harley global

Date of Survey:	**14.03.2012**
Survey Method:	**RTK GNSS/VRS**
Coordinates:	**MGA 94 Zone 50**
Height:	**AHD**
Surveyor:	**MA**

Aurora environmental

Date of drilling: 24.01.12 - 27.01.12
Drilling Co: Cape Drilling
Drilling Method: Rotary Mud
Bore diameter: 50mm
Logged By: DB

** SWL Levls in Monitoring Data Sheets are taken to Top of Casing

							Drilling Notes				
HOLE ID	***EASTING***	***NORTHING***	***OWNER***	***NOTES***	**RL Casing**	**RL Ground**	**Upstream/Downstream**	**Screened Depth (BGS)**	**Top of Screen Depth (RL)**	**Geological unit (PB 2013)**	**Aquifer**
MB1s	354907.676	6261727.394	Monitoring Bore		118.02	117.44	Up	13.5-19.5	103.94	Mowen aquitard	Leederville
MB1d	354908.731	6261730.660	Monitoring Bore		117.84	117.31	Up	53.5-59.5	63.81	Mowen aquitard	Leederville
MB2	354548.716	6262504.803	Monitoring Bore		74.44	73.92	Up	13.5-19.5	60.42	Mowen aquitard	Leederville
MB3	353409.438	6262871.330	Monitoring Bore		47.88	47.36	Down	13.5-19.5	33.86	Mowen aquitard	Leederville
MB4	354475.979	6263105.529	Monitoring Bore		54.49	53.95	Up	13.5-19.5	40.45	Mowen aquitard	Leederville
MB5	353379.787	6263262.447	Monitoring Bore		40.67	40.09	Down	13.5-19.5	26.59	Mowen aquitard	Leederville
MB6s	354298.028	6263373.182	Monitoring Bore		45.79	45.23	Down	13.5-19.5	31.73	Superficial and Mowen aquitard	Superficial and Leederville
MB6d	354297.972	6263375.772	Monitoring Bore		45.69	45.19	Down	53.5-59.5	-8.31	Mowen aquitard	Leederville
MB7	355397.202	6263978.843	Monitoring Bore		53.61	53.03	Down	13.5-19.5	39.53	Superficial and Mowen aquitard	Superficial and Leederville

	YMB1S **AVERAGE**	**RANGE/MAX**	**YMB1D** **AVERAGE**	**RANGE/MAX**	**YMB2** **AVERAGE**	**RANGE/MAX**	**YMB3** **AVERAGE**	**RANGE/MAX**	**YMB4** **AVERAGE**	**RANGE/MAX**	**YMB5** **AVERAGE**	**RANGE/MAX**	**YMB6S** **AVERAGE**	**RANGE/MAX**	**YMB6D** **AVERAGE**	**RANGE/MAX**	**YMB7** **AVERAGE**	**RANGE/MAX**
SWL (m)	14.01666667	12.31-17.19	43.63	43.59-43.67	13.72		9.276	8.09-10.18	10.54	8.67-11.92	2.642	1.97-3.06	3.82	2.35-4.79	17.91	17.61-18.21	4.8025	2.68-5.92
pH	*4.366666667*	*4.17-4.59*	6.235	6.17-6.3	*4.86*	*4.86*	*5.504*	*5.24-5.63*	*5.112*	*4.45-5.86*	6.032	5.39-6.31	*4.89*	*4.36-5.52*	6.7	6.55-6.85	*5.731666667*	5.41-6.05
Temp ©	19.15	19.1-19.2	9.35	18.7	21	21	16.84	20.8-22.3	17.1	20.8-22.6	12.2	19.2-21.7	13.51666667	19.9-21.2	10	20	13.08333333	19.5-20.3
Cond (EC)	583.3333333	530-630	565	550-580	410	410	266	230-300	254	240-270	296	250-350	427.6333333	310-660	510	490-530	290	250-330
Salinity	293.3333333	260-320					130	110-140	128	120-140	146	120-170	265	200-310	255	240-270	141.6666667	120-160
Al (filtered)	1.113333333	2.9	0.163333333	0.49	0.025	0.05	0.03718	0.12	0.051	0.15	0.04692	0.17	0.168833333	0.59	0.362666667	0.018-0.59	0.083833333	0.13
Al(Total)	**7.51**	**22**	1.133333333	3.4	0.55	1.1	0.0756	0.21	0.1166	0.41	0.06156	0.23	0.201333333	0.62	1.06	0.36-2.2	0.274333333	1.1
As	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-
B	0	-	0	-	0	-	0		0		0		0		0		0	
Cd	0.00026	0.00026	0.00005	0.00015	<0.0001	-	0		0		0		0		0		<0.0001	-
Ca	0	-	0	-	<0.001	-	0.000038	0.00019	0.00013	0.00065	0.000048	-	0.000086	0.00043	0.001966667	0.0059	0	
Cr	0.002	0.002	<0.001	-	0	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-
Co	0	-	0	-	0	-	0		0		0		0		0		0	
Cu	0	-	0	-	0	-	0		0		0		0		0		0	
Fe (Filtered)	**0.672666667**	**1.9**	**8.333333333**	**25**	**2.619**	**5.2**	0.1302	**0.24**	0.1778	**0.46**	0.1126	**0.26**	**0.348333333**	**1.5**	**7.833333333**	**11**	**2.678333333**	**12**
Fe (Total)	**4.467666667**	**13**	**9.333333333**	**32**	**4.2**	**7.5**	0.1884	**0.37**	**0.279**	**0.9**	0.1275	**0.35**	**0.403**	**1.6**	**9.533333333**	**14**	**7.06**	**38**
Pb	0		0	-	0	-	0		0		0		0		0		0	
Mg	0.025666667	0.051	0.136666667	0.41	0.167	0.33	0.034	0.066	0.013	0.053	0.0067	0.014	0.029166667	0.04	0.233333333	0.36	0.1009	0.55
Mn	0	-	0	-	0	-	0		0		0		0		0		0	
Mercury	0	-	0	-	0	-	0		0		0		0		0		0	
Molybdenum	0	-	0	-	0	-	0		0		0		0		0		0	
Ni	0.005666667	0.012	0.000966667	0.0029	**0.3735**	**0.74**	0.00114	0.0017	0.00044	0.0011	0.00094	0.002	0.00355	0.0049	0.008966667	0.0096	0.00205	0.0073
Se	<0.001	<0.001	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-	<0.001	-
U	0	-	0	-	0	-	0		0		0		0		0		0	
Zn	0.018866667	0.047	0.005333333	0.025	0.003	0.006	0.00938	0.0095	0.0122	0.031	0.0169	0.032	0.015333333	0.031	0.07		0.028	0.073
Fl as F	0	-	0	-	0	-	0		0		0		0		0		0	
CaCO3	220	290	25.66666667	180	61	71	62.4	100	74.4	100	29.8	53	102	150	58.66666667	70	89.16666667	190
CaCO3	3.5	4	17.66666667	76	29.5	55	12.2	18	9.2	17	15.4	19	8.833333333	31	47.66666667	57	27.83333333	71
NH3-N	0.006	0.018	0.018333333	0.055	<0.01	-	0.0052	0.026	0.007	0.035	<0.010	-	0.012666667	0.04	0.396666667	0.95	0.005666667	0.019
Cl	151.6666667	170	37.66666667	140	100	100	54.8	60	59.4	80	42.8	60	124.3333333	150	100	130	71.66666667	120
EC	560	580	173.3333333	580	425	480	264	290	274	290	284	320	480	540	443.3333333	530	323.3333333	590
O2	4.63	5.1	2.256666667	6.77	5.5	5.6	4.116	5.5	4.238	5.65	5.782	9.5	5.525	8.6	4.64	5.1	5.165	7.8
P	<0.005	-	<0.005	-	0.145	0.29	<0.005	-	<0.005	-	<0.005	-	<0.005	-	<0.005	-	0.000833333	0.005
pH Lab	4.633333333	4.8	2.1	6.3	5.7	6.3	5.68	5.8	5.4	5.8	6.06	6.2	5.15	6	6.333333333	6.5	5.866666667	6
Sulphate	12.66666667	14	3	14	7.5	9	11.2	14	8.2	13	12.2	13	12	14	8	11	10.33333333	18
TDS	290	320	100	320	215	250	138	140	134	150	160	180	248.3333333	300	220	270	178.3333333	360
N	4.483333333	**12**	0.633333333	1.9	2.665	5	2.9	**5.1**	4.46	**12**	**9.46**	**9.7**	2.033333333	3.6	2.466666667	3.6	0.74	1.4
Phos	**0.096666667**	**0.29**	0.019666667	0.063	0.445	0.77	<0.005	0.03	0.007	0.035	0.0024	0.012	0.006166667	0.022	**0.205**	**0.3**	0.021333333	**0.1**

Exceed long-term irrigation criteria (ANZECC & ARMCANZ 2000)

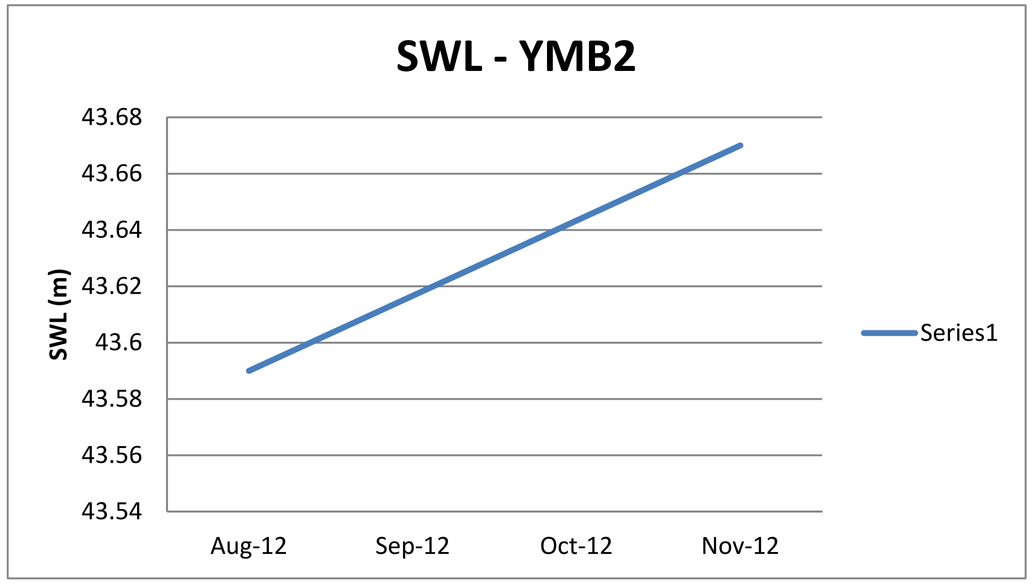
Exceed 95% trigger for freshwater (ANZECC & ARMCANZ 2000)

Metals and nutrients in mg/L

Salinity in mg/L

Conductivity in uS/cm

					Background Quality	
YMB1		**May-12**	**Aug-12**	**Nov-12**	Average	Range/Maximum
Date		29/05/2012	13/08/2012	29/10/2012		
Depth of bore		60.70	60.70	60.70		
SWL (m)			43.59	43.67	43.63	43.59-43.67
m AHD					0	
Purge				204	102	
pH			6.17	6.3	6.235	6.17-6.3
Temp				18.7	9.35	18.7
Cond (EC)			550	580	565	550-580
Salinity						
TTA			280	290	285	280-290
Comments					0	
Al (filtered)		0.04	0.49	0.15	0.163333	0.49
Al(Total)		0.11	3.4	0.38	1.133333	3.4
As		<0.001	<0.001	<0.001	<0.001	-
B					0	-
Cd		<0.0001	0.00015	<0.0001	0.00005	0.00015
Ca					0	-
Cr		<<0.001	<0.001	<0.0012	<0.001	-
Co					0	-
Cu					0	-
Fe (Filtered)		0.049	25	19	8.333333	25
Fe (Total)		0.32	28	32	9.333333	32
Pb					0	-
Mg		0.051	0.41	0.33	0.136667	0.41
Mn					0	-
Mercury					0	-
Molybdenum					0	-
Ni		0.002	0.0029	0.0022	0.000967	0.0029
Se		<0.001	<0.001	<0.001	<0.001	-
U					0	-
Zn		0.0036	0.016	0.025	0.005333	0.025
Fl as F					0	-
CaCO3		180	77	150	25.66667	180
CaCO3		4	53	76	17.66667	76
NH3-N		<0.010	<0.085	0.055	0.018333	0.055
Cl		140	113	130	37.66667	140
EC		560	520	580	173.3333	580
O2		5.1	6.77	4.8	2.256667	6.77
P		<0.005	<0.005	<0.005	<0.005	-
pH Lab		4.8	6.3	6.2	2.1	6.3
Sulphate		14	9	11	3	14
TDS		270	300	320	100	320
N		1.3	1.9	0.43	0.633333	1.9
Phos		<0.005	0.059	0.063	0.019667	0.063



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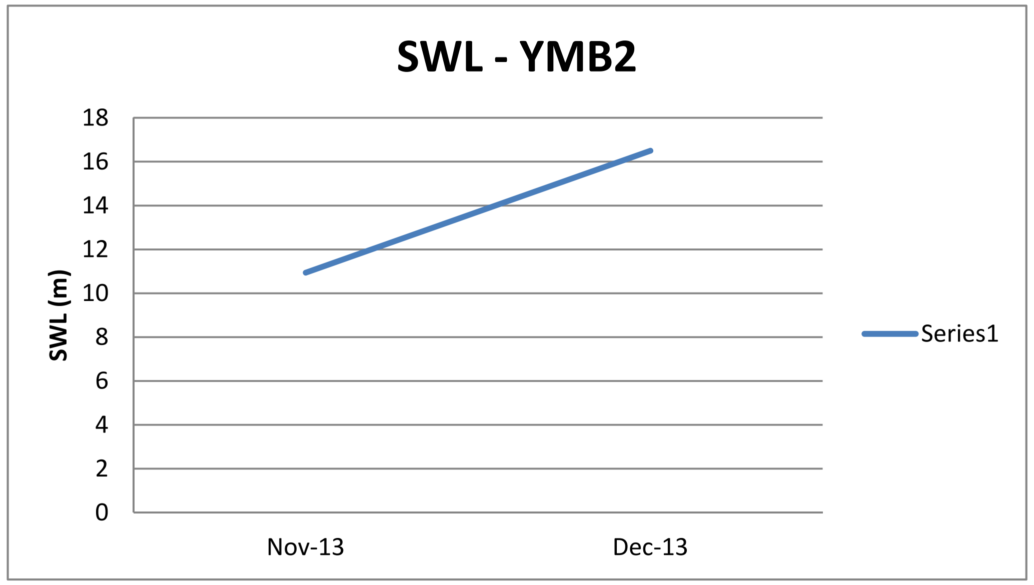
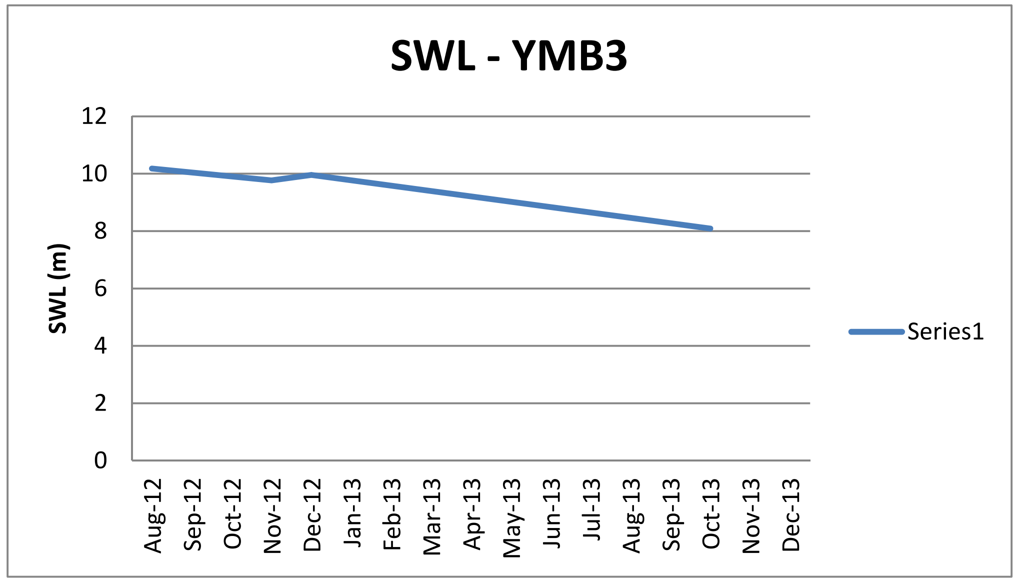
					Background Quality	
					Average	Range/Maximum
YMB2		**May-12**	**Nov-13**	**Dec-13**		
Date		29/05/2012	**5/11/2013**	**3/12/2013**		
Depth of bore			18.05	18.05		
SWL (m)			10.94	16.5	13.72	
m AHD					0	
Purge			20L			
pH			4.86		4.86	4.86
Temp			21		21	21
Cond (EC)			410		410	410
Salinity						
TTA			200		200	200
Comments				Dry		
Al (filtered)		<0.005	0.05		0.025	0.05
Al(Total)		0.12	1.1		0.55	1.1
As		<0.001	<0.001		<0.001	-
B					0	-
Cd		<0.0001	<0.0001		<0.0001	-
Ca		<0.001	<0.001		<0.001	-
Cr					0	-
Co					0	-
Cu					0	-
Fe (Filtered)		5.2	0.038		2.619	5.2
Fe (Total)		7.5	0.9		4.2	7.5
Pb					0	-
Mg		0.33	0.004		0.167	0.33
Mn					0	-
Mercury					0	-
Molybdenum					0	-
Ni		0.007	0.74		0.3735	0.74
Se		<0.001	<0.001		<0.001	-
U					0	-
Zn		<0.001	0.006		0.003	0.006
Fl as F					0	-
CaCO3		71	51		61	71
CaCO3		55	4		29.5	55
NH3-N		<0.010	<0.010		<0.01	-
Cl		100	100		100	100
EC		480	370		425	480
O2		5.6	5.4		5.5	5.6
P		<0.005	0.29		0.145	0.29
pH Lab		6.3	5.1		5.7	6.3
Sulphate		9	6		7.5	9
TDS		250	180		215	250
N		0.33	5		2.665	5
Phos		0.12	0.77		0.445	0.77

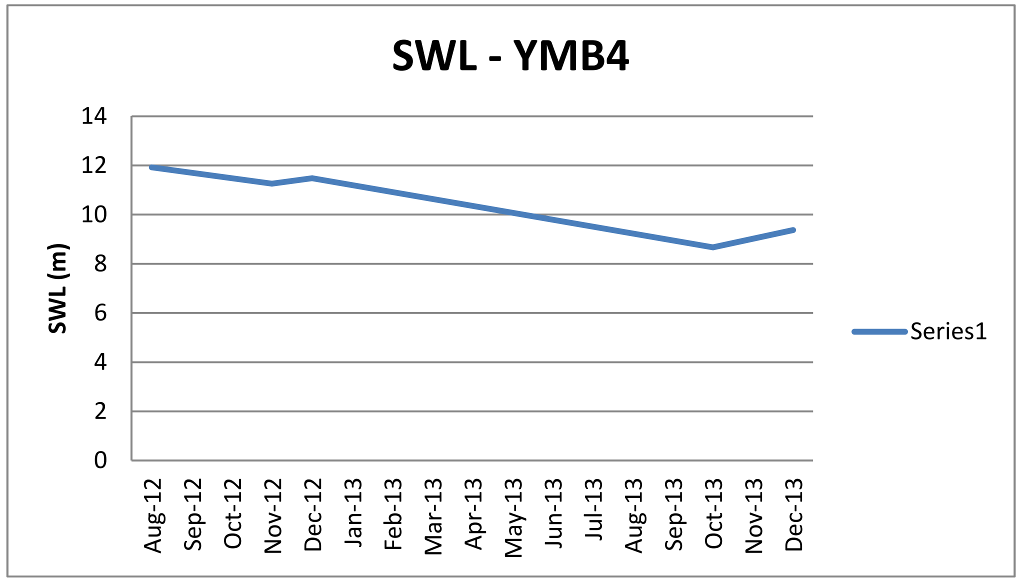
🟩 Not in data provided by Doral



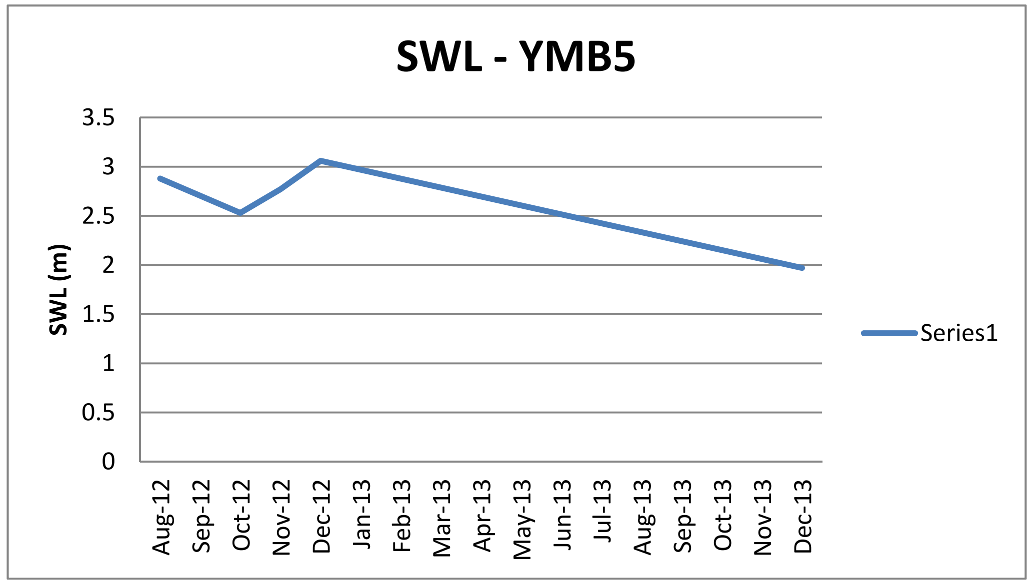
									Background Quality	
									Average	Range/Maximum
YMB3		**May-12**	**Aug-12**	**Nov-12**	**Dec-12**	**Oct-13**	**Nov-13**	**Dec-13**		
Date		29/05/2012	13/08/2012	29/10/2012	10/12/2012	**24/10/2013**		**3/12/2013**		
Depth of bore		20.78	20.78	20.78	20.78	20.78	20.78	20.78		
SWL (m)			10.18	9.77	9.96	8.09		8.38	9.276	8.09-10.18
m AHD									0	
Purge			40	132	129	152		149	120.4	
pH			5.55	5.76	5.63	5.34		5.24	5.504	5.24-5.63
Temp				21.3	22.3	20.8		19.8	16.84	20.8-22.3
Cond (EC)			230	290	240	270		300	266	230-300
Salinity			110	140	120	130		150	130	110-140
TTA										
Comments										
Al (filtered)		0.039	0.12	0.013	0.0079	0.006			0.03718	0.12
Al(Total)		0.21	0.12	0.016	0.024	0.008			0.0756	0.21
As		<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	-
B									0	
Cd									0	
Ca		<0.0001	0.00019	<0.0001	<0.0001	<0.0001			0.000038	0.00019
Cr		<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	-
Co									0	
Cu									0	
Fe (Filtered)		0.24	0.21	0.18	0.011	0.010			0.1302	0.24
Fe (Total)		0.37	0.28	0.22	0.021	0.051			0.1884	0.37
Pb									0	
Mg		<0.001	0.066	0.028	0.059	0.017			0.034	0.066
Mn									0	
Mercury									0	
Molybdenum									0	
Ni		<0.001	0.0017	0.0014	0.0016	0.001			0.00114	0.0017
Se		<0.001	<0.001	<0.001	<0.001	<0.001			<0.001	-
U									0	
Zn		0.007	0.019	0.0095	0.0064	0.005			0.00938	0.0095
Fl as F									0	
CaCO3		100	58	43	74	37			62.4	100
CaCO3		18	11	11	11	10			12.2	18
NH3-N		<0.010	0.026	<0.010	<0.010	<0.010			0.0052	0.026
Cl		50	54	60	60	50			54.8	60
EC		270	250	290	260	250			264	290
O2		5.5	5.44	3.2	2.84	3.6			4.116	5.5
P		<0.005	<0.005	<0.005	<0.005	<0.005			<0.005	-
pH Lab		5.6	5.7	5.8	5.6	5.7			5.68	5.8
Sulphate		10	8	13	11	14			11.2	14
TDS		140	130	140	140	140			138	140
N		3.2	1.2	2.8	2.2	5.1			2.9	5.1
Phos		0.009	0.030	<0.005	<0.005	<0.005			<0.005	0.03



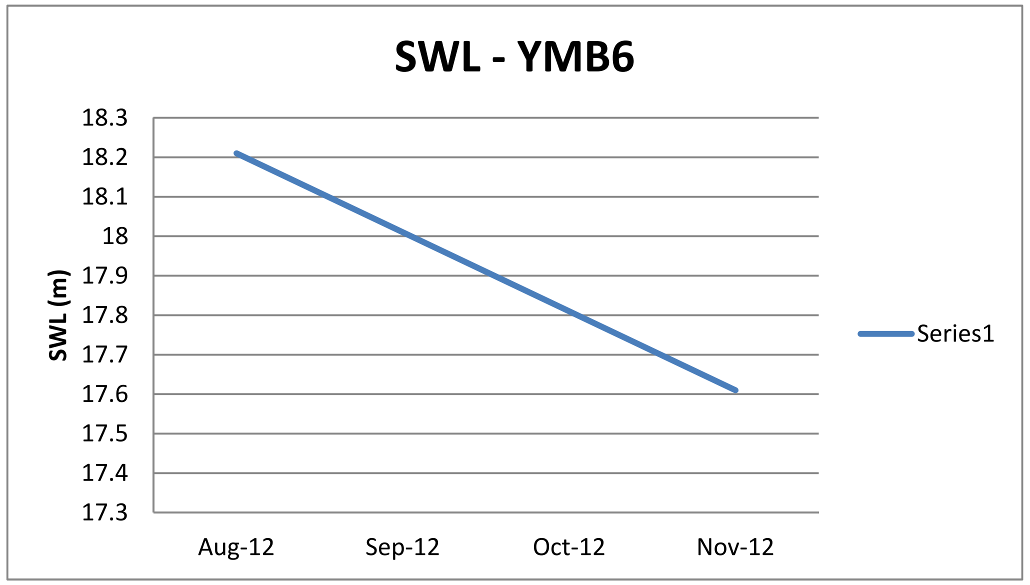
								Background Quality	
								Average	Range/Maximum
YMB4		**May-12**	**Aug-12**	**Nov-12**	**Dec-12**	**Oct-13**	**Dec-13**		
Date		29/05/2012	13/08/2012	29/10/2012	10/12/2012	**24/10/2013**	**3/12/2013**		
Depth of bore		20.55	20.55	20.55	20.55	20.55	20.55		
SWL (m)			11.92	11.26	11.48	8.67	9.37	10.54	8.67-11.92
m AHD								0	
Purge			40	111	108	143	134	107.2	
pH			5.86	5.22	5.26	4.77	4.45	5.112	4.45-5.86
Temp				21.1	22.6	21	20.8	17.1	20.8-22.6
Cond (EC)			250	270	270	240	240	254	240-270
Salinity			120	140	140	120	120	128	120-140
TTA								0	
Comments								0	
Al (filtered)		0.005	0.15	0.055	0.024	0.021		0.051	0.15
Al(Total)		0.025	0.41	0.097	0.029	0.022		0.1166	0.41
As		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
B								0	
Cd								0	
Ca		<0.0001	0.00065	<0.0001	<0.0001	<0.0001		0.00013	0.00065
Cr		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
Co								0	
Cu								0	
Fe (Filtered)		0.25	0.46	0.12	0.046	0.013		0.1778	0.46
Fe (Total)		0.25	0.9	0.15	0.055	0.04		0.279	0.9
Pb								0	
Mg		0.053	0.007	0.0021	0.0029	<0.001		0.013	0.053
Mn								0	
Mercury								0	
Molybdenum								0	
Ni		0.0011	0.0011	<0.001	<0.001	<0.001		0.00044	0.0011
Se		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
U								0	
Zn		0.0048	0.031	0.017	0.0062	0.002		0.0122	0.031
Fl as F								0	
CaCO3		65	69	71	100	67		74.4	100
CaCO3		12	17	7	5	5		9.2	17
NH3-N		<0.010	0.035	<0.010	<0.010	<0.010		0.007	0.035
Cl		60	57	70	80	30		59.4	80
EC		290	290	280	280	230		274	290
O2		4.9	5.65	3.8	3.14	3.7		4.238	5.65
P		<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	-
pH Lab		5.6	5.8	5.3	5.1	5.2		5.4	5.8
Sulphate		13	6	7	7	8		8.2	13
TDS		130	140	130	150	120		134	150
N		1.6	2.7	3.2	2.8	12		4.46	12
Phos		<0.005	0.035	<0.005	<0.005	<0.005		0.007	0.035



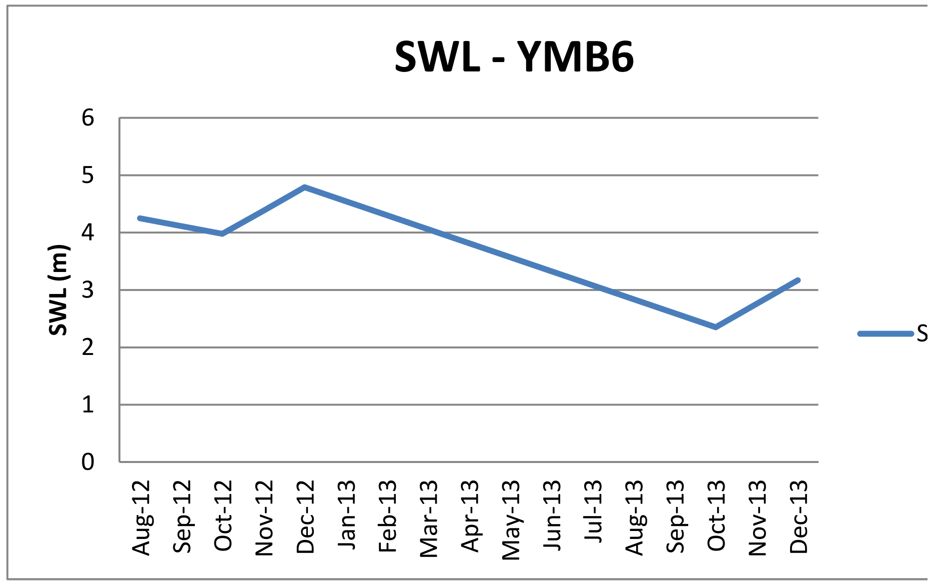
								Background Quality	
								Average	Range/Maximum
YMB5		**May-12**	**Aug-12**	**Oct-12**	**Nov-12**	**Dec-12**	**Dec-13**		
Date		29/05/2012	14/08/2012	1/10/2012	29/10/2012	10/12/2012	**3/12/2013**		
Depth of bore		21.38	21.38	21.38	21.38	21.38	21.38		
SWL (m)			2.88	2.53	2.77	3.06	1.97	2.642	1.97-3.06
m AHD								0	
Purge			40	226.2	223	219	233	188.24	
pH			6.31	6.05	6.29	6.12	5.39	6.032	5.39-6.31
Temp					20.1	21.7	19.2	12.2	19.2-21.7
Cond (EC)			250	280	320	280	350	296	250-350
Salinity			120	140	160	140	170	146	120-170
TTA								0	
Comments								0	
Al (filtered)		0.014	0.17	0.031	0.012	0.0076		0.04692	0.17
Al(Total)		0.023	0.23	0.033	0.012	0.0098		0.06156	0.23
As		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
B								0	
Cd								0	
Ca		<0.0001	0.00024	<0.0001	<0.0001	<0.0001		0.000048	-
Cr		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
Co								0	
Cu								0	
Fe (Filtered)		0.25	0.26	0.029	0.024	<0.005		0.1126	0.26
Fe (Total)		0.25	0.35	0.0095	0.028	<0.005		0.1275	0.35
Pb								0	
Mg		0.014	0.0094	0.0055	0.0027	0.0019		0.0067	0.014
Mn								0	
Mercury								0	
Molybdenum								0	
Ni		0.001	0.0017	0.002	<0.001	<0.001		0.00094	0.002
Se		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
U								0	
Zn		0.013	0.025	0.032	0.0054	0.0091		0.0169	0.032
Fl as F								0	
CaCO3		53	15	20	29	32		29.8	53
CaCO3		13	12	14	19	19		15.4	19
NH3-N		<0.010	<0.010	<0.010	<0.010	<0.010		<0.010	-
Cl		40	34	40	60	40		42.8	60
EC		280	260	260	320	300		284	320
O2		4.7	7.99	9.5	3.6	3.12		5.782	9.5
P		<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	-
pH Lab		5.7	6.2	6.2	6.2	6		6.06	6.2
Sulphate		12	12	12	13	12		12.2	13
TDS		140	150	170	160	180		160	180
N		7.2	9.7	9.5	7.9	13		9.46	9.7
Phos		<0.005	0.012	<0.005	<0.005	<0.005		0.0024	0.012



