APPENDIX

7. Methodology of Gravity Data Analysis and Results

Gravity data analysis methods

The procedures of the gravity data analysis are demonstrated below.

1. Location of gravity measurement stations

The location map of gravity stations in Korosi and Chepchuk is shown in Fig.Gr-01 and in Paka is shown in Fig.Gr-02. The coordinates of gravity measurement stations in Korosi and Chepchuk are shown in Table.Gr-01 and in Paka are shown in Table.Gr-02, respectively.

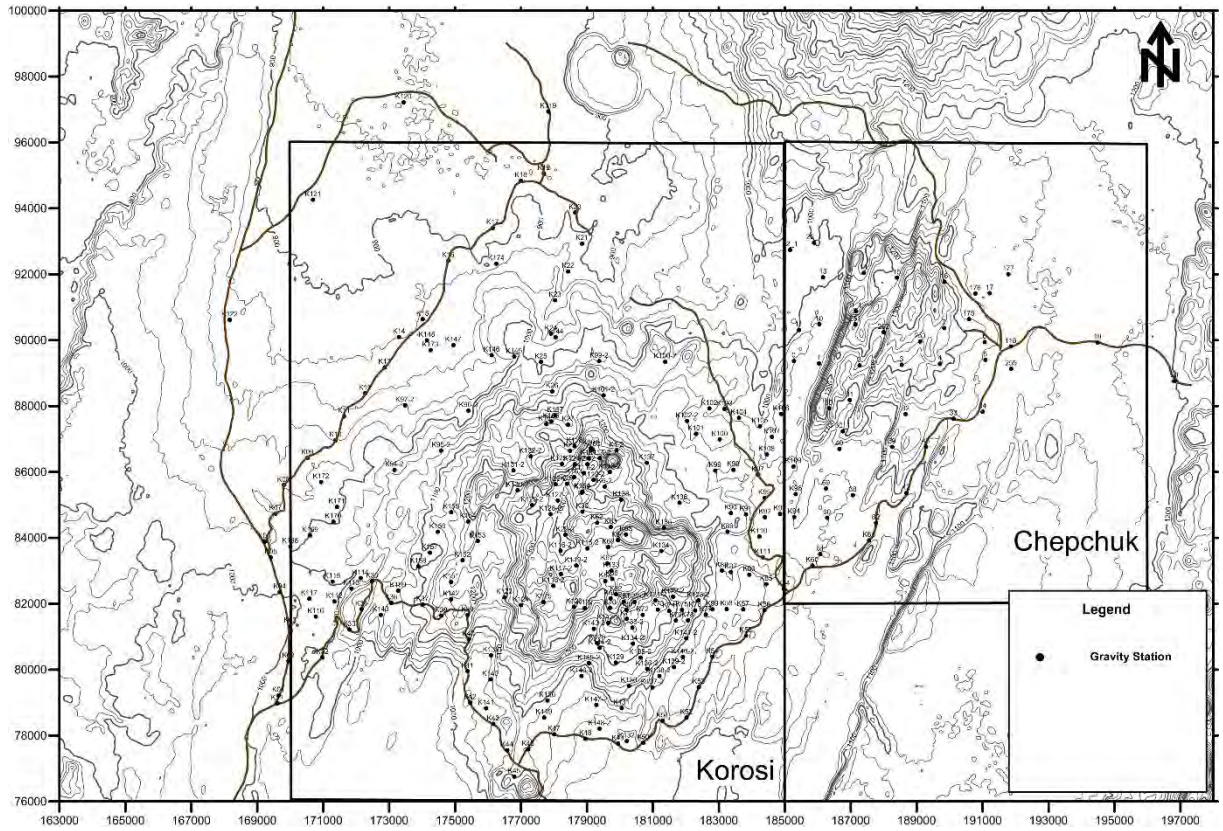


Fig.Gr-01 Location map of gravity stations in Korosi and Chepchuk

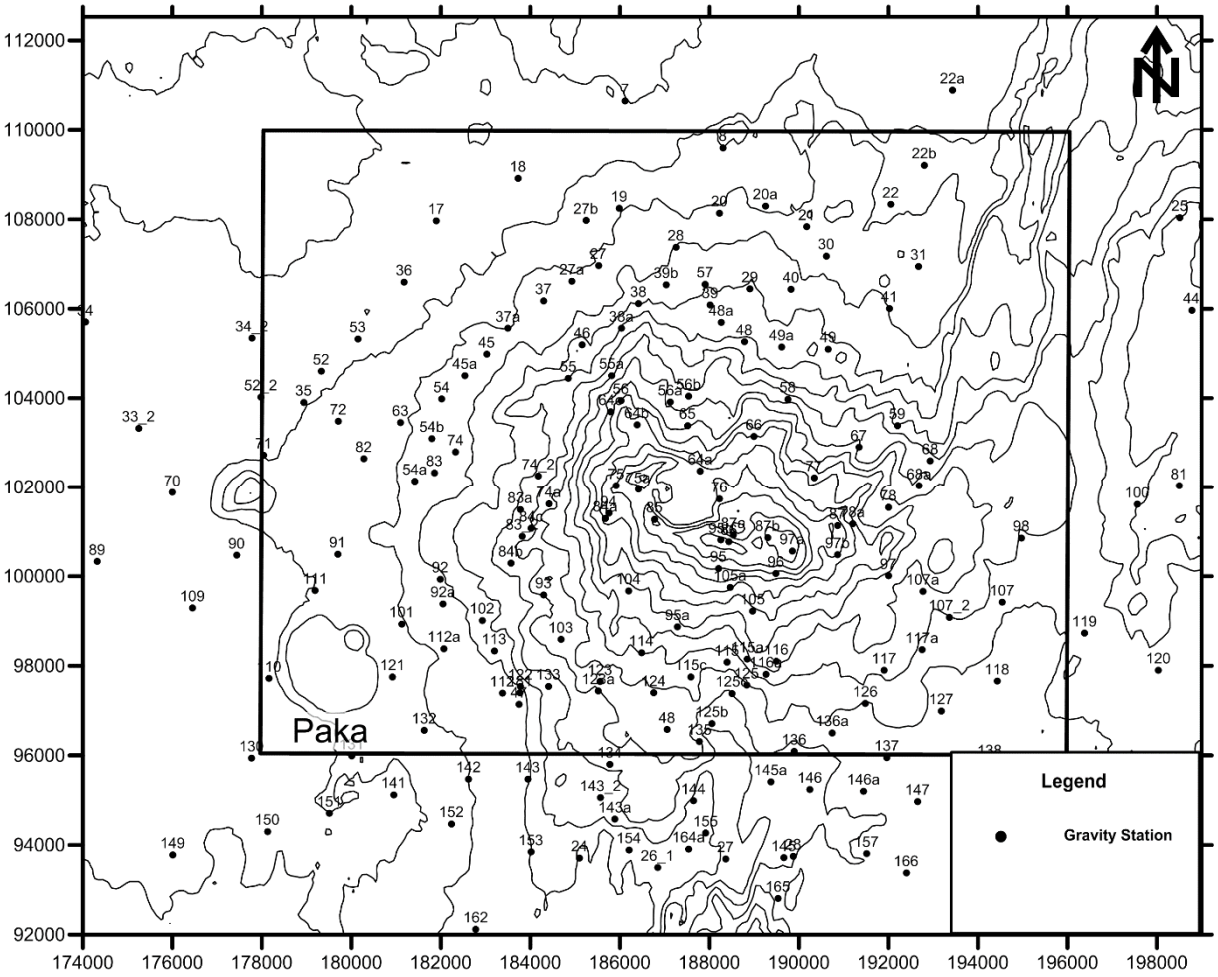


Fig.Gr-02 Location map of gravity stations in Paka

Table.Gr-01(1) Coordinates of gravity measurement stations in Korosi and Chepchuk

Station	UTM(ZONE37S)		WGS84		Elevation	Station	UTM(ZONE37S)		WGS84		Elevation
	E_utm	N_utm	Lat	Lon			E_utm	N_utm	Lat	Lon	
K01	169645	79217	0.7157	36.0323	986	K59	182803	81835	0.7395	36.1504	1075
K02	169947	80257	0.7251	36.0350	984	K60	185837	83161	0.7515	36.1776	1040
K03	170001	81324	0.7348	36.0355	1000	K61	187556	83922	0.7584	36.1930	1053
K04	169684	82355	0.7441	36.0326	993	K62	179306	84460	0.7632	36.1190	1404
K05	169415	83407	0.7536	36.0302	978	K63	179723	84327	0.7620	36.1227	1376
K06	169223	83885	0.7579	36.0285	973	K64	179937	83928	0.7584	36.1246	1378
K07	169556	84737	0.7656	36.0315	974	K65	180185	84104	0.7599	36.1269	1436
K08	169800	85598	0.7734	36.0336	961	K66	179652	83719	0.7565	36.1221	1341
K09	170526	86432	0.7809	36.0402	967	K67	179616	83223	0.7520	36.1218	1324
K10	171376	86966	0.7858	36.0478	952	K68	179763	82758	0.7478	36.1231	1326
K11	171634	87687	0.7923	36.0501	937	K69	179712	82160	0.7424	36.1226	1328
K12	172273	88387	0.7986	36.0558	925	K70	179701	81871	0.7398	36.1225	1300
K13	172865	89177	0.8057	36.0611	919	K71	180208	81543	0.7368	36.1271	1247
K14	173302	90096	0.8140	36.0650	912	K72	180687	81661	0.7379	36.1314	1216
K15	174020	90635	0.8189	36.0715	916	K73	181150	81827	0.7394	36.1355	1215
K16	174793	92415	0.8350	36.0784	907	K74	181490	81781	0.7390	36.1386	1198
K17	176141	93407	0.8440	36.0905	879	K75	181886	81813	0.7393	36.1421	1171
K18	176998	94838	0.8569	36.0982	875	K76	182283	81800	0.7391	36.1457	1113
K19	177692	95056	0.8589	36.1044	875	K77	182603	81670	0.7380	36.1486	1072
K20	178640	93870	0.8482	36.1129	883	K78	182060	81493	0.7364	36.1437	1135
K21	178850	92933	0.8397	36.1148	900	K79	181695	81491	0.7363	36.1404	1172
K22	178431	92087	0.8321	36.1111	907	K80	180195	81813	0.7392	36.1270	1273
K23	178034	91209	0.8241	36.1075	919	K81	180118	82064	0.7415	36.1263	1301
K24	177913	90194	0.8150	36.1064	958	K82	179881	82288	0.7435	36.1241	1355
K25	177606	89339	0.8072	36.1037	983	K83	179556	82690	0.7472	36.1212	1320
K26	177948	88447	0.7992	36.1068	1061	K84	184977	82450	0.7450	36.1699	1069
K27	178429	87440	0.7901	36.1111	1126	K85	184442	82598	0.7464	36.1651	1054
K28	178484	86641	0.7829	36.1116	1222	K86	183921	82884	0.7490	36.1604	1057
K29	178396	85643	0.7738	36.1108	1329	K87	183369	82961	0.7496	36.1554	1056
K30	178862	84796	0.7662	36.1150	1360	K88	183096	83008	0.7501	36.1530	1059
K31	169611	78974	0.7135	36.0320	984	K89	183260	84182	0.7607	36.1545	1097
K32	170977	80369	0.7261	36.0442	999	K90	183362	84756	0.7659	36.1554	1088
K33	171796	81214	0.7338	36.0516	1047	K91	183819	84713	0.7655	36.1595	1078
K34	172165	81832	0.7394	36.0549	1077	K92	184401	84625	0.7647	36.1647	1033
K35	172487	82685	0.7471	36.0578	1064	K93	184856	84730	0.7656	36.1688	1031
K36	173063	82026	0.7411	36.0630	1056	K94	185284	84636	0.7648	36.1726	1029
K37	174016	81979	0.7407	36.0715	1118	K95	184391	85213	0.7700	36.1646	1021
K38	174584	81634	0.7376	36.0766	1128	K96	185334	85325	0.7710	36.1731	1018
K39	175382	81656	0.7378	36.0838	1169	K97	184192	85921	0.7764	36.1628	1020
K40	175411	80918	0.7311	36.0840	1111	K98	183443	86069	0.7777	36.1561	1058
K41	175380	79949	0.7224	36.0838	1026	K99	182888	86040	0.7775	36.1511	1066
K42	175459	78998	0.7138	36.0845	1015	K100	183026	86987	0.7860	36.1523	1046
K43	176156	78352	0.7080	36.0907	1036	K101	182308	87159	0.7876	36.1459	1037
K44	176582	77556	0.7008	36.0946	1042	K102	182712	87927	0.7945	36.1495	1043
K45	176798	76752	0.6935	36.0965	1095	K103	183175	87910	0.7944	36.1537	1036
K46	177216	77583	0.7010	36.1003	1079	K104	183610	87641	0.7919	36.1576	1006
K47	178002	78039	0.7051	36.1073	1064	K105	184249	87389	0.7897	36.1633	1001
K48	178957	77907	0.7040	36.1159	1029	K106	184892	87762	0.7930	36.1691	1017
K49	179942	77757	0.7026	36.1247	1018	K107	184613	87068	0.7868	36.1666	1017
K50	180709	77778	0.7028	36.1316	1027	K108	184455	86534	0.7819	36.1652	1019
K51	181293	78449	0.7089	36.1368	1043	K109	185265	86170	0.7787	36.1725	1019
K52	182023	78547	0.7097	36.1434	1046	K110	184228	84039	0.7594	36.1632	1027
K53	182392	79469	0.7181	36.1467	1067	K111	184331	83409	0.7537	36.1641	1029
K54	182804	80391	0.7264	36.1504	1056	K112	171342	82070	0.7415	36.0475	986
K55	183821	81035	0.7322	36.1595	1051	K113	171857	82461	0.7451	36.0521	991
K56	184383	81806	0.7392	36.1646	1054	K114	172139	82777	0.7479	36.0547	994
K57	183735	81828	0.7394	36.1587	1068	K115	171280	82670	0.7469	36.0469	1000
K58	183234	81840	0.7395	36.1542	1069	K116	170776	81608	0.7373	36.0424	997

Table.Gr-01(2) Coordinates of gravity measurement stations in Korosi and Chepchuk

Station	UTM(ZONE37S)		WGS84		Elevation	Station	UTM(ZONE37S)		WGS84		Elevation
	E_utm	N_utm	Lat	Lon			E_utm	N_utm	Lat	Lon	
K117	170578	82153	0.7423	36.0406	990	K124-2	178631	86232	0.7792	36.1129	1284
K118	178627	86789	0.7842	36.1129	1171	K125-2	178238	86247	0.7793	36.1094	1238
K119	177829	96938	0.8759	36.1056	887	K126-2	178046	85624	0.7737	36.1077	1336
K120	173438	97221	0.8784	36.0662	879	K127-2	178115	85130	0.7692	36.1083	1325
K121	170694	94259	0.8516	36.0416	890	K128-2	177897	84722	0.7655	36.1063	1312
K122	168167	90617	0.8187	36.0189	927	K129-2	177335	84992	0.7680	36.1013	1285
K123	176495	82200	0.7427	36.0938	1155	K130-2	176895	85448	0.7721	36.0973	1213
K124	176996	81960	0.7406	36.0982	1248	K131-2	176768	86046	0.7775	36.0962	1122
K125	177687	82055	0.7414	36.1045	1300	K132-2	177293	86473	0.7813	36.1009	1152
K126	178610	81905	0.7401	36.1127	1363	K133-2	180378	81276	0.7344	36.1286	1233
K127	178941	81867	0.7397	36.1157	1310	K134-2	180390	80787	0.7300	36.1287	1218
K128	179314	80811	0.7302	36.1191	1191	K135-2	180620	80368	0.7262	36.1308	1188
K129	179879	80213	0.7248	36.1241	1200	K136-2	180824	80020	0.7231	36.1326	1160
K130	180278	79510	0.7184	36.1277	1170	K137-2	180985	79460	0.7180	36.1341	1074
K131	180054	78836	0.7123	36.1257	1101	K138-2	181198	79807	0.7211	36.1360	1082
K132	180208	77833	0.7033	36.1271	1008	K139-2	181637	80080	0.7236	36.1399	1067
K133	179741	83002	0.7500	36.1229	1342	K140-2	181911	80382	0.7263	36.1424	1068
K134	181256	83601	0.7554	36.1365	1336	K141-2	182009	80949	0.7315	36.1433	1093
K135	181333	84306	0.7618	36.1372	1167	K142-2	179644	81420	0.7357	36.1220	1286
K136	181803	85063	0.7686	36.1414	1130	K143-2	179210	81241	0.7341	36.1181	1202
K137	180815	86275	0.7796	36.1325	1164	K144-2	179388	80662	0.7288	36.1197	1192
K138	180035	85162	0.7695	36.1255	1266	K145-2	179060	80196	0.7246	36.1168	1108
K139	176093	80434	0.7268	36.0902	1051	K146-2	178837	79807	0.7211	36.1148	1066
K140	176071	79704	0.7202	36.0900	1033	K147-2	179282	78924	0.7131	36.1188	1042
K141	175941	78829	0.7123	36.0888	1031	K148-2	179382	78209	0.7067	36.1197	1027
K142	174884	82134	0.7421	36.0793	1171	K149	177699	78549	0.7097	36.1046	1074
K143	172748	81665	0.7379	36.0601	1042	K150	177801	79066	0.7144	36.1055	1088
K144	178050	90089	0.8140	36.1077	943	K151	174878	82662	0.7469	36.0792	1170
K145	176792	89502	0.8087	36.0964	995	K152	175226	83319	0.7528	36.0824	1165
K146	176111	89544	0.8091	36.0903	968	K153	175685	83902	0.7581	36.0865	1142
K147	174949	89848	0.8118	36.0798	924	K154	175399	84498	0.7635	36.0839	1162
K148	174149	89998	0.8132	36.0726	915	K155	174881	84780	0.7660	36.0793	1125
K97-2	173480	88023	0.7953	36.0667	956	K156	174473	84182	0.7606	36.0756	1109
K96-2	175408	87864	0.7939	36.0840	977	K157	174234	83550	0.7549	36.0735	1090
K95-2	174580	86647	0.7829	36.0765	1059	K158	173884	83135	0.7512	36.0703	1094
K94-2	173162	86061	0.7776	36.0638	1021	K159	173274	82399	0.7445	36.0648	1071
K201	179114	86721	0.7836	36.1172	1271	K160	179167	86675	0.7832	36.1177	1297
K101-2	179506	88328	0.7981	36.1207	1093	K161	179051	86410	0.7808	36.1167	1315
K102-2	182036	87546	0.7911	36.1435	1063	K162	179011	86237	0.7792	36.1163	1317
K100-2	181375	89346	0.8073	36.1375	1018	K163	178609	85846	0.7757	36.1127	1343
K99-2	179372	89364	0.8075	36.1195	1014	K164	178863	85402	0.7717	36.1150	1348
K111-2	178907	85964	0.7768	36.1154	1313	K165	177772	87457	0.7902	36.1052	1161
K112-2	179202	85758	0.7749	36.1180	1301	K166	177918	87533	0.7909	36.1065	1147
K6-2	179539	85555	0.7731	36.1211	1247	K167	178037	87715	0.7926	36.1076	1123
K113-2	179692	86001	0.7771	36.1224	1265	K168	170002	83741	0.7566	36.0355	987
K1-2	179897	86654	0.7830	36.1243	1281	K169	170609	84072	0.7596	36.0409	992
K114-2	179384	86419	0.7809	36.1197	1307	K170	171308	84489	0.7634	36.0472	989
K202	178848	85368	0.7714	36.1149	1375	K171	171417	84937	0.7674	36.0482	986
K115-2	179017	83679	0.7561	36.1164	1327	K172	170940	85695	0.7743	36.0439	985
K29-2	178346	84091	0.7598	36.1104	1292	K173	174255	89694	0.8104	36.0736	920
K116-2	178199	83606	0.7554	36.1090	1288	K174	176253	92323	0.8342	36.0915	905
K117-2	178213	82899	0.7490	36.1092	1348	175	190585	90637	0.8191	36.2202	1184
K118-2	177983	82542	0.7458	36.1071	1363	176	190778	91415	0.8261	36.2219	1157
K119-2	178675	83159	0.7514	36.1133	1328	177	191784	92004	0.8314	36.2309	1154
K120-2	180433	82054	0.7414	36.1291	1283	61	186078	83507	0.7546	36.1798	1037
K121-2	181081	82104	0.7419	36.1349	1215	62	187766	84450	0.7631	36.1949	1050
K122-2	181613	82213	0.7429	36.1397	1139	42	188691	85360	0.7714	36.2032	1080
K123-2	182380	82101	0.7419	36.1466	1091	43	189280	86772	0.7841	36.2085	1113

Table.Gr-01(3) Coordinates of gravity measurement stations in Korosi and Chepchuk

Station	UTM(ZONE37S)		WGS84		Elevation
	E_utm	N_utm	Lat	Lon	
33	190122	87614	0.7917	36.2160	1149
34	191003	87829	0.7937	36.2240	1144
6	191063	89946	0.8128	36.2245	1169
5	191087	89398	0.8079	36.2247	1155
255	191865	89131	0.8055	36.2317	1145
19	194487	89930	0.8127	36.2552	1169
20	196820	88762	0.8021	36.2762	1198
118	191854	89805	0.8115	36.2316	1149
60	186284	84605	0.7645	36.1816	1076
69	186254	85496	0.7726	36.1813	1037
38	187066	85298	0.7708	36.1886	1038
40	186657	86702	0.7835	36.1849	1050
30_1	186763	87235	0.7883	36.1859	1082
30	186342	87926	0.7945	36.1821	1164
31	186970	88185	0.7969	36.1877	1118
17	191217	91424	0.8262	36.2258	1153
16	189840	91776	0.8293	36.2135	1198
15	188405	91895	0.8304	36.2006	1208
14	187398	92044	0.8317	36.1916	1120
13	186162	91910	0.8305	36.1805	993
12_1	185163	92741	0.8380	36.1715	986
25_1	185891	92956	0.8400	36.1780	997
7	189832	90370	0.8166	36.2134	1234
253	189109	89961	0.8129	36.2069	1241
4	189707	89284	0.8068	36.2123	1227
3	188546	89249	0.8065	36.2019	1218
32	188666	87755	0.7930	36.2030	1146
39	188256	86764	0.7840	36.1993	1152
2	187265	89235	0.8064	36.1904	1170
1	186038	89295	0.8069	36.1794	1015
0	185275	89368	0.8075	36.1725	1019
11	185428	90307	0.8160	36.1739	1021
10	186046	90482	0.8176	36.1794	1019
9_1	187159	90882	0.8212	36.1894	1164
251	187142	90478	0.8176	36.1893	1211
252	188000	90239	0.8154	36.1970	1184

