



APPENDICES

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่

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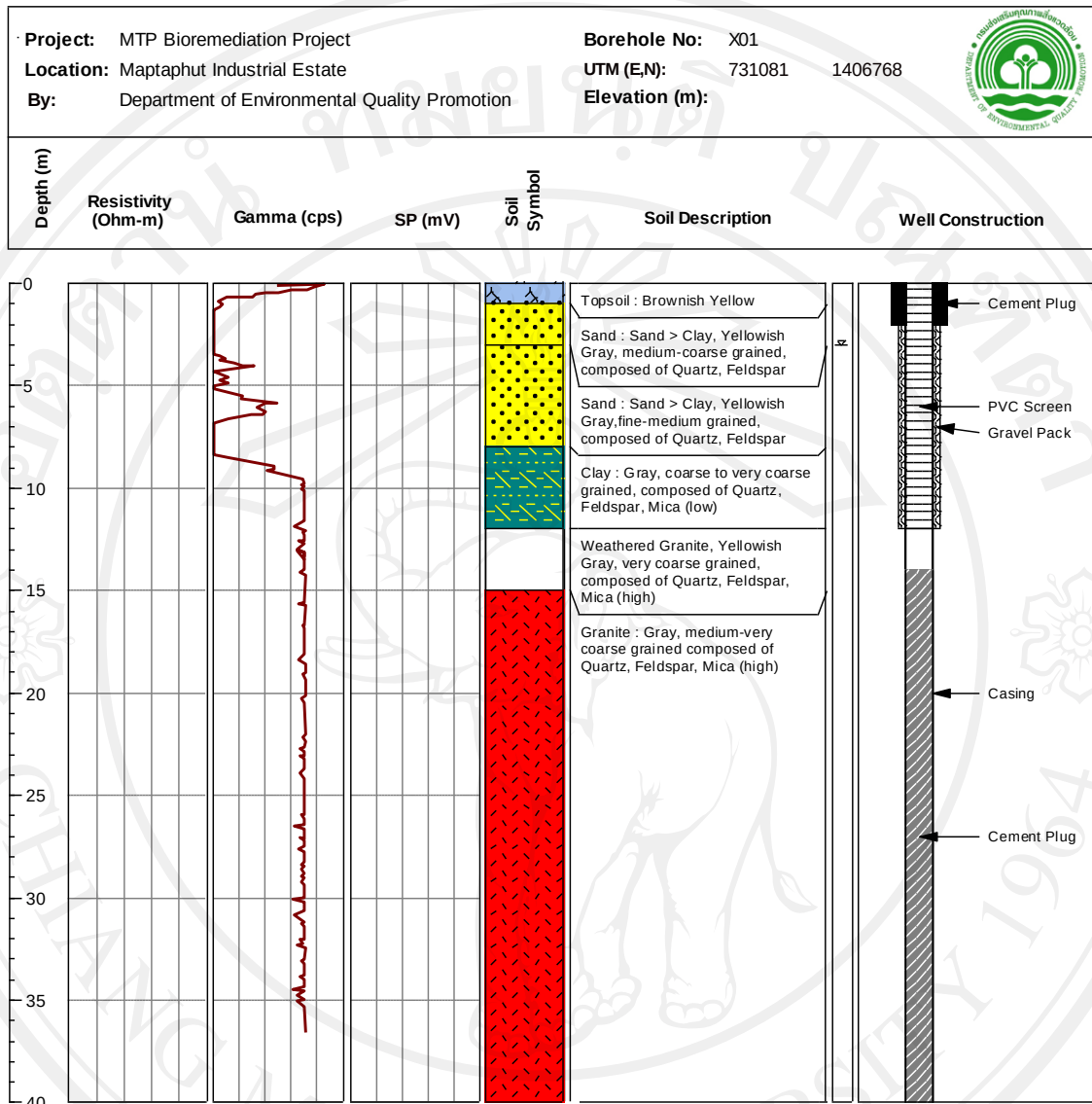


APPENDIX A

(Borehole Data)

