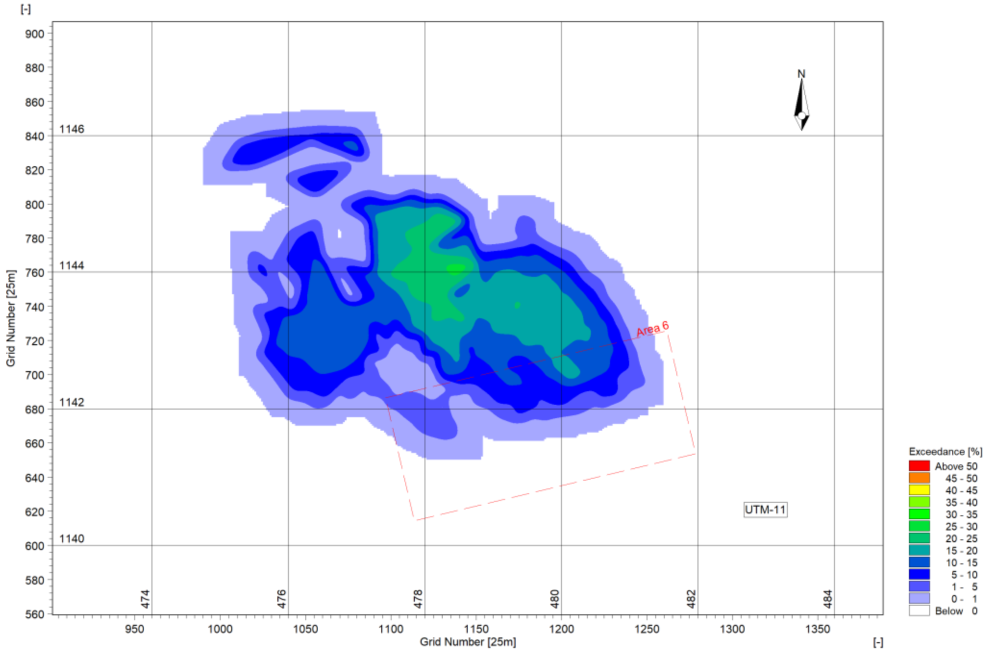

Figure 3.77 Scenario STR3a: Exceedance percentage of 0.1mg/l, 24 hours post-production at 20m above the seabed

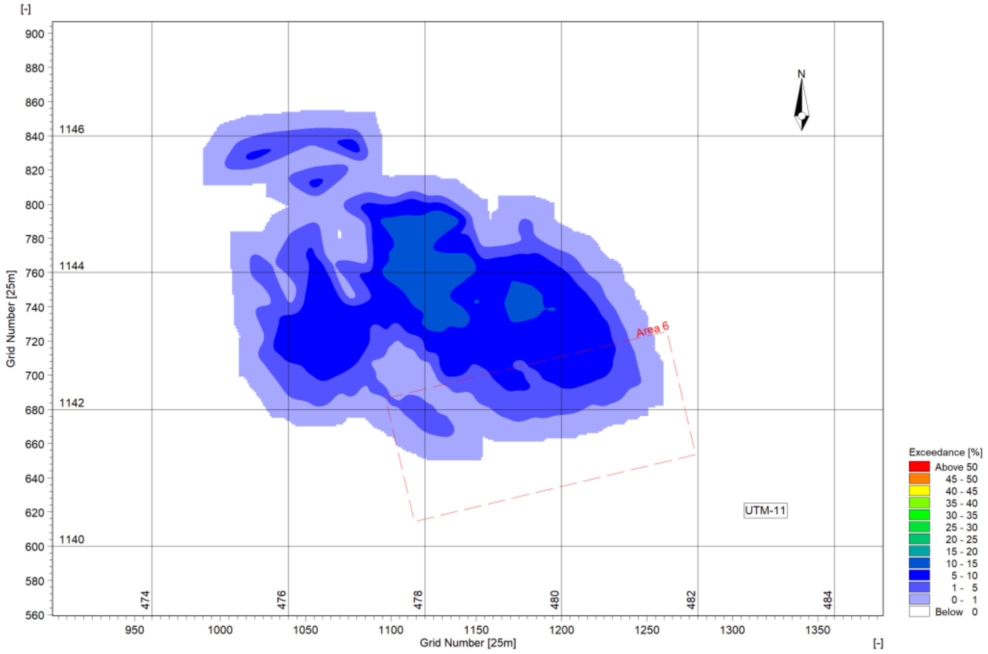

Figure 3.78 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

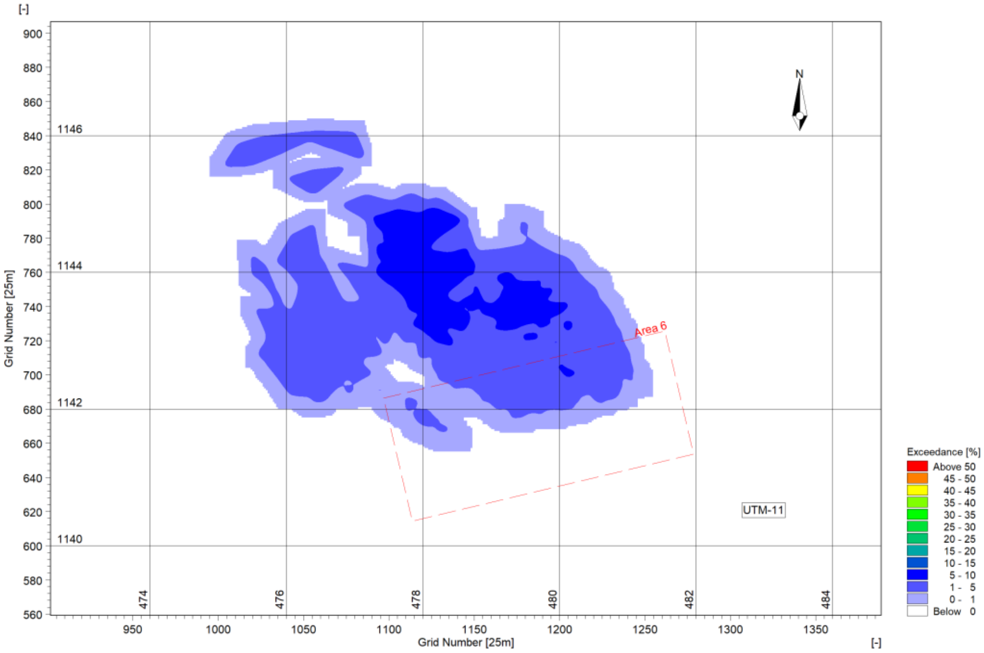

Figure 3.79 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 20m above the seabed

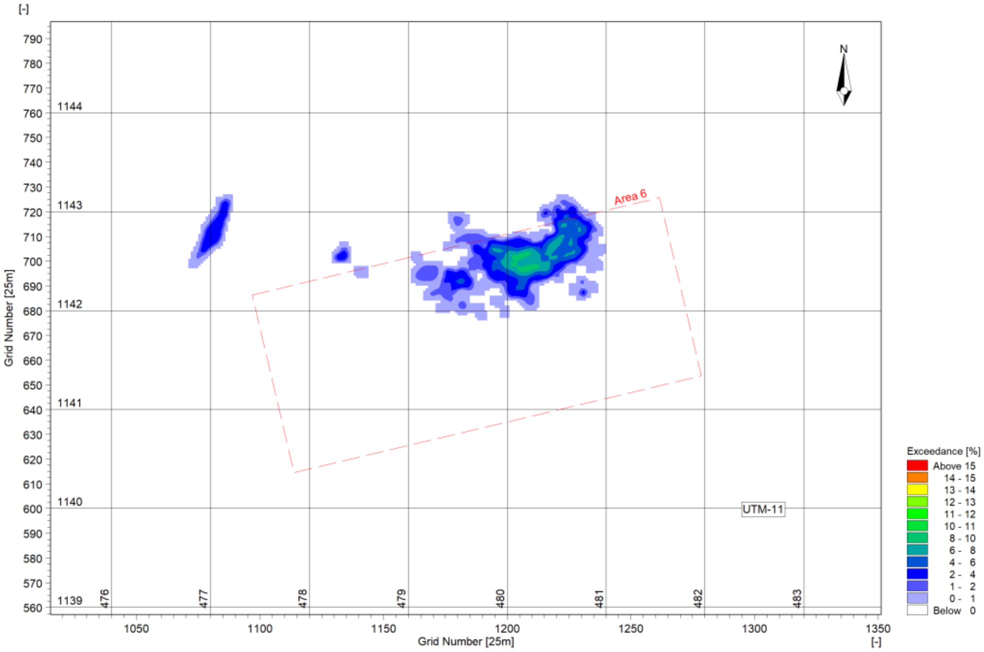

Figure 3.80 Scenario STR3a: Exceedance percentage of 1mg/l, 24 hours post-production at 20m above the seabed

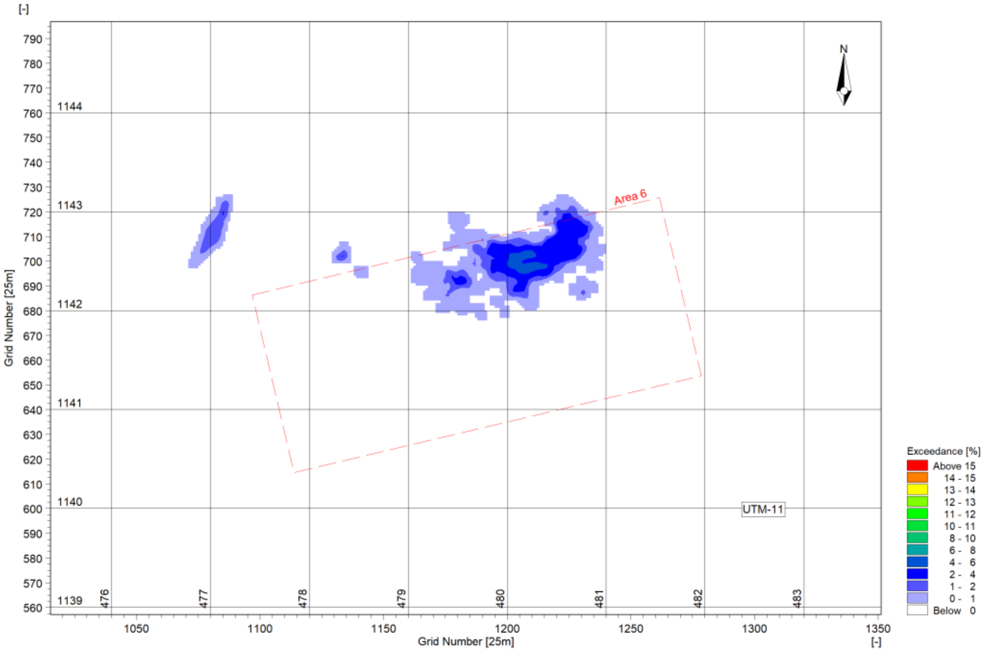

Figure 3.81 Scenario STR3a: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

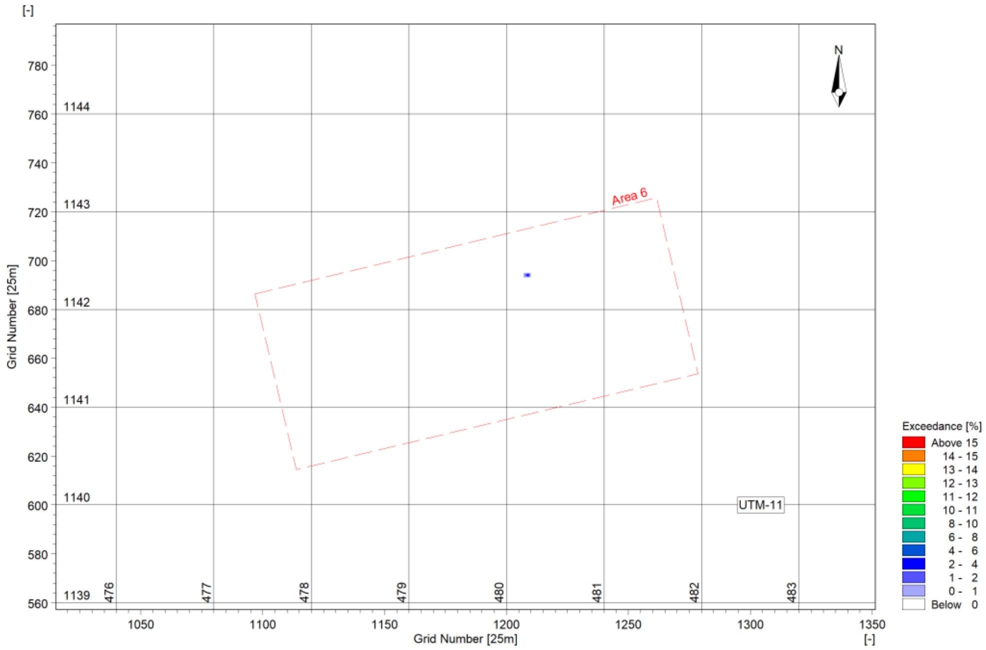

Figure 3.82 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

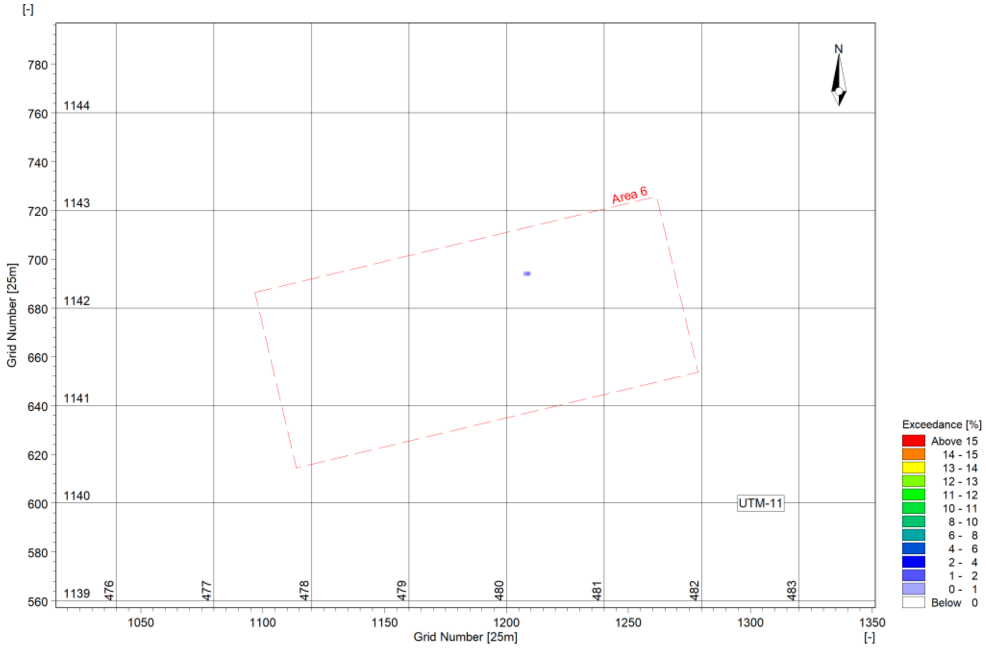

Figure 3.83 Scenario STR3a: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

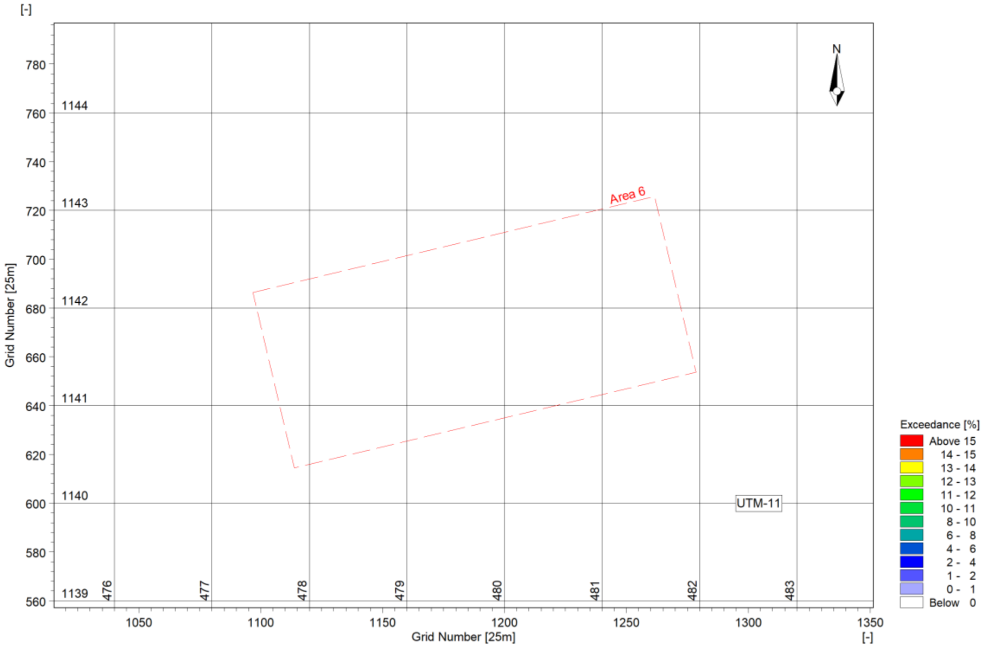

Figure 3.84 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

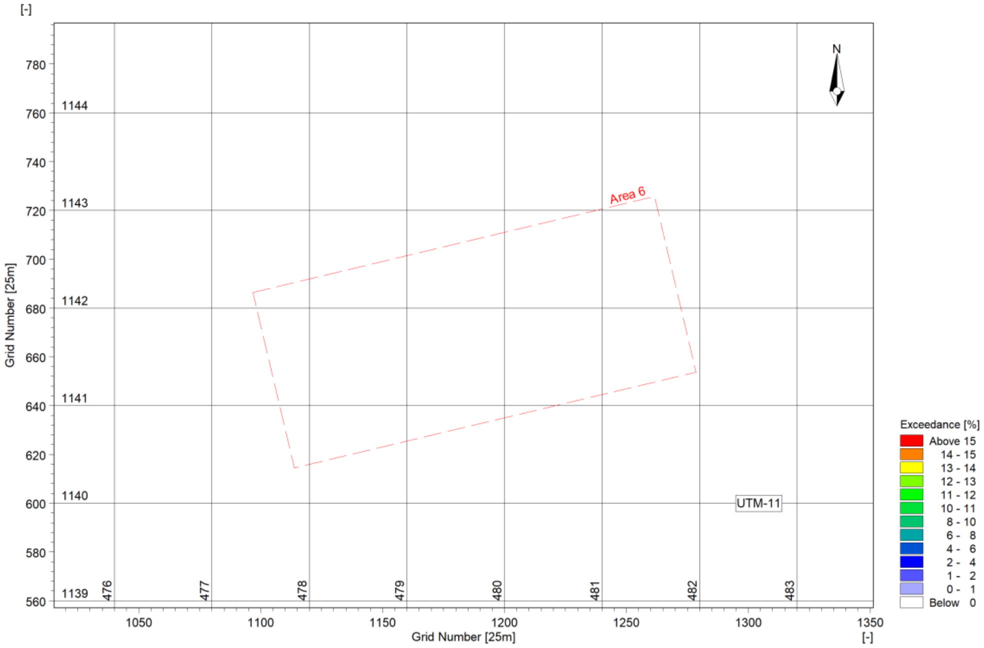

Figure 3.85 Scenario STR3a: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.4.4 TSS at Mid-Water Column Discharge