Table.Gr-02(1)　Coordinates of gravity measurement stations in Paka

Station	UTM(ZONE37S)		WGS84		Elevation	Station	UTM(ZONE37S)		WGS84		Elevation
	E_utm	N_utm	Lat	Lon			E_utm	N_utm	Lat	Lon	
69	173721	101151	0.9139	36.0687	885	143	183943	95470	0.8627	36.1605	1012
89	174323	100328	0.9065	36.0741	884	135	187780	96313	0.8703	36.1950	1168
109	176454	99291	0.8972	36.0933	877	125	188832	97568	0.8817	36.2044	1198
110	178164	97718	0.8830	36.1086	877	125b	188058	96711	0.8739	36.1975	1112
130	177774	95941	0.8669	36.1051	877	125c	188503	97386	0.8800	36.2014	1142
121	180920	97754	0.8833	36.1334	916	116a	189264	97812	0.8839	36.2083	1266
112	183373	97388	0.8800	36.1554	968	116	189498	98102	0.8865	36.2104	1315
101	181125	98936	0.8940	36.1352	940	115a	188849	98150	0.8869	36.2045	1273
111	179192	99681	0.9007	36.1179	903	115	188392	98077	0.8863	36.2004	1209
51	173795	102193	0.9234	36.0694	872	115c	187586	97755	0.8834	36.1932	1232
70	176004	101878	0.9205	36.0892	876	95a	187288	98869	0.8934	36.1905	1318
122	183777	97541	0.8814	36.1590	988	75	185918	102033	0.9220	36.1782	1489
133	184403	97543	0.8814	36.1646	1071	75a	186412	101948	0.9212	36.1826	1528
123	185557	97646	0.8824	36.1750	1152	95b	188260	100809	0.9110	36.1992	1662
124	186753	97396	0.8801	36.1857	1156	95	188203	100175	0.9052	36.1987	1548
114	186482	98294	0.8882	36.1833	1229	105a	188464	99753	0.9014	36.2011	1428
104	186195	99671	0.9007	36.1807	1314	105	188966	99221	0.8966	36.2056	1403
94	185753	101410	0.9164	36.1767	1447	96	189489	100060	0.9042	36.2103	1504
85	186776	101277	0.9152	36.1859	1559	86	188439	100771	0.9106	36.2008	1659
76	188229	101736	0.9193	36.1990	1578	84a	185674	101297	0.9153	36.1760	1427
65	187512	103388	0.9343	36.1925	1357	64a	187799	102363	0.9250	36.1951	1470
57	187907	106550	0.9628	36.1960	1058	56a	187127	103912	0.9390	36.1891	1248
53	180144	105327	0.9517	36.1264	897	56b	187538	104046	0.9402	36.1927	1247
35	178936	103907	0.9389	36.1155	900	39	188019	106088	0.9587	36.1970	1061
28	187257	107377	0.9703	36.1902	1002	29	188906	106443	0.9619	36.2050	1047
19	185986	108247	0.9781	36.1788	948	40	189828	106436	0.9618	36.2133	1015
18	183725	108917	0.9842	36.1585	878	30	190612	107180	0.9685	36.2203	967
17	181898	107968	0.9756	36.1421	867	21	190175	107834	0.9744	36.2164	951
36	181182	106597	0.9632	36.1357	878	20a	189252	108298	0.9786	36.2081	942
7	186121	110647	0.9998	36.1800	848	20	188228	108140	0.9772	36.1989	964
8	188303	109601	0.9904	36.1996	926	64b	186382	103404	0.9344	36.1824	1384
72	179710	103485	0.9351	36.1225	909	64c	185793	103697	0.9370	36.1771	1338
82	180279	102640	0.9274	36.1276	923	56	186027	103944	0.9393	36.1792	1386
83	181859	102325	0.9246	36.1418	968	55a	185818	104508	0.9444	36.1773	1230
74	182331	102795	0.9289	36.1460	991	55	184849	104445	0.9438	36.1686	1093
63	181099	103454	0.9348	36.1349	938	46	185159	105196	0.9506	36.1714	1024
120	198034	97904	0.8848	36.2870	1213	38a	186037	105560	0.9539	36.1792	1104
119	196385	98727	0.8922	36.2722	1206	38	186416	106114	0.9589	36.1827	1066
107	194541	99420	0.8984	36.2556	1197	39b	187036	106538	0.9627	36.1882	978
98	194971	100857	0.9114	36.2595	1218	92	181988	99935	0.9030	36.1430	991
81	198497	102031	0.9221	36.2911	1305	92a	182049	99384	0.8980	36.1435	980
100	197561	101614	0.9183	36.2827	1310	91	179695	100491	0.9080	36.1224	906
44	198776	105970	0.9577	36.2936	1307	90	177441	100468	0.9078	36.1021	883
25	198510	108038	0.9764	36.2912	1303	54a	181421	102136	0.9229	36.1378	946
165	189533	92808	0.8387	36.2107	1182	54b	181802	103093	0.9315	36.1412	958
145	189664	93714	0.8468	36.2119	1147	54	182022	103981	0.9396	36.1432	962
166	192399	93379	0.8438	36.2365	1156	45a	182540	104508	0.9443	36.1479	975
108	172291	97633	0.8821	36.0559	869	45	183025	104982	0.9486	36.1522	975
32	170490	105827	0.9562	36.0397	854	37a	183501	105561	0.9539	36.1565	970
33	172171	105771	0.9557	36.0548	852	37	184296	106178	0.9594	36.1636	954
34	174060	105701	0.9550	36.0717	854	27a	184930	106616	0.9634	36.1693	973
52	179330	104602	0.9452	36.1191	891	27	185522	106965	0.9666	36.1746	941
71	178044	102724	0.9282	36.1075	896	27b	185242	107974	0.9757	36.1721	925
170	178061	91844	0.8299	36.1078	913	69_2	171759	102411	0.9253	36.0511	869
171	180008	91779	0.8293	36.1252	917	51_2	173359	103714	0.9371	36.0655	861
172	182103	91795	0.8295	36.1440	948	33_2	175246	103325	0.9336	36.0824	863
162	182783	92122	0.8324	36.1501	955	34_2	177781	105343	0.9518	36.1051	873
153	184015	93844	0.8480	36.1612	998	52_2	177978	104025	0.9399	36.1069	884

Table.Gr-02(2)　Coordinates of gravity measurement stations in Paka

Station	UTM(ZONE37S)		WGS84		Elevation	Station	UTM(ZONE37S)		WGS84		Elevation
	E_utm	N_utm	Lat	Lon			E_utm	N_utm	Lat	Lon	
48a	188268	105694	0.9551	36.1993	1063	102	182924	99015	0.8947	36.1514	1020
48	188782	105260	0.9512	36.2039	1107	113	183193	98334	0.8886	36.1538	998
49a	189614	105141	0.9501	36.2114	1062	150	178125	94303	0.8521	36.1083	886
49	190657	105099	0.9497	36.2207	1052	149	176011	93779	0.8473	36.0893	882
58	189753	103979	0.9396	36.2126	1264	151	179511	94706	0.8557	36.1207	884
66	188999	103142	0.9320	36.2059	1444	141	180944	95123	0.8595	36.1336	880
123a	185520	97442	0.8805	36.1747	1140	152	182239	94473	0.8537	36.1452	915
112a	182073	98386	0.8890	36.1437	956	142	182619	95475	0.8627	36.1486	953
87a	188539	100926	0.9120	36.2017	1652	132	181630	96560	0.8725	36.1398	939
87b	189302	100859	0.9114	36.2086	1580	131	180009	95988	0.8673	36.1252	893
87	190862	101133	0.9139	36.2226	1493	128	173754	98164	0.8870	36.0690	873
78a	191202	101172	0.9143	36.2257	1409	24	185102	93712	0.8468	36.1709	991
78	192001	101542	0.9176	36.2328	1360	26_1	186843	93499	0.8449	36.1866	1002
68a	192686	102030	0.9220	36.2390	1275	27	188365	93691	0.8466	36.2002	1058
68	192935	102595	0.9271	36.2412	1201	28	189874	93750	0.8472	36.2138	1143
59	192200	103386	0.9343	36.2346	1201	47	183747	97140	0.8778	36.1588	984
67	191342	102899	0.9299	36.2269	1210	48	187056	96576	0.8727	36.1885	1170
77	190339	102210	0.9236	36.2179	1405						
22a	193433	110888	1.0021	36.2456	872						
22b	192804	109211	0.9869	36.2400	927						
22	192053	108332	0.9790	36.2332	943						
31	192678	106945	0.9664	36.2389	970						
41	192025	106004	0.9579	36.2330	993						
97a	189850	100565	0.9088	36.2135	1669						
97b	190865	100478	0.9080	36.2226	1460						
97	192000	100010	0.9038	36.2328	1322						
107a	192769	99663	0.9006	36.2397	1280						
107_2	193362	99086	0.8954	36.2451	1246						
117a	192752	98359	0.8888	36.2396	1226						
117	191906	97901	0.8847	36.2320	1261						
126	191488	97160	0.8780	36.2282	1210						
136a	190749	96505	0.8721	36.2216	1188						
136	189897	96090	0.8683	36.2140	1153						
145a	189371	95410	0.8622	36.2093	1129						
144	187646	94987	0.8583	36.1938	1043						
155	187919	94266	0.8518	36.1962	1061						
164a	187538	93911	0.8486	36.1928	1048						
154	186202	93892	0.8484	36.1808	1004						
143a	185891	94577	0.8546	36.1780	1011						
143_2	185570	95055	0.8589	36.1751	1066						
134	185777	95799	0.8657	36.1770	1102						
146	190248	95240	0.8606	36.2171	1127						
157	191512	93805	0.8477	36.2285	1155						
147	192654	94968	0.8582	36.2387	1157						
138	194263	95849	0.8662	36.2532	1175						
118	194430	97656	0.8825	36.2547	1187						
127	193183	96993	0.8765	36.2435	1179						
137	191966	95951	0.8671	36.2325	1164						
146a	191447	95199	0.8603	36.2279	1159						
84b	183563	100290	0.9062	36.1571	1065						
84c	184020	101072	0.9133	36.1612	1151						
74a	184417	101622	0.9183	36.1647	1198						
74_2	184180	102249	0.9239	36.1626	1130						
83a	183774	101496	0.9171	36.1590	1103						
83_2	183820	100893	0.9117	36.1594	1139						
181	183771	97397	0.8801	36.1590	983						
103	184683	98588	0.8909	36.1672	1180						
93	184297	99585	0.8999	36.1637	1159						

2. Data processing and analysis method

(a) Data processing

Some necessary corrections were applied to the acquired data at each station to calculate Bouguer anomaly values at each station. Fig.Gr-03 shows the procedure used to process the gravity data.

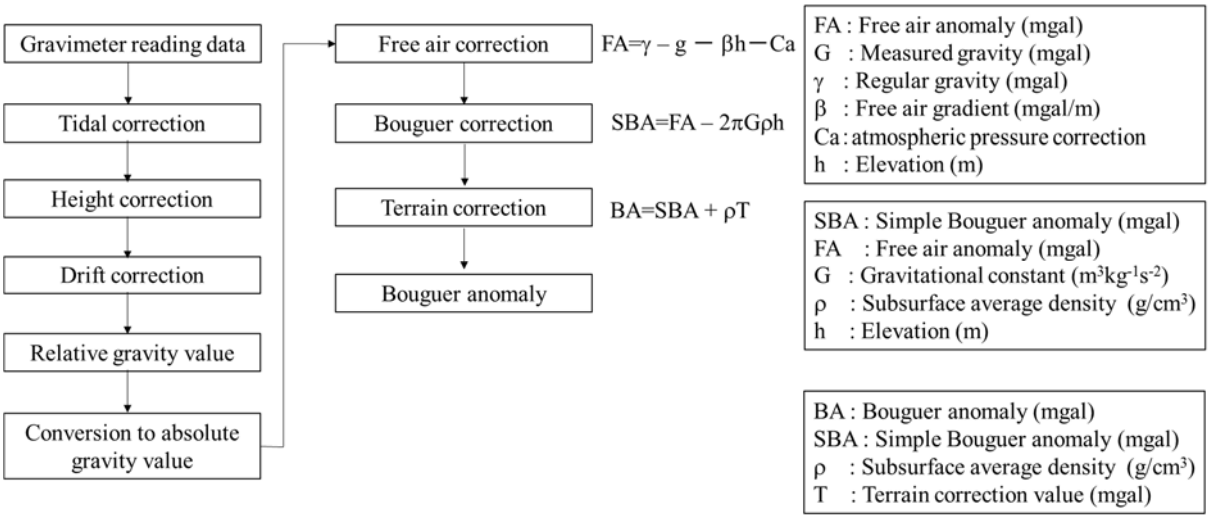


Fig.Gr-03 Data processing procedure

(i) Tidal correction

A gravimeter is sensitive enough to record the gravity changes caused by the movements of the Sun and the Moon, which vary according to latitude and time. Tidal correction is conducted to eliminate the influence of the attraction caused by the movement of the Sun and the Moon. In this survey the Scintrex CG-5 gravimeter was used. The Scintrex CG-5 utilizes an analytical program to correct automatically for tidal values, during gravity measurements.

(ii) Height correction

Correction of gravimeter height from the ground surface is necessary since the gravity value decreases when the distance between the station and the datum surface increases. This is done using vertical gravity gradient height correction (0.3086 mgal/m), which is expressed by the following equation:

$$V_{hi} = 0.3086 \times Hi$$

V_{hi} : height correction value (mgal)

Hi : the height of the gravimeter from the surface(m)

(iii) Drift correction

The spring in the gravimeter extends by itself with time, and the measured gravity value is influenced by this extension of the spring. The error in gravity value caused by the extension of the spring length with time is called “drift”. When the spring length increases, the measured gravity value becomes larger than

the value without drift. This gravity change caused by drift is corrected by drift correction. Errors caused by the rapid change of temperature and by impacts on the gravimeter during transport are also removed by the drift correction. In order to determine the level of drift, a base station for gravity measurement is established. Next, gravity measurements are taken at multiple locations, starting and ending at the base station. The gravity difference at the base station between start point and end point is regarded as the drift value because no gravity difference would occur at same station without drift effects. The drift value at each station is prorated depending on the elapsed time since the first measurement of the day occurred.

(iv) Free air correction

Free air correction corrects for the influence caused by the difference between the measurement elevation and the geoid level. The vertical gravity gradient is not necessarily constant, but in this survey an average value of 0.3086 mgal/m was used. The equation is shown below:

$F = 0.3086 \times h$

F : free air correction value(mgal)

h : elevation of the stations (m)

(v) Bouguer correction

The Bouguer correction accounts for the gravitational attraction of the material between the station and the datum plane that is ignored in the free air correction. The Bouguer correction is conducted by using the equation shown below. The estimated density is included in the equation. The method used to determine the estimated density is shown in a following section. In this survey, 2.4g/cm^3 was used as the value of the estimated density.

$B = 2\pi G\rho h$

B : Bouguer correction value(mgal)

G : Gravitational constant($6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$)

ρ : Estimated density(g/cm^3)

H : Elevation of the stations(m)

(vi) Terrain correction

Terrain correction is used to eliminate the influence of the undulation of terrain on the measured gravity value. In this survey, the effect of terrain within a 60 km radius centering on the measuring station was calculated by using the digital elevation data of the SRTM (Shuttle Radar Topography Mission). This circular range is divided into four zones depending on the distance from the measuring stations; extremely near zone (0~500m), near zone (500m~4km), medium zone (4~16km) and far zone (16~60km). The terrain

correction value was calculated in each zone using the analytical program for terrain correction developed by Komazawa (1980)

(vii) Calculation of the Bouguer anomaly

After calculating each correction, the Bouguer anomaly is formulated by the following equation:

$$\Delta B = g_{obs} - \gamma + \beta h - 2\pi G \rho h + \rho T$$

ΔB : Bouguer anomaly(mgal)

g_{obs} : Measured gravity value(mgal)

γ : Regular gravity (mgal)

β : Free air gradient(mgal/m)

h : Elevation(m)

G : Gravitational constant($6.67\times10^{-11}m^3kg^{-1}s^{-2}$)

ρ : Estimated density(g/cm^3)

T : Terrain correction value(mgal)

(b) Evaluation of the estimated density

There are various methods which can be used to estimate surface density such as directly measuring the density of core samples, comparing the distribution of the Bouguer anomaly with a topography map, the G-H and F-H correlation methods etc. In this project, the G-H and F-H correlation methods and CVUR method were used to calculate the estimated density. The details of each of the methods of calculating estimated density are demonstrated below.

(i) CVUR method (comparison of variance of upward-continuation residual)

In this method, the upward-continuation residuals between 2 points at different heights which express the shortwave component of the Bouguer anomaly, are calculated. The estimated density is determined when the residual variance becomes the smallest, because the minimum value of the residual variance reflects the smallest correlation between topography and the Bouguer anomaly. Upward-continuation at 0m and 250 m was completed and $2.41g/cm^3$ was obtained as the average density within a 5 km radius centering on the area of the gravity survey as shown in Fig.Gr-04.

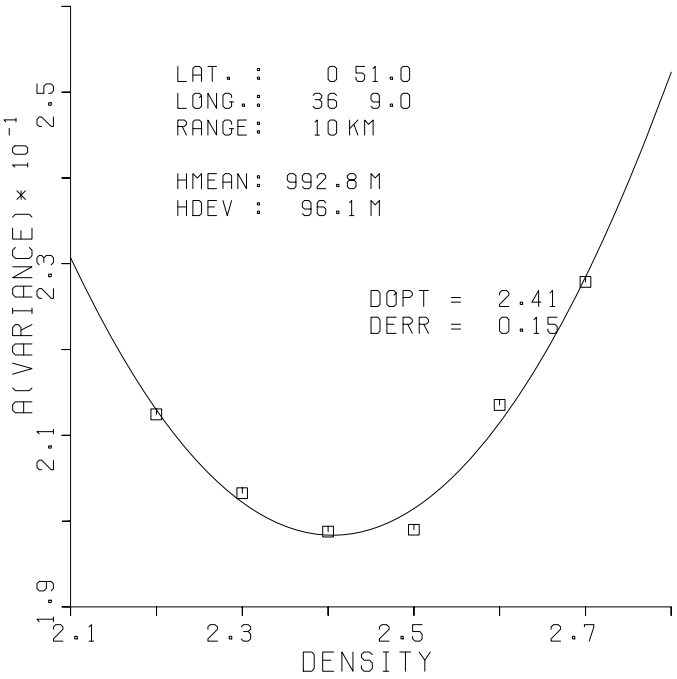


Fig.Gr-04 Result of CVUR method

(ii) G-H correlation method

The equation to calculate the Bouguer anomaly values ($\Delta B = g_{obs} - \gamma + \beta h - 2\pi G\rho_B h + \rho_T T$) was performed as shown below.

$\gamma + \rho_T T = \Delta B - (\beta - 2\pi G\rho_B) h$

When assigning an arbitrary value to h, h and $g_{obs} - \gamma + \rho_T T$ were plotted at horizontal axis and vertical axis, respectively. An approximate line of these plotted points was drawn by the least-square method and a gradient of the line $-(\beta - 2\pi G\rho_B)$ was decided and ρ_B was calculated. When the value of ρ_T became quite similar to the value of ρ_B , the value of ρ_T was decided as the estimated density by using trial-and-error process changing the value of ρ_T . Fig.Gr-5 shows the result of the G-H correlation method. In this method, 2.4 g/cm^3 was decided to be the estimated density.

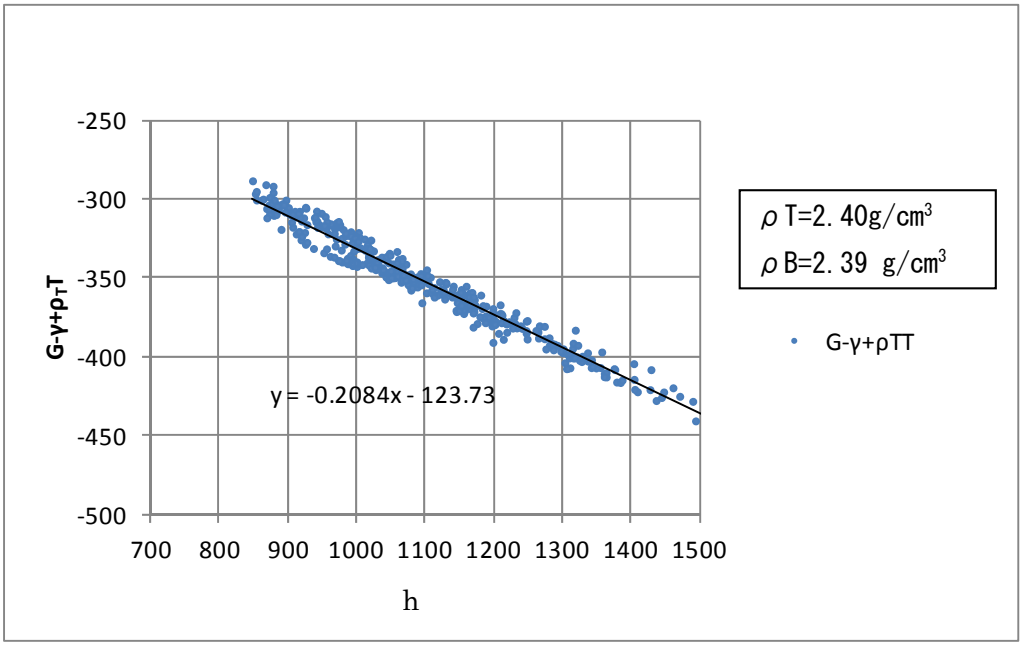


Fig.Gr-05 Result of G-H correlation method

(iii) F-H correction method

The equation to calculate the Bouguer anomaly values ($\Delta B = g_{obs} - \gamma + \beta h - 2\pi G \rho_B h + \rho_T T$) was performed as shown below.

$F = \rho H + g$

Where,

$F = g_{obs} - \gamma + \beta h$

$H = 2\pi Gh - T$

The values of H and F were plotted at the horizontal axis and vertical axis, respectively and an approximate line of these plotted points by was drawn by the least-square method, and then the value of ρ was calculated as the gradient of the approximate line. In the result of the F-H correlation method shown in Fig.Gr-06, 2.4 g/cm^3 was employed as the estimated density.

By evaluating the results of the three methods of calculating the estimated density demonstrated above, 2.4 g/cm3 was decided as the estimated density in Korosi, Chepchuk and Paka.

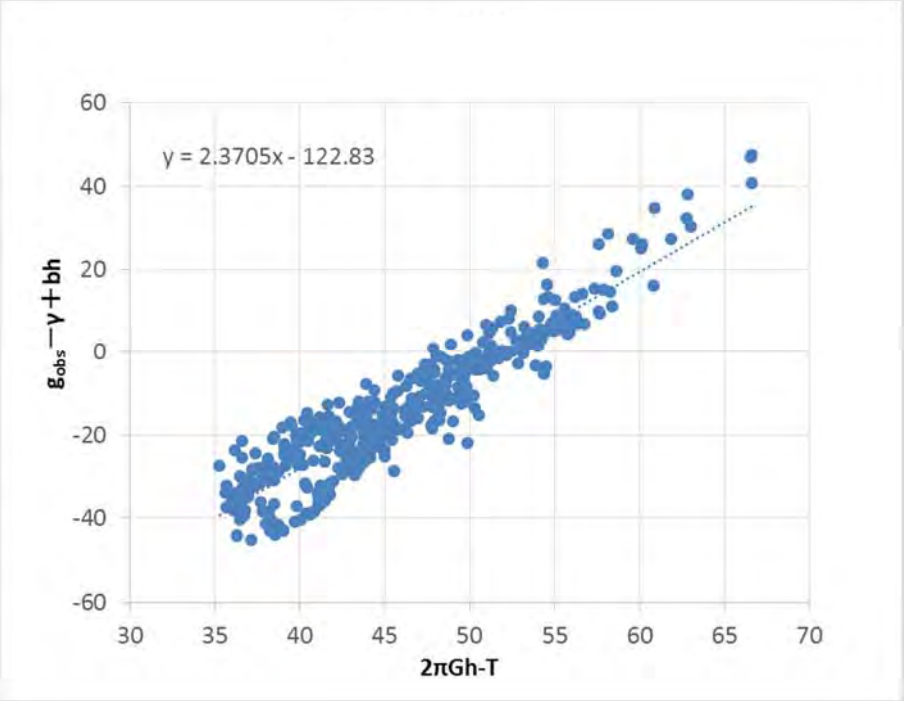


Fig.Gr-06 result of F-H correlation method

(c) Bouguer anomaly

The Bouguer anomaly, caused by the heterogeneous character of the density distribution in the subsurface, is calculated in data processing. The distribution of the subsurface density can be estimated from the Bouguer anomaly. The gravity value is the net force, both the centrifugal force caused by the Earth's rotation and the attracting force occurring between the Earth, the Sun and the Moon. The magnitude of the centrifugal force of the Earth's rotation is at its maximum at the equator and at its minimum at the poles, which causes the gravity value to vary based on latitude. In addition, the gravity value at higher elevations is lower because the attracting force of the Earth is smaller. The tidal force depends on the position of the stations relative to the Sun and the Moon, so the measured gravity changes with time at the measuring stations. The terrain effect is caused by the attracting force occurring near a body with large mass such as a mountain. Even if these corrections are conducted, the corrected gravity has different values at each of the stations. The difference between the corrected gravity and the average gravity is called the Bouguer anomaly. It is caused by the heterogeneous character of the density distribution in the subsurface and elucidating this is the purpose of the gravity survey.