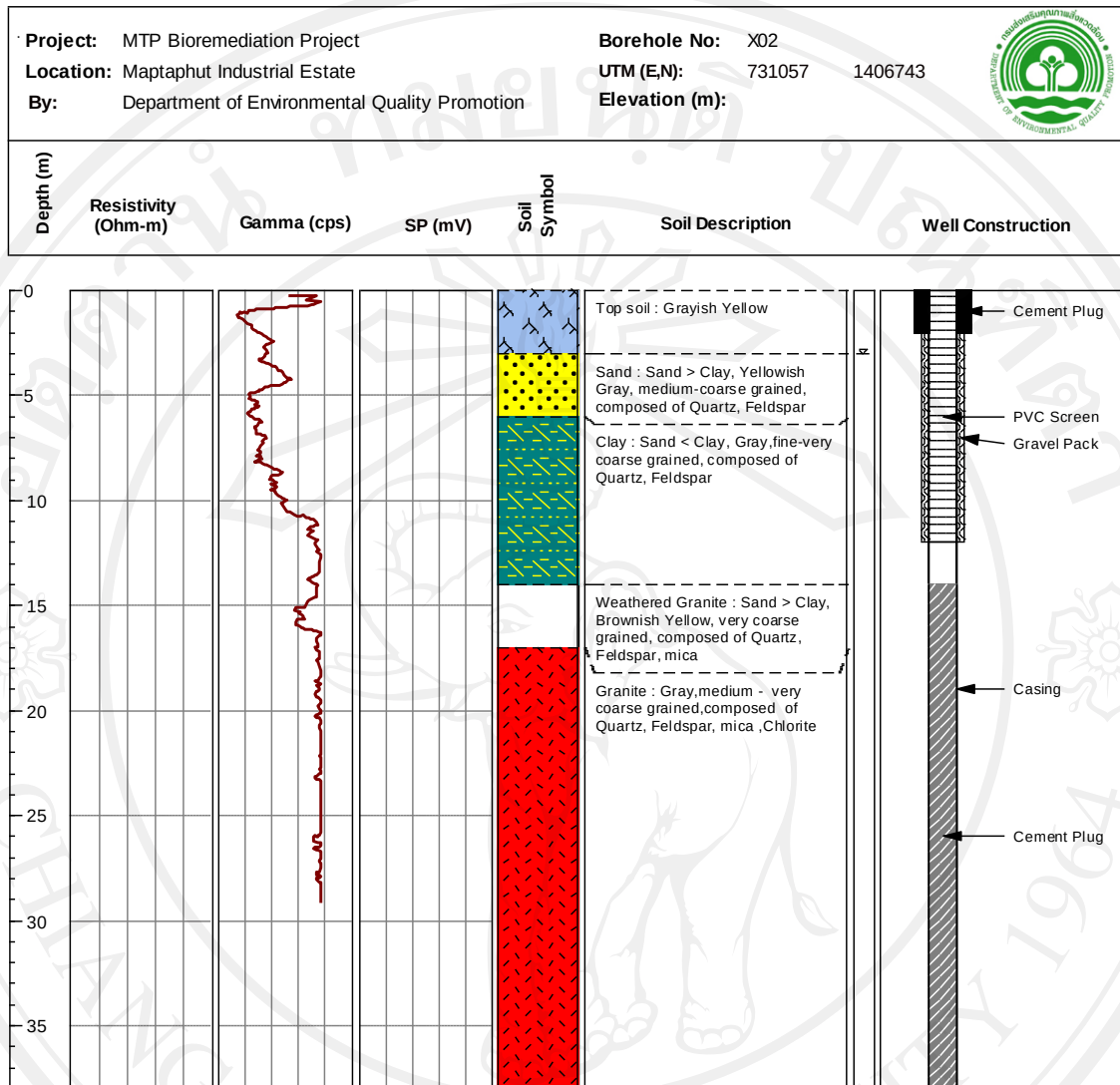
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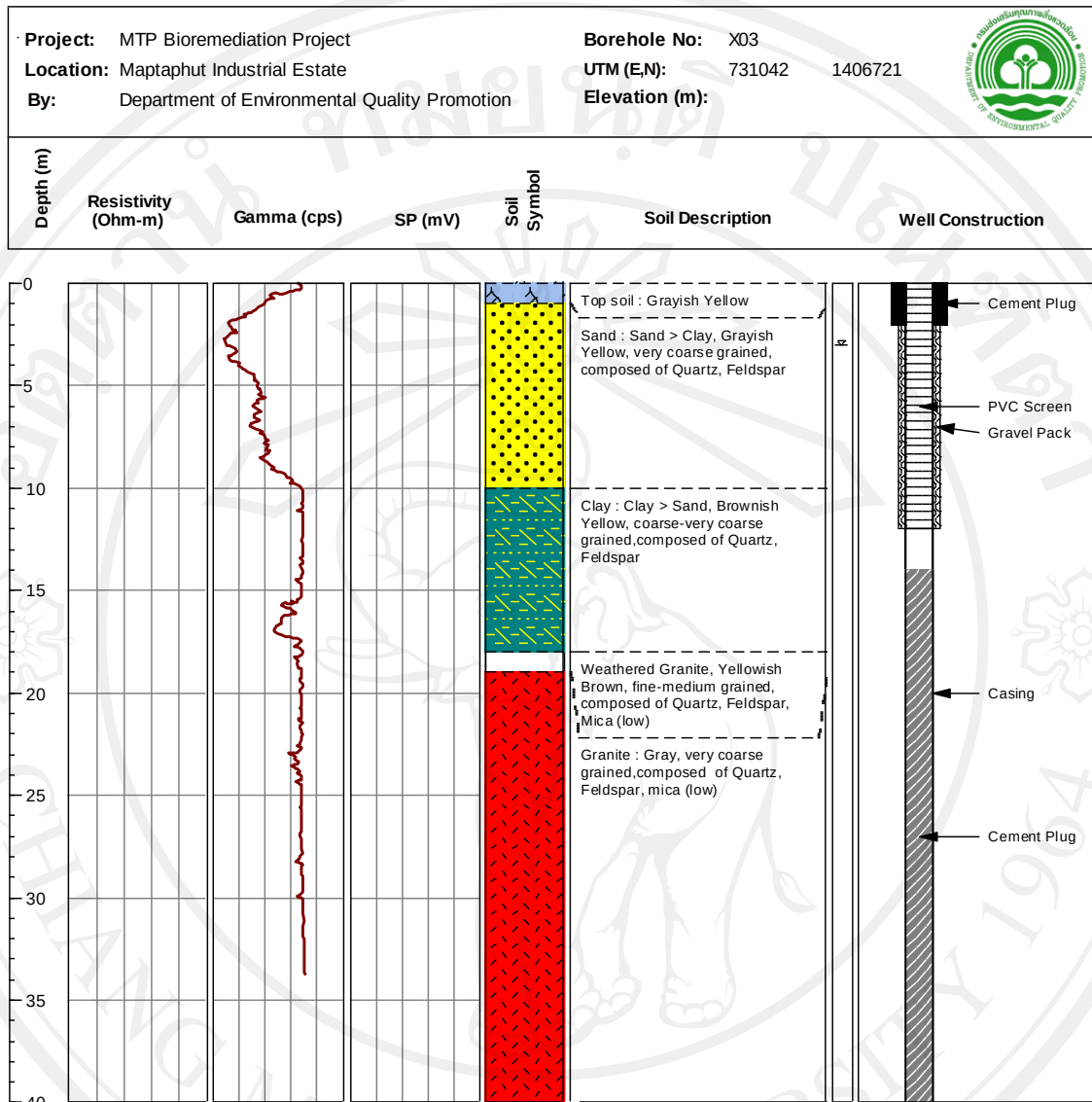
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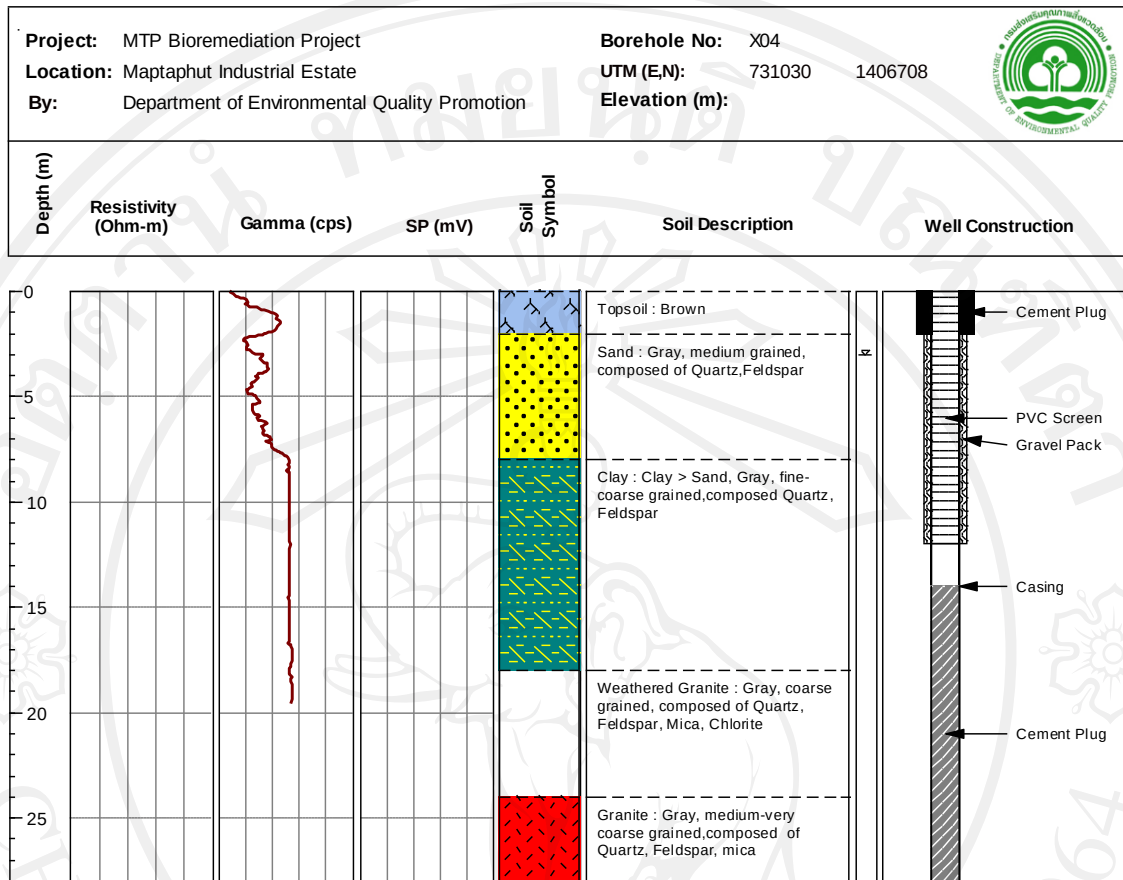
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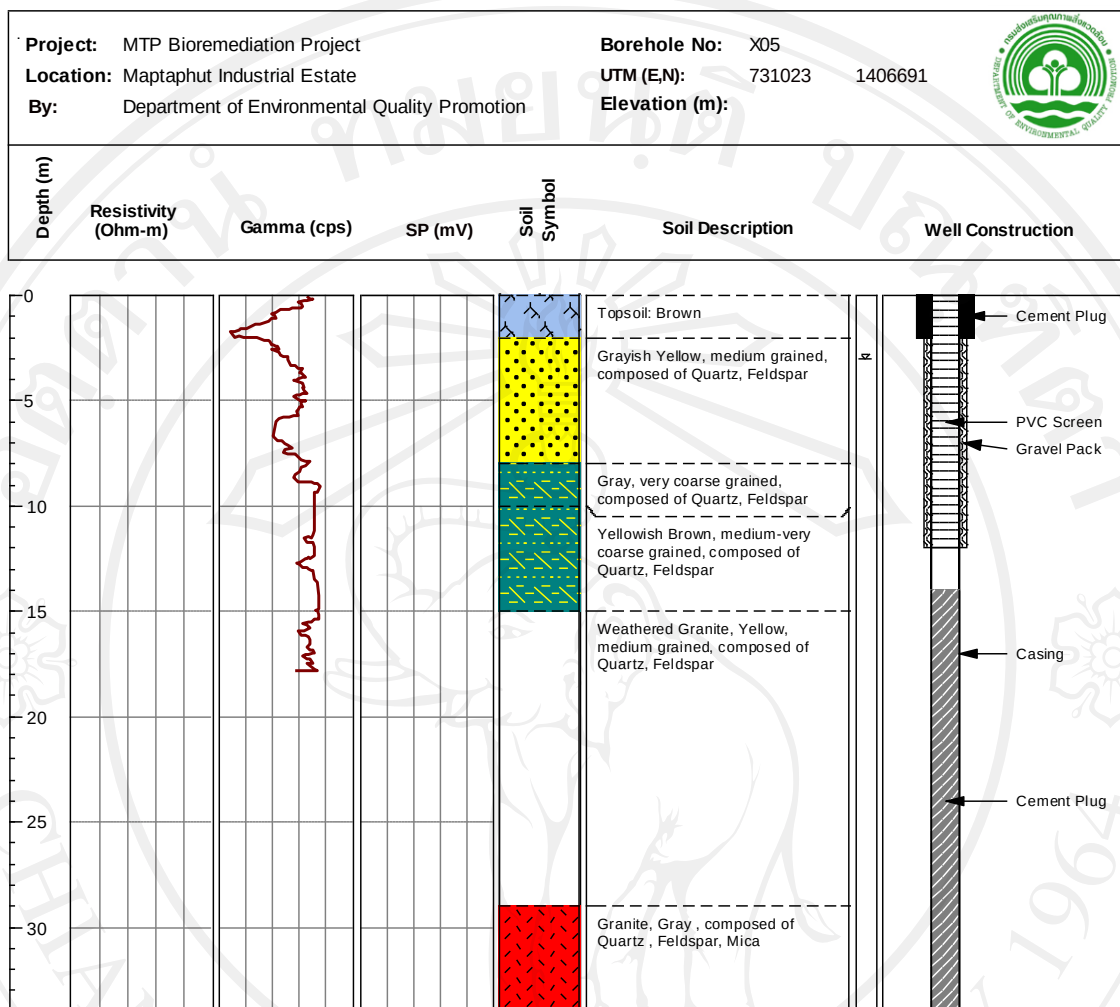
Department of Geological Sciences
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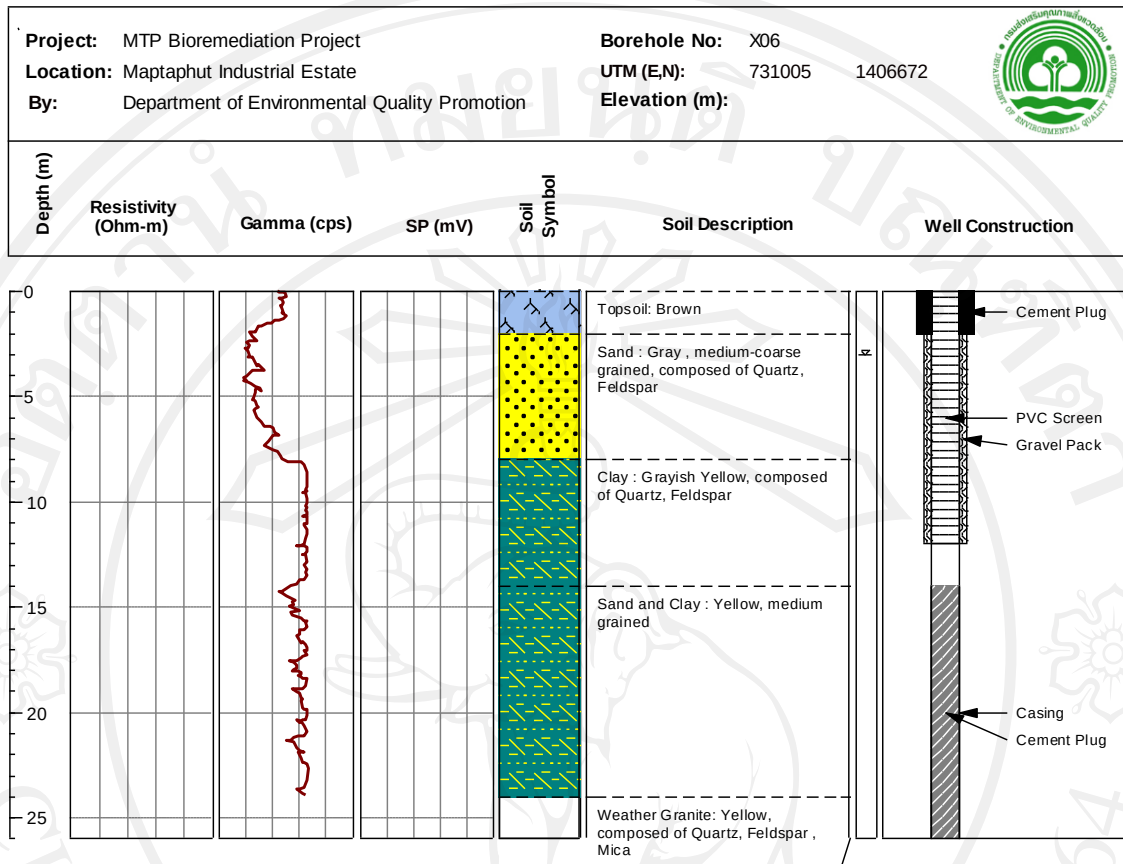
Department of Geological Sciences
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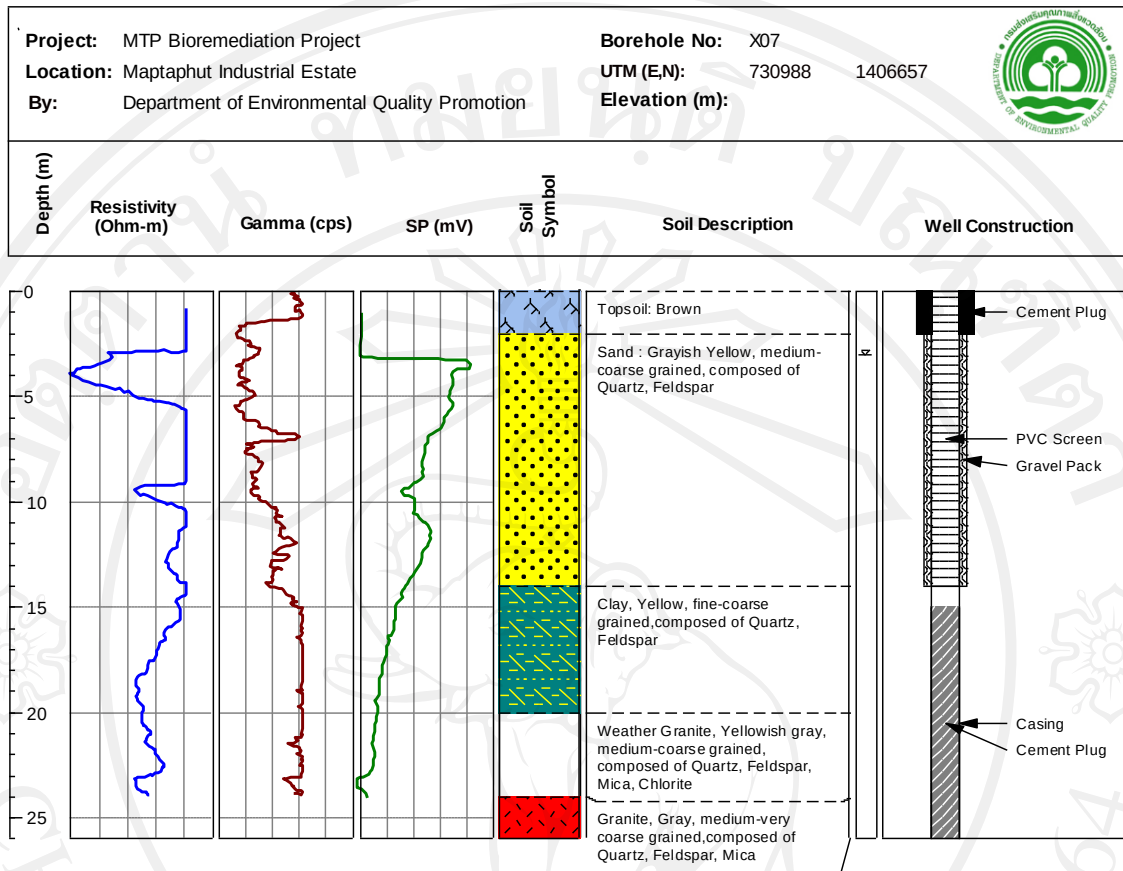
Department of Geological Sciences
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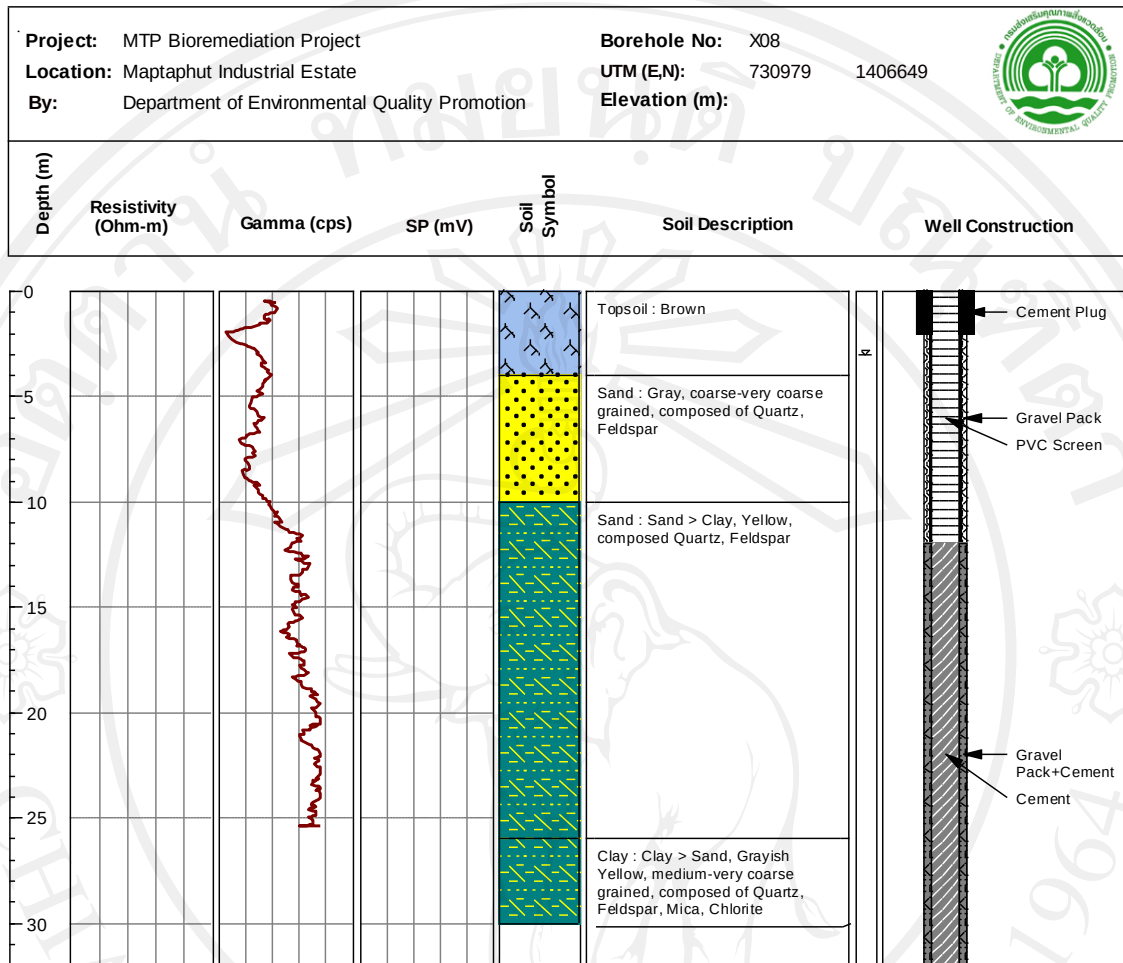
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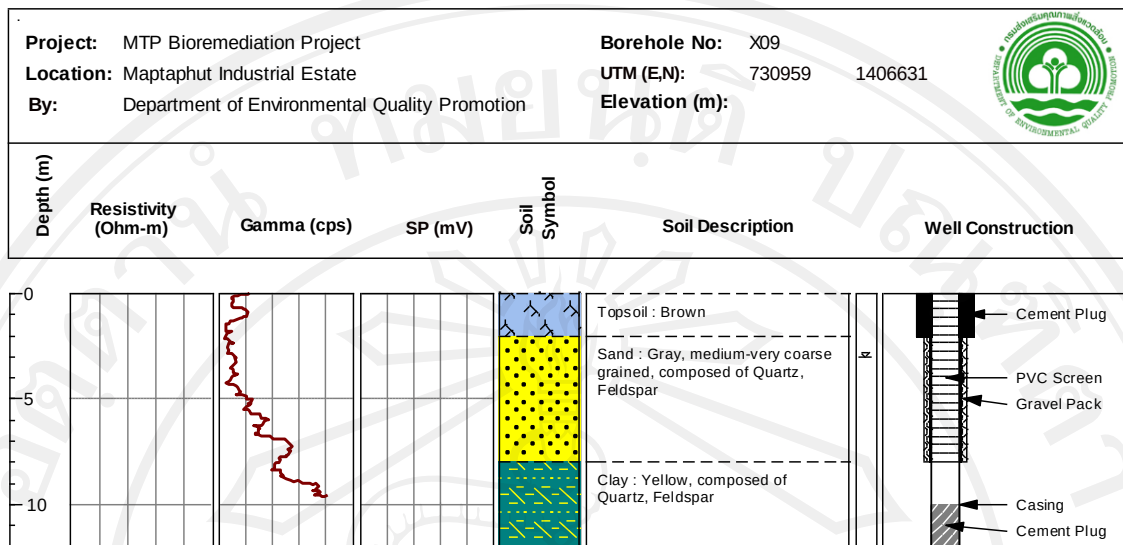
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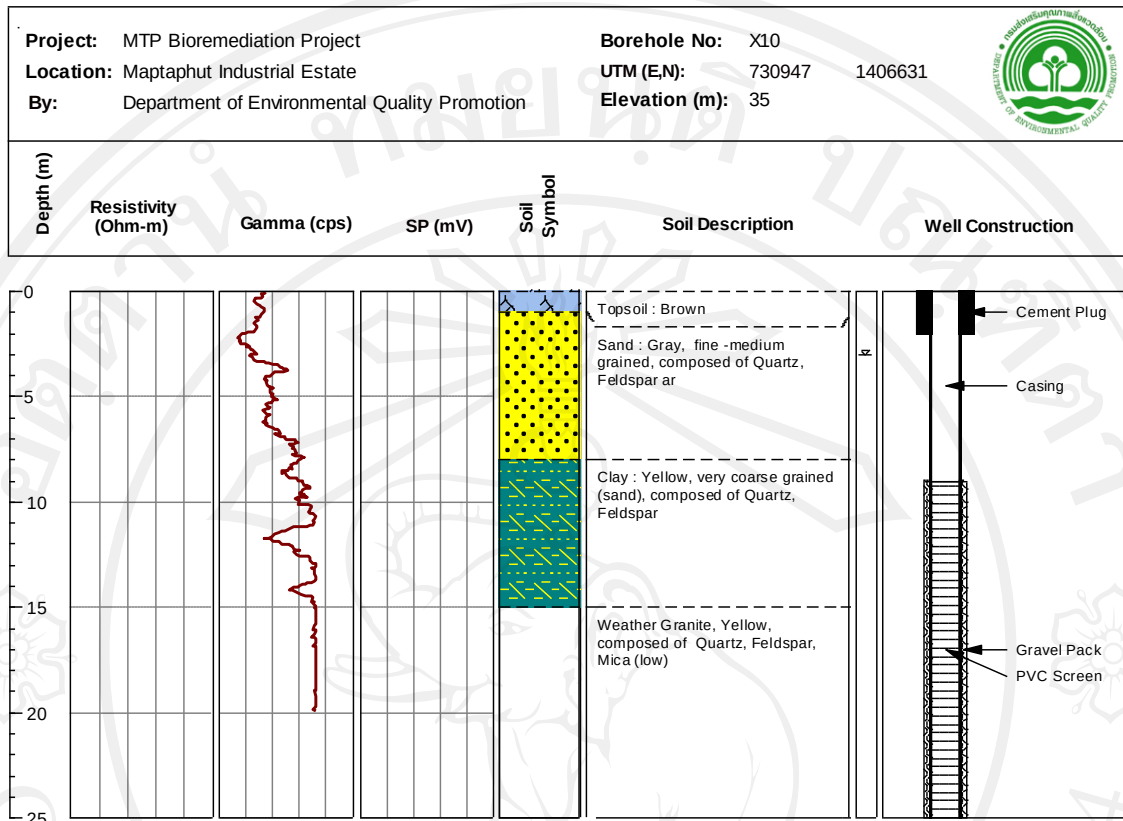
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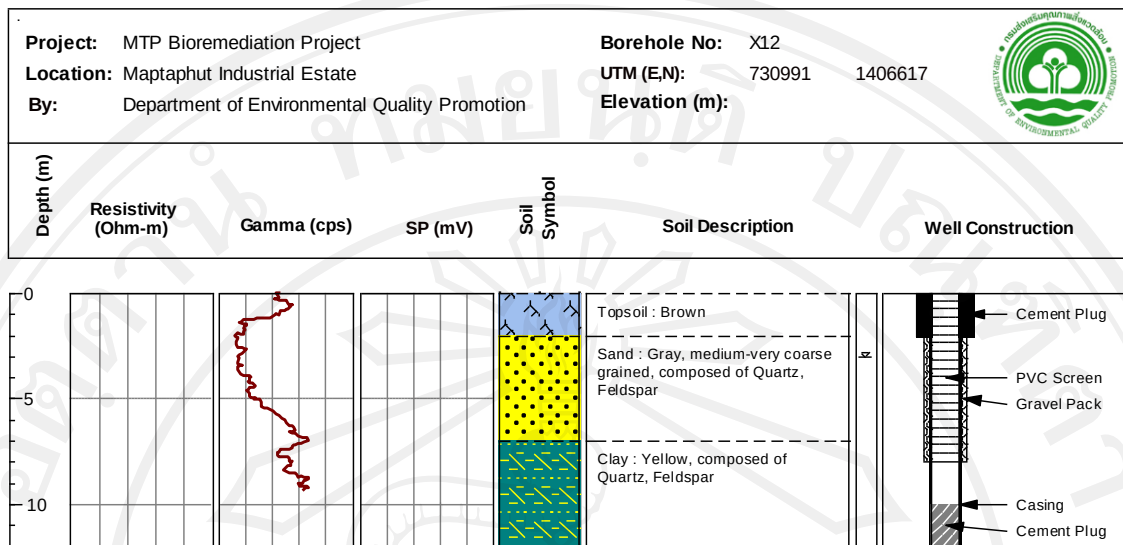
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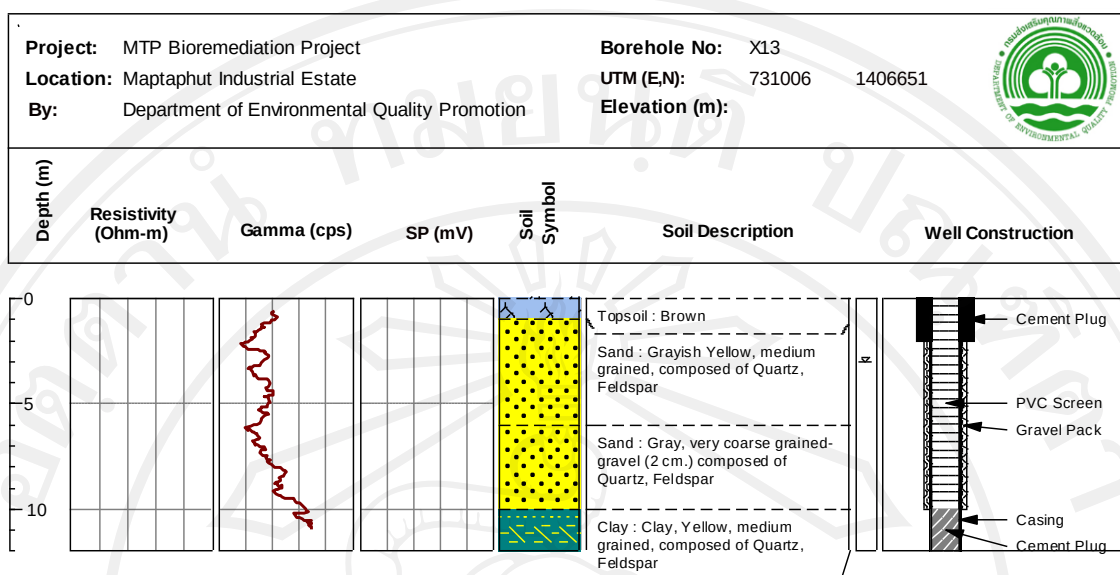
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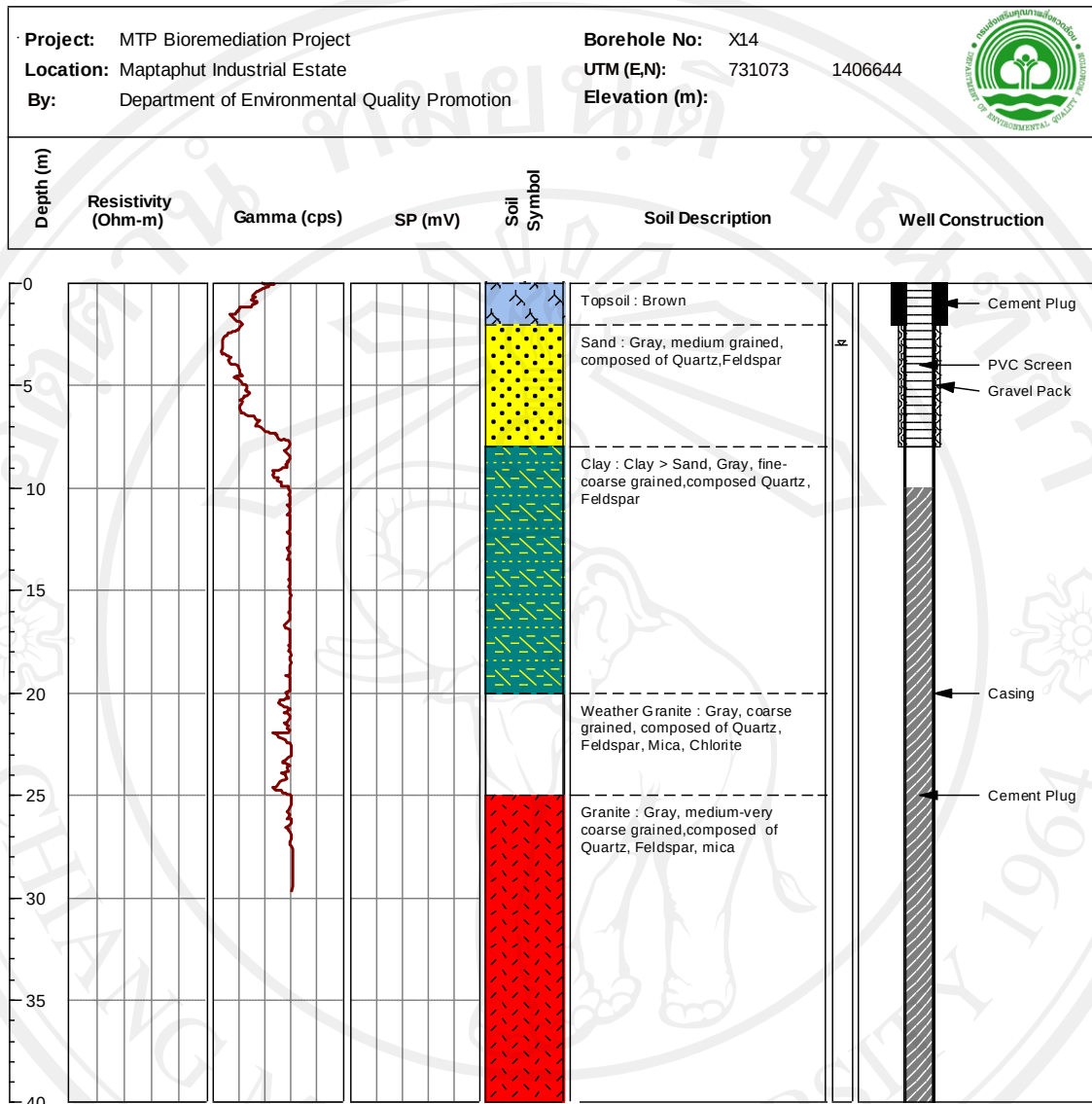
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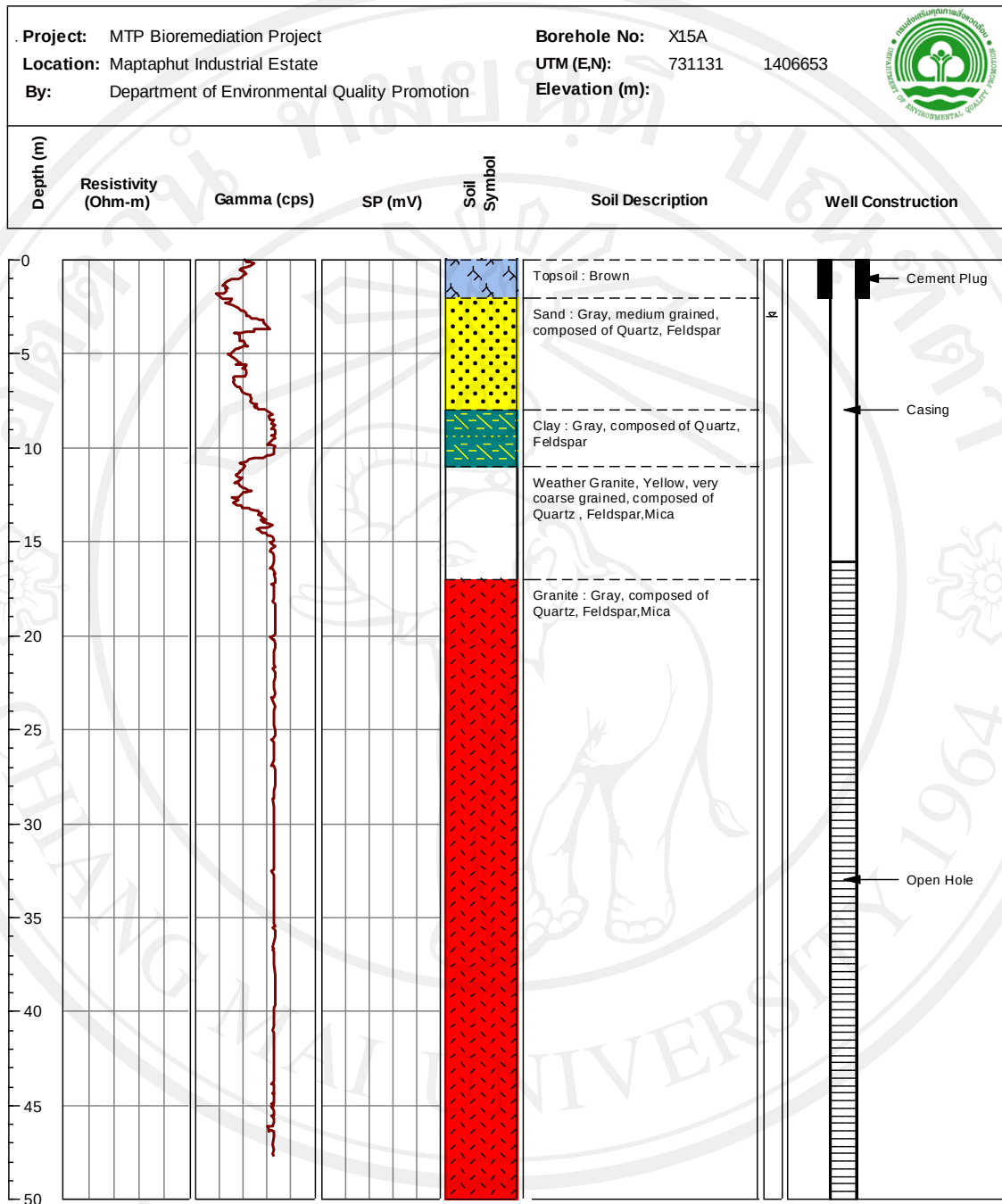
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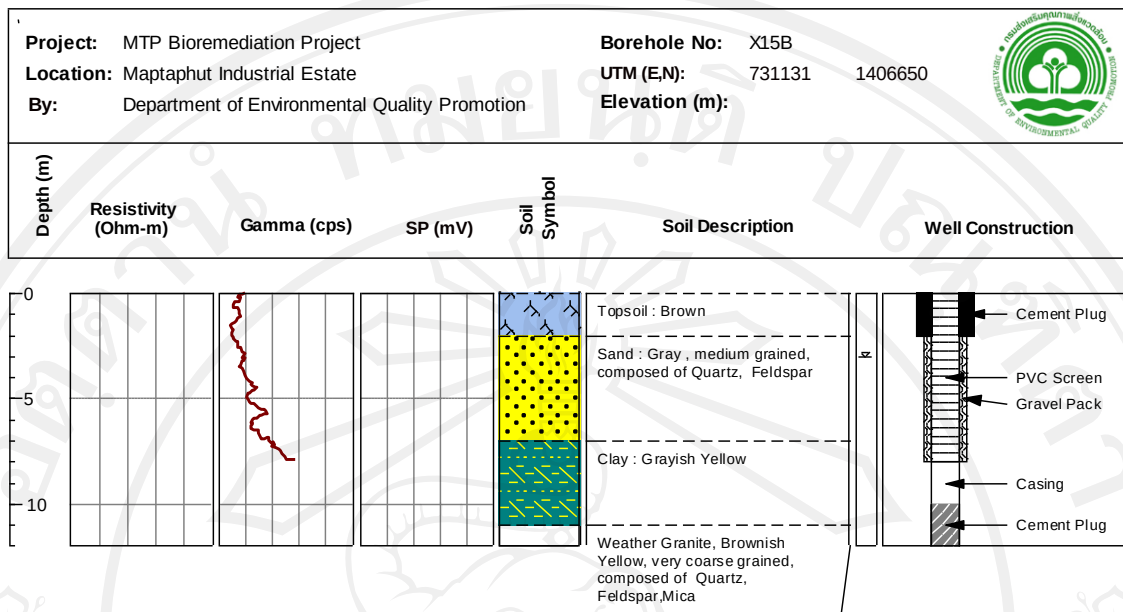
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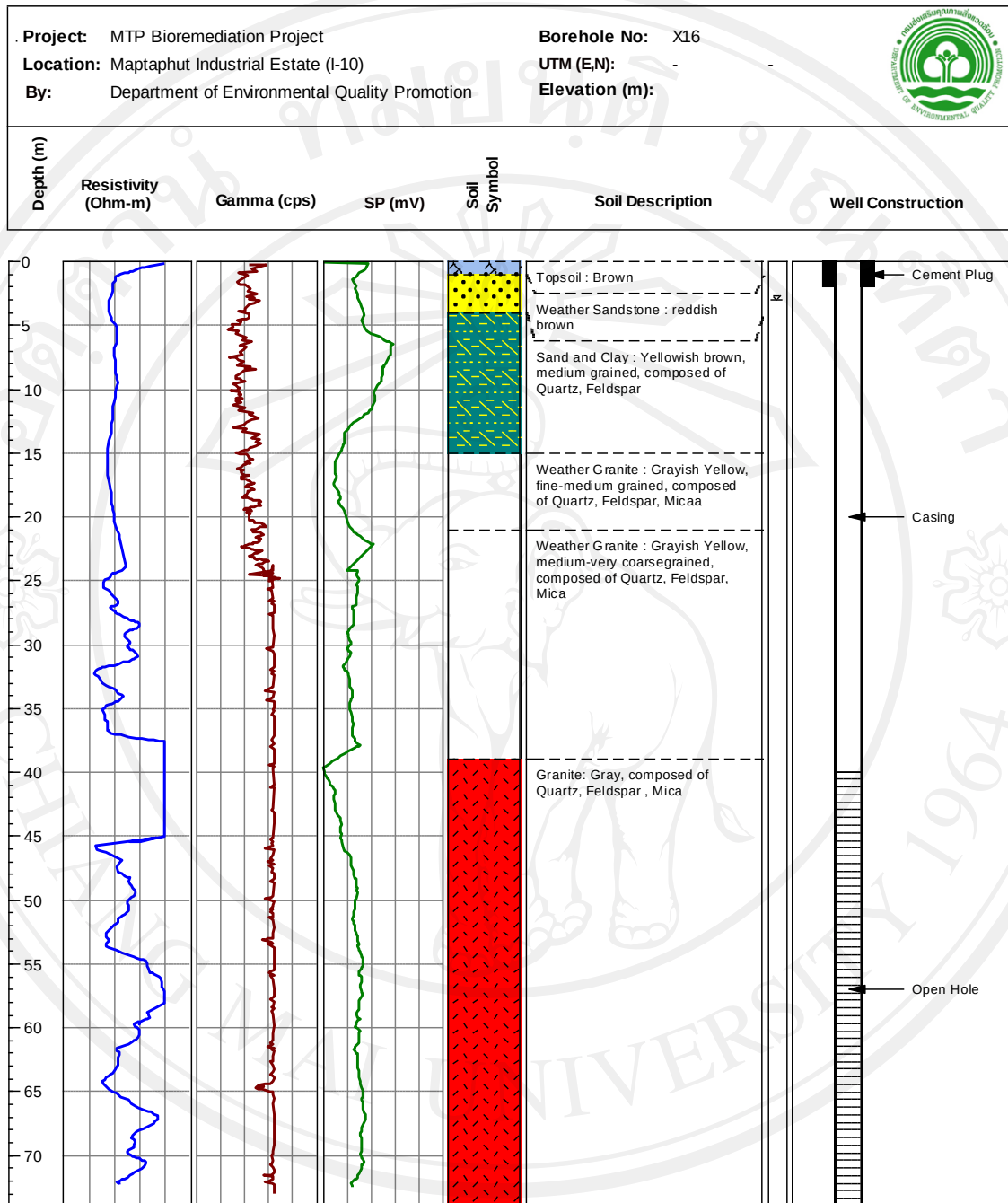
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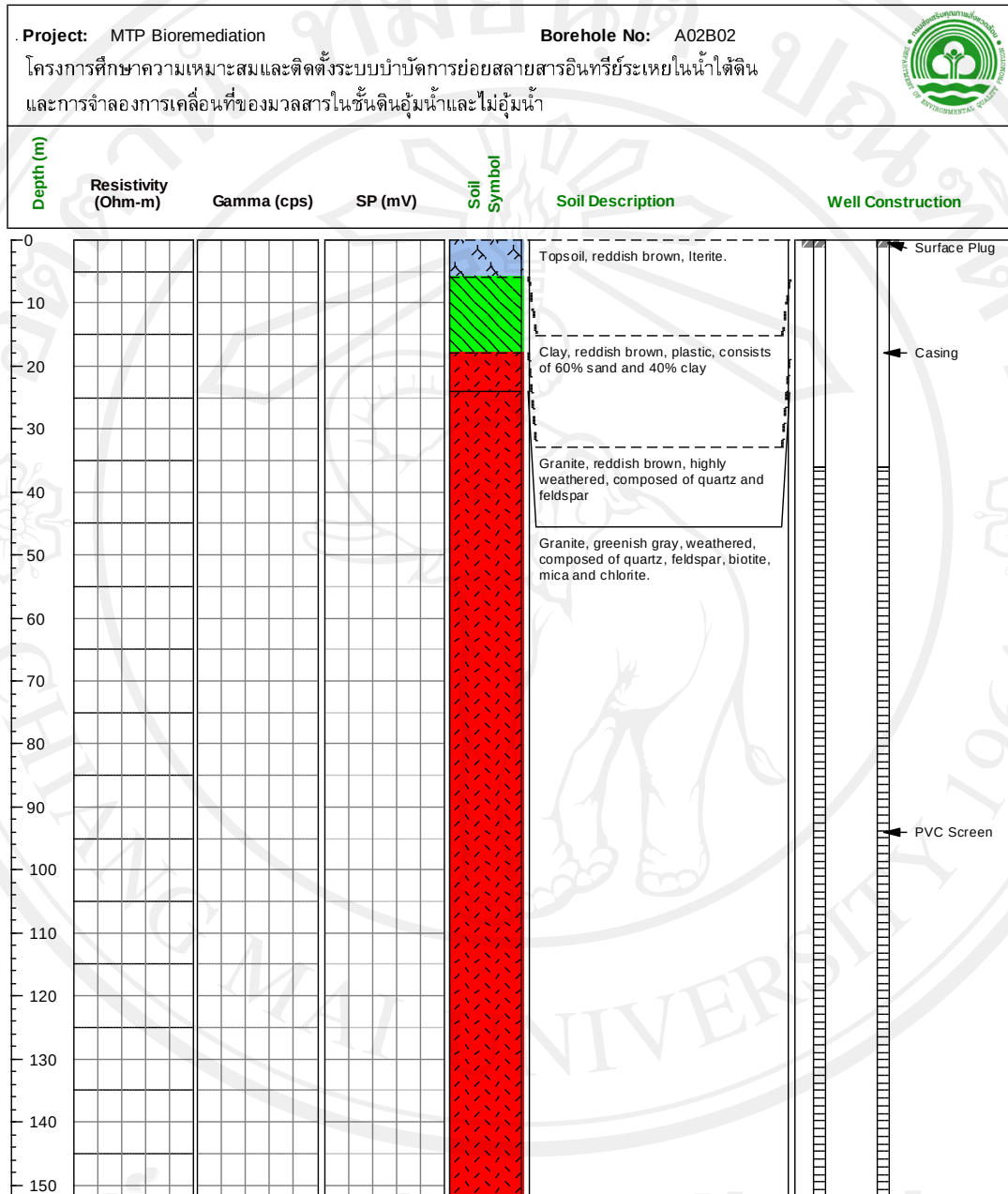
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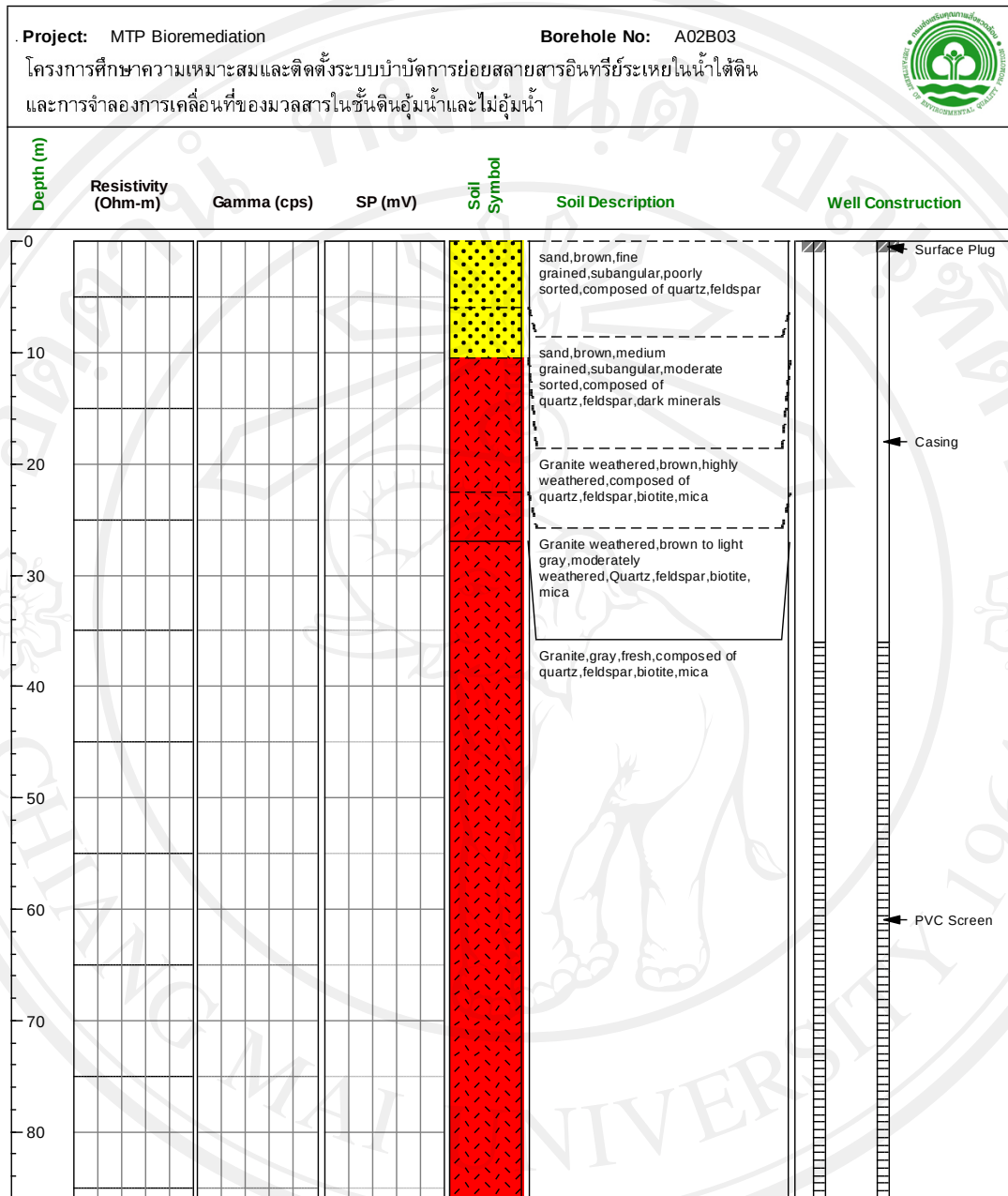
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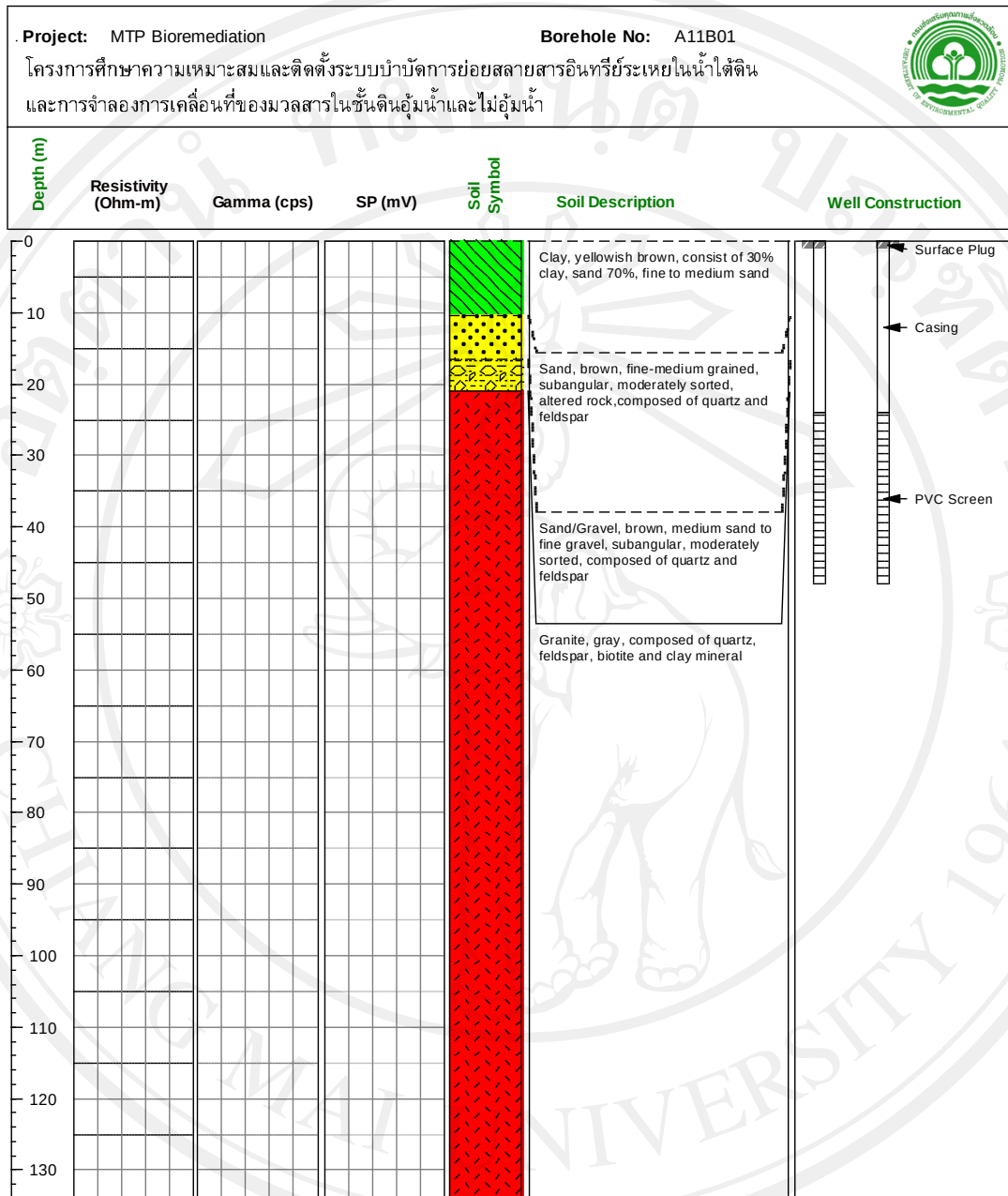
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หมายเหตุ: ข้อมูลลักษณะชั้นดิน-ตะกอนและชั้นหินอุ้มน้ำที่แสดงนี้ เป็นข้อมูลที่รวบรวมจากการเจาะสำรวจซึ่งได้ดำเนินการโดย
 หน่วยงานหลาย ๆ ฝ่าย ได้แก่ (1) กองน้ำบาดาล กรมทรัพยากรธรณี (2) กรมทรัพยากรน้ำบาดาล (3) กรมโยธาธิการ (4)
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 ลักษณะและรูปแบบการไหลของน้ำใต้ดินในแอ่งระยอง