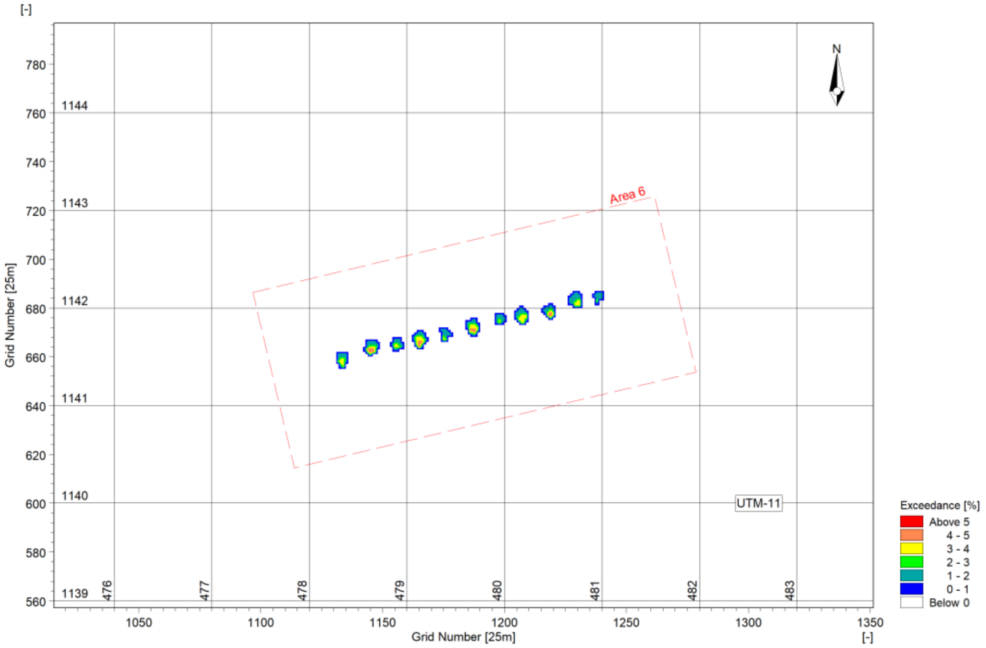

Figure 3.86 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

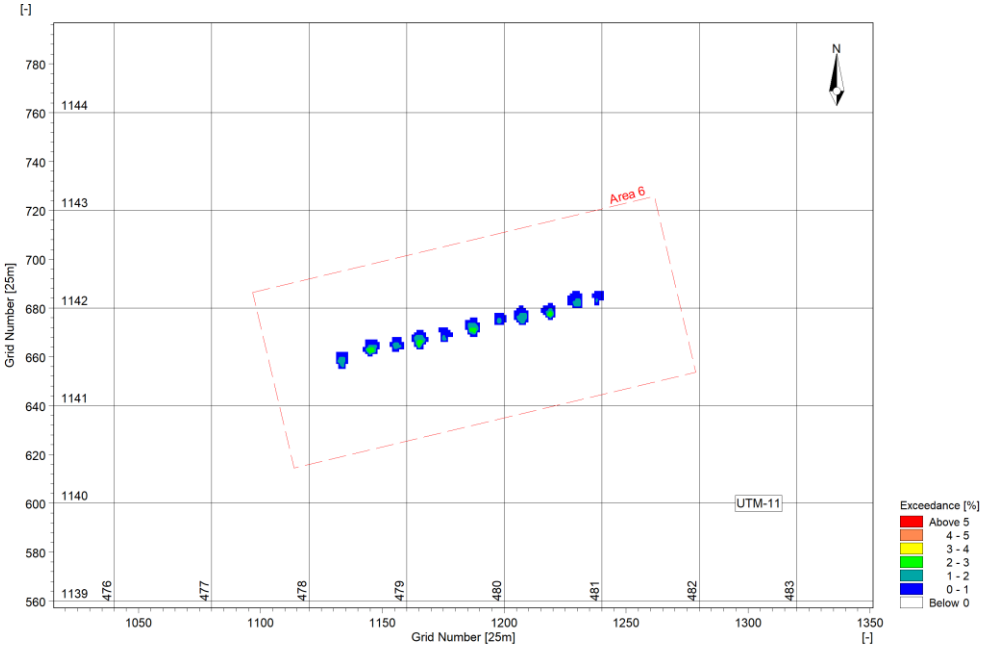

Figure 3.87 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

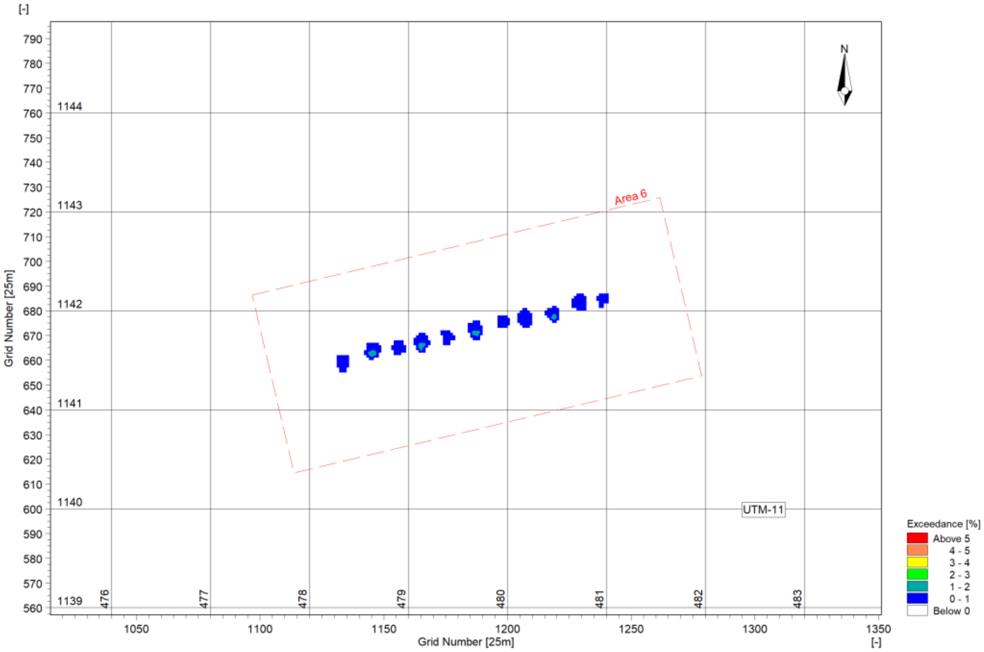

Figure 3.88 Scenario STR3a: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

3.5 Scenario STR3b Results

Sedimentation results for Scenario STR3b are presented in Section 3.5.1, Exceedance of threshold concentrations 5m above the seabed and presented in Section 3.5.2, 20m above the seabed in Section 3.5.3 and at 1050m for the mid-water column discharge in Section 3.5.4.

3.5.1 Sedimentation

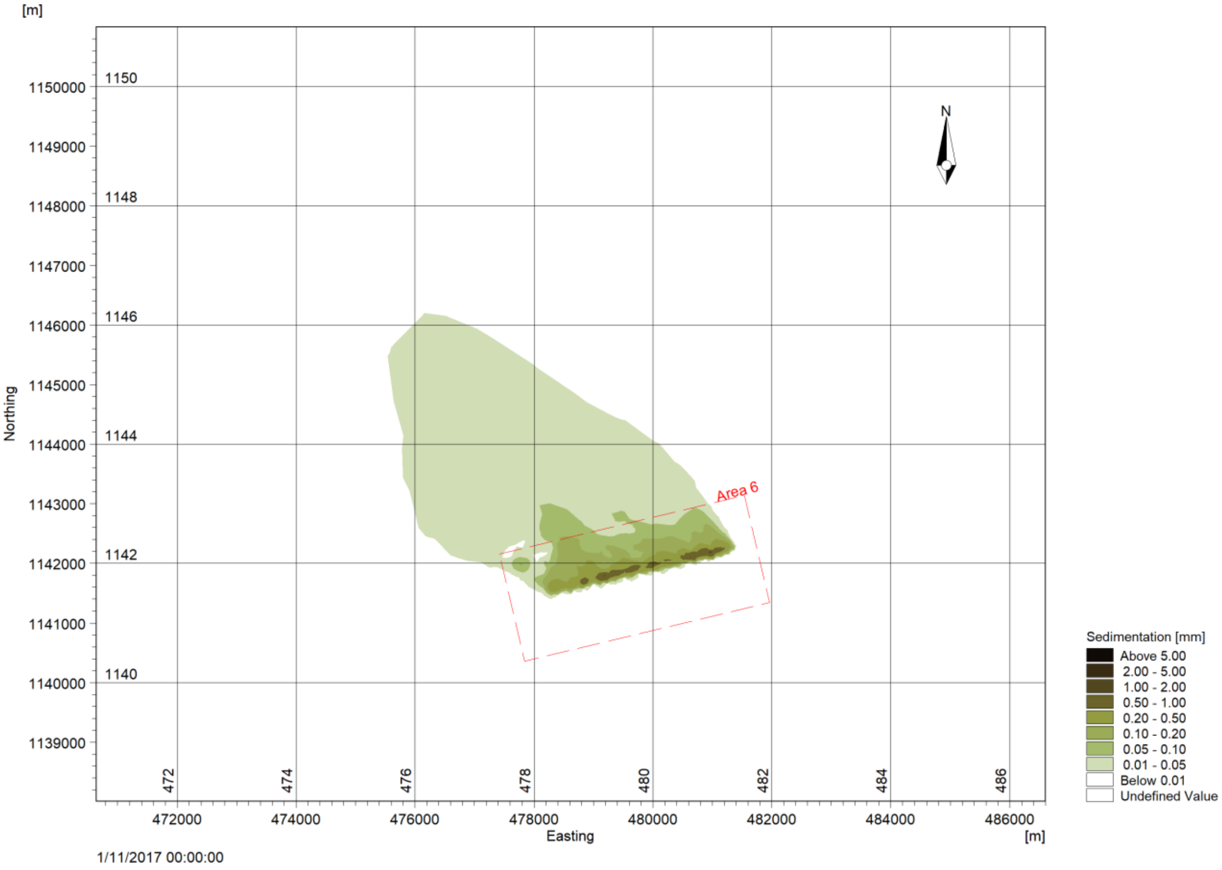

Figure 3.89 Scenario STR3b: Sedimentation (mm) ca. 10.5 days after completion of operation

3.5.2 TSS 5m Above Seabed

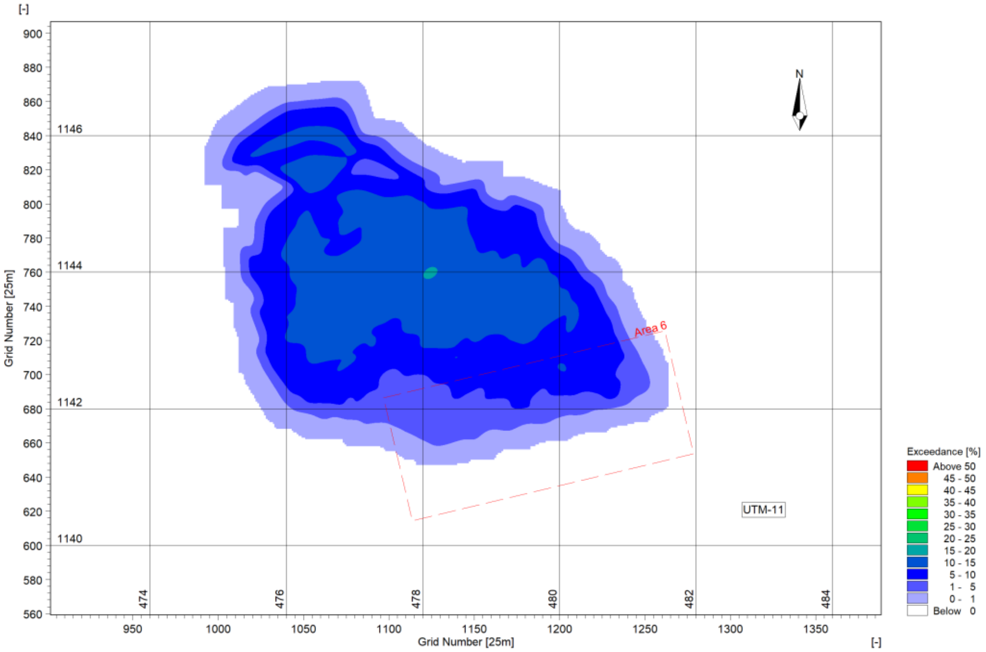

Figure 3.90 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

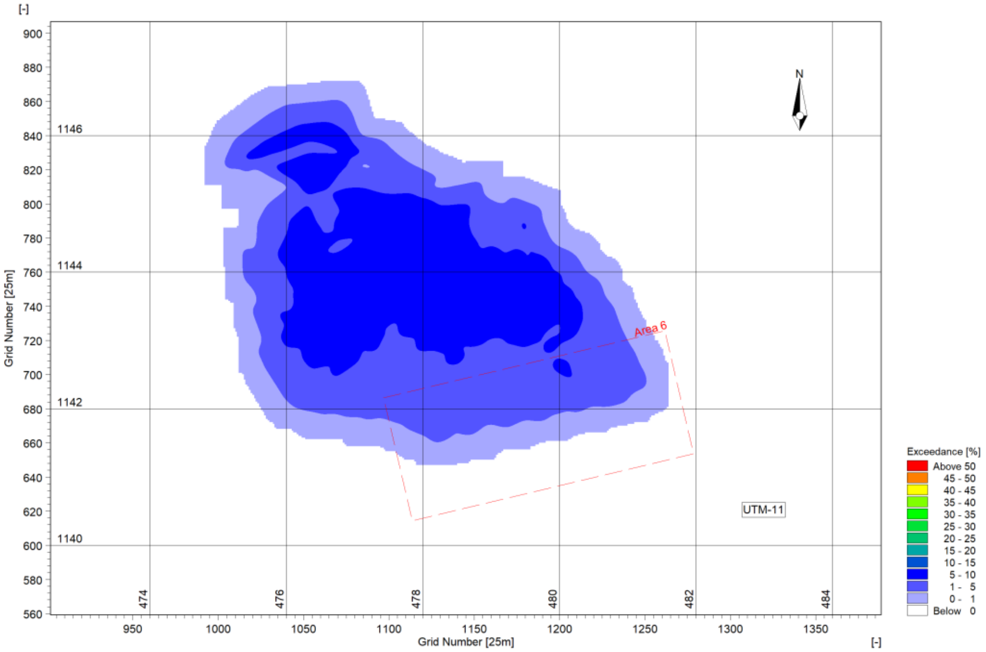

Figure 3.91 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

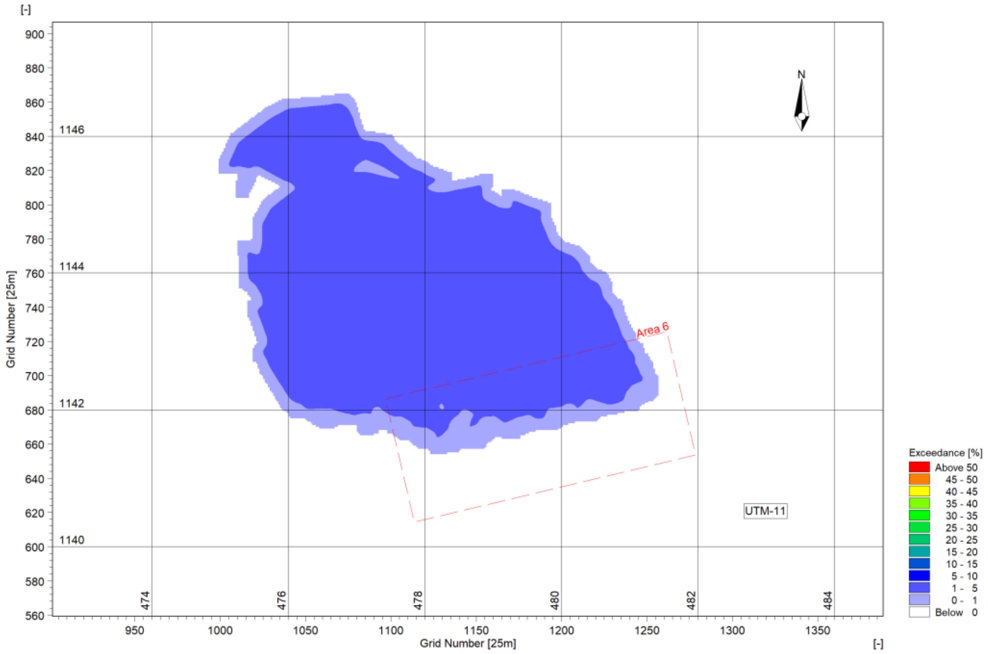

Figure 3.92 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 5m above the seabed

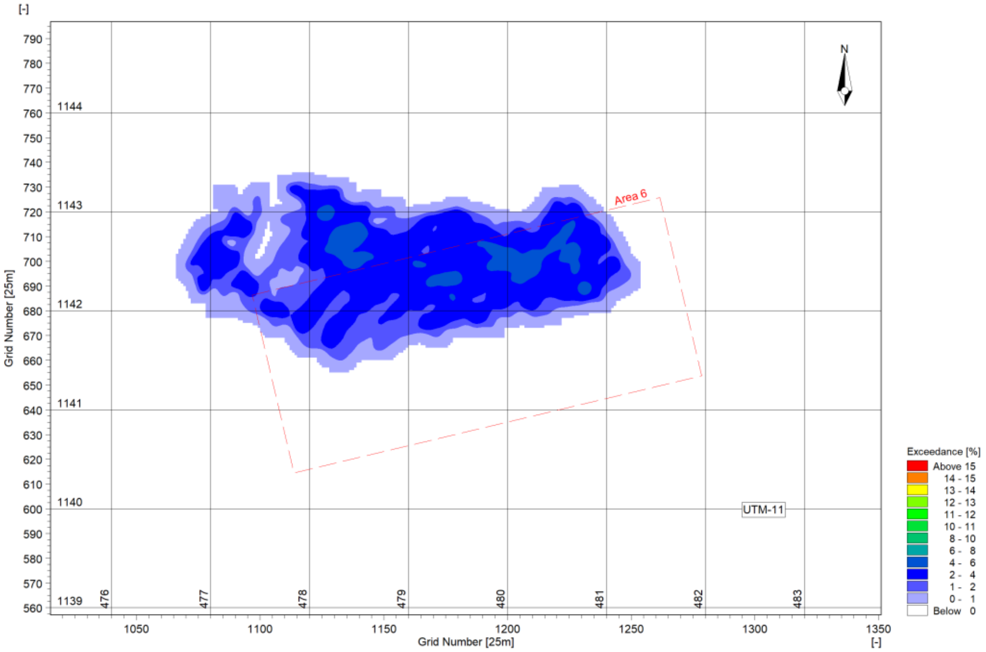

Figure 3.93 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 5m above the seabed

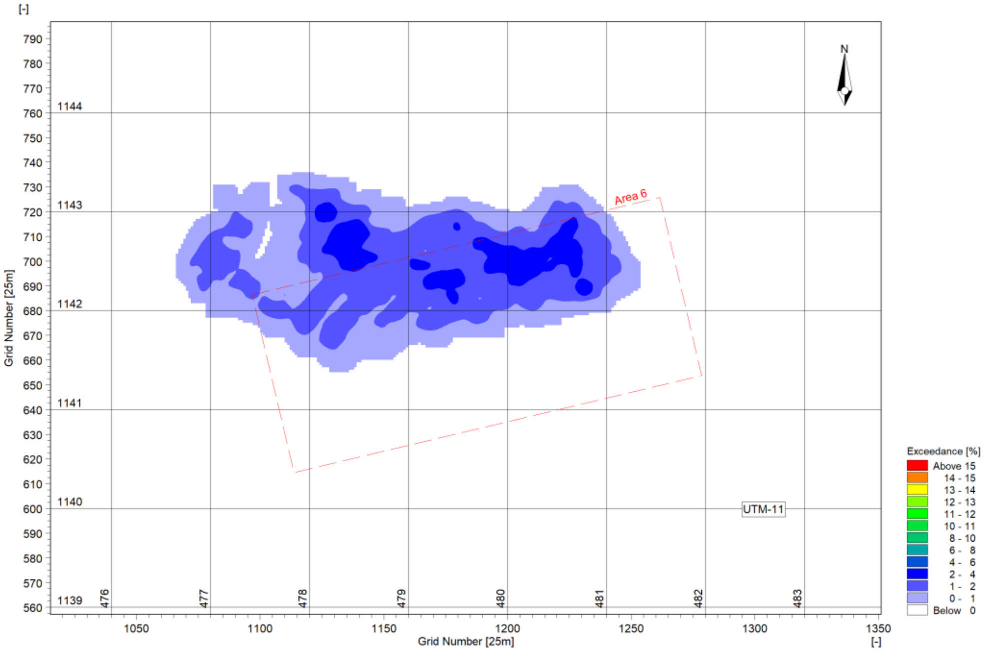

Figure 3.94 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 5m above the seabed

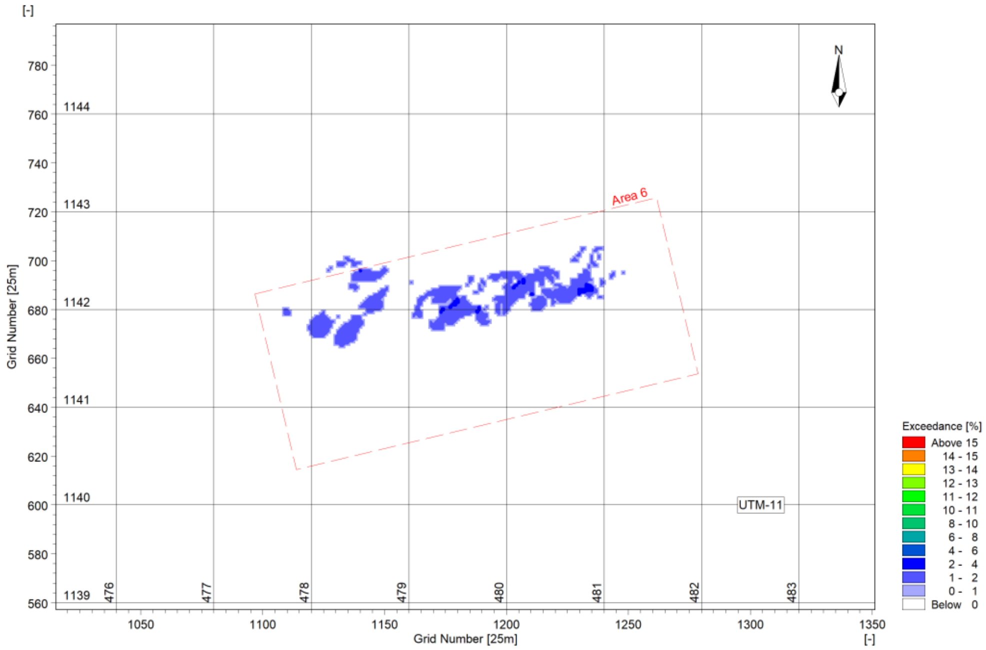

Figure 3.95 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 5m above the seabed

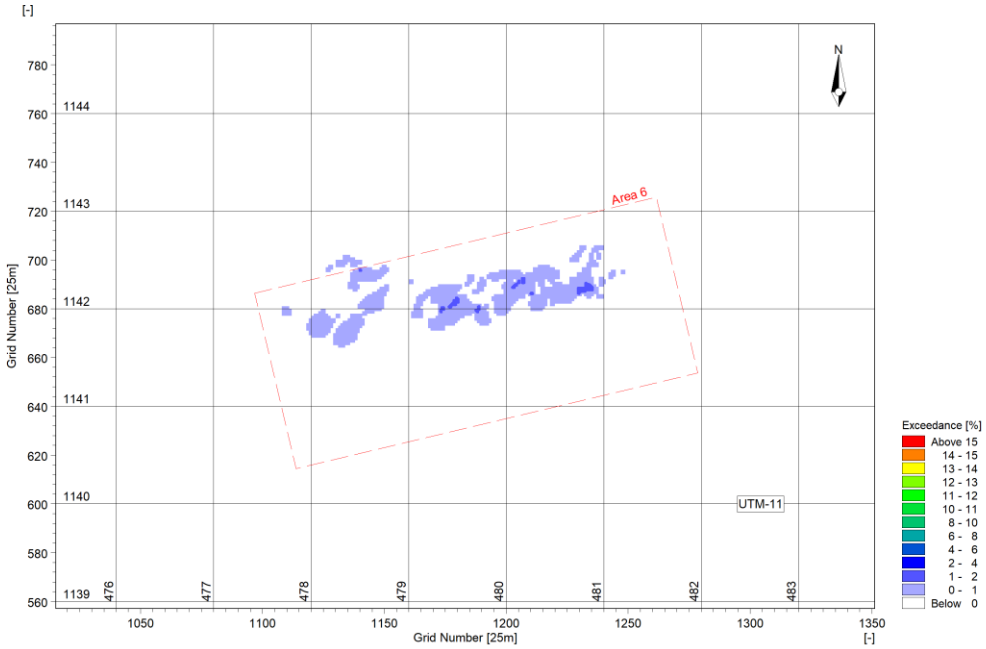

Figure 3.96 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 5m above the seabed