(d) Trend surface analysis

The objective of trend surface analysis is to extract the longwave component of the Bouguer anomaly derived from the deep subsurface composition as shown in Fig.Gr-07. The trend surface is obtained by approximating the longwave component of the Bouguer anomaly by an n-order curved surface. Each coefficient is solved by applying least squares approximation to the Bouguer anomaly in the following equation:

- First order trend surface : $\Delta G_1(x, y) = a_0 + a_1 x + a_2 y$
- Second order trend surface : $\Delta G_2(x, y) = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2$
- N order trend surface :

$$\Delta G_n(x, y) = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2 + \cdots + a_{m-1} xy^{n-1} + a_m y^n$$

where m=n(n+3)/2

The n-order trend surface residual is obtained by subtracting the n-th trend surface from the Bouguer anomaly value ($\Delta g(x, y) - \Delta G(x, y)$)

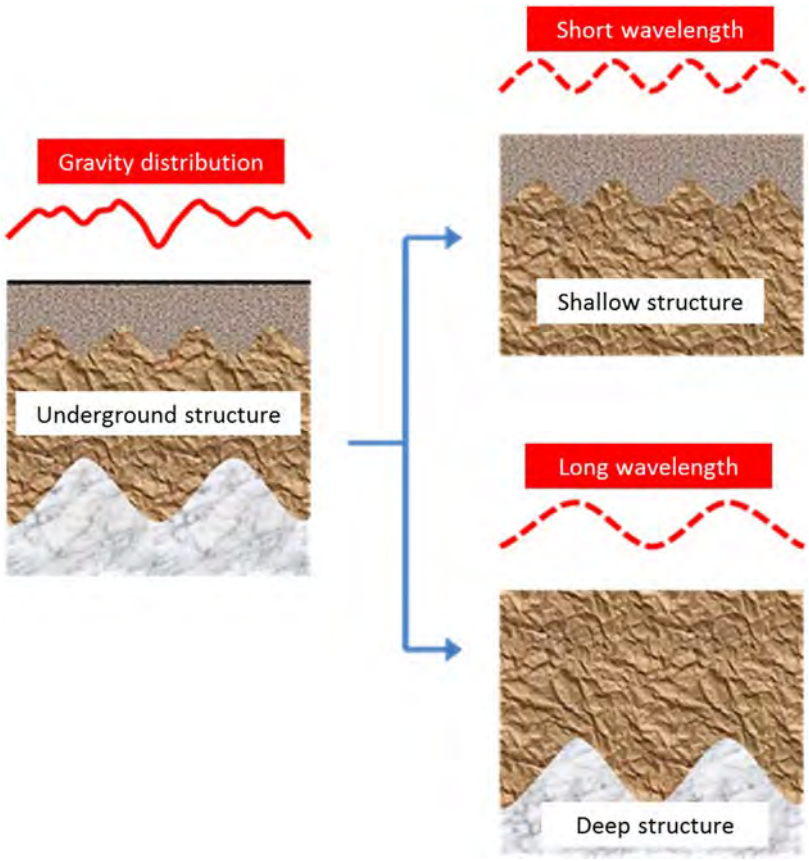


Fig. Gr-07 Conceptual diagram of trend surface analysis filter

(e) Spectrum analysis

In a spectrum analysis, the Bouguer anomaly values are separated into a long wavelength component mainly caused by the deep density structures and a short wavelength component mainly caused by shallow density structures by analyzing the wavelength characteristics of the Bouguer anomaly values. When Fourier series of the Bouguer anomaly Δg(x, y) in the rectangular area of L1×L2 is defined as shown below.

$$\Delta g(x, y) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \{ A_{mn} \cos(m\omega_1 x) \cos(n\omega_2 y) + B_{mn} \cos(m\omega_1 x) \sin(n\omega_2 y) + C_{mn} \sin(m\omega_1 x) \cos(n\omega_2 y) + D_{mn} \sin(m\omega_1 x) \sin(n\omega_2 y) \}$$

$0 \leqq x \leqq L1, \quad 0 \leqq y \leqq L2$

ω1＝2π／L1,　ω2＝2π／L2

m,　n：wave number of x and y direction

Power spectrum values of Pmn is defined as shown in a following equation.

$$P_{mn} = \frac{1}{16}\left\{(A_{mn} - D_{mn})^2 + (B_{mn} + C_{mn})^2\right\}$$

And Fourier coefficient Amn can be calculated by the following equation.

$$A_{mn} = \frac{4}{\varepsilon_{mn} L_1 L_2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Delta g(x,y)\cos(m\omega_1 x)\cos(n\omega_2 y)dxdy$$

$$\varepsilon_{mn} = \begin{cases} 2 : m = n = 0 \\ 1 : m, n = 1,2,3,4,\cdots\cdots \end{cases}$$

Finally, the power spectrum value is calculated by following equation.

$$InP_{mn} = C - 4\pi D\sqrt{\left(\frac{m}{L_1}\right)^2 + \left(\frac{n}{L_2}\right)^2}$$

C：constant value

D：depth of density boundary

L_1，L_2：x and y length

m，n：wave number

The values of $\sqrt{(m/L_1)^2+(n+L_2)^2}$ and $\ln P_{mn}$ were plotted at the horizontal axis and vertical axis, respectively and several approximate lines could be drawn. The gradients of several lines correspond to depth of the density boundary. It is thought that the lines in the low frequency area show a deep density boundary, on the other hand, the lines in the high frequency area show a shallow density boundary An average boundary depth of densities can be calculated by dividing the gradient into -4π.

In this project, the Fourier transform was conducted to Bouguer anomaly values (31km×20km). Fif.Gr-08 shows a results of the power spectrum analysis. In this analysis, three boundaries of densities were calculated as shown below.

- A trend component whose boundary depth is more than 2,474m which corresponds to the gravity basement in this area.
- A regional component whose boundary depth is from 30m to 2,474m
- A noise component whose boundary depth is less than 30m

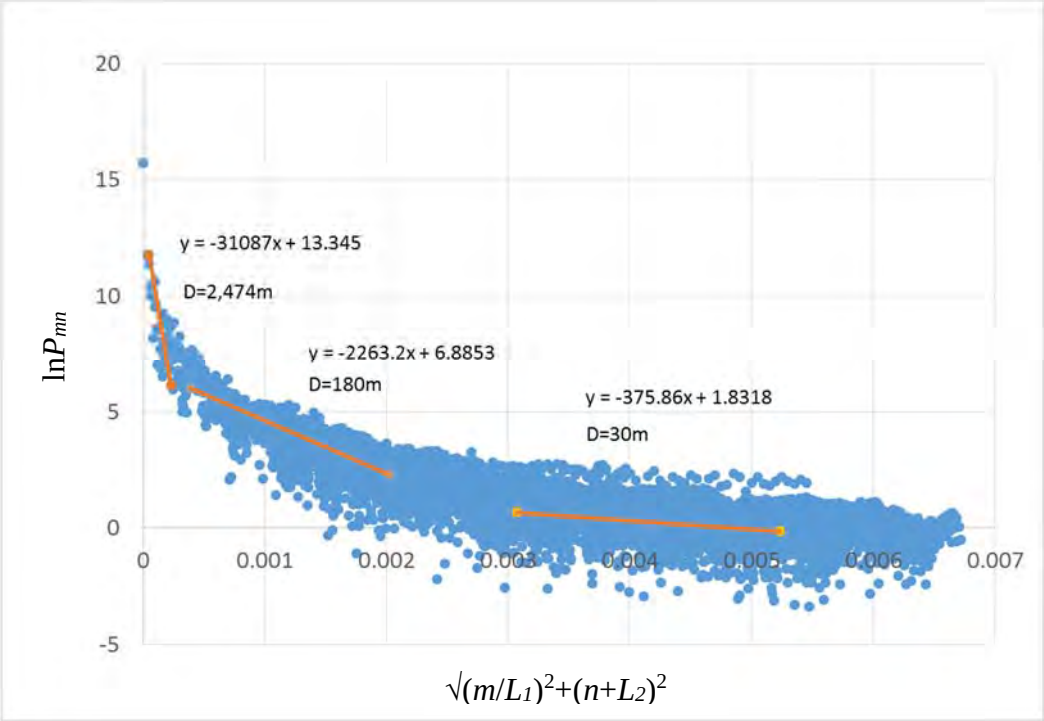


Fig.Gr-08 Result of power spectrum analysis

(f) Upward continuation filter

The Bouguer anomaly at a given elevation is calculated by using the upward-continuation filter analysis. This process means that the Fourier coefficient of the wave number m of x direction and n of y direction is weighted by using the following equation.

$$w_{mn} = \exp\left(-\sqrt{(m^2 + n^2)}H\right)$$

The long wave component of the Bouguer anomaly can be extracted by using upward-continuation filter analysis. Upward-continuation filter analysis at two different heights can play the role of a band pass filter.

(g) Horizontal first derivation (Fig. Gr-09)

Horizontal derivative filtering is one of the high-pass filtering processes which emphasizes the boundaries of the structures, using the horizontal first derivative values of the Bouguer anomaly. Based on the results of the horizontal first derivation, faults and/or intrusive rock can be detected. However, since density boundaries situated at shallow depths create a remarkably high anomaly in the horizontal derivative distribution, and deep-seated density boundaries only create a slightly high anomaly, the deep-seated density anomalies are easily overlooked. For this reason, the locations of points showing the maximum values of horizontal first derivative distribution were determined using a mathematical method, and the locations were used as additional information for detecting subsurface structures such as faults and/or intrusive rock.

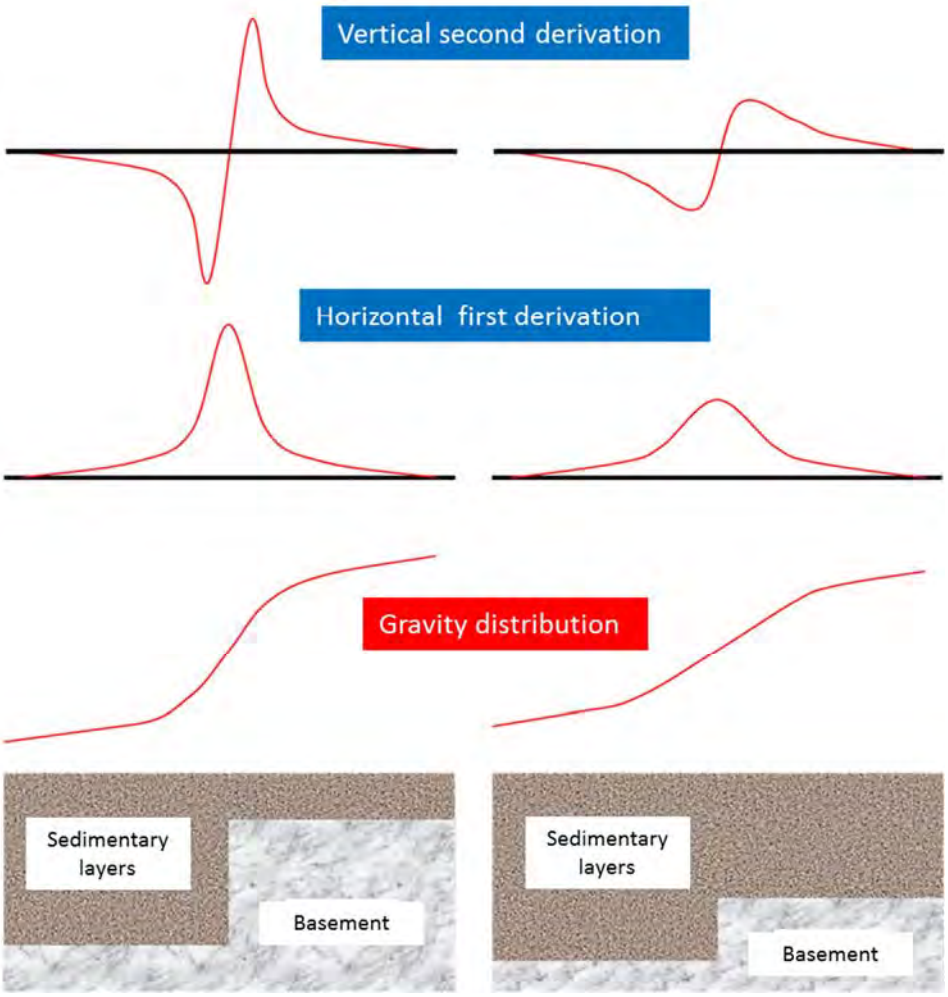


Fig.Gr-09 Conceptual diagram of horizontal first derivation

(h) 3D gravity inversion of basement relief

The illustration below demonstrates the gravity value, which is caused by the rectangular-shaped body infinitely extending downward vertically, at a specific point (A, B, C)(Fig.Gr-10) can be calculated using the following equation.

$$G = \gamma\rho\{F(X1,Y1,Z) - F(X2,Y1,Z) - F(X1,Y2,Z) + F(X2,Y2,Z)\}$$

Where,

$$X1 = A - x1, \quad X2 = A - x2$$
$$Y1 = B - y1, \quad Y2 = B - y2$$
$$Z = |z - C|$$

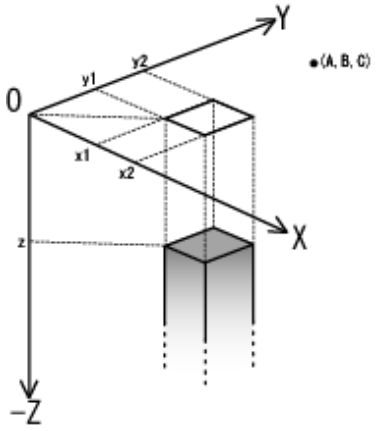


Fig.Gr-10 Conceptual model of Three-dimensional gravity inversion of basement relief

$$F(x,y,z) = -\iiint \frac{z\,dx\,dy\,dz}{\left(x^2+y^2+z^2\right)^{3/2}}$$
$$= x\ln\left(\frac{y+\sqrt{x^2+y^2+z^2}}{\sqrt{x^2+z^2}}\right) + y\ln\left(\frac{x+\sqrt{x^2+y^2+z^2}}{\sqrt{y^2+z^2}}\right) - z\tan^{-1}\left(\frac{xy}{z\sqrt{x^2+y^2+z^2}}\right)$$

If the gravity stations and rectangular bodies representing the basement are aligned along the x and y coordinates in a grid system, a relative gravity anomaly, $\Delta G_{ij}(z)$ caused by the rectangular density body representing the basement relief can be calculated by following equation.

$$\Delta G_{ij}(z) = \sum_k \sum_l \left\{ G_{ij}^{\ kl}(z, D_{kl}) - G_{ij}^{\ kl}(z, D_0) \right\}$$

Where,

D_{kl} : the depth of top of a rectangular body

D_0 : the average depth of basement relief

G_{ij}^{kl} : gravity value caused by rectangular density bodies at a station (x_i, y_i, z)

The initial approximation of the basement relief, D_{kl} is set using following equation for the gravity inversion.

$$D_{kl}^{(1)} = D_0 + \lambda\delta g_{ij} * / 2\pi\gamma\rho$$

Where,

δg* = observed gravity value – average value of all the observed gravity values

The gravity anomaly values at each station are determined by the initial density model and are calculated by using the following equation.

$$g_{ij}^{(1)} = \Delta G_{ij}(z_{ij}) = \sum_k \sum_l \left\{ G_{ij}^{kl}(z_{ij}, D_{kl}^{(1)}) - G_{ij}^{kl}(z_{ij}, D_0) \right\} \quad \cdots\cdots(4)$$

If an error sum of squares for $\delta g_{ij}^{(1)}$and δg* is sufficiently small, the D_{kl} will be a final density in the gravity inversion process. If the sum of squares is not sufficiently small, equation (3) is used to obtain the second approximation for the final density model.

$$D_{ij}^{(2)} = D_{ij}^{(1)} + \lambda \left(\delta g_{ij}^{*} - \delta g_{ij}^{(1)} \right) / 2\pi\gamma\rho \quad \cdots\cdots(5)$$

Where

$\delta g_{ij}^{(1)} = g_{ij}^{(1)}$ – (an average value of $g_{ij}^{(1)}$)

After combining the equation (5) with equation (2), the following equation is derived.

$$g_{ij}^{(2)} = \Delta G_{ij}(z_{ij}) = \sum_k \sum_l \left\{ G_{ij}^{kl}(z_{ij}, D_{kl}^{(2)}) - G_{ij}^{kl}(z_{ij}, D_0) \right\}$$

An iterative least-square method is employed to determine the final basement relief model (depth of the top of each rectangular body, D_{kl}) until the error sum of squares for $\delta g_{ij}^{(1)}$ and δg* become sufficiently small

(i) 2D density structure analysis

Talwani,Worzel and Landisman (1959) shows the analytical solution of gravity anomaly caused by polygonal 2D body of constant density.

Fig.Gr-11 demonstrates an example of polygonal 2D body ABCDEF. In this case, the results of curvilinear integral are equal to the sum of curvilinear integral of each segment and the sum is calculated by using the below equation (1).

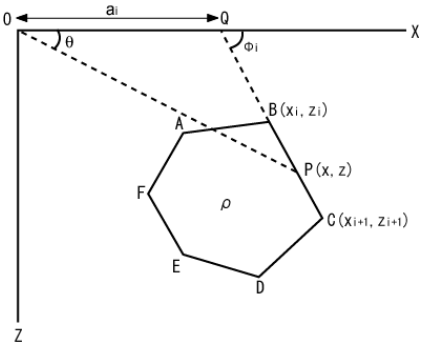


Fig.Gr-11 Explanation drawing of polygonal 2D body ABCDEF

$$\oint z d\theta = \oint_{AB} z d\theta + \oint_{BC} z d\theta + \ldots + \oint_{EF} z d\theta + \oint_{FA} z d\theta \quad \cdots\cdots(1)$$

In segment BC, z in equation (1) is expressed by equation (2)

$$z = x \tan\theta \quad \cdots\cdots(2)$$

Where,

x and z coordinates at point P (x axis and z axis)

θ angle between X axis and segment OP

a_i X coordinate at the intersection of segment BC with X axis

ϕ_i angle between X axis and segment QC

z can be also expressed by using ϕ_i as shown in equation (3)

$$z = (x - a_i)\tan\phi_i \quad \cdots\cdots(3)$$

Equation (3) is assigned to equation (2) for deleting x and equation (4) can be developed.

$$z = \frac{a_i \tan\theta \tan\phi_i}{\tan\phi_i - \tan\theta} \quad \cdots\cdots(4)$$

The equation of curvilinear integral of segment BC is expressed by equation (5).

$$Z_i = \int_B^C z d\theta = \int_B^C \frac{a_i \tan\theta \tan\phi_i}{\tan\phi_i - \tan\theta} d\theta \quad \cdots\cdots(5)$$

Equation (5) can be applied in each of the segments so Bouguer anomaly value (g) is calculated by equation (6) when the number of segments are n.

$$g = 2G\rho \sum_{i=1}^{n} Z_i \quad \cdots\cdots(6)$$

The part of integral in equation (7) can be analytically dissolved as shown below.

$$Z_i = a_i \sin\phi_i \cos\phi_i \left[\theta_i - \theta_{i+1} + \tan\phi_i \log \frac{\cos\theta_i (\tan\theta_i - \tan\phi_i)}{\cos\theta_{i+1} (\tan\theta_{i+1} - \tan\phi_i)} \right] \quad \cdots\cdots(7)$$

Where,

$$\theta_i = \tan^{-1}\frac{z_i}{x_i} \qquad \theta_{i+1} = \tan^{-1}\frac{z_{i+1}}{x_{i+1}}$$

$$\phi_i = \tan^{-1}\frac{z_{i+1} - z_i}{x_{i+1} - x_i} \quad a_i = x_{i+1} + z_{i+1}\frac{x_{i+1} - x_i}{z_i - z_{i+1}}$$

When the specific conditions are satisfied as shown below, equation (8) can be simplified.

In the case of $x_i = 0$

$$Z_i = -a_i \sin\phi_i \cos\phi_i \left[\theta_{i+1} - \frac{\pi}{2} + \tan\phi_i \log\{\cos\theta_{i+1} (\tan\theta_{i+1} - \tan\phi_i)\} \right]$$

In the case of $x_{i+1} = 0$

$$Z_i = a_i \sin\phi_i \cos\phi_i \left[\theta_i - \frac{\pi}{2} + \tan\phi_i \log\{\cos\theta_i (\tan\theta_i - \tan\phi_i)\} \right]$$

In the case of $z_i = z_{i+1}$

$$Z_i = z_i (\theta_{i+1} - \theta_i)$$

In the case of $x_i = x_{i+1}$

$$Z_i = x_i \log \frac{\cos\theta_i}{\cos\theta_{i+1}}$$

In the case of $\theta_i = \theta_{i+1}$ or $x_i = z_i = 0$ or $x_{i+1} = z_{i+1} = 0$

$$Z_i = 0$$

3. Results of gravity data analysis

(a) Bouguer anomaly

Fig.Gr-12 shows the Bouguer anomaly map in Korosi and Chepchuk and Fig.Gr-13 shows the Bouguer anomaly map in Paka, respectively.

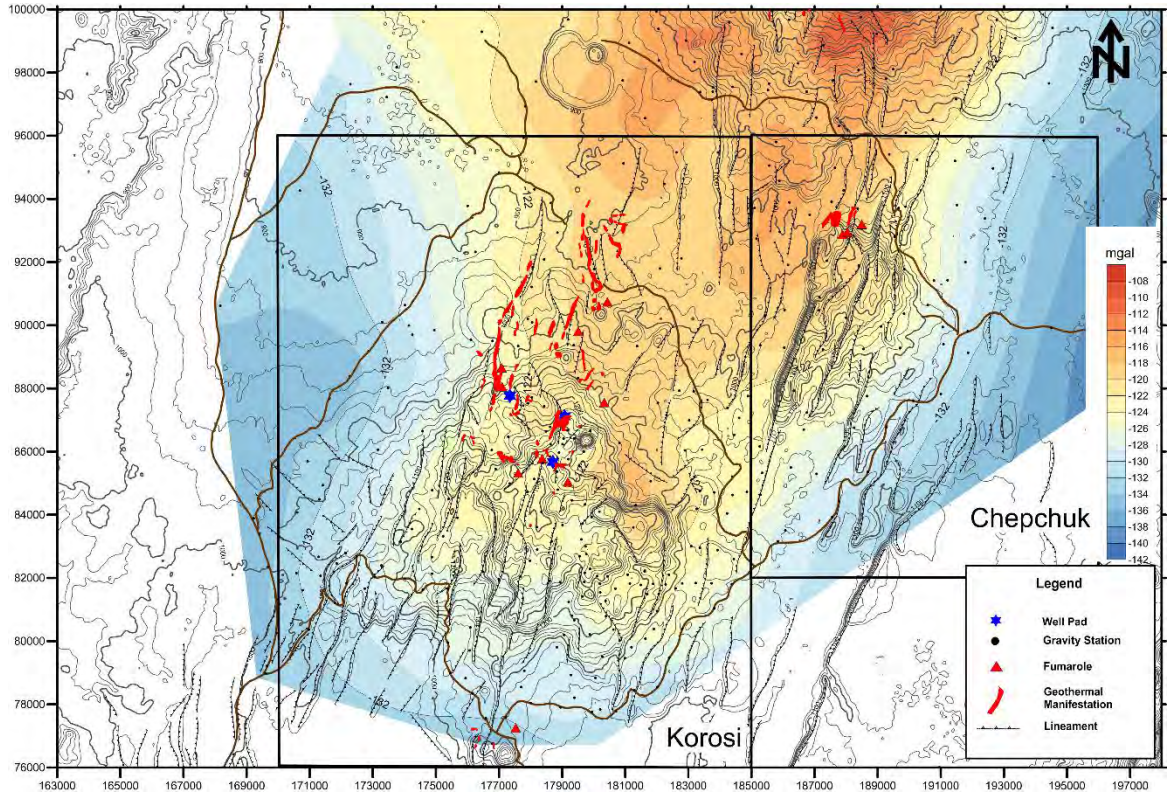


Fig.Gr-12 Bouguer anomaly map in Korosi and Chepchuk (estimated density：2.4g/cm^3)

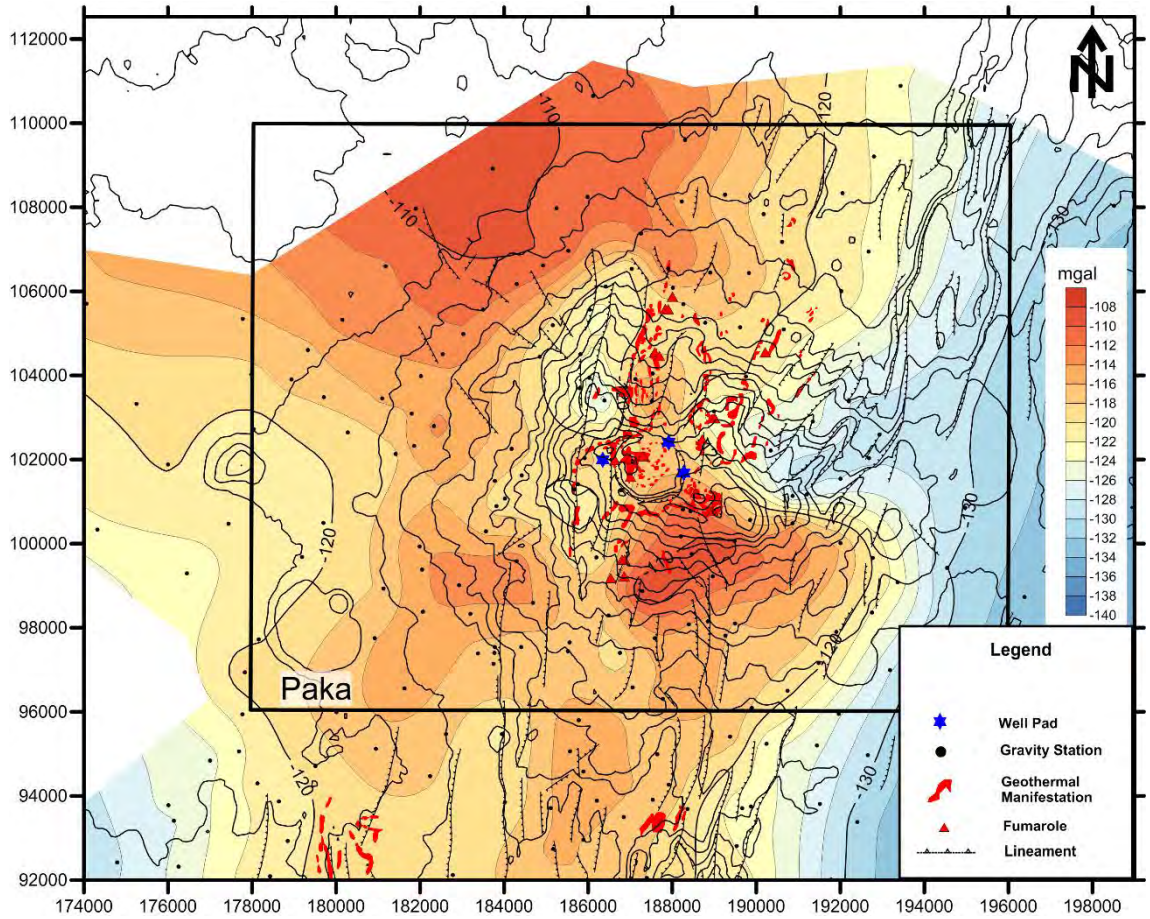


Fig.Gr-13　Bouguer anomaly map in Paka (estimated density：2.4g/cm^3)

(b) Trend surface analysis and residual of trend surface

A trend surface analysis is conducted to extract regional components of the Bouguer anomaly values. Since in this project, third trend surface was considered to express a comprehensive gravity distribution, third trend surface was employed to extract the regional component of the Bouguer anomaly values in Korosi, Chepchuk and Paka. Fig.Gr-14 and Fig.Gr-15 shows maps of the trend surface and the residual of the trend surface in Korosi and Chepchuk, respectively. Fig.Gr-16 and Fig.Gr-17 shows maps of the trend surface and the residual of the trend surface in Paka, respectively.