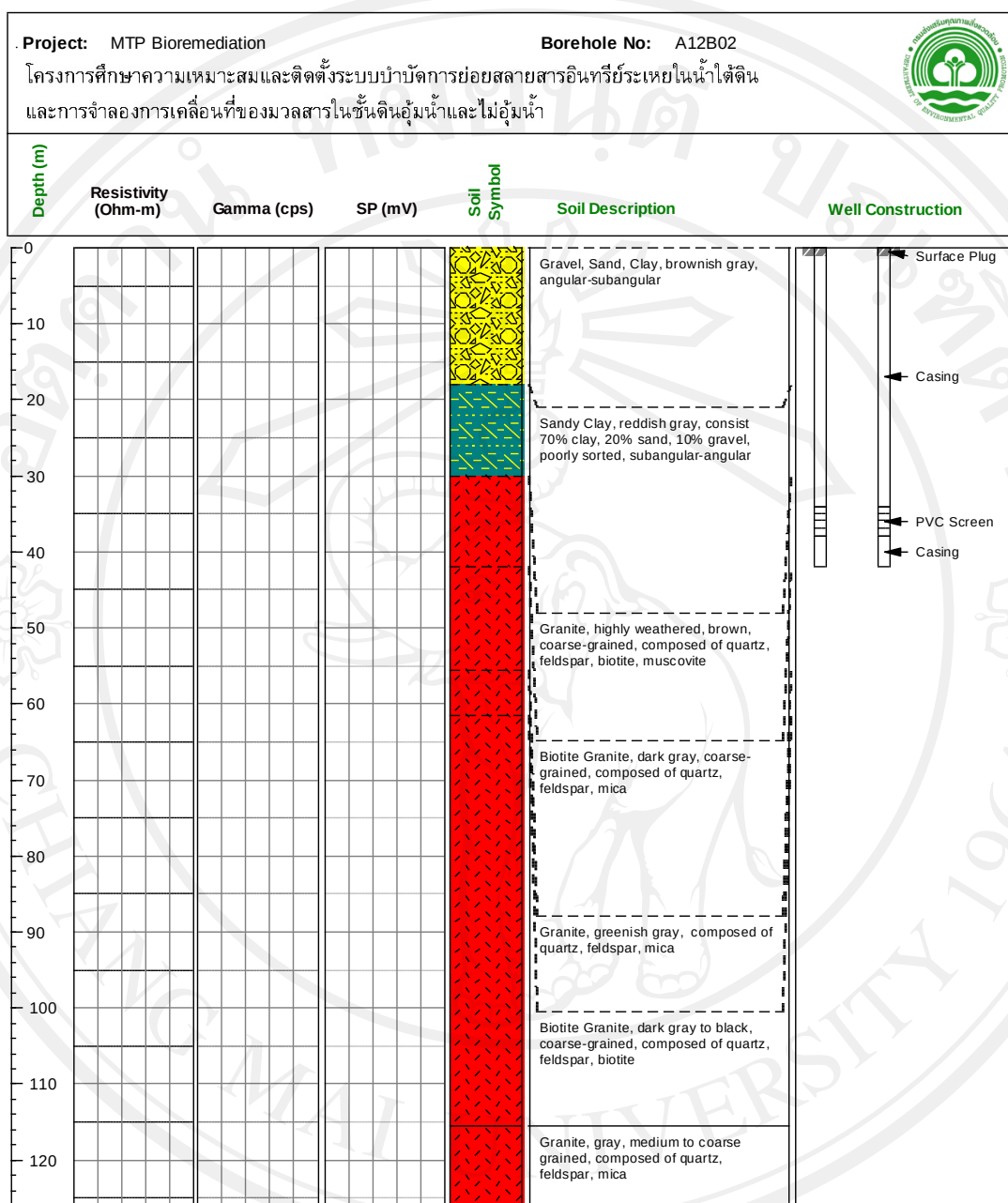
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หมายเหตุ: ข้อมูลลักษณะชั้นดิน-ตะกอนและชั้นหินอุ้มน้ำที่แสดงนี้ เป็นข้อมูลที่รวบรวมจากการเจาะสำรวจซึ่งได้ดำเนินการโดย
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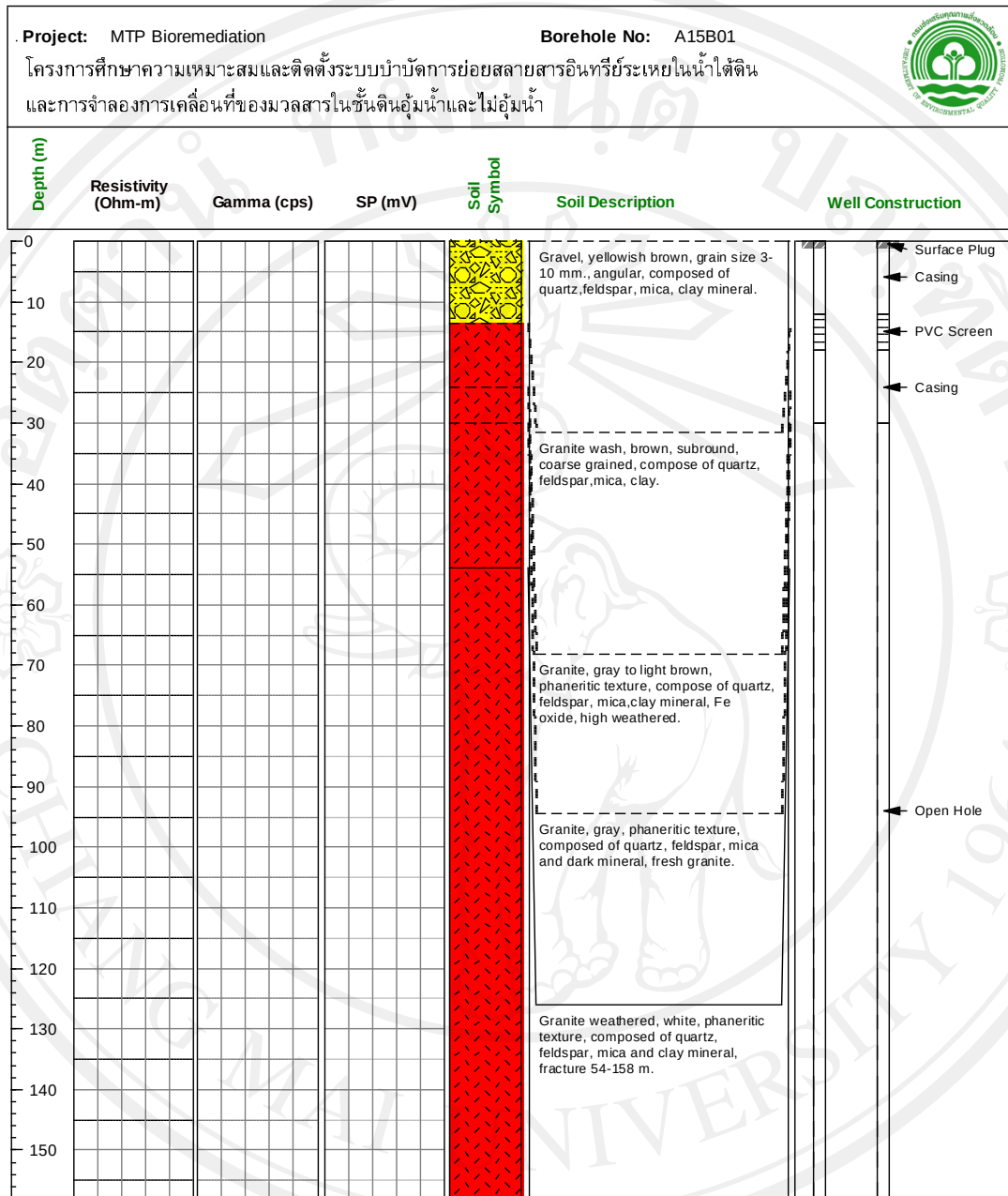
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หมายเหตุ: ข้อมูลลักษณะชั้นดิน-ตะกอนและชั้นหินอุ้มน้ำที่แสดงนี้ เป็นข้อมูลที่รวบรวมจากการเจาะสำรวจซึ่งได้ดำเนินการโดย
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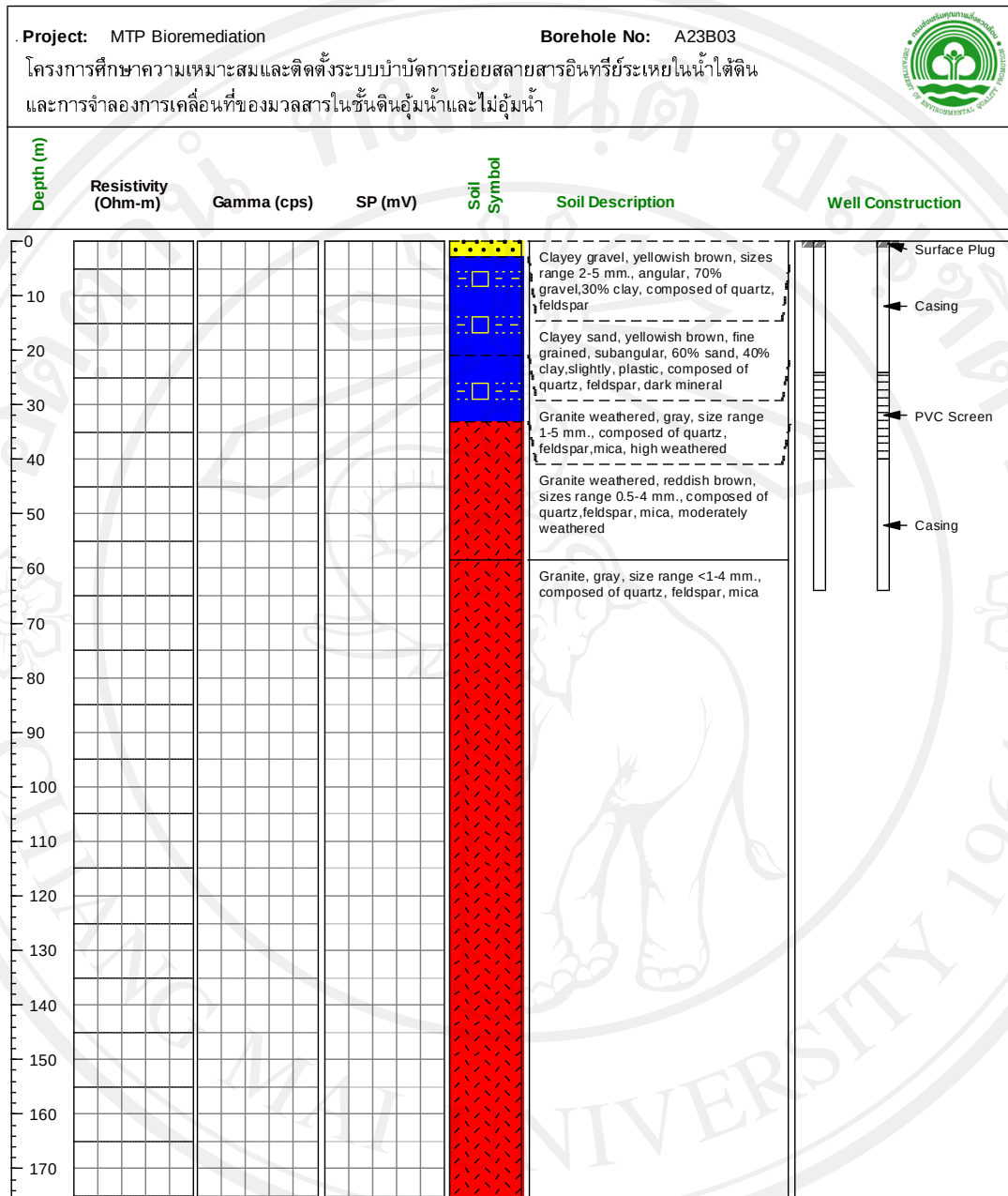
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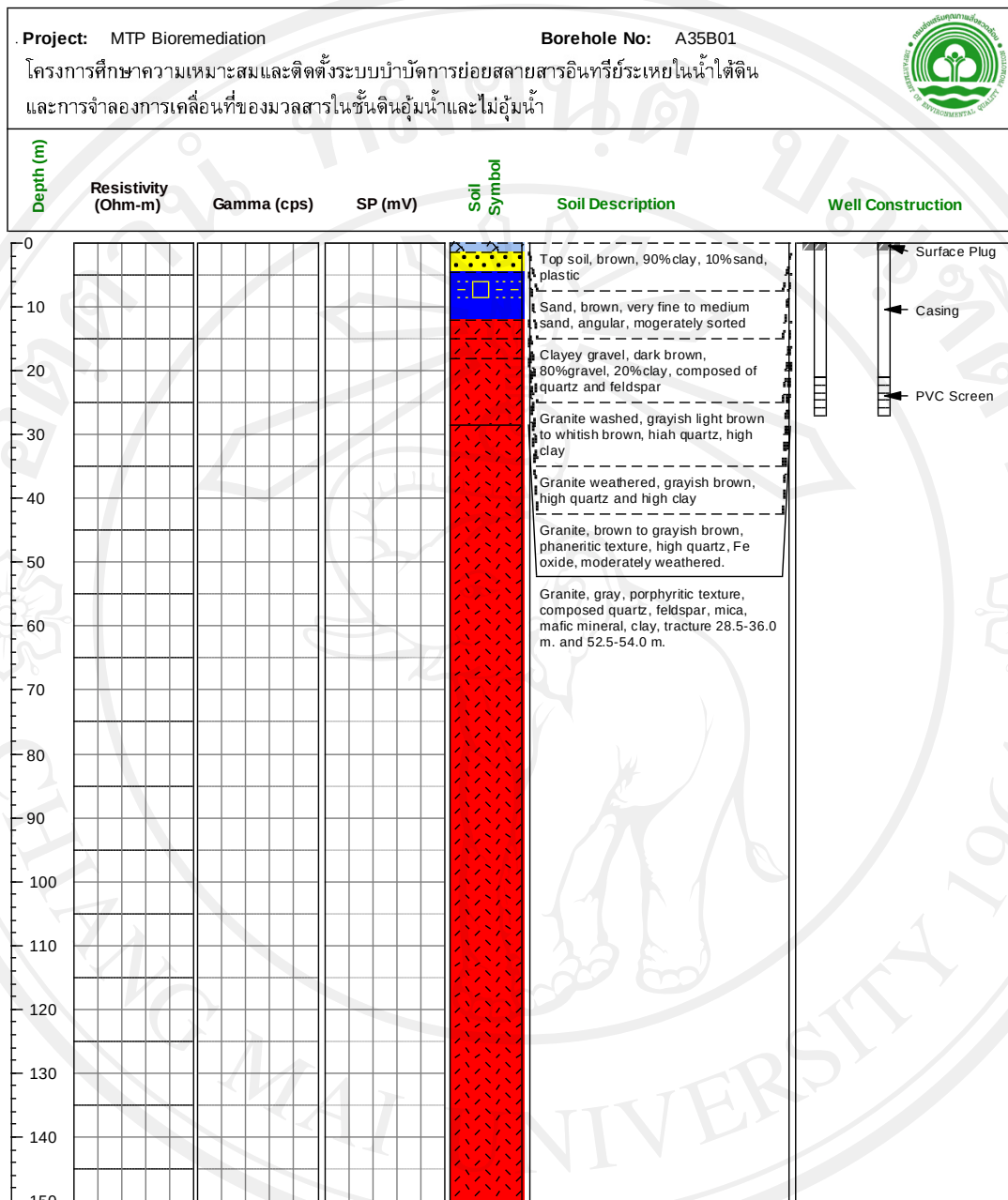
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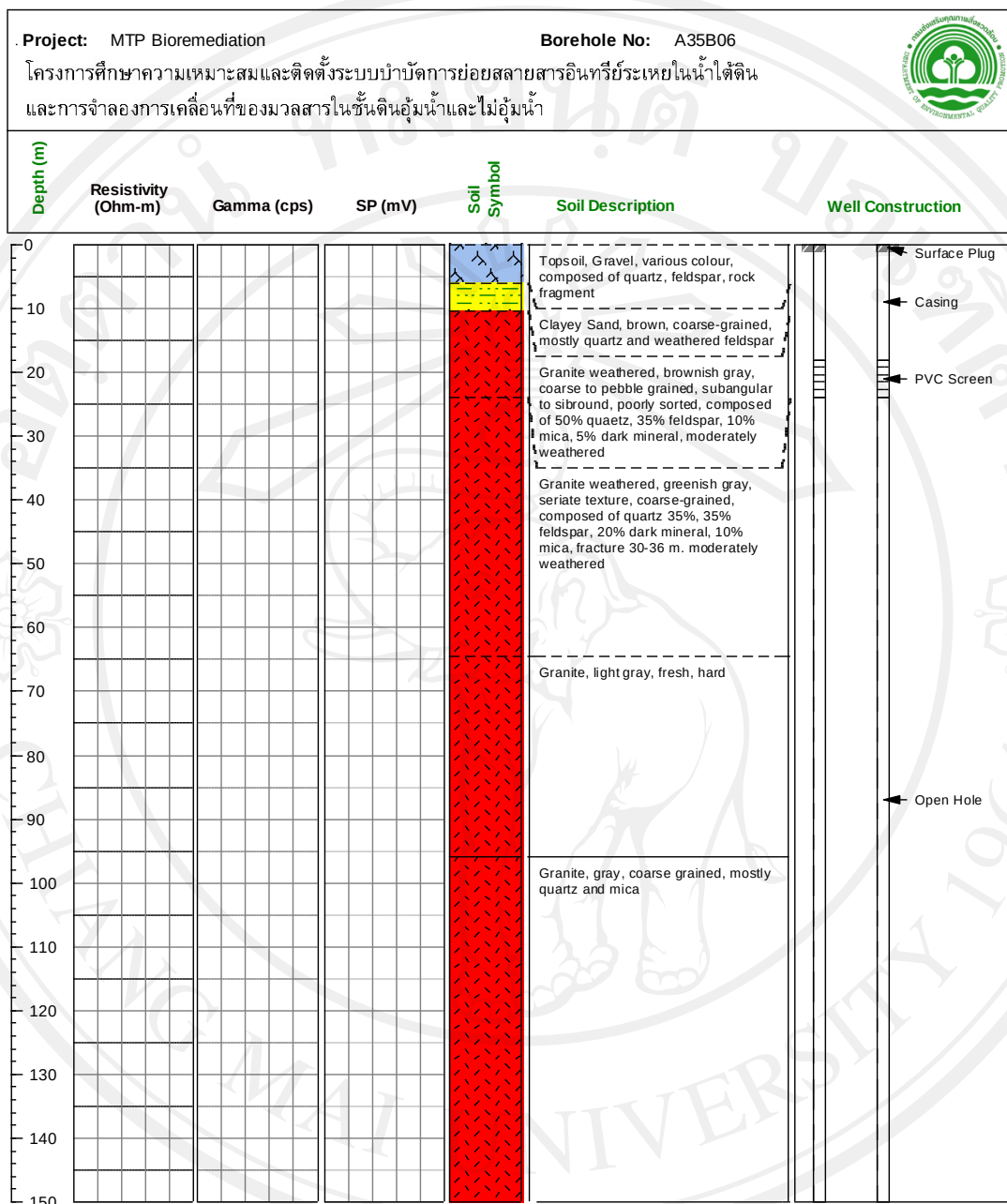
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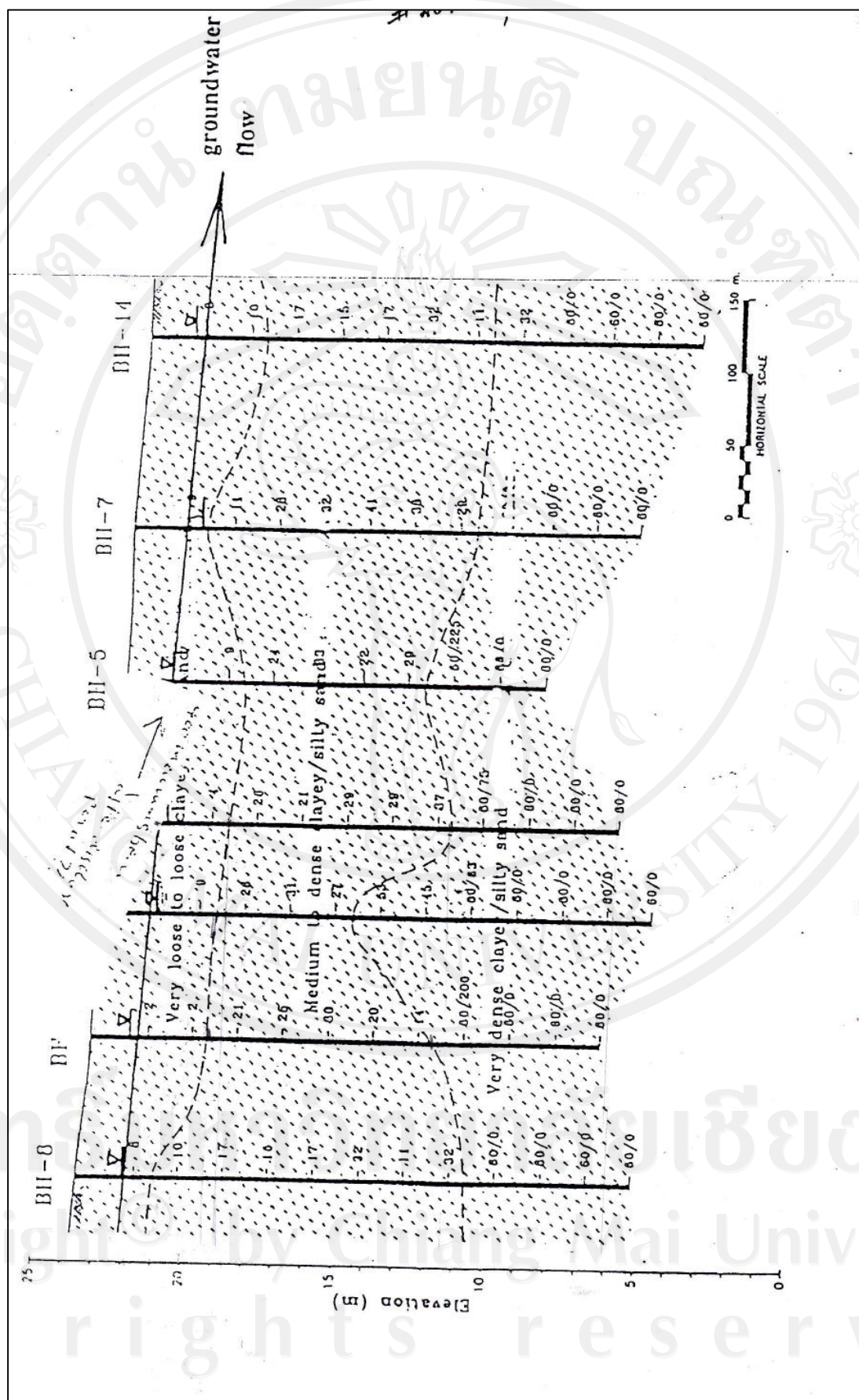
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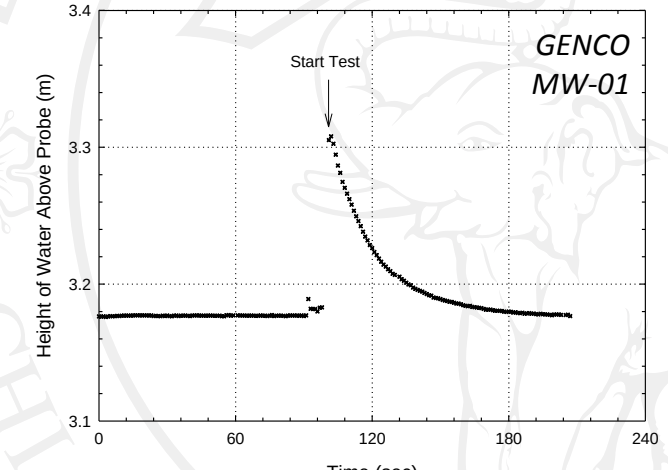
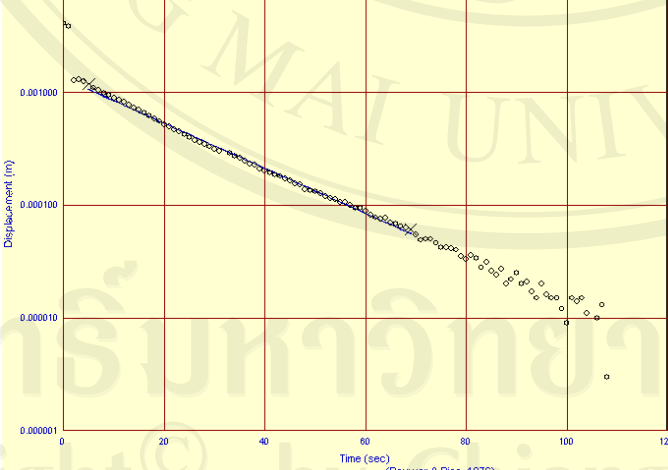