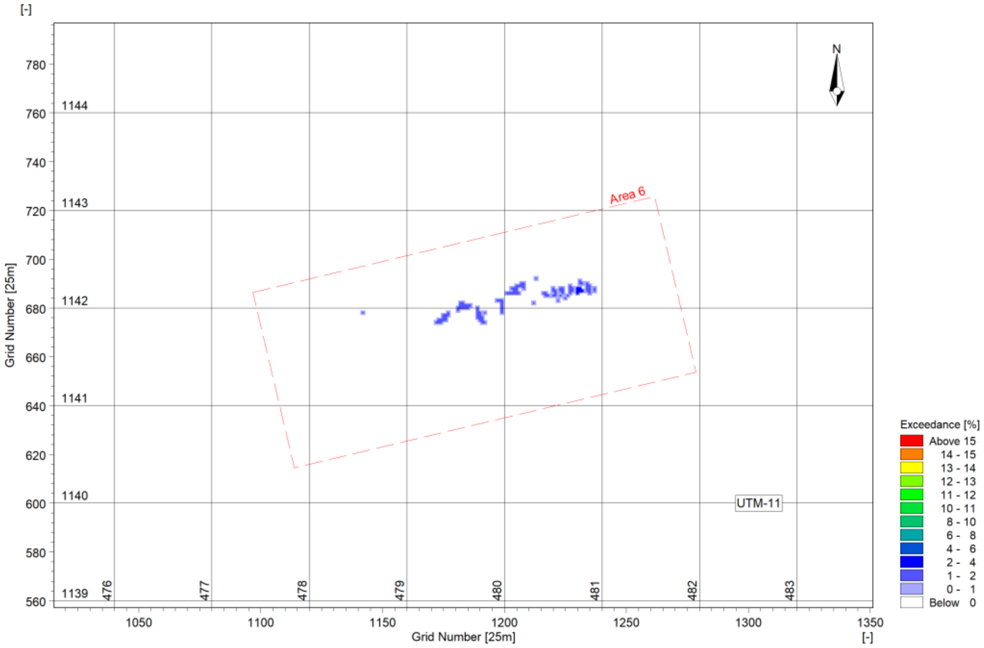

Figure 3.97 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 5m above the seabed

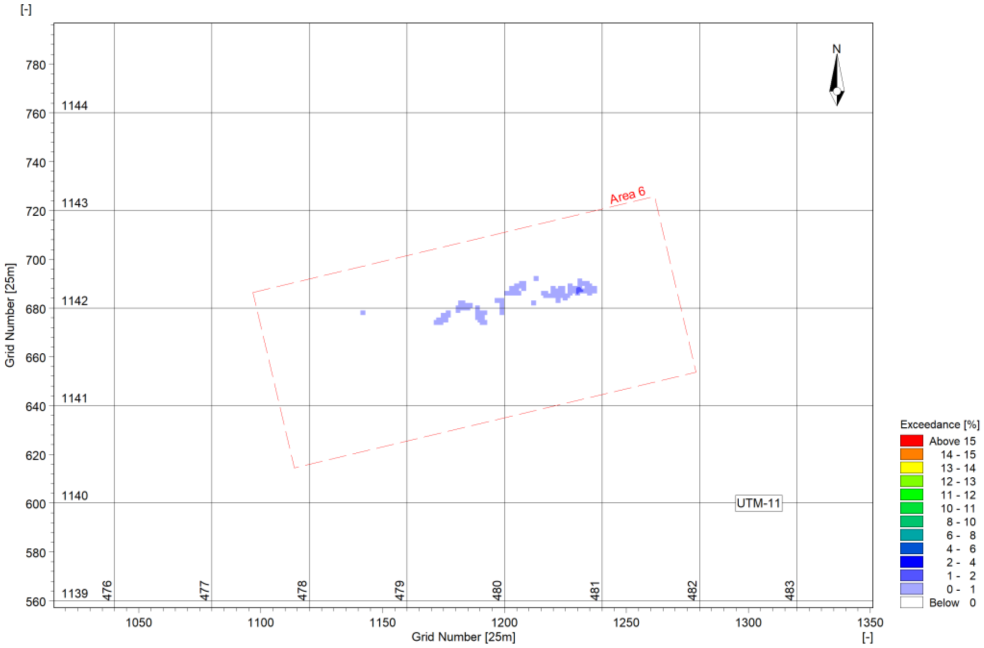

Figure 3.98 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 5m above the seabed

3.5.3 TSS 20m Above Seabed

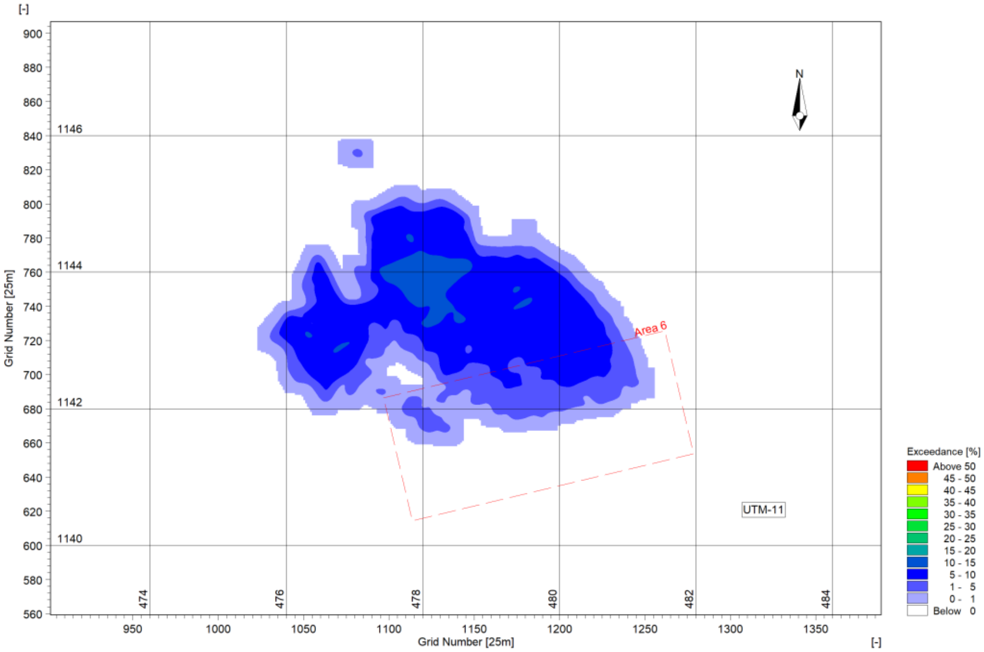

Figure 3.99 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

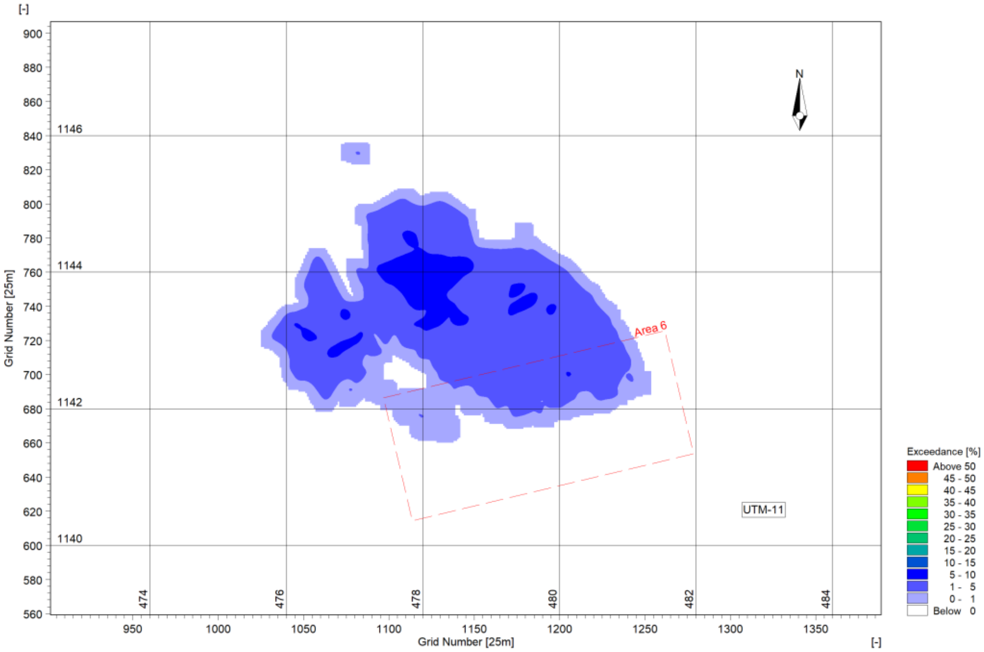

Figure 3.100 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

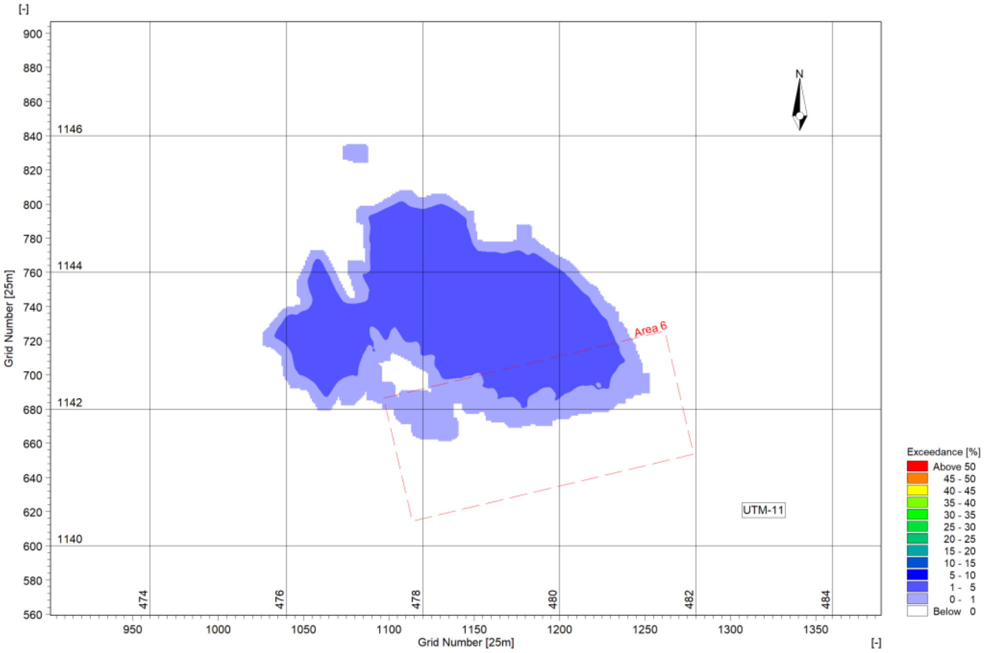

Figure 3.101 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 20m above the seabed

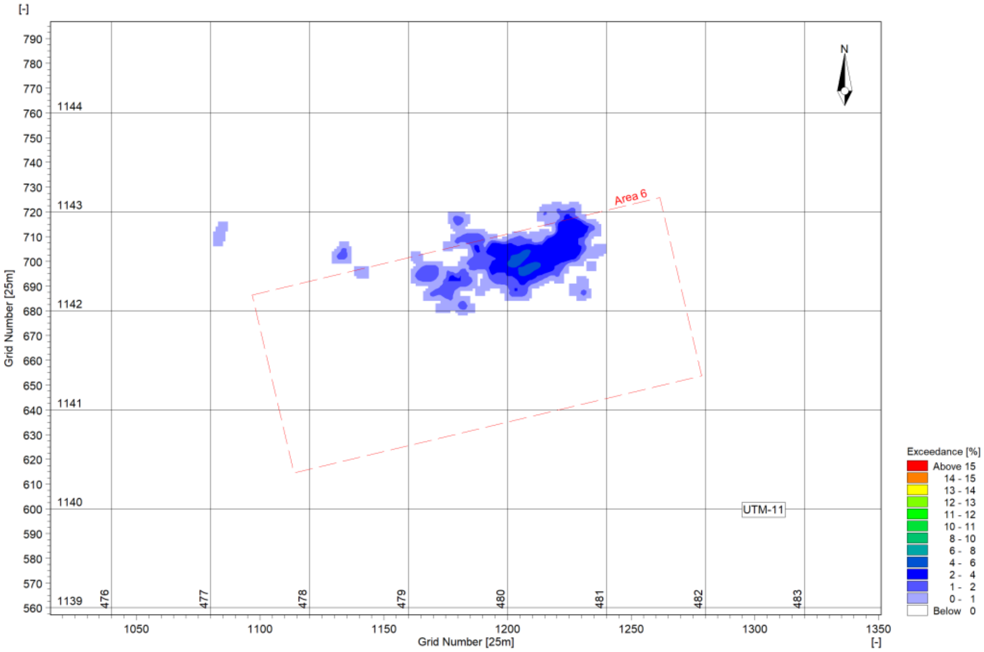

Figure 3.102 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 24 hours post-production at 20m above the seabed

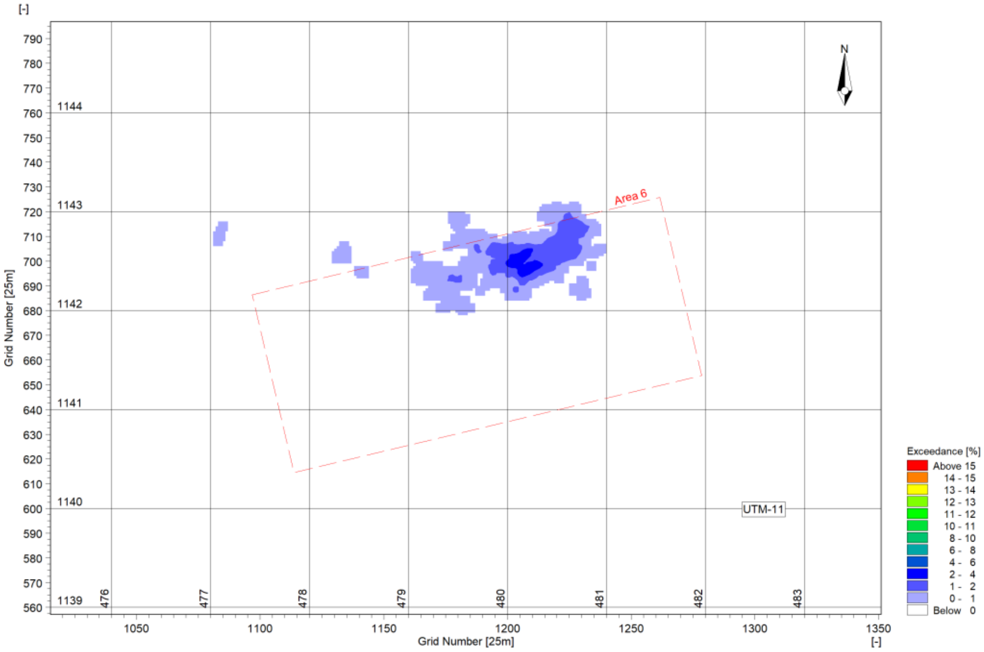

Figure 3.103 Scenario STR3b: Exceedance percentage of 1mg/l, from the start of production to 48 hours post-production at 20m above the seabed

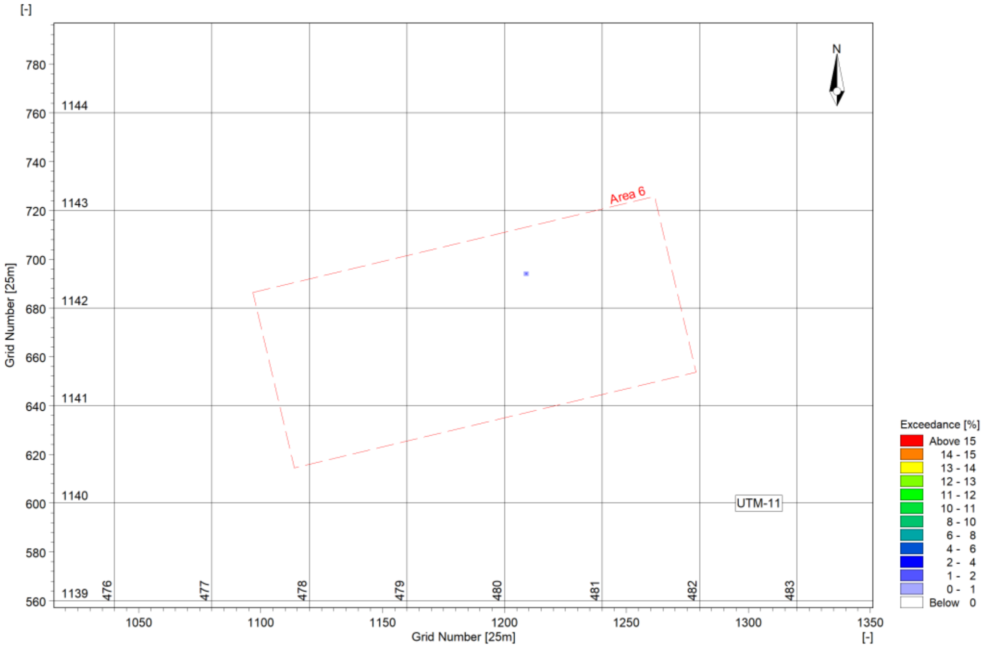

Figure 3.104 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 24 hours post-production at 20m above the seabed

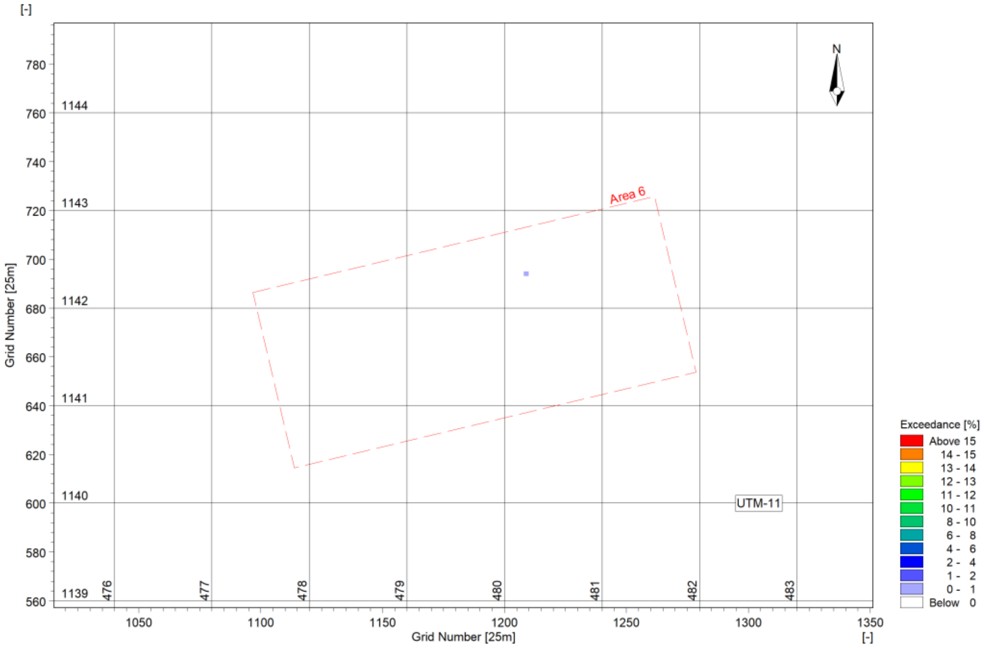

Figure 3.105 Scenario STR3b: Exceedance percentage of 5mg/l, from the start of production to 48 hours post-production at 20m above the seabed

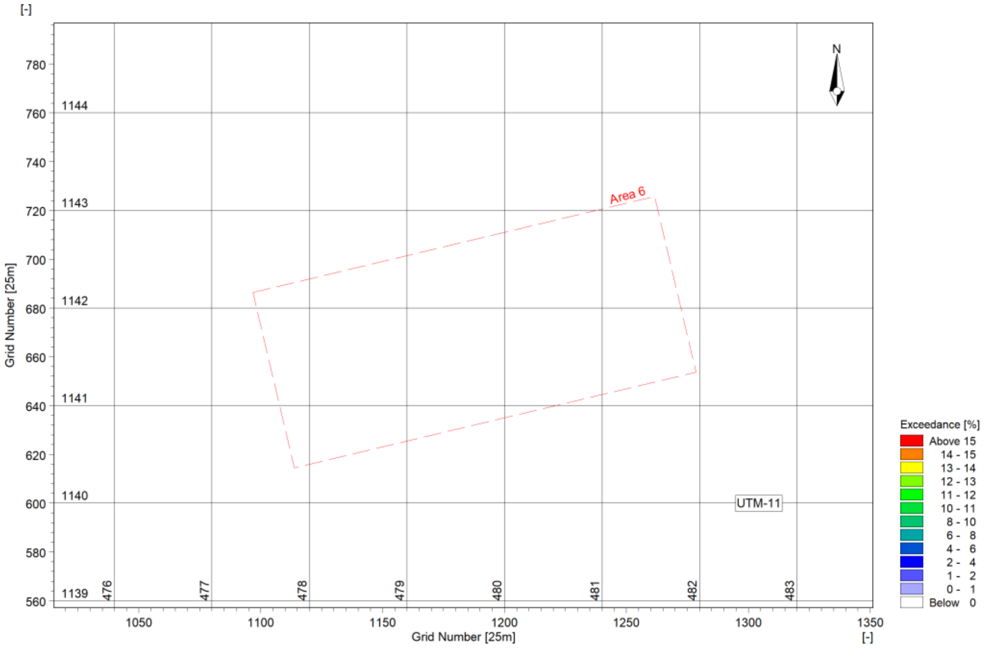

Figure 3.106 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 24 hours post-production at 20m above the seabed