YMB6		May-12	Aug-12	Nov-12	Background Quality Average	Range/Maximum
Date		29/05/2012	13/08/2012	29/10/2012		
Depth of bore		63.22	63.22	63.22		
SWL (m)			18.21	17.61	17.91	17.61-18.21
m AHD					0	
Purge			40	547	293.5	
pH			6.85	6.55	6.7	6.55-6.85
Temp				20	10	20
Cond (EC)			490	530	510	490-530
Salinity			240	270	255	240-270
TTA					0	
Comments					0	
Al (filtered)		0.59	0.48	0.018	0.362666667	0.018-0.59
Al(Total)		0.62	2.2	0.36	1.06	0.36-2.2
As		<0.001	<0.001	<0.001	<0.001	-
B					0	
Cd					0	
Ca		<0.0001	0.0059	<0.0001	0.001966667	0.0059
Cr		<0.001	<0.001	<0.001	<0.001	-
Co					0	
Cu					0	
Fe (Filtered)		1.5	11	11	7.833333333	11
Fe (Total)		1.6	14	13	9.533333333	14
Pb					0	
Mg		0.01	0.33	0.36	0.233333333	0.36
Mn					0	
Mercury					0	
Molybdenum					0	
Ni		0.0013	0.016	0.0096	0.008966667	0.0096
Se		<0.001	<0.001	<0.001	<0.001	-
U					0	
Zn		0.017	0.17	0.023	0.07	
Fl as F					0	
CaCO3		70	56	50	58.66666667	70
CaCO3		31	57	55	47.66666667	57
NH3-N		0.04	0.20	0.95	0.396666667	0.95
Cl		60	110	130	100	130
EC		300	500	530	443.3333333	530
O2		5.1	4.92	3.9	4.64	5.1
P		<0.005	<0.005	<0.015	<0.005	-
pH Lab		6	6.5	6.5	6.333333333	6.5
Sulphate		11	6	7	8	11
TDS		130	260	270	220	270
N		3.6	1.5	2.3	2.466666667	3.6
Phos		0.015	0.3	0.3	0.205	0.3

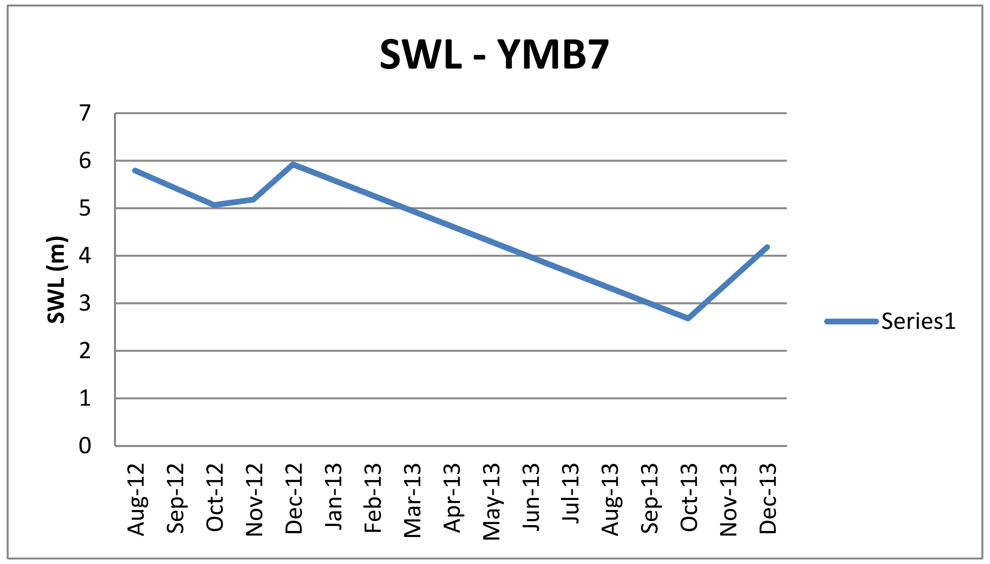


									Background Quality	
									Average	Range/Maximum
YMB6		**May-12**	**Aug-12**	**Oct-12**	**Nov-12**	**Dec-12**	**Oct-13**	**Dec-13**		
Date		29/05/2012	13/08/2012	1/10/2012	29/10/2012	10/12/2012	**24/10/2013**	**3/12/2013**		
Depth of bore		20.70	20.70	20.70	20.70	20.70	20.70	20.70		
SWL (m)			4.25	3.98	4.38	4.79	2.35	3.17	3.82	2.35-4.79
m AHD									0	
Purge			40	200.64	196	190	220	210	176.1067	
pH			5.52	4.93	4.88	5.11	4.36	4.54	4.89	4.36-5.52
Temp					21.2	20	19.9	20	13.51667	19.9-21.2
Cond (EC)			460	660	550	310	5.8	580	427.6333	310-660
Salinity			230	310	270	200	290	290	265	200-310
TTA									0	
Comments									0	
Al (filtered)		0.59	0.2	0.07	0.049	0.051	0.053		0.168833	0.59
Al(Total)		0.62	0.35	0.083	0.052	0.048	0.055		0.201333	0.62
As		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
B									0	
Cd									0	
Ca		<0.0001	0.00043	<0.0001	<0.0001	<0.0001	<0.0001		0.000086	0.00043
Cr		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
Co									0	
Cu									0	
Fe (Filtered)		1.5	0.32	0.13	0.085	0.045	0.01		0.348333	1.5
Fe (Total)		1.6	0.61	0.036	0.098	0.045	0.029		0.403	1.6
Pb									0	
Mg		0.01	0.031	0.04	0.038	0.033	0.023		0.029167	0.04
Mn									0	
Mercury									0	
Molybdenum									0	
Ni		0.0013	0.0034	0.0049	0.0034	0.0043	0.004		0.00355	0.0049
Se		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
U									0	
Zn		0.017	0.031	0.014	0.014	0.01	0.006		0.015333	0.031
Fl as F									0	
CaCO3		70	70	100	92	150	130		102	150
CaCO3		31	7	5	4	3	3		8.833333	31
NH3-N		0.04	0.036	<0.010	<0.010	<0.010	<0.010		0.012667	0.04
Cl		60	116	140	140	140	150		124.3333	150
EC		300	480	520	530	510	540		480	540
O2		5.1	6.44	8.6	6.4	3.41	3.2		5.525	8.6
P		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	-
pH Lab		6	5.3	5.1	4.9	4.8	4.8		5.15	6
Sulphate		11	11	12	14	11	13		12	14
TDS		130	240	300	270	280	270		248.3333	300
N		3.6	2	1.6	1.7	1.7	1.6		2.033333	3.6
Phos		0.015	0.022	<0.005	<0.005	<0.005	<0.005		0.006167	0.022




Series1

YMB7		Jun-12	Aug-12	Oct-12	Nov-12	Dec-12	Oct-13	Dec-13	Background Quality Average	Range/Maximum
Date			13/08/2012	1/10/2012	29/10/2012	10/12/2012	**24/10/2013**	**3/12/2013**		
Depth of bore		18.71	18.71	18.71	18.71	18.71	18.71	18.71		
SWL (m)			5.79	5.065	5.18	5.92	2.68	4.18	4.8025	2.68-5.92
m AHD									0	
Purge			40	156.42	162	153	192	174	146.2366667	
pH			6.05	5.85	5.82	5.76	5.41	5.5	5.731666667	5.41-6.05
Temp					19.8	20.3	19.5	18.9	13.08333333	19.5-20.3
Cond (EC)			250	330	250	270	380	260	290	250-330
Salinity			120	160	120	130	190	130	141.6666667	120-160
TTA									0	
Comments									0	
Al (filtered)		0.014	0.12	0.12	0.13	0.11	0.009		0.083833333	0.13
Al(Total)		1.1	0.12	0.16	0.11	0.14	0.016		0.274333333	1.1
As		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
B									0	
Cd		0.00019	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	-
Ca									0	
Cr		<0.001	<0.001	<0.001	<0.001	0.0011	<0.001		<0.001	-
Co									0	
Cu									0	
Fe (Filtered)		12	0.27	0.45	1.5	0.75	1.1		2.678333333	12
Fe (Total)		38	0.3	0.16	1.2	1.3	1.4		7.06	38
Pb									0	
Mg		0.55	0.0079	0.0088	0.023	0.0097	0.006		0.1009	0.55
Mn									0	
Mercury									0	
Molybdenum									0	
Ni		0.0073	<0.001	0.0015	0.002	0.0015	<0.001		0.00205	0.0073
Se		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	-
U									0	
Zn		0.073	0.016	0.034	0.023	0.018	0.004		0.028	0.073
Fl as F									0	
CaCO3		190	42	61	73	79	90		89.16666667	190
CaCO3		71	18	17	22	22	17		27.83333333	71
NH3-N		0.015	0.019	<0.010	<0.010	<0.010	<0.010		0.005666667	0.019
Cl		120	60	60	60	60	70		71.66666667	120
EC		590	260	260	280	270	280		323.3333333	590
O2		7.8	6.42	5.9	3.4	4.67	2.8		5.165	7.8
P		<0.005	<0.005	<0.005	0.005	<0.005	<0.005		0.000833333	0.005
pH Lab		6	6	5.9	5.8	5.8	5.7		5.866666667	6
Sulphate		18	6	8	11	9	10		10.33333333	18
TDS		360	130	140	150	150	140		178.3333333	360
N		0.89	0.67	0.25	1.4	1.1	0.13		0.74	1.4
Phos		0.1	0.022	<0.005	0.006	<0.005	<0.005		0.021333333	0.1



YMB8		May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
Date																					
Depth of bore																					
SWL (m)																					
m AHD																					
Purge																					
pH																					
Temp																					
Cond (EC)																					
TTA																					
Comments																					
Al (filtered)			0.33																		
Al(Total)			1.1																		
As			<0.001																		
B																					
Cd			<0.0001																		
Ca																					
Cr			<0.001																		
Co																					
Cu																					
Fe (Filtered)			0.066																		
Fe (Total)			4.4																		
Pb																					
Mg			0.038																		
Mn																					
Mercury																					
Molybdenum																					
Ni			0.0087																		
Se			<0.001																		
U																					
Zn			0.019																		
Fl as F																					
CaCO3			210																		
CaCO3			<1																		
NH3-N			<0.010																		
Cl			140																		
EC			570																		
O2			7.3																		
P			<0.005																		
pH Lab			4.5																		
Sulphate			15																		
TDS			290																		
N			0.85																		
Phos			0.039																		

Doral Mineral Sands Pty Ltd

Yoongarillup hydrogeological investigation and groundwater modelling report

24 January 2014

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Abbreviation

BOM	Bureau of Meteorology
d	day
DoW	Department of Water
ET	Evapotranspiration
GDE	Groundwater dependent ecosystem
K	Hydraulic conductivity
kh	Horizontal hydraulic conductivity
kL	Kilo litres
km	kilometre
km^2	Square kilometres
kz	Vertical hydraulic conductivity
L/sec	Litre per second
m	Metre
m^3	Cubic metre
mAHD	m above Australian Height Datum
mbgl	Metre below ground level
ML	Mega litre
mm	Millimetre
RMS	Root mean square
Sy	Specific Yield
S	Storage coefficient
T	Transmissivity
USG	Unstructured grid

Executive summary

Doral Mineral Sands Pty Ltd (Doral) proposes to mine its Yoongarillup mineral sands deposit, located approximately 15 km south-east of Busselton, in Western Australia. The Yoongarillup mineral sands deposit is located within Mining Leases M 7000458 and M 7000459. To enable optimum resource recovery, it is likely mining will occur below the groundwater table and, hence, dewatering of the pits will be required.

Parsons Brinckerhoff Australia Pty Ltd (Parsons Brinckerhoff) was commissioned by Doral to conduct a groundwater investigation to obtain a baseline hydrogeological characterisation of the site and inform the environmental approval process. The focus of the work was to establish a hydrogeological framework to develop a conceptual model and to build a numerical groundwater flow model of the study area incorporating the proposed Yoongarillup mining area. The numerical model was then used to predict the likely drawdown, and pit inflows associated with the proposed mining activities.

In carrying out the groundwater assessment Parsons Brinckerhoff conducted the following:

- Desktop study to establish geological and hydrogeological framework for Yoongarillup and the surrounding area and to make recommendations for new borehole locations to establish a monitoring network;
- Field Investigation comprising aquifer tests at new monitoring bores. Nine boreholes were tested and aquifer properties were determined from these tests;
- Development of a conceptual model and numerical modelling to predict groundwater inflow to the mine pits and groundwater drawdown as a result of dewatering.

The results of the predictive modelling are based on the current mine plan and are summarised as follows:

- Predicted total groundwater inflows for the combined pits over the mine life are approximately 306 ML of which 11.8% are predicted to come from the Leederville Formation. Groundwater inflows are predicted to reach a maximum of approximately 1,500 m^3/day. The average monthly predicted inflow is 306 m^3/day.
- Predicted drawdown south of the proposed mine is limited in both, the Superficial Aquifer and Mowen Member, such that the 1 m contour does not extend south beyond the pit extents.
- No mining related drawdown in the Vasse Member and Yarragadee Aquifer is predicted.
- A maximum drawdown of 1.3 m is predicted adjacent to the proposed production wells screened in the Yarragadee Aquifer. The 1m drawdown contour may extend up to 90 m radially from the production bores.
- Inflow rates and drawdown effects are greatest when mining is active in the northern pits due to increasing saturated thickness of the Superficial Aquifer towards the north.
- None of the private bores located within the study area, are expected to experience drawdown of more than 1.0 m during the life of the mining operations.
- Groundwater levels will recover after mining ceases such that groundwater levels will have returned to 90% of their pre-mining levels within 36 months of mine closure.

The following recommendations are proposed:

- Preparation of an operating strategy in accordance with the requirements of the Department of Water including a water level monitoring plan and water quality sampling protocol prior to the commencement of mining activities.

- A census of private bores should be carried out to provide a baseline and allow identification of impacts to local groundwater users. Private bores should be included in the monitoring program where possible.
- Installation of five to seven additional bores in the Superficial Aquifer to supplement the existing bores screened within the Mowen Member.

1. Introduction

Doral Mineral Sands Pty Ltd (Doral) proposes to mine its Yoongarillup mineral sands deposit, located approximately 15 km south-east of Busselton (Figure 1.1). The Yoongarillup mineral sands deposit is located within Mining Leases M 7000458 and M 7000459. To enable optimum resource recovery, mining will occur below the groundwater table and, hence, dewatering of the pits will be required. Parsons Brinckerhoff Australia Pty Ltd (Parsons Brinckerhoff) was commissioned by Doral to conduct a groundwater investigation to support the environmental approval processes.

The focus of the work was to establish a hydrogeological framework to develop a conceptual model and to build a numerical groundwater flow model of the study area incorporating the Yoongarillup mining area. The numerical model was then used to predict the likely drawdown, and pit inflows, associated with the proposed mining activities.

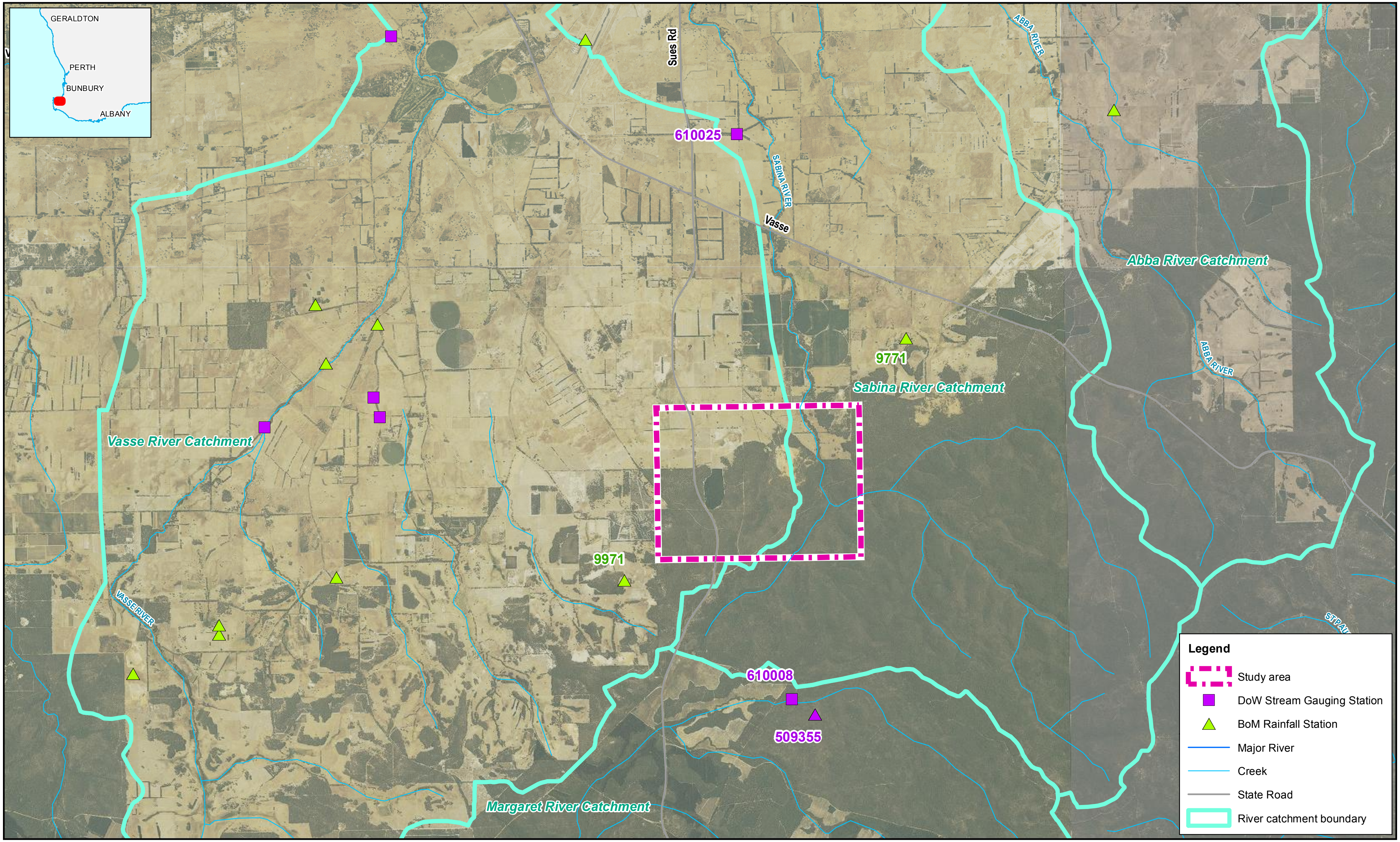
The program of works was carried out in four phases:

- **Phase 1:** ***Desktop study***. The main task was to collate and collect data to establish a geological and hydrogeological framework for Yoongarillup and the surrounding area, and to make recommendations for new borehole locations to comprise a monitoring network;
- **Phase 2:** ***Field Investigation***. Establishment of a groundwater monitoring network. Carry out field investigations to further understand the hydrogeological conditions of the study area, including hydraulic testing of monitoring boreholes to determine hydraulic parameters to characterise hydrogeological conditions at the site and to input to the groundwater flow model;
- **Phase 3:** ***Conceptual and numerical groundwater flow model development***. Based on the findings from Phase 1 and Phase 2 the conceptualisation of the study area was established. A numerical groundwater flow model was developed based on the hydrogeological conceptualisation and input parameters derived from the field investigation. The model, once calibrated, was used to determine the dewatering volume requirements associated with the proposed mine plan and assess potential drawdown impacts associated with the dewatering;
- **Phase 4:** ***Reporting***. Preparation of an integrated final report describing the field investigations, study area conceptualisation, numerical model results and conclusions.

During the desktop study (phase 1), data from numerous sources including published Government and consultants reports were collected and collated to develop initial preliminary appreciation understanding of the hydrogeological conceptualisation of the study area. On the basis of information gathered, and in consultation with the Department of Water (DoW), a groundwater monitoring network was proposed. Nine monitoring bores were subsequently installed during phase 2. Parsons Brinckerhoff hydrogeologists conducted aquifer tests on each of the bores to ascertain aquifer parameters.

Following completion of phase 2, the information obtained from the site investigation was used to update the conceptual model and a numerical groundwater flow model was developed for the study area (phase 3).

This document is a revised and updated version of an earlier report (PB 2012) and comprises the results of the previous phases and the results of the numerical modelling (Phase 4) incorporation a new mine schedule PB received 18 October 2013 from Doral. This report will support the regulatory environmental approvals process for the proposed mining activity at Yoongarillup.



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APPROVED FOR AND ON BEHALF OF
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Revision: B

Date: 19/12/2013

Drawn By: SH / JV

Checked by: SF

Data Source: Landgate; SLIP (2011)

Doral Mineral Sands Pty Ltd
Hydrogeological investigation and groundwater modelling for Yoongarillup mineral sands deposits

Location of Yoongarillup mining area
Figure 1-1

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2. Physical Setting

2.1 Climate

The climate is Mediterranean type (Köppen classification Csb) characterised by hot dry summers and cool wet winters. The average annual rainfall at Bureau of Meteorology (BOM) gauging station 9771 located approximately three kilometre north-east of the proposed mining area is 849 mm/year. Most rainfall occurs from May to September. Annual potential evaporation is about 1400 mm (BOM, 2011).

2.2 Physiography

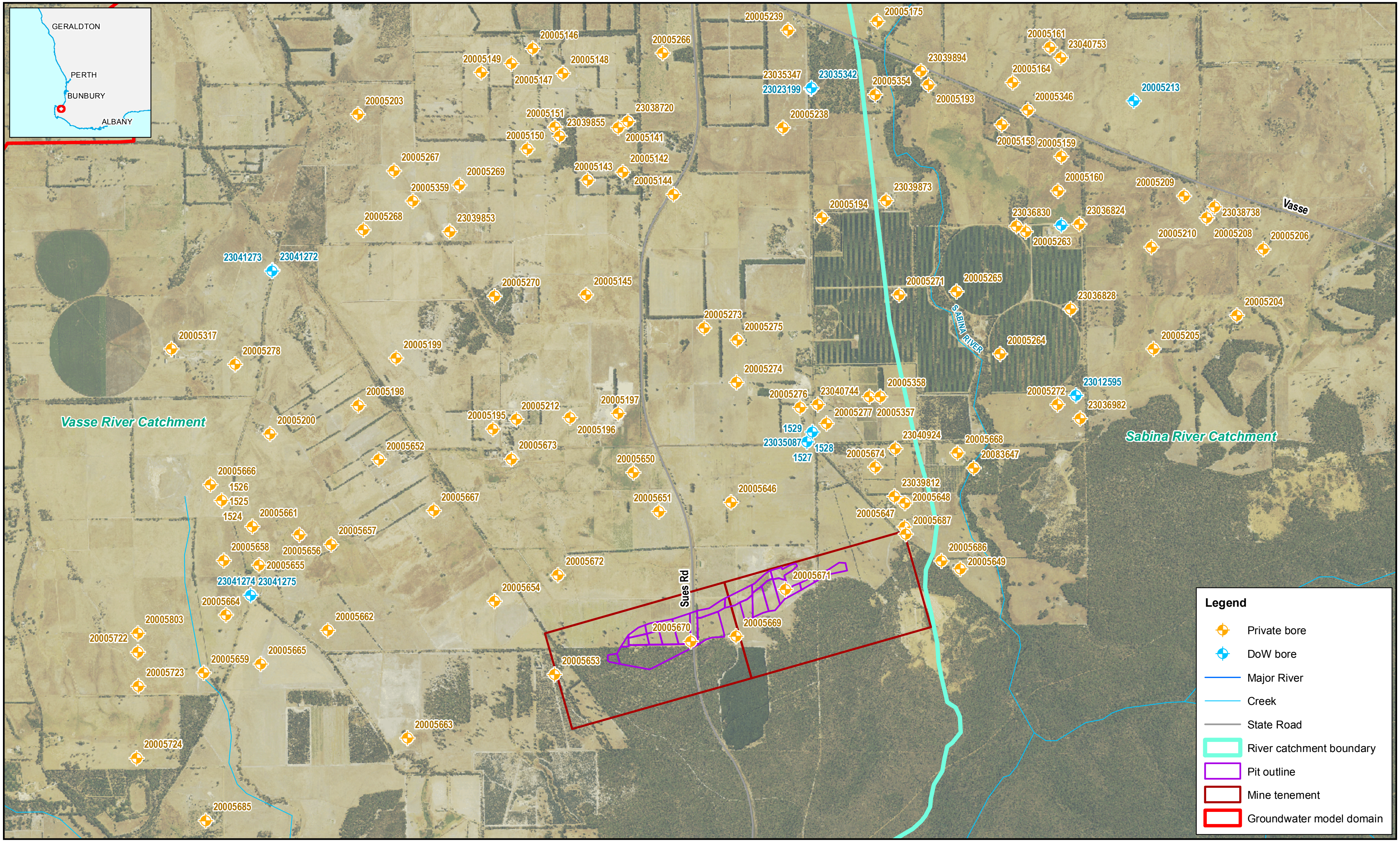
The study area is located 15 km southeast of Busselton at the foot of the Whicher Scarp. It is located within the southern part of the Perth Basin. The key physiographic features associated with the site are the coastal plain, the Whicher Scarp and the Blackwood Plateau (Schafer et al., 2008). The flat lying plain occupies the northern part of the study area, and most of the plain is bordered to the south by the Whicher Scarp which rises steeply from coastal plains to an elevation of approximately 40-60 mAHD. The southern part of the study area lies within the Blackwood Plateau ranging in elevation between 80 to 180 mAHD (GSWA, 1976).

2.2.1 Water Management Areas

The proposed mineral sands mine is located in the catchment area of the Vasse River Basin which forms part of the Busselton-Capel Groundwater Area (PB, 2011). The Vasse River originates in the Blackwood Plateau. Its only tributary is the Sabina River. The Vasse River has been modified by several stream diversions (PB, 2011). The Vasse Diversion Drain is located in the lower catchment and receives water from 65% of the Sabina River Catchment and 90% of the Vasse River Catchment, diverting it away from the Vasse-Wonnerup Estuary and directly into Geographe Bay west of Busselton (Paper Daisy Environmental Services, 2000). The catchment is dominated by agricultural land; consequently approximately 80% of the catchment has been cleared. The proposed mine lease area falls in the south-east of the Vasse River catchment.

2.2.2 Private bores

A review of the database register indicates there are 48 private landowner bores located within 5 km radius of the proposed Yoongarillup mine site. These are shown in Figure 2-1 and are predominantly located to the north of the proposed mine. Information for these bores is limited; with bore construction and groundwater level data generally unavailable.



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Location of private bores

Figure 2-1

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2.3 Geology

The Yoongarillup mineral sands deposit is located in the southern part of the Perth Basin (Figure 2.2). The Perth Basin is a deep linear trough containing sedimentary rocks (Jurrasic to Quaternary) extending north-south for some 1,000 km and covers an area of 45,000 km^2 onshore and 55,000 km^2 offshore (GSWA 1976). The Perth Basin is essentially a half-graben structure bounded on the east by north-trending Darling Fault, 1000 km long, which separates the Basin from the Archean rocks of the Yilgarn Block (GSWA 1976).

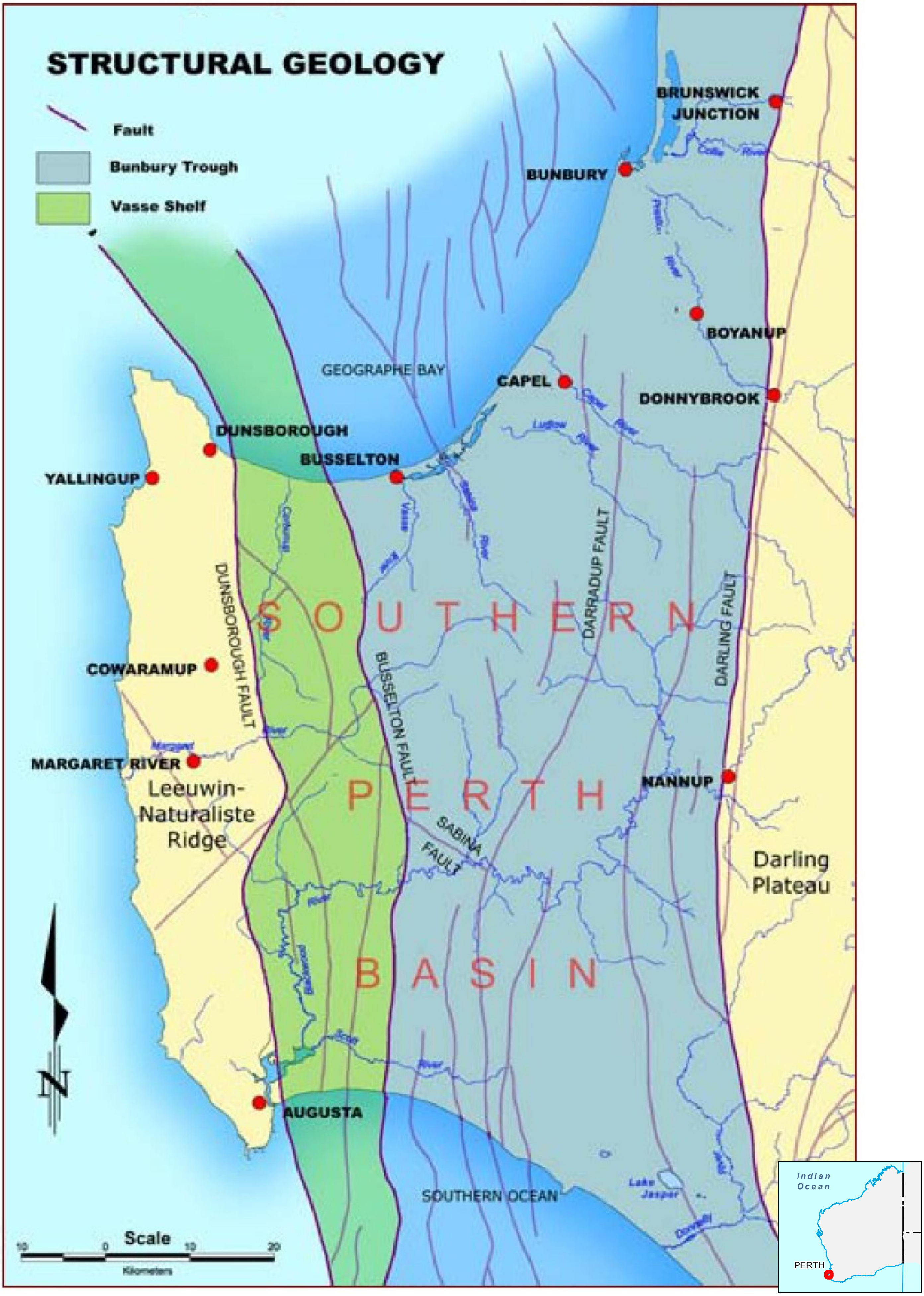
The regional geology associated with the study area is dominated by a sedimentary sequence deposited within the graben in the southern Perth Basin (Schafer et al., 2008). This part of the Basin comprises two main geological structures: the Bunbury trough and the Vasse Shelf. The major north-south trending Busselton Fault subdivides the graben structure into two major structural units: the deep Bunbury Trough to the east and a relatively shallow fault block, known as the Vasse Shelf, to the west (Schafer et al., 2008). The study area is situated on the eastern side of the graben structure, entirely within the Bunbury Trough (Figure 2.2).

The geological setting of the area comprises (from oldest to youngest):

- The Yarragadee Formation
- The Leederville Formation
  - Vasse Member
  - Mowen Member
- The Superficial Deposits
  - Yoganup Formation
  - Guildford Clay
  - Bassendean Sand

The Yarragadee Formation comprises Jurassic aged laterally discontinuous interbedded feldspathic-sandstone, siltstone and shale deposits that are up to 2 km in thickness (Varma, 2009). The Yarragadee Formation is sub divided into 4 Units of which unit 3 and 4 are present in the project area with a total thickness of 550 to 800 m (Baddock et al., 2005) underlying the Vasse Member of the Leederville Formation.