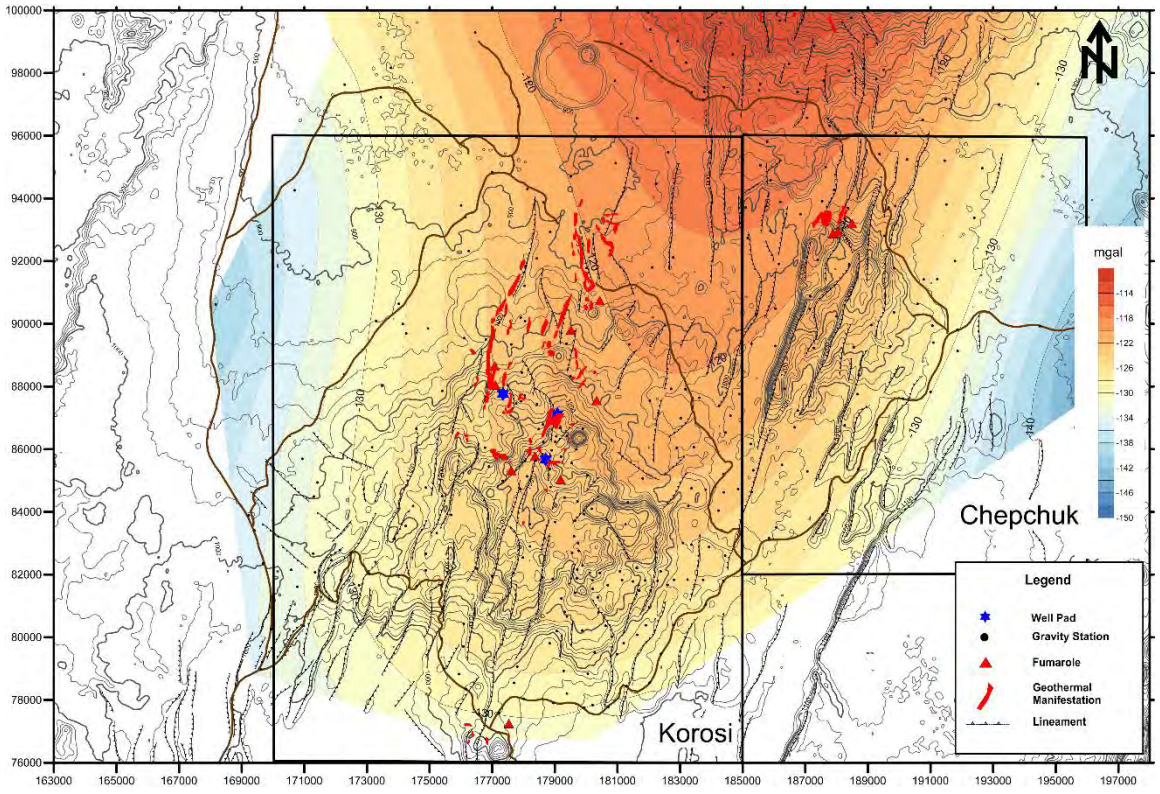


Fig. Gr-14 Third trend surface map in Korosi and Chepchuk

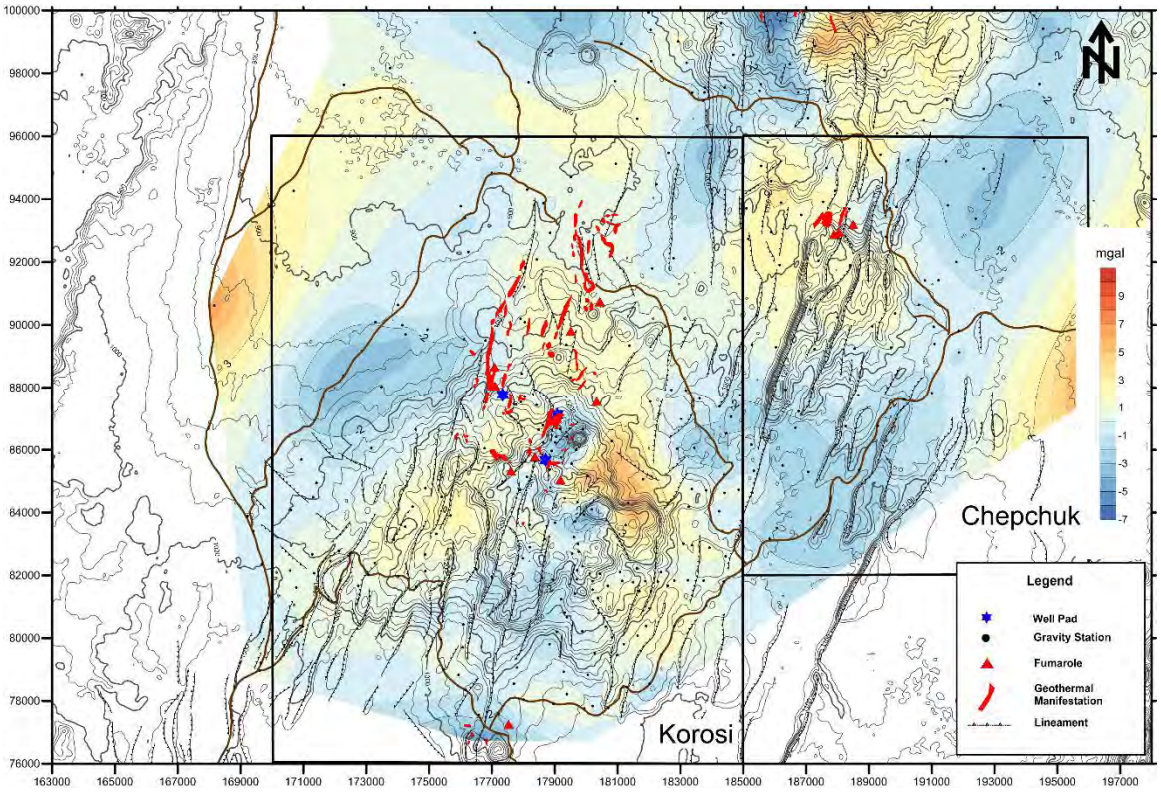


Fig.Gr-15 Residual of third trend surface in Korosi and Chepchuk

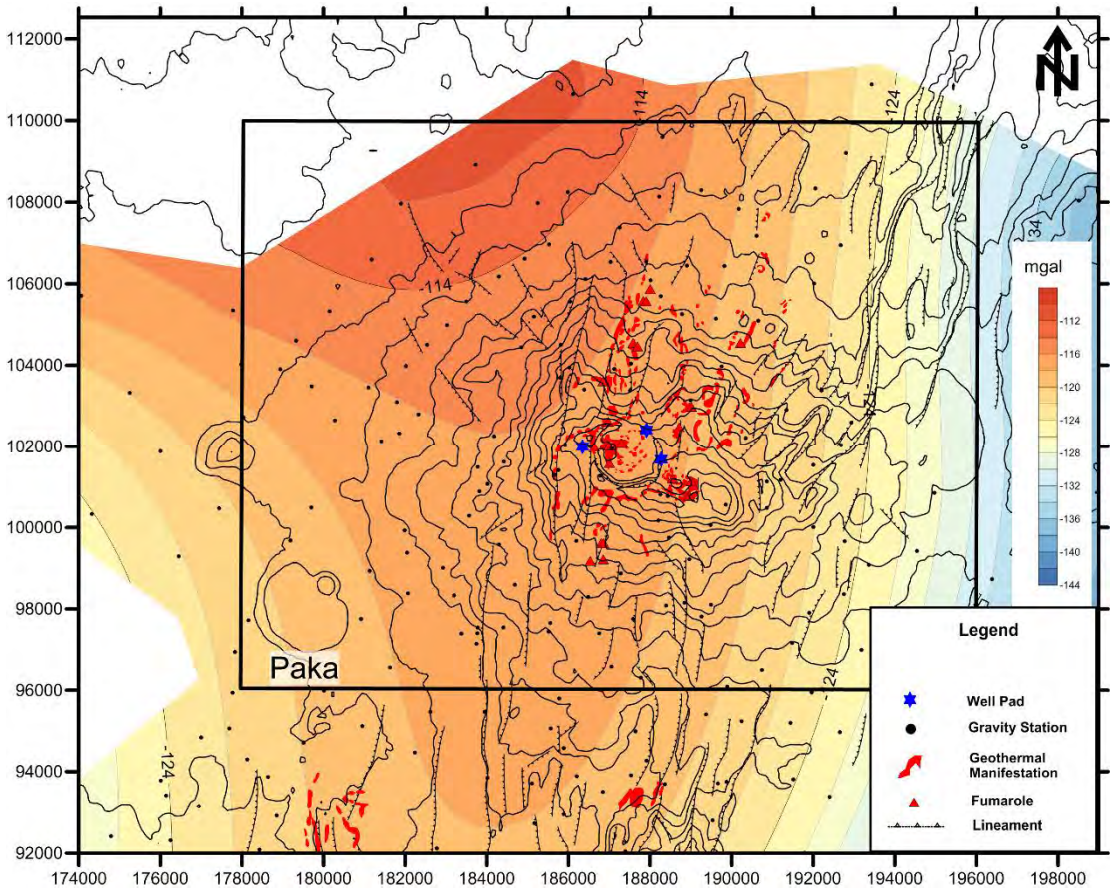


Fig. Gr-16 Third trend surface map in Paka

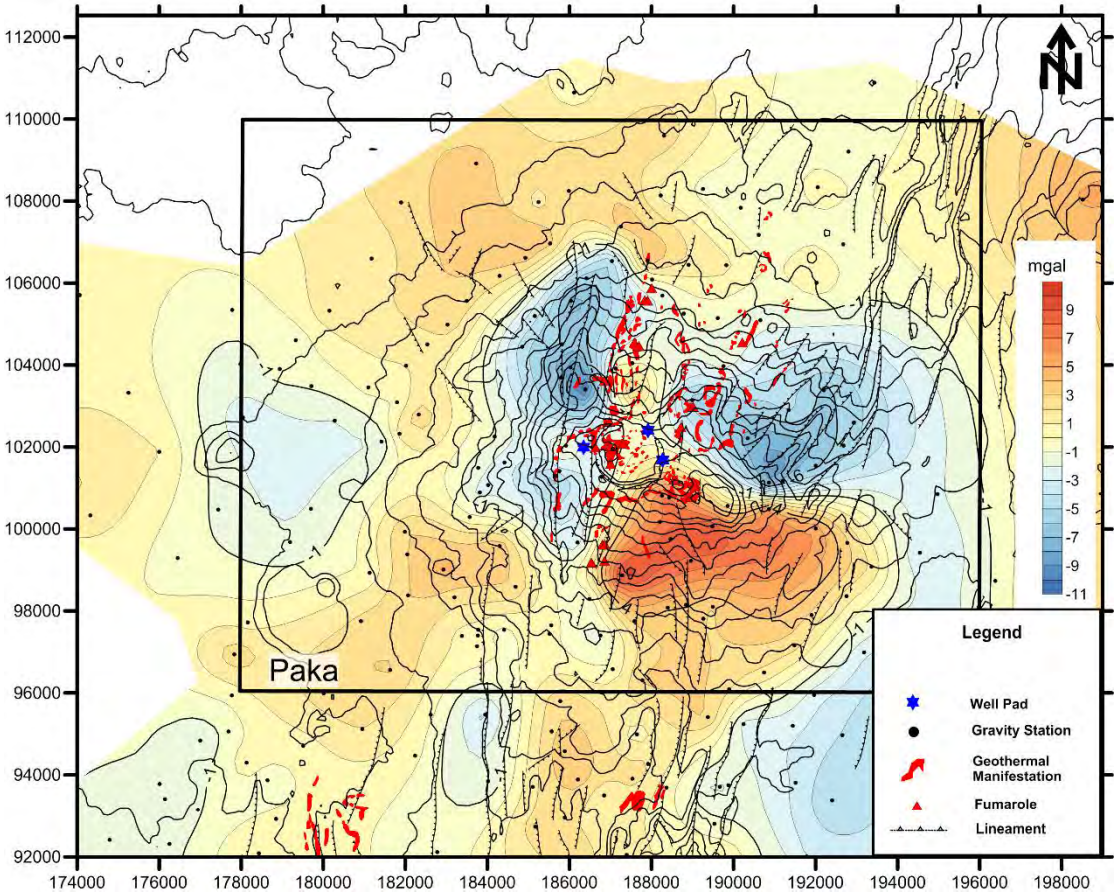


Fig.Gr-17 Residual of third trend surface in Paka

(c) Upward continuation analysis

Fig.Gr-18 shows the residual map of the 50-2,500m upward continuation in Korosi and Chepchuk, and Fig.Gr-19 shows the residual map of the 50-2,500m upward continuation in Paka.

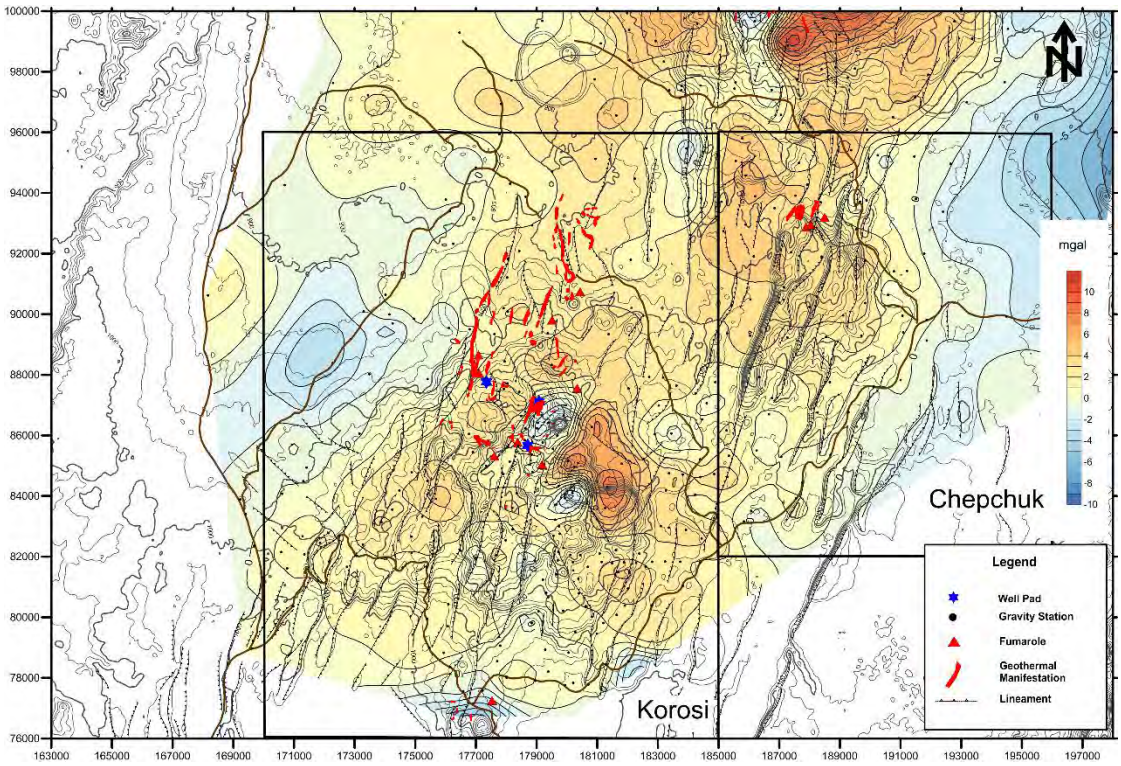


Fig.Gr-18 Residual map of the 50-2,500m upward continuation in Korosi and Chepchuk

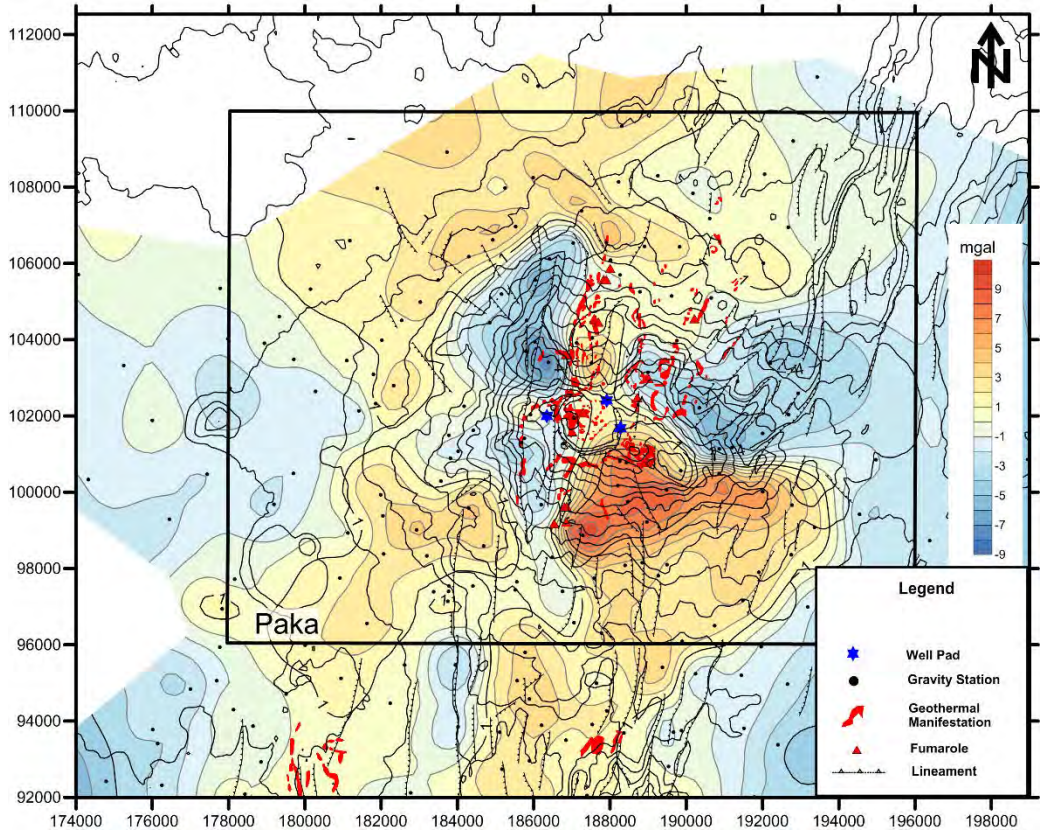


Fig.Gr-19 Residual map of the 50-2,500m upward continuation in Paka

(d) Horizontal first derivation

Fig.Gr-20 shows a horizontal first derivative map of residual of third trend surface in Korosi and Chepchuk and Fig.Gr-21 shows a horizontal first derivative map of residual of third trend surface in Paka. Fig.Gr-22 shows a horizontal first derivative map of residual of upward continuation (50-2,500m) in Korosi and Chepchuk, and Fig.Gr-23 shows a horizontal first derivative map of residual of upward continuation (50-2,500m) in Paka.

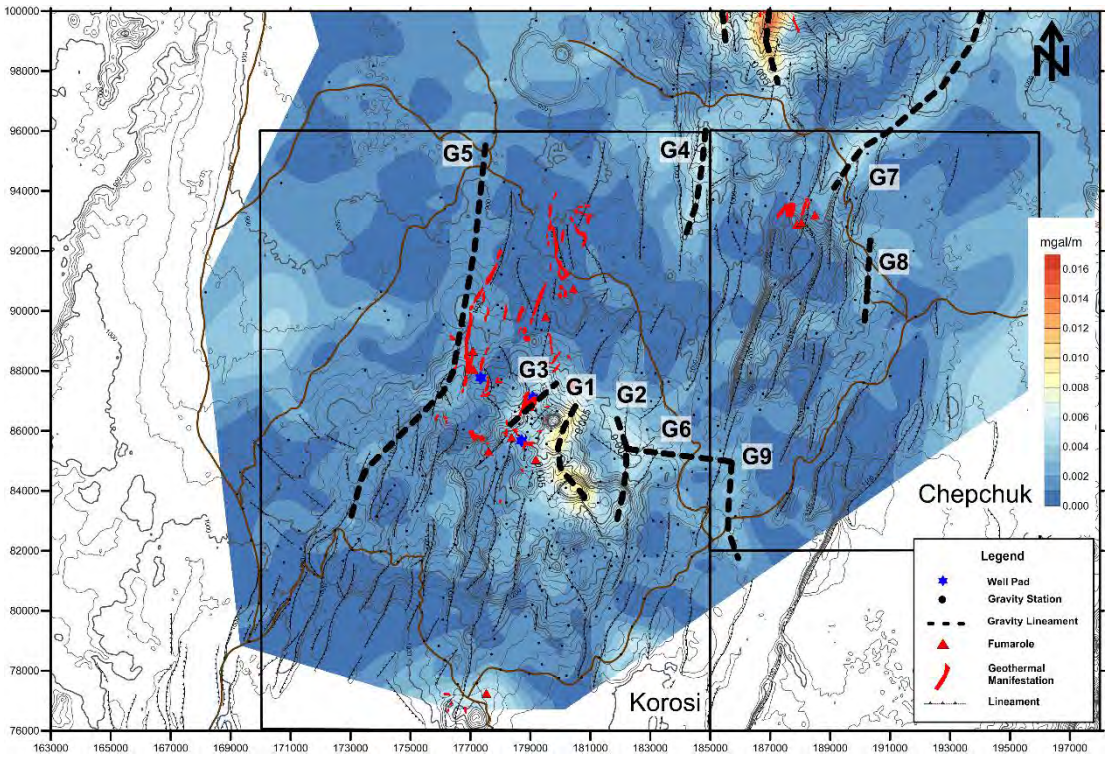


Fig.Gr-20 Horizontal first derivative map of residual of third trend surface in Korosi and Chepchuk

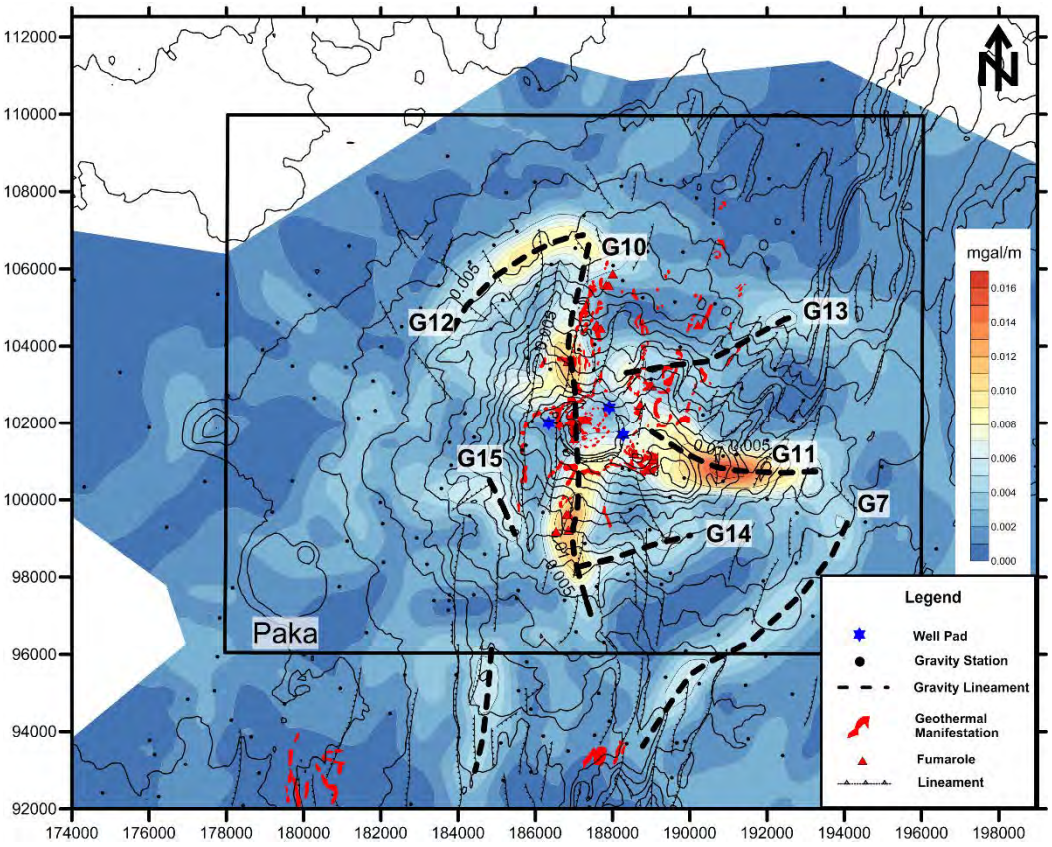


Fig.Gr-21 Horizontal first derivative map of residual of third trend surface in Paka