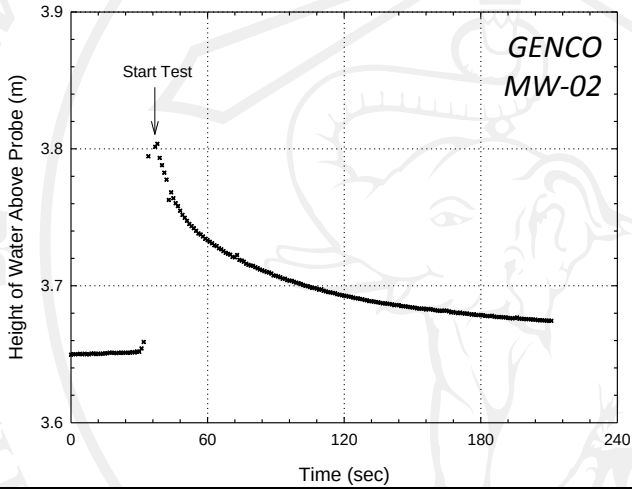
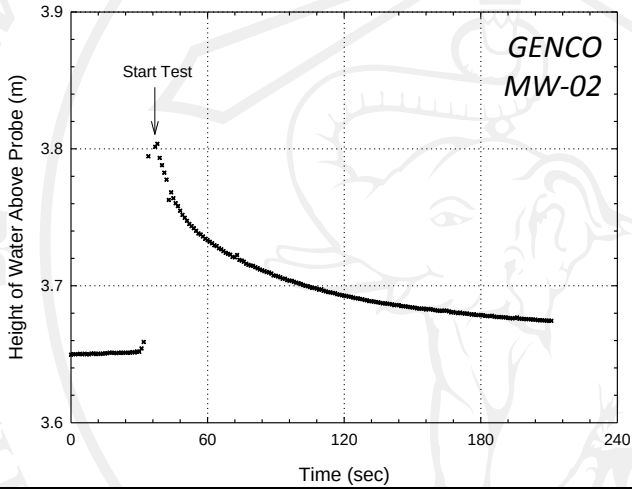
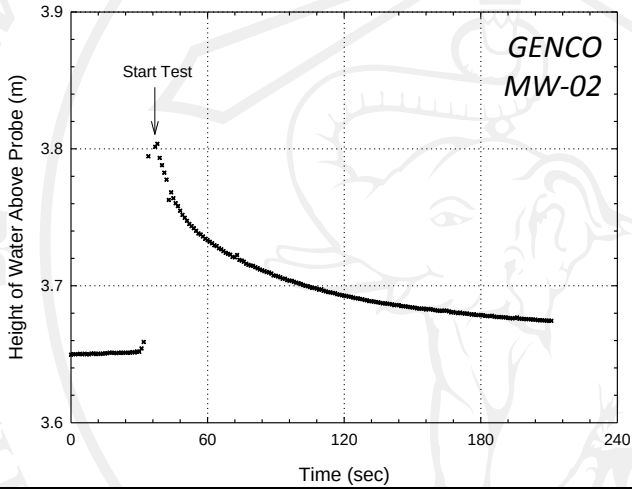
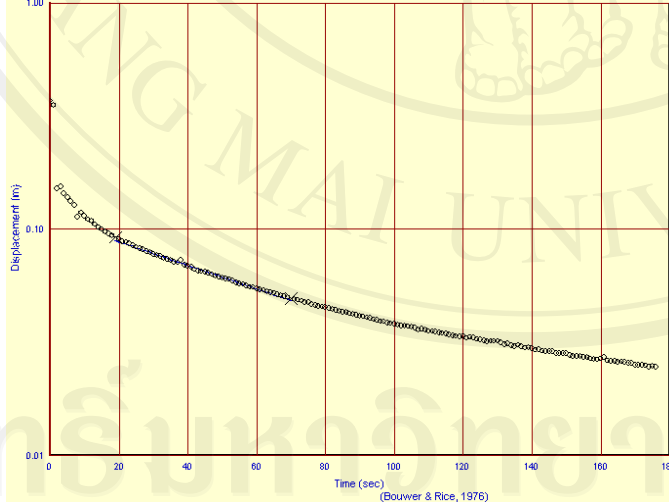
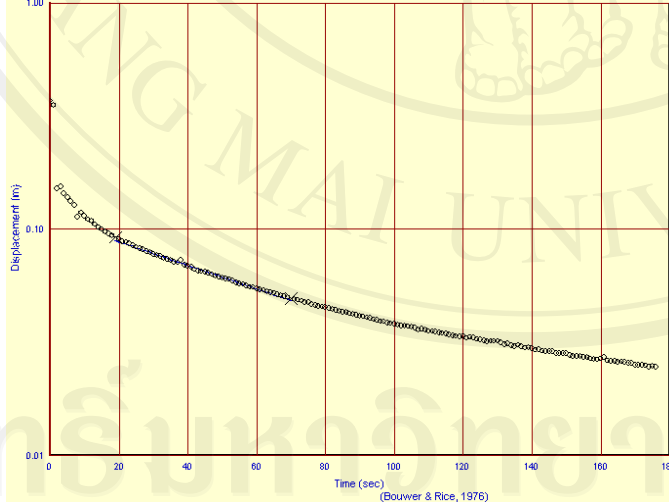
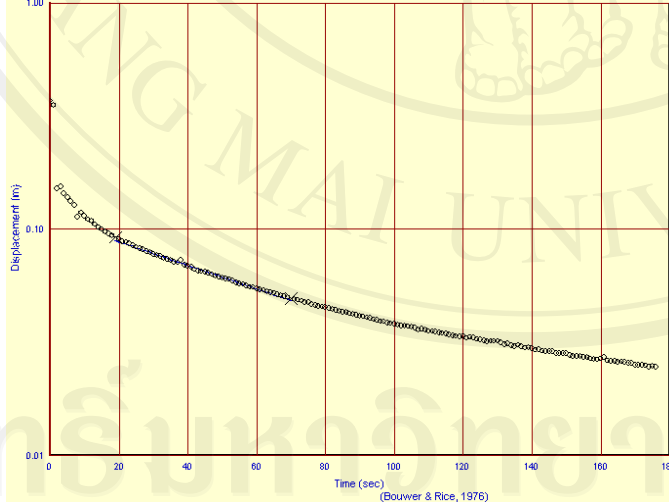
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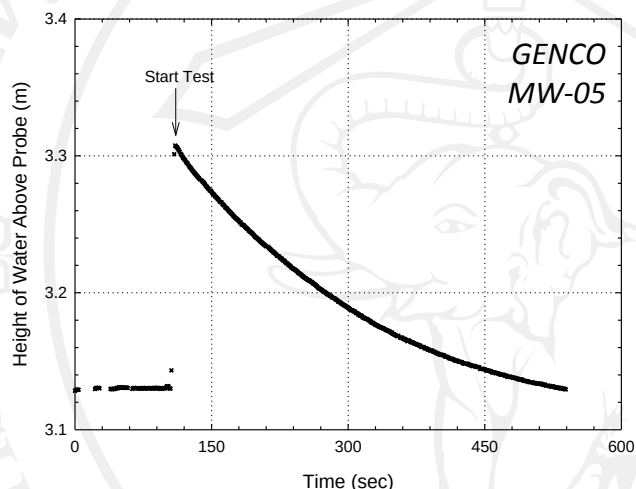
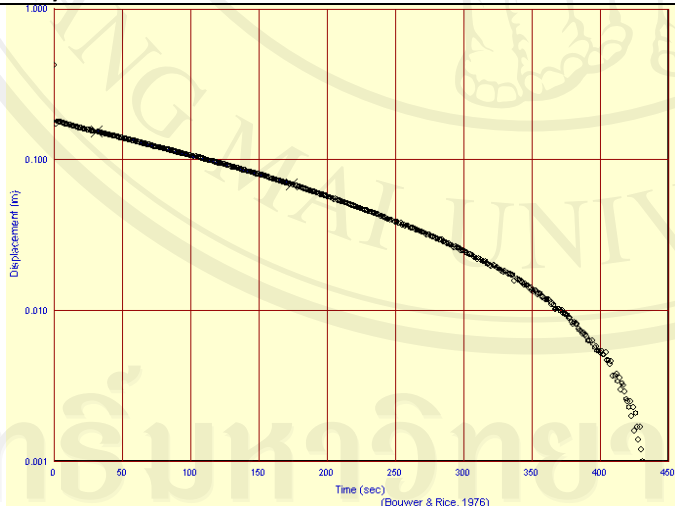
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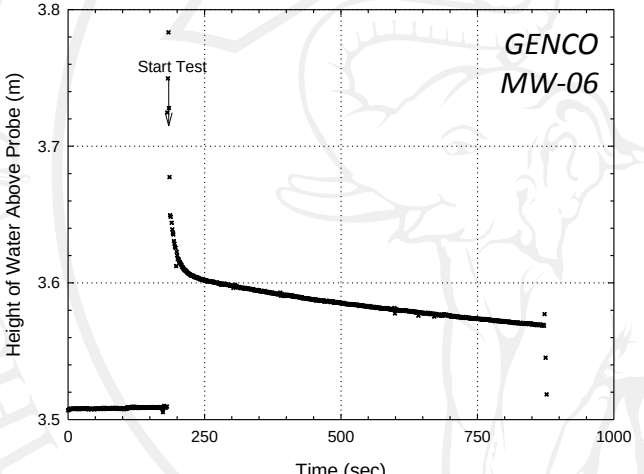
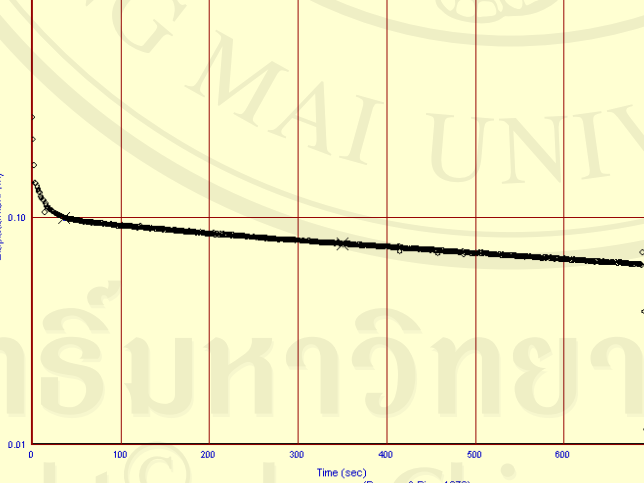
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	Department of Geological Sciences Faculty of Science, Chiang Mai University Chiang Mai, Thailand 50200 Tel. 0-5394-3417 Fax. 0-5394-3444 http://www.geol.science.cmu.ac.th	Slug Test Analysis Report	
Test Well Name MW-01 Well Information Depth: 14 m Radius: 0.051 m DTW: 3.76 m		Location: UTM-E: 731311 UTM-N: 1406605 TOC: 0.54 m	
Test Data			
		Probe: Solinst Level Logger®	
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Analysis Results			
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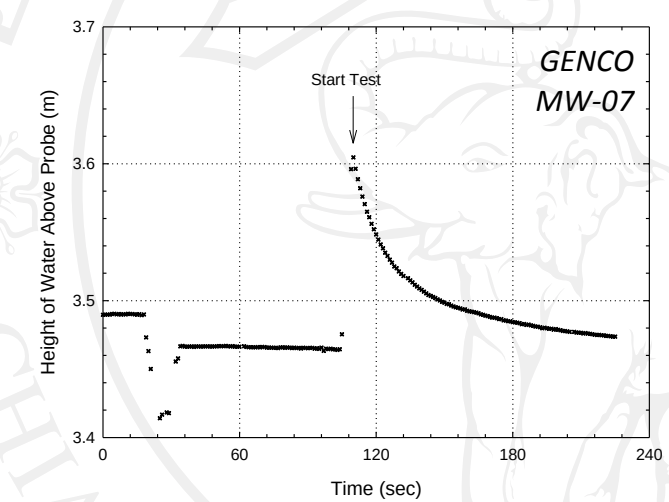
	Department of Geological Sciences Faculty of Science, Chiang Mai University Chiang Mai, Thailand 50200 Tel. 0-5394-3417 Fax. 0-5394-3444 http://www.geol.science.cmu.ac.th		Slug Test Analysis Report																			
			Test Date: 17-21 Sept 08																			
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Test Well Name Well Information	MW-02		Location UTM-E: 731253 UTM-N: 1406535 TOC: 0 m																			
	Depth:	12 m																				
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Analysis Results		Hydraulic Conductivity (m/day):																				
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		Problems or Comments: n/a																				