The Cretaceous aged Leederville Formation unconformably overlies the Yarragadee Formation and comprises discontinuous interbedded sandstone and shales. The sediments are essentially flat-lying with a gentle slope to the north and have a weathering profile, up to 150 m thick, where outcropping occurs mainly along the Whicher Scarp and the Blackwood Plateau (Schafer et al., 2008). Based on the studies east of the study area, the Leederville Formation has been divided into Vasse and Mowen Members (Schafer et al., 2008). The Vasse Member is the aquifer and the Mowen Member is a confining layer (aquitard) (Schafer et al., 2008).



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Structural geology of the Region

Figure 2-2

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The Pliocene-Quaternary aged superficial deposits overlie the Leederville Formation and collectively comprise the Yoganup Formation, Guildford Formation and the Bassendean Sand (Schafer et al., 2008). The maximum thickness of Quaternary deposits in the Perth Basin amounts to about 150 m, but in most areas they are less than 20 m thick (GSWA, 1976).

The superficial deposits form a relatively thin cover over most of the coastal plain. The oldest superficial deposit is the Yoganup Formation, which occurs along the base of the Whicher Scarp. It comprises leached and ferruginous beach sand with localised concentrations of heavy minerals (Schafer et al., 2008) and consists of white coarse sand rich in heavy metals and sandy silt and clay respectively.

The Guildford Clay covers much of the coastal plain and is a composite unit of interfingering alluvial clay and sand. The Bassendean Sand consists of quartz-rich dunal sand that generally overlies or abuts the Guildford Clay.

The Yoganup Formation dominates the study area, whilst the Guildford Clay is observed mainly towards the northern boundaries. In these superficial deposits, a lateritic hardpan has developed due to water table fluctuation in many areas (Schafer et al., 2008). The Superficial Aquifer pinches out some 50 to 200 m south of the mine area.

A generalised lithostratigraphical and hydrostratigraphical description of the study area is presented in Table 2.1 below.

Table 2.1 Generalised regional and local stratigraphic sequence and hydrogeology of the project area (*Davidson, 1995)

Age	Stratigraphy	Maximum thickness (m)	Lithology	Aquifer system
Quaternary–late Tertiary	**Superficial Formation**			
	Bassendean Sand	80*	Fine to medium sub-rounded quartz sand	Superficial aquifer
	Guildford Formation	35*	Brown to dark grey clays with isolated lenses of silt and sand towards the base.	Local aquitard
	Yoganup Formation	10*	White to yellowish-brown unconsolidated, poorly sorted sand, gravel and pebbles with local subordinate clay, ferruginised grains and heavy minerals	Superficial aquifer
Cretaceous	**Leederville Formation**	600*	Interbedded units of partly consolidated sand and shales. Generally divided in to upper, predominantly shaly section (Mowen Member) and lower sandy section. (Vasse Member)	Leederville aquifer including the Mowen aquitard
Mid to late Jurassic	**Yarragadee Formation**	2,000*	Weakly consolidated sandstone, siltstone and shales.	Yarragadee aquifer
Early Jurassic	**Cockleshell Gully Formation**		Angular to sub angular, weakly cemented quartz sandstone containing accessory pyrite and garnet, and weakly consolidated siltstone and shale	Yarragadee aquifer

2.4 Hydrogeology

2.4.1 Desktop study

Parsons Brinckerhoff carried out a Department of Water (DoW) database search of all recorded bores in the vicinity of the study area. Locations of selected bores identified as being in the vicinity of the mine area were validated in January 2014 by using a hand held GPS. The findings of this search were utilised to collate water level data while relating it to geology and to gain an understanding of the hydrogeological system associated with the proposed mine site. The search also identified other groundwater users who may be potentially impacted by the proposed mining activities. Based on this search, in consultation with Doral and the DoW, Parsons Brinckerhoff proposed the construction of nine new piezometers to comprise a mine specific groundwater monitoring network.

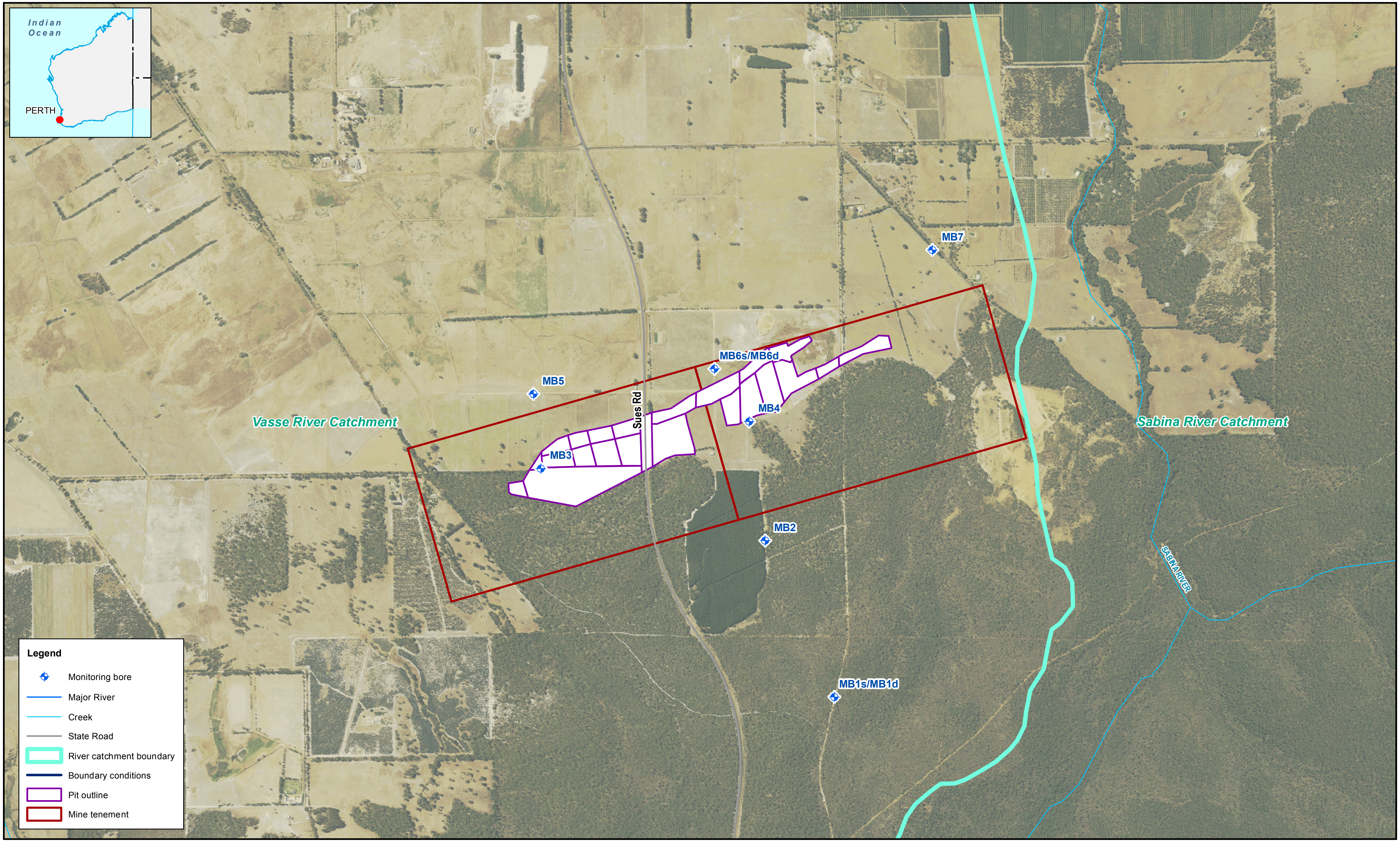
2.4.2 Site investigation

In 2012, Doral implemented phase 1 of the hydrogeological assessment and coordinated the construction of nine boreholes. The drilling was supervised by Aurora Environmental and the program comprised nine exploration holes which were completed as monitoring bores at seven different locations. The detailed logs are shown in Appendix A. A summary of the borehole completion details are presented in Table 2.2 and the locations of these monitoring bores are shown in Figure 2.3.

Table 2.2 Bore completion details

Bore	Date of Commencement	Date of completion	Casing diameter (mm)	Drilled depth (m)	Screened Interval (mbgl – mbgl)	Likely screened unit*
MB1S	24/01/2012	24/01/2012	50	20	14 - 20	Mowen Member
MB1D	24/01/2012	24/01/2012	50	60	54 – 60	Mowen Member/Vasse Member
MB2	24/01/2012	24/01/2012	50	20	14 - 20	Mowen Member
MB3	27/01/2012	27/01/2012	50	20	14 - 20	Mowen Member
MB4	27/01/2012	27/01/2012	50	20	14 - 20	Mowen Member
MB5	27/01/2012	27/01/2012	50	20	14 - 20	Mowen Member
MB6S	25/01/2012	25/01/2012	50	20	14 - 20	Superficial and Mowen Member
MB6D	24/01/2012	24/01/2012	50	60	54 - 60	Mowen aquitard
MB7	27/01/2012	27/01/2012	50	20	14 - 20	Superficial and Mowen Member

*based on the geological model and screened depth



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Location of new monitoring borewells
Figure 2-3

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In 2012, Parsons Brinckerhoff carried out hydraulic testing on these monitoring bores using rising and/or falling head tests ("slug tests"). A slug test is an in-situ method for estimating aquifer permeability, which typically involves monitoring the groundwater response after the instantaneous displacement of water in a bore. Testing was completed on eight of the nine monitoring bores as the monitoring bore MB2 was dry during the site visit. The slug testing data were evaluated and an appropriate solution (KGS model, Hyder et al (1994) or Cooper et al (1967)) was adopted to derive hydraulic conductivity (K) values. Reliable hydraulic conductivity values were obtained from seven of eight monitoring bores with the exception of MB1D where the groundwater response was slow. Slug testing details are summarised in Table 2.3 and individual plots are shown in Appendix B.

Table 2.3 Slug testing results

Bore	Likely screened unit	Type of test	Solution	K (m/day)
MB1S	Mowen Member	Rising	KGS	0.02
MB3	Mowen Member	Rising	KGS	0.66
MB3	Mowen Member	Falling	KGS	0.37
MB4	Mowen Member	Rising	KGS	0.25
MB5	Mowen Member	Injection	KGS	0.01
MB6S	Superficial aquifer and Mowen Member	Rising	KGS	1.34
MB6S	Mowen Member	Falling	KGS	0.97
MB6S	Mowen Member	Injection	KGS	0.71
MB6D	Mowen Member	Falling	Cooper	0.03
MB6D	Mowen Member	Injection	Cooper	0.04
MB7	Superficial aquifer and Mowen Member	Falling	KGS	0.02

2.4.3 Conceptual model

The conceptual hydrogeological model represents the understanding of the hydraulic behaviour and dynamics of the aquifer systems and provides the technical foundation for the numerical model design and framework.

Figure 2.4 presents a north-south cross-section through the mine area. The conceptual hydrogeology compliments the stratigraphy and hence three aquifers are recognised locally:

- the Superficial Aquifer;
- the Leederville Aquifer (incorporating the Mowen Member aquitard), and
- the underlying Yarragadee Aquifer.

The Superficial Aquifer is an unconfined aquifer and comprises the Bassendean Sand towards the top and the Yoganup Sand towards the base. The Guildford Clay is locally present between the two aquifers. The hydraulic conductivity of the Superficial Aquifer is likely to be variable.

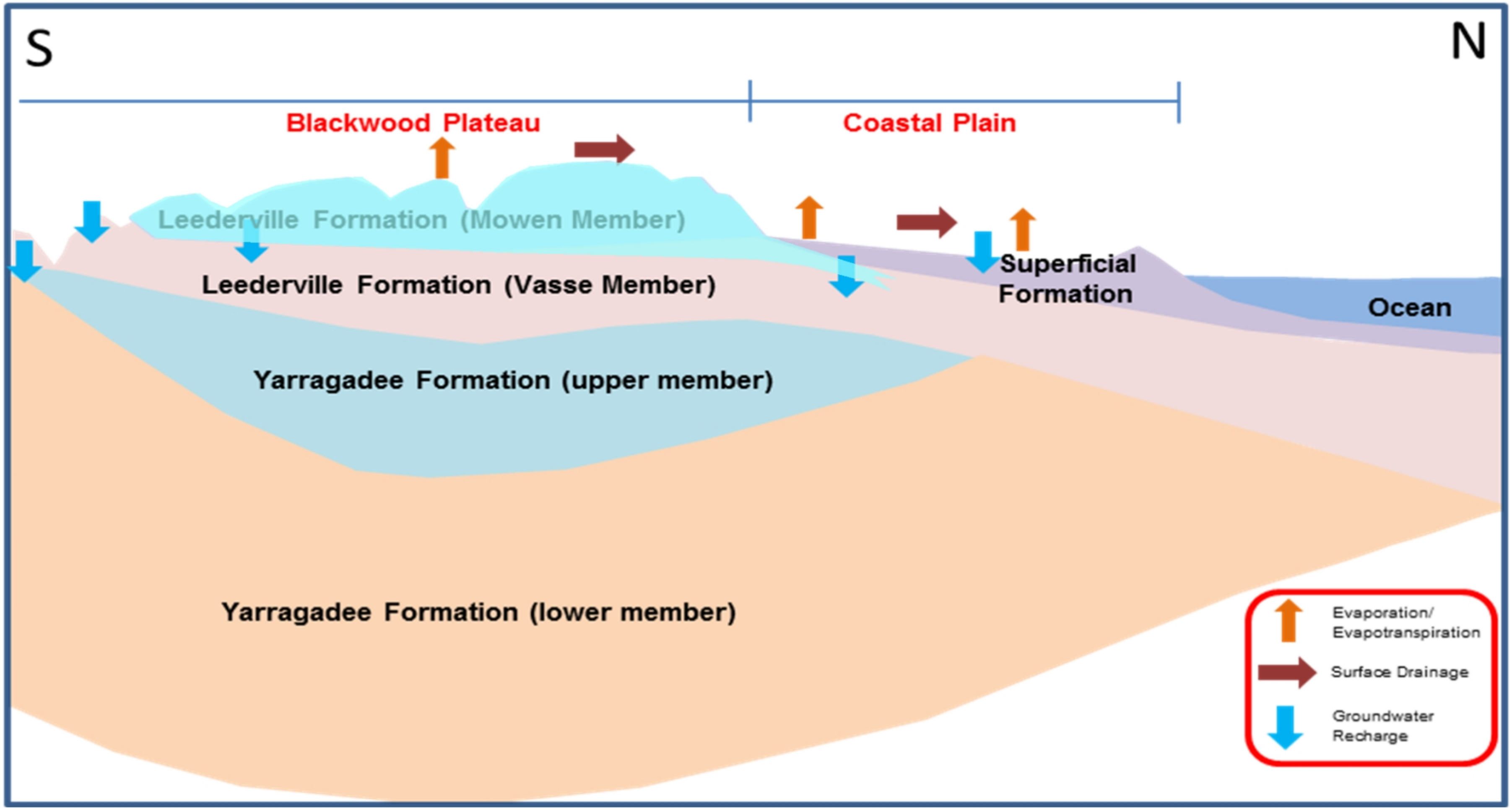


Figure 2-4: Representative cross-section

The Leederville Aquifer is a multi-layered aquifer system comprising discontinuous interbedded sequences of sandstone and clay. The horizontal hydraulic conductivity of sandstone beds in the Leederville aquifer, derived from pumping tests is about 10 m/d, and that of the siltstone and shale beds is assumed to be about 1 x 10^{-6} m/d (Davidson W A, 1995). If the interbedded sandstones, siltstones and shales are laterally extensive, the average horizontal hydraulic conductivity of the aquifer will approach 5 m/d (as the sandstones constitute approximately half the aquifer thickness). Sandy beds that comprise the Vasse Member constitute the main aquifer.

The sandy beds underlie the Mowen Member which comprises an aquitard. The Mowen Member is assumed to be present in the entire modelled area.

The Leederville Aquifer becomes more consolidated with depth resulting in permeability decrease with depth. The Leederville Aquifer extensively outcrops throughout the Blackwood Plateau (Schafer et al., 2008). The Yarragadee Aquifer is composed primarily of non-marine fluvial feldspathic, poorly sorted sandstones which are porous and poorly cemented and, hence, allow for considerable groundwater reserves. It grades from a shale-siltstone dominated base to a cleaner sandstone in the upper portions of the Formation, probably representing increased subsidence or filling of the basin during the late Jurassic (Varma, 2009).

The Yarragadee Formation is divided into 4 Units. Unit 3, which underlays the Vasse Member in the project area, is reported to be the most transmissive unit (Baddock et al., 2005). The average horizontal hydraulic conductivity is 14 m/d, however, isotopic dating of groundwater indicates an average hydraulic conductivity of 8 m/day (Baddock et al., 2005).

2.4.3.1 Groundwater flow

The direction of groundwater flow within the Superficial Aquifer is generally controlled by the topography, drainage and surface geology. The flow direction is generally north to north-west from the elevated Blackwood Plateau which is located immediately to the south of the study area, and moves in a north-westerly direction away from the Millbrook State Forest. Groundwater elevation contours for the Superficial Aquifer essentially follow the land surface from the Whicher Scarp to the Vasse River and Vasse Diversion Drain.

The groundwater flow direction in the Leederville and Yarragadee Aquifers is similar, generally to the north-west i.e., from Blackwood Plateau towards the coast (Schafer et al., 2008).

2.4.3.2 Aquifer recharge

The primary source of recharge to the Superficial Aquifer is through direct infiltration of rainfall. During winter season, the Superficial Aquifer is often fully saturated and leads to ponding of water in some areas. The surface water drainage network across the plain captures and diverts this excess water towards the ocean. The primary drainage features in the area (Vasse River, Sabrina River and Vasse River Diversion Drain) flow in a northerly and westerly direction respectively, before discharging into the Ocean. The recharge estimates for Perth Basin based on different land use and climatic conditions varies between 5% and 40% of the rainfall depending upon location and land use (Davidson, 1995). Surface water yield estimates indicate that the Vasse River sub-catchment, where the proposed pit is to be located, has an annual runoff yield of approximately 1.78 GL/yr (PB, 2011).

The Leederville and Yarragadee Aquifers are recharged directly by rainfall infiltration on the Blackwood Plateau in areas of downward potentiometric head. Recharge into the Leederville Aquifer from the overlying Superficial Aquifer may occur where confining beds are largely absent beneath the plain, and where there is a downward hydraulic gradient. The Leederville Aquifer overlies the Yarragadee Aquifer throughout the study area.

3. Groundwater Modelling

3.1 Modelling objective and background

The objective of the numerical groundwater flow model was to provide an assessment of dewatering requirements and groundwater drawdown associated with the development of the Yoongarillup mineral sands project. The key features of the model are discussed in the following sections.

The main water balance components are summarised as follows:

- Direct recharge to groundwater from rainfall;
- Groundwater evapotranspiration from the shallow water table;
- Groundwater inflows and outflows based on the available information where the aquifer crosses the model boundaries;
- Dewatering of below water table mineral sands deposit proposed for the mining activity
- Groundwater abstraction bores for mine water supply.

3.2 Confidence level

The Australian Modelling Guidelines (Barrett et al., 2012) recommends that the target confidence level of the model should be established and classified according to a set of semi-quantitative criteria. The confidence level relates to the degree of confidence with which the models predictions can be used and relied upon.

The confidence level classification comprises three classes; Class 1, Class 2 and Class 3, in order of increasing confidence level. The level of confidence typically depends on the available data, calibration procedures, consistency between the calibration conditions and predictive analysis scenario, and the level or severity of stresses being simulated. The confidence level classification is often constrained by the available data, budget and/or time. Typically in impact assessments for mining projects, the paucity of time series and spatial data for calibration compared with the proposed development timeframe is such that a Class 2 confidence level is the highest feasible.

In this context the numerical groundwater model developed as part of this work is defined as a Class 2 model. Such models are intended to reflect the fundamental purpose of the modelling objectives, in this instance the projection of groundwater drawdown in response to stresses imposed by mining. With this approach in mind, where understanding or data have been limited, conservative model input parameters (e.g. hydraulic conductivity, recharge) have been adopted (within realistic ranges) in order to simulate the potential impacts to the aquifer. Note that the model is not suitable for predicting the response of a system to arbitrary changes in hydrogeological conditions beyond the purpose for which it is intended.

3.3 Model code selection

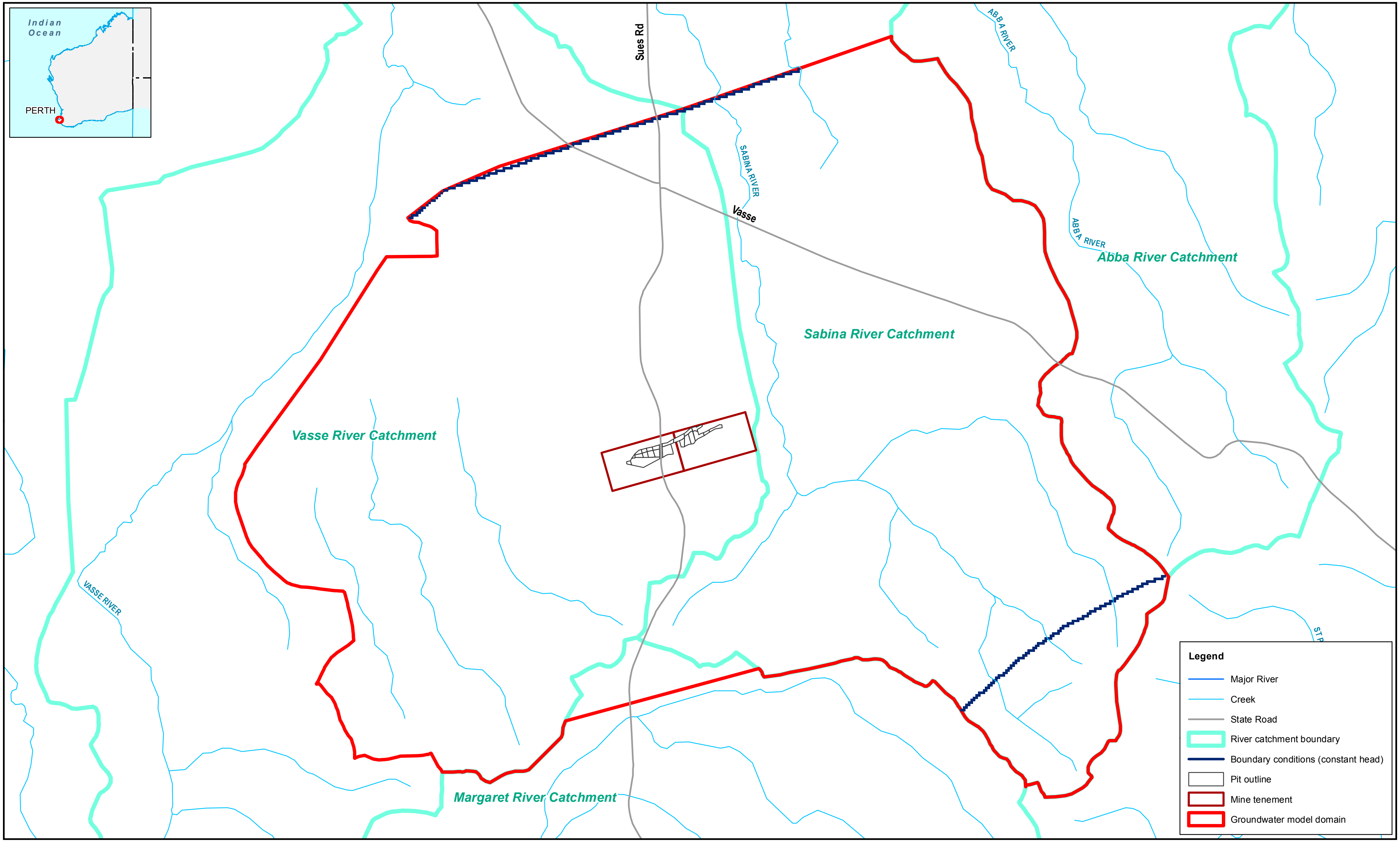
The model was created using the Groundwater Vistas (GWV) graphical user interface (Version 6.55). MODFLOW was used in conjunction with MODFLOW-USG (Panday et al., 2013). MODFLOW-USG (unstructured grid) is a recently developed code based on the control volume finite difference method (CVFD). It has many advantages over the original finite difference codes (MODFLOW, Surfact) in that it can operate with unstructured and irregular grids, can pinch out layers that outcrop or sub-crop, and has the capability to approximate unsaturated conditions that can develop in mining situations. MODFLOW and its related programs are well documented and widely used in the groundwater field and are accepted by most regulators as industry standard.

3.4 Model grid and extent

The model domain is shown in Figure 3.1. Coordinates of the four corners of the model domain are presented in Table 3.1. The model domain is approximately 20 km x 15.5 km, with uniform cell sizes of 50 m x 50 m. This results in a total of 310 rows and 390 columns. A nested grid (Modflow USG) was included around the mining area dividing each cell into 4 daughter cells resulting in a finer grid of 25 x 25 m. The entire model domain consists of 510,600 cells over the four model layers of which 315,000 are active flow cells.

Table 3.1 Groundwater model domain

Grid Position	Easting (MGA 94)	Northing (MGA 94)
North East	365,000	6,271,500
North West	345,000	6,271,500
South West	345,000	6,256,000
South East	365,000	6,256,000



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Model extent and boundary conditions

Figure 3-1

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3.5 Model geometry

The model configuration includes four layers consistent with the hydrogeological conceptualisation (paragraph 2.4.3). Each layer comprises one or more hydrogeological units. The model layers can be summarised as follows:

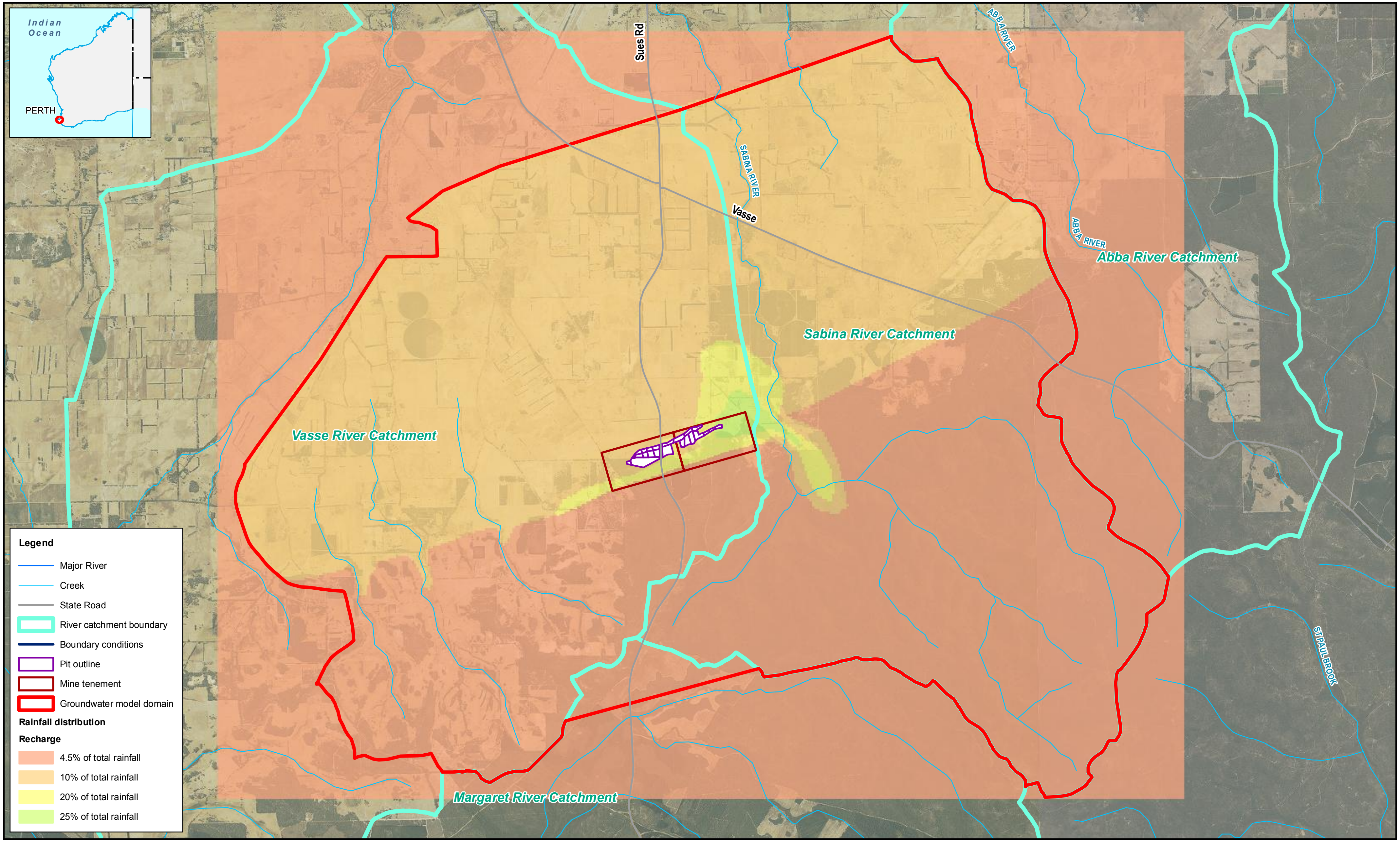
- Layer 1 represents the Superficial Aquifer including the Bassendean Sands, Guildford Clay and Yoganup Sands. Groundwater within the Superficial Aquifer is unconfined across the model domain.
- The Leederville Aquifer was represented as two layers.
  - The upper layer (model Layer 2) represent the Mowen Member.
  - The lower layer (model Layer 3) represents the Vasse Member which is the main aquifer within the Leederville Formation.
- The Leederville Aquifer (Layers 2 and 3) comprise the model top at the Blackwood Plateau where it outcrops. It underlies the Superficial deposits across the coastal plain and the Whicher Scarp. The Mowen Member is modelled as unconfined layer and the Vasse Member as a confined layer.
- Layer 4 represents the Yarragadee Aquifer, a confined layer.

The elevation of the top of layer 1 (ground level) was interpolated from the Landgate contours (5 m contour interval) and spot height elevation database. The elevation for the bottom of Layer 1 was assigned consistent with information derived from exploration drilling and data provided by Doral. As a result, the thickness of the aquifer is irregular, reaching its maximum of 20m below the northern pit boundaries. The bottom of Layer 2 was set at varying thickness of 8 to 38 m and bottom of layer 3 was set at a uniform thickness of 32 m consistent with available literature (Schafer et al., 2008). Based on Baddock et al (2005), the thickness of unit 3 of the Yarragadee aquifer at the project location is between 250 and 300m. The thickness of layer 4 is a uniform 100m, but was parameterised to reflect the total transmissivity of the aquifer.

3.6 Groundwater inflows and outflows

3.6.1 Rainfall recharge

Inflow to the groundwater system is provided via rainfall recharge as a proportion of the rainfall. The average annual rainfall recorded for the region is around 849 mm per year. The percentage of rainfall recharge assigned as a proportion of recorded rainfall was adjusted during model calibration. Modelled rainfall recharge is assigned at a rate of 84.9 mm/year and 38.25 mm/year over the Superficial and Leederville Aquifers respectively (i.e. 10% and 4.5% of the average annual rainfall recharge). Groundwater levels imply higher recharge (20%) in the area east and south of the mine likely deriving from the increased runoff infiltration. The distribution of modelled rainfall recharge is shown in Figure 3.2.



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Modelled rainfall recharge distribution
Figure 3-2

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3.6.2 Evapotranspiration

Evapotranspiration is a potential discharge mechanism that is active in those regions where the water table is found at relatively shallow depths. Evaporation from the shallow water table across the model domain is modelled using the Evapotranspiration package in Modflow such a way that if aquifer water levels are at or above a specified depth ET occurs at maximum specified rate. If the aquifer water levels drop below the specified level (depth), the ET rate decreases linearly to zero as the predicted water level reaches an elevation equal to the ET surface minus the extinction depth. The ET rate is also set to zero wherever the aquifer water level is below the elevation equal to the ET surface minus the extinction depth.

The average annual evaporation in the area is approximately 1400 mm. The modelled maximum evapotranspiration rate is set somewhat lower than the average annual evaporation i.e., 70% of average annual evaporation in order to provide a better approximation to actual plant water uptake and evaporation from subsurface. The evapotranspiration extinction depth is set at 3 m below the ground surface. The modelled maximum ET rate is uniform across the model domain.