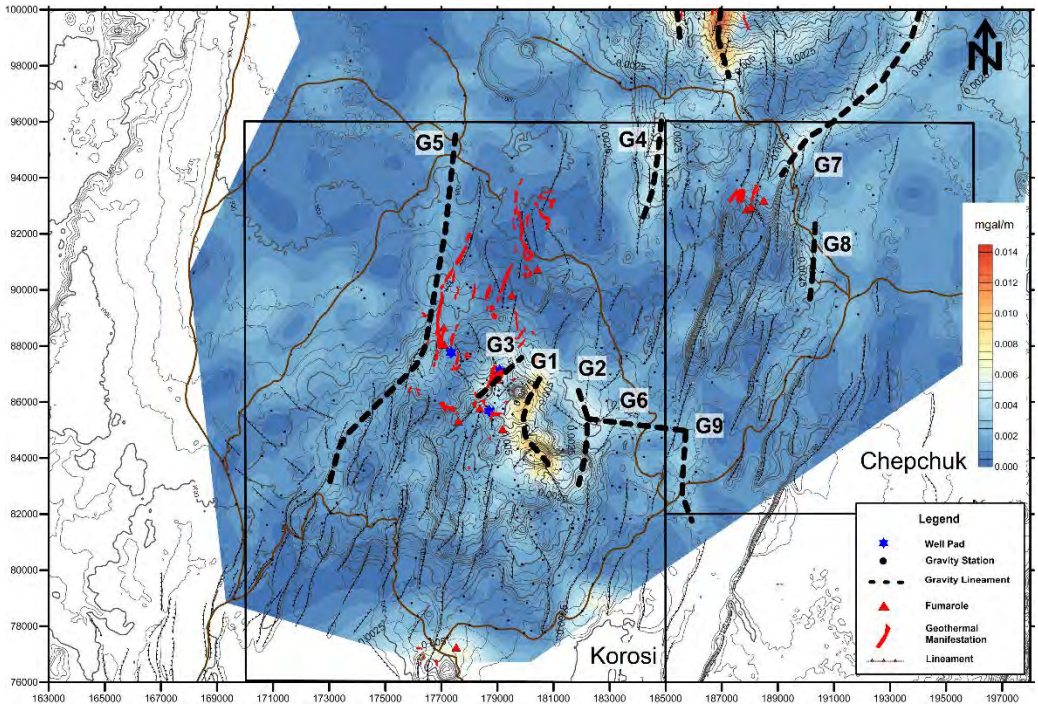


Fig.Gr-22 horizontal first derivative map of residual of upward continuation (50-2,500m) in Korosi and Chepchuk

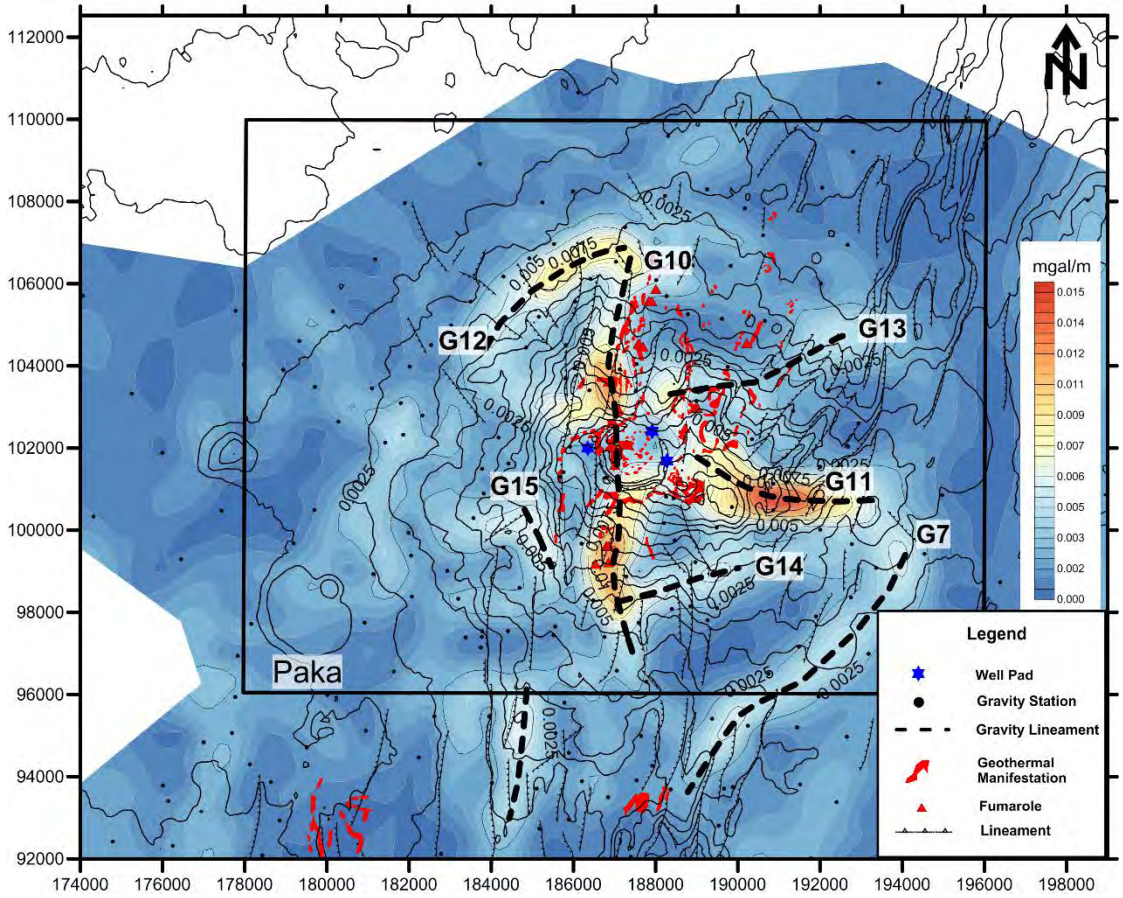


Fig.Gr-23 horizontal first derivative map of residual of upward continuation (50-2,500m) in Paka

(e) 3D gravity inversion of basement relief

Fig.Gr-24 shows the result of a 3D gravity inversion of basement relief in Korosi and Chepchuk and Fig.Gr-25 shows the result of a 3D gravity inversion of basement relief in Paka.

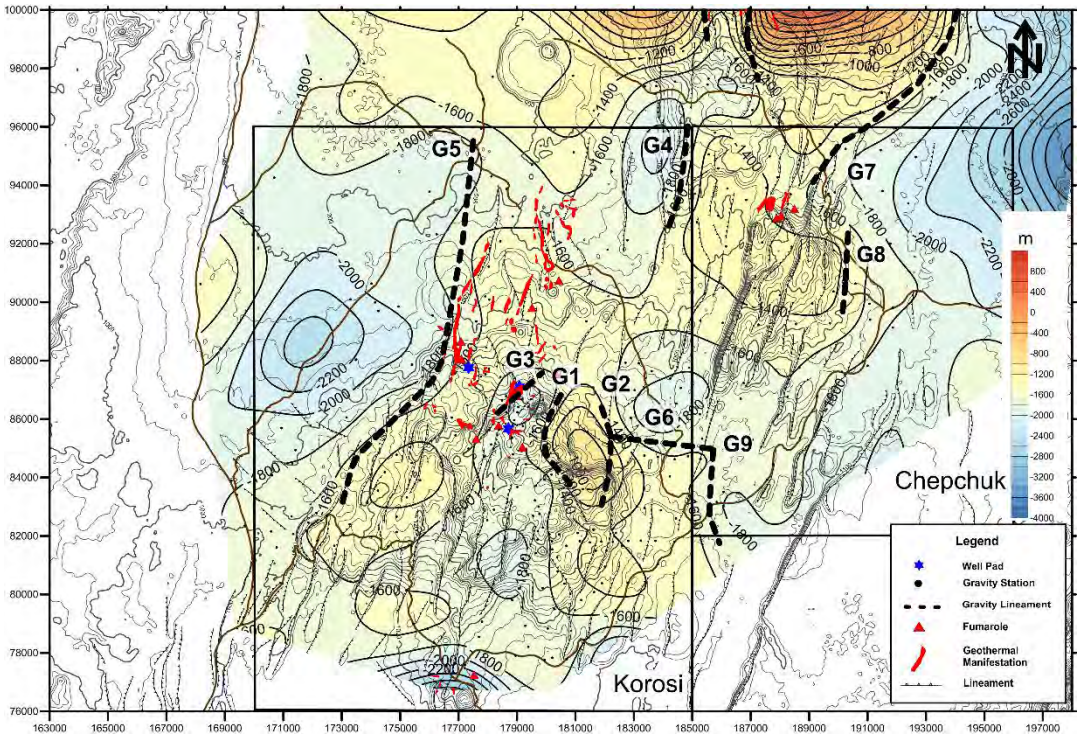


Fig.Gr-24 Result of a 3D gravity inversion of basement relief in Korosi and Chepchuk

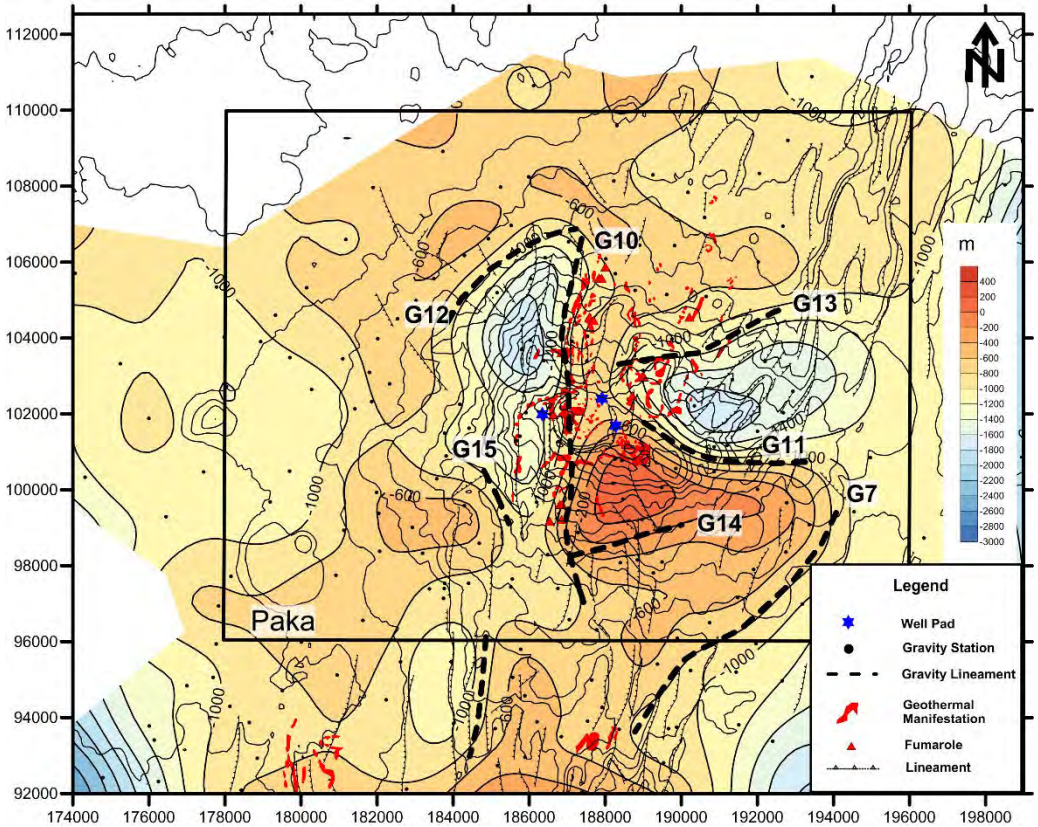


Fig.Gr-25 Result of a 3D gravity inversion of basement relief in Paka

(f) 2D density structure analysis

Fig.Gr-26 shows a location map of cross sections for 2D density structure analysis and Fig.Gr-27 and Fig.Gr-28 show results of the 2D density structure analysis in Korosi and Chepchuk. Fig.Gr-29 shows a location map of a cross section for 2D density structure analysis and Fig.Gr-30 shows results of the 2D density structure analysis in Paka.

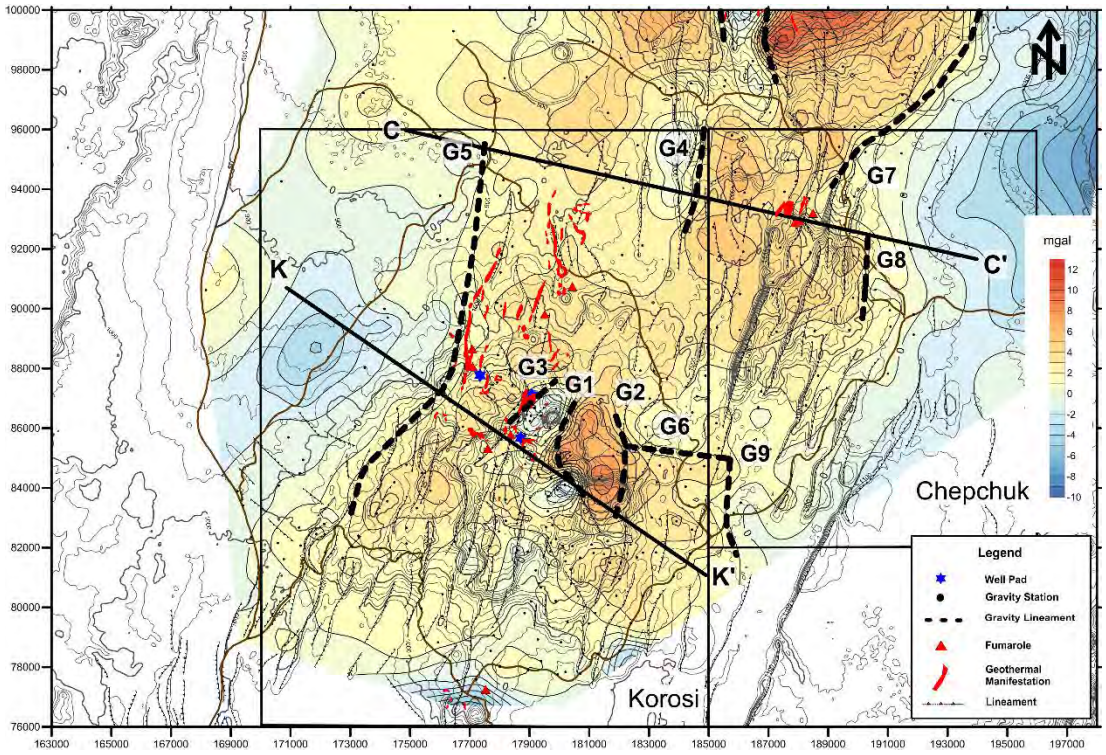


Fig.Gr-26 Location map of cross sections for 2D density structure analysis in Korosi and Chepchuk

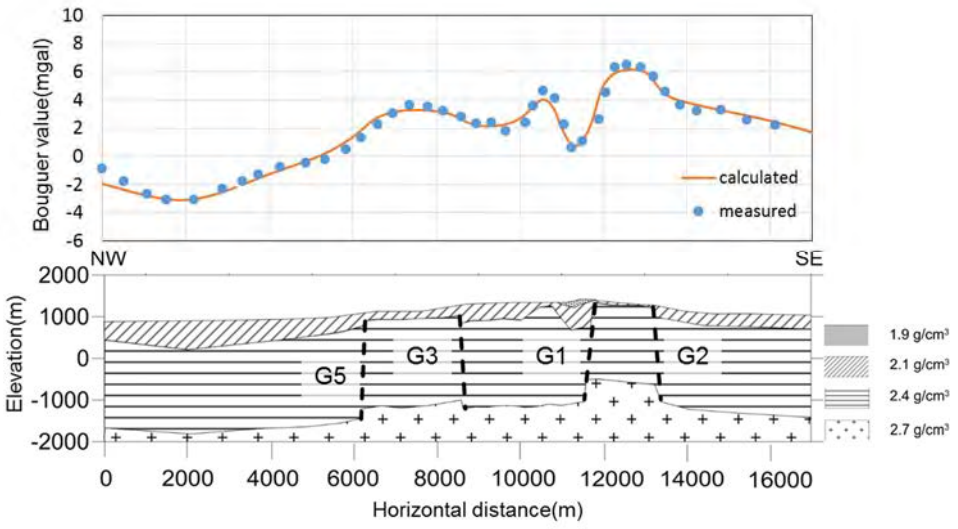


Fig.Gr-27 Result of the 2D density structure analysis in Korosi (K-K'section)

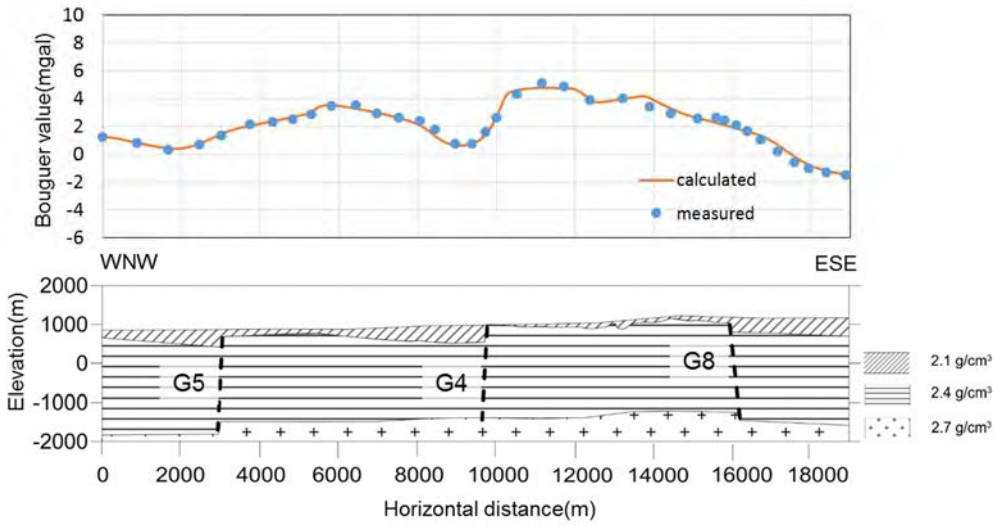


Fig.Gr-28 Result of the 2D density structure analysis in Chepchuk (C-C'section)

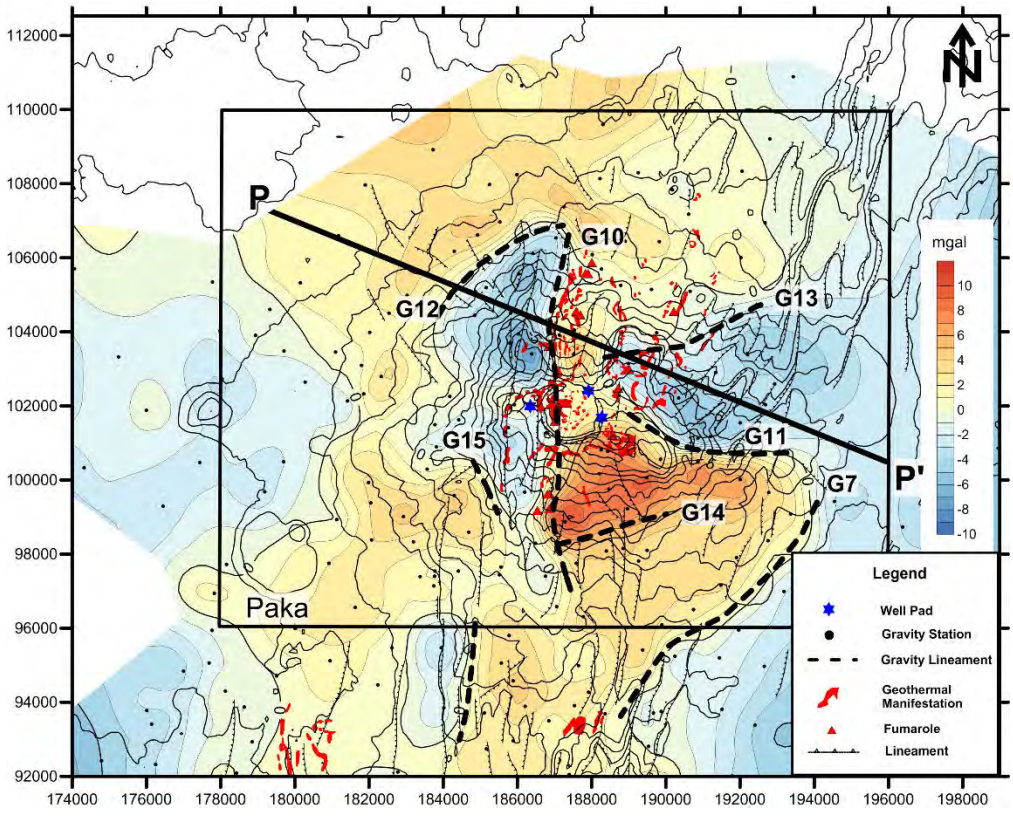


Fig.Gr-29 Location map of a cross section for 2D density structure analysis in Paka

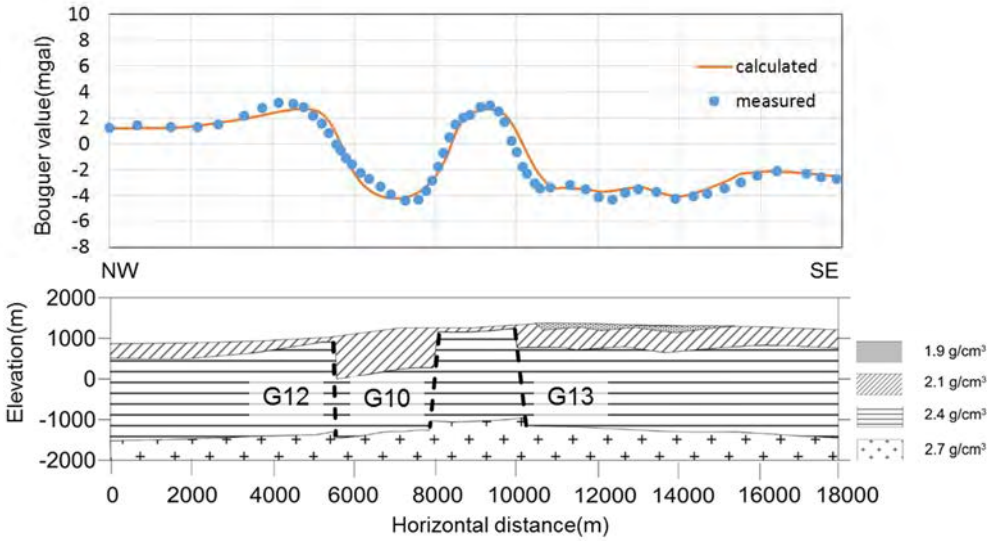


Fig.Gr-30 Result of the 2D density structure analysis in Paka (P-P'section)

APPENDIX

8. Results of the Supplementary Study on Environmental and Social Considerations

RESULTS OF THE SUPPLEMENTRAY STUDY ON ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

1 . INITIAL ENVIRONMENTAL AND IMPACT ASSESSMENT

Table 1.1 Initial EIA Results for Arus

Items		Notes
Natural environment	Location	Arus-Bogoria geothermal is situated between Menengai geothermal prospect to the south and Lake Baringo prospect to the north.
	Air Quality	H_2S concentration levels were zero (0.0 ppm) in all places where measurements were taken, except near the mouths of Lokortabim fumaroles and within Lake Bogoria Hot spring jets, where the reading were 1.4 ppm H_2S and 3.3 ppm H_2S respectively. The concentrations are expected to be more than 1.0 ppm H_2S during drilling, well discharge testing and project operation which is far below the WHO threshold for human exposure limit value of 10 ppm. The current H_2S background concentrations at receptor sites were 0.0 ppm (below detection limit).
	Topography (geography & geology)	Arus–Bogoria area encompasses several features of geological significance that are considered indicators of possible geothermal potential. These include intense fumarolic activity at Arus, the vigorous spouting springs and hot springs at L. Bogoria, Loboi, and Maji Moto areas, hot waters in boreholes at Mugurin and Emining areas, and CO emitting holes at Esageri areas. The rough terrain marked by recent tectonism that resulted in intense faulting and block tilting which are indicators of high tectono magmatic activity in the area. Young eruptions have taken place along these fractures producing extensive low gas lavas and pyroclastics that cover over 98% of the surface in the area. Some few centralized volcanic centers occur in the area.
	Soil	The soil types and distribution in the Arus-Bogoria area have been influenced by the topography. The steep slopes and rolling hills have soils developed from volcanic rocks, which are well drained varying from deep to shallow depths. Soils in these low-lying area (lowlands) have developed on volcanic rocks and alluvial. In most areas, the bedrock is basaltic and some pyroclastics. This has weathered over time under dry climatic conditions to give rise to sandy loam soils in texture. They are well drained, moderately deep to very deep, brown to dark loams, sandy loams or clay loams and very erosive. There are pockets of sedimentary rocks mainly shale and silt in depressions especially where streams enter swampy areas. Around Mugurin and Molo Sirwe, soils have low water holding capacity, very shallow and extremely gravely clayloams. At the escarpments soils have moderate water holding capacity, shallow depth, stony, gravely clay loams. Thick clay loam of alluvial origin is found around Marigat.
	Flora & fauna	In Arus hills the vegetation is evergreen shrubland dominated by Euclea divinorum at highest elevations which changes to bushland dominated by the Acacia species at lower elevations. The vegetation in the lower elevations is mainly thorny bushland dominated by the species of Acacia, Balanites and Commiphora with patches of riverine woodland containing Ficus capensis, Acacia xanthophloea and Acacia tortilis. In the lower slopes of the Siricho Escarpment, Combretum and Grewia thickets dominate. Faunal Species: Among the faunal species in the project area based on local community knowledge include gazelles, Baboons, monkeys, dikdik, rabbits,

Items		Notes
		hyenas, squirrels, scorpions. Avifauna such as Heron birds and Ostriches, doves, weaver birds and the horn bills (were identified) within the project area. Among reptiles that are likely to be found include the monitor lizards, geckos, tortoises and snakes such as Rock Pythons, Puff Adders and the Black mamba. Several insects were also identified in the project impact area. Among the prominent ones were dragon flies and butterflies
	Rare species	Barbus intermedius and Labeo cylindricus
Social Environment	Population distribution	In Arus' suburban area resides Emining and Mochongoi, a comparatively big community (division). According to the 2009 KNBS statistical record, there were 16,067 and 25,737 people residing in the areas, respectively.
	Education	Education level is low especially in areas away from urban centres. Social background such as early marriage, pastoral lifestyle and high poverty levels are one the reason of low rates of enrolment.
	Language	English (official language in Kenya, Swahili is the national language in Kenya, the local languages includes Turgen, Pokot, Ilchamus/Njemps
	Religion	Christian religion mainly dominates **Baringo County**. However, there are other religions like Islam and traditional faiths.
	Regional Characteristics	Most of the community members live in traditional huts. Men and women still dress in traditional clothing. For instance, the men wear shukas around their waists, a practice that has been abandoned by most communities in Kenya. The women still wear traditional beads around their necks. . The region suffers from several social and cultural related problems. The main one being insecurity as a result of inter-ethnic conflicts. These are caused by either cattle rustling or boundary disputes, between Pokots, Turkana, Samburu and to a smaller extent Turgens and Marakwets. Besides wealth and cultural ego, one of the main reasons that propel cattle rustling is the high bride price men have to pay the brides. Conflict over resources (pasture and water) intensifies particularly during drought periods. This is worsened by the access to light fire arms by the local communities in recent times.
	Income, Livelihood	The primary economic activity is livestock keeping followed by bee keeping and honey harvesting. Some people engage in small scale farming. Urban self-employment includes small-scale business (wholesale and retail trades, hotels) and informal sector enterprises (e.g. welding and carpentry) in urban and market centres. In general, most of the labor force within the project area is unskilled and semi-skilled.
	Poverty	The poverty level in the prospect area is more than 50% are below poverty line.
	Land use	Main land use is bush, grazing land and small scale farming.
	Landownership	Most of the lands in the proposed project area are communal land (trust lands).
	Infrastructure (e.g. sewerage system, roads, electricity, hospital)	Road connect is not good. Only a few places within the project area are connected to the electricity power grid. These are mainly the trading centres located along the power distribution grid. There is water scarcity in the project area.
	Cultural/heritage sites	No national cultural sites in the project area. Hot spring is considered as a sacred place by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. It is better to consult with local people when the project proceeds further. (More for cultural aspect and also have an aspect of landscape.)