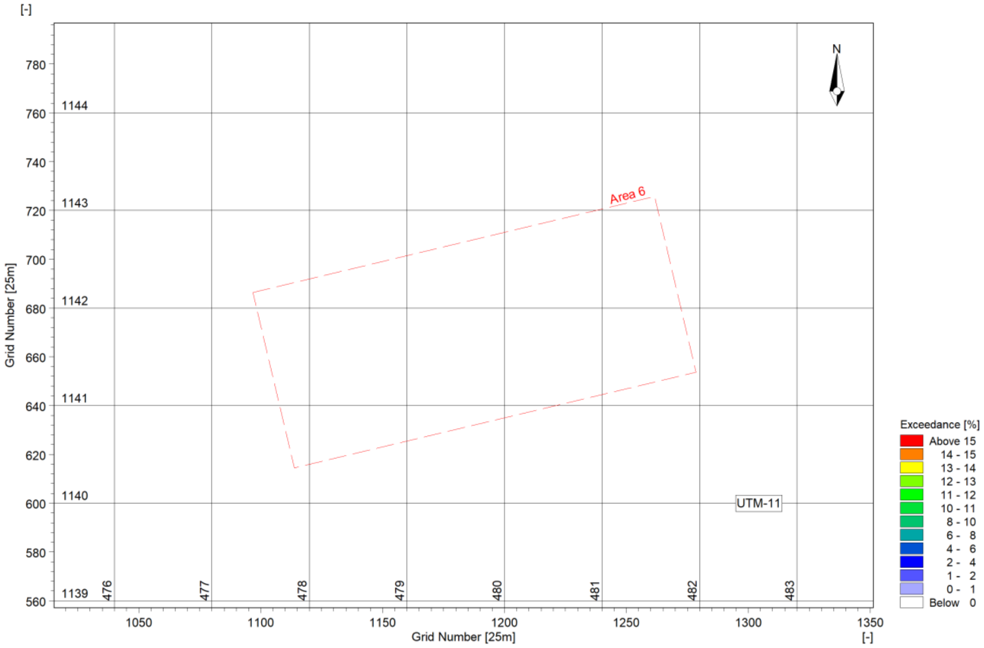

Figure 3.107 Scenario STR3b: Exceedance percentage of 10mg/l, from the start of production to 48 hours post-production at 20m above the seabed

3.5.4 TSS at Mid-Water Column Discharge

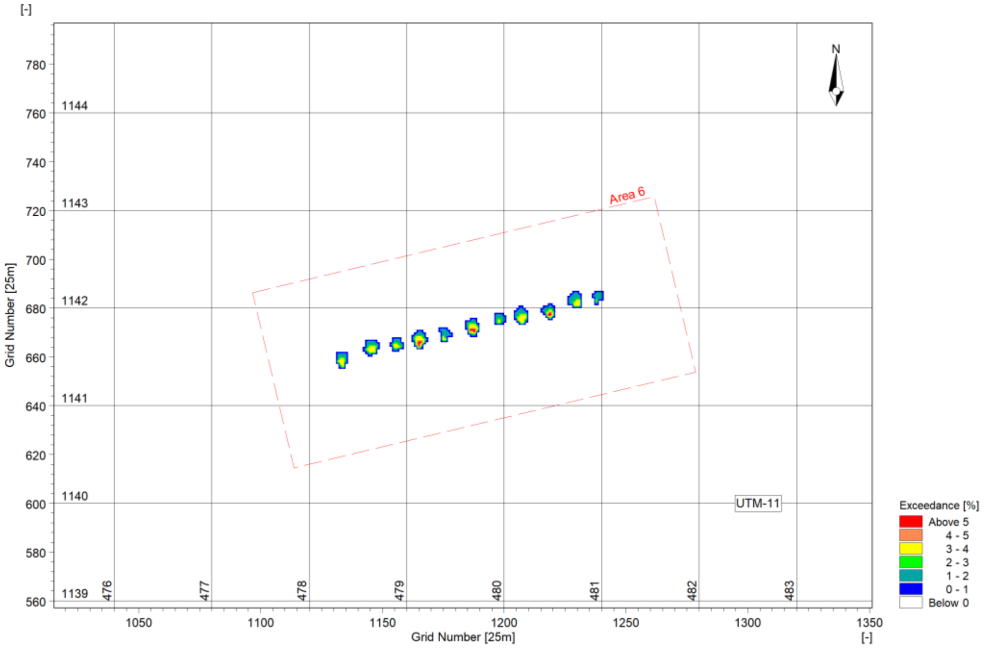

Figure 3.108 Scenario SR3b: Exceedance percentage of 0.1mg/l, from the start of production to 24 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

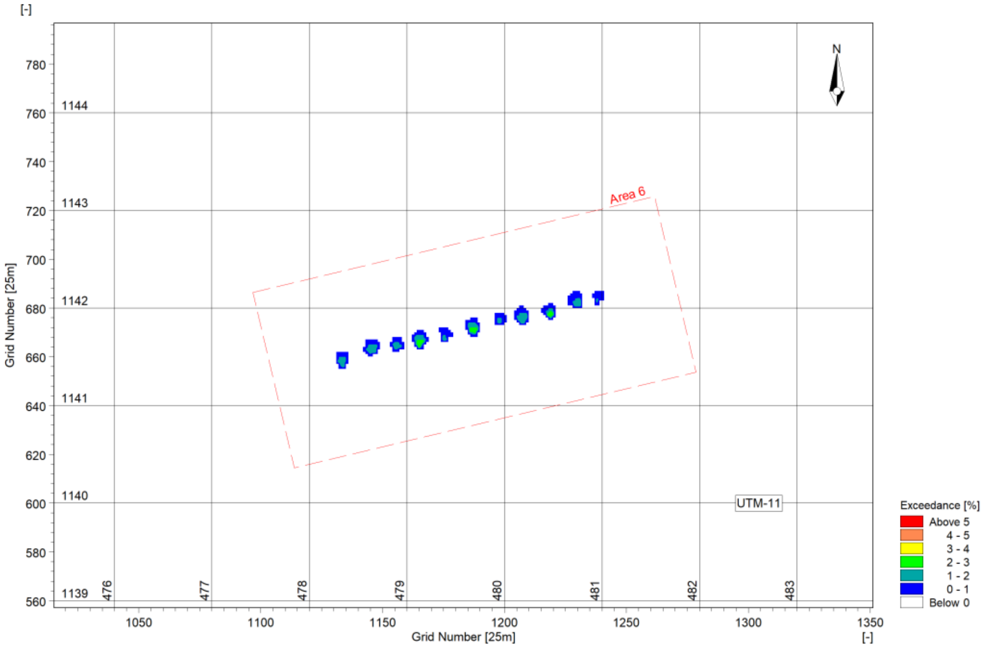

Figure 3.109 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 48 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

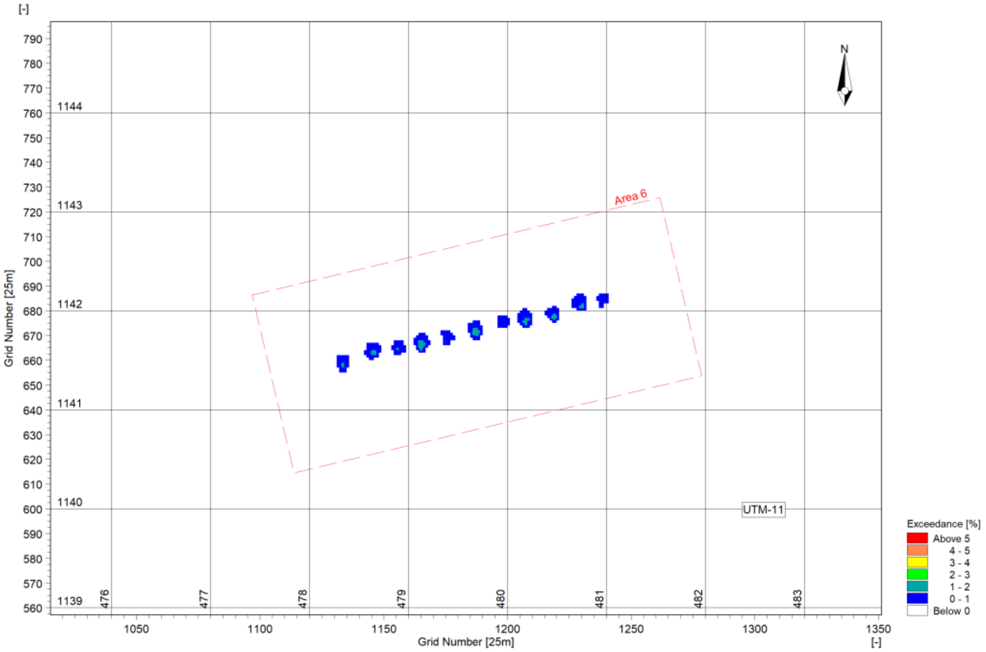

Figure 3.110 Scenario STR3b: Exceedance percentage of 0.1mg/l, from the start of production to 96 hours post-production at 50m below the mid-water column discharge location (or 1050m below the surface)

4 Cumulative Result of Pilot Collector Test Operation

The results presented in Section 3 represent the Suspended sediment plume and sedimentation associated with the five individual pilot test operations that generate significant sediment spill. These five scenarios will be executed over a period of 61.5hrs in sequence over a number of days (259hours), such that it is also important to consider the cumulative effect of these five scenarios on sedimentation and suspended sediment concentration.

4.1 Sedimentation

The relative location of the individual run lines may vary scenario to scenario in the field. To provide an indication of the sensitivity of the net sedimentation field to the specific offset of the individual test run lines, three sensitivity tests have been undertaken.

The base cumulative scenario is all tracks as per Section 2.3.5. Results for this base case are presented in Figure 4.1. For the two sensitivity tests, the centrelines of the tracks are offset as per Table 4.1, with positive offsets representing a northerly shift of the individual tracks and a negative offset, a southerly shift of the individual scenario tracks. Results for these two sensitivity tests are presented in Figure 4.2 and Figure 4.3.

Table 4-1 STR Track centreline offsets for cumulative sedimentation sensitivity testing

Cumulative Scenario	Offset (m) for each sensitivity test				
	STR1b	STR2a	STR2b	STR3a	STR3b
Base	0	0	0	0	0
Shift 1	-150	0	150	50	100
Shift 2	-300	0	300	100	200

Results are presented to a threshold of 0.01mm (10% of background as documented in Appendix C). Presenting results to a threshold of 0.01mm results in the capture of 97% of the deposited material (i.e. only 3% of deposited material is found in areas with sedimentation thickness <0.01mm).

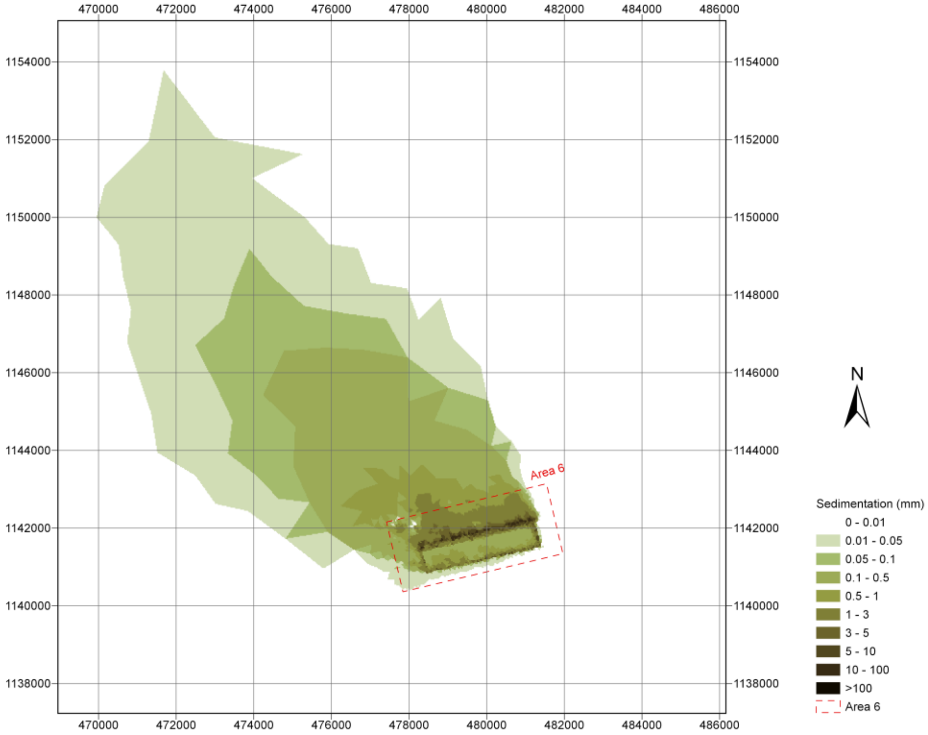

Figure 4.1 Cumulative sedimentation (mm) Base Case

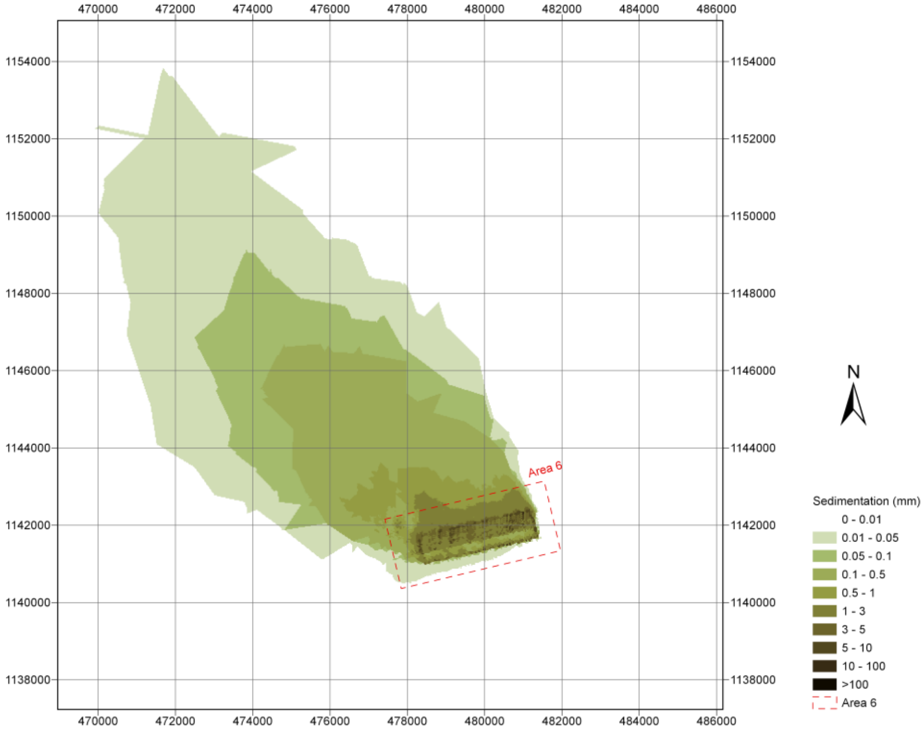

Figure 4.2 Cumulative sedimentation (mm) Sensitivity Test Shift 1

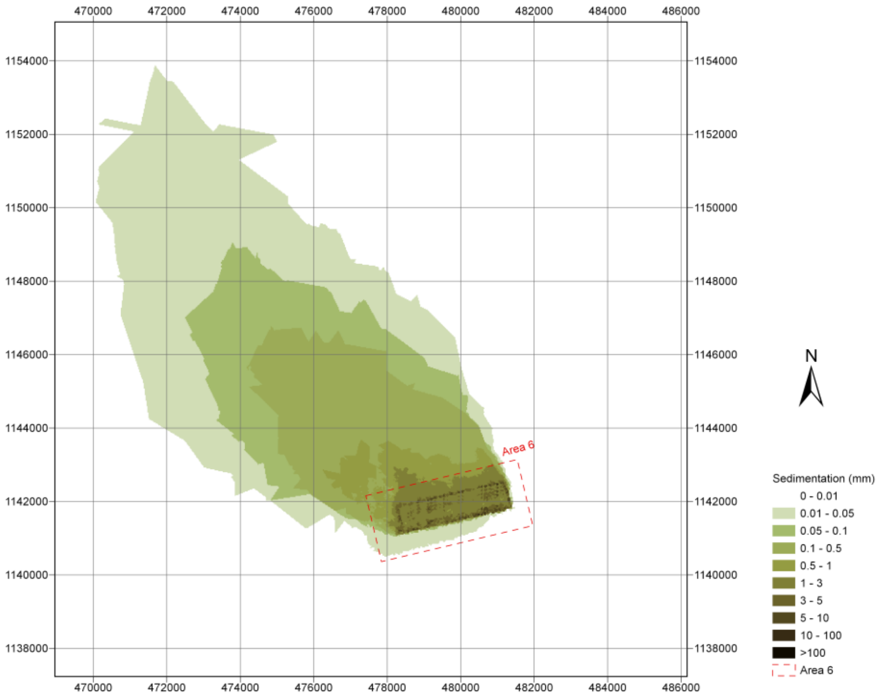

Figure 4.3 Cumulative sedimentation (mm) Sensitivity Test Shift 2

4.2 Suspended Sediments

For the cumulative total suspended sediment concentrations, the specific timing of the individual pilot tests activities is more important than the relative location of the tracks (within the limits addressed in Table 4.1). Allseas have provided an estimate of the sequence and likely timing of the five pilot test activities generating significant sediment spill as documented in Table 4.2. It is noted that the PNCT operations generating spill constitute only 61.5hours out of the total 259 hours STR operation.

Cumulative Exceedance of threshold concentrations 5m above the seabed are presented in Section 4.2.1, 20m above the seabed in Section 4.2.2 and at 1050m for the mid-water column discharge in Section 4.2.3. Summary statistics are provided in Section 4.2.4. Exceedance data is provided with a statistical analysis period up to 24hrs after completion of the PNCT operations. It is noted that (based on the analysis in Appendix A), adopting an analysis period extending 24 hours after completion of the operations ensures that the exceedance results represent maximum plume extent at a threshold of 0.1mg/l.

Table 4-2 STR sequence and start time offset for cumulative suspended sediment assessment

STR Order	Total time Per STR	STR start time shift from previous STR start
1b	95hrs	0
2a	41hrs	95hrs
2b	61hrs	41hrs
3a	29hrs	61hrs
3b	33hrs	29hrs

4.2.1 TSS 5m Above Seabed

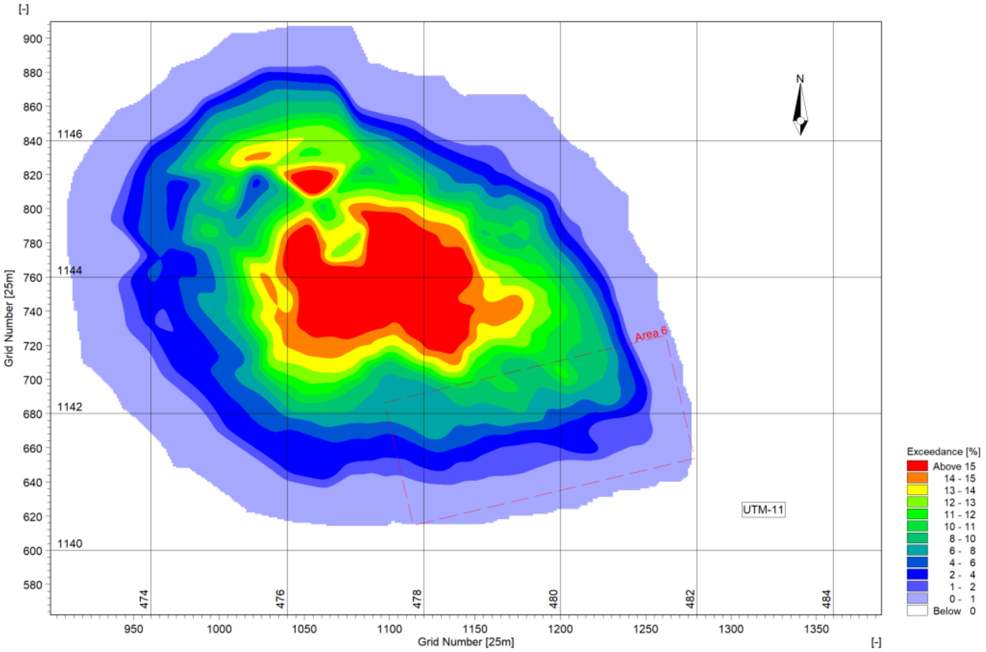

Figure 4.4 Net exceedance percentage of 0.1mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

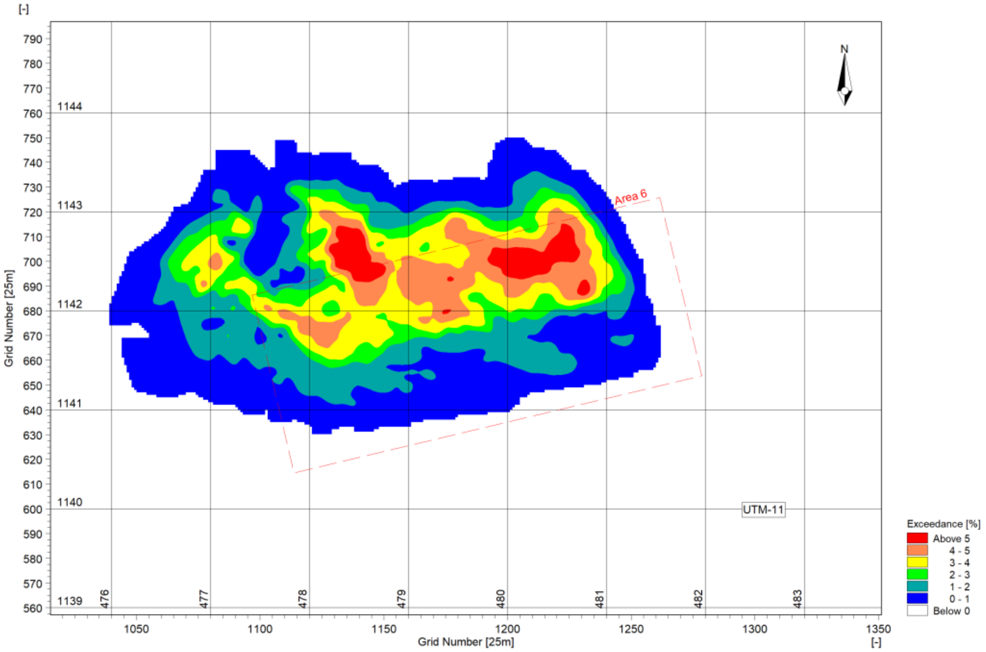

Figure 4.5 Net exceedance percentage of 1mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