3.7 Boundary conditions

The general direction of groundwater flow through the modelled area is from south to north from the southernmost model boundary towards the ocean. The southern, eastern and western boundaries of the model were set to be consistent with the surface water catchment divide. As groundwater flow follows surface topography, these model boundaries were assigned as no flow boundaries. The northern boundary is located approximately 10 km north of the Yoongarillup site. The groundwater outflow along northern boundary is simulated as a constant head boundary and is set to be consistent with groundwater levels in the area at an elevation of 18 mAHD. A constant head was assigned in the south east of the model and set to likely groundwater levels in that area. The location of model boundaries is shown in Figure 3-1.

3.8 Adopted aquifer parameters

3.8.1 Hydraulic conductivity

Calibrated hydraulic parameters for the Superficial, Leederville and Yarragadee Aquifers and aquitards are shown in Table 3.2 below. The calibration process is described in section 3.9. For the parsimony of modelling, only one layer was included in the model for Superficial deposits. Slug testing indicated a varying hydraulic conductivity for the Mowen Member. However, given the Mowen Member acts as an aquitard regionally, the lower range value was adopted (0.03 m/day). The hydraulic conductivity of Vasse Member is consistent with similar hydrogeological environments (Schafer et al., 2009). The distribution of aquifer parameters in layer 1 is shown in Figure 3.3. The value of 1.4 m/day reflects a bulk hydraulic conductivity considering interfingered clay lenses as well as the results of the slug testing in bores screened across both, the Superficial Aquifer and Mowen Member.

The Yarragadee aquifer of which Unit 3 and 4 are present in the project area has a reported hydraulic conductivity of 8 m/day (Baddock et al. 2005). In order to maintain a realistic transmissivity of the aquifer, the permeability was multiplied by 3 to account for the layer thickness in the model as k = T/b where k is the hydraulic conductivity, T is transmissivity and b the aquifer thickness.

The vertical hydraulic conductivity for all layers was assumed to be 10% of the horizontal permeability to account for stratification.

Table 3.2 Calibrated hydraulic properties for model layers

Model layer	Equivalent geological unit(s)	Kh (m/d)	Kz (m/d)	Sy (no units)	S (no units)
1	Bassendean Sands*	1.4	0.14	0.15	10^{-4}
	Guildford Clay*				
	Yoganup Formation*				
1, 2	Mowen Member**	0.03	0.003	0.05	10^{-4}
3	Vasse Member**	1.5	0.15	N/A	10^{-4}
4	Yarragadee Unit 3	24	24	N/A	10^{-4}

Kh = horizontal hydraulic conductivity; Kz = vertical hydraulic conductivity; Sy = specific yield (for unconfined conditions) Storativity (for confined conditions); *= superficial aquifer; **= Leederville aquifer;

3.8.2 Storage

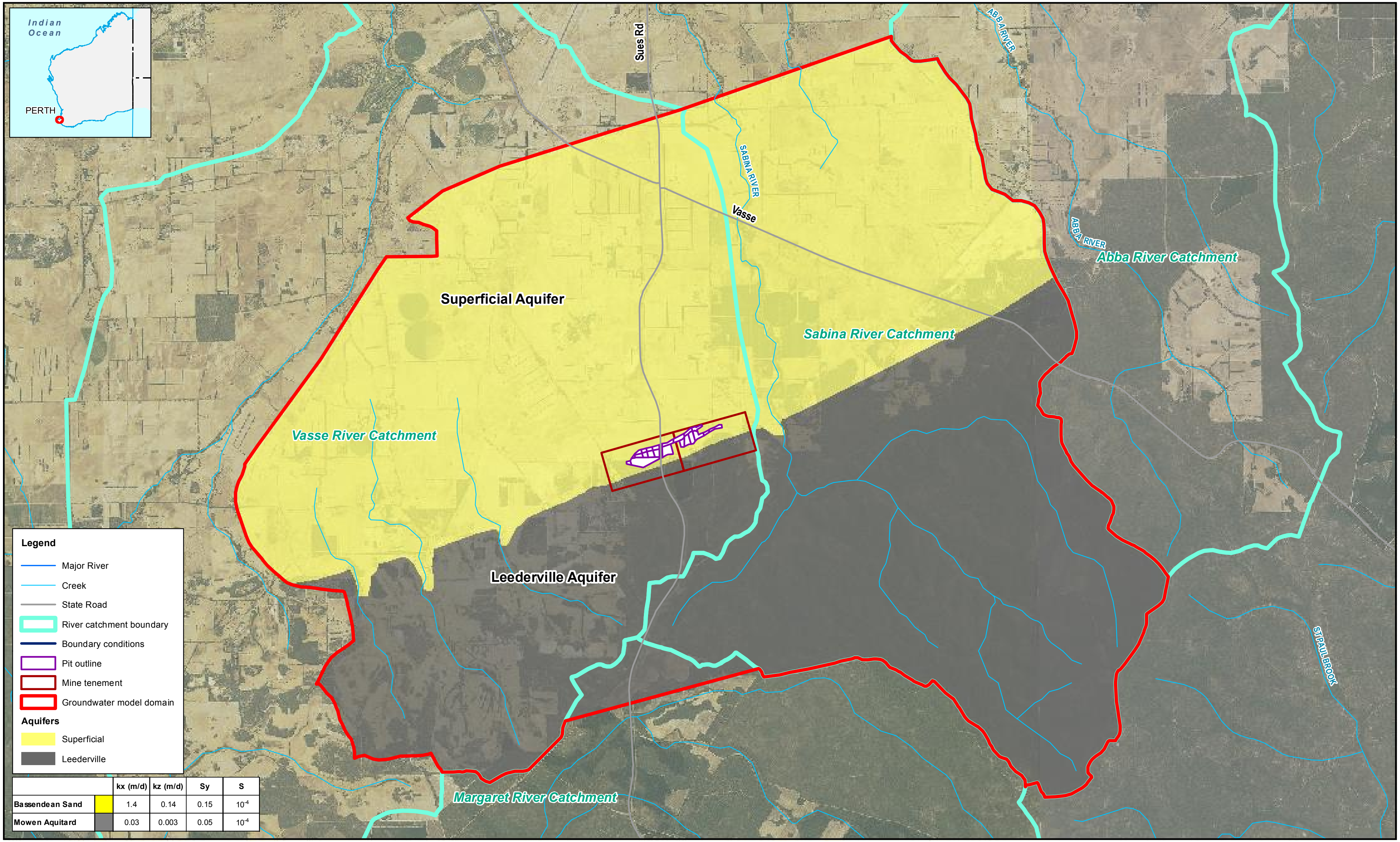
Adopted storage parameters (both unconfined and confined) were consistent with similar hydrogeological environments (Schafer et al., 2009). Table 3.2 shows the assumed storage values adopted for the modelled layers.

3.9 Model calibration

Model calibration is the process by which the independent variables of a model are adjusted within a realistic reasonable limit, to produce the best match between the simulated and observed data. The calibration process includes refining the initially selected aquifer properties, boundary conditions and percentage of recharge infiltration to improve agreement between observed and simulated data.

The model has been calibrated to steady state (long term average water levels), from a total of 74 boreholes throughout the region within the Superficial Aquifer and 7 bores screened within the Mowen Member. The location of these boreholes and difference in modelled and observed head (residuals) are shown in Figure 3.4. It is expected that groundwater fluctuates seasonally, in response to seasonal rainfall. However, sufficient data is currently not available to allow transient or time varying calibration. Calibrated water levels contours for the Superficial Aquifer and Mowen Member are shown in Figure 3.4 and Figure 3.5.

Figure 3.6 presents a scatter plot of the observed versus modelled water level data. The scaled RMS error, as a proportion of measured range of heads is 3.0%. This value is considered low indicating an acceptable calibration. To calculate the RMS and residuals, the newly installed monitoring bores had a lower weighting applied as these bores may be screened across both the Superficial Aquifer and Mowen Member. The model calibration in the vicinity of the mine area is considered very good as shown in Figure 3.4. The modelled water balance for the calibrated steady state model is presented in Table 3.3.



		kx (m/d)	kz (m/d)	Sy	S
Bassendean Sand	🟨	1.4	0.14	0.15	10^{-4}
Mowen Aquitard	⬛	0.03	0.003	0.05	10^{-4}

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Hydrogeological investigation and groundwater modelling
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Modelled aquifer properties (Layer 1)
Figure 3-3

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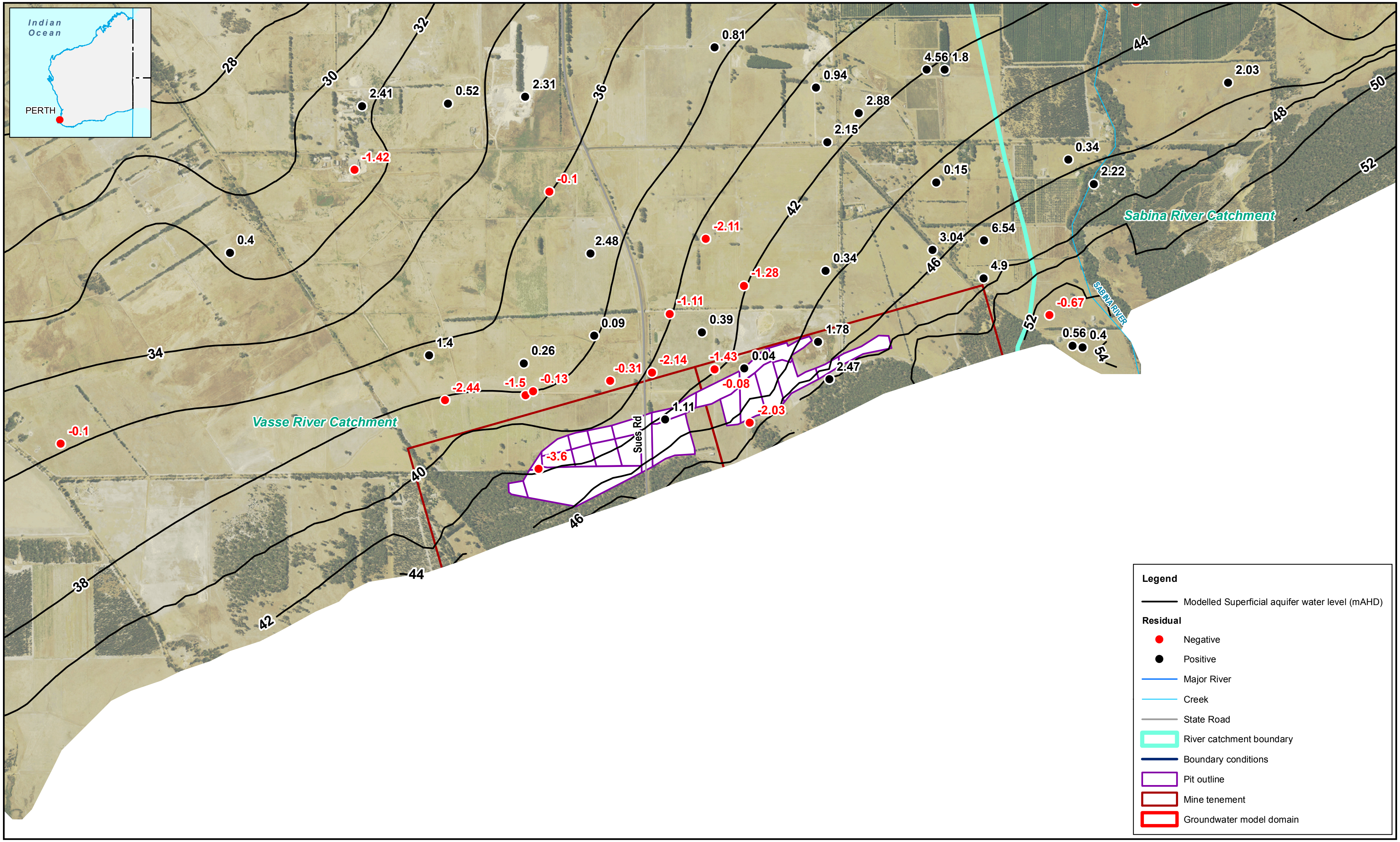

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Modelled steady state water level in mAHD (Superficial aquifer)
Figure 3-4

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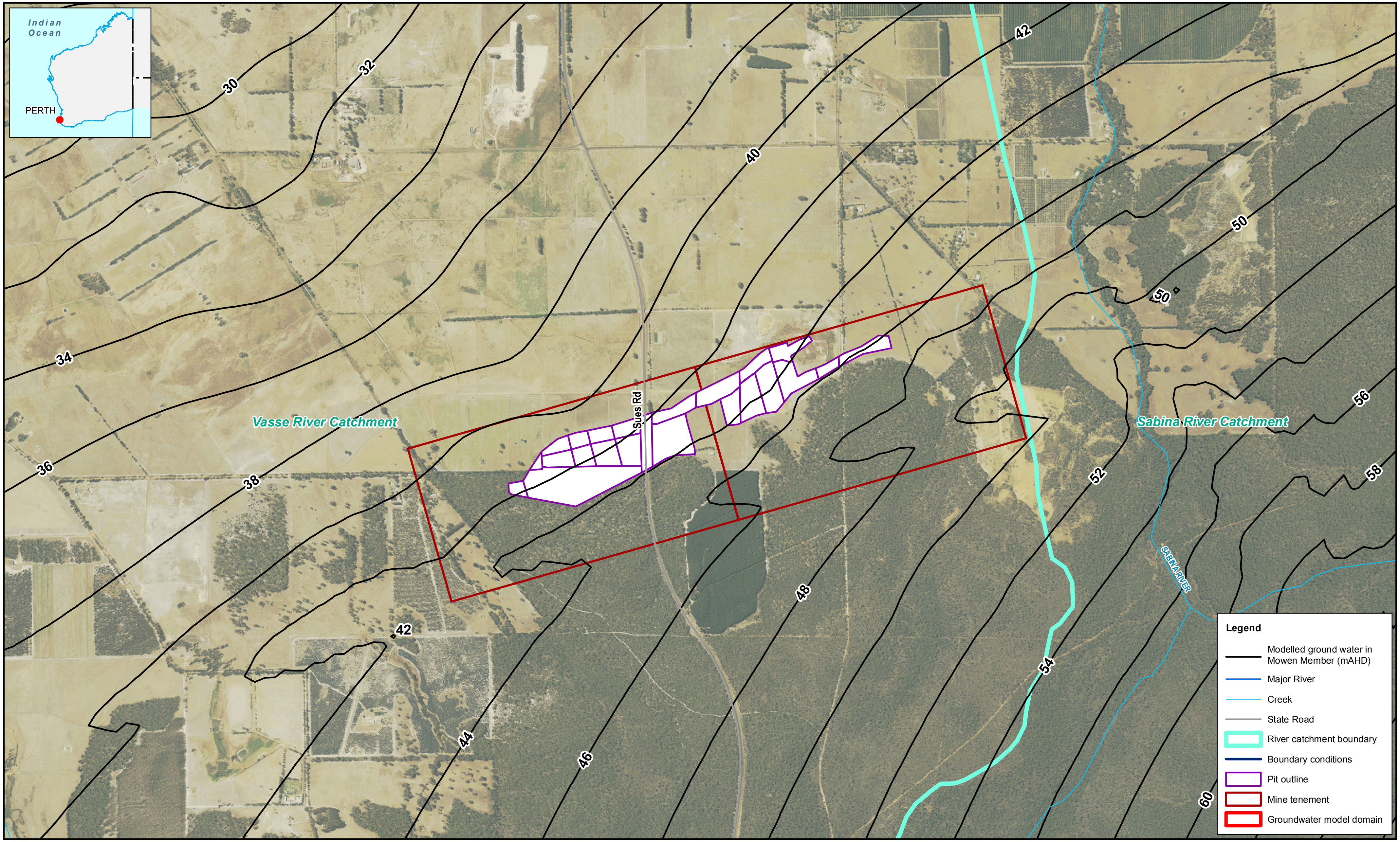

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Hydrogeological investigation and groundwater modelling for Yoongarillup mineral sands deposits

Modelled steady state water level in mAHD (Mowen Member)

Figure 3-5

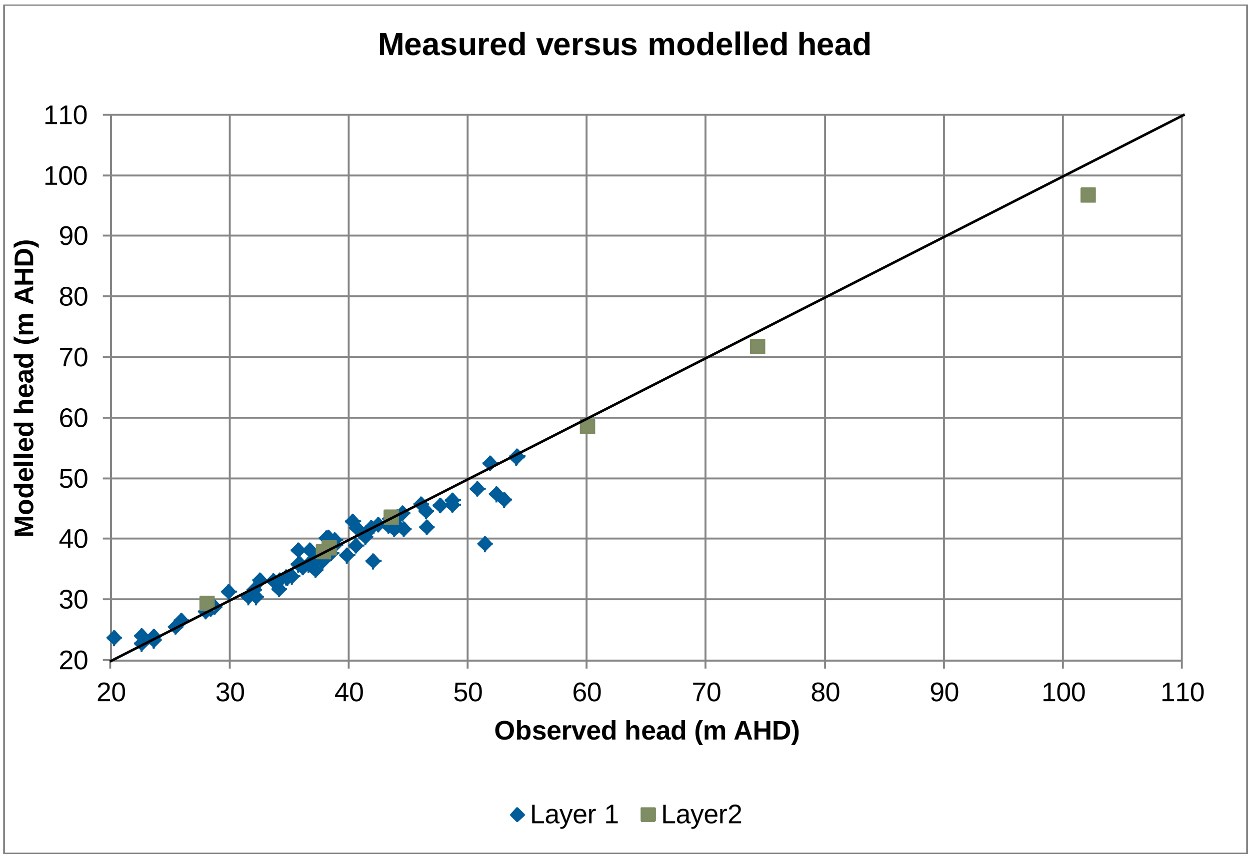


Figure 3.6 Measured versus modeled water level

Table 3.3 Modelled steady state water balance

	In (kL/d)	Out (kL/d)
Groundwater Inflow	145,970	-
Groundwater Outflow	-	108,114
Recharge	32,770	-
Evapotranspiration	-	70,626
Total	178,740	178,740

3.10 Model prediction

3.10.1 Model prediction set up

The calibrated groundwater model was used to predict the dewatering required to draw water levels to the proposed base of mining. The adopted mine schedule is summarised in Appendix C (received on 18 October 2013 from Doral). The scheduled mine life for Yoongarillup is about 33 months. Details of the model setup for the predictive simulations are summarised as follows:

- The prediction was run using 58 monthly time increments (or stress periods) to predict variations in groundwater inflows during mining, and included 24 stress periods to simulate recovery of groundwater levels after mining ceases.
- Rainfall recharge and evaporation assigned as per the steady state mode.

- The model assumes that the mine pits are developed as per the mine schedule and that groundwater levels are drawn to just below the base of mining pit at the start of each monthly stress period.
- Drain cells (Modflow boundary condition) with a high conductance value (938 m^2/d) were used to simulate dewatering. The elevation of each drain cell was set at the proposed pit bottom elevation (received as dxf file 19 November 2013). Drain cells were made inactive immediately once the pits were mined out, allowing groundwater levels to recover.
- Two water supply bores were included in the model with a total abstraction rate of 50 L/sec throughout mining activities to assess potential drawdown effects due to water abstraction from the Yarragadee Aquifer. The modelled pumping rate reflects a 1.6 GL/year groundwater abstraction license which Doral is in the process of applying for.

3.10.2 Predicted pit inflows

Predicted average monthly groundwater inflow rates from the Superficial and Leederville Aquifers over the life of mine are presented in Table 3.4 and are shown graphically in Figure 3.7. In order to determine the contribution from the Mowen Member to the pit inflows, the reported upward flow to Layer 1 from the steady state model was subtracted from the upward flow from the transient model for each stress period and associated active drain cells. The total inflows for the combined pits over the mine life are approximately 306 ML. Groundwater inflow rates are predicted to reach approximately 1,600 m^3/day in February 2017 (month 20) followed by another peak of approximately 1000 m^3/day in June 2017 (month 24). The average monthly predicted inflow is 306 m^3/day. It should be noted that the actual dewatering rates (pumping rates) are likely to be somewhat lower than the predicted amount due to direct evaporation from the pit walls and floor.

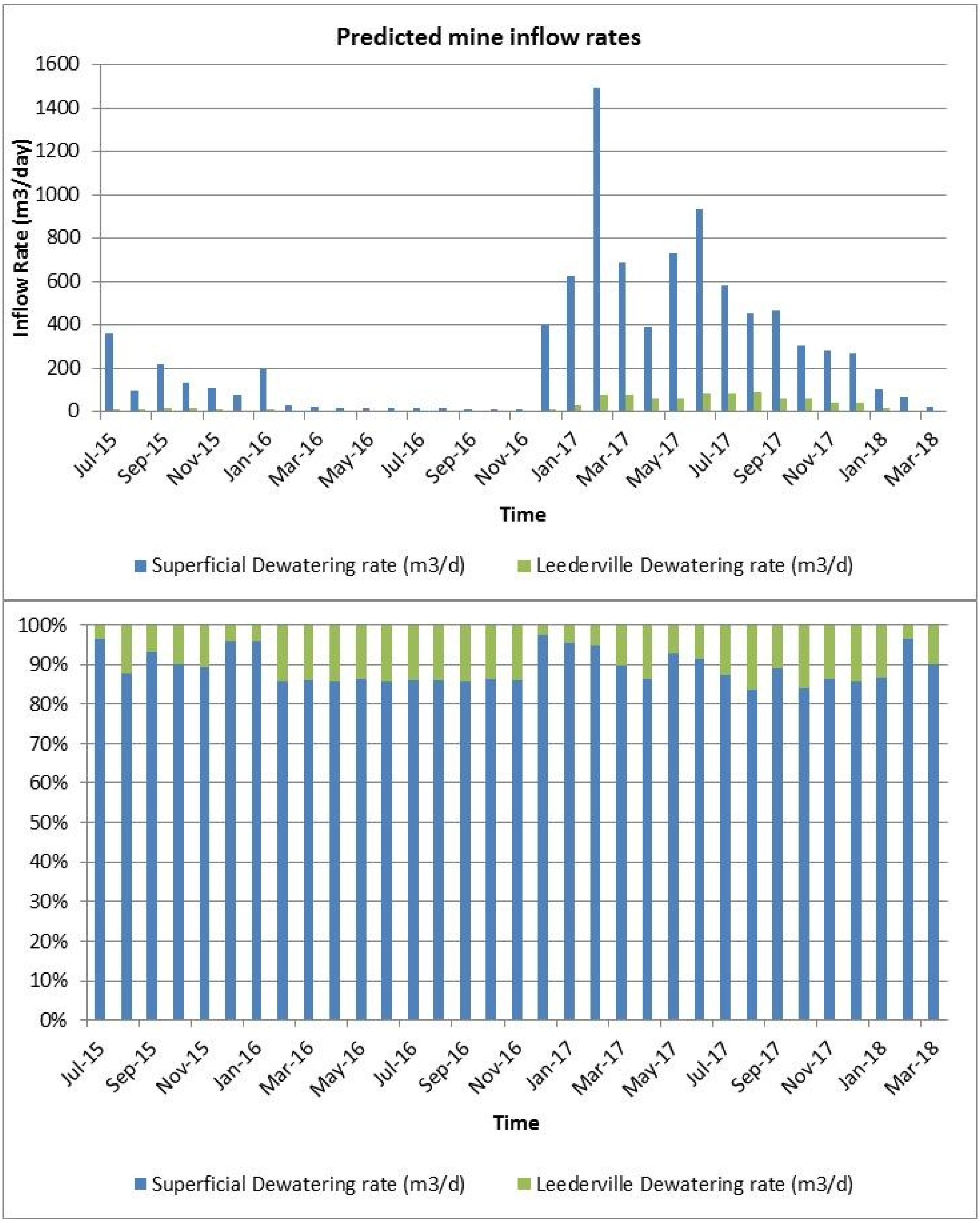


Figure 3.7 Predicted dewatering rate (m^3/day)

The predicted contribution from the Leederville Aquifer to total pit inflows varies between 0 and 20% with an average of 11.8%.

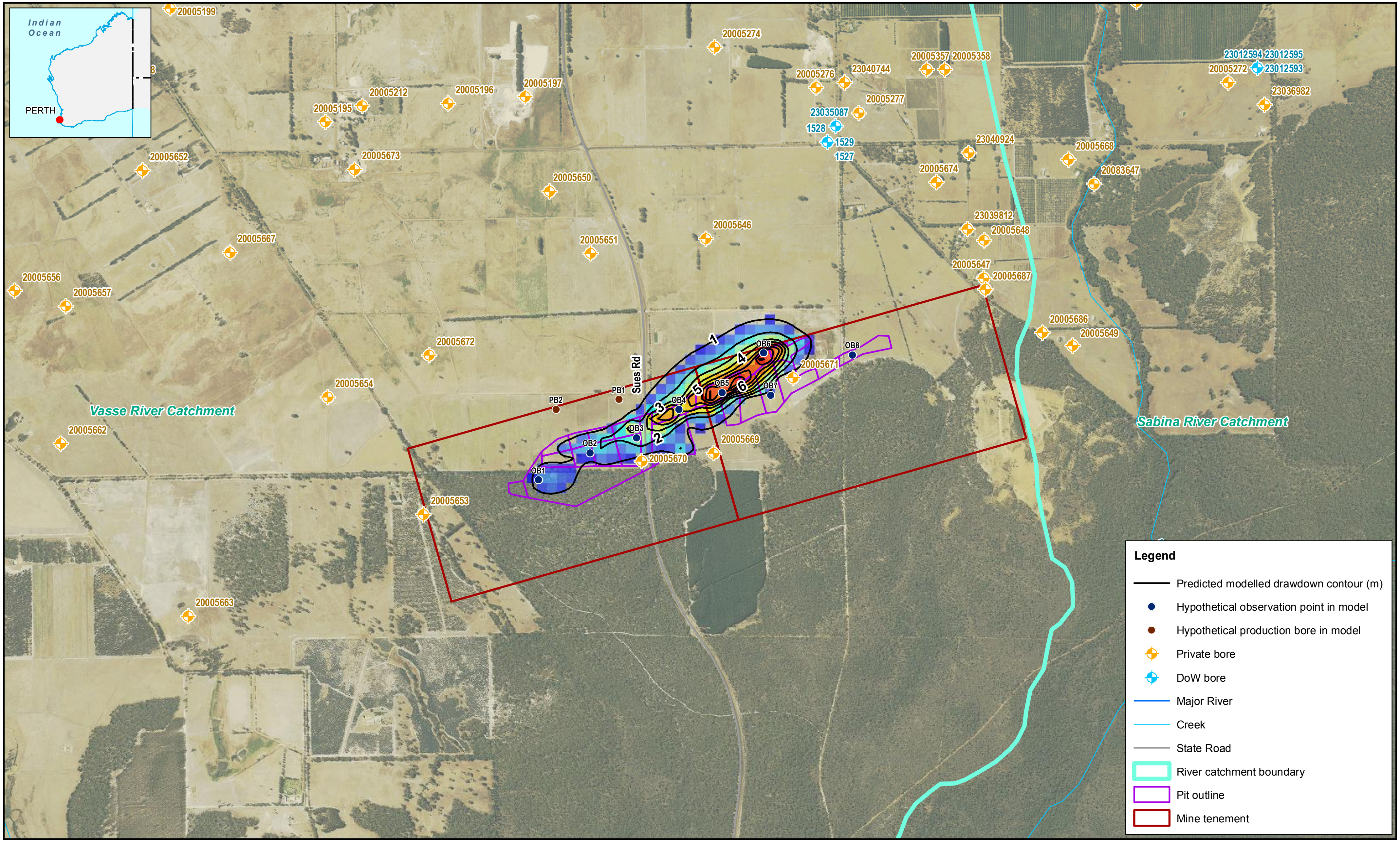
Table 3.4 Predicted dewatering rates

Month	Superficial		Leederville			
	Dewatering rate (m^3/d)	Dewatering rate (L/s)	Dewatering rate (m^3/d)	Dewatering rate (L/s)	Total outflow (m^3/day)	Cumulative dewatering volume (ML)
Jul-15	364	4.2	14	0.16	377	12
Aug-15	97	1.1	14	0.16	110	15
Sep-15	223	2.6	17	0.19	239	22
Oct-15	134	1.5	15	0.17	148	27
Nov-15	112	1.3	14	0.16	125	31
Dec-15	80	0.9	4	0.04	84	33
Jan-16	197	2.3	9	0.10	206	40
Feb-16	29	0.3	5	0.06	34	41
Mar-16	22	0.3	4	0.00	26	41
Apr-16	20	0.2	3	0.04	23	42
May-16	18	0.2	3	0.03	21	43
Jun-16	16	0.2	3	0.03	19	43
Jul-16	16	0.2	3	0.03	18	44
Aug-16	15	0.2	2	0.03	17	44
Sep-16	14	0.2	2	0.03	16	45
Oct-16	14	0.2	2	0.03	16	45
Nov-16	13	0.1	2	0.02	15	46
Dec-16	400	4.6	11	0.12	410	58
Jan-17	627	7.3	29	0.34	656	79
Feb-17	1,495	17.3	81	0.93	1,575	123
Mar-17	687	7.9	80	0.92	766	147
Apr-17	390	4.5	61	0.71	451	160
May-17	730	8.4	58	0.67	788	185
Jun-17	932	10.8	86	1.00	1,018	215
Jul-17	582	6.7	84	0.97	666	236
Aug-17	455	5.3	89	1.03	544	253
Sep-17	464	5.4	58	0.67	522	268
Oct-17	307	3.6	58	0.67	365	280
Nov-17	284	3.3	45	0.52	328	289
Dec-17	268	3.1	45	0.52	312	299
Jan-18	103	1.2	16	0.19	119	303
Feb-18	68	0.8	3	0.03	70	305
Mar-18	23	0.3	3	0.03	25	306

3.10.3 Predicted drawdowns

Predicted drawdown contours for the life of mine (LOM) are shown in Figure 3.8 to Figure 3.11. The LOM drawdown contours represent the maximum drawdown at any time throughout mining activities. These predicted drawdown contour maps indicate that drawdown will be limited to mostly within and immediately surrounding the mine pits. Given the uncertainties of the model and seasonal natural fluctuations, the minimum drawdown contour plotted is the 1m contour. The predicted extent of groundwater drawdown is described below:

- The LOM predicted 1 m drawdown contour is expected to extend to approximately 0.35 km from pit boundary in a northerly direction;
- The 1 m drawdown contour is expected to extend to approximately. 0.2 km from pit boundary for the Mowen Member in a northerly direction;
- Predicted drawdown in both the Superficial Aquifer and Mowen Member to the south of the mine is limited such that the 1 m drawdown contour is not expected to extend beyond the mine pit boundary.
- No mining related drawdown is predicted in the Vasse Member and Yarragadee Aquifer.
- Abstraction from the proposed Yarragadee water supply wells will cause localised groundwater drawdown in both the Yarragadee Aquifer and the Vasse Member. A maximum drawdown of some 1.3 m adjacent to the production wells is predicted with the 1m drawdown contour extending up to 90 m from the production bores in the Yarragadee Aquifer and up to 80 m in the Vasse Member.