Items		Notes
	Landscape	Baringo and Bogoria Lake are improtant places for landscape
	Tribes	Tugens
	Minority groups and indigenous people	There is no minorites and marignalized people.
	Relevant parties	NEMA, KWS, KFS, Ministry of Agriculture, Ministry of Public Health Water Resource Management Authority (WRMA) Water Resource Users Association, Representative of Education County Government –(Governor, Representative of Youth and Women and Officials) County Commissioner, Member of County Assembly (MCA) Administrative local leaders (Chief and Assistant Chief)Local Community Community Based Organizations (CBOs, such as women group and youth group) NGO, Member of Parliament, Group Ranch Official

Table 1.2 Initial EIA Results for Baringo

Items		Notes
Natural environment	Location	Baringo County is situated in the rift valley region and borders Turkana and Samburu Counties to the North, Laikipia to the east, Nakuru to the south, Uasin Gishu to the southwest, and Elgeyo Marakwet and West Pokot to the west. It is located between longitudes 35º 30'E and 36º 30'E and between latitudes 0º 10'N and 1º 40'N
	Climate	Baringo County is classified as an arid and semi-arid area. Two seasons of rainfall are experienced and the rainfall varies from 300- 750 mm in the Rift Valley floor near Lake Bogoria to 1200 mm in the highlands near Eldama Ravine town. The rainfall is about 50% reliable. Temperature varies from 15ºC to 35ºC and follows the rainfall pattern. Evaporation in the area varies from 1,800 mm to more than 2,200 mm per year.
	Topography (geography & geology)	The project areas can be divided into three broad physiographic regions, the floor of the Rift Valley, the escarpment/plateau and the volcanoes. The Kenya rift valley is part of the African rift system that runs from Afar triple junction in the north to Beira, Mozambique in the south. It forms a classic graben averaging 40-80 km wide. The floor of the rift valley lies below 1000m a.s.l and extends in the north-east direction. On the eastern side of the floor lies the Laikipia Plateau and the Loriu Plateau in the western side, both rising from 1000m to above 2000 m a.s.l.
	Water environment	The eastern and western margins of Loriu and Laikipia plateaus drain into the northern sector of the Gregory valley. There are no permanent rivers in the Paka-Silali area but the formation of seasonal streams, which drain into Suguta River at the floor of the valley is largely controlled by the structural geology and soil characteristics of the area. The dense radial form of gullies that originate from the volcanoes not only depict areas of unconsolidated volcaniclastics, but also are representative of runoff paths that drain into the rivers at the floor of the valley. The main rivers at the floor of the valley run in a NNE direction which is parallel to the ridges and drains in the same direction. The surface water resources in project area are scanty. There are two lakes; Baringo and Bogoria, which are served by permanent and seasonal rivers and hot and cold springs. Other water resources in project area are water dams, water pans and boreholes. Wetlands in the prospect area include the Greater Loboi Swamp and the Kesubo Swamp located to

Items		Notes
		the north of the Lake Bogoria. They cover an area of 2 km2 and 1 km2 respectively. Most of the rivers in the region are seasonal except for the Suguta, Kerio, Molo, Pekera, Endau and Mukutan which flow throughout the year. Drainage is controlled by the main structural elements of the region. The crest of the eastern shoulder of the rift acts as a watershed between rivers that flow westwards through steep gorges into the inner trough and rivers with gentler profiles that drain the high plateau areas and flow eastwards to the Ewaso Ng'iro. Within the inner trough are two drainage systems namely the Lake Baringo catchment in the south and the Suguta in the north
	Protected Area	Lake Bogoria and part of its catchment area is rich in fauna hence has been protected as Lake Bogoria National Reserve (LBNR) and covers an area of 107 km2. It was gazetted in 1973 and is currently managed by Baringo and Koibatek County Councils. Recently the LBNR was designated as a third Ramsar site after Lake Nakuru and Naivasha. The lake is saline and covers an area of 34 km2. It is rich in biodiversity, hosting about half of the world's population of lesser flamingos (Phoeniconaias minor). It is also a habitat to other bird species including greater flamingos (Phoeniconaias rubber), black-necked grebe (Podiceps nigricollis), ostriches, fish eagles and several migratory species. Due to its avifauna richness, it has been designated as an Important Bird Area (IBA). The mammalian fauna in LBNR include zebras, gazelles, buffaloes, several primates and the only relatively accessible population of greater kudus. In addition to its rich biodiversity, Lake Bogoria has numerous hot springs.
	Flora & fauna	Lake Baringo is a fresh water body and is an important habitat for seven fish species. The fish species compositions of the lake include Tilapia Oreochromis niloticus, Protopterus aethiopicus, Clarias gariepinus, Barbus intermedius and Labeo cylindricus. The lake provides critical habitat and refuge for nearly 500 bird species, some of which are of regional and global conservation significance. The site is also a habitat for many species of animals such as Hippopotamus amphibious and Crocodylus niloticus and a wide range of mammals, amphibians, reptiles and invertebrate communities. The area around the western shore of the Lake is mainly habitated by Acacia tortilis woodland, with small bush-covered hills, gorges and cliffs. Ficus spp. grows on the cliff faces. The north and east have denser bush, thinning out towards the south, dominated by Acacia mellifera, A. reficiens and species of Boscia coriecea, Commiphora, Terminalia and Balanites aegyptiaca. The open, flat southern part is bushland interspersed with dry riverbeds and stands of Acacia tortilis and A. elatior. Swampy wetlands, with Typha latifolia reeds and Echinochloa marsh grass, occur at the mouths of rivers draining into the lake, notably the Ndau, Molo and Mukutan, and much of the shore is lined with Ambatch Aeschynomene sp.
	Rare species	Barbus intermedius and Labeo cylindricus, The tilapia Oreochromis niloticus baringoensis is endemic to the lake Baringo
Social Environment	Population distribution	In 2009, the population of Baringo County was 555,561, this being 1.4% of the Kenyan population with 50.2% male and 49.8% female. It has a population density of 282perons per square kilometers. The County has 6 constituencies namely Tiaty (East Pokot), Baringo South (Marigat), Mogotio, Eldama Ravine (Koibatek), Baringo Central and Baringo North. Kabarnet Town is the largest urban population center with a population of 5%, Eldama Ravine 3%, Marigat 1%, Maji Mazuri 1%, Mogotio 1% and Timboroa 1% of the Baringo population.
	Education	Education level is low especially in areas away from urban centres. Social background such as early marriage, pastoral lifestyle and high poverty levels are one the reason of low rates of enrolment.

Items		Notes
	Language	English (official language in Kenya, Swahili is the national language in Kenya, the local languages includes Turgen, Pokot, Ilchamus/Njemps
	Religion	Christian religion mainly dominates Baringo County. However, there are other religions like Islam and traditional faiths.
	Regional Characteristics	Most of the community members live in traditional huts. Men and women still dress in traditional clothing. For instance, the men wear shukas around their waists, a practice that has been abandoned by most communities in Kenya. The women still wear traditional beads around their necks. . The region suffers from several social and cultural related problems. The main one being insecurity as a result of inter-ethnic conflicts. These are caused by either cattle rustling or boundary disputes, between Pokots, Turkana, Samburu and to a smaller extent Turgens and Marakwets. Besides wealth and cultural ego, one of the main reasons that propel cattle rustling is the high bride price men have to pay the brides. Conflict over resources (pasture and water) intensifies particularly during drought periods. This is worsened by the access to light fire arms by the local communities in recent times.
	Income, Livelihood	The primary economic activity is livestock keeping followed by bee keeping and honey harvesting.Some people engage in small scale farming. Urban self-employment includes small-scale business (wholesale and retail trades, hotels) and informal sector enterprises (e.g. welding and carpentry) in urban and market centres. In general, most of the labor force within the project area is unskilled and semi-skilled.
	Poverty	The poverty level in the prospect area is more than 50% are below poverty line.
	Land use	Main land use is bush, grazing land and small scale farming.
	Landownership	Most of the lands in the proposed project area are communal land (trust lands).
	Infrastructure (e.g. sewerage system, roads, electricity, hospital)	Road connect is not good. Only a few places within the project area are connected to the electricity power grid. These are mainly the trading centres located along the power distribution grid. There is water scarcity in the project area.
	Cultural/heritage sites	No national cultural sites in the project area. Hot spring is considered as a sacred place by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. It is better to consult with local people when the project proceeds further. (More for cultural aspect and also have an aspect of landscape.)
	Landscape	Baringo and Bogoria Lake are improtant places for landscape
	Tribes	Tugen, Pokot, Ilchamus
	Minority groups and indigenous people	Il Chamus is consider as minority. The Constitution of Kenya recognizes the minority and marginalized groups within the country but there are no specific actions defined to be taken if they are affected by any project
	Greenhouse gas (GHG) effect	Tower Power, a private electricity producer, is setting up Kenya's first commercial biomass power plant in Marigat, Baringo County. The 11.5MW power plant will feed on Prosopis juliflora tree, also known as the Mathenge, transforming the tree from a noxious weed to a cash crop. The electricity generated will be sold to the Kenya Power Company (KPC), and in so doing abate approximately 31145 tCO2e per annum.
	Relevant parties	NEMA KWS KFS Ministry of Agriculture Ministry of Public Health

Items		Notes
		Water Resource Management Authority (WRMA) Water Resource Users Association Representative of Education County Government -(Governor, Representative of Youth and Women and Officials) County Commissioner Member of County Assembly (MCA) Administrative local leaders (Chief and Assistant Chief)Local Community Community Based Organization (CBO, such as women group and youth group) NGO Warden of Lake Baringo Fishery Department Fisher man Member of Parliament Group Ranch Official Church

Table 1.3 Initial EIA Results for Korosi

Items		Notes
Natural environment	Location	Korosi geothermal prospect is located in the northern sector of the actively faulting Kenya Rift Valley, approximately 300km from the Nairobi capital at approximately 0º45'N and 36º 05'E. The Korosi volcano neighbors Lake Baringo to the south and Paka volcano to the north.
	Air Quality	H2S concentration levels were zero (0.0 ppm) in all places where measurements were taken, except near the mouths of Lokortabim fumaroles and within Lake Bogoria Hot spring jets where the reading were 1.4 ppm H2S and 3.3 ppm H2S respectively. The concentrations are expected to be more than 1.0 ppm H2S during drilling, well discharge testing and project operation which is far below the WHO threshold for human exposure limit value of 10 ppm. The current H2S background concentrations at receptor sites were 0.0 ppm (below detection limit).
	Climate	The area is semi-arid with average rainfall ranging from 450-750 mm.
	Topography (geography & geology)	Korosi volcano rises between 450 - 500m above the surrounding floor of the rift's inner trough. The geology of Korosi is mainly dominated by the intermediate lavas mainly trachytes and trachy-andesite which cover the central and eastern sectors of the prospect area and basalts dominating the south, north and western sectors. The south-western plain is, however, dominated by fluvial and alluvial deposits whereas the airfall pumice deposits dominate the western plains.
	Soil	Most of the soil have had minimal development i.e. lithosols that have developed on undifferentiated tertiary volcanic rocks. The majority of these soils are well-drained, shallow, stony and rocky, dark reddish brown, friable, strongly calcareous clay loams and very erosive.
	Flora & fauna	Away from the Lake shores the terrestrial vegetation is mainly thorny bushland dominated by the species of Acacia, Balanites and Commiphora with patches of riverine woodland containing Ficus capensis, Acacia xanthophloea and Acacia tortilis. In the lower slopes of the Siricho Escarpment, Combretum and Grewia thickets dominate. Faunal Species: Among the faunal species in the project area based on local community

Items		Notes
		knowledge include gazelles, Baboons, monkeys, dikdik, rabbits, hyenas, squirrels, scorpions. Avifauna such as Heron birds and Ostriches, doves, weaver birds and the horn bills (were identified) within the project area. Among reptiles that are likely to be found include the monitor lizards, geckos, tortoises and snakes such as Rock Pythons, Puff Adders and the Black mamba. Several insects were also identified in the project impact area. Among the prominent ones were dragon flies and butterflies
	Rare species	Barbus intermedius and Labeo cylindricus
Social Environment	Education	Education level is low especially in areas away from urban centres. Social background such as early marriage, pastoral lifestyle and high poverty levels are one the reason of low rates of enrolment.
	Language	English (official language in Kenya, Swahili is the national language in Kenya, the local languages includes Turgen, Pokot, Ilchamus/Njemps
	Religion	Christian religion mainly dominates Baringo County. However, there are other religions like Islam and traditional faiths.
	Regional Characteristics	Most of the community members live in traditional huts. Men and women still dress in traditional clothing. For instance, the men wear shukas around their waists, a practice that has been abandoned by most communities in Kenya. The women still wear traditional beads around their necks. . The region suffers from several social and cultural related problems. The main one being insecurity as a result of inter-ethnic conflicts. These are caused by either cattle rustling or boundary disputes, between Pokots, Turkana, Samburu and to a smaller extent Turgens and Marakwets. Besides wealth and cultural ego, one of the main reasons that propel cattle rustling is the high bride price men have to pay the brides. Conflict over resources (pasture and water) intensifies particularly during drought periods. This is worsened by the access to light fire arms by the local communities in recent times.
	Income, Livelihood	The primary economic activity is livestock keeping followed by bee keeping and honey harvesting. Some people engage in small scale farming. Urban self-employment includes small-scale business (wholesale and retail trades, hotels) and informal sector enterprises (e.g. welding and carpentry) in urban and market centres. In general, most of the labor force within the project area is unskilled and semi-skilled
	Poverty	The poverty level in the prospect area is more than 50% are below provery line.
	Land use	Main land use is bush, grazing land and small scale farming.
	Landownership	Most of the lands in the proposed project area are communal land (trust lands).
	Infrastructure (e.g. sewerage system, roads, electricity, hospital)	Road connect is not good. Only a few places within the project area are connected to the electricity power grid. These are mainly the trading centres located along the power distribution grid. There is water scarcity in the project area.
	Cultural/heritage sites	No national cultural sites in the project area. Local people go and pray to mountain tops however exact location is not identified. It is better to consult with local people when the project proceeds further. (More for cultural aspect and also have an aspect of landscape.)
	Landscape	Local people go and pray to mountain tops however exact location is not identified. This has more for cultural aspect and also have an aspect of landscape.
	Tribes	Pokots

Items		Notes
	Minority groups and indigenous people	There is no minorites and marignalized people.
	Relevant parties	NEMA, KWS, KFS, Ministry of Agriculture, Ministry of Public Health Water Resource Management Authority (WRMA) Water Resource Users Association, Representative of Education County Government –(Governor, Representative of Youth and Women and Officials) County Commissioner, Member of County Assembly (MCA) Administrative local leaders (Chief and Assistant Chief)Local Community Community Based Organizations (CBOs, such as women group and youth group) NGO , Member of Parliament, Group Ranch Official

Table 1.4 Initial EIA Results for Chepchuk

Items		Notes
Natural environment	Location	Chepckuk is the name given to the highest point (1380m) of a series of prominent north to south trending ridges that rise 220m above the plains to the Northeast of Korosi and southeast of Paka
	Air Quality	H2S concentration levels were zero (0.0 ppm) in all places where measurements were taken, except near the mouths of Lokortabim fumaroles and within Lake Bogoria Hot spring jets where the reading were 1.4 ppm H2S and 3.3 ppm H2S respectively. The concentrations are expected to be more than 1.0 ppm H2S during drilling, well discharge testing and project operation which is far below the WHO threshold for human exposure limit value of 10 ppm. The current H2S background concentrations at receptor sites were 0.0 ppm (below detection limit).
	Climate	The area is semi-arid with average rainfall ranging from 450-750 mm.
	Topography (geography & geology)	The geology of Chepchuk is characterized by faulted Plio-pleistocene flood trachytes and younger basaltic flows occupying micro-grabens. The area is heavily faulted with half of the Chepchuk volcanic complex down faulted westward. Chepchuk volcanic complex consists of a sequence of flows of trachyte with inter-layering of basaltic lavas of various ages and pyroclastics.
	Soil	Most of the soil have had minimal development i.e. lithosols that have developed on undifferentiated tertiary volcanic rocks. The majority of these soils are well-drained, shallow, stony and rocky, dark reddish brown, friable, strongly calcareous clay loams and very erosive.
	Flora & fauna	In Chepchuk area, the physiognomy of vegetation is a bushland dominated by the Acacia species. The undergrowth is composed of mainly the herbaceous and grass species most of which are annuals. Faunal Species: Among the faunal species in the project area based on local community knowledge include gazelles, Baboons, monkeys, dikdik, rabbits, hyenas, squirrels, scorpions. Avifauna such as Heron birds and Ostriches, doves, weaver birds and the horn bills (were identified) within the project area. Among reptiles that are likely to be found include the monitor lizards, geckos, tortoises and snakes such as Rock Pythons, Puff Adders and the Black mamba. Several insects were also identified in the project impact area. Among the prominent ones were dragon flies and butterflies

	Items	Notes
	Rare species	Barbus intermedius and Labeo cylindricus,
Social Environment	Population distribution	In Chepchuk's suburban area resides Tangulbei, a comparatively big community (division). According to the 2009 KNBS statistical record, there were 17,251 people residing in the area.
	Education	Education level is low especially in areas away from urban centres. Social background such as early marriage, pastoral lifestyle and high poverty levels are one the reason of low rates of enrolment.
	Language	English (official language in Kenya, Swahili is the national language in Kenya, the local languages includes Turgen, Pokot, Ilchamus/Njemps
	Religion	Christian religion mainly dominates Baringo County. However, there are other religions like Islam and traditional faiths.
	Regional Characteristics	Most of the community members live in traditional huts. Men and women still dress in traditional clothing. For instance, the men wear shukas around their waists, a practice that has been abandoned by most communities in Kenya. The women still wear traditional beads around their necks. . The region suffers from several social and cultural related problems. The main one being insecurity as a result of inter-ethnic conflicts. These are caused by either cattle rustling or boundary disputes, between Pokots, Turkana, Samburu and to a smaller extent Turgens and Marakwets. Besides wealth and cultural ego, one of the main reasons that propel cattle rustling is the high bride price men have to pay the brides. Conflict over resources (pasture and water) intensifies particularly during drought periods. This is worsened by the access to light fire arms by the local communities in recent times.
	Income, Livelihood	The primary economic activity is livestock keeping followed by bee keeping and honey harvesting.Some people engage in small scale farming. Urban self-employment includes small-scale business (wholesale and retail trades, hotels) and informal sector enterprises (e.g. welding and carpentry) in urban and market centres. In general, most of the labor force within the project area is unskilled and semi-skilled.
	Poverty	The poverty level in the prospect area is more than 50% are below provery line.
	Land use	Main land use is bush, grazing land and small scale farming.
	Landownership	Most of the lands in the proposed project area are communal land (trust lands).
	Infrastructure (e.g. sewerage system, roads, electricity, hospital)	Road connect is not good. Only a few places within the project area are connected to the electricity power grid. These are mainly the trading centres located along the power distribution grid.There is water scarcity in the project area.
	Cultural/heritage sites	No national cultural sites in the project area. It is better to consult with local people when the project proceeds further. (More for cultural aspect and also have an aspect of landscape.)
	Landscape	Baringo and Bogoria Lake are improtant places for landscape
	Tribes	Pokots
	Minority groups and indigenous people	There is no minorites and marignalized people.
	Relevant parties	NEMA, KWS, KFS, Ministry of Agriculture, Ministry of Public Health Water Resource Management Authority (WRMA) Water Resource Users Association, Representative of Education County Government –(Governor, Representative of Youth and Women and

Items		Notes
		Officials), County Commissioner, Member of County Assembly (MCA) Administrative local leaders (Chief and Assistant Chief)Local Community Community Based Organizations (CBOs, such as women group and youth group) NGO , Member of Parliament, Group Ranch Official

Table 1.5 Initial EIA Results for Paka

Items		Notes
Natural environment	Location	Paka volcano is situated approximately 25 km north of Lake Baringo at 00° 25'N and 36° 12'E
	Air Quality	Hydrogen sulphide and methane were generally below detection limit and thus recorded 0 ppm at all sites. Oxygen and carbon dioxide were within ambient levels 20.9% and 150-200 ppm respectively. Overall air quality depicted uncontaminated air.
	Noise	The noise levels are generally below the WHO (1997) recommended standards (85 dB). The noise levels are within background noise levels.
	Climate	The project area falls within the arid-semi arid zone, mostly agro-ecological zones LM5 and LM6 and experiences two seasons of rainfall that is: the long and the short rains. The average rainfall varies from 486-755 mm per year. The mean annual maximum temperature is about 30°C and occasionally rises to over 35°C. The hottest months are from January to March.
	Topography (geography & geology)	Paka volcano lies in the inner trough of the Kenya Rift with the volcano massif extending over an area of about 280 km2 and rises between 600-700 m above the rift floor. The Paka central volcano rises to a height of 1697 masl and is surrounded by plains to the north, south, west and east. At the summit is a well preserved caldera of about 1.5 km in diameter, which is filled with young basaltic flows. Several craters dotting the massif are aligned in a NNE direction. The volcano is cut on its central and eastern flanks by a swarm of NNE trending faults. Paka is a small shield volcano constructed largely by trachyte and basaltic lavas and pyroclastic deposits. Much of the shields forming lavas are covered by trachytic pyroclastic deposits which are seen to cover the areas around the volcano. Basalt, hawaiite and mugearite lavas were erupted from a series of fissure and fault zones located on the lower northeastern and southern flanks. Volcanic activity commenced by 390 ka and continued to within 10 ka. Broadly contemporaneous trachytic and basaltic activity occurred on a number of small satellite centres peripheral to the main volcanic edifice. The oldest exposed rocks are the Lower Trachytes, which constructed an early volcanic shield. Subsequent fracturing of the shield by the NNE-trending faults was accompanied by eruption of the Lower Basalts from fissure sources on the eastern flanks of the volcano
	Soil	The hilly to flat, through undulating form of the Paka-Silale area, coupled with the geology form part of the main controls of soil characteristics in the area. Thus the soil types depict the geomorphology, volcanic nature and geochemical processes of the environment.
	Water environment	Like other volcanos in other parts of the rift valley, they are sandwitched between the parallel ridges that form Loriu plateau on the western side and the Laikipia plateau to the eastern side. Thus, the eastern and western margins of the respective plateaus drain into the northern sector of the gregory valley. There are no permanent rivers in the Paka-Silale area but the formation of seasonal streams, which drain into Suguta river at the floor of