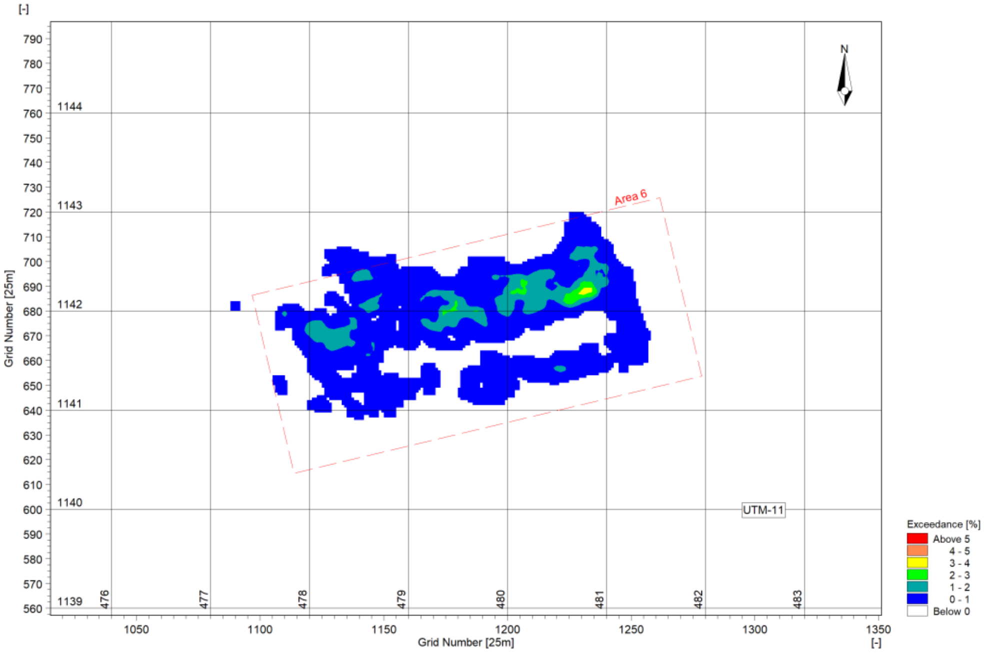

Figure 4.6 Net exceedance percentage of 5mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

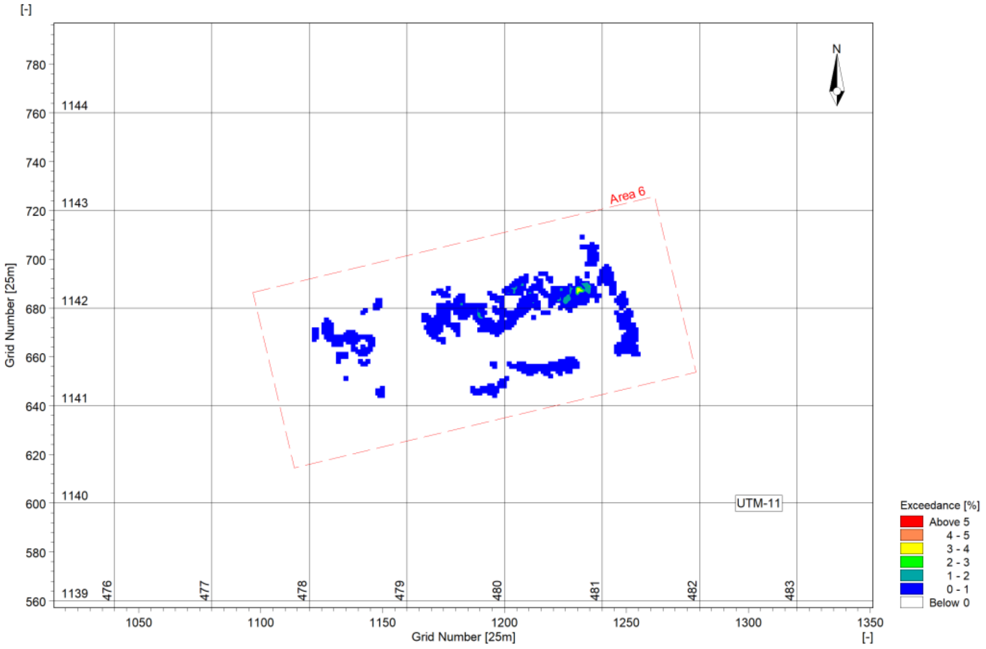

Figure 4.7 Net exceedance percentage of 10mg/l at 5m above the seabed from start of STR1b to 24hrs after completion of STR3b

4.2.2 TSS 20m Above Seabed

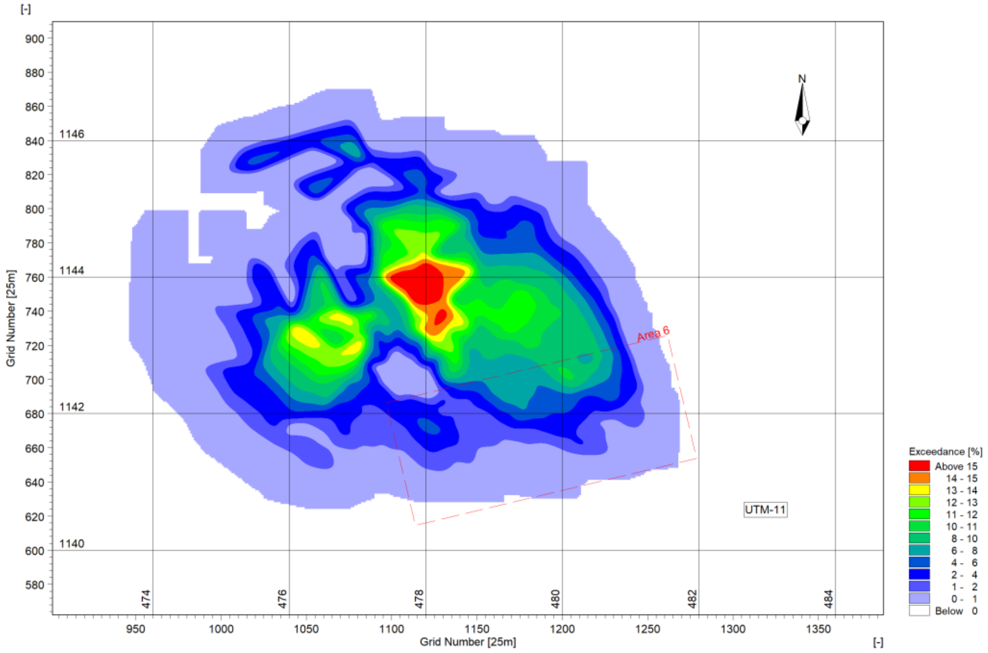

Figure 4.8 Net exceedance percentage of 0.1mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

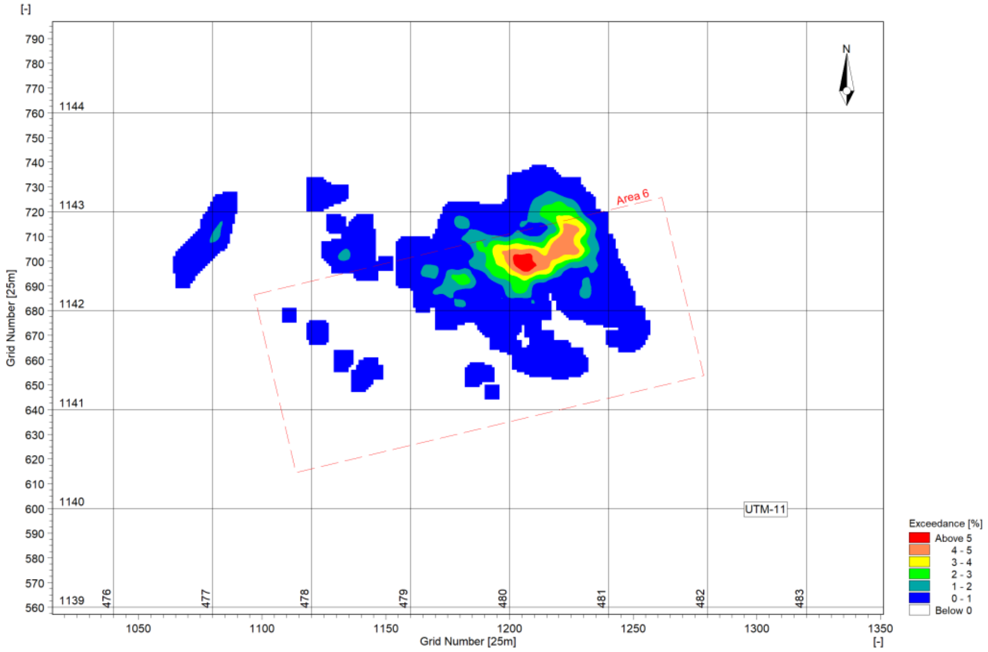

Figure 4.9 Net exceedance percentage of 1mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

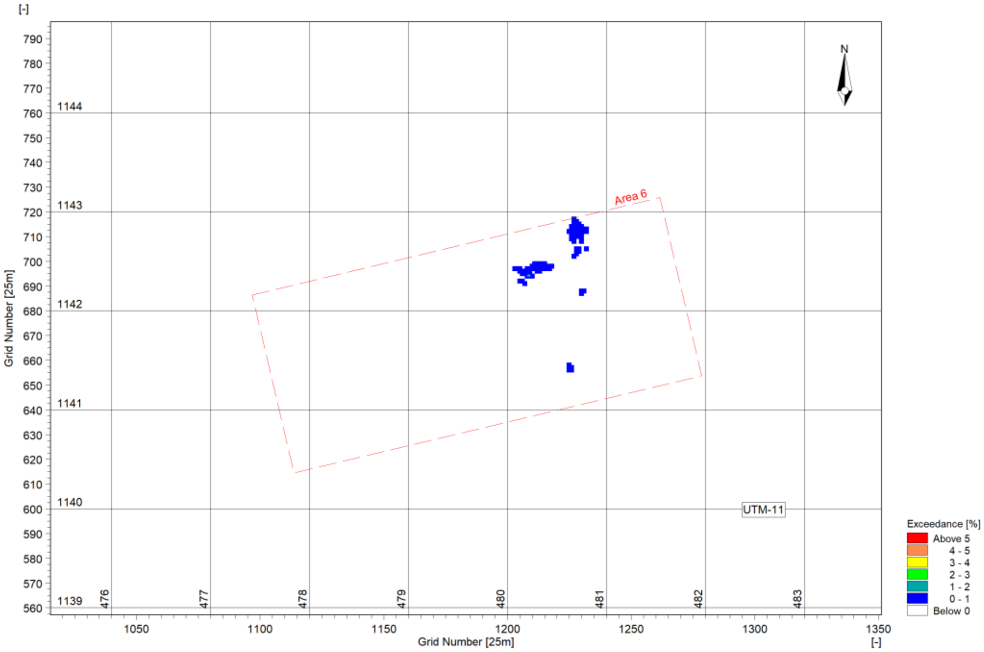

Figure 4.10 Net exceedance percentage of 5mg/l at 20m above the seabed from start of STR1b to 24hrs after completion of STR3b

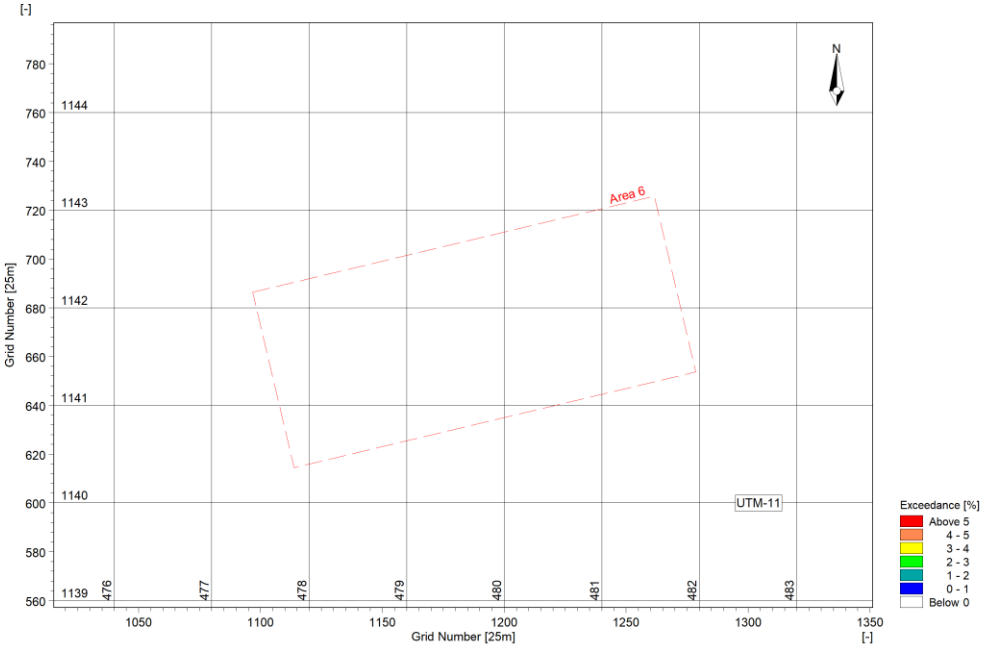

Figure 4.11 Net exceedance percentage of 10mg/l at 20m above the seabed from start of STR2a to 24hrs after completion of STR3b

4.2.3 TSS at Mid-Water Column Discharge

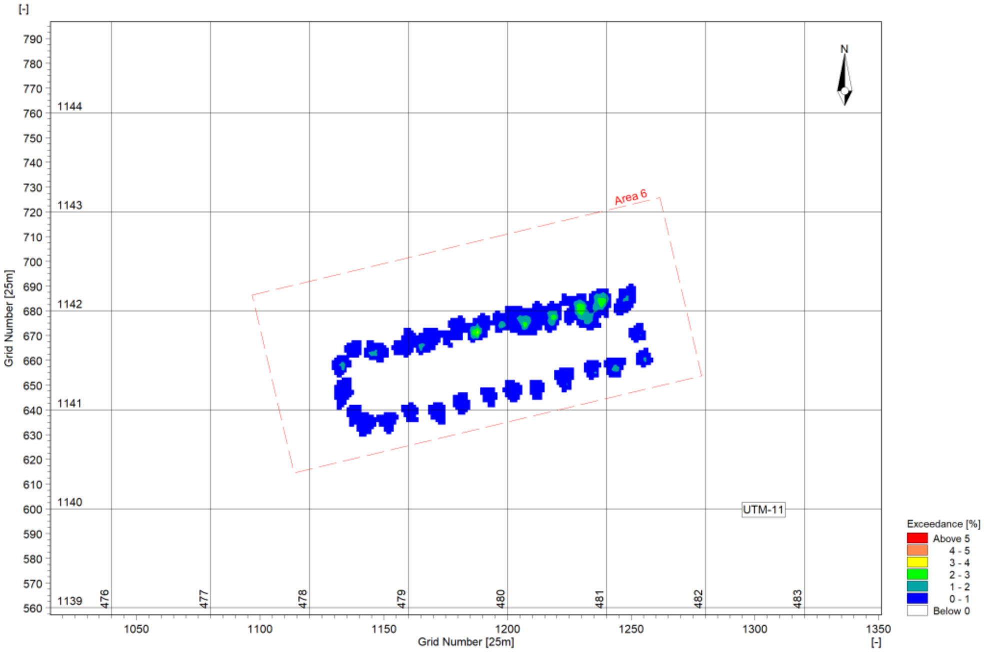

Figure 4.12 Net exceedance percentage of 0.1mg/l at 50m below the mid-water column discharge location (or 1050m below the surface) from start of STR2a to 24hrs after completion of STR3b

4.2.4 TSS Summary Statistics

Summary statistics for the cumulative pilot test operation are provided in the following figures. Results are presented for 5m above seabed, 20m above seabed and at 1050m for the mid-water column discharge for the following parameters:

Total duration (hours) where 1mg/l is exceeded. This is similar to the exceedance results presented in the previous sections, but expressed in hours rather than as a percentage of time.

***Time to first exceedance* of 1mg/l**. This provides an indicator of how long after the pilot test starts different areas will first experience concentrations above 1mg/l above background.

Number of times exceeded provides a description of the persistence of the exceedance events at a specific location. For example, a value of 12 would mean that the concentration went above and fell back below 1mg/l above background 12 times during the pilot test program.

4.2.4.1 Allseas Base Sequence

Figure 4.13 to Figure 4.21 present summary results for the Allseas base STR sequence presented in Table 4-2.

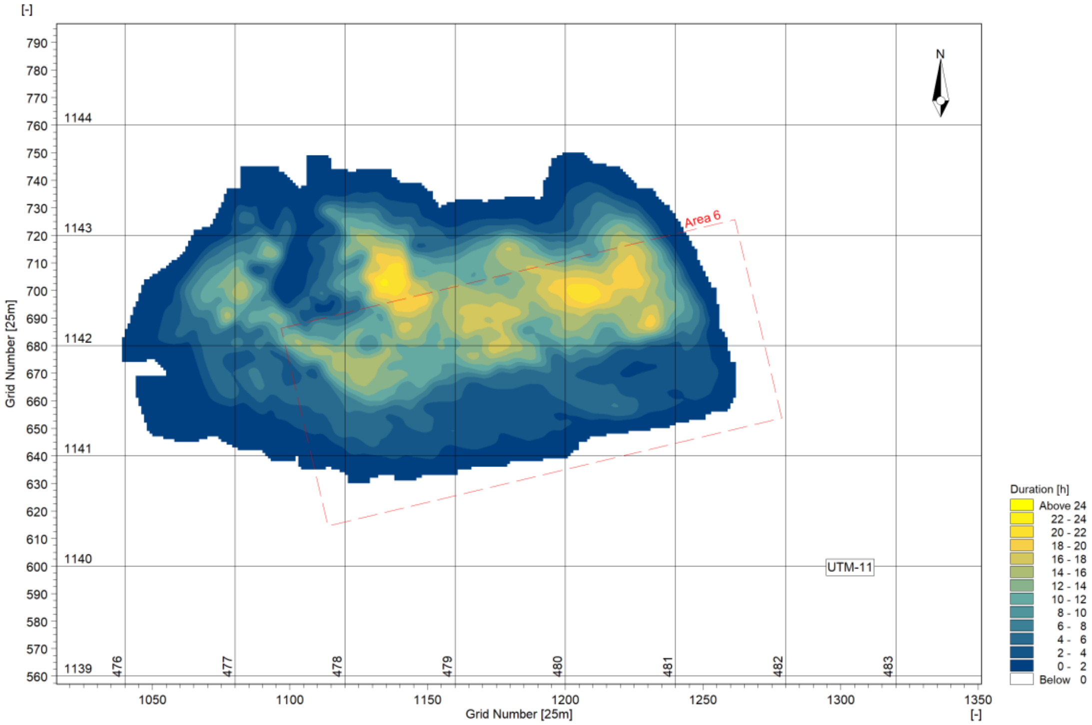

Figure 4.13 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed

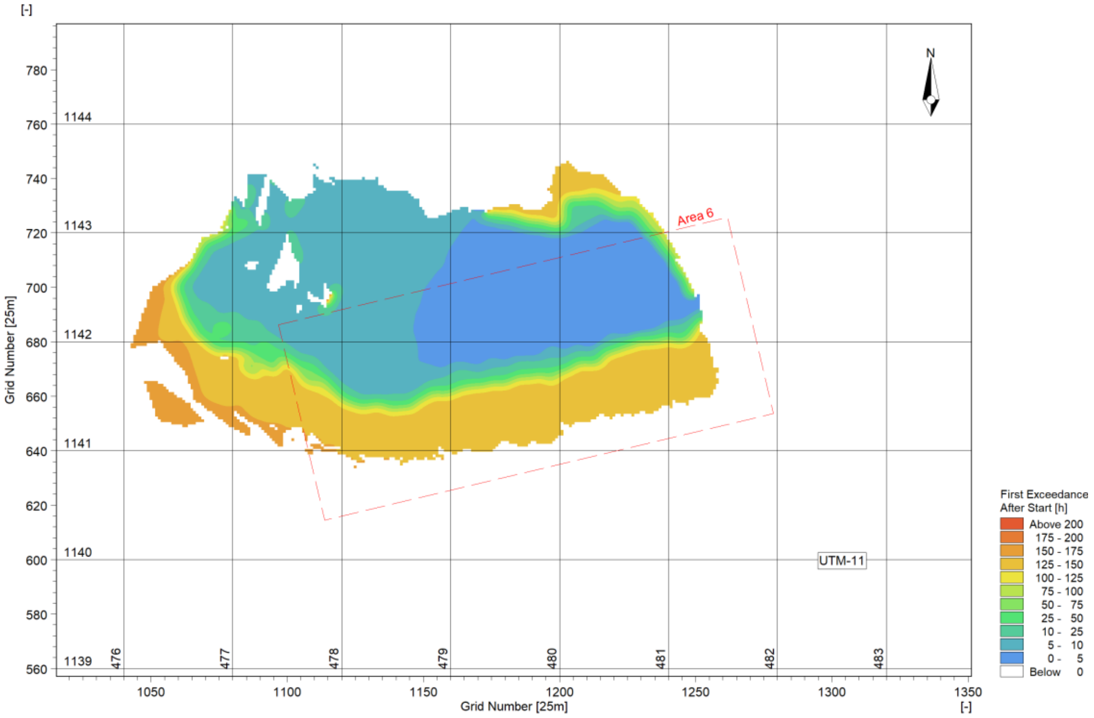

Figure 4.14 Time to first exceedance of 1mg/l after the start of the PNCT operations at 5m above the seabed