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Predicted modelled drawdown contours LOM (Layer 1)

Figure 3-8

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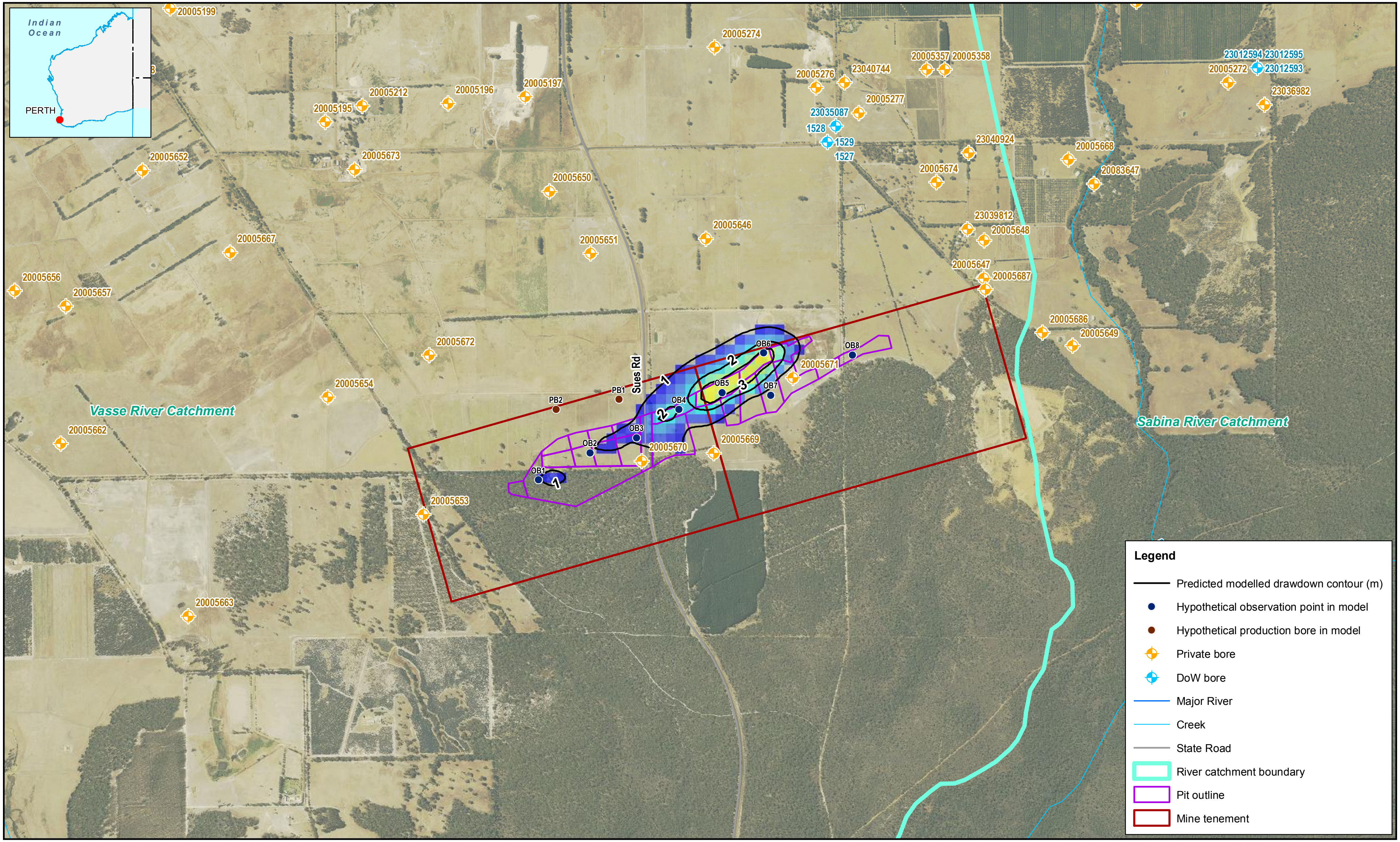

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Predicted modelled drawdown contours LOM (Layer 2)
Figure 3-9

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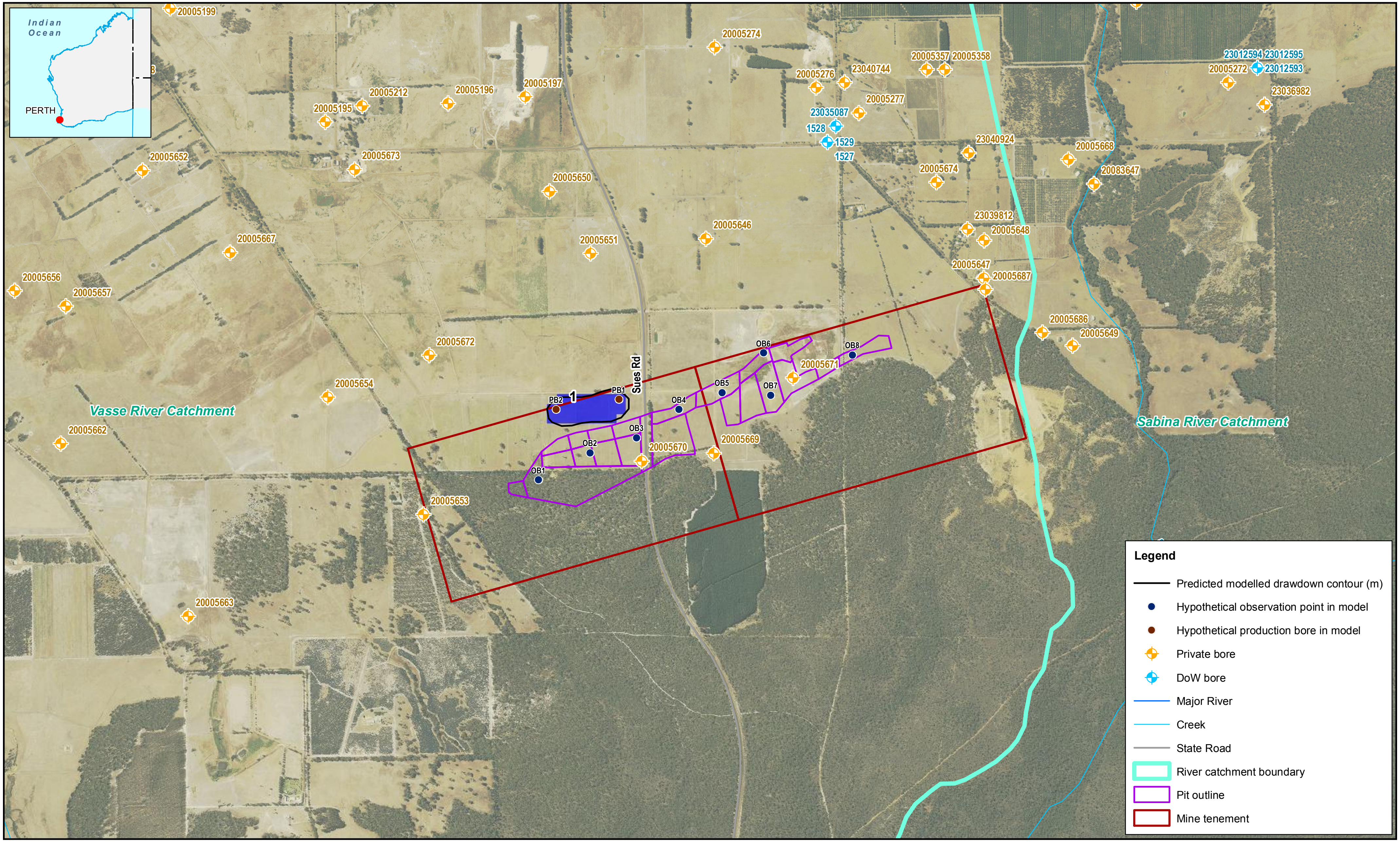

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Predicted modelled drawdown contours LOM (Layer 3)

Figure 3-10

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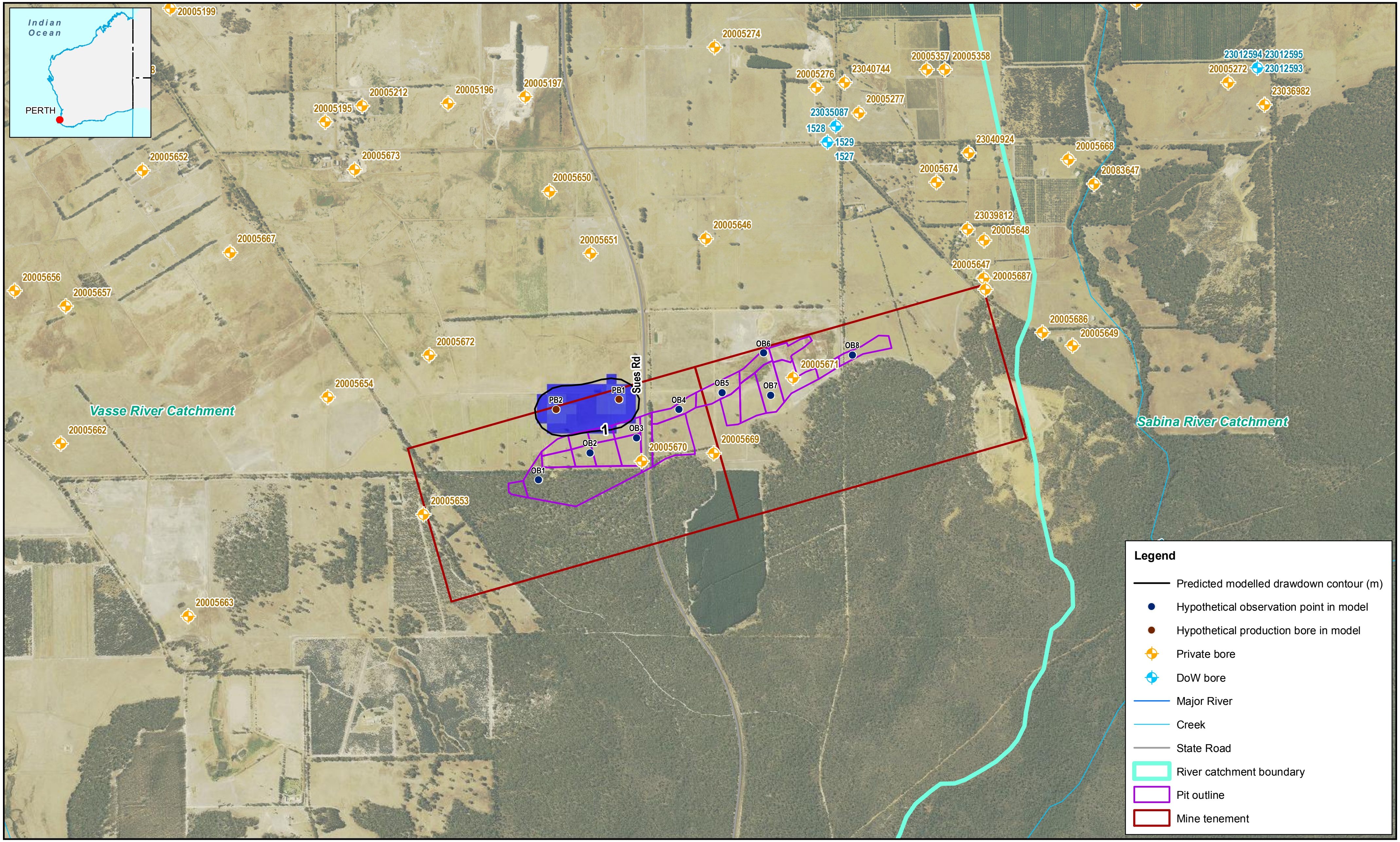

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Predicted modelled drawdown contours LOM (Layer 4)
Figure 3-11

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3.10.4 Drawdown impacts on private bores

Privately owned groundwater bores identified in the project area (PB 2011) are shown in Figure 3.8 along with contours of maximum predicted drawdown for the life of mine in the Superficial Aquifer. The results suggest that none of the identified private bores will experience drawdown of more than 1 m during the life of the mine relating to impacts associated with the proposed mine (Figure 3.13). Three bores (20005669, 20005670 and 20005671) are located proximal to the predicted 1.0 m contour line and may therefore experience some drawdown up to 1.0 m. The impact of groundwater drawdown on water supply bores will likely be a temporary decrease in yield, and slight increase in pumping costs. Bore owners may also need to lower the pump in the well to maintain yields and prevent cavitation.

3.10.5 Potential impacts from the Yarragadee Aquifer abstraction

Abstraction from the proposed Yarragadee water supply wells will cause localised groundwater drawdown in both the Yarragadee Aquifer and the Vasse Member. A maximum drawdown of some 1.3 m adjacent to the production wells is predicted with the 1 m drawdown contour extending radially up to 90 m from the production bores in the Yarragadee Aquifer and up to 80 m in the Vasse Member. Leakage is limited by the Mowen Member (Aquitard) such that no pumping related drawdown greater than 1 m is predicted for the Mowen Member and Superficial Aquifer. As there are no known production bores within that area screened in the Yarragadee Aquifer, it is unlikely that other beneficial users will be impacted by mining related water abstraction.

3.10.6 Recovery prediction

Once mining is complete at Yoongarillup, dewatering will cease and groundwater levels will recover. Groundwater levels will continue to increase until a steady state or equilibrium water level is resumed. Groundwater inflows to the mine voids are driven by water level gradients between the mine voids and the surrounding areas. As groundwater levels within the mine pits increase and gradient decrease, groundwater inflow will also decrease.

In order to illustrate the mine related drawdown and recovery of groundwater levels within the mine lease, eight imaginary observation bores (Bore OB1 to Bore OB8), were inserted into the model to allow hypothetical hydrographs to be generated at each location (Figure 3.14). These hydrographs are shown in Figure 3.12. Simulated bore hydrographs for the existing monitoring bores are also shown in Figure 3.13. The results suggest that 90% recovery is expected to occur within 36 months of mine closure.

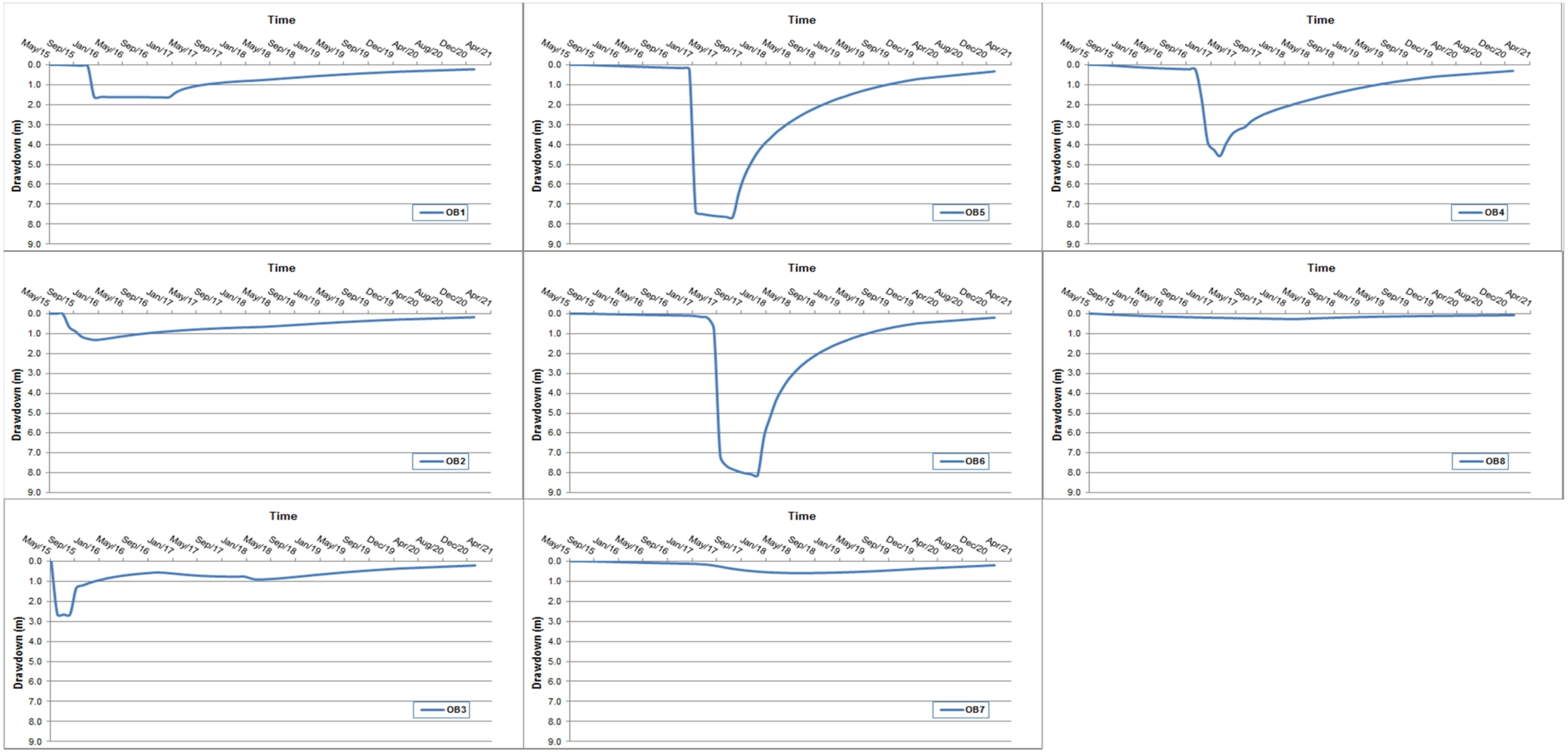

Figure 3-12: Predicted drawdown at hypothetical observation points

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YOONGARILLUP DEPOSITS

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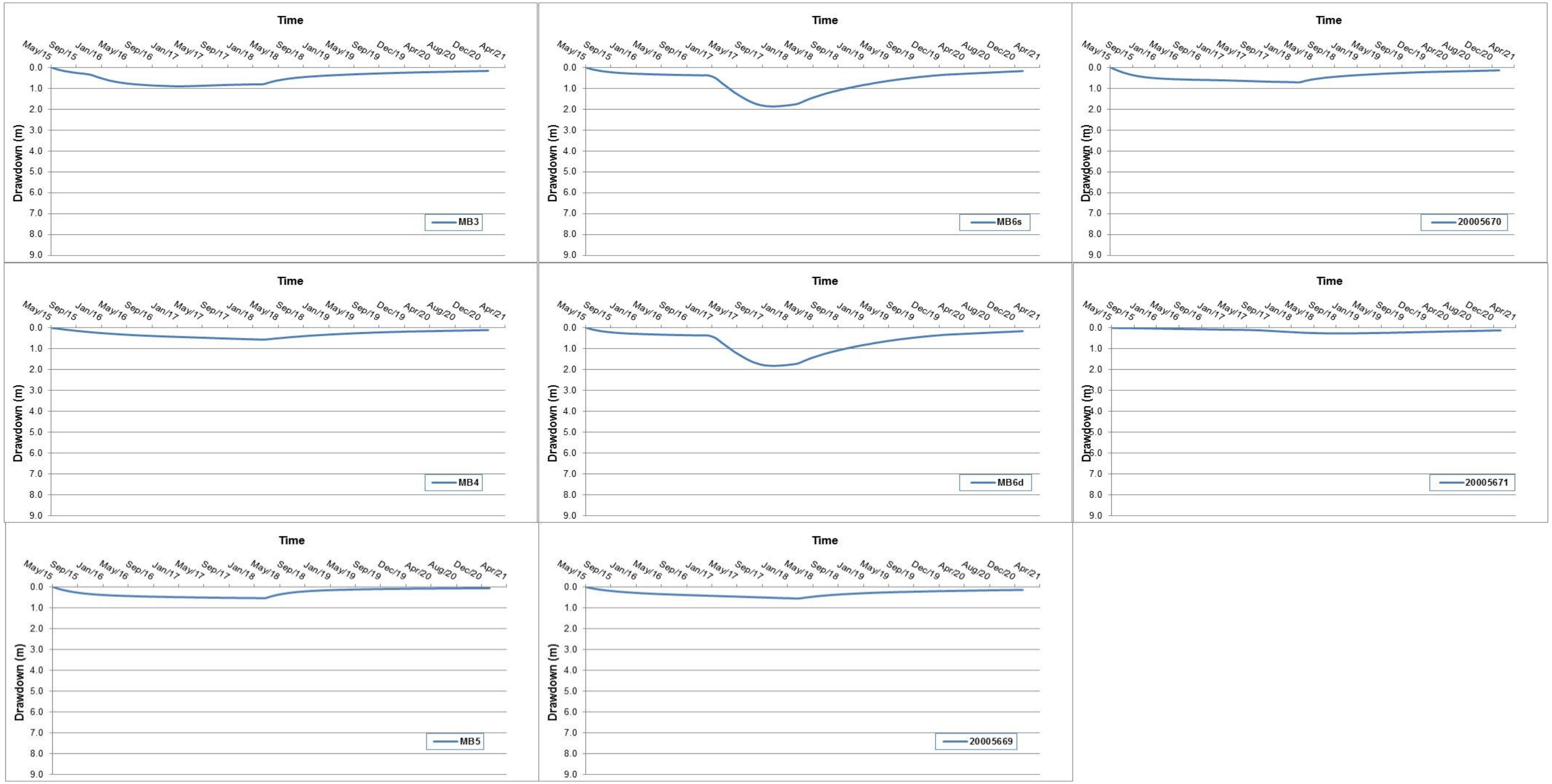

Figure 3-13: Predicted drawdown at existing monitoring points and private bores

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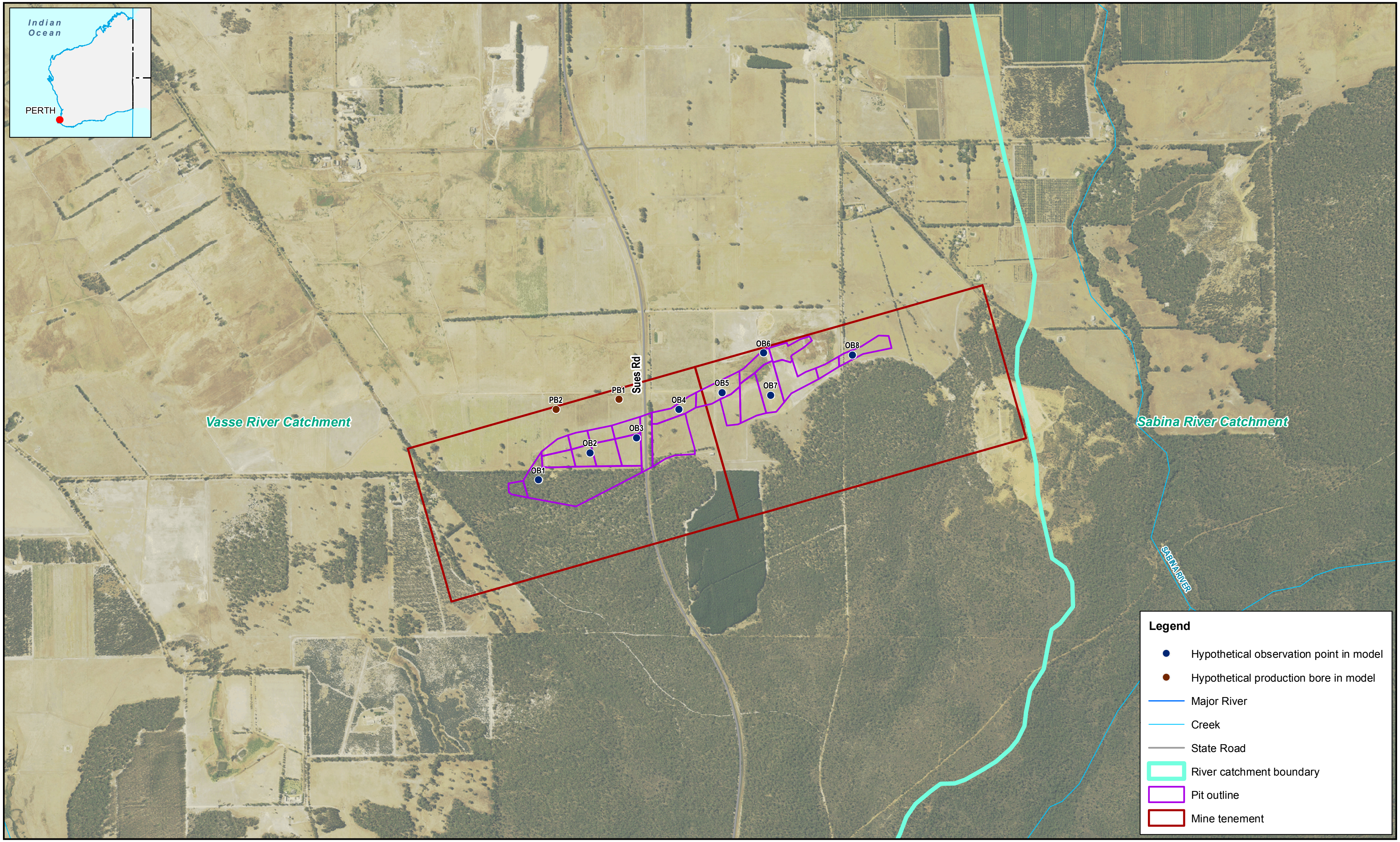

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Location of hypothetical production and observation bores
Figure 3-14

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3.11 Model sensitivity

Uncertainty in the adopted model parameters was assessed by undertaking a model sensitivity analysis. This was conducted on the model predictions to assess the potential uncertainty in predictions of dewatering volumes. The analysis involved running the model consecutively with the key model parameters varied within a plausible range of values. The details of the sensitivity runs are discussed below:

- Sensitivity run 1: doubling the hydraulic conductivity of Superficial Aquifer with respect to calibrated model.
- Sensitivity run 2: halving the hydraulic conductivity of Superficial Aquifer with respect to calibrated model.
- Sensitivity run 3: doubling the specific yield of Superficial Aquifer with respect to calibrated model.
- Sensitivity run 4: halving the specific yield of Superficial Aquifer with respect to calibrated model.

The model sensitivity run results (Appendix D) indicate that:

- maximum predicted inflows are 47 % (on average) higher in scenarios where hydraulic conductivity is double compared to calibrated model parameters (base case) and maximum predicted inflows are 34 % (on average) lower in scenarios where hydraulic conductivity is half compared to the calibrated model parameters.
- maximum predicted inflows are 11 % (on average) higher in scenarios where specific yield is double compared to calibrated model parameters and maximum predicted inflows are 5 % (on average) lower in scenarios where specific yield is half compared to the calibrated model parameters.

3.12 Model limitations

As with all groundwater flow models, there are limitations associated with the data availability, conceptualisation and representation of dynamic flow processes. The model is calibrated to the available data and is fit for the purpose of predicting the dewatering requirements and assessing groundwater drawdown associated with the proposed mine.

The numerical model is a simplification of the hydrogeological processes. It was developed based on a number of assumptions:

- The model was calibrated to steady state condition to the available water level data. To date, insufficient long term groundwater monitoring data are available to calibrate the model to transient or seasonally varying groundwater conditions.
- Currently the model does not include any additional stress outside the study area i.e. groundwater abstraction on nearby farming properties, agricultural drain influences etc;
- No perched aquifers were included in the numerical groundwater flow model. Perched groundwater may develop in some areas seasonally.
- Groundwater abstraction other than pit inflow is limited to two production wells screened in the Yarragadee and is constant throughout the life of mine (50 l/sec based on a 1.6 GL/year abstraction license)
- For the purpose of this modelling exercise the base and walls of the evaporation ponds and process water ponds are assumed to be effectively impermeable due to accumulation of fines and slimes and the stored water does not influence the groundwater flow and level

4. Conclusions and recommendations

As part of the groundwater assessment for the proposed Yoongarillup mineral sands deposits, Parsons Brinckerhoff has undertaken the following works:

- Desktop study to establish geological and hydrogeological framework for Yoongarillup and the surrounding area, and the establishment of a groundwater monitoring network;
- Field Investigation comprising aquifer tests to the aforementioned monitoring bores;
- Development of a conceptual and numerical model.

The results of the groundwater modelling are summarised as follows:

- Due to decreasing saturated thickness of the Superficial Aquifer south of the mine, drawdown effects and pit inflows are limited in this area.
- Inflow rates and drawdown effects are highest when mining the northern pits due to increasing saturated thickness of the Superficial Aquifer towards the north.
- None of the private bores located within the study area, are expected to experience drawdown of greater than 1.0 m during the life of the mining operations.
- Three bores (20005669, 20005670 and 20005671) are located proximal to the 1.0 m drawdown contour and are likely to show a minor drawdown during the LOM.
- Recovery after mining ceases is slowest in the eastern part of the mine. It is possible that the recovery in that area is quicker in reality as the model may underestimate the recharge in that area.

Despite the uncertainties, the model is considered to provide reasonable estimates of groundwater pit inflow and drawdown. Sensitivity analysis whereby the model was re-run with a range of plausible parameter values suggests that uncertainty in the predictions may be in the order of ± 40%.

The following recommendations are proposed:

- Preparation of an operating strategy in accordance with the requirements of the Department of Water including a water level monitoring plan and water quality sampling protocol prior to the commencement of mining activities.
- A census of private bores should be carried out to provide a baseline and allow identification of impacts to local groundwater users. Private bores should be included in the monitoring program where possible.
- Installation of five to seven additional bores in the Superficial Aquifer to supplement the existing bores screened within the Mowen Member.

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Schafer, DB and Johnson, SL, 2009, Groundwater resources assessment of the Western Busselton-Capel Groundwater Area, Department of Water, Hydrogeological Record Series, HG38.