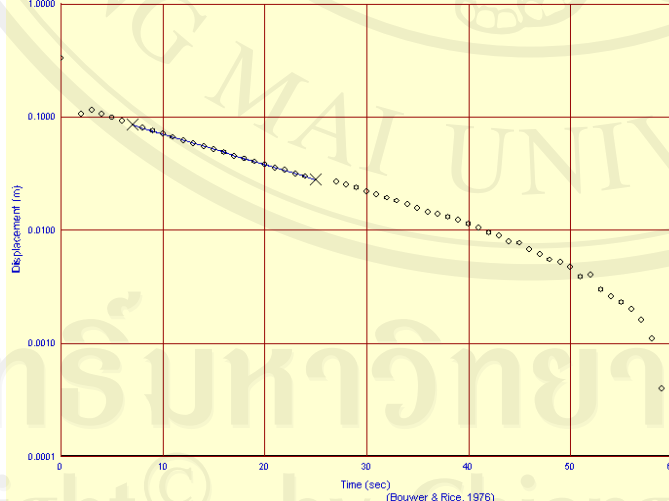
	Department of Geological Sciences Faculty of Science, Chiang Mai University Chiang Mai, Thailand 50200 Tel. 0-5394-3417 Fax. 0-5394-3444 http://www.geol.science.cmu.ac.th		Slug Test Analysis Report																		
			Test Date: 17-21 Sept 08																		
			Tested & Analyzed By CMU & ERTC																		
<table border="1"> <tr> <td rowspan="4"> Test Well Name: Well Information </td> <td colspan="2"> MW-05 </td> <td colspan="2"> Location: </td> </tr> <tr> <td> Depth: </td> <td> 15 m </td> <td> UTM-E: </td> <td> 731323 </td> </tr> <tr> <td> Radius: </td> <td> 0.051 m </td> <td> UTM-N: </td> <td> 1406327 </td> </tr> <tr> <td> DTW: </td> <td> 2.83 m </td> <td> TOC: </td> <td> 0.04 m </td> </tr> </table>					Test Well Name: Well Information	MW-05		Location:		Depth:	15 m	UTM-E:	731323	Radius:	0.051 m	UTM-N:	1406327	DTW:	2.83 m	TOC:	0.04 m
Test Well Name: Well Information	MW-05		Location:																		
	Depth:	15 m	UTM-E:	731323																	
	Radius:	0.051 m	UTM-N:	1406327																	
	DTW:	2.83 m	TOC:	0.04 m																	
Test Data																					
			Probe: Solinst Level Logger® Problems or Comments: n/a																		
Analysis Results																					
			Hydraulic Conductivity (m/day): <table border="1"> <tr> <td>Hvorslev:</td> <td>-</td> </tr> <tr> <td>Bouwer & Rice:</td> <td>0.22-0.33</td> </tr> </table> Problems or Comments: n/a		Hvorslev:	-	Bouwer & Rice:	0.22-0.33													
Hvorslev:	-																				
Bouwer & Rice:	0.22-0.33																				

	Department of Geological Sciences Faculty of Science, Chiang Mai University Chiang Mai, Thailand 50200 Tel. 0-5394-3417 Fax. 0-5394-3444 http://www.geol.science.cmu.ac.th	Slug Test Analysis Report	
		Test Date: 17-21 Sept 08	
		Tested & Analyzed By CMU & ERTC	
Test Well Name: MW-06 Well Information Depth: 14 m Radius: 0.051 m DTW: 3.41 m		Location: UTM-E: 731241 UTM-N: 1402387 TOC: 0 m	
Test Data			
		Probe: Solinst Level Logger® Problems or Comments: n/a	
Analysis Results			
		Hydraulic Conductivity (m/day): Hvorslev: - Bouwer & Rice: 0.0321-0.0456 Problems or Comments: n/a	

	Department of Geological Sciences Faculty of Science, Chiang Mai University Chiang Mai, Thailand 50200 Tel. 0-5394-3417 Fax. 0-5394-3444 http://www.geol.science.cmu.ac.th	Slug Test Analysis Report	
		Test Date: 17-21 Sept 08	
		Tested & Analyzed By CMU & ERTC	

Test Well Nam : MW-07	Location:
Well Information Depth: 14 m	UTM-E: 731428
Radius: 0.051 m	UTM-N: 1406402
DTW: 3.37 m	TOC: 0.30 m

Test Data	
	Probe: Solinst Level Logger® Problems or Comments: n/a

Analysis Results					
	Hydraulic Conductivity (m/day): <table border="1"> <tr> <td>Hvorslev:</td> <td>-</td> </tr> <tr> <td>Bouwer & Rice:</td> <td>2.71-3.55</td> </tr> </table> Problems or Comments: n/a	Hvorslev:	-	Bouwer & Rice:	2.71-3.55
Hvorslev:	-				
Bouwer & Rice:	2.71-3.55				



APPENDIX C

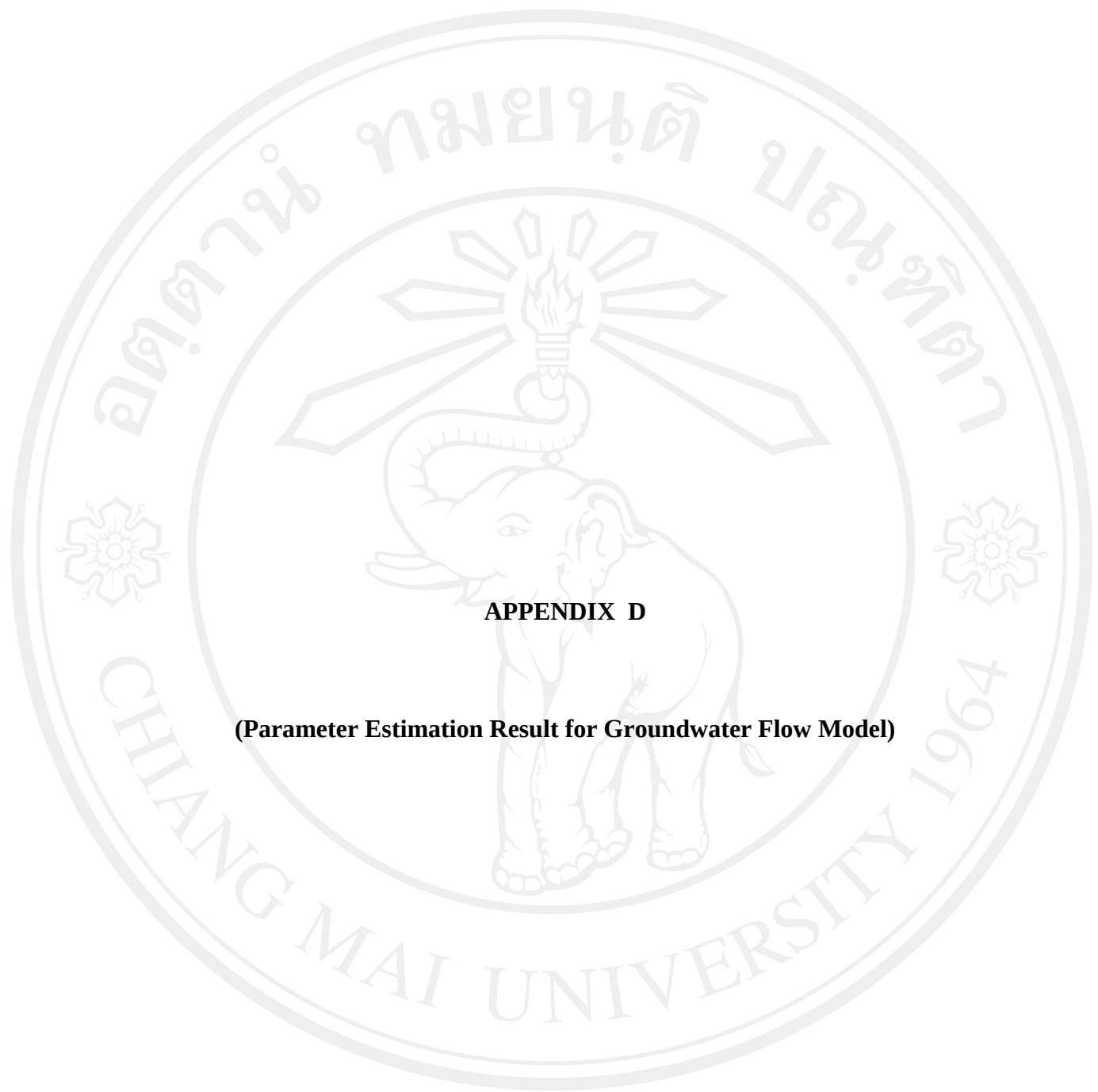
(Hydrochemical Test Results)

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Well	Date	Temperature (°C)	pH	Eh (mV)	Conductivity (μS/cm)	Sum of Anions (meq/l)	Sum of Cations (meq/l)	Balance (%)	Total dissolved solids (mg/l)	Total hardness (mg/l CaCO ₃)	Alkalinity (mg/l CaCO ₃)
1	19/9/2550	33.00			704.00	4.67	4.74	0.73		45.45	
1	23/6/2551	34.00	5.50	49.00	360.00	8.89	5.80	-21.03	179.00	64.93	110.00
1	18/9/2551	32.00	5.80	47.00	297.00	8.51	5.20	-24.19	148.00	71.44	129.00
1	15/12/2551	33.00	5.10	33.00	302.00	6.75	4.62	-18.73	151.00	49.43	61.00
1	11/1/2553	31.00	5.70	-1.00	530.00	6.13	4.73	-12.89	529.00	72.98	76.00
1	10/3/2553	33.00	6.10	319.00	623.00	8.27	12.18	19.08	298.00	151.81	76.00
1	23/4/2553	31.00	6.70	23.00	651.00	8.37	12.38	19.31	300.00	139.32	64.00
1	27/5/2553	30.00	5.90	130.00	525.00	7.92	12.16	21.13	282.00	154.31	68.00
2	18/1/2551	32.00	6.00	-130.00	493.00	5.93	4.01	-19.30		86.37	219.00
2	23/6/2551	31.00	5.70	-108.00	320.00	6.80	5.44	-11.15	159.00	124.09	244.00
2	18/9/2551	31.00	6.30	-63.00	312.00	4.03	4.09	0.80	158.00	105.14	96.00
2	15/12/2551	30.00	5.80	-150.00	294.00	5.86	4.07	-18.07	148.00	100.61	212.00
2	12/1/2553	30.00	6.10	18.00	724.00	5.80	3.93	-19.25	251.00	99.55	222.00
2	10/3/2553	29.00	6.50	125.00	643.00	6.34	10.72	25.71	251.00	216.61	206.00
2	22/4/2553	30.00	6.20	-10.00	610.00	6.65	11.66	27.34	303.00	234.83	216.00
2	27/5/2553	30.00	6.10	59.00	578.00	6.76	12.03	28.01	288.00	242.33	212.00
3	18/1/2551	31.00	6.00	-19.00	526.00	4.45	4.62	1.95		82.17	86.00
3	23/6/2551	32.00	6.10	-147.00	794.00	11.90	29.87	43.02	392.00	234.97	166.00
3	18/9/2551	32.00	6.10	-50.00	379.00	12.20	6.35	-31.50	190.00	121.31	232.00
3	15/12/2551	31.00	5.80	-1.00	295.00	6.16	4.72	-13.26	148.00	79.37	84.00
3	11/1/2553	29.00	6.10	-53.00	619.00	9.28	5.68	-24.03	300.00	112.73	130.00
3	9/3/2553	30.00	6.90	102.00	1253.00	11.18	12.95	7.36	360.00	226.33	120.00
3	22/4/2553	30.00	6.10	-43.00	1637.00	15.46	32.34	35.32	737.00	701.48	210.00
3	27/5/2553	30.00	6.40	26.00	1496.00	14.20	31.74	38.18	695.00	648.42	194.00
4	23/1/2551	30.00	6.00	-44.00	320.00	3.96	2.88	-15.80		45.98	55.00
4	15/12/2551	28.00	5.60	-39.00	187.00	4.13	2.84	-18.61	93.00	37.77	64.00
4	12/1/2553	29.00	5.90	103.00	421.00	4.00	2.94	-15.25	178.00	54.65	84.00
4	10/3/2553	28.00	6.30	180.00	420.00	5.51	8.37	20.55	178.00	127.58	84.00
4	23/4/2553	28.00	5.10	36.00	386.00	5.73	8.76	20.92	219.00	131.70	82.00
4	27/5/2553	29.00	6.10	89.00	384.00	5.56	9.07	24.03	208.00	120.09	84.00
5	23/1/2551	30.00	6.00	10.00	289.00	3.37	2.80	-9.24		41.86	70.00
5	15/12/2551	29.00	5.80	31.00	176.00	3.57	2.64	-14.93	88.00	33.12	70.00
6	23/1/2551	30.00	6.00	80.00	202.00	2.25	1.97	-6.44		35.57	61.00
6	15/12/2551	30.00	5.20	56.00	118.00	2.48	1.91	-12.98	59.00	31.71	72.00
7	18/1/2551	29.00	6.00	47.00	217.00	3.06	1.97	-21.55		35.57	77.00
7	15/12/2551	29.00	5.40	79.00	147.00	2.37	1.87	-11.77	73.00	31.96	66.00
7	9/3/2553	28.00	6.40	163.00	418.00	4.94	8.08	24.17	181.00	145.06	98.00
7	22/4/2553	28.00	6.10	15.00	420.00	5.84	9.23	22.50	191.00	146.68	92.00
7	27/5/2553	29.00	5.80	29.00	388.00	5.09	8.99	27.74	206.00	155.80	90.00