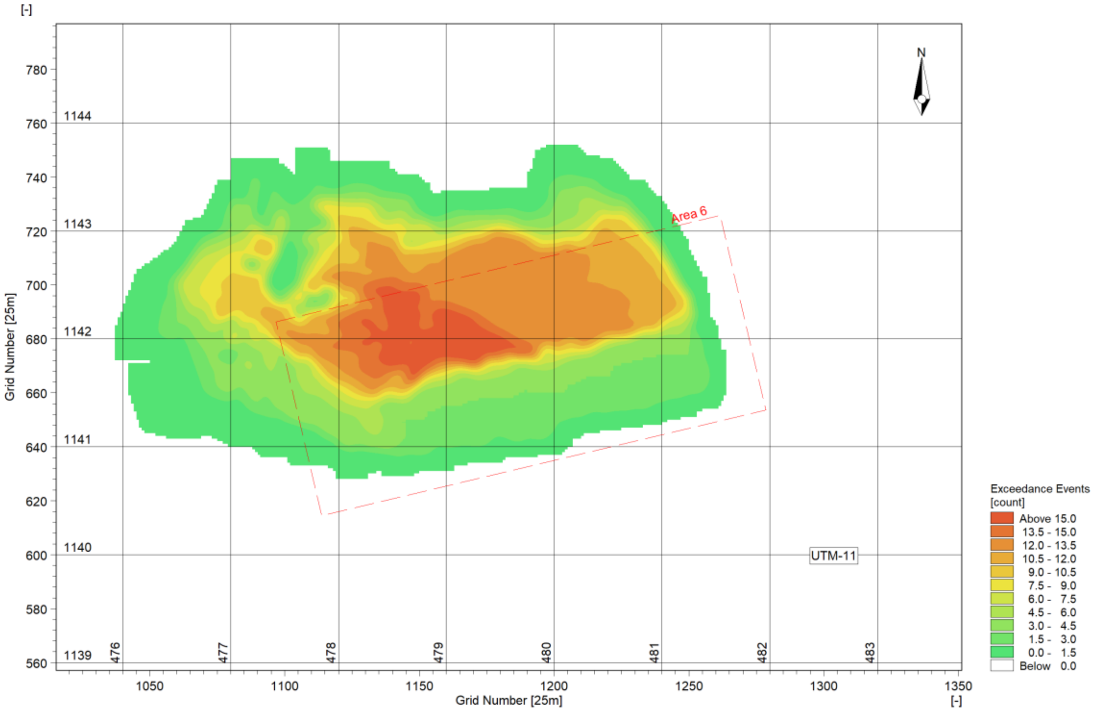

Figure 4.15 Total number of exceedance events above 1mg/l at 5m above the seabed

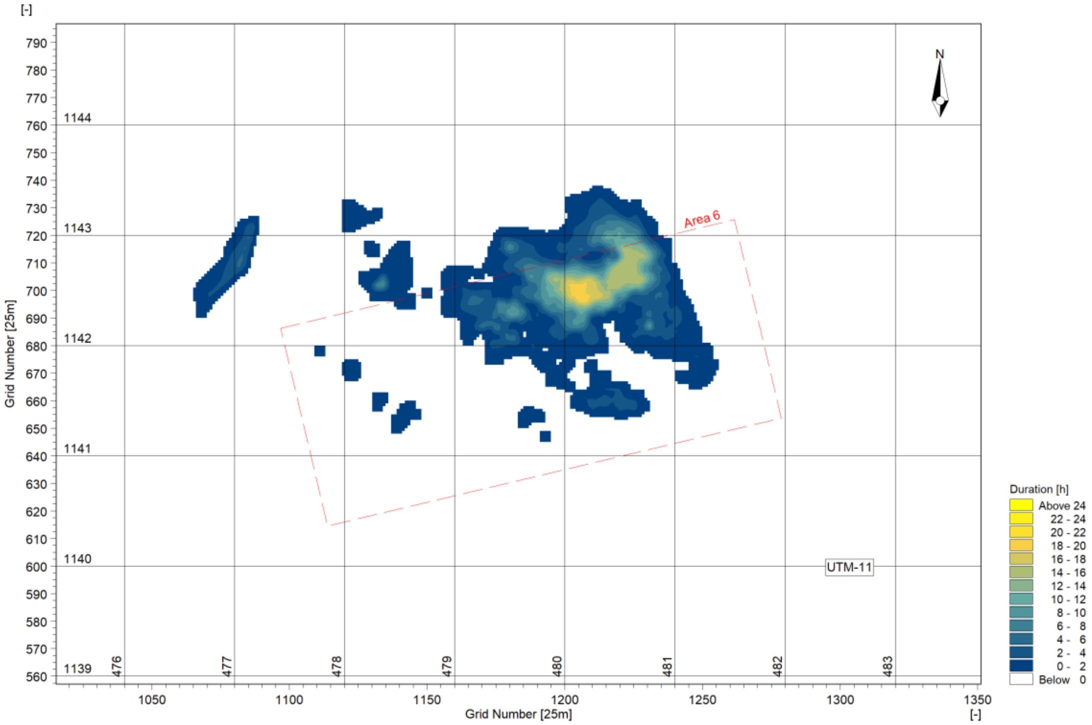

Figure 4.16 Total duration (hours) where 1mg/l is exceeded at 20m above the seabed

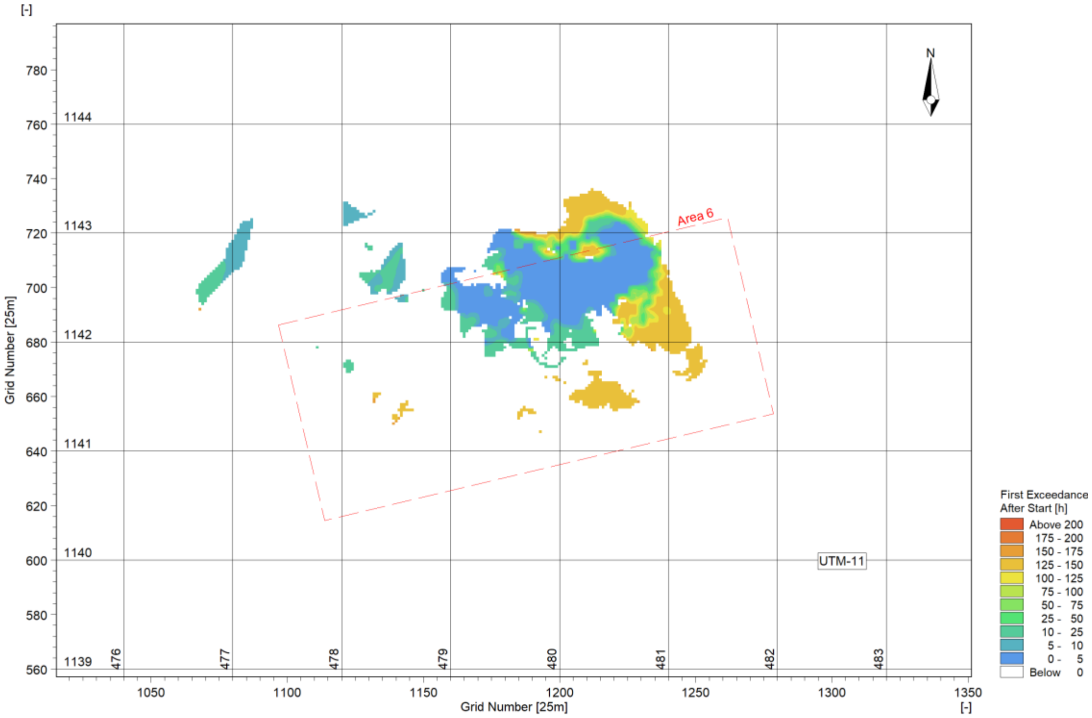

Figure 4.17 Time to first exceedance of 1mg/l after the start of the PNCT operation at 20m above the seabed

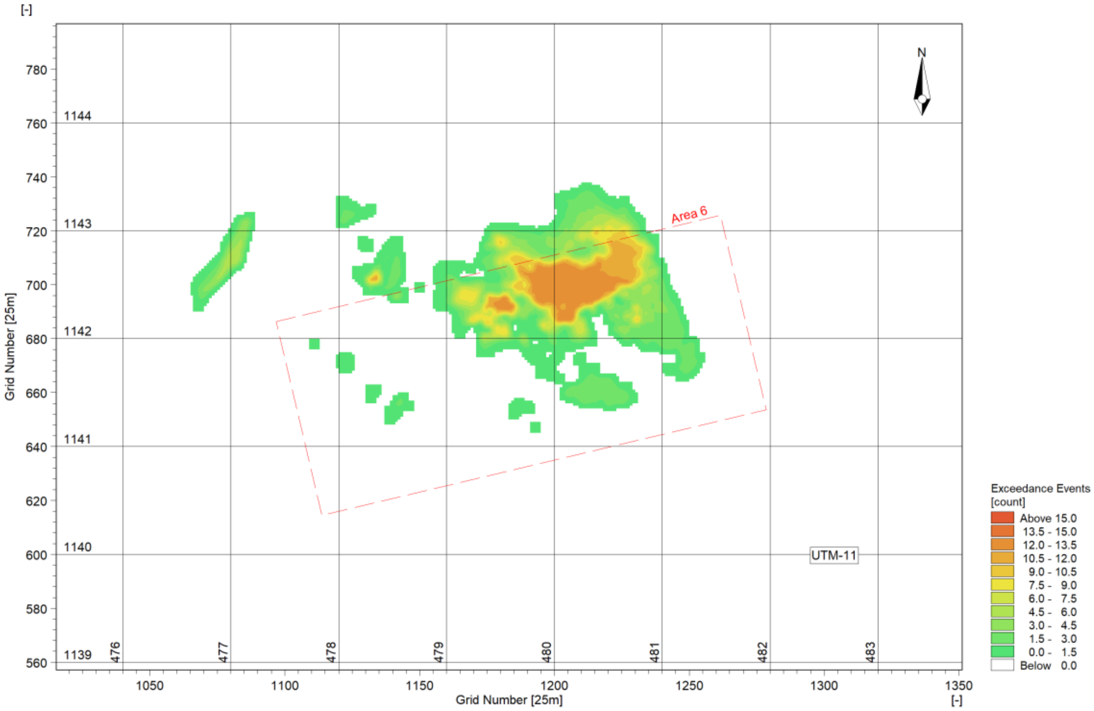

Figure 4.18 Total number of exceedance events above exceed 1mg/l at 20m above the seabed

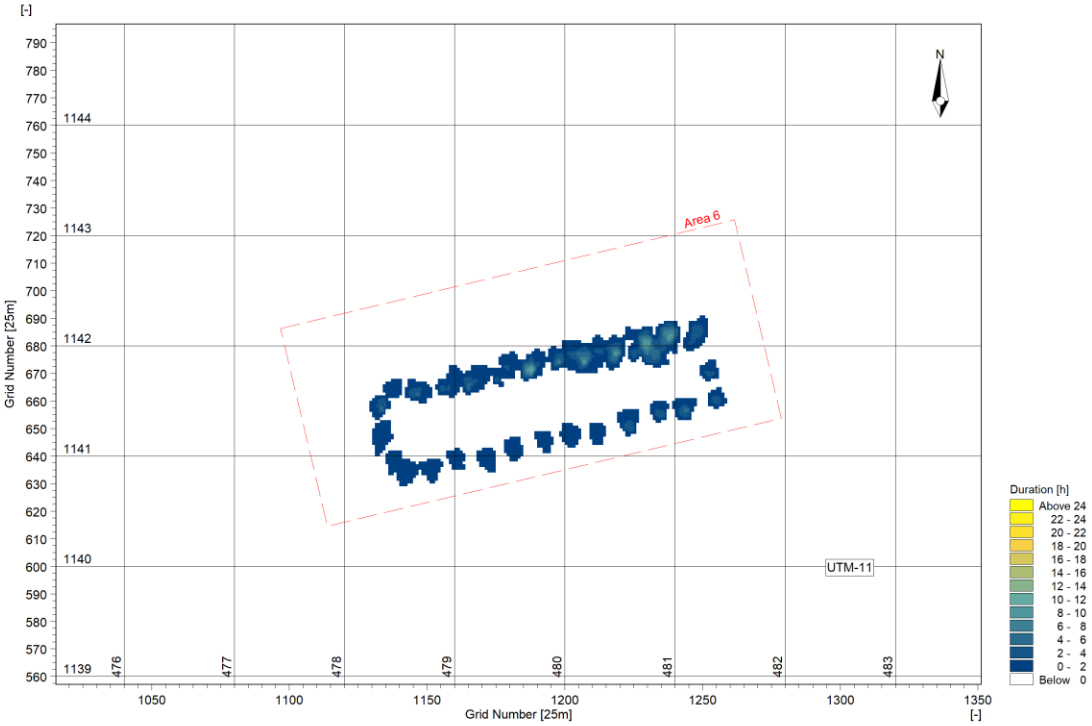

Figure 4.19 Total duration (hours) where 0.1mg/l is exceeded at 50m below the mid-water column discharge location (or 1050m below the surface)

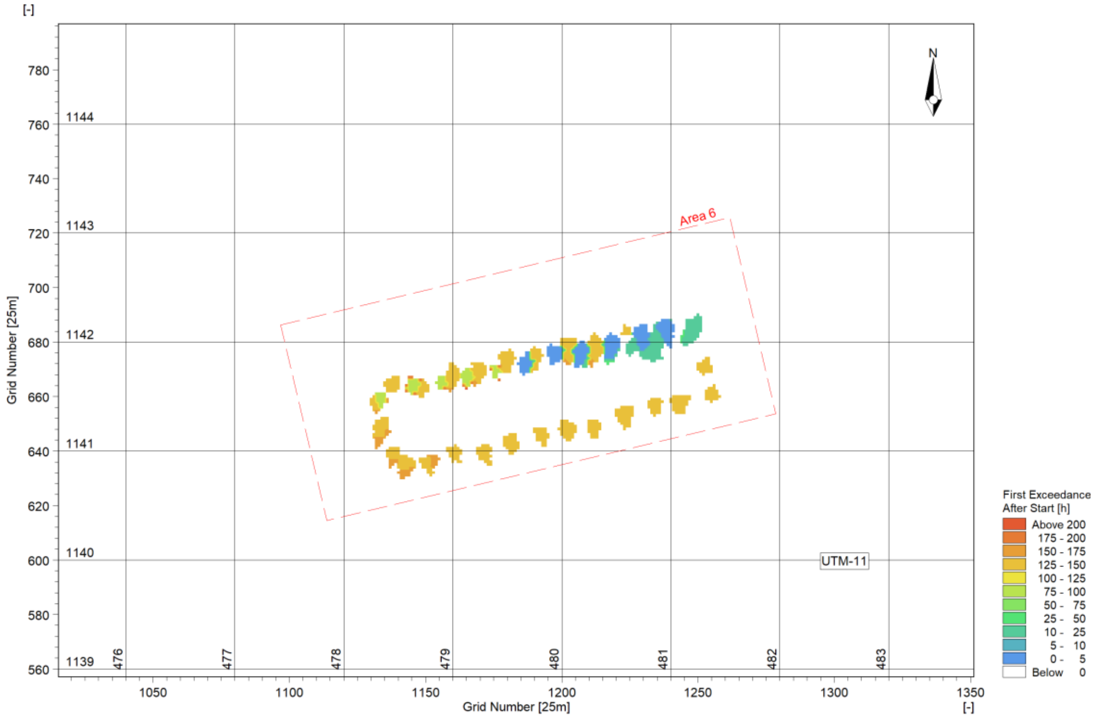

Figure 4.20 Time to first exceedance of 0.1mg/l after the start of the PNCT operation at 50m below the mid-water column discharge location (or 1050m below the surface)

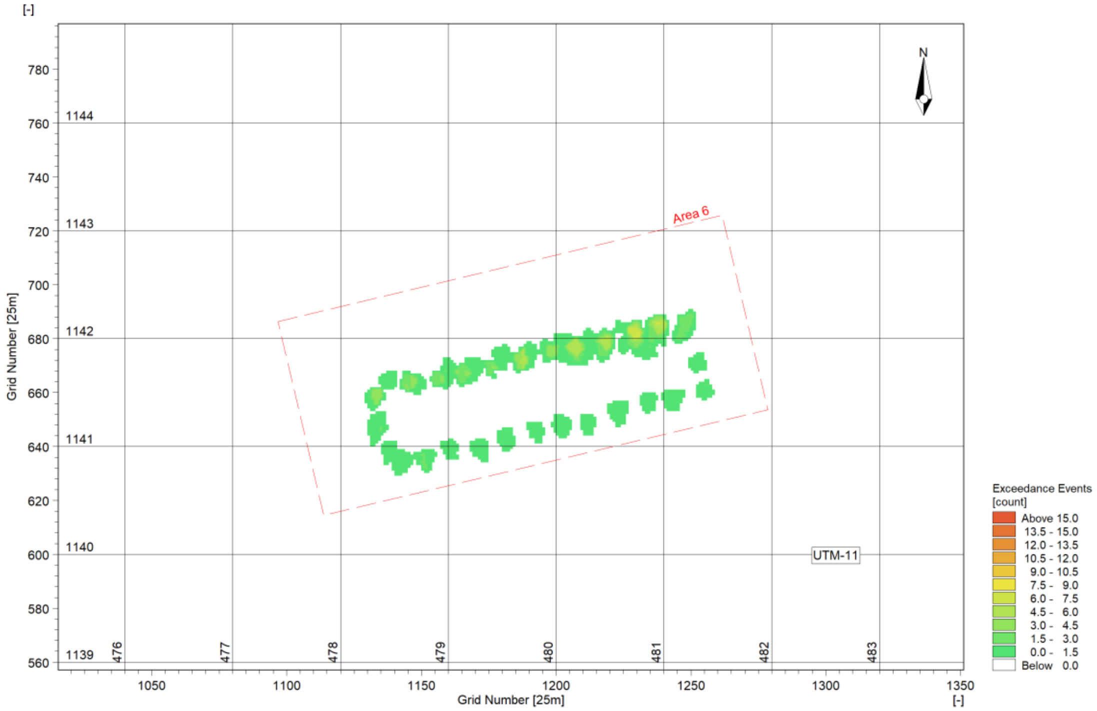

Figure 4.21 Total number of exceedance events above 0.1mg/l at 50m below the mid-water column discharge location (or 1050m below the surface)

4.2.4.2 Sensitivity to Sequence and Timing

As variation in the test sequence may occur due to operational reasons, the sensitivity of the suspended sediment results to the test sequence has been assessed (sedimentation being insensitive to the test sequence). One alternate test sequence is provided in Table 4-3, with results in in terms of total duration exceeding 1mg/l provided in Figure 4.22.

Table 4-3 STR sequence and start time offset for cumulative suspended sediment assessment with shifted sequence

STR Order	Total time Per STR	STR start time shift from previous STR start
2a	95hrs	0
3a	41hrs	95hrs
1b	61hrs	41hrs
2b	29hrs	61hrs
3b	33hrs	29hrs

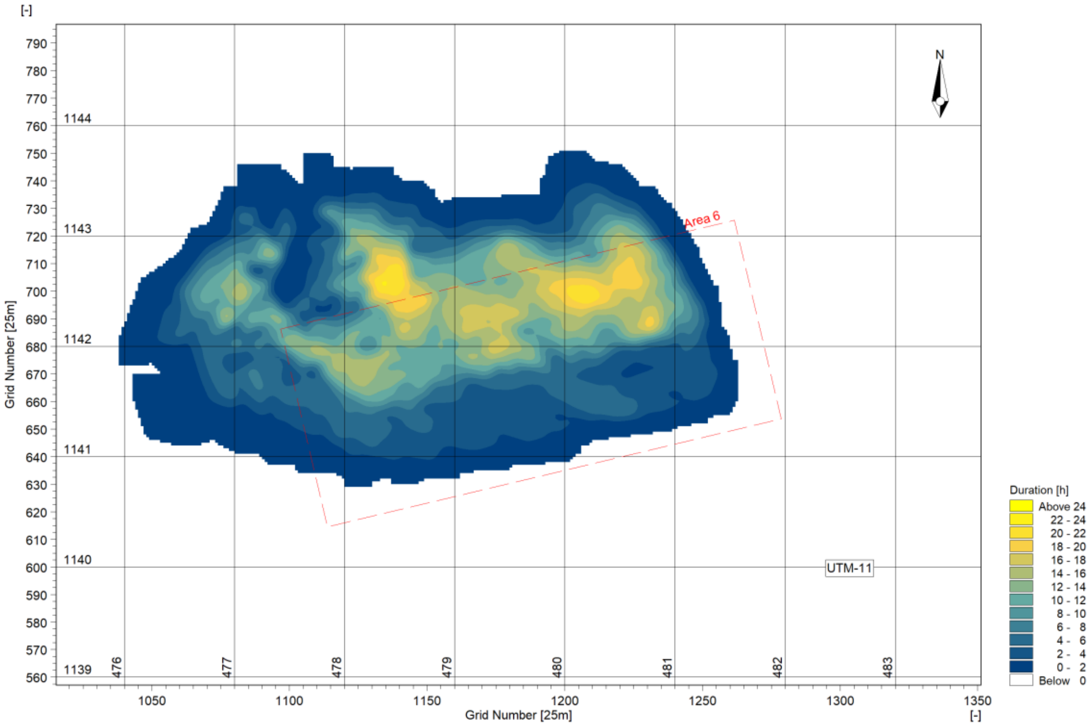

Figure 4.22 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed. Alternate STR sequence per Table 4-3

Comparing the base sequence results (Figure 4.13) with those of the alternate sequence (Figure 4.22) only small differences can be observed. It is thus reasonable to conclude that, provided that the overall test sequence (of the main sediment plume generating tests) is carried out in a period not significantly different from that proposed by Allseas at the time of writing (259hrs), the overall magnitude and spatial extent of the plume will be largely insensitive to the sequence of the specific STR tests.