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Appendix A

Bore logs

Aurora environmental

Lithology and Construction Details

Lithology		Construction	
░	Sand	▒	cuttings
░	Clayey Sand	▓	bentonite
░	Silty Sand	▒	gravel
▒	Gravelly Sand	▤	screen
▧	Clay	■	casing
▧	Sandy Clay	▥	concrete/grout
▧	Silty Clay		
▩	Gravelly Clay		
▩	Gravel		
▩	Sandy Gravel		
▦	Clayey Gravel		
▤	Silt		

Aurora environmental

Borehole Log

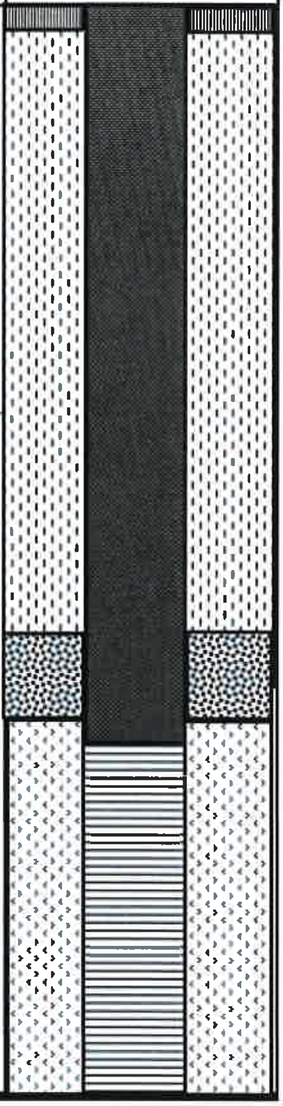
Borehole No:
MB1s

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001
DATE COMMENCED: 24/01/2012
DATE COMPLETED: 24/01/2012
LOGGED BY: D Bourke
CHECKED BY: GMA

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm
Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 20.0m
Static Water Level:
Surface RL:
Datum:
Top of Casing RL:
Water Strike:
Easting: 354902
Northing: 6261720

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION
0.5	▨	Pale yellowish brown clay, with trace of medium grained, sub angular, poorly sorted sand and gravel.
1.0		
1.5		
2.0		
2.5		
3.0	▩	Moderate brown gravelly clay.
3.5		
4.0	▨	Moderate brown sandy clay, medium grained, sub angular, poorly sorted sand, with some gravel.
4.5		
5.0		
5.5		
6.0		
6.5		
7.0		
7.5		
8.0	▨	Grey/pink clay, with some gravel and medium grained, sub rounded, moderately sorted sand.
8.5		
9.0		
9.5		
10.0		
10.5		
11.0		
11.5		
12.0	▨	Grey/pink sandy clay, fine grained, sub rounded to sub angular, moderately sorted sand with some black angular shale pieces to 2mm.
12.5		
13.0		
13.5		
14.0		
14.5		
15.0		
15.5		
16.0	▨	Dark grey silty clay, with some medium grained, sub angular, moderately sorted sand.
16.5		
17.0		
17.5		
18.0		
18.5		
19.0		
19.5		
20.0		

WELL CONSTRUCTION



Borehole Log

Borehole No:
MB1d

CLIENT: Doral Mineral Sands
DATE COMMENCED: 24/01/2012
PROJECT: Yoongarillup
DATE COMPLETED: 24/01/2012
LOCATION: Yoongarillup
LOGGED BY: D Bourke
JOB NUMBER: DMS/2011/001
CHECKED BY: GMA

Drilling Co: Cape Drilling
Drilling Method: Rotary Mud
Surface RL:
Easting: 354902
Driller: Phil Williams
Weather: Fine
Datum:
Northing: 6261720
Class 18 PVC
Total Depth of Hole: 60.0m
Top of Casing RL:
Bore diameter: 50mm
Static Water Level:
Water Strike:

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5	▨	Pale yellowish brown clay, with trace of medium grained, sub angular, poorly sorted sand and gravel.	
1.0			
1.5			
2.0			
2.5			
3.0	▨	Moderate brown gravelly clay.	
3.5			
4.0	▨	Moderate brown sandy clay, medium grained, sub angular, poorly sorted sand, with some gravel.	
4.5			
5.0			
5.5			
6.0			
6.5			
7.0			
7.5			
8.0	▨	Grey/pink clay, with some gravel and medium grained, sub rounded sand.	
8.5			
9.0			
9.5			
10.0			
10.5			
11.0			
11.5			
12.0	▨	Grey/pink sandy clay, fine grained, sub rounded to sub angular, moderately sorted sand with some black angular shale to 2mm.	
12.5			
13.0			
13.5			
14.0			
14.5			
15.0			
15.5			
16.0	▨	Dark grey silty clay, with some medium grained, sub angular, moderately sorted sand.	
16.5			
17.0			
17.5			
18.0			
18.5			
19.0			
19.5			
20.0			

Borehole Log

Borehole No:
MB1d

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001
DATE COMMENCED: 24/01/2012
DATE COMPLETED: 24/01/2012
LOGGED BY: D Bourke
CHECKED BY:

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm
Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 60.0m
Static Water Level:
Surface RL:
Datum:
Top of Casing RL:
Water Strike:
Easting: 354902
Northing: 6261720

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
20.5	▨	Dark grey/black silty clay, with trace of fine grained, sub angular, moderately sorted sand.	
21.0			
21.5			
22.0			
22.5			
23.0			
23.5			
24.0			
24.5			
25.0			
25.5			
26.0	▨	Dark grey/black silty clay, with some black angular shale pieces to 2mm.	
26.5			
27.0			
27.5			
28.0			
28.5			
29.0			
29.5			
30.0	▨	Dark grey/black stiff clay.	
30.5			
31.0			
31.5			
32.0	▨	Dark grey/black silty clay, with trace coarse grained, sub angular, moderately sorted sand.	
32.5			
33.0			
33.5			
34.0			
34.5			
35.0			
35.5			
36.0	▨	Dark grey silty clay.	
36.5			
37.0			
37.5			
38.0			
38.5			
39.0	▨	Dark grey silty clay, with some coarse grained, sub angular, moderately sorted sand and some black angular pieces of shale to 2mm.	
39.5			
40.0			

Borehole Log

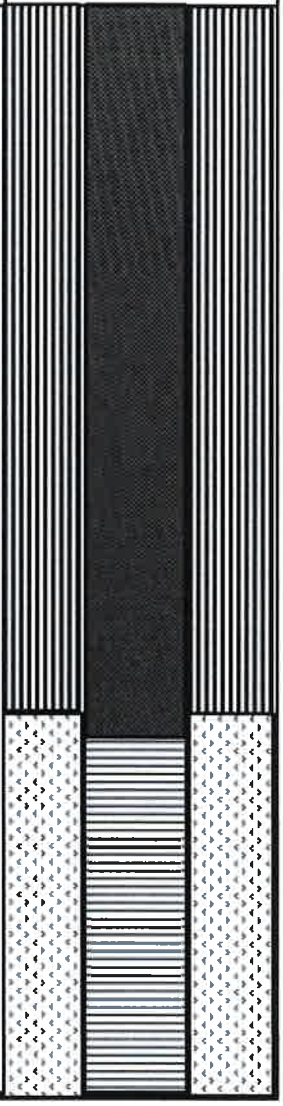
Borehole No:
MB1d

CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	24/01/2012
PROJECT:	Yoongarillup	**DATE COMPLETED:**	24/01/2012
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	354902
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6261720
Class 18 PVC		**Total Depth of Hole:**	60.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION
40.5	▨	Dark grey silty clay, with some black angular pieces of shale to 2mm.
41.0		
41.5		
42.0		
42.5		
43.0		
43.5		
44.0		
44.5		
45.0		
45.5		
46.0		
46.5		
47.0		
47.5		
48.0		
48.5		
49.0		
49.5		
50.0		
50.5		
51.0		
51.5		
52.0		
52.5		
53.0		
53.5		
54.0		
54.5		
55.0		
55.5		
56.0		
56.5		
57.0		
57.5		
58.0		
58.5		
59.0		
59.5		
60.0		

WELL CONSTRUCTION



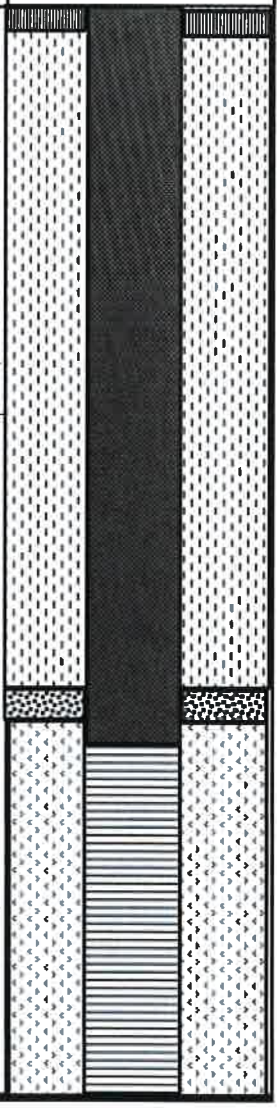
Aurora environmental

Borehole Log

Borehole No:
MB2

CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	24/01/2011
PROJECT:	Yoongarillup	**DATE COMPLETED:**	24/01/2011
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	GMA

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	354553
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6262509
Class 18 PVC		**Total Depth of Hole:**	20.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

Depth (mBGL)	GRAPHICAL LOG	LITHOLOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5		Pale yellowish brown clayey gravel, with trace of medium grained, sub rounded, moderately sorted sand.	
1.0			
1.5			
2.0			
2.5			
3.0		Light grey clayey gravel.	
3.5			
4.0			
4.5			
5.0			
5.5			
6.0			
6.5			
7.0		Moderate red silt, with some coarse grained, sub angular, poorly sorted sand and gravel.	
7.5			
8.0		Light grey/pink silt, with trace of medium grained, sub angular, moderately sorted sand.	
8.5			
9.0			
9.5			
10.0		Light grey/pink clay, with trace of medium grained, sub angular, moderately sorted sand.	
10.5			
11.0		Moderate brown silty clay, with some gravel.	
11.5			
12.0			
12.5			
13.0			
13.5			
14.0			
14.5			
15.0			
15.5			
16.0			
16.5			
17.0		Dark grey stiff clay, with trace of coarse grained, sub angular, moderately sorted sand and gravel.	
17.5			
18.0			
18.5			
19.0			
19.5			
20.0			

Aurora environmental

Borehole Log

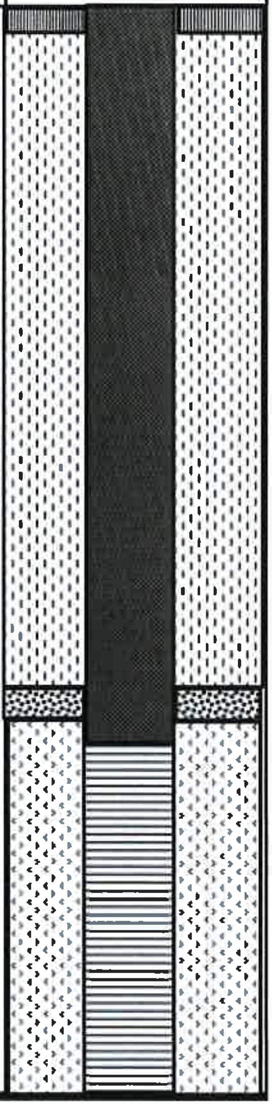
Borehole No: **MB3**

CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	27/01/2011
PROJECT:	Yoongarillup	**DATE COMPLETED:**	27/01/2011
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	GMA

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	353420
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6262874
Class 18 PVC		**Total Depth of Hole:**	20.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION
0.5		
1.0		Yellowish brown sand, fine to medium grained, sub-rounded to sub-angular, moderately sorted sand.
1.5		
2.0		
2.5		
3.0		Yellowish brown/light grey stiff clay, with hard lateritic layer from 4.0-5.0m.
3.5		
4.0		
4.5		
5.0		
5.5		
6.0		Light grey/pink stiff clay.
6.5		
7.0		
7.5		Light grey/yellowish brown stiff clay, with some lateritic gravel, trace of coarse grained, sub angular, moderately sorted sand.
8.0		
8.5		
9.0		Light grey/yellowish brown/red gravelly clay.
9.5		
10.0		
10.5		
11.0		
11.5		
12.0		
12.5		
13.0	No sample	No sample (loss of drill fluid and sample return in formation - possible void).
13.5		
14.0		
14.5		
15.0		
15.5		
16.0		
16.5		
17.0		
17.5		
18.0		Dark grey stiff clay.
18.5		
19.0		
19.5		
20.0		

WELL CONSTRUCTION

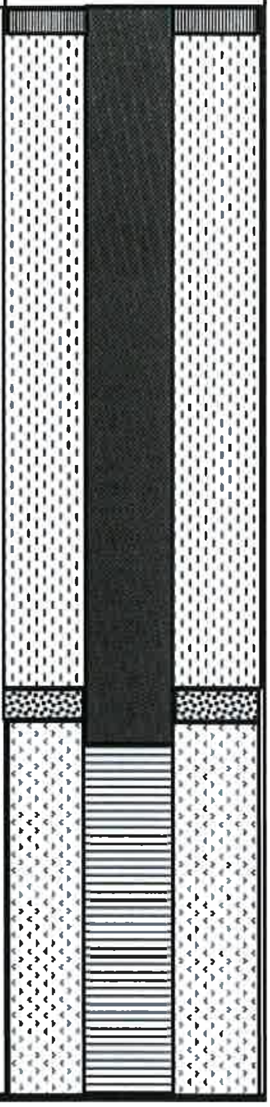


Borehole Log

Borehole No:
MB4

CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	27/01/2011
PROJECT:	Yoongarillup	**DATE COMPLETED:**	27/01/2011
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	GMA

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	354472
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6263111
Class 18 PVC		**Total Depth of Hole:**	20.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5		Reddish brown gravelly sand, moderate to coarse grained, sub angular, moderately sorted sand.	
1.0			
1.5			
2.0			
2.5		Pale yellowish brown stiff clay.	
3.0			
3.5			
4.0			
4.5			
5.0			
5.5			
6.0			
6.5			
7.0			
7.5		Lightg grey/pink stiff clay.	
8.0			
8.5			
9.0			
9.5			
10.0			
10.5			
11.0			
11.5			
12.0			
12.5			
13.0			
13.5			
14.0			
14.5			
15.0			
15.5			
16.0			
16.5			
17.0			
17.5			
18.0			
18.5			
19.0			
19.5			
20.0			

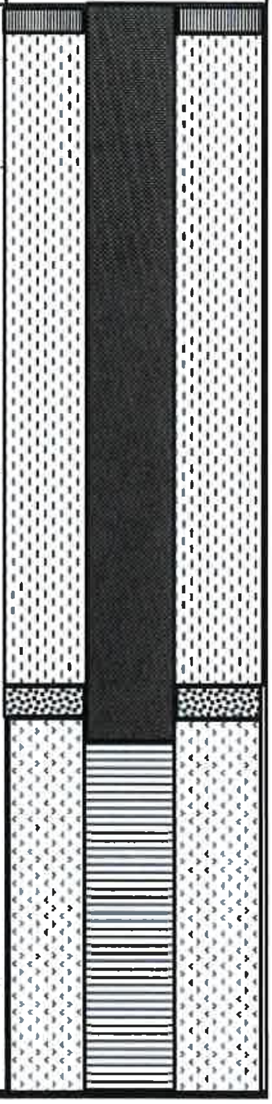
Aurora environmental

Borehole Log

Borehole No:
MB5

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001
DATE COMMENCED: 27/01/2011
DATE COMPLETED: 27/01/2011
LOGGED BY: D Bourke
CHECKED BY: GMA

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm
Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 20.0m
Static Water Level:
Surface RL:
Datum:
Top of Casing RL:
Water Strike:
Easting: 353382
Northing: 6263250

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5	░	Grey sand, fine grained, sub rounded, well sorted.	
1.0	░		
1.5	▩	Brown sandy lateritic gravel, medium grained, sub angular, moderately sorted. Hard lateritic layer at 2m.	
2.0	▩		
2.5	▦	Reddish brown clayey gravel.	
3.0	▦		
3.5	▩	Light grey gravelly clay.	
4.0	▩		
4.5	▩		
5.0	▩		
5.5	▩		
6.0	▩		
6.5	▩		
7.0	▩	Light grey/moderate reddish brown gravelly clay.	
7.5	▩		
8.0	▩		
8.5	▩		
9.0	▧	Yellowish brown stiff clay with some gravel.	
9.5	▧		
10.0	▧		
10.5	▧		
11.0	▧		
11.5	▧		
12.0	▧		
12.5	▧		
13.0	▧	Yellowish brown stiff clay with trace of coarse grained, sub rounded, moderately sorted sand.	
13.5	▧		
14.0	▧		
14.5	▧		
15.0	▧		
15.5	▧		
16.0	▧		
16.5	▧		
17.0	▧		
17.5	▧		
18.0	▧		
18.5	▧	Dark grey stiff clay.	
19.0	▧		
19.5	▧		
20.0	▧		

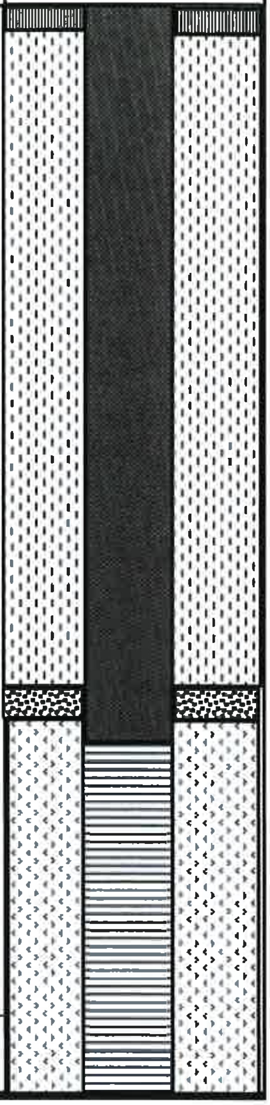
Aurora environmental

Borehole Log

Borehole No:
MB6s

CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	25/01/2011
PROJECT:	Yoongarillup	**DATE COMPLETED:**	25/01/2011
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	GMA

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	354298
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6263377
Class 18 PVC		**Total Depth of Hole:**	20.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

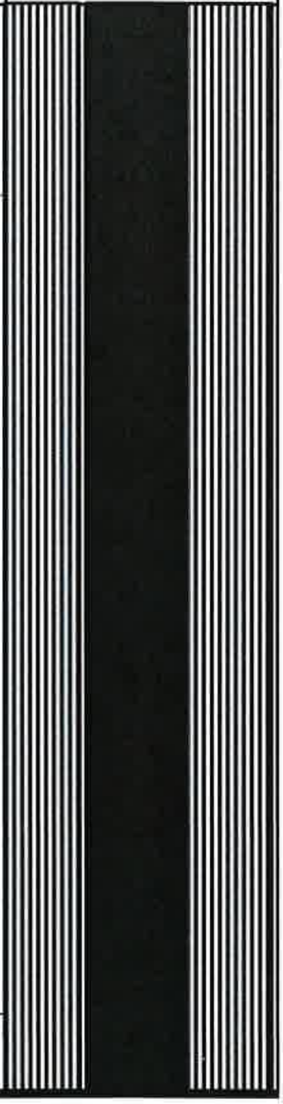
Depth (mBGL)	GRAPHICAL LOG	LITHOLOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5			
1.0			
1.5			
2.0		Grey silty sand.	
2.5			
3.0			
3.5			
4.0			
4.5			
5.0			
5.5			
6.0		Grey/brown silty sand.	
6.5			
7.0			
7.5			
8.0			
8.5			
9.0			
9.5			
10.0			
10.5			
11.0		Light grey/pink sandy clay, fine to medium grained, sub rounded, moderately sorted sand.	
11.5			
12.0			
12.5			
13.0			
13.5			
14.0			
14.5		Moderate red sandy clay, medium grained, sub rounded to sub angular, moderately sorted sand.	
15.0			
15.5			
16.0			
16.5			
17.0		Yellow sandy clay, coarse grained, sub angular, moderately sorted sand.	
17.5			
18.0			
18.5			
19.0			
19.5		Dark grey stiff clay	
20.0			

Borehole Log

Borehole No:
MB6d

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001
DATE COMMENCED: 25/01/2012
DATE COMPLETED: 25/01/2012
LOGGED BY: D Bourke
CHECKED BY:

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm
Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 60.0m
Static Water Level:
Surface RL:
Datum:
Top of Casing RL:
Water Strike:
Easting: 354298
Northing: 6263377

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5	░	Grey silty sand.	
1.0			
1.5			
2.0			
2.5			
3.0			
3.5			
4.0		Grey/brown silty sand.	
4.5			
5.0			
5.5			
6.0			
6.5			
7.0			
7.5			
8.0			
8.5			
9.0	▨	Light grey/pink sandy clay, fine to medium grained, sub rounded, moderately sorted sand.	
9.5			
10.0			
10.5			
11.0			
11.5			
12.0			
12.5			
13.0			
13.5			
14.0		Moderate red sandy clay, medium grained, sub rounded to sub angular, moderately sorted sand.	
14.5			
15.0			
15.5			
16.0		Yellow sandy clay, coarse grained, sub angular, moderately sorted sand.	
16.5			
17.0			
17.5			
18.0			
18.5			
19.0		Dark grey stiff clay.	
19.5			
20.0			

Aurora environmental

Borehole Log

Borehole No:
MB6d

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001

DATE COMMENCED: 24/01/2012
DATE COMPLETED: 24/01/2012
LOGGED BY: D Bourke
CHECKED BY:

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm

Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 60.0m
Static Water Level:

Surface RL:
Datum:
Top of Casing RL:
Water Strike:

Easting: 354902
Northing: 6261720

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION
20.5	▨	
21.0	▨	
21.5	▨	
22.0	▨	Dark grey stiff clay.
22.5	▨	
23.0	▨	
23.5	▨	
24.0	▨	
24.5	▨	
25.0	▨	Dark grey stiff clay, with some medium to coarse grained, sub angular, moderately sorted sand.
25.5	▨	
26.0	▨	
26.5	▨	
27.0	▨	
27.5	▨	
28.0	▨	
28.5	▨	
29.0	▨	Dark grey stiff clay.
29.5	▨	
30.0	▨	
30.5	▨	
31.0	▨	
31.5	▨	
32.0	▧	
32.5	▧	
33.0	▧	
33.5	▧	Brown/grey sandy clay, medium to coarse grained, sub angular, moderately sorted sand.
34.0	▧	
34.5	▧	
35.0	▧	
35.5	▧	
36.0	▦	
36.5	▦	Moderate yellowish brown clayey gravel.
37.0	▦	
37.5	▦	
38.0	▨	Dark grey stiff clay.
38.5	▨	
39.0	▨	
39.5	▨	
40.0	▨	

WELL CONSTRUCTION

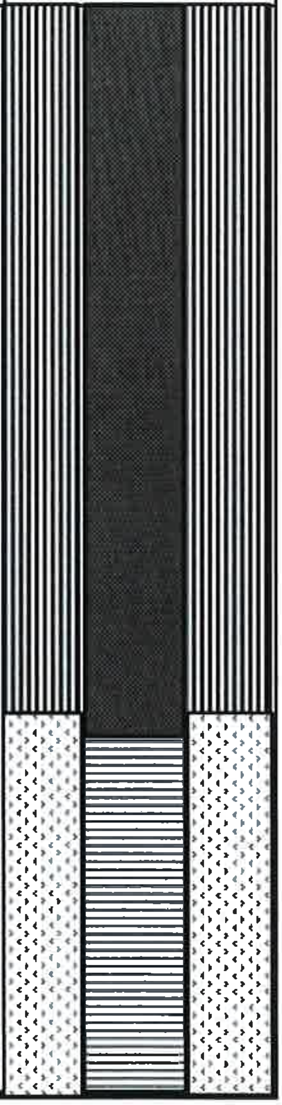
Aurora environmental

Borehole Log

Borehole No:
MB6d

CLIENT: Doral Mineral Sands
PROJECT: Yoongarillup
LOCATION: Yoongarillup
JOB NUMBER: DMS/2011/001
DATE COMMENCED: 24/01/2012
DATE COMPLETED: 24/01/2012
LOGGED BY: D Bourke
CHECKED BY: GMA

Drilling Co: Cape Drilling
Driller: Phil Williams
Class 18 PVC
Bore diameter: 50mm
Drilling Method: Rotary Mud
Weather: Fine
Total Depth of Hole: 60.0m
Static Water Level:
Surface RL:
Datum:
Top of Casing RL:
Water Strike:
Easting: 354902
Northing: 6261720



Depth (mBGL)	LITHOGICAL DESCRIPTION
40.5	Grey stiff clay.
41.0	
41.5	
42.0	Grey silty clay.
42.5	
43.0	
43.5	
44.0	Dark grey stiff clay.
44.5	
45.0	
45.5	
46.0	
46.5	
47.0	Grey stiff clay with trace of fine to medium grained, sub angular, moderately sorted sand.
47.5	
48.0	Grey stiff clay.
48.5	
49.0	
49.5	
50.0	Grey stiff clay ,with trace of fine to medium grained, sub angular, moderately sorted sand.
50.5	
51.0	
51.5	
52.0	
52.5	
53.0	
53.5	
54.0	
54.5	
55.0	
55.5	
56.0	
56.5	
57.0	
57.5	
58.0	
58.5	
59.0	
59.5	
60.0	

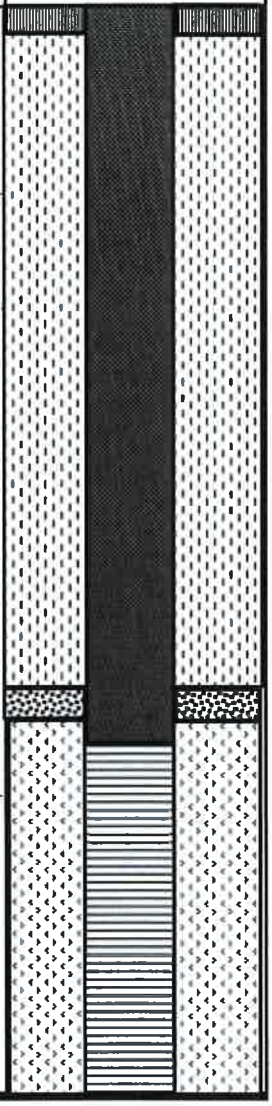
WELL CONSTRUCTION

Borehole Log

Borehole No:
MB7

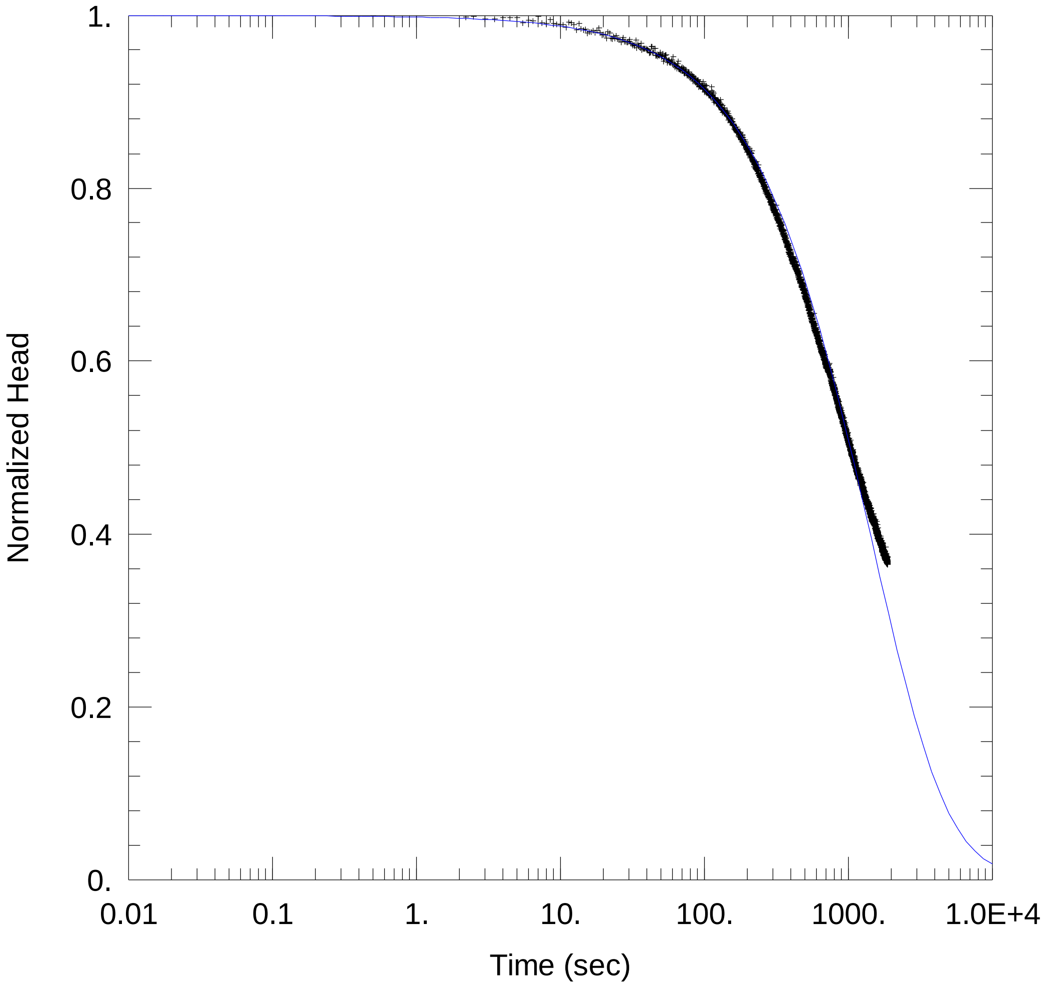
CLIENT:	Doral Mineral Sands	**DATE COMMENCED:**	27/01/2011
PROJECT:	Yoongarillup	**DATE COMPLETED:**	27/01/2011
LOCATION:	Yoongarillup	**LOGGED BY:**	D Bourke
JOB NUMBER:	DMS/2011/001	**CHECKED BY:**	GMA

Drilling Co:	Cape Drilling	**Drilling Method:**	Rotary Mud	**Surface RL:**		**Easting:**	355399
Driller:	Phil Williams	**Weather:**	Fine	**Datum:**		**Northing:**	6263978
Class 18 PVC		**Total Depth of Hole:**	20.0m	**Top of Casing RL:**			
Bore diameter:	50mm	**Static Water Level:**		**Water Strike:**			

Depth (mBGL)	GRAPHICAL LOG	LITHOGICAL DESCRIPTION	WELL CONSTRUCTION
0.5	░	Grey sand, medium to coarse grained, sub rounded, moderately sorted sand.	
1.0			
1.5			
2.0			
2.5			
3.0	▨	Pale yellowish brown/light greenish grey clay, with some coarse grained, sub rounded, moderately sorted sand and gravel.	
3.5			
4.0		Light greenish grey clay with some gravel, hard lateritic layer between 4.0-5.0m.	
4.5			
5.0			
5.5			
6.0		Moderate yellowish brown clay with some coarse grained, sub angular, poorly sorted sand and gravel.	
6.5			
7.0			
7.5			
8.0			
8.5			
9.0		Light greeny grey/moderate red clay.	
9.5			
10.0			
10.5			
11.0		Light greenish grey/pink clay.	
11.5			
12.0			
12.5			
13.0			
13.5			
14.0		Light greenish grey/pink clay with some coarse grained, sub angular moderately, sorted sand.	
14.5			
15.0		Light greenish grey/pink clay with trace of medium to coarse grained sand.	
15.5			
16.0			
16.5			
17.0			
17.5			
18.0			
18.5			
19.0			
19.5			
20.0			

Appendix B

Slug testing results



MB1(S)

Data Set: \...\MB1S_Falling.aqt
Date: 04/03/12
Time: 09:14:06

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB1S
Test Date: 22/03/12

AQUIFER DATA

Saturated Thickness: 15.05 m

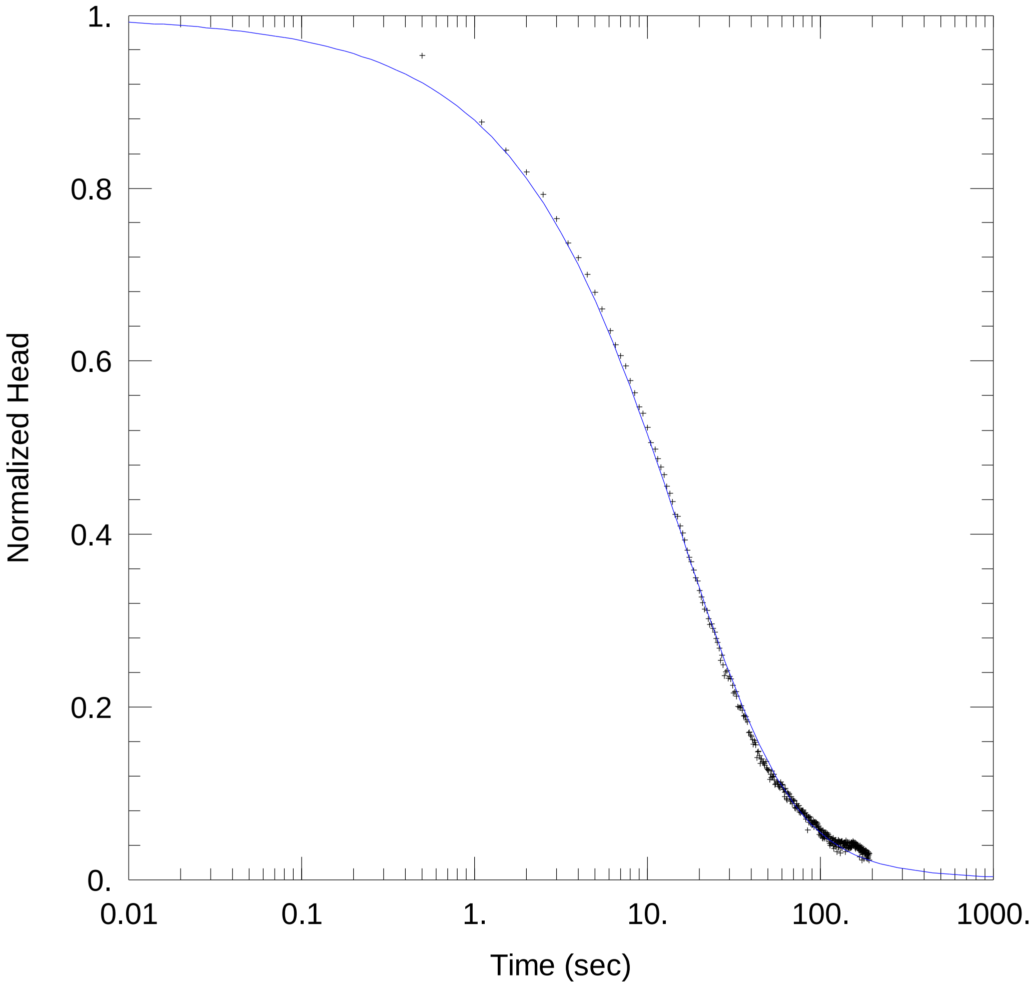
WELL DATA (MB1S)

Initial Displacement: 0.6179 m
Total Well Penetration Depth: 6. m
Casing Radius: 0.025 m
Static Water Column Height: 5.05 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.01564 m/day
Kz/Kr = 0.001
Ss = 1.0E-6 m^{-1}