Well	Date	Major ion composition (mg/l)										Water Type
		Na	K	Ca	Mg	Cl	SO ₄	NO ₃	HCO ₃	Fe	Mn	
1	19/9/2550	78.00	16.00	8.80	5.70	149.00	21.00	0.91				Na-Cl
1	23/6/2551	94.00	15.00	26.00		217.00	26.00	0.08	134.00			Na-Cl-HCO ₃
1	18/9/2551	79.00	13.00	23.00	3.40	194.00	22.00	0.05	157.27			Na-Cl-HCO ₃
1	15/12/2551	77.00	11.00	16.00	2.30	167.00	39.00		73.93	23.00		Na-Cl-HCO ₃
1	11/1/2553	69.00	9.90	19.00	6.20	160.00	3.80	0.03	92.59	6.00	0.50	Na-Cl-HCO ₃
1	10/3/2553	195.00	22.00	41.00	12.00	225.00	13.00	3.00	92.66	12.30	0.02	Na-Ca-Cl
1	23/4/2553	206.00	21.00	36.00	12.00	240.00	9.80		78.03	13.10	0.10	Na-Cl
1	27/5/2553	192.00	23.00	42.00	12.00	221.00	10.00		82.88	10.20	0.11	Na-Ca-Cl
2	18/1/2551	34.00	16.00	27.00	4.60	52.00	3.80	0.10	267.09			Na-Ca-HCO ₃ -Cl
2	23/6/2551	41.00	21.00	36.00	8.30	64.00	5.40		297.54			Na-Ca-HCO ₃ -Cl
2	18/9/2551	34.00	16.00	36.00	3.70	65.00	13.00		117.07			Na-Ca-HCO ₃ -Cl
2	15/12/2551	34.00	15.00	36.00	2.60	50.00	10.00		258.53			Na-Ca-HCO ₃ -Cl
2	12/1/2553	35.00	16.00	27.00	7.80	45.00	4.10	0.05	270.76	6.80	0.20	Na-Ca-HCO ₃ -Cl
2	10/3/2553	114.00	32.00	62.00	15.00	72.00	5.50		251.22	14.30	0.07	Na-Ca-HCO ₃ -Cl
2	22/4/2553	121.00	38.00	66.00	17.00	76.00	6.40		263.44	13.80	0.07	Na-Ca-HCO ₃ -Cl
2	27/5/2553	126.00	38.00	69.00	17.00	74.00	18.00		258.56	12.10	0.09	Na-Ca-HCO ₃ -Cl
3	18/1/2551	55.00	15.00	24.00	5.40	96.00		0.05	204.85	11.10	0.10	Na-Ca-HCO ₃ -Cl
3	23/6/2551		40.00	71.00	14.00	303.00			202.45			Na-Ca-HCO ₃ -Cl
3	18/9/2551	78.00	21.00	40.00	5.20	162.00	142.00		282.96			Na-Ca-HCO ₃ -Cl-SO ₄
3	15/12/2551	61.00	17.00	27.00	2.90	84.00	100.00		102.38			Na-Ca-HCO ₃ -Cl-SO ₄
3	11/1/2553	68.00	18.00	27.00	11.00	123.00	153.00	0.01	158.53	7.80	0.20	Na-Cl-SO ₄ -HCO ₃
3	9/3/2553	167.00	33.00	56.00	21.00	133.00	236.00		146.28	16.60	0.15	Na-Ca-SO ₄ -Cl
3	22/4/2553	342.00	91.00	177.00	63.00	393.00			256.12	14.10	0.20	Na-Ca-Mg-Cl
3	27/5/2553	355.00	87.00	164.00	58.00	360.00	4.60		236.00	12.90	0.08	Na-Ca-Mg-Cl
4	23/1/2551	39.00	10.00	10.00	5.10	97.00	4.90	0.06	67.03			Na-Cl-HCO ₃
4	15/12/2551	42.00	10.00	11.00	2.50	95.00	5.90		77.92			Na-Cl-HCO ₃
4	12/1/2553	36.00	11.00	11.00	6.60	71.00	14.00	0.02	102.40	6.70		Na-Cl-HCO ₃
4	10/3/2553	117.00	23.00	28.00	14.00	101.00	41.00		102.43	6.50	0.01	Na-Ca-Cl-HCO ₃
4	23/4/2553	122.00	25.00	28.00	15.00	103.00	49.00		99.00	6.80	0.10	Na-Cl-HCO ₃
4	27/5/2553	135.00	25.00	25.00	14.00	101.00	43.00		102.42	7.00	0.01	Na-Cl-HCO ₃
5	23/1/2551	36.00	12.00	10.00	4.10	58.00	15.00	0.06	85.33			Na-Cl-HCO ₃
5	15/12/2551	39.00	11.00	9.80	2.10	66.00	12.00	0.12	85.30			Na-Cl-HCO ₃
6	23/1/2551	24.00	7.40	8.80	3.30	34.00	2.00	0.06	74.35			Na-Ca-HCO ₃ -Cl
6	15/12/2551	25.00	7.40	9.40	2.00	34.00	2.00		87.45			Na-Ca-HCO ₃ -Cl
7	18/1/2551	24.00	7.40	8.80	3.30	46.00	9.50	0.08	93.87			Na-HCO ₃ -Cl
7	15/12/2551	24.00	7.30	9.50	2.00	34.00	1.90		80.28			Na-Ca-HCO ₃ -Cl
7	9/3/2553	99.00	25.00	35.00	14.00	67.00	43.00	4.30	119.51	13.80		Na-Ca-HCO ₃ -Cl
7	22/4/2553	123.00	26.00	34.00	15.00	71.00	90.00		112.18	13.10	0.03	Na-Ca-Cl-SO ₄ -HCO ₃
7	27/5/2553	112.00	28.00	36.00	16.00	70.00	57.00		109.70	12.10	0.04	Na-Ca-Cl-HCO ₃



APPENDIX D

(Parameter Estimation Result for Groundwater Flow Model)

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PEST MAIN OUTPUT FILE (.REC)

PEST RUN RECORD: CASE p_e_1

PEST run mode:-

Parameter estimation mode

Case dimensions:-

Number of parameters	:	14
Number of adjustable parameters	:	14
Number of parameter groups	:	1
Number of observations	:	27
Number of prior estimates	:	0

Model command line(s):-

p_e_1_bat1.bat

Jacobian command line:-

na

Model interface files:-

Templates:

p_e_1.tpl_1

for model input files:

p_e_1.snn_1

(Parameter values written using single precision protocol.)

(Decimal point always included.)

Instruction files:

p_e_1.ins

for reading model output files:

p_e_1.os

PEST-to-model message file:-

na

Derivatives calculation:-

Param group	Increment type	Increment	Increment low bound	Forward or central switch	Multiplier (central)	Method (central) outside_pts
general	relative	1.0000E-02	none		2.000	

Parameter definitions:-

Name	Trans-formation	Change limit	Initial value	Lower bound	Upper bound
hk_1	log	factor	0.265710	1.000000E-10	1.000000E+10
hk_3	log	factor	12.0000	1.000000E-10	1.000000E+10
hk_2	log	factor	3.00000	1.000000E-10	1.000000E+10
hk_4	log	factor	2.617470E-06	1.000000E-10	1.000000E+10
hk_5	log	factor	3.823320E-06	1.000000E-10	1.000000E+10
hk_6	log	factor	0.196820	1.000000E-10	1.000000E+10
vani_7	log	factor	6.00000	1.000000E-10	1.000000E+10
riv_10	log	factor	200.000	1.000000E-10	1.000000E+10
riv_11	log	factor	200.000	1.000000E-10	1.000000E+10
riv_12	log	factor	200.000	1.000000E-10	1.000000E+10
riv_13	log	factor	200.000	1.000000E-10	1.000000E+10
riv_14	log	factor	200.000	1.000000E-10	1.000000E+10
ghb_8	log	factor	1500.00	1.000000E-10	1.000000E+10
ghb_9	log	factor	3000.00	1.000000E-10	1.000000E+10

Name	Group	Scale	Offset	Model command number
hk_1	general	1.00000	0.00000	1
hk_3	general	1.00000	0.00000	1
hk_2	general	1.00000	0.00000	1
hk_4	general	1.00000	0.00000	1
hk_5	general	1.00000	0.00000	1
hk_6	general	1.00000	0.00000	1
vani_7	general	1.00000	0.00000	1
riv_10	general	1.00000	0.00000	1
riv_11	general	1.00000	0.00000	1
riv_12	general	1.00000	0.00000	1
riv_13	general	1.00000	0.00000	1
riv_14	general	1.00000	0.00000	1
ghb_8	general	1.00000	0.00000	1
ghb_9	general	1.00000	0.00000	1

Prior information:-

No prior information supplied

Observations:-

Observation name	Observation	Weight	Group
hed1	20.6600	1.960	head
hed2	20.3600	1.960	head
hed3	20.0000	1.960	head
hed4	20.2300	1.960	head
hed5	20.0700	1.960	head
hed6	20.2300	1.960	head
hed7	19.9600	1.960	head
hed8	20.0700	1.960	head
hed9	21.3400	1.960	head
hed10	20.3300	1.960	head
hed11	20.5800	1.960	head
hed12	20.2100	1.960	head
hed13	20.3900	1.960	head
hed14	20.3400	1.960	head
hed15	20.5400	1.960	head
hed16	20.2800	1.960	head
hed17	19.9800	1.960	head
hed18	20.5100	1.960	head
hed19	20.5500	1.960	head
hed20	20.8900	1.960	head
no_rivf0	1.00000	1.0000E-19	river
no_rivf1	1.00000	1.0000E-19	river
no_rivf2	1.00000	1.0000E-19	river
no_rivf3	1.00000	1.0000E-19	river
no_rivf4	1.00000	1.0000E-19	river
no_ghbf0	1.00000	1.0000E-19	ghb
no_ghbf1	1.00000	1.0000E-19	ghb

Control settings:-

Initial lambda	: 10.000
Lambda adjustment factor	: 2.0000
Sufficient new/old phi ratio per optimisation iteration	: 0.30000
Limiting relative phi reduction between lambdas	: 3.00000E-02
Maximum trial lambdas per iteration	: 10
Forgive model run failure during lamda testing	: no
Perform Broyden's update of Jacobian matrix	: no

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Maximum factor parameter change (factor-limited changes) : 5.0000
Maximum relative parameter change (relative-limited changes) : na
Fraction of initial parameter values used in computing
change limit for near-zero parameters : 1.00000E-03
Allow bending of parameter upgrade vector : no
Allow parameters to stick to their bounds : no

Relative phi reduction below which to begin use of
central derivatives : 0.10000
Iteration at which to first consider derivatives switch : 1

Relative phi reduction indicating convergence : 0.50000E-02
Number of phi values required within this range : 3
Maximum number of consecutive failures to lower phi : 3
Minimal relative parameter change indicating convergence : 0.50000E-02
Number of consecutive iterations with minimal param change : 3
Maximum number of optimisation iterations : 20

Attempt automatic user intervention : no

Attempt reuse of parameter sensitivities : no

File saving options: -

Save multiple JCO files : no
Save multiple REI files : no

OPTIMISATION RECORD

INITIAL CONDITIONS:

Sum of squared weighted residuals (ie phi) = 8.3222
Contribution to phi from observation group "head" = 8.3222
Contribution to phi from observation group "river" = 8.80554E-32
Contribution to phi from observation group "ghb" = 9.09686E-32

Current parameter values

hk_1 0.265710
hk_3 12.0000
hk_2 3.00000
hk_4 2.617470E-06
hk_5 3.823320E-06
hk_6 0.196820
vani_7 6.00000
riv_10 200.000

```

riv_11      200.000
riv_12      200.000
riv_13      200.000
riv_14      200.000
ghb_8       1500.00
ghb_9       3000.00

```

```

OPTIMISATION ITERATION NO.      : 1
Model calls so far              : 1
Starting phi for this iteration  : 8.3222
Contribution to phi from observation group "head" : 8.3222
Contribution to phi from observation group "river" : 8.80554E-32
Contribution to phi from observation group "ghb" : 9.09686E-32

```

```

Lambda = 10.000 ----->
Phi = 8.6772 ( 1.043 times starting phi)

```

```

Lambda = 5.0000 ----->
Phi = 8.8883 ( 1.068 times starting phi)

```

```

Lambda = 20.000 ----->
Phi = 8.3761 ( 1.006 times starting phi)

```

```

Lambda = 40.000 ----->
Phi = 8.0790 ( 0.971 of starting phi)

```

```

Lambda = 80.000 ----->
Phi = 8.0624 ( 0.969 of starting phi)

```

```

No more lambdas: relative phi reduction between lambdas less than 0.0300
Lowest phi this iteration: 8.0624
Relative phi reduction between optimisation iterations less than 0.1000
Switch to central derivatives calculation

```

Current parameter values		Previous parameter values	
hk_1	0.244090	hk_1	0.265710
hk_3	13.1797	hk_3	12.0000
hk_2	1.46733	hk_2	3.00000
hk_4	1.673717E-06	hk_4	2.617470E-06
hk_5	2.943222E-06	hk_5	3.823320E-06
hk_6	0.125810	hk_6	0.196820
vani_7	11.1476	vani_7	6.00000
riv_10	177.610	riv_10	200.000
riv_11	118.685	riv_11	200.000
riv_12	199.909	riv_12	200.000
riv_13	126.212	riv_13	200.000

riv_14	132.948	riv_14	200.000
ghb_8	949.111	ghb_8	1500.00
ghb_9	2571.41	ghb_9	3000.00
Maximum factor change:	2.045	["hk_2"]	
Maximum relative change:	0.8579	["vani_7"]	

OPTIMISATION ITERATION NO. : 2
 Model calls so far : 27
 Starting phi for this iteration : 8.0624
 Contribution to phi from observation group "head" : 8.0624
 Contribution to phi from observation group "river" : 7.02581E-32
 Contribution to phi from observation group "ghb" : 7.26777E-32

Lambda =	80.000	----->
Phi =	8.0429	(0.998 of starting phi)
Lambda =	40.000	----->
Phi =	8.0487	(0.998 of starting phi)
Lambda =	160.00	----->
Phi =	8.0313	(0.996 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0300
 Lowest phi this iteration: 8.0313

Current parameter values		Previous parameter values	
hk_1	0.235631	hk_1	0.244090
hk_3	16.1526	hk_3	13.1797
hk_2	1.50341	hk_2	1.46733
hk_4	1.935548E-06	hk_4	1.673717E-06
hk_5	3.037419E-06	hk_5	2.943222E-06
hk_6	0.629051	hk_6	0.125810
vani_7	13.2629	vani_7	11.1476
riv_10	187.431	riv_10	177.610
riv_11	115.787	riv_11	118.685
riv_12	180.290	riv_12	199.909
riv_13	95.4047	riv_13	126.212
riv_14	124.009	riv_14	132.948
ghb_8	1046.17	ghb_8	949.111
ghb_9	2764.17	ghb_9	2571.41
Maximum factor change:	5.000	["hk_6"]	
Maximum relative change:	4.000	["hk_6"]	

OPTIMISATION ITERATION NO. : 3
 Model calls so far : 60

Starting phi for this iteration : 8.0313
 Contribution to phi from observation group "head" : 8.0313
 Contribution to phi from observation group "river" : 7.94158E-32
 Contribution to phi from observation group "ghb" : 8.23974E-32

Lambda = 160.00 ----->
 Phi = 7.9927 (0.995 of starting phi)

Lambda = 80.000 ----->
 Phi = 8.0116 (0.998 of starting phi)

Lambda = 320.00 ----->
 Phi = 7.9597 (0.991 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0300
 Lowest phi this iteration: 7.9597

Current parameter values	Previous parameter values
hk_1 0.261295	hk_1 0.235631
hk_3 9.77988	hk_3 16.1526
hk_2 1.33030	hk_2 1.50341
hk_4 1.656597E-06	hk_4 1.935548E-06
hk_5 2.505146E-06	hk_5 3.037419E-06
hk_6 3.14525	hk_6 0.629051
vani_7 18.5860	vani_7 13.2629
riv_10 218.155	riv_10 187.431
riv_11 152.055	riv_11 115.787
riv_12 184.682	riv_12 180.290
riv_13 71.2270	riv_13 95.4047
riv_14 136.193	riv_14 124.009
ghb_8 2273.09	ghb_8 1046.17
ghb_9 2538.65	ghb_9 2764.17
Maximum factor change: 5.000	["hk_6"]
Maximum relative change: 4.000	["hk_6"]

OPTIMISATION ITERATION NO. : 4
 Model calls so far : 94
 Starting phi for this iteration : 7.9597
 Contribution to phi from observation group "head" : 7.9597
 Contribution to phi from observation group "river" : 1.01196E-31
 Contribution to phi from observation group "ghb" : 1.03258E-31

Lambda = 320.00 ----->
 Phi = 7.9415 (0.998 of starting phi)
 Lambda = 160.00 ----->

```

Phi = 7.9439 ( 0.998 of starting phi)
Lambda = 640.00 ----->
Phi = 7.9348 ( 0.997 of starting phi)

No more lambdas: relative phi reduction between lambdas less than 0.0300
Lowest phi this iteration: 7.9348

```

Current parameter values		Previous parameter values	
hk_1	0.265924	hk_1	0.261295
hk_3	1.95598	hk_3	9.77988
hk_2	0.790421	hk_2	1.33030
hk_4	1.962597E-06	hk_4	1.656597E-06
hk_5	2.596657E-06	hk_5	2.505146E-06
hk_6	2.96483	hk_6	3.14525
vani_7	21.9278	vani_7	18.5860
riv_10	219.466	riv_10	218.155
riv_11	178.788	riv_11	152.055
riv_12	166.857	riv_12	184.682
riv_13	39.5923	riv_13	71.2270
riv_14	116.268	riv_14	136.193
ghb_8	1988.68	ghb_8	2273.09
ghb_9	1194.30	ghb_9	2538.65
Maximum factor change: 5.000 ["hk_3"]			
Maximum relative change: 0.8000 ["hk_3"]			

```

OPTIMISATION ITERATION NO.      : 5
Model calls so far              : 128
Starting phi for this iteration  : 7.9348
Contribution to phi from observation group "head" : 7.9348
Contribution to phi from observation group "river" : 9.71254E-32
Contribution to phi from observation group "ghb"   : 9.75326E-32

```

```

Lambda = 640.00 ----->
Phi = 7.9301 ( 0.999 of starting phi)

Lambda = 320.00 ----->
Phi = 8.0175 ( 1.010 times starting phi)

Lambda = 1280.0 ----->
Phi = 8.0150 ( 1.010 times starting phi)

```

```

No more lambdas: phi rising
Lowest phi this iteration: 7.9301

```

Current parameter values	Previous parameter values
--------------------------	---------------------------

hk_1	0.239314	hk_1	0.265924
hk_3	1.99807	hk_3	1.95598
hk_2	0.769821	hk_2	0.790421
hk_4	2.165263E-06	hk_4	1.962597E-06
hk_5	2.493623E-06	hk_5	2.596657E-06
hk_6	2.83660	hk_6	2.96483
vani_7	21.4393	vani_7	21.9278
riv_10	209.762	riv_10	219.466
riv_11	180.015	riv_11	178.788
riv_12	172.603	riv_12	166.857
riv_13	45.1798	riv_13	39.5923
riv_14	116.290	riv_14	116.268
ghb_8	2117.61	ghb_8	1988.68
ghb_9	1185.67	ghb_9	1194.30
Maximum factor change:	1.141	["riv_13"]	
Maximum relative change:	0.1411	["riv_13"]	

Optimisation complete: the 3 lowest phi's are within a relative distance of eachother of 5.000E-03

Total model calls: 160

The model has been run one final time using best parameters.
Thus all model input files contain best parameter values, and model output files contain model results based on these parameters.

OPTIMISATION RESULTS

Parameters ----->

Parameter	Estimated value	95% percent confidence limits	
		lower limit	upper limit
hk_1	0.239314	5.744655E-78	9.969496E+75
hk_3	1.99807	1.998069-300	1.000000+300
hk_2	0.769821	7.698207-301	7.698207+299
hk_4	2.165263E-06	1.134065-222	4.134122+210
hk_5	2.493623E-06	5.641466-154	1.102223+142
hk_6	2.83660	2.836602-300	1.000000+300
vani_7	21.4393	4.721302E-52	9.735564E+53
riv_10	209.762	2.097624-298	1.000000+300
riv_11	180.015	1.171018-110	2.767285+114
riv_12	172.603	5.466464-213	5.449898+216
riv_13	45.1798	1.502235-227	1.358786+230
riv_14	116.290	1.162899-298	1.000000+300
ghb_8	2117.61	7.774043-140	5.768247+145
ghb_9	1185.67	1.185673-297	1.000000+300

Note: confidence limits provide only an indication of parameter uncertainty.
They rely on a linearity assumption which may not extend as far in
parameter space as the confidence limits themselves - see PEST manual.

See file p_e_1.sen for parameter sensitivities.

Observations ----->

Observation	Measured value	Calculated value	Residual	Weight	Group
hed1	20.6600	20.4806	0.179440	1.960	head
hed2	20.3600	20.5312	-0.171220	1.960	head
hed3	20.0000	20.3987	-0.398740	1.960	head
hed4	20.2300	20.4818	-0.251780	1.960	head
hed5	20.0700	20.3077	-0.237650	1.960	head
hed6	20.2300	20.3076	-7.756000E-02	1.960	head
hed7	19.9600	20.3550	-0.395010	1.960	head
hed8	20.0700	20.4025	-0.332500	1.960	head
hed9	21.3400	20.4291	0.910910	1.960	head
hed10	20.3300	20.4436	-0.113560	1.960	head
hed11	20.5800	20.4575	0.122520	1.960	head
hed12	20.2100	20.4500	-0.239960	1.960	head
hed13	20.3900	20.4715	-8.146000E-02	1.960	head
hed14	20.3400	20.5508	-0.210790	1.960	head
hed15	20.5400	20.5602	-2.019000E-02	1.960	head
hed16	20.2800	20.4646	-0.184590	1.960	head
hed17	19.9800	20.4126	-0.432630	1.960	head
hed18	20.5100	20.4695	4.052000E-02	1.960	head
hed19	20.5500	20.3993	0.150670	1.960	head
hed20	20.8900	20.4011	0.488900	1.960	head
no_rivf0	1.00000	2981.07	-2980.07	1.0000E-19	river
no_rivf1	1.00000	11.5891	-10.5891	1.0000E-19	river
no_rivf2	1.00000	6.67963	-5.67963	1.0000E-19	river
no_rivf3	1.00000	2.68680	-1.68680	1.0000E-19	river
no_rivf4	1.00000	5.03461	-4.03461	1.0000E-19	river
no_ghbf0	1.00000	-2985.30	2986.30	1.0000E-19	ghb
no_ghbf1	1.00000	-21.6021	22.6021	1.0000E-19	ghb

See file p_e_1.res for more details of residuals in graph-ready format.

See file p_e_1.seo for composite observation sensitivities.

Objective function ----->

Sum of squared weighted residuals (ie phi) = 7.930

```
Contribution to phi from observation group "head" = 7.930
Contribution to phi from observation group "river" = 8.8810E-32
Contribution to phi from observation group "ghb" = 8.9185E-32
```

Correlation Coefficient ----->

```
Correlation coefficient = 0.9995
```

Analysis of residuals ----->

All residuals:-

```
Number of residuals with non-zero weight = 27
Mean value of non-zero weighted residuals = -9.1080E-02
Maximum weighted residual [observation "hed9"] = 1.785
Minimum weighted residual [observation "hed17"] = -0.8479
Standard variance of weighted residuals = 0.6100
Standard error of weighted residuals = 0.7810
```

Note: the above variance was obtained by dividing the objective function by the number of system degrees of freedom (ie. number of observations with non-zero weight plus number of prior information articles with non-zero weight minus the number of adjustable parameters.) If the degrees of freedom is negative the divisor becomes the number of observations with non-zero weight plus the number of prior information items with non-zero weight.