Reducing the time between tests while maintaining production (Table 4-4) will ultimately tend to increase absolute cumulative magnitudes of exceedance. However, for the test sequence and time between tests put forward by Allseas (Table 4-2), there is significant leeway in the time between tests to avoid significant time overlap of the plumes. Consequently, even a 25% reduction in time between tests (Table 4-4) does not result in any appreciable change in cumulative exceedance of 1mg/l (Figure 4.23) as the period between STRs remains larger than the period of time for the concentration to drop below 0.1mg/l (Appendix A).

Table 4-4 STR sequence and start time offset for cumulative suspended sediment assessment with base sequence but with 25% reduction in test time

STR Order	Total test time Per STR	STR start time shift from previous STR start
1b	71hrs	0
2a	31hrs	71hrs
2b	46hrs	31hrs
3a	22hrs	46hrs
3b	25hrs	22hrs

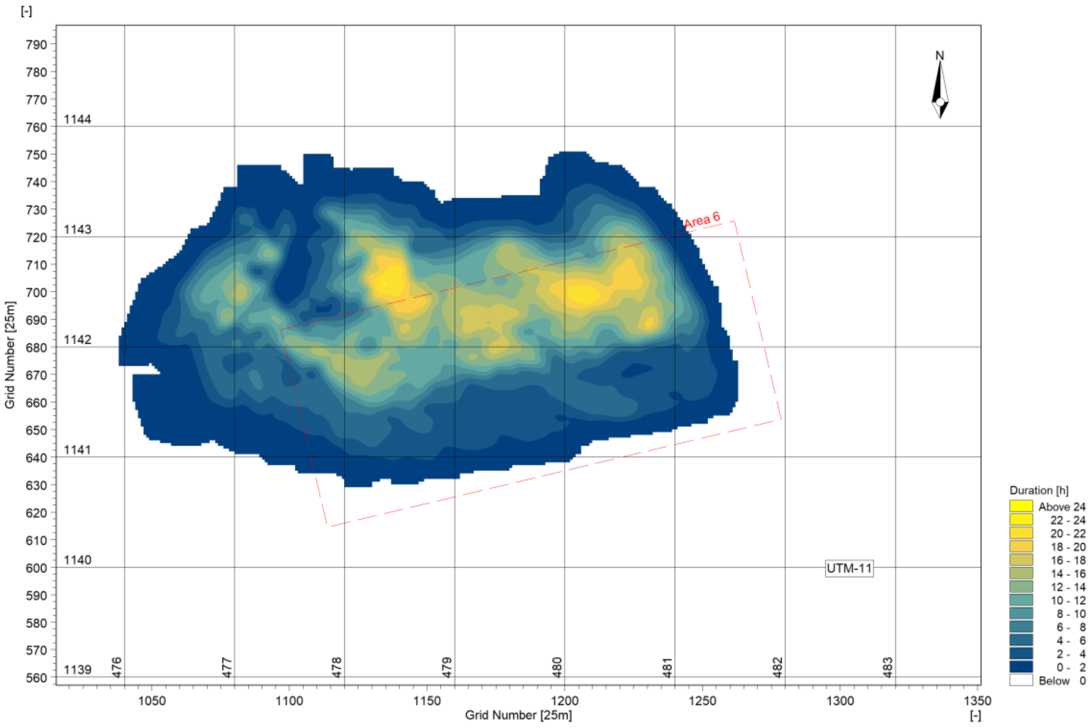

Figure 4.23 Total duration (hours) where 1mg/l is exceeded at 5m above the seabed. Alternate STR test timing per Table 4-4

Overall, provided the production totals and production rates presented in Section 2.3 are closely adhered to, the sensitivity tests indicate that there is considerable flexibility in the sequence and schedule for the PNCT operations without impacting the exceedance of a 1mg/l above background threshold.

4.3 Effect of Seasonality

As indicated in the preceding sections, the sediment plume modelling for the PNCT operation has been based on a pilot collector test program occurring during January 2022. This was the best information available at the time of simulation.

Ultimately it is recognized that the schedule for the pilot collector test may vary. Due to variability in the prevailing current conditions at the site (both seasonal and inter-annual variability due to the presence / absence of macro eddies, strength of oceanic processes etc.) some variability in the net migration of the sediment plume, depending on the ultimate schedule of the pilot test program, is to be expected. Figure 4.24 shows the average 2004 to 2018 monthly near-bed current roses based upon the HYCOM model data (HYCOM 2021) that are used as boundary conditions to the sediment plume model (Section 2.2). Based upon these current roses and consistent with the sediment plume results, a pilot collector test campaign undertaken during typical (i.e. average) January conditions is likely to see a north-westerly drift of the plume as documented in Section 3. Conversely, the same program occurring during June would likely see a net easterly plume drift, with a similar overall magnitude, but slightly higher spatial extent (in terms of area).

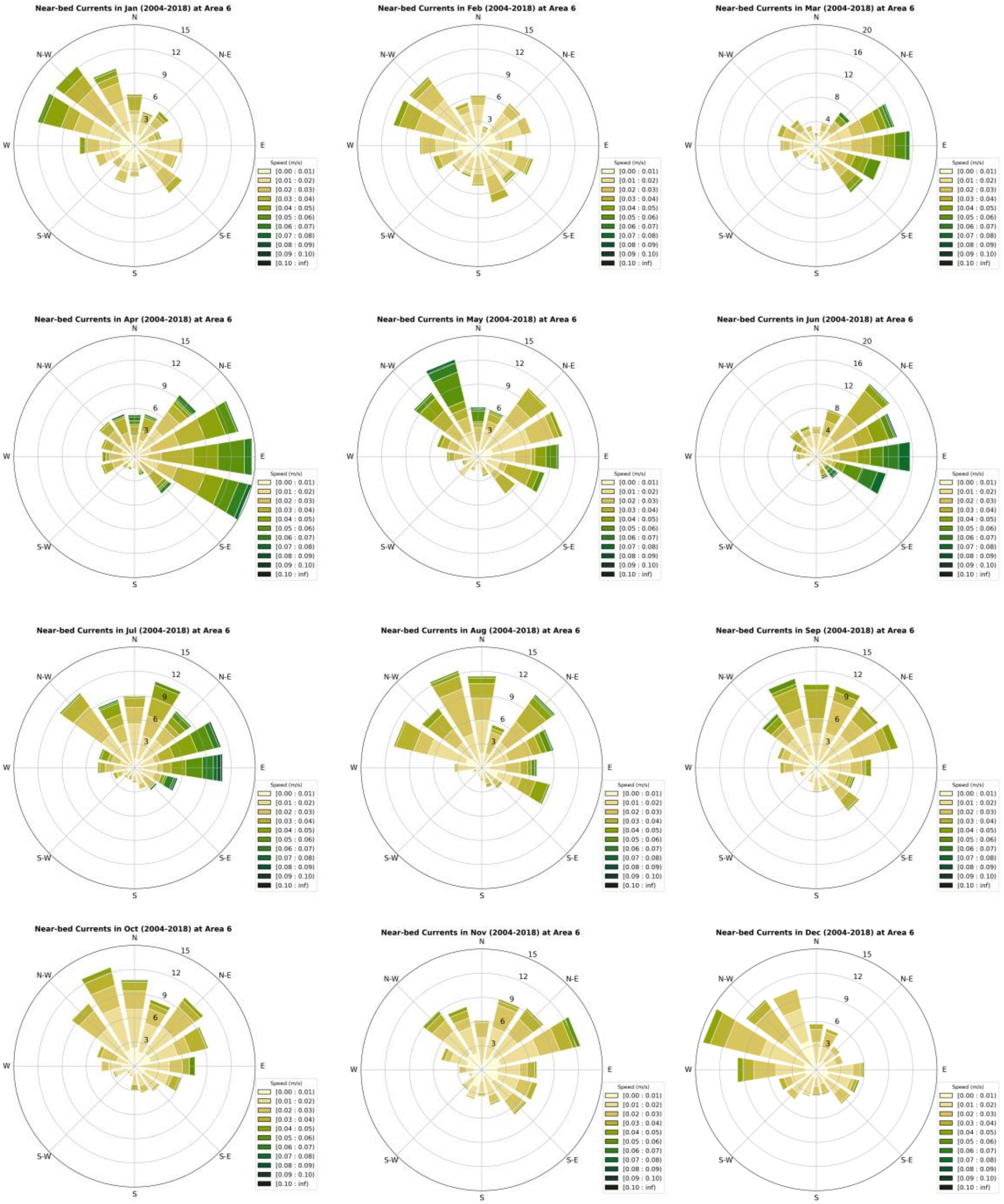

Figure 4.24 Seasonal variability in near bed current conditions (current flowing to) at the location of the long mooring in the NORI-D area based on HYCOM data 2004 to 2018 (HYCOM 2021)

4.4 Effect of Mid-water Column Discharge Depth

As indicated in the preceding sections, the sediment plume modelling has been based on a mid-water column discharge located at 1000m below the surface. This was the best information available at the time of simulation. Ultimately, design decisions may result in some minor (within a few 100m) adjustment to this discharge depth. Figure 4.25 presents the measured current conditions at approximately 1000m and 1200m below the surface from the NORI-D long mooring data available at the time of writing (CSA 2020). This indicates that, as expected, there is a slight decrease in current speed with depth, and a slight shift in the dominant current direction. It can thus be concluded that, while there will be some minor differences in the behaviour of the plume depending on discharge depth (slight change in spatial extent and slight change in dominant drift direction), these differences will not be significant from an overall plume impact perspective for mid-water column discharges falling within this depth range of 1000m to 1200m.

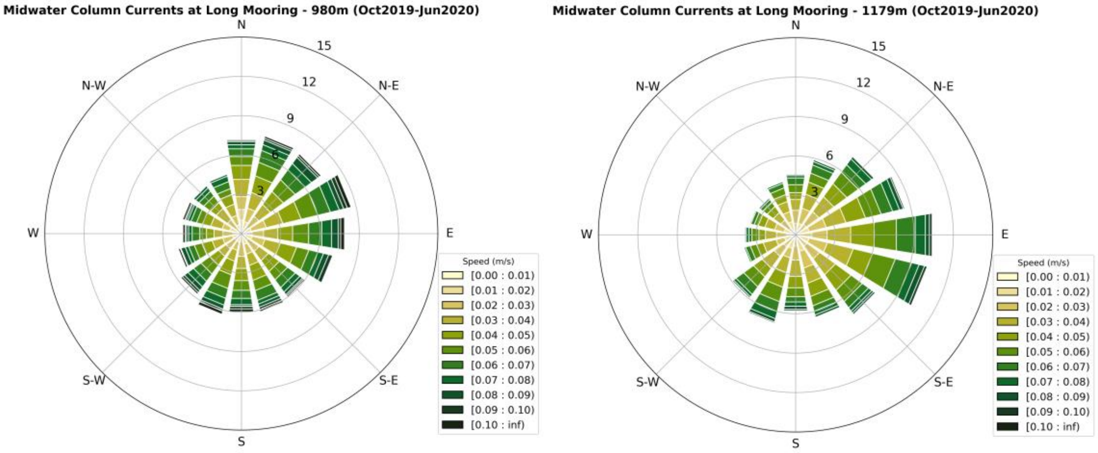

Figure 4.25 Measured current conditions at the NORI-D long mooring (current flowing to) at approximately 980m and 1179m (right) below the surface - 14 October 2019 to 26 June 2020

5 References

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Appendix A

Example Sediment Plume Time Series

Example Sediment Plume Time Series

The temporal transport, dispersion and settling of the plume is an important factor to consider in assessing the overall simulation duration and the duration adopted for determination of exceedance statistics. Figure A.1 provides a time series (every 6 hours) of instantaneous plume concentrations for PNCT operation STR2b from start of operation until the plume concentration has fallen below 0.02mg/l (2% of background see Appendix C). STR2b has an operational duration of 20.6hours. TSS generated from the operation is seen to fall below an incremental concentration of 0.02mg/l (5m above the bed) between 15 and 21 hours after the end of the STR2b operation. Adopting a limit of 10% of background (0.1mg/l) the concentration would have fallen below this limit between 9 and 15 hours after the end of the STR2b operation.

Overall the time series presented in Figure A.1 demonstrates that a simulation length of 11 days (Operation + 10 or 10.5 days depending on scenario) adopted for the assessment of the PNCT operation is adequate to allow suspended sediment concentrations to fall below the adopted threshold limit of 10% background (0.1mg/l) by a significant margin. Further presenting exceedance values 24 and 48 hours after completion of the PNCT operation is seen to be conservative (i.e. as concentration fall below the 0.1mg/l threshold 9 to 15 hours after the end of operations, such that exceedance levels will decline with time for any duration longer than 9 to 15 hours).

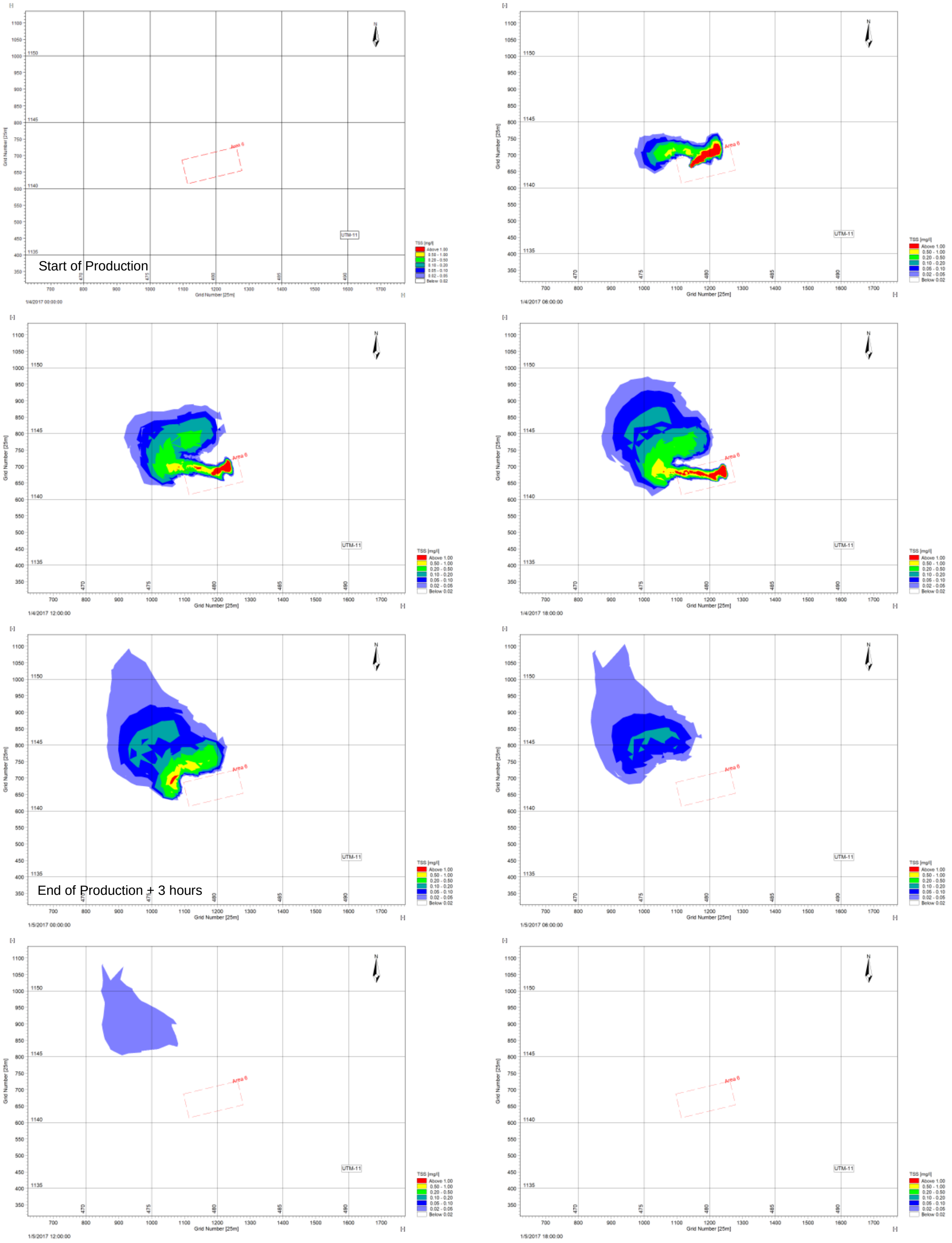


Table A.1 Time series of TSS concentration 5m above bed. STR2b. Time stamps every 6 hours from immediately prior to start of production to ca. 21 hours after end of production

Appendix B

Sensitivity to Settling Velocity

Sensitivity to Settling Velocity

Sediment settling velocity is an important parameter in determining the fate of the sediment plume released from the PNCT operations. The settling parameters utilized in the PNCT sediment plume modelling for the NORI-D area are based upon laboratory experiments undertaken by iSeaMC (2020) on seabed sediment samples collected from the NORI-D area, as described in Section 2.3.1 of the present report. It is relevant to compare this laboratory derived information for NORI-D sediments to literature values based on laboratory tests and field experiments of bed material from other sites in the CCZ. Further, it is relevant to assess the sensitivity of the present PNCT sediment plume model results to the settling characteristics within the range identified in literature.

Key reference material from the CCZ includes Muñoz Royo et al. (2021) that points towards a lower bound settling velocity of 0.1mm/s to 0.2mm/s and Purkiani et al (2021) that points towards D25 settling velocity of 0.3mm/s. This is to be compared to the present study that has a D25 settling velocity of 0.57mm/s.

Purkiani K et al (2021) refers to laboratory experiments undertaken in 2019 (Gillard et al (2019)). These laboratory tests adopt a procedure similar to that undertaken by iSeaMC on the NORI-D sediment. As test procedures between the two data sets are similar, it can be concluded that the primary differences in sediment settling characteristics between Gillard et al (2019) and the present study can largely be attributed to differences in the sediment characteristics (base size, minerology etc.).

Muñoz Royo et al. (2021) base their determination of settling characteristics on a single field experiment. Two factors are of note in this reference:

- The conclusion is drawn that, despite an 8g/l discharge concentration, flocculation did not occur. This is contrary to iSeaMC’s findings that indicate a flocculation factor in the order of 7 at these concentrations at the laboratory shear rates tested. The argumentation put forward by Muñoz Royo et al. is that the shear rate at the discharge is sufficiently high ($10s^{-1}$) to disaggregated flocs. In DHI’s opinion this is reasonable and this conclusion is embedded in the modelling approach in that sediment entering the far field domain is assumed to be disaggregated. However, the shear rate will decrease rapidly towards the limit of the active plume and concentrations will in, DHI’s opinion, remain sufficiently high to allow some flocculation to occur in the initial stages of the passive plume. Flocculation is therefore allowed in the passive plume based upon the prevailing concentrations and flocculation factors determined from the iSeaMC laboratory experiments.
- In terms of the resulting settling velocities the presented settling velocity information in Muñoz Royo et al. should be considered as only one possible interpretation of a single set of field measurements. Other interpretations of the same data set could yield settling velocities in the order of 0.4mm/s [See Muñoz Royo et al. 2021 Figure 5 Time 350min centre of mass drop relative to isopycnals of 10m rather than 5m quoted] and other factors could explain the relationship between tracer and sediment used by Muñoz Royo et al. to set down the settling velocity to a value in the order of 0.1mm/s. Further, in the absence of a mass balance (a fundamental requirements for reliable dredge plume monitoring), it could be argued that a portion of the plume mass with higher settling velocities is not captured due to the time delay between release and detection of the plume. The intention of these statements is not to imply that Muñoz Royo et al does not represent a potentially valid settling velocity for the deep-sea sediments in the general CCZ area, rather, it is important to recognize that higher settling velocities based upon

laboratory measurements, at the time of writing and until more detailed filed data is recovered from pilot test operations, equally valid interpretation of settling characteristics.

Given the uncertainty in settling velocity characteristics it is relevant to undertake sensitivity tests across the range of settling velocities discussed above, namely

- Present Study un-flocculated settling velocity 0.57mm/s
- Gillard et al 2019 un-flocculated settling velocity 0.3mm/s
- Muñoz Royo et al 2021 un-flocculated settling velocity 0.1mm/s

Results of the sensitivity test in terms of maximum plume concentration as a result of the midwater discharge for PNCT operation STR2b is shown in Figure B.1. At a threshold concentration of 0.1mg/l (10% of background) the differences between the present study and the maximum plume extent utilizing settling velocity from Muñoz Royo et al 2021 is found to be 37% per the area of affect presented below:

U-flocculated settling velocity 0.57mm/s	2.1km^2
Un-flocculated settling velocity 0.3mm/s	2.5km^2
Un-flocculated settling velocity 0.1mm/s	3.3km^2

At a lower threshold concentration of 0.02mg/l (2% of background), the difference between the minimum and maximum plume area is seen to increase to 47%.

In considering these sensitivity test results it is relevant to highlight that forcing an un-flocculated settling rate of 0.1mm/s results in very poor agreement between the resultant theoretical settling velocity curve and the iSeaMC laboratory data as seen in Figure B.2. Consequently, while the sensitivity tests confirm that, as expected, the un-flocculated settling rate has an effect on plume excursion, at the threshold rates relevant for the present assessment (10% of background) it is DHI's opinion that the laboratory data from the specific NORI-D sediments developed by iSeaMC provides the best settling characteristic data for the present PNCT sediment plume modelling assessment. Results from monitoring during the PNCT and additional laboratory experiments will allow an improved understanding and quantification of settling characteristics period to the sediment plume assessment of full scale production.