MB3_RISING

Data Set: \...\MB3_Rising.aqt
Date: 04/03/12 Time: 09:49:32

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB1S
Test Date: 22/03/12

AQUIFER DATA

Saturated Thickness: 14.87 m

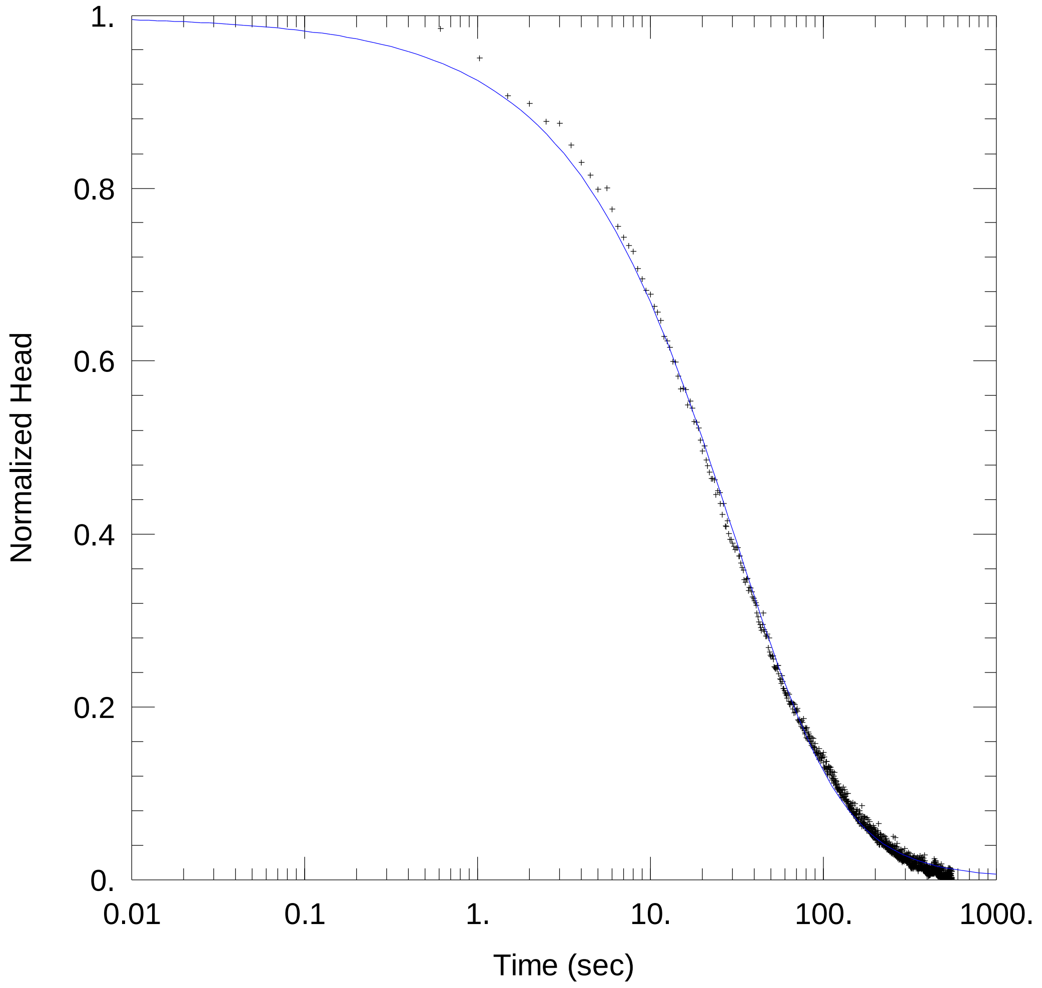
WELL DATA (MB3)

Initial Displacement: -0.6689 m
Total Well Penetration Depth: 9.87 m
Casing Radius: 0.025 m
Static Water Column Height: 9.87 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.6618 m/day
Ss = 0.000229 m^{-1}
Kz/Kr = 0.01



MB3

Data Set: \...\MB3_Falling.aqt
Date: 04/03/12 Time: 09:48:10

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB3
Test Date: 22/03/12

AQUIFER DATA

Saturated Thickness: 14.87 m

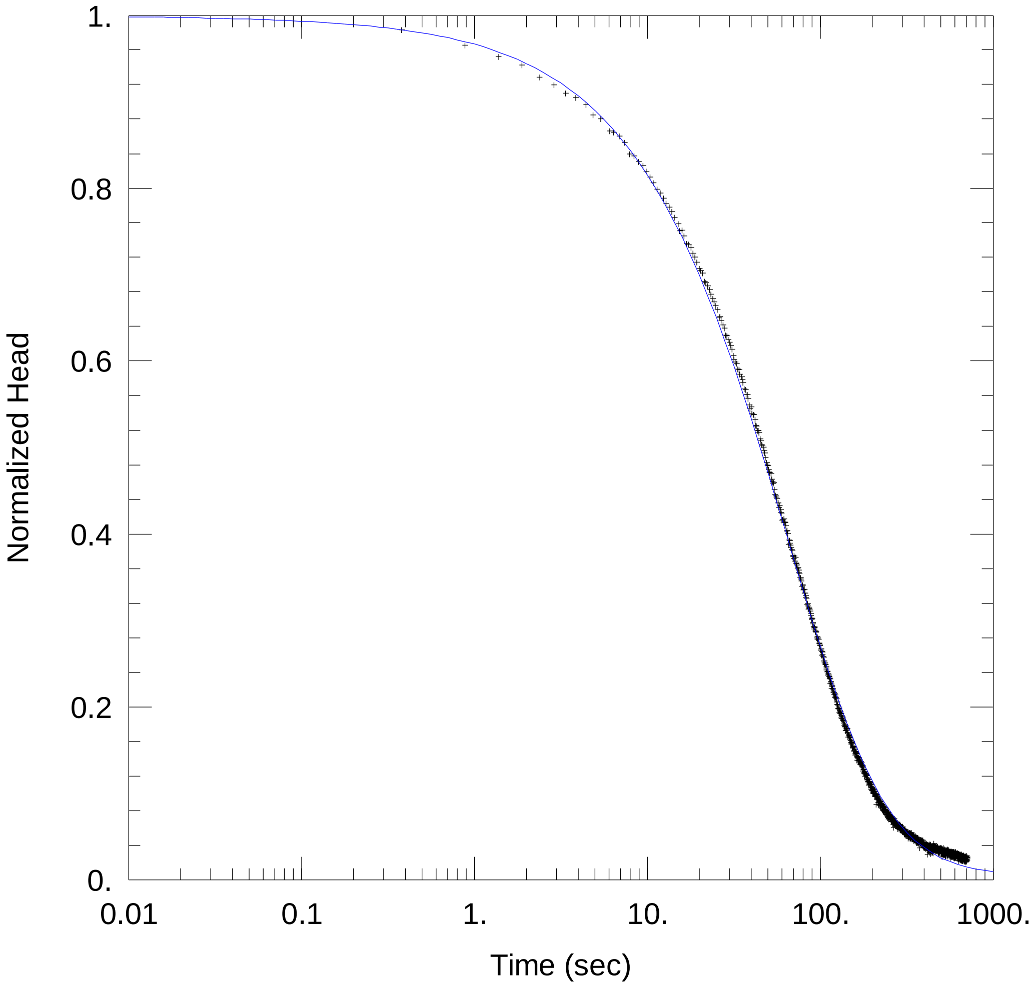
WELL DATA (MB3)

Initial Displacement: 0.4945 m
Total Well Penetration Depth: 9.87 m
Casing Radius: 0.025 m
Static Water Column Height: 9.87 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.3684 m/day
Ss = 0.0001606 m^{-1}
Kz/Kr = 0.01



MB4

Data Set: \...\MB4_Rising.aqt
Date: 04/03/12 Time: 09:56:35

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB4
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 18.3 m

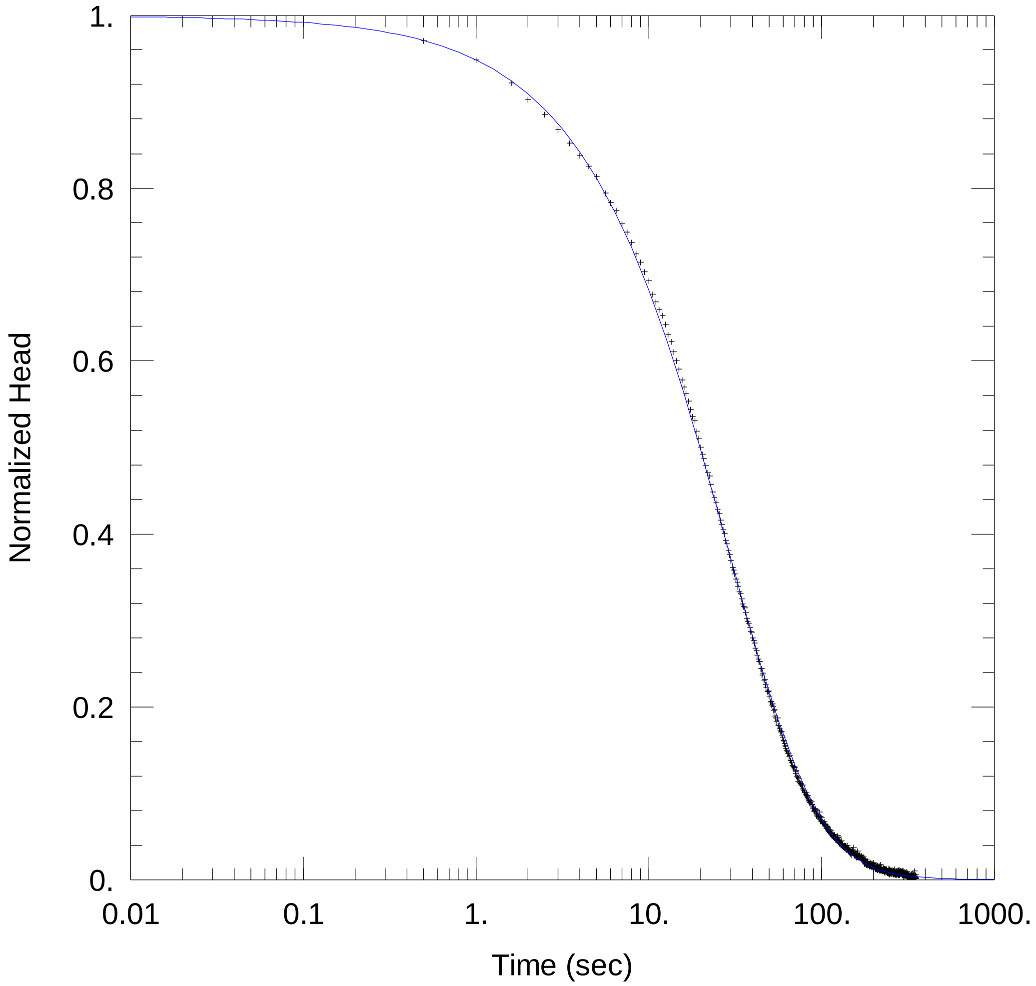
WELL DATA (MB4)

Initial Displacement: -0.9044 m
Static Water Column Height: 8.3 m
Total Well Penetration Depth: 8.3 m
Screen Length: 6. m
Casing Radius: 0.025 m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.2455 m/day
Ss = 2.226E-5 m^{-1}
Kz/Kr = 0.01



MB6 (S)

Data Set: \...\MB6S_Injection.aqt
Date: 04/03/12 Time: 10:28:55

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB6S
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 14.7 m

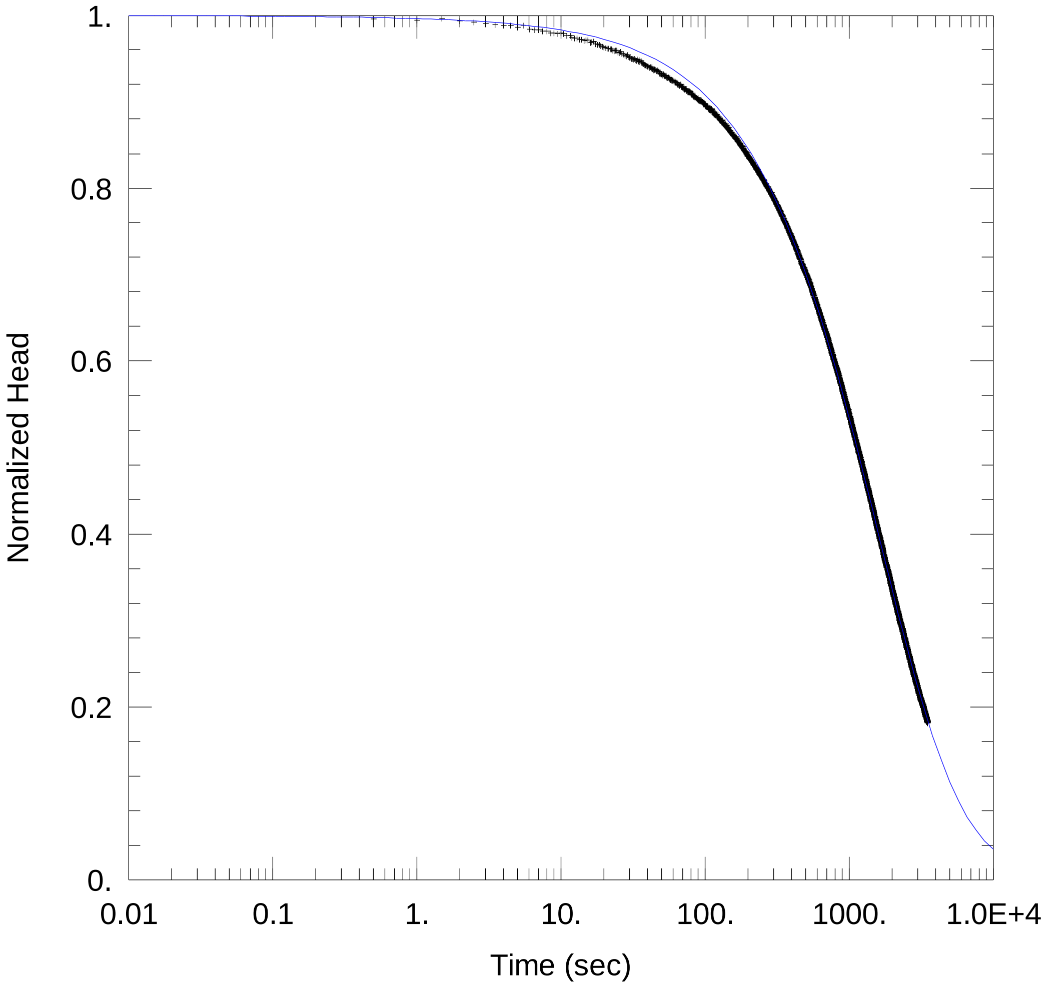
WELL DATA (MB6S)

Initial Displacement: 1.139 m
Total Well Penetration Depth: 14.7 m
Casing Radius: 0.025 m
Static Water Column Height: 14.7 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.7092 m/day
Kz/Kr = 0.1
Ss = 3.005E-6 m^{-1}



MB5

Data Set: \...\MB5_Injection.aqt
Date: 04/03/12 Time: 10:08:01

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB5
Test Date: 22/03/12

AQUIFER DATA

Saturated Thickness: 13.7 m

WELL DATA (MB5)

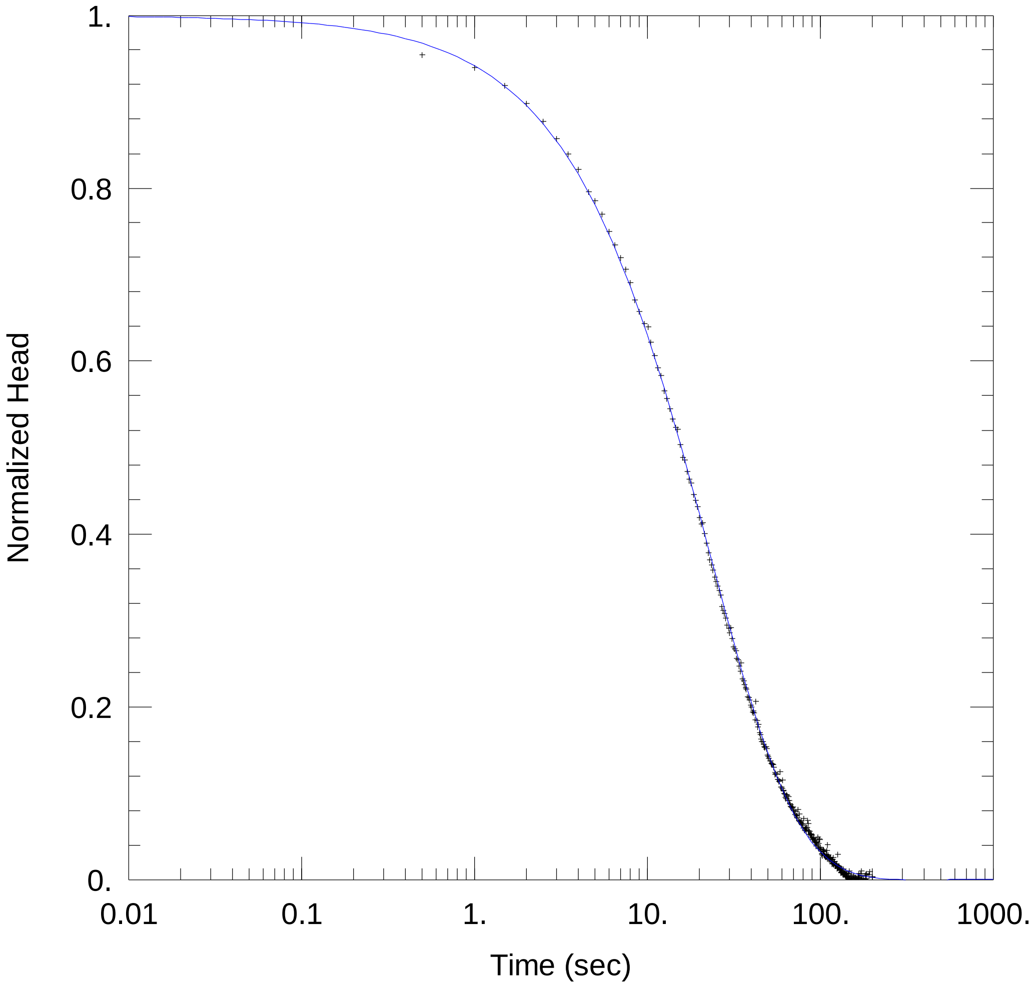
Initial Displacement: 3.452 m
Total Well Penetration Depth: 13.7 m
Casing Radius: 0.025 m

Static Water Column Height: 13.7 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.009719 m/day
Ss = 2.175E-5 m^{-1}
Kz/Kr = 0.1



MB6 (S)

Data Set: \...\MB6S_Falling.aqt
Date: 04/03/12 Time: 10:30:27

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB6S
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 14.7 m

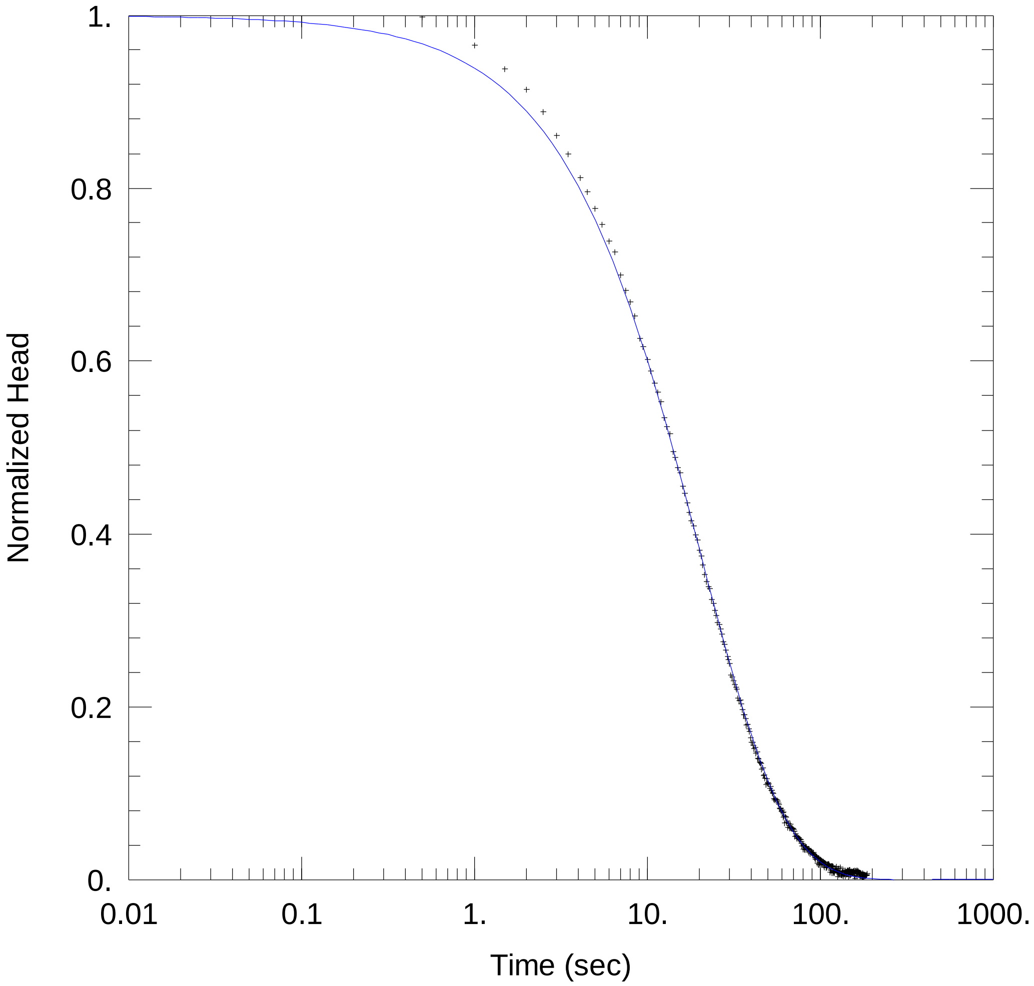
WELL DATA (MB6S)

Initial Displacement: 0.4795 m
Total Well Penetration Depth: 14.7 m
Casing Radius: 0.025 m
Static Water Column Height: 14.7 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.9736 m/day
Kz/Kr = 0.1
Ss = 1.09E-6 m^{-1}



MB6 (S)

Data Set: \...\MB6S_Rising.aqt
Date: 04/03/12 Time: 10:27:22

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB6S
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 14.7 m

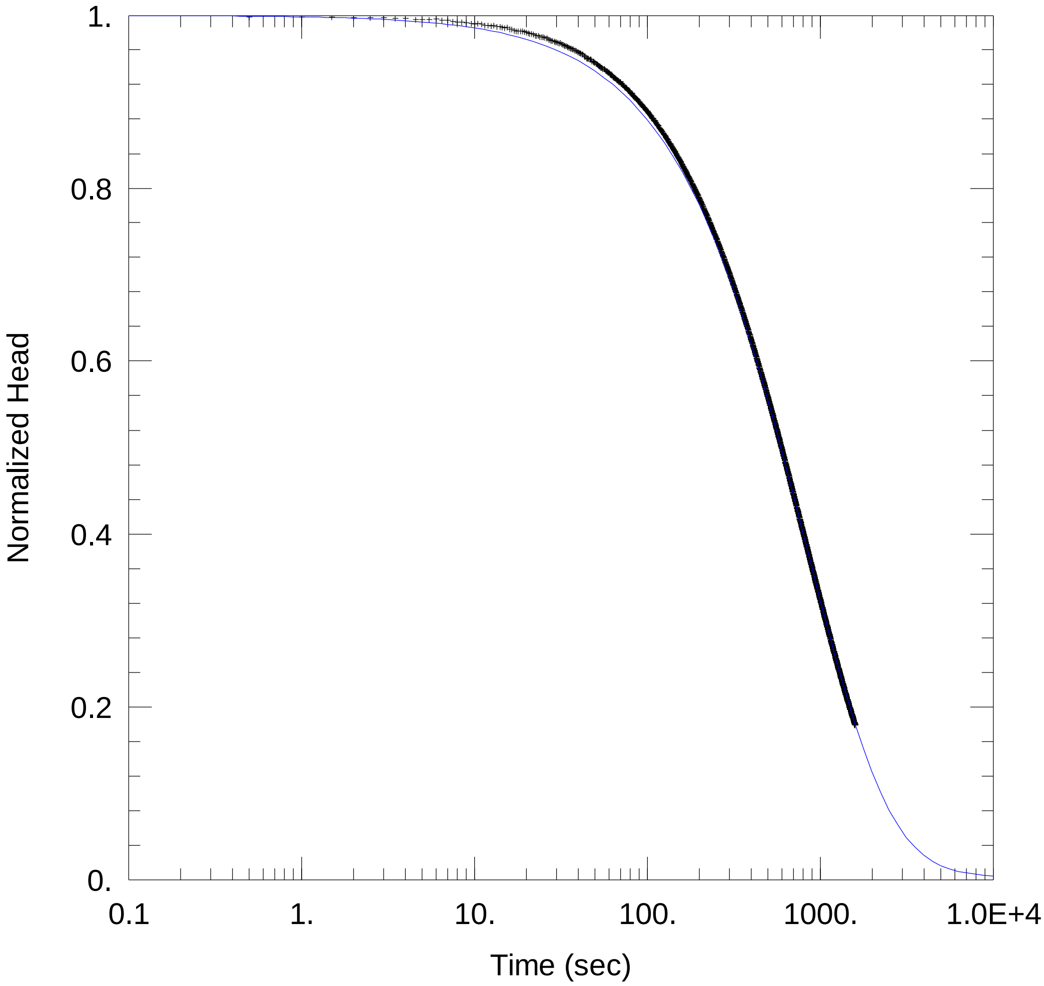
WELL DATA (MB6S)

Initial Displacement: -0.7997 m
Static Water Column Height: 14.7 m
Total Well Penetration Depth: 14.7 m
Screen Length: 6. m
Casing Radius: 0.025 m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 1.344 m/day
Ss = 1.399E-7 m^{-1}
Kz/Kr = 0.01



MB6 (D)

Data Set: \...\MB6D_Injection.aqt
Date: 04/03/12 Time: 10:21:40

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB6D
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 46.2 m
Anisotropy Ratio (Kz/Kr): 0.1

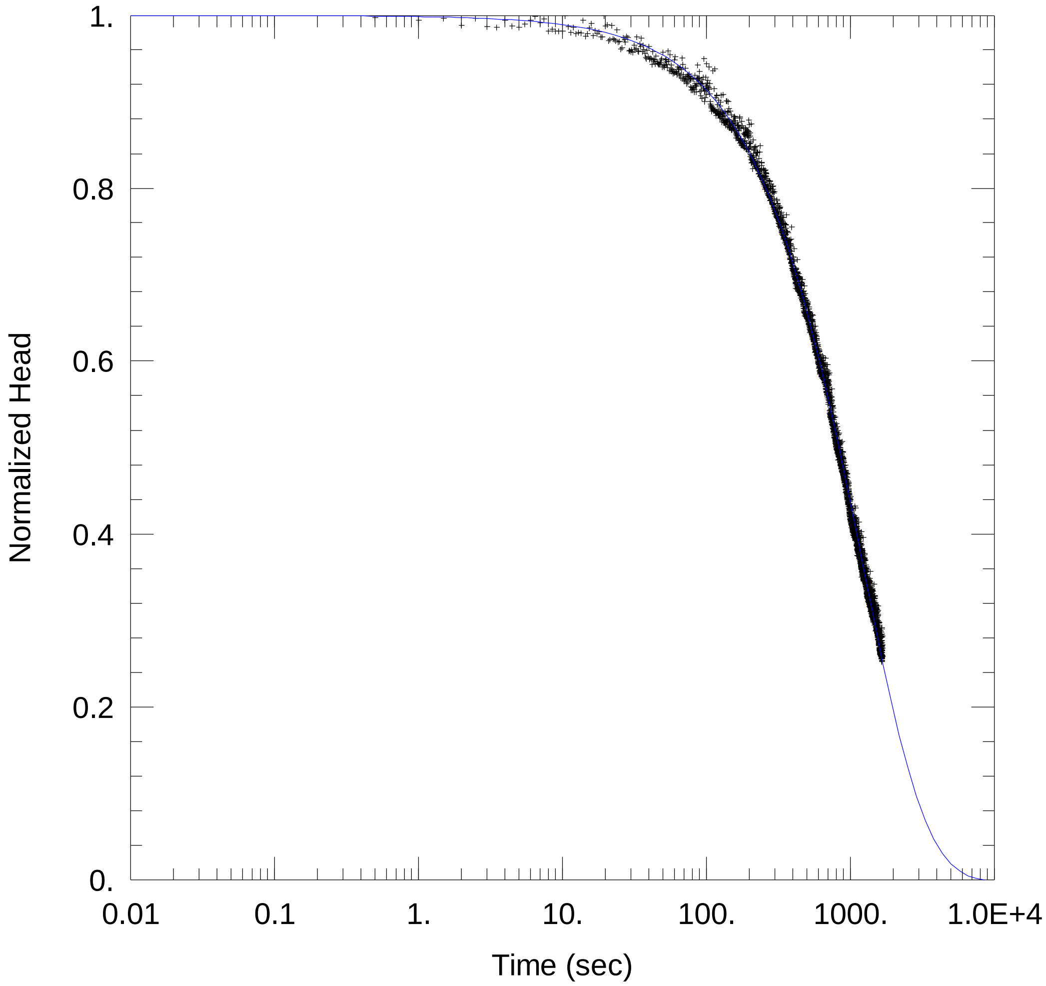
WELL DATA (MB6D)

Initial Displacement: 8.564 m
Static Water Column Height: 41.2 m
Total Well Penetration Depth: 41.2 m
Screen Length: 6. m
Casing Radius: 0.025 m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

T = 0.3506 m^2/day
S = 1.0E-10



MB7

Data Set: \...\MB7_Falling.aqt
Date: 04/03/12
Time: 10:33:36

PROJECT INFORMATION

Company: Parsons Brinckerhoff
Client: Doral
Project: 2172609A
Location: Yoongarillup
Test Well: MB7
Test Date: 21/03/12

AQUIFER DATA

Saturated Thickness: 15.4 m

WELL DATA (MB7)

Initial Displacement: 0.2277 m
Total Well Penetration Depth: 13.4 m
Casing Radius: 0.025 m
Static Water Column Height: 13.4 m
Screen Length: 6. m
Well Radius: 0.08 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.01925 m/day
Kz/Kr = 0.1
Ss = 6.398E-8 m^{-1}

Appendix C

Mine plan

Modelled mining schedule

Pit No.	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18
2																													■	■	■	■	
4																													■	■	■		
5																											■	■	■	■	■		
6																										■	■	■	■	■			
7																								■	■	■	■	■	■	■			
8																							■	■	■	■	■	■					
9																							■	■	■	■	■	■					
10																				■	■	■	■	■	■	■							
11																				■	■	■	■	■	■								
12																			■	■	■												
13																		■		■	■	■	■	■	■								
14	■	■	■																														
15	■	■	■																														
16				■	■																												
17			■	■	■																												
18				■	■																												
19					■	■	■																										
20					■	■	■																										
21						■	■	■																									
22							■	■																									
23																																■	■
24							■	■	■	■	■	■	■	■	■	■	■	■	■														
25									■	■	■	■																					

■ Active Mining / Active drain cells

Appendix D

Sensitivity analysis results

Month	Sensitivity Run 1	Sensitivity Run 2	Sensitivity Run 3	Sensitivity Run 4
	Dewatering rate (L/s)			
Nov-13	5	2	4	2
Dec-13	4	1	2	2
Jan-14	4	2	3	2
Feb-14	4	1	2	2
Mar-14	3	1	2	2
Apr-14	3	1	2	2
May-14	2	1	2	1
Jun-14	1	1	1	1
Jul-14	4	2	4	3
Aug-14	2	1	2	1
Sep-14	2	1	2	1
Oct-14	2	1	1	1
Nov-14	15	7	13	9
Dec-14	12	4	8	7
Jan-15	12	4	7	7
Feb-15	11	4	7	7
Mar-15	11	4	7	7
Apr-15	16	7	14	10
May-15	13	5	9	8
Jun-15	13	5	9	8
Jul-15	2	2	2	2
Aug-15	11	5	8	7
Sep-15	9	4	6	6
Oct-15	6	4	6	5
Nov-15	6	3	4	4
Dec-15	1	1	2	2

PARSONS
BRINCKERHOFF

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www.pbworld.com

Certified to ISO 9001, ISO 14001, AS/NZS 4801
A GRI Rating: Sustainability Report 2011

29 January 2014

Amy Walton
Project Manager – Yoongarillup
Doral Mineral Industries
Lot 7 Harris Road
PICTON WA 6229

Our ref: 2200516A-WAT-LTR-001 RevB

Your ref: email 16 Sep 2013

By email
Amy.Walton@doral.com.au

Dear Amy

Surface water assessment for the proposed Yoongarillup Mineral Sands Project

1. Introduction

This letter report provides an update to the findings of the preliminary surface water assessment for the proposed Doral Yoongarillup mineral sands project that were previously reported in a letter (Parsons Brinckerhoff, 2011). This revision was commissioned by Doral Mineral Sands Pty Ltd (Doral) to Parsons Brinckerhoff Pty Ltd (PB) on 5 Nov 2013 to update the findings for the revised mine pit footprint. The preliminary surface water assessment is required as part of the approvals process for the proposed Doral Yoongarillup mineral sands project. This assessment reflects the mine plan provided to Parsons Brinckerhoff dated 28 October 2013 (design_5_mining_depth.dxf).