Items		Notes
		the valley is largely controlled by the structural geology, soil characteristics of the area. The dense radial form of gulleys that originate from the volcanoes not only depict areas of unconsolidated volcaniclastics, but also are representative of runoff paths that drain into the rivers at the floor of the valley. The main rivers at the floor of the valley run in a NNE direction which is parallel to the ridges and drains in the same direction.
	Flora & fauna	Flora: The project area has moderate plant diversity typical of semi and arid regions in Kenya. Acacia raficiens is the most abundant plant species. The most common plant species include; Acacia meliffera, Salvadora persica, Boscia coriacea. Frequent plant species include; Acacia seyal, Euphorbia tirucallii (finger like), Euphorbia candelabrum, Balanites aegyptiaca, Solanum incanum, Comiphora Africana, Opuntia vulgaris Aloe scabrifolia, Aloe turkanensis. Occasional plants are palms (Brahea edulis), Grewia tenax, Cordia sinensis, Adenium obesum (desert rose), Balanites orbicularis, Erythina Abyssinica,Rhus natalensis, Ziziphus natalensis, Diospyrus scabra, Faurea saligna, Terminalia cattapa and Terminalia mantaly. Some species in the project area that are considered rare included: Acacia xanthopholea, Acacia abyssinica, Acacia drepanolobium, delonix elata, Capparis tomentosa. Fauna: The Paka-Silale area is considered to be naturally rich in terms of animal diversity this is due to the existing natural habitats. Among the faunal species observed are termites, Weaver birds. Hornbill and Lizards. Goats that are the main stay of the community livelihoods are a common sight in the project area. The wild animals in the area included dikdik.
	Rare species	Acacia xanthopholea, Acacia abyssinica, Acacia drepanolobium, Delonix elata, Capparis tomentosa
Social Environment	Population distribution	The demographic structure of the female and the male composition are about the same that is 39,122 and 39,324 male and female respectively. In Paka's suburban area resides Nginyang, a comparatively big community (division). According to the 2009 KNBS statistical record, there were 20,758 people residing in the area.
	Education	The current literacy level in the area stands less than 5%. The district has 60 ECD centers, 34 primary schools 3 secondary schools and 1 tertiary institution. Of the primary schools, the whole of Kapedo location in Turkana East district, has only 3 public primary schools.
	Language	English (official language in Kenya, Swahili is the national language in Kenya, the local languages includes Turgen, Pokot, Ilchamus/Njemps
	Religion	Christian religion mainly dominates Baringo County. However, there are other religions like Islam and traditional faiths.
	Regional Characteristics	The region suffers from several social and cultural related problems. The main one being insecurity as a result of inter-ethnic conflicts. These are caused by either cattle rustling or boundary disputes, between Pokots, Turkana, Samburu and to a smaller extent Turgens and Marakwets. Besides wealth and cultural ego, one of the main reasons that propel cattle rustling is the high bride price men have to pay the brides. This is worsened by the access to light fire arms by the local communities in recent times.
	Income, Livelihood	Pastoralism is the mainstay of the community. Main animals of economic importance are goats, cattle, camels and sheep.
	Land use	Pastoralism and bee keeping
	Landownership	Land use in the project area is communal land (trust lands)
	Infrastructure (e.g. sewerage system, roads, electricity, hospital)	Water and Sanitation Water is scarce in the project area. This is typical of an arid area. The communities depend on seasonal rivers and water pans for domestic use including water for livestock. Sanitation is also poor and it exacerbated by cultural practices. There are few health facilities in the proposed project area. Based on the 2008 - 2011 East Pokot district

Items		Notes
		development plan, the district has 30 dispensaries, 4 health centres and 1 private clinic.
	Cultural/heritage sites	No national cultural sites in the project area. Local people go and pray to mountain tops however exact location is not identified. It is better to consult with local people when the project proceeds further. (More for cultural aspect and also have an aspect of landscape.)
	Landscape	Local people go and pray to mountain tops however exact location is not identified. This has more for cultural aspect and also have an aspect of landscape.
	Tribes	Pokots
	Minority groups and indigenous people	There is no minorites and marignalized people.
	Relevant parties	NEMA, KWS, KFS, Ministry of Agriculture, Ministry of Public Health Water Resource Management Authority (WRMA) Water Resource Users Association, Representative of Education County Government –(Governor, Representative of Youth and Women and Officials), County Commissioner, Member of County Assembly (MCA) Administrative local leaders (Chief and Assistant Chief)Local Community Community Based Organizations (CBOs, such as women group and youth group), NGO, Member of Parliament, Group Ranch Official

2. SELECTED ENVIRONMENTAL IMPACT ASSESSMENT ITEMS

The geothermal development project may cause environmental and social impacts during its exploration, construction and operation phases. Based on the initial environmental and social impact assessment conducted in each potential geothermal site, EIA items related to potential impacts of the project, have been selected in this study.

Detailed plans to construct facilities and wells have not been developed in some of the planned development sites. Thus, assumptions regarding the potential risks/impacts were made based on a worse case scenario, to be on the safe side.

Tables 2.1 to 2.5 present the initial assessment of potential environmental and social impacts of the project in each region.

Table 2.1 Selected EIA Result for Arus

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Social Environment	Involuntary resettlement	C	D	・The planned geothermal development area is located in a place with few permanent residents. Surrounding nomadic people use scattered portions of land from time to time. Thus, resettlement is unlikely. ・Since roads have been constructed up to the geothermal development area, the possibility of new relocation during exploration works is comparatively low. However, the need for resettlement depends on the detailed plan of the proposed development, thus it remains uncertain at this stage.
	Employment, livelihood, & local economy	B	B	・There are high hopes for the positive impacts of the project to the local economy and the lives of the residents, such as increase in employment opportunities, increase in local procurement of materials and equipment, provision of infrastructure through project development, among others. ・There is a possibility of impacting the local economy and the lives of the residents due to the decrease in rangeland from land expropriation, rangeland usage restrictions (nearby the power plant's planned construction site). In such cases, the impact on residents' lives can continue even after project construction and operation.
	Land use and use of local resources	B	B	・Land and local resources will be used for the base installation needed in exploration and construction phases. ・The power plant and other facilities are expected to use land and local resources.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Social organization: social capital, local decision-making body, etc.	C	C	In the area, there are several organizations – government organizations (local government, tribal communities), social organizations (educational institutions), sectoral groups (women group, youth groups), religious organizations (Christian groups), NGOs, community conservancies, etc. There is a need to obtain the consensus of these groups and organizations. At this stage, the impacts of each project are still unclear. However, in the interview regarding direct use, there were many positive opinions regarding the geothermal development in the areas. The people have high hopes of the positive impacts of the project.
	Existing social infrastructure & social services	C	D	・Improvement of social infrastructure through construction and installation of roads and water distribution facilities, during exploration and construction phases of the project, can be expected. On the other hand, transporting construction equipment and materials may cause stress and damage to existing roads. However, these impacts are still unclear at this stage. ・Positive impacts are also anticipated, such as construction of roads (including operation and maintenance), and electricity distribution to residents.
	Poor people, indigenous people, minority groups	C	C	・Around 50% of the population around the development area is below the poverty line. There are high hopes for the positive economic impacts from the construction of the power plant. ・There are no minority or socially marginalized groups nearby the development area. There may be a certain level of impact on the local infrastructure, which is nomadic in nature. However, these are still unclear at this stage.
	Unequal distribution of benefits and harm	C	C	・There may be concentration of pollution in specific areas or unequal damage, depending on the site location and planning of the power plant. There is also a possibility that certain areas and specific groups/persons will benefit from the project. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Cultural Heritage	C	C	・There are no cultural heritage sites within the planned development area. On the other hand, the community used to consider hot springs as a sacred place and even now by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. There is a need to consult the community and carefully consider these things during the detailed planning of the development.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
				・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Conflict of local interest	C	C	There may be conflict between groups that support and oppose the project within the area. At this stage, however, it is not clear.
	Water use, water rights, communal rights	B	B	・During exploration and construction phases, the use of surface water for well excavation works may affect the amount of river flow and water level of the lake. Since the surrounding areas are arid, using water from rivers can have comparatively significant impacts depending on the season. Using small quantities of water from the lake may have less impact. Therefore, it is necessary to confirm the quantity of water intake, usage of bodies of water, and water rights during the feasibility study. ・Regarding water withdrawal, there is a need to obtain a permit from WRMA.
	Public Health	C	D	Public health may worsen because of insufficient treatment capacity and lack/absence of health facilities, during exploration and construction phases. At this stage, details of these impacts are still unknown because these would depend on the development plan.
	Disaster (hazards), Infectious diseases like HIV/AIDS	C	D	・There is a high risk of spreading infectious diseases like HIV/AIDS through the engagement of several construction workers from outside during the construction period. On the other hand, since population density is low in the development areas and majority of the population are nomadic (not permanent residents), details of the impacts are unclear, at this stage. ・Impact during operation may be minimal because there is low possibility of engaging workers from outside and industrial workers will be limited.
Natural Environment	Topography, geology	B	D	・The topography of the area may be changed due to engineering/construction works during exploration and construction phases. ・There will be very minimal impact on topography and geology during operation phase.
	Soil erosion	A	D	・During exploration and construction phases, shaping of the foundation platform can expose bare land. The exposed soil is vulnerable to erosion particularly when it rains. ・There will be very minimal soil erosion during operation phase because there will be no big-scale engineering/construction work anticipated.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Hot spring	B	A	・Drilling and exploration of geothermal wells may temporarily affect existing hot springs around the potential power plant sites. ・During operation, continuous extraction and reinjection of geothermal fluid from and to deep underground may also affect existing hot springs around the potential power plant sites.
	Groundwater	D	D	・There will be no withdrawal of groundwater. From the experience with other geothermal power plant projects, it is highly unlikely that well drilling and other activities will affect the amount and level of groundwater.
	Condition of rivers, lakes, & wetlands	B	C	・During exploration and construction phases, there will be no engineering or construction work that could significantly alter the condition of rivers, lakes and wetlands. However, since there are plans to withdraw water from the nearby Molo River, impacts will be anticipated depending on the plan. ・During operation, water to be used in the power plant will be withdrawn from nearby water bodies. This may affect river flow and lake water level. However, since the amount of water that will be withdrawn is small, the impact on water quantity is anticipated to be small. In the case of discharging brine water from power generation, the salt concentration may be high. With low river flow and high discharge quantity, water quality of the river will be affected. However, since this depends on the detailed development plan, the scale of the impact is unclear at this stage.
	Flora, fauna & biodiversity	C	C	・During exploration and construction phases, clearing of vegetation and land conversion can cause temporary impacts on flora and fauna. However, since the area is dry, the density of vegetation is low, thus the scale of the impact may not be as big as expected. At this stage, it is still unclear. ・There will be minimal impacts on flora, fauna and biodiversity during operation phase. Details are still unclear at this point.
	Landscape	B	B	・Depending on the location, the construction of the power plant, its surrounding facilities, and access roads can affect the view and natural landscape of the area. Lake Bogoria, near Arus region, has visual significance. ・Depending on the power plant site, presence of facilities and white smoke (steam), may affect the area's landscape.

Items			Impact Rating		Explanation (scope and likelihood of potential impacts)
			Exploration/ Construction Phase	Operation Phase	
	Global warming		D	D	・Bringing construction equipment, machineries, and materials used in exploration and construction phases, in and out of the site can emit low amount of greenhouse gases. The anticipated impact is temporary and minor. ・CO2 emission during operation is expected. However, GHG emissions would be less compared to alternative power generation processes as it uses a very clean technology. Thus, several positive impacts are expected.
Pollution	Air pollution	H_2S	B	A	・With the conduct of production test to evaluate geothermal reservoirs, H_2S will be released and would temporarily affect the surrounding areas. ・Geothermal fluid containing H_2S is used as steam for power generation. In the process, steam with H_2S is released from the cooling tower. This can cause environmental impacts to areas surrounding the power plant.
		Dust	B	D	・Vehicles transporting equipment and materials during construction will hoist dirt and create dust clouds. However, the affected area will be limited. Impacts are anticipated if there are residents near access roads. ・ There will be minimal impact during operation due to limited passing of vehicles.
	Water Pollution		A	A	・Muddy water from drilling works and water effluent from construction can cause water pollution. Also, with exposure of bare soil during site development, rainwater with eroded soil can pollute surface water. ・During operation, effluent from the power plant may affect surrounding water bodies.
	Soil Pollution		B	C	・During exploration and construction, excavation sludge and leakage from temporary accumulation of hot water may cause pollution to surrounding soil. ・During construction of facilities, there will be no handling/use of materials that can pollute soil. ・During operation, there will be no handling/use of materials that can pollute soil. On the other hand, with direct use, the use of steam and brine water, which contain heavy metals, may cause soil pollution. Details of the impacts are still unclear at this stage.
	Waste		A	A	・During exploration and construction, industrial waste (excavation sludge, waste) will be generated. ・During operation, industrial waste (e.g. sludge and waste oil) will be generated.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Noise and vibration	B	A	・Noise and vibration will be generated from the discharge test, operation of construction equipment, and construction works. Since these will be temporary, the anticipated environmental impact is low. ・During operation, the cooling tower, steam turbine, and generator will produce noise and vibration and these can affect the environment.
	Land subsidence	D	A	・Extraction of geothermal fluid during exploration and construction phases, happens for a short period of time, thus significant impact is not foreseen. ・Extraction of hot water from deep underground during operation, may cause land subsidence to the power plant's surrounding areas.
	Offensive Odor	C	C	・Foul odor of H_2S from the discharge test may temporarily affect surrounding areas. Since the population density there is low, the extent of the impact is still unknown. ・Foul odor of H_2S from the power plant during operation, may temporarily affect surrounding areas. Since the population density there is low, the extent of the impact is still unknown.
	Accident	C	C	・The possibility of accidents caused by H_2S gas from the discharge test is low but not negligible. ・Accidents during construction and operation (H_2S gas leakage) are possible.

Rating
A：Serious negative impacts are expected.
B：Some negative impacts are expected.
C：Extent of impact is unknown.
D：No significant impact. IEE/EIA is not necessary.

Table 2.2 Selected EIA Result for Baringo

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Social Environment	Involuntary resettlement	C	D	・The planned geothermal development area is located at the east shore of Lake Baringo, wherein there are few permanent residents. Portions of land that are used by surrounding nomadic people are scattered. ・Since roads have been constructed up to the geothermal development area, the possibility of new relocation during exploration works is comparatively low. However, the need for resettlement depends on the detailed plan of the proposed development, thus it remains uncertain at this stage.
	Employment, livelihood, and local economy	B	B	・There are high hopes for the positive impacts of the project to the local economy and the lives of the residents, such as increase in employment opportunities, increase in local procurement of materials and equipment, provision of infrastructure through project development, direct use of geothermal energy, among others. ・There is a possibility of impacting the local economy and the lives of the residents due to the decrease in rangeland from land expropriation, rangeland usage restrictions (nearby the power plant's planned construction site). In such cases, the impact on residents' lives can continue even after project construction and operation.
	Land use and use of local resources	B	B	・Land and local resources will be used for the base installation needed in exploration and construction. ・The power plant and other facilities are expected to use land and local resources.
	Social organization: social capital, local decision-making body, etc.	C	C	In the area, there are several organizations – government organizations (local government, tribal communities), social organizations (educational institutions), industrial organizations (Baringo Lake Management Association, fishery groups), sectoral groups (women group, youth groups), religious organizations (Christian groups), NGOs, Ruko community conservancy (East Coast of Lake Baringo), etc. There is a need to obtain the consensus of these groups and organizations. At this stage, the impacts of the project are still unclear. However, in the interview regarding direct use, there were many positive opinions regarding the geothermal development in the area. The people have high hopes of the positive impacts of the project.
	Existing social infrastructure	C	D	・Improvement of social infrastructure through construction and installation of roads and water

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	and social services			distribution facilities, during exploration and construction of the project, can be expected. On the other hand, transporting construction equipment and materials may cause stress and damage to existing roads. However, negative impacts are still unclear at this stage. ・Positive impacts are also anticipated, such as construction of roads (including operation and maintenance), and electricity distribution to residents.
	Poor people, indigenous people, minority groups	C	C	・Around 50% of the population around the development area is below the poverty line. There are high hopes for positive economic impacts from the construction of the power generating facility. ・Ilchamus minority group resides at the east coast of Lake Baringo. There is no minority group or socially marginalized people in the surrounding area of the development site at the west coast of Lake Baringo. There may be a certain level of impact on the local infrastructure, which is nomadic in nature, for most part of the prospect areas. However, these are still unclear at this stage.
	Unequal distribution of benefits & harm	C	C	・There may be concentration of pollution in specific areas or unequal damage, depending on the site location and planning of the power plant. There is also a possibility that certain areas and specific groups/persons will benefit from the project. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Cultural Heritage	C	C	・There are no cultural heritage sites within the planned development areas. On the other hand, the community used to consider hot springs as a sacred place and even now by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. There is a need to consult the community and carefully consider these things during the detailed planning of the development. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Conflict of local interest	C	C	There may be conflict between groups that support and oppose the project within the area. At this stage, however, it is not clear.
	Water use, water rights, communal rights	B	B	・During exploration and construction phases, the use of surface water for well excavation works may affect the amount of river flow and water level of the lake. Since the surrounding areas are arid, using water from rivers can have comparatively significant

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
				impacts depending on the season. Using small quantities of water from the lake may have less impact. Therefore, it is necessary to confirm the quantity of water intake, usage of bodies of water, and water rights during the feasibility study. ・Regarding water withdrawal, there is a need to obtain a permit from WRMA.
	Public Health	C	D	Public health may worsen because of insufficient treatment capacity and lack/absence of health facilities, during exploration and construction phases. At this stage, details of these impacts are still unclear because these would depend on the development plan.
	Disaster (hazards), Infectious diseases like HIV/AIDS	C	D	・There is a high risk of spreading infectious diseases such as HIV and AIDS through the engagement of several construction workers from outside. On the other hand, since population density is low in the development areas and majority of the population are nomadic (not permanent residents), details of the impacts are unclear, at this stage. ・Impact during operation may be minimal because there is low possibility of engaging workers from outside and industrial workers will be limited.
Natural Environment	Topography, geology	B	D	・The topography of the area may be changed due to engineering/construction works during exploration and construction phases. ・There will be very minimal impact on topography and geology during operation phase.
	Soil erosion	A	D	・During exploration and construction phases, shaping of the foundation platform can expose bare land. The exposed soil is vulnerable to erosion particularly when it rains. ・There will be very minimal soil erosion during operation phase because there will be no big-scale engineering/construction work anticipated.
	Hot spring	B	A	・Drilling and exploration of geothermal wells may temporarily affect existing hot springs around the potential power plant sites. ・During operation, continuous extraction and reinjection of geothermal fluid from and to deep underground may also affect existing hot springs around the potential power plant sites.
	Groundwater	D	D	・There will be no withdrawal of groundwater. From the experience with other geothermal power plant projects, it is highly unlikely that well drilling and other activities will affect the amount and level of groundwater.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Condition of rivers, lakes, and wetlands	C	C	・During exploration and construction phases, there will be no engineering or construction work that could significantly alter the condition of rivers, lakes and wetlands. However, there are plans to withdraw water from Lake Baringo for the nearby development area. At this point, the scale of the impact is still unclear. ・During operation, water withdrawal for the power plant may affect the water level of the lake. However, since the amount of water that will be withdrawn is small, the impact on water quantity is anticipated to be small. In the case of discharging brine water from power generation, the salt concentration may be high. With low river flow and high discharge quantity, water quality of the river will be affected. However, since this depends on the detailed development plan, the scale of the impact is unclear at this stage.
	Flora, fauna & biodiversity	C	C	・During exploration and construction phases, clearing of vegetation and land conversion can cause temporary impacts on flora and fauna. However, since the area is dry, the density of vegetation is low, thus the scale of the impact may not be as big as expected. At this stage, it is still unclear. ・There will be minimal impacts on flora, fauna and biodiversity during operation phase. Details are still unclear at this point. ・There is high demand for direct use of geothermal energy (use of steam and brine water). Since brine water may contain heavy metals, discharge to Lake Baringo may impact flora and fauna. The extent of the impact is unclear at this point.
	Landscape	B	B	・Depending on the location, the construction of the power plant, its surrounding facilities, and access roads can affect the view and natural landscape of the area. Lake Baringo has visual significance. ・Depending on the power plant site, presence of facilities and white smoke (steam) may affect the area's landscape.
	Global warming	D	D	・Bringing construction equipment, machineries, and materials used in exploration and construction phases, in and out of the site can emit low amount of greenhouse gases. The anticipated impact is short-lived and minor. ・CO_2 emission during operation is expected. However, with the use of a clean technology, GHG emissions would be less compared to alternative power generation processes/technologies. Thus, several positive impacts are expected.

Items			Impact Rating		Explanation (scope and likelihood of potential impacts)
			Exploration/ Construction Phase	Operation Phase	
Pollution	Air pollution	H_2S	B	A	・With the conduct of production test to evaluate geothermal reservoirs, H_2S will be released and would temporarily affect the surrounding areas. ・Geothermal fluid containing H_2S is used as steam for power generation. In the process, steam with H_2S is released from the cooling tower. This can cause environmental impacts to areas surrounding the power plant.
		Dust	B	D	・Vehicles transporting equipment and materials during construction will hoist dirt and create dust clouds. However, this will be limited to areas near roads. Also, impacts are anticipated if there are residents near access roads. ・ There will be minimal impact during operation due to limited passing of vehicles.
	Water Pollution		A	A	・Muddy water from drilling works and water effluent from construction can cause water pollution. Also, with exposure of bare soil during site development, rainwater with eroded soil can pollute surface water. ・During operation, effluent from the power plant may affect surrounding water bodies. Water use in the area depends on Lake Baringo. There is a need to carefully consider this point.
	Soil Pollution		B	C	・During exploration and construction, excavation sludge and leakage from temporary accumulation of hot water may cause pollution to surrounding soil. ・During construction of facilities, there will be no handling/use of materials that can pollute soil. ・During operation, there will be no handling/use of materials that can pollute soil. On the other hand, with direct use, the use of steam and brine water, which contain heavy metals, may cause soil pollution. Details of the impacts are still unclear at this stage.
	Waste		A	A	・During exploration and construction, industrial waste (excavation sludge, construction waste and debris) will be generated. ・During operation, industrial waste (e.g. sludge and waste oil) will be generated.
	Noise & vibration		B	A	・Noise and vibration will be generated from the discharge test, operation of construction equipment, and construction works. Since these will be temporary, the anticipated environmental impact is low. ・During operation, the cooling tower, steam turbine, and generator will produce noise and vibration and these can affect the environment.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Land subsidence	D	A	・Extraction of geothermal fluid during exploration and construction phases, happens for a short period of time, thus significant impact is unforeseen. ・Extraction of hot water from deep underground during operation, may cause land subsidence to the surrounding areas.
	Offensive Odor	C	C	・Foul odor of H_2S from the discharge test may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown. ・Foul odor of H_2S from the power plant during operation, may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown.
	Accident	C	C	・The possibility of accidents caused by H_2S gas from the discharge test is low but not negligible. ・Accidents during construction and operation (H_2S gas leakage) are possible.

Rating
A：Serious negative impacts are expected.
B：Some negative impacts are expected.
C：Extent of impact is unknown.
D：No significant impact. IEE/EIA is not necessary.