Residuals for observation group "head":-

```
Number of residuals with non-zero weight = 20
Mean value of non-zero weighted residuals = -0.1230
Maximum weighted residual [observation "hed9"] = 1.785
Minimum weighted residual [observation "hed17"] = -0.8479
"Variance" of weighted residuals = 0.3965
"Standard error" of weighted residuals = 0.6297
```

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

Residuals for observation group "river":-

```
Number of residuals with non-zero weight = 5
Mean value of non-zero weighted residuals = -6.0041E-17
Maximum weighted residual [observation "no_rivf3"] = -1.6868E-19
Minimum weighted residual [observation "no_rivf0"] = -2.9801E-16
"Variance" of weighted residuals = 1.7762E-32
"Standard error" of weighted residuals = 1.3327E-16
```

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

Residuals for observation group "ghb":-

Number of residuals with non-zero weight	= 2
Mean value of non-zero weighted residuals	= 1.5045E-16
Maximum weighted residual [observation "no_ghbf0"]	= 2.9863E-16
Minimum weighted residual [observation "no_ghbf1"]	= 2.2602E-18
"Variance" of weighted residuals	= 4.4592E-32
"Standard error" of weighted residuals	= 2.1117E-16

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

K-L information statistics ----->

AIC	= -3.079608
AICC	= 40.55676
BIC	= 16.35794
KIC	= -114.4236

Parameter covariance matrix ----->

	hk_1 riv_11	hk_3 riv_12	hk_2 riv_13	hk_4 riv_14	hk_5 ghb_8	hk_6 ghb_9	vani_7	riv_10
hk_1	1258. -243.0	-714.7 -2772.	-5090. 602.8	1349. 4982.	741.4 470.4	3404. -8690.	-185.9	471.2
hk_3	-714.7 2545.	2.9676E+04 6657.	-9805. 1.4786E+04	-1.4762E+04 5.5557E+04	-9527. -8057.	5.5480E+04 4.0350E+04	-3722.	-2.3725E+04
hk_2	-5090. -3737.	-9805. 5342.	3.3695E+04 -6289.	2089. -5.3362E+04	1779. -1292.	-3.8174E+04 9536.	2819.	8172.
hk_4	1349. -1309.	-1.4762E+04 -6435.	2089. -6856.	1.0026E+04 -2.6469E+04	6726. 3660.	-2.5244E+04 -3.0365E+04	1841.	1.3208E+04
hk_5	741.4 -588.3	-9527. -4012.	1779. -4525.	6726. -1.8104E+04	4672. 2152.	-1.6576E+04 -1.9219E+04	1204.	8602.
hk_6	3404. 2689.	5.5480E+04 315.9	-3.8174E+04 3.5809E+04	-2.5244E+04 1.2954E+05	-1.6576E+04 -1.7090E+04	1.3142E+05 4.5391E+04	-8478.	-4.9662E+04
vani_7	-185.9	-3722.	2819.	1841.	1204.	-8478.	594.3	3332.

	-374.1	-437.1	-2108.	-9148.	926.8	-3980.		
riv_10	471.2	-2.3725E+04	8172.	1.3208E+04	8602.	-4.9662E+04	3332.	2.2228E+04
	-980.8	-4780.	-1.3995E+04	-4.7791E+04	7674.	-3.2927E+04		
riv_11	-243.0	2545.	-3737.	-1309.	-588.3	2689.	-374.1	-980.8
	2698.	2641.	-686.6	6079.	710.8	9094.		
riv_12	-2772.	6657.	5342.	-6435.	-4012.	315.9	-437.1	-4780.
	2641.	9862.	-1068.	4360.	-224.9	3.1674E+04		
riv_13	602.8	1.4786E+04	-6289.	-6856.	-4525.	3.5809E+04	-2108.	-1.3995E+04
	-686.6	-1068.	1.1189E+04	3.0248E+04	-6085.	1.0570E+04		
riv_14	4982.	5.5557E+04	-5.3362E+04	-2.6469E+04	-1.8104E+04	1.2954E+05	-9148.	-4.7791E+04
	6079.	4360.	3.0248E+04	1.5030E+05	-1.0591E+04	4.9944E+04		
ghb_8	470.4	-8057.	-1292.	3660.	2152.	-1.7090E+04	926.8	7674.
	710.8	-224.9	-6085.	-1.0591E+04	4348.	-8229.		
ghb_9	-8690.	4.0350E+04	9536.	-3.0365E+04	-1.9219E+04	4.5391E+04	-3980.	-3.2927E+04
	9094.	3.1674E+04	1.0570E+04	4.9944E+04	-8229.	1.2226E+05		

Parameter correlation coefficient matrix ----->

	hk_1 riv_11	hk_3 riv_12	hk_2 riv_13	hk_4 riv_14	hk_5 ghb_8	hk_6 ghb_9	vani_7	riv_10
hk_1	1.000	-0.1170	-0.7816	0.3799	0.3058	0.2647	-0.2150	8.9101E-02
	-0.1319	-0.7868	0.1606	0.3623	0.2011	-0.7006		
hk_3	-0.1170	1.000	-0.3101	-0.8558	-0.8090	0.8884	-0.8863	-0.9238
	0.2845	0.3891	0.8115	0.8319	-0.7093	0.6699		
hk_2	-0.7816	-0.3101	1.000	0.1136	0.1418	-0.5737	0.6299	0.2986
	-0.3920	0.2931	-0.3239	-0.7498	-0.1067	0.1486		
hk_4	0.3799	-0.8558	0.1136	1.000	0.9828	-0.6955	0.7541	0.8848
	-0.2517	-0.6472	-0.6473	-0.6819	0.5544	-0.8673		
hk_5	0.3058	-0.8090	0.1418	0.9828	1.000	-0.6689	0.7224	0.8440
	-0.1657	-0.5911	-0.6259	-0.6832	0.4774	-0.8041		
hk_6	0.2647	0.8884	-0.5737	-0.6955	-0.6689	1.000	-0.9594	-0.9189
	0.1428	8.7743E-03	0.9339	0.9217	-0.7149	0.3581		

vani_7	-0.2150 -0.2955	-0.8863 -0.1806	0.6299 -0.8176	0.7541 -0.9680	0.7224 0.5765	-0.9594 -0.4669	1.000	0.9167
riv_10	8.9101E-02 -0.1267	-0.9238 -0.3229	0.2986 -0.8874	0.8848 -0.8268	0.8440 0.7806	-0.9189 -0.6316	0.9167	1.000
riv_11	-0.1319 1.000	0.2845 0.5120	-0.3920 -0.1250	-0.2517 0.3019	-0.1657 0.2075	0.1428 0.5008	-0.2955	-0.1267
riv_12	-0.7868 0.5120	0.3891 1.000	0.2931 -0.1017	-0.6472 0.1132	-0.5911 -3.4352E-02	8.7743E-03 0.9122	-0.1806	-0.3229
riv_13	0.1606 -0.1250	0.8115 -0.1017	-0.3239 1.000	-0.6473 0.7376	-0.6259 -0.8724	0.9339 0.2858	-0.8176	-0.8874
riv_14	0.3623 0.3019	0.8319 0.1132	-0.7498 0.7376	-0.6819 1.000	-0.6832 -0.4143	0.9217 0.3684	-0.9680	-0.8268
ghb_8	0.2011 0.2075	-0.7093 -3.4352E-02	-0.1067 -0.8724	0.5544 -0.4143	0.4774 1.000	-0.7149 -0.3569	0.5765	0.7806
ghb_9	-0.7006 0.5008	0.6699 0.9122	0.1486 0.2858	-0.8673 0.3684	-0.8041 -0.3569	0.3581 1.000	-0.4669	-0.6316

Normalized eigenvectors of parameter covariance matrix ----->

	Vector_1 Vector_9	Vector_2 Vector_10	Vector_3 Vector_11	Vector_4 Vector_12	Vector_5 Vector_13	Vector_6 Vector_14	Vector_7	Vector_8
hk_1	0.3966 6.2396E-02	-0.4540 3.1707E-02	0.3001 9.0827E-03	-0.3901 4.2436E-02	-0.1537 9.7306E-02	-0.2894 -6.2446E-03	0.1367	-0.5020
hk_3	0.1661 0.3433	-0.2173 -0.7424	-0.1285 -3.6458E-02	0.2203 -0.1579	-0.1150 -9.0900E-02	-0.1265 -0.2653	0.1398	0.1934
hk_2	-7.8726E-03 -0.1555	0.1346 -0.2694	9.7351E-02 0.4194	-9.5593E-02 -0.5427	9.2593E-02 -0.3354	0.1236 0.1661	-0.3494	-0.3319
hk_4	-0.2974 -0.3327	-5.1602E-02 -0.2797	-0.4338 -0.2597	-4.2760E-02 2.8106E-02	-0.2183 0.1395	0.2749 0.1367	0.2951	-0.4617
hk_5	-5.8253E-03 -0.4473	-4.4849E-02 -0.2486	0.5188 -0.3070	0.3422 5.5759E-03	0.4618 8.3737E-02	-0.1145 9.0351E-02	0.1156	-2.4999E-02

hk_6	0.1331 -1.5297E-02	6.3169E-02 0.1093	0.1517 -0.3480	-0.2251 -0.4228	2.4262E-02 0.2177	0.4694 -0.5661	-5.0923E-02	3.3898E-02
vani_7	-7.4002E-02 8.3850E-02	0.3985 -1.2516E-02	0.5036 2.9501E-03	0.2647 -2.9743E-03	-0.6853 -8.2499E-03	4.6202E-02 3.9130E-02	0.1518	-9.1588E-02
riv_10	-0.2710 0.4943	0.2704 -0.3004	0.2447 -0.1366	-0.4689 0.2213	0.2895 6.1282E-02	0.1630 0.2300	4.3963E-02	-5.1006E-02
riv_11	2.8192E-03 -6.0461E-02	5.1881E-02 -0.1411	-6.1458E-02 -0.4806	-3.4796E-02 0.2000	-0.2121 -4.3087E-02	-0.2285 -2.6702E-02	-0.7689	-8.3311E-02
riv_12	-0.2803 -0.3642	-0.3883 -0.1474	0.2442 0.1242	-0.3779 0.1744	-0.2563 -0.2541	0.1852 -4.4836E-02	-2.3394E-02	0.4483
riv_13	-0.7195 0.2578	-0.3440 0.1991	0.1031 -5.6886E-02	0.1400 -0.3207	1.5709E-02 5.2391E-02	-0.2786 -0.1433	-5.0133E-02	-0.1338
riv_14	-0.1735 -0.1607	0.2054 -0.1705	2.3556E-02 0.4569	-6.2624E-03 0.3850	0.1009 0.2581	-0.1172 -0.6049	-9.1995E-02	-0.2245
ghb_8	5.7652E-02 0.2462	-0.4080 3.8951E-02	0.1239 0.1251	0.4072 0.2981	4.7393E-02 1.9207E-02	0.6076 6.5070E-02	-0.2581	-0.1995
ghb_9	-1.6240E-02 5.1026E-02	8.6563E-02 0.1448	-1.3005E-02 -0.2174	3.4471E-02 0.1997	0.1276 -0.8099	1.4819E-02 -0.3270	0.2058	-0.2417
Eigenvalues ---->	5.4967E-03 969.9	0.4772 2718.	1.214 4129.	3.337 2.9053E+04	7.674 1.2327E+05	12.62 3.7395E+05	45.75	57.55

SENSITIVITY MAIN OUTPUT FILE (.SEN)

PARAMETER SENSITIVITIES: CASE p_e_1

OPTIMISATION ITERATION NO. 1 ----->

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.265710	4.192073E-03
hk_3	general	12.0000	5.623760E-03
hk_2	general	3.00000	1.973702E-02
hk_4	general	2.617470E-06	3.970622E-02
hk_5	general	3.823320E-06	1.845463E-02
hk_6	general	0.196820	2.036955E-02
vani_7	general	6.00000	2.499310E-02
riv_10	general	200.000	5.211187E-03
riv_11	general	200.000	2.382327E-02
riv_12	general	200.000	4.516115E-03
riv_13	general	200.000	2.305928E-02
riv_14	general	200.000	2.049875E-02
ghb_8	general	1500.00	1.868333E-02
ghb_9	general	3000.00	4.958438E-03

OPTIMISATION ITERATION NO. 2 ----->

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.244090	1.447551E-04
hk_3	general	13.1797	3.394039E-03
hk_2	general	1.46733	3.771747E-03
hk_4	general	1.673717E-06	2.932762E-02
hk_5	general	2.943222E-06	2.950606E-02
hk_6	general	0.125810	2.144629E-03
vani_7	general	11.1476	2.029029E-02
riv_10	general	177.610	1.321429E-04
riv_11	general	118.685	1.385928E-04
riv_12	general	199.909	2.250313E-04
riv_13	general	126.212	3.521049E-04
riv_14	general	132.948	3.154862E-04
ghb_8	general	949.111	2.250311E-04
ghb_9	general	2571.41	1.447551E-04

OPTIMISATION ITERATION NO. 3 ----->

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.235631	9.343907E-05
hk_3	general	16.1526	3.439017E-03
hk_2	general	1.50341	3.309383E-03
hk_4	general	1.935548E-06	2.990453E-02
hk_5	general	3.037419E-06	2.958768E-02
hk_6	general	0.629051	4.782766E-04
vani_7	general	13.2629	1.978393E-02
riv_10	general	187.431	1.447552E-04
riv_11	general	115.787	1.506662E-04
riv_12	general	180.290	1.914931E-04
riv_13	general	95.4047	2.472165E-04
riv_14	general	124.009	1.506657E-04
ghb_8	general	1046.17	2.771846E-04
ghb_9	general	2764.17	1.821462E-04

OPTIMISATION ITERATION NO. 4 ----->

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.261295	1.506661E-04
hk_3	general	9.77988	4.468107E-03
hk_2	general	1.33030	1.819445E-02
hk_4	general	1.656597E-06	2.897718E-02
hk_5	general	2.505146E-06	2.885369E-02
hk_6	general	3.14525	1.023574E-04
vani_7	general	18.5860	1.823665E-02

riv_10	general	218.155	5.909606E-05
riv_11	general	152.055	1.105586E-04
riv_12	general	184.682	1.506659E-04
riv_13	general	71.2270	1.202427E-03
riv_14	general	136.193	1.772885E-04
ghb_8	general	2273.09	1.181921E-04
ghb_9	general	2538.65	1.971100E-03

OPTIMISATION ITERATION NO. 5 ----->

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.265924	0.156253
hk_3	general	1.95598	6.565625E-02
hk_2	general	0.790421	7.475362E-03
hk_4	general	1.962597E-06	0.116696
hk_5	general	2.596657E-06	1.575352E-02
hk_6	general	2.96483	5.240578E-02
vani_7	general	21.9278	3.683023E-02
riv_10	general	219.466	0.106841
riv_11	general	178.788	5.307642E-03
riv_12	general	166.857	0.110956
riv_13	general	39.5923	0.281133
riv_14	general	116.268	6.827064E-02
ghb_8	general	1988.68	2.960846E-02
ghb_9	general	1194.30	7.559458E-03

COMPLETION OF OPTIMISATION PROCESS

Composite sensitivities for observation group "head" ----->

Number of observations with non-zero weight =		20	
Parameter name	Group	Current value	Sensitivity
hk_1	general	0.239314	0.210942
hk_3	general	1.99807	8.863594E-02
hk_2	general	0.769821	1.009174E-02
hk_4	general	2.165263E-06	0.157540
hk_5	general	2.493623E-06	2.126725E-02
hk_6	general	2.83660	7.074781E-02
vani_7	general	21.4393	4.972081E-02
riv_10	general	209.762	0.144235
riv_11	general	180.015	7.165316E-03
riv_12	general	172.603	0.149790
riv_13	general	45.1798	0.379529
riv_14	general	116.290	9.216537E-02
ghb_8	general	2117.61	3.997142E-02
ghb_9	general	1185.67	1.020527E-02

Composite sensitivities for observation group "river" ----->

Number of observations with non-zero weight =		5	
Parameter name	Group	Current value	Sensitivity
hk_1	general	0.239314	1.829215E-19
hk_3	general	1.99807	9.946472E-19
hk_2	general	0.769821	2.792011E-19
hk_4	general	2.165263E-06	6.103167E-20
hk_5	general	2.493623E-06	1.322628E-19
hk_6	general	2.83660	2.212511E-20
vani_7	general	21.4393	5.717848E-19
riv_10	general	209.762	1.425209E-16
riv_11	general	180.015	1.179276E-19
riv_12	general	172.603	8.557603E-20
riv_13	general	45.1798	1.523786E-19
riv_14	general	116.290	1.628702E-19
ghb_8	general	2117.61	2.729456E-19
ghb_9	general	1185.67	5.230844E-20

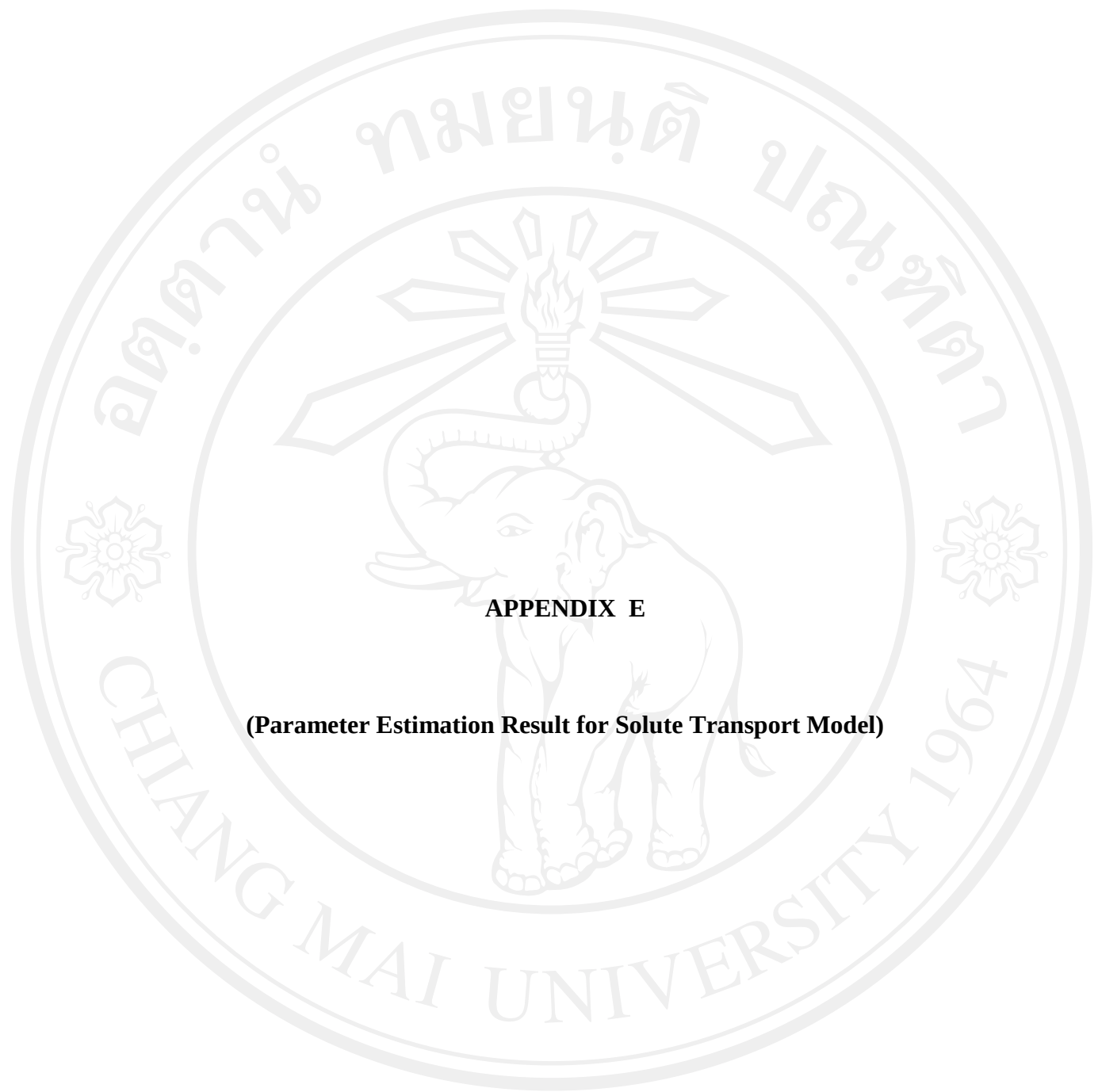
Composite sensitivities for observation group "ghb" ----->

Number of observations with non-zero weight = 2

Parameter name	Group	Current value	Sensitivity
hk_1	general	0.239314	8.019169E-18
hk_3	general	1.99807	3.693435E-18
hk_2	general	0.769821	9.612116E-19
hk_4	general	2.165263E-06	7.142779E-19
hk_5	general	2.493623E-06	3.413420E-19
hk_6	general	2.83660	3.590425E-19
vani_7	general	21.4393	2.051683E-18
riv_10	general	209.762	3.552398E-16
riv_11	general	180.015	1.307174E-19
riv_12	general	172.603	3.461400E-19
riv_13	general	45.1798	1.218098E-18
riv_14	general	116.290	3.851410E-19
ghb_8	general	2117.61	7.506918E-18
ghb_9	general	1185.67	9.163207E-19

Composite sensitivities for all observations/prior info ----->

Number of observations with non-zero weight =		27	
Parameter name	Group	Current value	Sensitivity
hk_1	general	0.239314	0.156253
hk_3	general	1.99807	6.565625E-02
hk_2	general	0.769821	7.475362E-03
hk_4	general	2.165263E-06	0.116696
hk_5	general	2.493623E-06	1.575352E-02
hk_6	general	2.83660	5.240578E-02
vani_7	general	21.4393	3.683023E-02
riv_10	general	209.762	0.106841
riv_11	general	180.015	5.307642E-03
riv_12	general	172.603	0.110956
riv_13	general	45.1798	0.281133
riv_14	general	116.290	6.827064E-02
ghb_8	general	2117.61	2.960846E-02
ghb_9	general	1185.67	7.559458E-03



APPENDIX E

(Parameter Estimation Result for Solute Transport Model)

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่

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PEST MAIN OUTPUT FILE (.REC)

PEST RUN RECORD: CASE rt3d_calib

PEST run mode:-

Parameter estimation mode

Case dimensions:-

Number of parameters	:	20
Number of adjustable parameters	:	10
Number of parameter groups	:	4
Number of observations	:	26
Number of prior estimates	:	0

Model command line(s):-

run.bat

Jacobian command line:-

na

Model interface files:-

Templates:

rt3dbtn.dat.tpl
rt3ddsp.dat.tpl
rt3drct.dat.tpl
ucd.pre.tpl

for model input files:

rt3dbtn.dat
rt3ddsp.dat
rt3drct.dat
ucd.pre

(Parameter values written using single precision protocol.)

(Decimal point always included.)