2. Objective

The primary objectives of the preliminary surface water assessment were to:

1. Assess how the proposed pit will impact the surface water flows;
2. Estimate the surface runoff yield of the local catchment in which the proposed pit is to be located; and
3. Assess the reduction in flow volumes down gradient of the proposed pit.

3. Methodology

The preliminary surface water assessment was conducted by adopting the following approach:

- Collation of rainfall and runoff data so as to understand the existing streamflow characteristics;
- Delineation of the catchments of the local creeks and rivers that are likely to be affected by mining;
- Development of a simple rainfall-runoff relationship based on local gauged data;
- Assessment of the proportional contribution of runoff from the proposed mine footprint;

- Estimation of the pre-mining and post-mining catchment yield of surface runoff from the local catchments to assess the net change in surface water yield; and
- Presentation of the information as an average annual water balance.

4. Project location

The proposed Doral mineral sands mine is located approximately 16.0 km south-east of Busselton in the South-West region of Western Australia, and is situated in the foothills of the Whicher Range as shown on Figure 1. This assessment considers the proposed mining pit located to the west of Piggott Rd in the foothills of the Whicher Range within the lease boundary M7000459 and M7000458 (Figure 2).

5. Hydrology

5.1 Regional waterways

The proposed mineral sands mine is located in the upper reaches of the Vasse River basin as shown in Figure 1.

The Vasse River originates in the Whicher Ranges and flows into the Vasse Estuary; its only tributary is the Sabina River which similarly flows into the Vasse Estuary. The majority of the catchment is agricultural land; consequently approximately 80% of the catchment has been cleared. The proposed mine lease area falls within the south-eastern section of the Vasse River catchment. The Vasse River has been modified by several stream diversions.

5.2 Local waterways

There are no local waterways within the study area. Sheet flow or flow in small gullies is expected based on aerial observations. A smaller portion within the Vasse River catchment has been defined for the purposes of this assessment and is hereby referred to as the Vasse River sub-catchment in Figure 2. The Vasse River sub-catchment contains the top of the catchment upstream of the pit (referred to as the Foothills sub-catchment), the pit outline and the overland flow path downstream of the mine where runoff from this local sub-catchment meets the Vasse River.

5.3 Rainfall and Runoff

Table 1 summarises rainfall and stream flow gauge information.

The Department of Water (DoW) has two gauging stations of interest within the vicinity of the proposed mine area:

- 610025 – Sabina Diversion, Wonnerup East Road, approximately 6.6 km north of the proposed pit; and
- 610008 – Margaret River North, approximately 4.6 km south of the proposed pit in the Whicher Ranges.

The gauged flows at 610025 receives runoff from the Whicher Ranges and the agricultural parts of the Sabina River catchment with an annual streamflow of 4.46 GL/yr based on data from 2001 to 2009. The Station 610008 is situated in the Whicher Ranges and receives flows from the headwaters of Margaret River and has an average annual streamflow of 1.44 GL/yr based on data from 1978 to 2012. Comparison of streamflows for a common period of 2006 to 2009 suggests much lower values (0.98 GL/yr for 610008 and 4.01 GL/yr for 610025). Runoff encountered from the hills has declined significantly (32% reduction) compared to the agricultural catchment (10% reduction) in recent times.

Several rain gauging stations are located within the vicinity of the study area:

- DoW 509355 – located at the same site as gauging station 610008;
- Bureau of Meteorology (BOM) 9771 – north-east of the study area;
- BOM 9971 – south-west of the study area.

The calculated average annual rainfalls based on data from 1978 to 2012 at gauging stations 9771 and 509355 are 795.6 mm/yr and 917.7 mm/yr respectively. The average annual rainfall for gauging station 9971 is 770.2 mm/y, based on data from 2001 to 2012. The calculated annual average rainfall for 2001 to 2012 for stations 9771 and 509355 are 718.5 mm/yr and 841.8 mm/yr respectively.

Table 1 Rainfall and stream gauging station summary

<table>
<tr><td></td><td colspan="6">Rainfall Stations</td></tr>
<tr><td></td><td colspan="2">9771
Yoongarillup BOM</td><td colspan="2">9971
Acton Park BOM</td><td colspan="2">509355
Dow</td></tr>
<tr><td>Data Start</td><td colspan="2">1957</td><td colspan="2">2000</td><td colspan="2">1977</td></tr>
<tr><td>Data Finish</td><td colspan="2">Operating</td><td colspan="2">Operating</td><td colspan="2">Operating</td></tr>
<tr><td>Years of Data</td><td colspan="2">57</td><td colspan="2">14</td><td colspan="2">37</td></tr>
<tr><td>Average Annual Rainfall, 1978 - 2012 (mm/yr)</td><td colspan="2">795.6</td><td colspan="2">770.2[1.]</td><td colspan="2">917.7</td></tr>
<tr><td></td><td colspan="6">Department of Water Streamflow Gauging Stations</td></tr>
<tr><td></td><td colspan="3">610008
Margaret River North</td><td colspan="3">610025
Sabina Diversion</td></tr>
<tr><td>Catchment Area (km^2)</td><td colspan="3">15.52</td><td colspan="3">77.6</td></tr>
<tr><td>Data Start</td><td colspan="3">May,1977</td><td colspan="3">Jul, 2000</td></tr>
<tr><td>Data Finish</td><td colspan="3">Operating</td><td colspan="3">Jul, 2010</td></tr>
<tr><td>Number of years without major gaps</td><td colspan="3">29 (1978-1999, 2006-2012)</td><td colspan="3">9 (2001-2009)</td></tr>
<tr><td>Data Gap</td><td colspan="3">Dec, 1999 – Jun, 2005</td><td colspan="3"></td></tr>
<tr><td>Common period of data</td><td colspan="3">2006-2009</td><td colspan="3">2006-2009</td></tr>
<tr><td>Average Annual Streamflow (GL/yr)</td><td colspan="3">0.98 (2006-2009)</td><td colspan="3">4.01 (2006-2009)</td></tr>
</table>

1. The average for this station are based on data from 2001 to 2012

6. Results

6.1 Catchment Areas

Table 2 summarises the estimated catchment areas of the sub-catchments around the proposed pit as shown in Figure 2. The total catchment area of the Vasse River sub-catchment within which the pit is located is 34.48 km^2.

The southern and upper part of the Vasse River sub-catchment is located within the Whicher Range, which is defined as the Foothills sub-catchment in this report. The catchment area of the Foothills sub-catchment is 10.79 km^2.

The total area of the pit outline is 0.40 km^2 and it intercepts 2.36 km^2 of the upstream catchment (which is part of the Foothills sub-catchment). The total intercepted area including the pit outline is 2.76 $km^{2.}$

These areas were used in assessing the relative surface runoff yields as discussed in Section 6.3 .

Table 2 Catchment areas

Mine	Vasse River Sub-catchment Area (km^2)	Pit Area (km^2)	Foothills sub-catchment Area (km^2)	Pit Area + intercepted upstream catchment (km^2)	Vasse River Sub-catchment area excluding pit footprint (km^2)
Yoongarillup Pit	34.48	0.40	10.79	2.76	34.08

6.2 Changes to waterways during mining

Once mining commences, it is assumed that the mine pit will be isolated from runoff and does not directly contribute to surface runoff. The intercepted area up-gradient of the proposed pits will drain surface runoff towards the proposed pit, possibly into the pit if it is not fully protected by bunds. If bunds are provided, then the surface runoff may accumulate up gradient of the pit and possibly flow around the pit depending on the topography. In either case, it is assumed that Doral will develop a water management plan to manage the runoff up gradient of the pit via a flow diversion structure. The study of the flow diversion alternatives was not within the scope of this study.

6.3 Estimated runoff volume change

As the proposed Yoongarillup pit and its intercepted catchment are located within the foothills of the Whicher Ranges, flows from the 610008 gauge and rainfall data from the DoW 509355 rain gauge were assumed to be representative of the expected rainfall and runoff characteristics for this part of the Vasse River sub-catchment. All available data for periods 1978-1999 and 2006-2012 were used in the rainfall-runoff analysis.

The results of data analysis are summarised in Figure 3. This figure shows the average monthly stream flow and rainfall for a period from 1978 to 2012, and estimated average monthly runoff coefficients for periods 1978- 2012 and 2006-2009. In this assessment the runoff coefficient is defined as the ratio between stream flow and rainfall depth over the sub-catchment area and is expressed as a percentage.

Stream flow in the local waterways is expected to occur from May, peaking in August and is then expected to decline from August through to January. It is important to note that the highest runoff coefficient of 30% occurs in October, three months after the peak stream flow. The peak runoff coefficient despite low monthly rainfall compared to June and July suggests that groundwater base flow dominates the total stream flow from October to December.

The monthly runoff coefficients presented in Figure 3 for the period 2006-2009 were used in estimating the runoff yield from the foothills section of the catchment up-gradient from the proposed mine pit which is summarised in Figure 4.

The annual yield from the Sabina River catchment, the Vasse River sub-catchment and the Foothills sub-catchment area were estimated as summarised in Table 3.

Table 3 Estimated yield based on flow data from 2006 – 2009

Catchment	Sabina River	Vasse River sub-catchment	Foothills sub-catchment	
Catchment Area (km^2)	77.6	34.5	10.79	
Monthly runoff (ML)	Based on measured data	Estimated by ratio of catchment areas	Estimated based on average runoff coefficients (1978-2012)	Estimated based on average runoff coefficients (2006-2009)
Jan	38.6	17.1	3.4	6.1
Feb	15.9	7.1	0.2	0.0
Mar	15.1	6.7	0.1	0.5
Apr	25.6	11.4	0.0	0.0
May	56.4	25.1	0.9	2.0
Jun	297.9	132.3	38.5	57.7
Jul	1212.8	538.6	167.0	236.2
Aug	955.9	424.5	276.4	425.4
Sep	980.7	435.5	272.5	399.3
Oct	255.5	113.5	158.7	198.3
Nov	89.7	39.9	69.3	92.5
Dec	65.1	28.9	20.3	48.5
Annual runoff yield (GL)	4.01	1.78	1.01	1.47
Yield % of the Vasse River sub-catchment		100%	57%	82%

The runoff yield for the foothills section of the catchment were assessed based on long term average (1978-2012) rainfall and runoff coefficients (the 4th column in Table 3) and short term average (2006-2009) rainfalls and runoff coefficients (the 5th column in Table 3).

Based on the revised yield estimates the foothills proportion of the Vasse River sub-catchment is likely to contribute between 57% (1.01 GL/yr) to 82%(1.47 GL/yr) of the total expected yield at the outlet of the Vasse River sub-catchment.

The percentage change in potential surface water runoff yield for the pre- and post-mining case; with and without diversions around the pit is summarised in Table 4 for the Vasse River sub-catchment and the foothills section of this sub-catchment (foothills sub-catchment).

Table 4 Surface water yield (%)

Catchments	Pre-mining yield (%)	Post-mining yield without diversion around pit (%)	Post-mining yield with diversion around pit (%)
The Vasse River sub-catchment	100	86.97	98.11
The foothills sub-catchment	100	74.45	96.30

Surface water yield from the Vasse River sub-catchment will be reduced by approximately 21% without any flow diversions around the pit; whereas with diversions around the pit the yield will be reduced by approximately 3% based on 2006-2009 average rainfall and runoff coefficients.

The reduction in surface water yield from the Vasse River sub-catchment without and with diversion around the proposed mine pit will be 13.0% and 1.9% respectively, if long term averages of rainfalls and runoff coefficients are used.

Additionally, the surface water yield from the foothills sub-catchment, which equates to 82% of the yield for the Vasse River sub-catchment during 2006-2009, will be reduced by approximately 25.5% without any flow diversions around the pit, while the yield will be reduced by approximately 3.7 % if surface water is diverted around the pit.

6.4 Water Balance

The proposed mining is expected to alter the water balance in the local catchments where the proposed mine pits are located. Changes in the water balance could be due to:

- A reduction in the surface runoff catchment area draining towards local waterways due to voids that will be created by the mine pit;
- A reduction in the surface runoff catchment area draining towards local waterways due to the interception of surface runoff from the drainage area up gradient of the proposed pit; and
- A reduction in groundwater through flow due to abstraction of groundwater to keep the mine pit dry during mining.
- A more detailed description of the project water balance is provided in the Yoongarillup Site Water Balance Report (Parsons Brinckerhoff, 2013)

7. Summary

A desktop study was undertaken by Parsons Brinckerhoff to characterise the current waterways and how they will be altered by the proposed mining. Surface water yield estimates indicate that the Vasse River sub-catchment, where the proposed pit is to be located, has an annual runoff yield of approximately 1.78 GL/yr.

The reductions in surface water yield from the Vasse River sub-catchment are likely range from approximately 14% to 21% without any flow diversions around the pit; whereas with diversions around the pit the reduction in yield may range from 2.0% to 3.0%.

Additionally, the surface water yield from the foothills sub-catchment, which can range from 57% to 82% of the yield for the Vasse River sub-catchment, will be reduced by approximately 25.5 % without any flow diversions around the pit, while the yield will be reduced by approximately 3.7 % if surface water is diverted around the pit.

A surface water diversion plan and an investigation of water quality issues related to potential erosion or potential contamination from mining operations were not part of the scope of this study. It is expected that Doral will prepare a Water Management Plan to manage surface water quality and quantity around the proposed mine site.

Yours sincerely

AJha

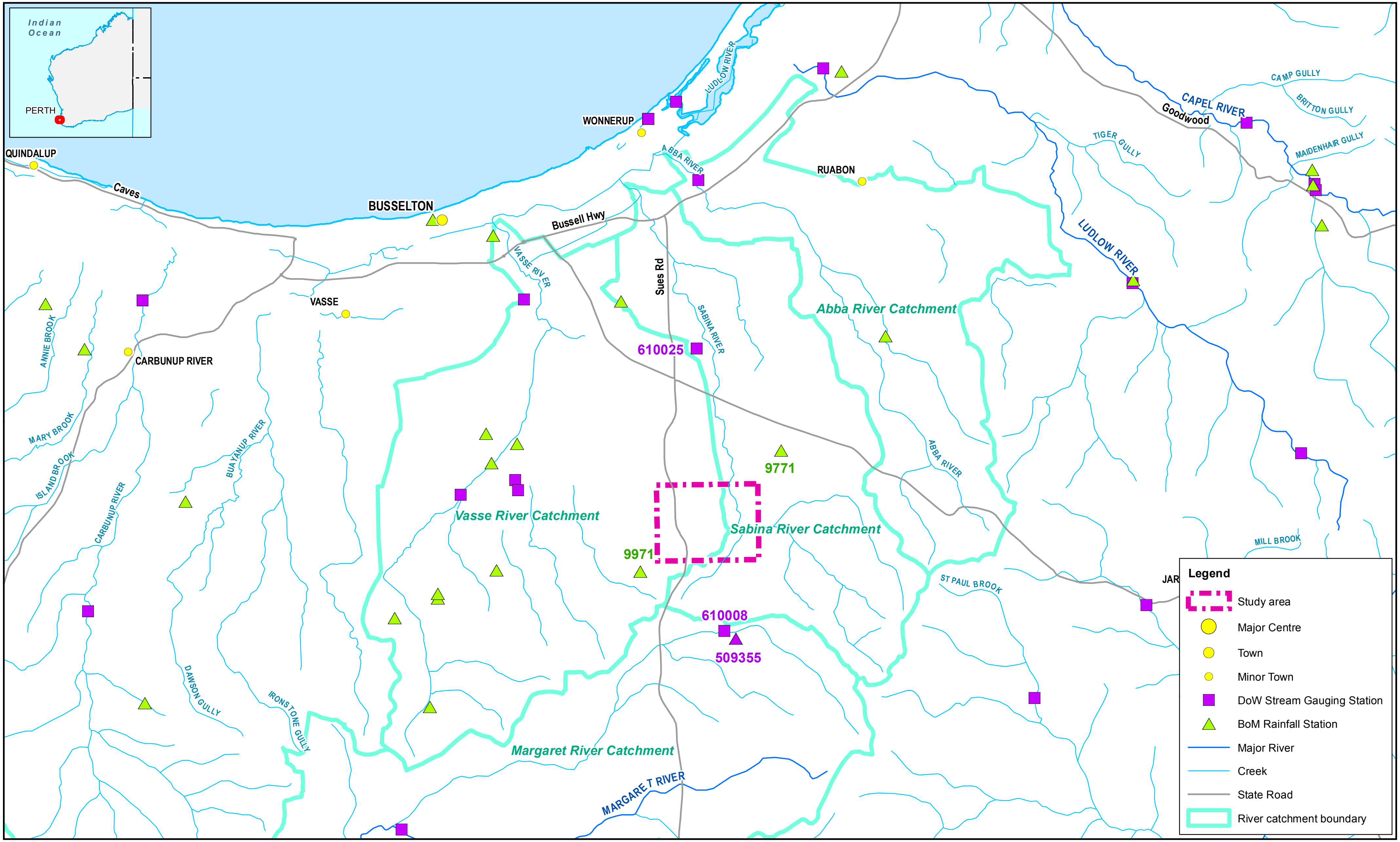
Dr Aditya Jha
Principal Engineer, Water Resources
Parsons Brinckerhoff

cc: Aurora Environmental - Damon Bourke

References

Parsons Brinckerhoff. (2011). *Surface water assessment for the proposed Yoongarillup pit, Doral Mineral Sands ref 201026254/PR2_23712/aj.* unpublished report prepared for Doral Mineral Industries.

Parsons Brinckerhoff. (2013). *Yoongarillup Site Water Balance.* unpublished report prepared for Doral Mineral Industries.



Doral

PARSONS BRINCKERHOFF

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Scale: 1:200,000 at A4

Coord. System.: MGA50 GDA94

NCSI Certified Quality System to ISO 9001

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Revision:	A	Date:	4/12/2013
Drawn By:	SH / JV	Checked by:	AJ
Data Source:	Landgate; SLIP (2011)		

Doral Mineral Sands Pty Ltd

Surface Water Assessment for Doral's Yoongarillup Mineral Sands Project

Study area location
Figure 1

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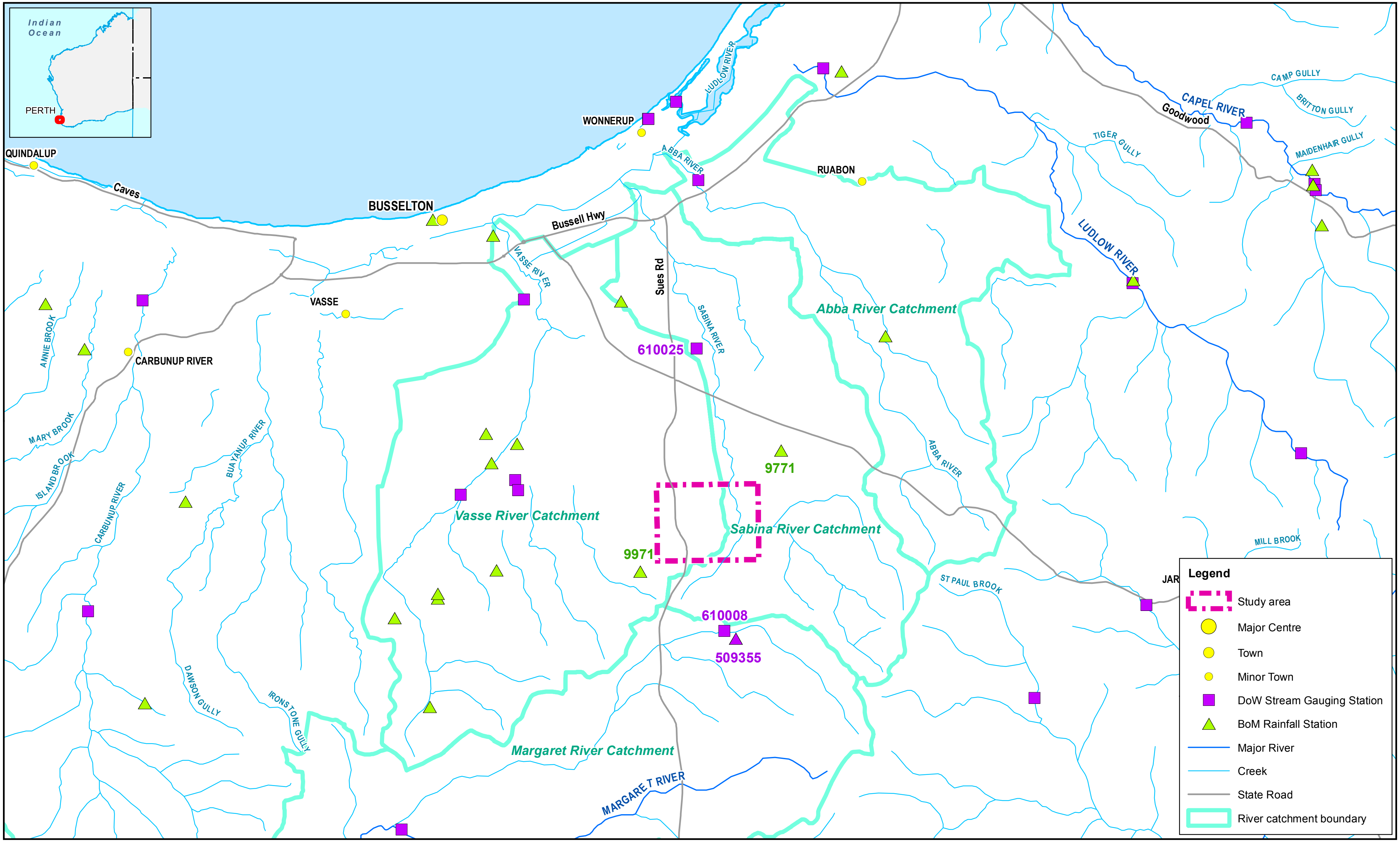

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Doral Mineral Sands Pty Ltd

Surface Water Assessment for Doral's Yoongarillup Mineral Sands Project

Study area location
Figure 1

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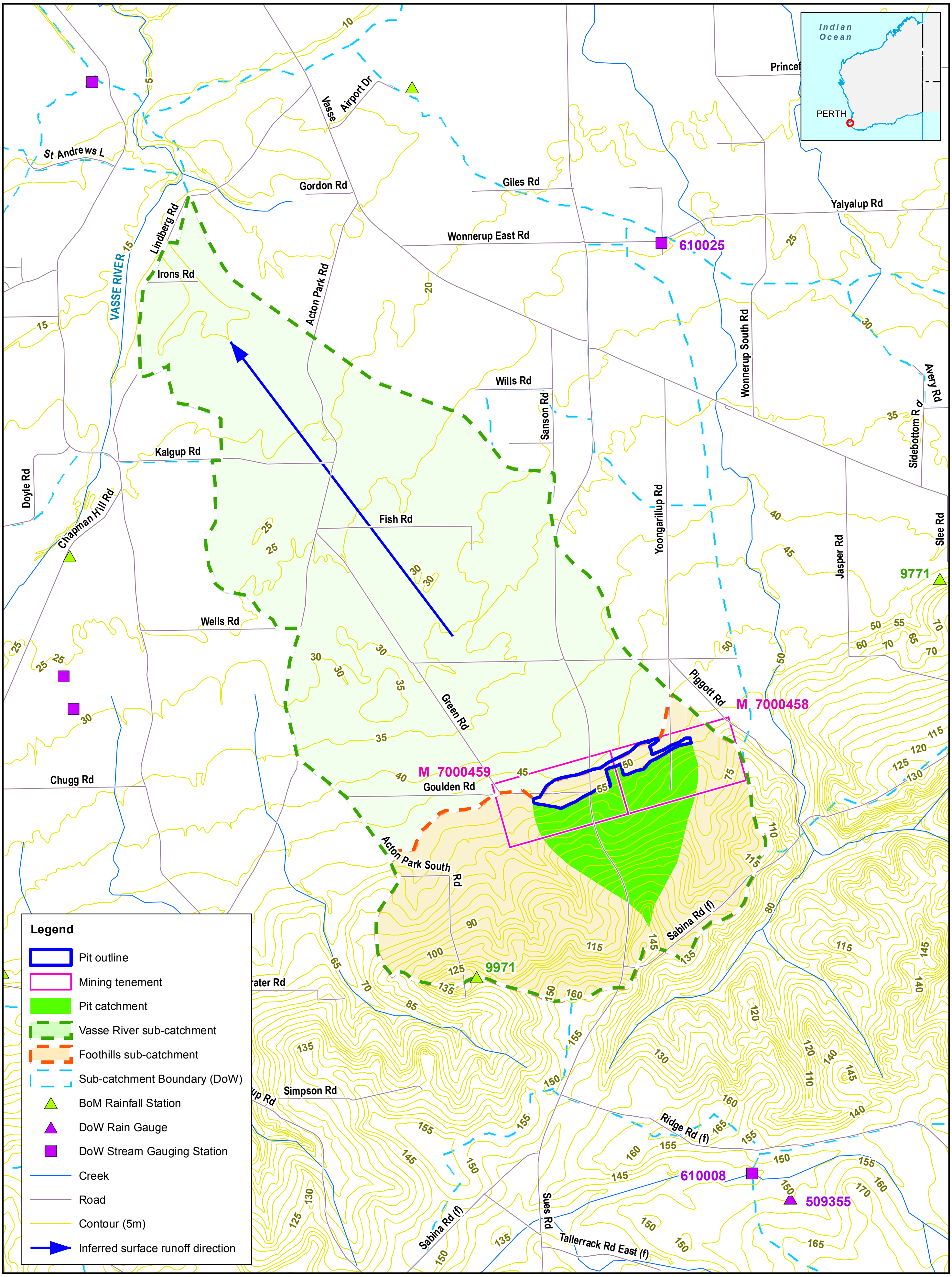

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Drawing No.: 2172609A_GIS_F028

Revision: A

Date: 03/12/2013

Drawn By: SH

Checked by: AJ

Data Source: Landgate, DoW, Doral (2013)

Doral Mineral Industries

Surface Water Assessment for Doral's Yoongarillup Mineral Sands Project

Catchment plan

Figure 2

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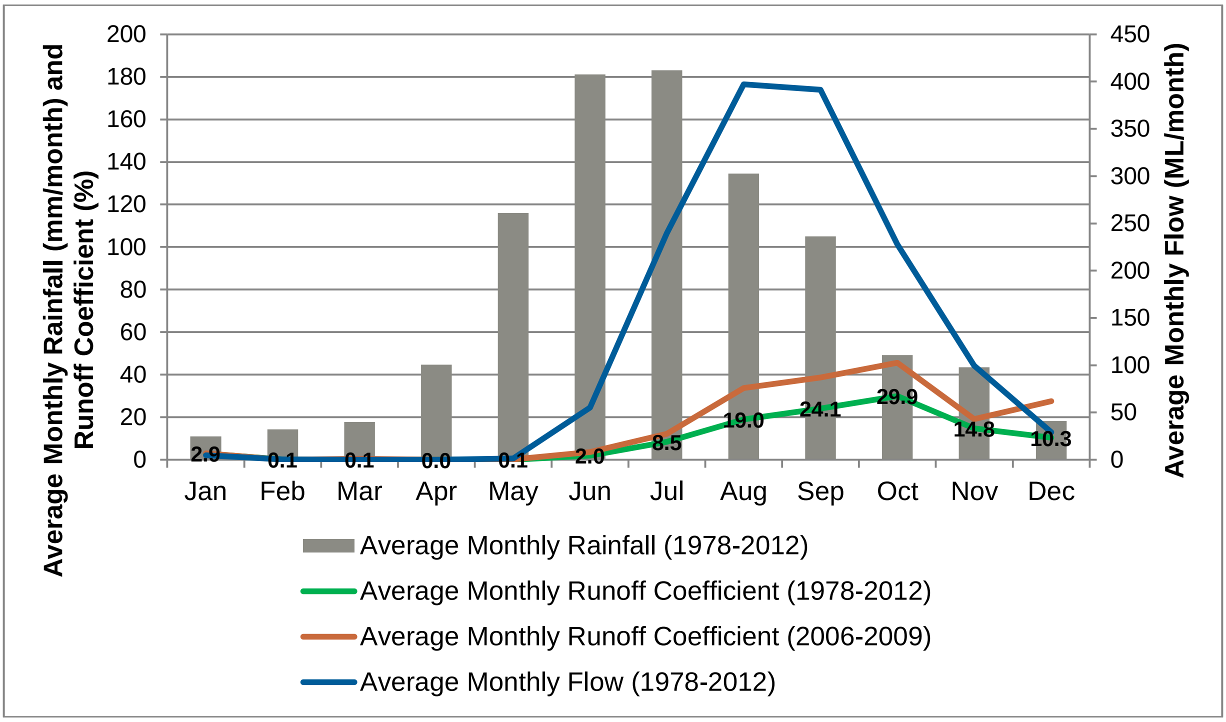

Figure 3 Study area hydrological characteristics

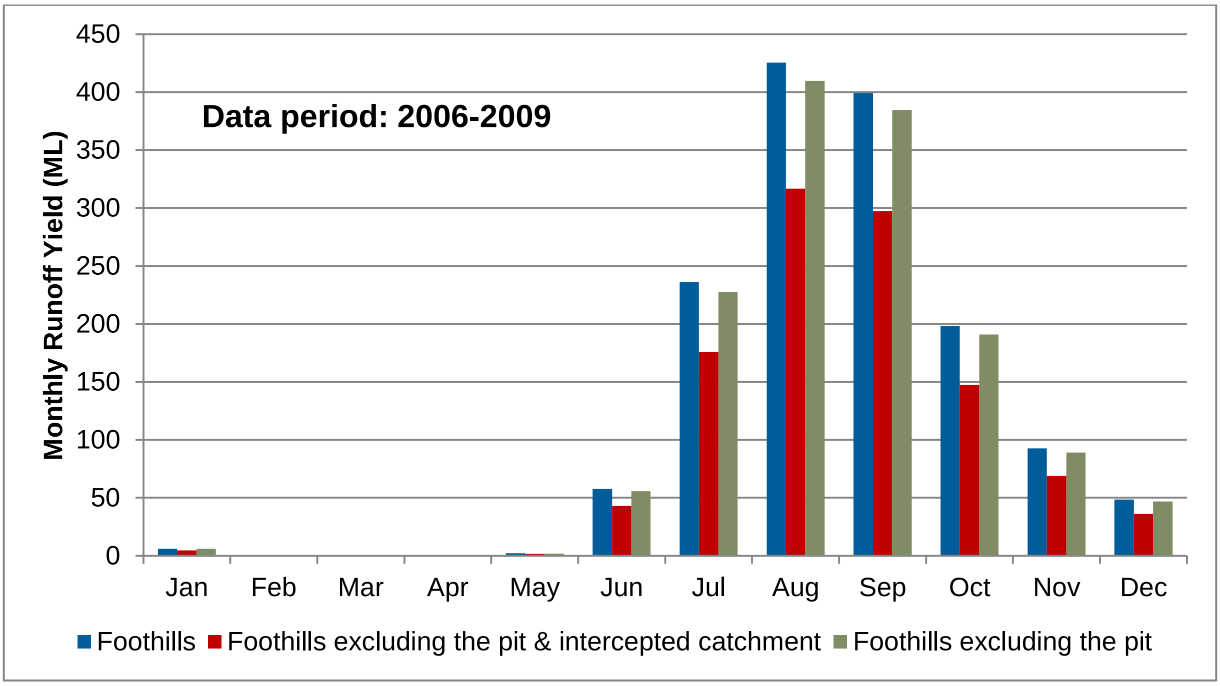

Figure 4 Surface water runoff yields for the foothills sub-catchment