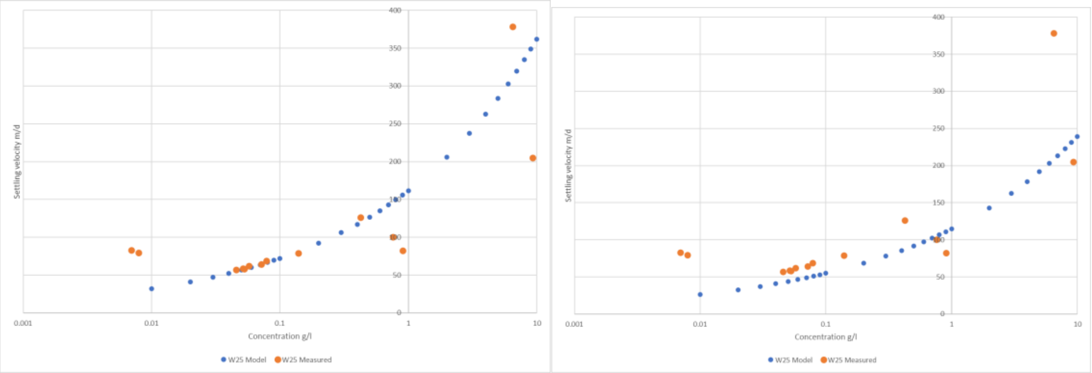
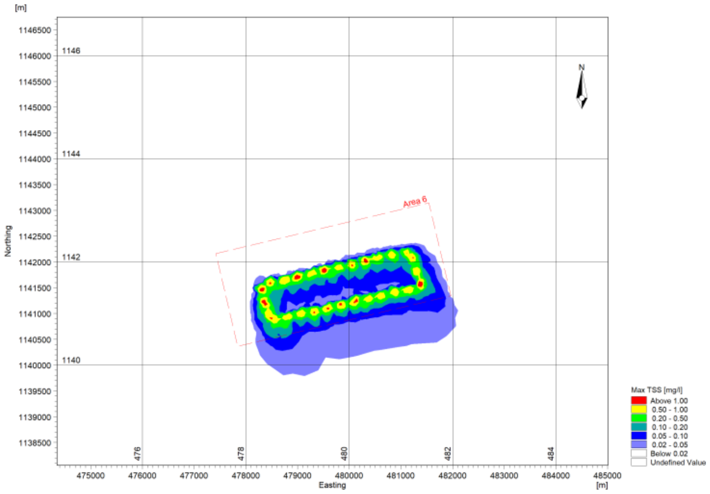
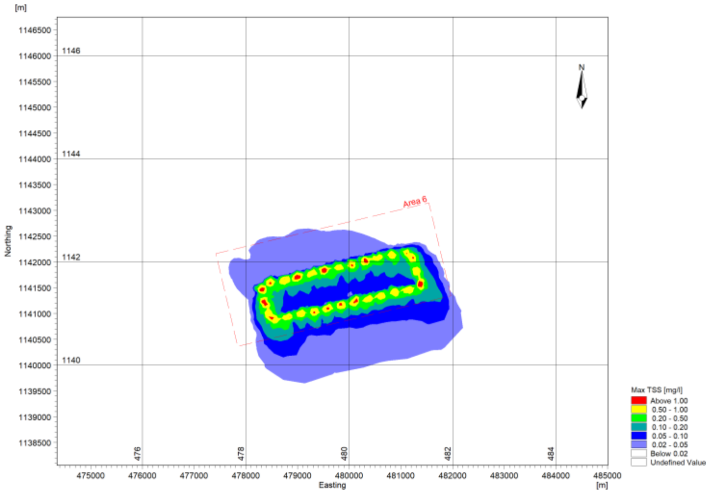


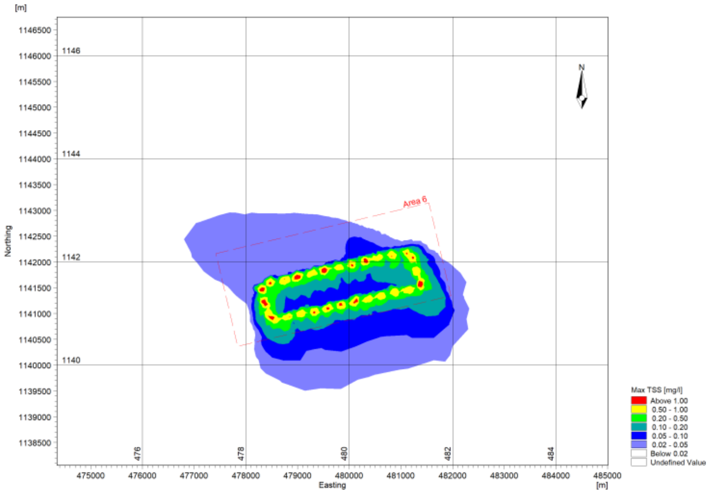
Figure B.2 Comparison of theoretical settling velocity curve with un-flocculated settling velocity of 0.57mm/s (left : absolute average error 15%) as used throughout the present study and 0.1mm/s (right : absolute average error 25%) against iSeaMC (2020) laboratory data



Un-flocculated settling velocity based upon iSeaMC 2020 laboratory data as adopted throughout the present study



Un-flocculated settling velocity based upon Gillard et al 2019 laboratory data



Un-flocculated settling velocity based upon Muñoz Royo et al 2021 interpretation of field experiment data

Figure B.1 Maximum mid water column plume concentration sensitivity to un-flocculated settling velocity

Appendix C

Background TSS and Sedimentation

Background TSS and Sedimentation

TSS, turbidity and sedimentation data from the NORI-D area has been used to establish background suspended sediment concentration and sedimentation in the PNCT area and thereby establish results presentation limits. Typically, in the absence of biologic system tolerance limits, sediment plume model result presentation threshold limits are set at 10% background data or one standard deviation of background, whichever is lower, with the argumentation that the biological system is adapted to variability at least in the order of one standard deviation from the mean. Consequently, an incremental affect below this limit should not have a significant consequence to the system, provided that the duration of the incremental effect is sufficiently short as to not influence the mean of the background. As the standard deviation in the available background data from the NORI-D area is relatively high, the results presentation threshold has been set at 10% of background.

Total Suspended Solids

The number of direct TSS measurements at the time of writing is limited. Data from the mid water column discharge (situated at 1000m) and near bed are presented in Table C.1. Nine of the 32 relevant samples are below detection limit. That detection limit is, however, relatively high at ca. 0.57mg/l. Depending on the approach taken to incorporate the below detection limit samples (either set the value to detection limit (non-conservative) or set to zero (conservative)) the mean background concentration at the mid water discharge ranges from 0.7 to 0.8mg/l and at the seabed from 1.0mg/l to 0.9mg/l.

Table C.1 TSS concentration measured in the proximity of the mid water discharge (1000m) and near bed

Depth	**TSS mg/l**			
	ND|001	**ND|002**	**ND|005**	**ND|006**
950 m	1	< 0.57	< 0.53	1.1
1150 m	1.3	< 0.57	0.6	< 0.57
1250 m	1.2	1	0.9	1.1
1500 m	1.8	0.7	0.6	< 0.57
B200m	0.7	1.1	1	< 0.57
B150m	1.5	1.1	< 0.57	1.5
B100m	0.9	2.3	< 0.59	< 0.57
B050m	1	0.7	< 0.56	1.1

While the data set is restricted at the time of writing, it is reasonable to conclude that the data that is available points towards a background concentration in the order of 1mg/l or slightly lower, with a relatively high standard deviation in the order of 0.4mg/l. Adopting a results presentation limit of 0.1mg/l (for short term effects from the PNCT operation) thus seems appropriate given the natural variability of several times this limit.

Turbidity

Near Bed turbidity data is available from October 2019 to June 2021 (Figure C.1 CSA 2021). Mean values are in the order of 0.17NTU across the 3 instruments, with a standard deviation of 0.13NTU. To date, no attempt has been made to carry out site specific calibration of the instrumentation against the specific TSS characteristics of the site (CSA 2021). However, literature calibration for fine clay material would indicate a NTU to TSS ratio somewhere in the order of 1:1 to 1:5. (DOER 2000) yielding a mean TSS in the order of 0.2 to 0.9mg/l and standard deviation of 0.1 to 0.6mg/l.

With the observed relatively high standard deviation in the Turbidity data, it is reasonable to conclude that the biological receptors are unlikely to be sensitive to incremental concentrations less than 0.1mg/l (i.e. less than 10% of background or one standard deviation of background depending on which calibration between NTU and TSS proves appropriate), which aligns with the Total Suspended Solids data presented above.

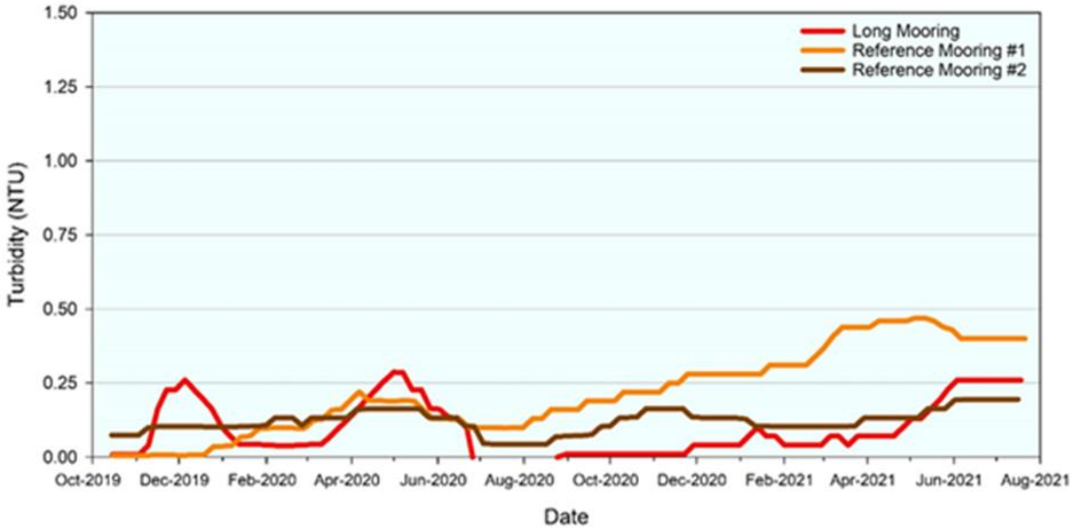


Figure C.1 Running median of near-seafloor turbidity values (NTU) in the NORI-D area (CSA 2021)

Sedimentation

77 valid sediment trap data sets are available from the near bed zone of the NORI-D area over the period October 2019 to June 202. Utilizing a deposition density of 180kg/m^3, for consistency with the model results, yields background sedimentation rates with mean of 0.08mm/year with a standard deviation of 0.09mm/year. The full data set is presented in Figure C.2. It is apparent from Figure C.2 that the sedimentation rate is characterised by persistent low sedimentation rates with a median in the order of 0.05mm/year, but with a number of high sedimentation events, with the highest event 5 standard deviations above the mean.

The measured mean background sedimentation rate from sediment traps form the NORI-D area of 0.08mm/year should be compared to literature values in the CCFZ (Volza et al. 2018) in the order of 0.2 and 1.15cm/k-year (0.002 to 0.011mm/year) based upon radioisotope analysis techniques. At face value the radioisotope analysis techniques indicate a natural sedimentation rate an order of magnitude lower than predicted from the sediment trap data. However, it is noted that the sampling presented in Volza et al 2018 commences from a core depth of 7.5cm and as such should not be considered representative of fresh deposits, rather deposits after several 1000 years of consolidation. Further, based upon the variability in the Turbidity data presented above, there is indication of re-suspension events in the NORI-D area. Consequently, although long-term sedimentation may be in the order of 0.1mm/year or lower, in DHI’s opinion, short term sedimentation and thereby adaptation of the biological system is most likely best described by the sediment trap data from the NORI-D area.

Based on the NORI-D sediment trap measurements, a plotting limit of 0.01mm has been adopted (i.e. 10% of the sediment trap short-term sedimentation background or equivalent order to the longer term consolidated sedimentation rate based upon radioisotope analysis), although given the level of variability in the sedimentation rate above the mean, it could certainly be argued that a plotting limit of 0.1mm (i.e. 1 standard deviation rounded up) may be more appropriate as, based upon the measurements the biological habitat is subjected to sedimentation rates several times background on an intermittent basis.

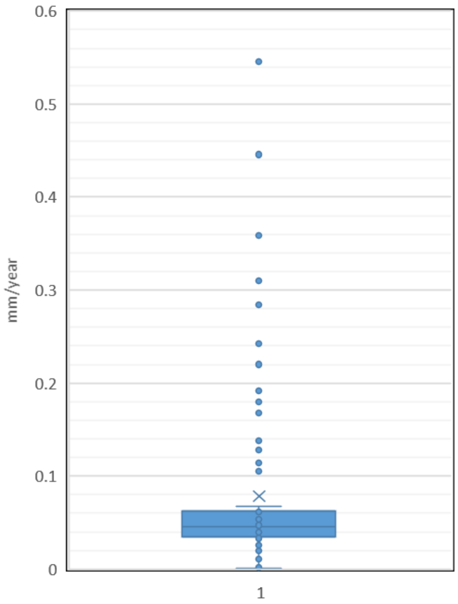


Figure C.2 Near bed sediment trap data from NORI-D area, October 2019 to June 2021 converted to sedimentation rate based on a density of 180kg/m^3

Appendix D

Sediment Plume Descriptors and Comparison of Plume Size to Literature

Sediment Plume Descriptors and Comparison of Plume Size to Literature

The characteristics of the sediment plume released from the PNCT operation varies in space and time as a result of, amongst other factors, transport, dispersion and settling processes. To assess the potential consequence of this plume it is necessary to describe this variability in a manner that best captures the potential consequence of the plume. As biological receptors respond to both magnitude and duration of exposure, it is normal practice for sediment plume assessment to present the results as a % exceedance above threshold limit. This recognizes the fact that biological receptors respond to both Magnitude and Duration of exposure. For example, a concentration 1mg/l above background for 1hr over the 259hrs of PNCT operations, will have a different consequence compared to 1mg/l above background for 48hrs over the PNCT operation.

Typical % exceedance of the 10% above background tolerance results for the mid water column discharge are shown in Figure D.1. As the % exceedence changes with depth below the intake it is typical to look at such information as a slice at a fixed depth. This shows an area of effect of approximately 2.5km^2 for a discharged mass of 259T.

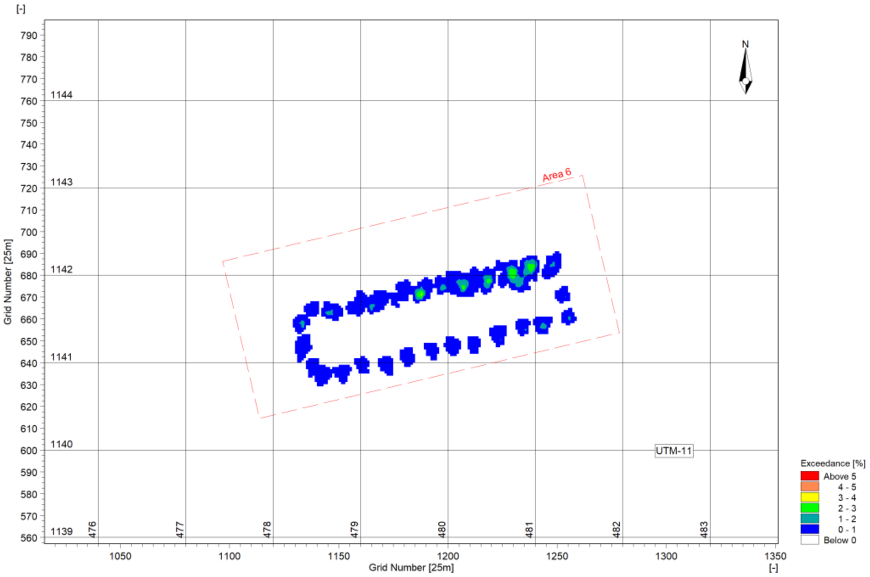


Figure D.1 Net exceedance percentage of 0.1mg/l at 50m below the mid-water column discharge location (or 1050m below the surface) for the cumulative PNCT operation from start of STR2a to 24hrs after completion of STR3b

Plotting maximum concentration in the plume (i.e. the single highest recorded value even if it is only present for 1hr in the (259+24hr period to be consistent with the duration of Figure D.1) throughout the plume depth increases the area of effect to 5km^2 (Figure D.2) This is however a poor representation of the consequence of the plume as there is no information of the persistence of these excess concentrations or indeed the amount of the water column effected.

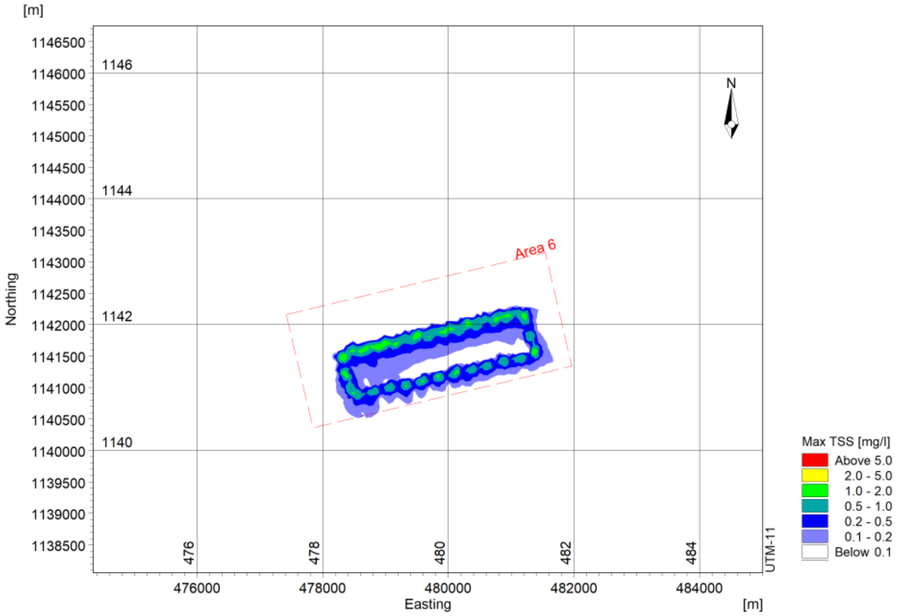


Figure D.2 Maximum excess plume concentration regardless of depth (plotted to a minimum of 10% of background) from the mid-water column discharge for the cumulative PNCT operation from start of STR2a to 24hrs after completion of STR3b.

Results presented in terms of Dilution Factors are also common in scientific literature. Muñoz Royo et al. 2021 quote plume results down to a dilution factor of 400,000 which, for the PNCT is approximately equivalent to a lower concentration limit of 0.02mg/l (a factor of 5 below background). Utilising a dilution factor of 400,000 is seen to increase the area of influence to approximately 16km^2. This is, however, presenting results to 2% of background which is a very low limit given the natural variability in background concentration is in the order of ±50% (See Appendix C).

In comparing plume dimensions from literature values presented as max concentrations or dilution factors to the % exceedance used for impact assessment purposes it is thus essential to compensate for the results presentation method. It is also essential to take into account differences in the amount of sediment released into the water column.

For example, the mid water plume presented by Muñoz Royo et al. 2021 generates an 11 days plume size of approximately 200km^2 at a 400,000 dilution level, However the mass released over that 11 days is approximately 15 times larger than that associated with the PNCT. While it is recognized that a linear relationship between amount of sediment released and plume size is an over-simplification, it is apparent that the plume from the NORI-D PNCT demonstrates a similar scale of effect when differences in sediment release and results presentation method are considered (i.e. 200km^2/15 = 13.3 km^2 to compensate for spill volume is similar to the 16km^2 PNCT results for the same 400,000 dilution limit)

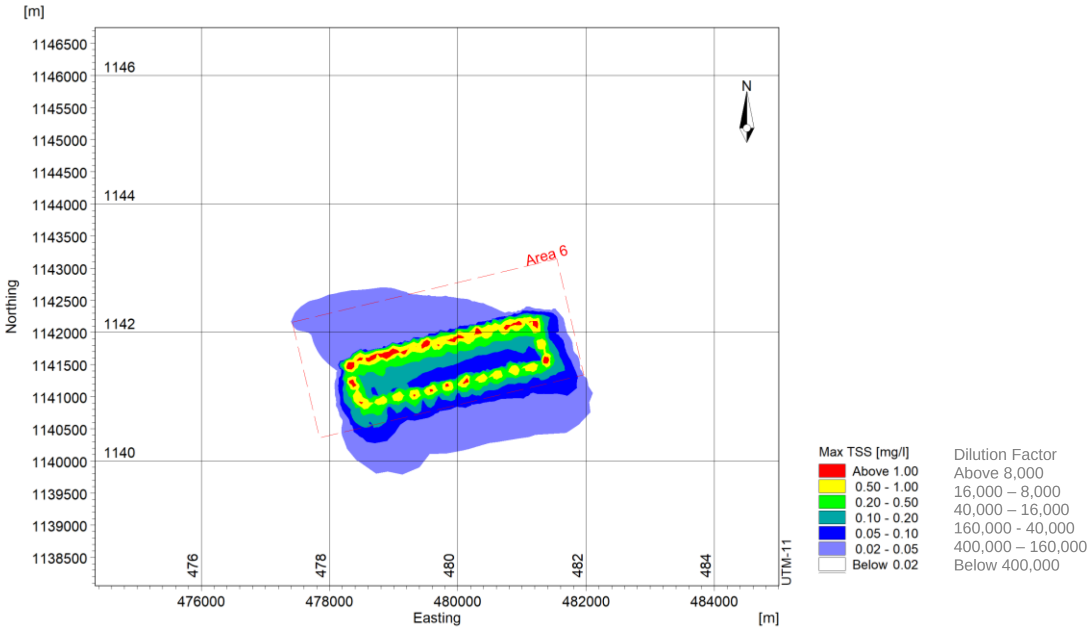


Figure D.2 Maximum excess plume concentration regardless of depth (plotted to a minimum to a dilution factor of 400,000 for consistency with Muñoz Royo et al. (2021)) from the mid-water column discharge for the cumulative PNCT operation from start of STR2a to 24hrs after completion of STR3b.

It is noted that the PNCT incorporates a moving source, which is absent in Muñoz Royo et al. 2021. This will further (correctly) reduce plume concentrations in the PCNT results compared to Muñoz Royo et al. 2021 stationary source. Further the current conditions anticipated in the NORI-D PNCT area during the season schedule for the PNCT are variable, not in a single dominant direction as used to determine the area of effect quoted above (Muñoz Royo et al. 2021 state that variable currents would results in a more compact plume). Consequently, the present NORI-D PNCT sediment plume results demonstrate a plume size that is most likely similar to that reported by Muñoz Royo et al. 2021 when all factors are equalized (released sediment mass, moving source and variable currents and results presentation method).