Instruction files:
 rt3d_calib_pce.ins
 rt3d_calib_tce.ins
 rt3d_calib_dce.ins
 for reading model output files:
 ForPlot_Avg.dat
 ForPlot_Avg.dat
 ForPlot_Avg.dat

PEST-to-model message file:-

na

Derivatives calculation:-

Param group	Increment type	Increment	Increment low bound	Forward or central	Multiplier (central)	Method (central)
porosity	relative	1.0000E-02	none	switch	2.000	outside_pts
dispersivity	relative	1.0000E-02	none	switch	2.000	outside_pts
rxn_rate	relative	1.0000E-02	none	switch	2.000	outside_pts
source_conc	relative	1.0000E-02	none	switch	2.000	outside_pts

Parameter definitions:-

Name	Trans-formation	Change limit	Initial value	Lower bound	Upper bound
por1	log	factor	0.300000	0.100000	0.550000
por2	tied por1	na	0.300000	na	na
por3	tied por1	na	0.300000	na	na
por4	tied por1	na	0.300000	na	na
por5	tied por1	na	0.300000	na	na
por6	tied por1	na	0.300000	na	na
alph_11	log	factor	1.00000	1.000000E-10	1.000000E+10
alph_12	tied alph_11	na	1.00000	na	na
alph_13	tied alph_11	na	1.00000	na	na
alph_14	tied alph_11	na	1.00000	na	na
alph_15	tied alph_11	na	1.00000	na	na
alph_16	tied alph_11	na	1.00000	na	na
k-pce	log	factor	3.000000E-03	1.000000E-10	1.000000E+10
k-tce	log	factor	8.500000E-03	1.000000E-10	1.000000E+10
k-dce	log	factor	5.000000E-04	1.000000E-10	1.000000E+10
k-vc	log	factor	3.000000E-03	1.000000E-10	1.000000E+10
pce_s1	log	factor	6.50000	1.000000E-10	1.000000E+10
tce_s1	log	factor	15.5000	1.000000E-10	1.000000E+10

pce_s2	log	factor	7.000000E-03	1.000000E-10	1.000000E+10
tce_s2	log	factor	0.250000	1.000000E-10	1.000000E+10

Name	Group	Scale	Offset	Model command number
por1	porosity	1.00000	0.00000	1
por2	porosity	1.00000	0.00000	1
por3	porosity	1.00000	0.00000	1
por4	porosity	1.00000	0.00000	1
por5	porosity	1.00000	0.00000	1
por6	porosity	1.00000	0.00000	1
alph_l1	dispersivity	1.00000	0.00000	1
alph_l2	dispersivity	1.00000	0.00000	1
alph_l3	dispersivity	1.00000	0.00000	1
alph_l4	dispersivity	1.00000	0.00000	1
alph_l5	dispersivity	1.00000	0.00000	1
alph_l6	dispersivity	1.00000	0.00000	1
k-pce	rxn_rate	1.00000	0.00000	1
k-tce	rxn_rate	1.00000	0.00000	1
k-dce	rxn_rate	1.00000	0.00000	1
k-vc	rxn_rate	1.00000	0.00000	1
pce_s1	source_conc	1.00000	0.00000	1
tce_s1	source_conc	1.00000	0.00000	1
pce_s2	source_conc	1.00000	0.00000	1
tce_s2	source_conc	1.00000	0.00000	1

Prior information:-

No prior information supplied

Observations:-

Observation name	Observation	Weight	Group
w1-1	1.80000	1.000	w1
w3-1	1.30000	1.000	w3
w1-2	1.30000	1.000	w1
w1-3	3.70000	1.000	w1
w1-4	7.70000	1.000	w1
w3-2	2.70000	1.000	w3
w3-3	9.10000	1.000	w3
w7-1	9.00000	1.000	w7
w2-1	1.60000	1.000	w2
w2-2	2.20000	1.000	w2
w2-3	4.10000	1.000	w2
w2-4	4.30000	1.000	w2
w2-5	6.00000	1.000	w2

w3-4	128.000	1.000
w3-5	3.30000	1.000
w3-6	105.000	1.000
w3-7	100.000	1.000
w3-8	99.0000	1.000
w3-9	122.000	1.000
w3-10	118.000	1.000
w7-2	202.000	1.000
w7-3	5.50000	1.000
w7-4	4.00000	1.000
w7-5	4.10000	1.000
w7-6	5.80000	1.000
w7-7	17.0000	1.000

w3
w3
w3
w3
w3
w3
w7
w7
w7
w7
w7
w7

Control settings:-

Initial lambda	: 10.000
Lambda adjustment factor	: 2.0000
Sufficient new/old phi ratio per optimisation iteration	: 0.30000
Limiting relative phi reduction between lambdas	: 3.00000E-02
Maximum trial lambdas per iteration	: 10
Forgive model run failure during lamda testing	: no

Perform Broyden's update of Jacobian matrix	: no
---	------

Maximum factor parameter change (factor-limited changes)	: 5.0000
Maximum relative parameter change (relative-limited changes)	: na
Fraction of initial parameter values used in computing change limit for near-zero parameters	: 1.00000E-03
Allow bending of parameter upgrade vector	: no
Allow parameters to stick to their bounds	: no

Relative phi reduction below which to begin use of central derivatives	: 0.10000
Iteration at which to first consider derivatives switch	: 1

Relative phi reduction indicating convergence	: 0.50000E-02
Number of phi values required within this range	: 3
Maximum number of consecutive failures to lower phi	: 3
Minimal relative parameter change indicating convergence	: 0.50000E-02
Number of consecutive iterations with minimal param change	: 3
Maximum number of optimisation iterations	: -1 (only compute Jacobian)

Attempt automatic user intervention	: no
-------------------------------------	------

Attempt reuse of parameter sensitivities	: no
--	------

File saving options: -

Save multiple JCO files : no
Save multiple REI files : no

OPTIMISATION RECORD

INITIAL CONDITIONS:

Sum of squared weighted residuals (ie phi) = 2.64808E+05
Contribution to phi from observation group "w1" = 74.072
Contribution to phi from observation group "w2" = 1094.4
Contribution to phi from observation group "w3" = 2.23234E+05
Contribution to phi from observation group "w7" = 40405.

Current parameter values

por1 0.300000
por2 0.300000
por3 0.300000
por4 0.300000
por5 0.300000
por6 0.300000
alph_11 1.00000
alph_12 1.00000
alph_13 1.00000
alph_14 1.00000
alph_15 1.00000
alph_16 1.00000
k-pce 3.000000E-03
k-tce 8.500000E-03
k-dce 5.000000E-04
k-vc 3.000000E-03
pce_s1 6.50000
tce_s1 15.5000
pce_s2 7.000000E-03
tce_s2 0.250000

OPTIMISATION ITERATION NO. : 1
Model calls so far : 1
Starting phi for this iteration : 2.64808E+05
Contribution to phi from observation group "w1" : 74.072
Contribution to phi from observation group "w2" : 1094.4
Contribution to phi from observation group "w3" : 2.23234E+05
Contribution to phi from observation group "w7" : 40405.

Optimisation complete: NOPTMAX supplied as -1 indicating that statistics for initial parameter set only are required.

Total model calls: 11

The model has been run one final time using best parameters.
Thus all model input files contain best parameter values, and model output files contain model results based on these parameters.

OPTIMISATION RESULTS

Adjustable parameters ----->

Parameter	Estimated value	95% percent confidence limits	
		lower limit	upper limit
por1	0.300000	3.229990E-02	2.78639
alph_11	1.00000	0.167348	5.97556
k-pce	3.000000E-03	5.514516E-04	1.632056E-02
k-tce	8.500000E-03	4.428352E-05	1.63153
k-dce	5.000000E-04	7.184615E-05	3.479658E-03
k-vc	3.000000E-03	1.066357E-04	8.439947E-02
pce_s1	6.50000	0.264319	159.845
tce_s1	15.5000	2.69710	89.0770
pce_s2	7.000000E-03	9.695652E-04	5.053812E-02
tce_s2	0.250000	3.261577E-02	1.91625

Note: confidence limits provide only an indication of parameter uncertainty.
They rely on a linearity assumption which may not extend as far in parameter space as the confidence limits themselves - see PEST manual.

Tied parameters ----->

Parameter	Estimated value
por2	0.300000
por3	0.300000
por4	0.300000
por5	0.300000
por6	0.300000
alph_12	1.00000
alph_13	1.00000
alph_14	1.00000
alph_15	1.00000
alph_16	1.00000

See file rt3d_calib.sen for parameter sensitivities.

Observations ----->

Observation	Measured value	Calculated value	Residual	Weight	Group
w1-1	1.80000	2.01321	-0.213210	1.000	w1
w3-1	1.30000	431.287	-429.987	1.000	w3
w1-2	1.30000	2.538930E-02	1.27461	1.000	w1
w1-3	3.70000	2.572430E-02	3.67428	1.000	w1
w1-4	7.70000	2.528230E-02	7.67472	1.000	w1
w3-2	2.70000	41.1331	-38.4331	1.000	w3
w3-3	9.10000	41.2357	-32.1357	1.000	w3
w7-1	9.00000	5.14775	3.85225	1.000	w7
w2-1	1.60000	15.9154	-14.3154	1.000	w2
w2-2	2.20000	18.0084	-15.8084	1.000	w2
w2-3	4.10000	18.6840	-14.5840	1.000	w2
w2-4	4.30000	19.6495	-15.3495	1.000	w2
w2-5	6.00000	19.8295	-13.8295	1.000	w2
w3-4	128.000	37.2594	90.7406	1.000	w3
w3-5	3.30000	37.9162	-34.6162	1.000	w3
w3-6	105.000	38.0682	66.9318	1.000	w3
w3-7	100.000	37.4960	62.5040	1.000	w3
w3-8	99.0000	36.8402	62.1598	1.000	w3
w3-9	122.000	36.2373	85.7627	1.000	w3
w3-10	118.000	35.5546	82.4454	1.000	w3
w7-2	202.000	1.73329	200.267	1.000	w7
w7-3	5.50000	1.69938	3.80062	1.000	w7
w7-4	4.00000	1.64823	2.35177	1.000	w7
w7-5	4.10000	1.58623	2.51377	1.000	w7
w7-6	5.80000	1.58782	4.21218	1.000	w7
w7-7	17.0000	1.51681	15.4832	1.000	w7

See file rt3d_calib.res for more details of residuals in graph-ready format.

See file rt3d_calib.seo for composite observation sensitivities.

Objective function ----->

Sum of squared weighted residuals (ie phi)	=	2.6481E+05
Contribution to phi from observation group "w1"	=	74.07
Contribution to phi from observation group "w2"	=	1094.
Contribution to phi from observation group "w3"	=	2.2323E+05
Contribution to phi from observation group "w7"	=	4.0405E+04
Correlation Coefficient ----->		
Correlation coefficient	=	-5.1743E-02

Analysis of residuals ----->

All residuals:-

Number of residuals with non-zero weight	=	26
Mean value of non-zero weighted residuals	=	3.322
Maximum weighted residual [observation "w7-2"]	=	200.3
Minimum weighted residual [observation "w3-1"]	=	-430.0
Standard variance of weighted residuals	=	1.6550E+04
Standard error of weighted residuals	=	128.6

Note: the above variance was obtained by dividing the objective function by the number of system degrees of freedom (ie. number of observations with non-zero weight plus number of prior information articles with non-zero weight minus the number of adjustable parameters.) If the degrees of freedom is negative the divisor becomes the number of observations with non-zero weight plus the number of prior information items with non-zero weight.

Residuals for observation group "w1":-

Number of residuals with non-zero weight	=	4
Mean value of non-zero weighted residuals	=	3.103
Maximum weighted residual [observation "w1-4"]	=	7.675
Minimum weighted residual [observation "w1-1"]	=	-0.2132
"Variance" of weighted residuals	=	18.52
"Standard error" of weighted residuals	=	4.303

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

Residuals for observation group "w2":-

Number of residuals with non-zero weight	=	5
Mean value of non-zero weighted residuals	=	-14.78
Maximum weighted residual [observation "w2-5"]	=	-13.83
Minimum weighted residual [observation "w2-2"]	=	-15.81
"Variance" of weighted residuals	=	218.9
"Standard error" of weighted residuals	=	14.79

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

Residuals for observation group "w3":-

Number of residuals with non-zero weight	=	10
Mean value of non-zero weighted residuals	=	-8.463
Maximum weighted residual [observation "w3-4"]	=	90.74
Minimum weighted residual [observation "w3-1"]	=	-430.0
"Variance" of weighted residuals	=	2.2323E+04

"Standard error" of weighted residuals = 149.4

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

Residuals for observation group "w7":-

Number of residuals with non-zero weight = 7
Mean value of non-zero weighted residuals = 33.21
Maximum weighted residual [observation "w7-2"] = 200.3
Minimum weighted residual [observation "w7-4"] = 2.352
"Variance" of weighted residuals = 5772.
"Standard error" of weighted residuals = 75.97

Note: the above "variance" was obtained by dividing the sum of squared residuals by the number of items with non-zero weight.

K-L information statistics ----->

AIC = 261.9452
AICC = 280.8024
BIC = 275.7843
KIC = 254.5743

Parameter covariance matrix ----->

	por1 pce_s2	alph_l1 tce_s2	k-pce	k-tce	k-dce	k-vc	pce_s1	tce_s1
por1	0.2085 -0.1371	-9.0499E-02 -0.1249	3.6811E-02	-0.4049	3.9856E-02	0.2255	0.2292	-6.8134E-02
alph_l1	-9.0499E-02 2.7382E-02	0.1341 7.6659E-02	-1.6949E-02	0.2204	-3.3405E-02	-0.1811	-9.9799E-02	5.1856E-02
k-pce	3.6811E-02 8.9168E-03	-1.6949E-02 9.6293E-03	0.1204	-0.1515	-7.2390E-02	4.4035E-04	9.9289E-02	2.8212E-02
k-tce	-0.4049 0.2744	0.2204 0.2223	-0.1515	1.160	-0.1603	-0.5112	-0.6466	3.1107E-02
k-dce	3.9856E-02 -5.0806E-02	-3.3405E-02 -7.2784E-02	-7.2390E-02	-0.1603	0.1580	6.4022E-02	9.7664E-02	-2.6123E-02
k-vc	0.2255 -0.1763	-0.1811 -0.1090	4.4035E-04	-0.5112	6.4022E-02	0.4673	0.2079	-0.1016

pce_s1	0.2292 -0.1562	-9.9799E-02 -0.1676	9.9289E-02	-0.6466	9.7664E-02	0.2079	0.4304	-1.7442E-02
tce_s1	-6.8134E-02 2.9433E-02	5.1856E-02 7.1449E-02	2.8212E-02	3.1107E-02	-2.6123E-02	-0.1016	-1.7442E-02	0.1283
pce_s2	-0.1371 0.1640	2.7382E-02 5.1577E-02	8.9168E-03	0.2744	-5.0806E-02	-0.1763	-0.1562	2.9433E-02
tce_s2	-0.1249 5.1577E-02	7.6659E-02 0.1741	9.6293E-03	0.2223	-7.2784E-02	-0.1090	-0.1676	7.1449E-02

Parameter correlation coefficient matrix ----->

	por1 pce_s2	alph_l1 tce_s2	k-pce	k-tce	k-dce	k-vc	pce_s1	tce_s1
por1	1.000 -0.7417	-0.5413 -0.6556	0.2324	-0.8234	0.2196	0.7224	0.7651	-0.4166
alph_l1	-0.5413 0.1846	1.000 0.5017	-0.1334	0.5587	-0.2295	-0.7235	-0.4154	0.3953
k-pce	0.2324 6.3457E-02	-0.1334 6.6514E-02	1.000	-0.4055	-0.5249	1.8564E-03	0.4362	0.2270
k-tce	-0.8234 0.6291	0.5587 0.4946	-0.4055	1.000	-0.3746	-0.6944	-0.9152	8.0632E-02
k-dce	0.2196 -0.3157	-0.2295 -0.4389	-0.5249	-0.3746	1.000	0.2356	0.3746	-0.1835
k-vc	0.7224 -0.6370	-0.7235 -0.3823	1.8564E-03	-0.6944	0.2356	1.000	0.4635	-0.4150
pce_s1	0.7651 -0.5879	-0.4154 -0.6124	0.4362	-0.9152	0.3746	0.4635	1.000	-7.4218E-02
tce_s1	-0.4166 0.2029	0.3953 0.4780	0.2270	8.0632E-02	-0.1835	-0.4150	-7.4218E-02	1.000
pce_s2	-0.7417 1.000	0.1846 0.3053	6.3457E-02	0.6291	-0.3157	-0.6370	-0.5879	0.2029
tce_s2	-0.6556	0.5017	6.6514E-02	0.4946	-0.4389	-0.3823	-0.6124	0.4780

	0.3053	1.000						
Normalized eigenvectors of parameter covariance matrix ----->								
	Vector_1 Vector_9	Vector_2 Vector_10	Vector_3	Vector_4	Vector_5	Vector_6	Vector_7	Vector_8
por1	-0.4294 -0.1130	-0.2652 -0.2771	-0.4758	0.4655	-9.7973E-02	0.4057	0.1960	-3.1928E-03
alph_l1	-0.1430 0.2424	8.8621E-03 0.1565	0.6244	0.3959	0.1372	0.4816	-0.2950	-0.1089
k-pce	-0.4327 0.3727	0.5927 -7.3751E-02	9.9320E-03	-0.1100	0.2078	9.9284E-03	0.3398	0.3823
k-tce	-0.4115 -0.2761	-8.5503E-02 0.7202	-6.2781E-03	-0.3555	-0.1544	0.2073	0.1629	-9.3546E-02
k-dce	-0.4497 -0.1234	0.2633 -0.1067	-0.1223	1.8626E-02	0.2553	-0.3378	-0.3752	-0.6054
k-vc	-0.2978 -0.6132	-2.7525E-02 -0.3612	0.4250	-9.1158E-02	-0.1306	-0.1023	-0.1523	0.4055
pce_s1	-0.2080 0.3615	-0.4591 -0.4051	0.2010	-0.5617	1.2125E-02	0.1198	0.1345	-0.2504
tce_s1	-0.2186 0.3971	9.3761E-03 5.5194E-02	-8.7002E-02	3.6422E-02	-0.7452	-0.2036	-0.4058	0.1454
pce_s2	-0.2051 0.1289	-0.3972 0.1922	0.2543	0.3861	9.3183E-02	-0.6153	0.3807	2.6545E-02
tce_s2	-0.1208 0.1309	-0.3637 0.1694	-0.2746	-0.1168	0.5082	-3.7993E-02	-0.4908	0.4666

Eigenvalues ----->

1.1673E-03 0.3665	5.0170E-03 2.151	2.1949E-02	2.5142E-02	4.7415E-02	0.1265	0.1651	0.2352
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SENSITIVITY MAIN OUTPUT FILE (.SEN)

PARAMETER SENSITIVITIES: CASE rt3d_calib

OPTIMISATION ITERATION NO. 1 ----->

Parameter name	Group	Current value	Sensitivity
por1	porosity	0.300000	68.6861
alph_11	dispersivity	1.00000	33.0108
k-pce	rxn_rate	3.000000E-03	75.6094
k-tce	rxn_rate	8.500000E-03	61.2141
k-dce	rxn_rate	5.000000E-04	68.6452
k-vc	rxn_rate	3.000000E-03	46.1657
pce_s1	source_conc	6.50000	48.0742
tce_s1	source_conc	15.5000	36.6671
pce_s2	source_conc	7.000000E-03	44.3825
tce_s2	source_conc	0.250000	35.2500

COMPLETION OF OPTIMISATION PROCESS

Composite sensitivities for observation group "w1" ----->

Number of observations with non-zero weight = 4

Parameter name	Group	Current value	Sensitivity
por1	porosity	0.300000	6.50117
alph_11	dispersivity	1.00000	12.7500
k-pce	rxn_rate	3.000000E-03	26.9752
k-tce	rxn_rate	8.500000E-03	5.19230
k-dce	rxn_rate	5.000000E-04	12.7053
k-vc	rxn_rate	3.000000E-03	6.87455
pce_s1	source_conc	6.50000	6.12105
tce_s1	source_conc	15.5000	5.33210
pce_s2	source_conc	7.000000E-03	19.3675
tce_s2	source_conc	0.250000	3.43022

Composite sensitivities for observation group "w2" ----->

Number of observations with non-zero weight = 5

Parameter name	Group	Current value	Sensitivity
por1	porosity	0.300000	223.285
alph_11	dispersivity	1.00000	113.654
k-pce	rxn_rate	3.000000E-03	84.7490
k-tce	rxn_rate	8.500000E-03	171.679
k-dce	rxn_rate	5.000000E-04	72.4878
k-vc	rxn_rate	3.000000E-03	140.281
pce_s1	source_conc	6.50000	174.565
tce_s1	source_conc	15.5000	107.229
pce_s2	source_conc	7.000000E-03	128.820
tce_s2	source_conc	0.250000	71.4191

Composite sensitivities for observation group "w3" ----->

Number of observations with non-zero weight = 10

Parameter name	Group	Current value	Sensitivity
por1	porosity	0.300000	139.328
alph_11	dispersivity	1.00000	64.0060
k-pce	rxn_rate	3.000000E-03	191.640
k-tce	rxn_rate	8.500000E-03	133.987
k-dce	rxn_rate	5.000000E-04	174.669
k-vc	rxn_rate	3.000000E-03	97.3228
pce_s1	source_conc	6.50000	89.3061
tce_s1	source_conc	15.5000	78.7603

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pce_s2      source_conc      7.000000E-03      95.4045
tce_s2      source_conc      0.250000      84.3524
Composite sensitivities for observation group "w7" ----->

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Number of observations with non-zero weight = 7
Parameter name      Group      Current value      Sensitivity
por1                porosity      0.300000      4.27782
alph_11             dispersivity      1.00000      5.41647
k-pce               rxn_rate      3.000000E-03      3.92788
k-tce               rxn_rate      8.500000E-03      3.37316
k-dce               rxn_rate      5.000000E-04      3.32260
k-vc                rxn_rate      3.000000E-03      4.14314
pce_s1              source_conc      6.50000      6.91566
tce_s1              source_conc      15.5000      3.61967
pce_s2              source_conc      7.000000E-03      3.25932
tce_s2              source_conc      0.250000      3.86910

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Composite sensitivities for all observations/prior info ----->

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Number of observations with non-zero weight = 26
Parameter name      Group      Current value      Sensitivity
por1                porosity      0.300000      68.6861
alph_11             dispersivity      1.00000      33.0108
k-pce               rxn_rate      3.000000E-03      75.6094
k-tce               rxn_rate      8.500000E-03      61.2141
k-dce               rxn_rate      5.000000E-04      68.6452
k-vc                rxn_rate      3.000000E-03      46.1657
pce_s1              source_conc      6.50000      48.0742
tce_s1              source_conc      15.5000      36.6671
pce_s2              source_conc      7.000000E-03      44.3825
tce_s2              source_conc      0.250000      35.2500

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Remediation Outcomes Using Stochastic Modeling Method. The 16th

International Annual Symposium on Computational Science and Engineering

(ANSCSE 16). (Oral Presentation)