Table 2.3 Selected EIA Results for Korosi

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Social Environment	Involuntary resettlement	C	D	・The planned geothermal development area has few permanent residents. Scattered portions of land are used by surrounding nomadic people. ・Roads have not been constructed in the geothermal development area. Although depending on the development plan, the possibility of new relocation during exploration works is comparatively low because of a low population density in the area. The need for resettlement would depend on the detailed plan of the proposed development and this remains uncertain at this stage.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Employment, livelihood, and local economy	B	B	・There are high hopes for the positive impacts of the project to the local economy and the lives of the residents, such as increase in employment opportunities, increase in local procurement of materials and equipment, provision of infrastructure through project development, direct use of geothermal energy, among others. ・There is a possibility of impacting the local economy and the lives of the residents due to the decrease in rangeland from land expropriation, rangeland usage restrictions (nearby the power plant's planned construction site). In such cases, the impact on residents' lives can continue even after project construction and operation.
	Land use and use of local resources	B	B	・Land and local resources will be used for the construction of access roads and base installation needed in exploration and construction phases. ・The power plant and other facilities are expected to use land and local resources.
	Social organization: social capital, local decision-making body, etc.	C	C	In the area, there are several organizations – government organizations (local government, tribal communities), social organizations (educational institutions), sectoral groups (women group, youth groups), religious organizations (Christian groups), NGOs, community conservancies, etc. There is a need to obtain the consensus of these groups and organizations. At this stage, the impacts of the project are still unclear. However, in the interview regarding direct use, there were many positive opinions regarding the geothermal development in the area. The people have high hopes of the positive impacts of the project.
	Existing social infrastructure and social services	C	D	・Improvement of social infrastructure through construction and installation of roads and water distribution facilities, during exploration and construction of the project, can be expected. On the other hand, transporting construction equipment and materials may cause stress and damage to existing roads. However, negative impacts are still unclear at this stage. ・Positive impacts are also anticipated, such as construction of roads (including operation and maintenance), and electricity distribution to residents.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Poor people, indigenous people, minority groups	C	C	・Around 50% of the population around the development area is below the poverty line. There are high hopes for positive economic impacts from the construction of the power generating facility. ・There are no minority groups or socially marginalized people in the surrounding area of the development site. There may be a certain level of impact on the local infrastructure, which is nomadic in nature, for most part of the region. However, these are still unclear at this stage.
	Unequal distribution of benefits & harm	C	C	・There may be concentration of pollution in specific areas or unequal damage, depending on the site location and planning of the power plant. There is also a possibility that certain areas and specific groups/persons will benefit from the project. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Cultural Heritage	C	C	・There are no cultural heritage sites within the planned development areas. On the other hand, the community used to consider hot springs as a sacred place and even now by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. There is a need to consult the community and carefully consider these things during the detailed planning of the development. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Conflict of local interest	C	C	There may be conflict between groups that support and oppose the project within the area. At this stage, however, it is not clear.
	Water use, water rights, communal rights	B	B	・During exploration and construction phases, the use of surface water for well excavation works may affect the amount of river flow and water level of the lake. Since the surrounding areas are arid, using water from rivers can have comparatively significant impacts depending on the season. Using small quantities of water from the lake may have less impact. Therefore, it is necessary to confirm the quantity of water intake, usage of bodies of water, and water rights during the feasibility study. ・Regarding water withdrawal, there is a need to obtain a permit from WRMA.
	Public Health	C	D	Public health may worsen because of insufficient treatment capacity and lack/absence of health facilities, during exploration and construction phases. At this stage, details of these impacts are still unclear because these would depend on the development plan.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Disaster (hazards), Infectious diseases like HIV/AIDS	C	D	・There is a high risk of spreading infectious diseases such as HIV and AIDS through the engagement of several construction workers from outside. On the other hand, since population density is low in the development areas and majority of the population are nomadic (not permanent residents), details of the impacts are unclear, at this stage. ・Impact during operation may be minimal because there is low possibility of engaging workers from outside and industrial workers will be limited.
Natural Environment	Topography, geology	A	D	・The topography of the area may be changed due to engineering/construction works (access roads, power plant, other facilities) during exploration and construction phases. ・There will be very minimal impact on topography and geology during operation phase.
	Soil erosion	A	D	・During exploration and construction phases, shaping of the foundation platform and construction of access roads can expose bare land. The exposed soil is vulnerable to erosion particularly when it rains. ・There will be very minimal soil erosion during operation phase because there will be no big-scale engineering/construction work anticipated.
	Hot spring	B	A	・Drilling and exploration of geothermal wells may temporarily affect existing hot springs around the potential power plant sites. ・During operation, continuous extraction and reinjection of geothermal fluid from and to deep underground may also affect existing hot springs around the potential power plant sites.
	Groundwater	D	D	・There will be no withdrawal of groundwater. From the experience with other geothermal power plant projects, it is highly unlikely that well drilling and other activities will affect the amount and level of groundwater.
	Condition of rivers, lakes, and wetlands	C	C	・During exploration and construction phases, there will be no engineering or construction work that could significantly alter the condition of rivers, lakes and wetlands. However, there are plans to withdraw water from Lake Baringo for the nearby development area. At this point, the scale of the impact is still unclear. ・During operation, water withdrawal for the power plant may affect the water level of the lake. However, since the amount of water that will be withdrawn is small, the impact on water quantity is anticipated to be small. In the case of discharging brine water from power generation, the salt concentration may be high. With low river flow and

Items			Impact Rating		Explanation (scope and likelihood of potential impacts)
			Exploration/ Construction Phase	Operation Phase	
					high discharge quantity, water quality of the river will be affected. However, since this depends on the detailed development plan, the scale of the impact is unclear at this stage.
	Flora, fauna & biodiversity		C	C	・During exploration and construction phases, clearing of vegetation and land conversion can cause temporary impacts on flora and fauna. However, since the area is dry, the density of vegetation is low, thus the scale of the impact may not be as big as expected. At this stage, it is still unclear. ・There will be minimal impacts on flora, fauna and biodiversity during operation phase. Details are still unclear at this point. ・There is high demand for direct use of geothermal energy (use of steam and brine water). Since brine water may contain heavy metals, discharge to Lake Baringo may impact flora and fauna. The extent of the impact is unclear at this point.
	Landscape		B	B	・Depending on the location, the construction of the power plant, its surrounding facilities, and access roads can affect the view and natural landscape of the area. Lake Baringo has visual significance. ・Depending on the power plant site, presence of facilities and white smoke (steam) may affect the area's landscape.
	Global warming		D	D	・Bringing construction equipment, machineries, and materials used in exploration and construction phases, in and out of the site can emit low amount of greenhouse gases. The anticipated impact is short-lived and minor. ・CO_2 emission during operation is expected. However, with the use of a clean technology, GHG emissions would be less compared to alternative power generation processes/technologies. Thus, several positive impacts are expected.
Pollution	Air pollution	H_2S	B	A	・With the conduct of production test to evaluate geothermal reservoirs, H_2S will be released and would temporarily affect the surrounding areas. ・Geothermal fluid containing H_2S is used as steam for power generation. In the process, steam with H_2S is released from the cooling tower. This can cause environmental impacts to areas surrounding the power plant.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Dust	B	D	・Vehicles transporting equipment and materials during construction will hoist dirt and create dust clouds. However, this will be limited to areas near roads. Also, impacts are anticipated if there are residents near access roads. ・ There will be minimal impact during operation due to limited passing of vehicles.
Water Pollution		A	A	・Muddy water from drilling works and water effluent from construction can cause water pollution. Also, with exposure of bare soil during site development, rainwater with eroded soil can pollute surface water. ・During operation, effluent from the power plant may affect surrounding water bodies.
Soil Pollution		B	C	・During exploration and construction, excavation sludge and leakage from temporary accumulation of hot water may cause pollution to surrounding soil. ・During construction of facilities, there will be no handling/use of materials that can pollute soil. ・During operation, there will be no handling/use of materials that can pollute soil. On the other hand, with direct use, the use of steam and brine water, which contain heavy metals, may cause soil pollution. Details of the impacts are still unclear at this stage.
Waste		A	A	・During exploration and construction, industrial waste (excavation sludge, construction waste and debris) will be generated. ・During operation, industrial waste (e.g. sludge and waste oil) will be generated.
Noise & vibration		B	A	・Noise and vibration will be generated from the discharge test, operation of construction equipment, and construction works. Since these will be temporary, the anticipated environmental impact is low. ・During operation, the cooling tower, steam turbine, and generator will produce noise and vibration and these can affect the environment.
Land subsidence		D	A	・Extraction of geothermal fluid during exploration and construction phases, happens for a short period of time, thus significant impact is unforeseen. ・Extraction of hot water from deep underground during operation, may cause land subsidence to the surrounding areas.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Offensive Odor	C	C	・Foul odor of H_2S from the discharge test may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown. ・Foul odor of H_2S from the power plant during operation, may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown.
	Accident	C	C	・The possibility of accidents caused by H_2S gas from the discharge test is low but not negligible. ・Accidents during construction and operation (H_2S gas leakage) are possible.

Rating
A：Serious negative impacts are expected.
B：Some negative impacts are expected.
C：Extent of impact is unknown.
D：No significant impact. IEE/EIA is not necessary.

Table 2.4 Selected EIA Result for Chepchuk

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Social Environment	Involuntary resettlement	C	D	・The planned geothermal development area has few permanent residents. Scattered portions of land are used by surrounding nomadic people. ・Roads have not been constructed in the geothermal development area. Although depending on the development plan, the possibility of new relocation during exploration works is comparatively low because of a low population density in the area. The need for resettlement would depend on the detailed plan of the proposed development and this remains uncertain at this stage.
	Employment, livelihood, and local economy	B	B	・There are high hopes for the positive impacts of the project to the local economy and the lives of the residents, such as increase in employment opportunities, increase in local procurement of materials and equipment, provision of infrastructure through project development, direct use of geothermal energy, among others. ・There is a possibility of impacting the local economy and the lives of the residents due to the decrease in rangeland from land expropriation,

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
				rangeland usage restrictions (nearby the power plant's planned construction site). In such cases, the impact on residents' lives can continue even after project construction and operation.
	Land use and use of local resources	B	B	・Land and local resources will be used for the construction of access roads and base installation needed in exploration and construction phases. ・The power plant and other facilities are expected to use land and local resources.
	Social organization: social capital, local decision-making body, etc.	C	C	In the area, there are several organizations – government organizations (local government, tribal communities), social organizations (educational institutions), sectoral groups (women group, youth groups), religious organizations (Christian groups), NGOs, community conservancies, etc. There is a need to obtain the consensus of these groups and organizations. At this stage, the impacts of the project are still unclear. However, in the interview regarding direct use, there were many positive opinions regarding the geothermal development in the area. The people have high hopes of the positive impacts of the project.
	Existing social infrastructure and social services	C	D	・Improvement of social infrastructure through construction and installation of roads and water distribution facilities, during exploration and construction of the project, can be expected. On the other hand, transporting construction equipment and materials may cause stress and damage to existing roads. However, negative impacts are still unclear at this stage. ・Positive impacts are also anticipated, such as construction of roads (including operation and maintenance), and electricity distribution to residents.
	Poor people, indigenous people, minority groups	C	C	・Around 50% of the population around the development area is below the poverty line. There are high hopes for positive economic impacts from the construction of the power generating facility. ・There are no minority groups or socially marginalized people in the surrounding area of the development site. There may be a certain level of impact on the local infrastructure, which is nomadic in nature, for most part of the region. However, these are still unclear at this stage.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Unequal distribution of benefits & harm	C	C	・There may be concentration of pollution in specific areas or unequal damage, depending on the site location and planning of the power plant. There is also a possibility that certain areas and specific groups/persons will benefit from the project. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Cultural Heritage	C	C	・There are no cultural heritage sites within the planned development areas. On the other hand, the community used to consider hot springs as a sacred place and even now by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. There is a need to consult the community and carefully consider these things during the detailed planning of the development. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Conflict of local interest	C	C	There may be conflict between groups that support and oppose the project within the area. At this stage, however, it is not clear.
	Water use, water rights, communal rights	B	B	・During exploration and construction phases, the use of surface water for well excavation works may affect the amount of river flow and water level of the lake. Since the surrounding areas are arid, using water from rivers can have comparatively significant impacts depending on the season. Using small quantities of water from the lake may have less impact. Therefore, it is necessary to confirm the quantity of water intake, usage of bodies of water, and water rights during the feasibility study. ・Regarding water withdrawal, there is a need to obtain a permit from WRMA.
	Public Health	C	D	Public health may worsen because of insufficient treatment capacity and lack/absence of health facilities, during exploration and construction phases. At this stage, details of these impacts are still unclear because these would depend on the development plan.
	Disaster (hazards), Infectious diseases like HIV/AIDS	C	D	・There is a high risk of spreading infectious diseases such as HIV and AIDS through the engagement of several construction workers from outside. On the other hand, since population density is low in the development areas and majority of the population are nomadic (not permanent residents), details of the impacts are unclear, at this stage. ・Impact during operation may be minimal because there is low possibility of engaging workers from outside and industrial workers will be limited.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Natural Environment	Topography, geology	A	D	・The topography of the area may be changed due to engineering/construction works (access roads, power plant, other facilities) during exploration and construction phases. ・There will be very minimal impact on topography and geology during operation phase.
	Soil erosion	A	D	・During exploration and construction phases, shaping of the foundation platform and construction of access roads can expose bare land. The exposed soil is vulnerable to erosion particularly when it rains. ・There will be very minimal soil erosion during operation phase because there will be no big-scale engineering/construction work anticipated.
	Hot spring	B	A	・Drilling and exploration of geothermal wells may temporarily affect existing hot springs around the potential power plant sites. ・During operation, continuous extraction and reinjection of geothermal fluid from and to deep underground may also affect existing hot springs around the potential power plant sites.
	Groundwater	D	D	・There will be no withdrawal of groundwater. From the experience with other geothermal power plant projects, it is highly unlikely that well drilling and other activities will affect the amount and level of groundwater.
	Condition of rivers, lakes, and wetlands	C	C	・During exploration and construction phases, there will be no engineering or construction work that could significantly alter the condition of rivers, lakes and wetlands. However, there are plans to withdraw water from Lake Baringo for the nearby development area. At this point, the scale of the impact is still unclear. ・During operation, water withdrawal for the power plant may affect the water level of the lake. However, since the amount of water that will be withdrawn is small, the impact on water quantity is anticipated to be small. In the case of discharging brine water from power generation, the salt concentration may be high. With low river flow and high discharge quantity, water quality of the river will be affected. However, since this depends on the detailed development plan, the scale of the impact is unclear at this stage.

Items			Impact Rating		Explanation (scope and likelihood of potential impacts)
			Exploration/ Construction Phase	Operation Phase	
	Flora, fauna & biodiversity		C	C	・During exploration and construction phases, clearing of vegetation and land conversion can cause temporary impacts on flora and fauna. However, since the area is dry, the density of vegetation is low, thus the scale of the impact may not be as big as expected. At this stage, it is still unclear. ・There will be minimal impacts on flora, fauna and biodiversity during operation phase. Details are still unclear at this point. ・There is high demand for direct use of geothermal energy (use of steam and brine water). Since brine water may contain heavy metals, discharge to Lake Baringo may impact flora and fauna. The extent of the impact is unclear at this point.
	Landscape		B	B	・Depending on the location, the construction of the power plant, its surrounding facilities, and access roads can affect the view and natural landscape of the area. Lake Baringo has visual significance. ・Depending on the power plant site, presence of facilities and white smoke (steam) may affect the area's landscape.
	Global warming		D	D	・Bringing construction equipment, machineries, and materials used in exploration and construction phases, in and out of the site can emit low amount of greenhouse gases. The anticipated impact is short-lived and minor. ・CO_2 emission during operation is expected. However, with the use of a clean technology, GHG emissions would be less compared to alternative power generation processes/technologies. Thus, several positive impacts are expected.
Pollution	Air pollution	H_2S	B	A	・With the conduct of production test to evaluate geothermal reservoirs, H_2S will be released and would temporarily affect the surrounding areas. ・Geothermal fluid containing H_2S is used as steam for power generation. In the process, steam with H_2S is released from the cooling tower. This can cause environmental impacts to areas surrounding the power plant.
		Dust	B	D	・Vehicles transporting equipment and materials during construction will hoist dirt and create dust clouds. However, this will be limited to areas near roads. Also, impacts are anticipated if there are residents near access roads. ・ There will be minimal impact during operation due to limited passing of vehicles.
	Water Pollution		A	A	・Muddy water from drilling works and water effluent from construction can cause water pollution. Also, with exposure of bare soil during site development, rainwater with eroded soil can pollute surface water. ・During operation, effluent from the power plant

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
				may affect surrounding water bodies.
	Soil Pollution	B	C	・During exploration and construction, excavation sludge and leakage from temporary accumulation of hot water may cause pollution to surrounding soil. ・During construction of facilities, there will be no handling/use of materials that can pollute soil. ・During operation, there will be no handling/use of materials that can pollute soil. On the other hand, with direct use, the use of steam and brine water, which contain heavy metals, may cause soil pollution. Details of the impacts are still unclear at this stage.
	Waste	A	A	・During exploration and construction, industrial waste (excavation sludge, construction waste and debris) will be generated. ・During operation, industrial waste (e.g. sludge and waste oil) will be generated.
	Noise & vibration	B	A	・Noise and vibration will be generated from the discharge test, operation of construction equipment, and construction works. Since these will be temporary, the anticipated environmental impact is low. ・During operation, the cooling tower, steam turbine, and generator will produce noise and vibration and these can affect the environment.
	Land subsidence	D	A	・Extraction of geothermal fluid during exploration and construction phases, happens for a short period of time, thus significant impact is unforeseen. ・Extraction of hot water from deep underground during operation, may cause land subsidence to the surrounding areas.
	Offensive Odor	C	C	・Foul odor of H_2S from the discharge test may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown. ・Foul odor of H_2S from the power plant during operation, may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown.
	Accident	C	C	・The possibility of accidents caused by H_2S gas from the discharge test is low but not negligible. ・Accidents during construction and operation (H_2S gas leakage) are possible.

Rating

A：Serious negative impacts are expected.

B：Some negative impacts are expected.

C：Extent of impact is unknown.

D：No significant impact. IEE/EIA is not necessary.

Table 2.5 Selected EIA Result for Paka

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
Social Environment	Involuntary resettlement	C	D	・The planned geothermal development area is located in a hilly region with very few permanent residents. Scattered portions of land are used by surrounding nomadic people. ・Most roads have not been constructed in the geothermal development area. There may be a possibility of resettlement caused by the construction of access roads. However, the population density in the area is low, thus the possibility may be lower than expected. The need for resettlement would depend on the detailed plan of the proposed development and this remains uncertain at this stage.
	Employment, livelihood, and local economy	B	B	・There are high hopes for the positive impacts of the project to the local economy and the lives of the residents, such as increase in employment opportunities, increase in local procurement of materials and equipment, provision of infrastructure through project development, direct use of geothermal energy, among others. ・There is a possibility of impacting the local economy and the lives of the residents due to the decrease in rangeland from land expropriation, rangeland usage restrictions (nearby the power plant's planned construction site). In such cases, the impact on residents' lives can continue even after project construction and operation.
	Land use and use of local resources	B	B	・Land and local resources will be used for the construction of access roads and base installation needed in exploration and construction phases. ・The power plant and other facilities are expected to use land and local resources.
	Social organization: social capital, local decision-making body, etc.	C	C	In the area, there are several organizations – government organizations (local government, tribal communities), social organizations (educational institutions), sectoral groups (women group, youth groups), religious organizations (Christian groups), NGOs, community conservancies, etc. There is a need to obtain the consensus of these groups and organizations. At this stage, the impacts of the project are still unclear. However, in the interview regarding direct use, there were many positive opinions regarding the geothermal development in the area. The people have high hopes of the positive impacts of the project.
	Existing social infrastructure	C	D	・Improvement of social infrastructure through construction and installation of roads and water

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	and social services			distribution facilities, during exploration and construction of the project, can be expected. On the other hand, transporting construction equipment and materials may cause stress and damage to existing roads. However, negative impacts are still unclear at this stage. ・Positive impacts are also anticipated, such as construction of roads (including operation and maintenance), and electricity distribution to residents.
	Poor people, indigenous people, minority groups	C	C	・Around 50% of the population around the development area is below the poverty line. There are high hopes for positive economic impacts from the construction of the power generating facility. ・There are no minority groups or socially marginalized people in the surrounding area of the development site. There may be a certain level of impact on the local infrastructure, which is nomadic in nature, for most part of the region. However, these are still unclear at this stage.
	Unequal distribution of benefits & harm	C	C	・There may be concentration of pollution in specific areas or unequal damage, depending on the site location and planning of the power plant. There is also a possibility that certain areas and specific groups/persons will benefit from the project. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Cultural Heritage	C	C	・There are no cultural heritage sites within the planned development areas. On the other hand, the community used to consider hot springs as a sacred place and even now by the community in the past but now with Christianity they only consider it as an important place manifesting God's work on the earth's surface. There is a need to consult the community and carefully consider these things during the detailed planning of the development. ・At this stage, details of these impacts (existence and extent) are still unclear because these would depend on the detailed plan of the development.
	Conflict of local interest	C	C	There may be conflict between groups that support and oppose the project within the area. At this stage, however, it is not clear.
	Water use, water rights, communal rights	B	B	・During exploration and construction phases, the use of surface water for well excavation works may affect the amount of river flow and water level of the lake. Since there are only seasonal rivers in the area, water from rivers is used. As an alternative, water from Baringo Lake can be used. Using small quantities of water from the lake may have small impacts. Therefore, it is necessary to confirm the

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
				quantity of water intake, usage of bodies of water, and water rights during the feasibility study. ・Regarding water withdrawal, there is a need to obtain a permit from WRMA.
	Public Health	C	D	Public health may worsen because of insufficient treatment capacity and lack/absence of health facilities, during exploration and construction phases. At this stage, details of these impacts are still unclear because these would depend on the development plan.
	Disaster (hazards), Infectious diseases like HIV/AIDS	C	D	・There is a high risk of spreading infectious diseases such as HIV and AIDS through the engagement of several construction workers from outside. On the other hand, since population density is low in the development areas and majority of the population are nomadic (not permanent residents), details of the impacts are unclear, at this stage. ・Impact during operation may be minimal because there is low possibility of engaging workers from outside and industrial workers will be limited.
Natural Environment	Topography, geology	A	D	・The topography of the area may be changed due to engineering/construction works (access roads, power plant, other facilities) during exploration and construction phases. ・There will be very minimal impact on topography and geology during operation phase.
	Soil erosion	A	D	・During exploration and construction phases, shaping of the foundation platform and construction of access roads can expose bare land. The exposed soil is vulnerable to erosion particularly when it rains. ・There will be very minimal soil erosion during operation phase because there will be no big-scale engineering/construction work anticipated.
	Hot spring	B	A	・Drilling and exploration of geothermal wells may temporarily affect existing hot springs around the potential power plant sites. ・During operation, continuous extraction and reinjection of geothermal fluid from and to deep underground may also affect existing hot springs around the potential power plant sites.
	Groundwater	D	D	・There will be no withdrawal of groundwater. From the experience with other geothermal power plant projects, it is highly unlikely that well drilling and other activities will affect the amount and level of groundwater.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Condition of rivers, lakes, and wetlands	C	C	・During exploration and construction phases, there will be no engineering or construction work that could significantly alter the condition of rivers, lakes and wetlands. However, there are plans to withdraw water from Lake Baringo for the nearby development area. Depending on the plan, the possibility of creating impacts cannot be neglected. At this point, however, the scale of the impact is still unclear. ・During operation, water withdrawal for the power plant may affect the water level of the lake. However, since the amount of water that will be withdrawn is small, the impact on water quantity is anticipated to be small. In the case of discharging brine water from power generation, the salt concentration may be high. With low river flow and high discharge quantity, water quality of the river will be affected. However, since this depends on the detailed development plan, the scale of the impact is unclear at this stage.
	Flora, fauna & biodiversity	C	C	・During exploration and construction phases, clearing of vegetation and land conversion can cause temporary impacts on flora and fauna. However, since the area is dry, the density of vegetation is low, thus the scale of the impact may not be as big as expected. At this stage, it is still unclear. ・There will be minimal impacts on flora, fauna and biodiversity during operation phase. Details are still unclear at this point.
	Landscape	B	B	・Depending on the location, the construction of the power plant, its surrounding facilities, and access roads can affect the view and natural landscape of the area. Lake Baringo has visual significance. ・Depending on the power plant site, presence of facilities and white smoke (steam) may affect the area's landscape.
	Global warming	D	D	・Bringing construction equipment, machineries, and materials used in exploration and construction phases, in and out of the site can emit low amount of greenhouse gases. The anticipated impact is short-lived and minor. ・CO_2 emission during operation is expected. However, with the use of a clean technology, GHG emissions would be less compared to alternative power generation processes/technologies. Thus, several positive impacts are expected.

Items			Impact Rating		Explanation (scope and likelihood of potential impacts)
			Exploration/ Construction Phase	Operation Phase	
Pollution	Air pollution	H_2S	B	A	・With the conduct of production test to evaluate geothermal reservoirs, H_2S will be released and would temporarily affect the surrounding areas. ・Geothermal fluid containing H_2S is used as steam for power generation. In the process, steam with H_2S is released from the cooling tower. This can cause environmental impacts to areas surrounding the power plant.
		Dust	B	D	・Vehicles transporting equipment and materials during construction will hoist dirt and create dust clouds. However, this will be limited to areas near roads. Also, impacts are anticipated if there are residents near access roads. ・ There will be minimal impact during operation due to limited passing of vehicles.
	Water Pollution		A	A	・Muddy water from drilling works and water effluent from construction can cause water pollution. Also, with exposure of bare soil during site development, rainwater with eroded soil can pollute surface water. ・During operation, effluent from the power plant may affect surrounding water bodies.
	Soil Pollution		B	C	・During exploration and construction, excavation sludge and leakage from temporary accumulation of hot water may cause pollution to surrounding soil. ・During construction of facilities, there will be no handling/use of materials that can pollute soil. ・During operation, there will be no handling/use of materials that can pollute soil. On the other hand, with direct use, the use of steam and brine water, which contain heavy metals, may cause soil pollution. Details of the impacts are still unclear at this stage.
	Waste		A	A	・During exploration and construction, industrial waste (excavation sludge, construction waste and debris) will be generated. ・During operation, industrial waste (e.g. sludge and waste oil) will be generated.
	Noise & vibration		B	A	・Noise and vibration will be generated from the discharge test, operation of construction equipment, and construction works. Since these will be temporary, the anticipated environmental impact is low. ・During operation, the cooling tower, steam turbine, and generator will produce noise and vibration and these can affect the environment.

Items		Impact Rating		Explanation (scope and likelihood of potential impacts)
		Exploration/ Construction Phase	Operation Phase	
	Land subsidence	D	A	・Extraction of geothermal fluid during exploration and construction phases, happens for a short period of time, thus significant impact is unforeseen. ・Extraction of hot water from deep underground during operation, may cause land subsidence to the surrounding areas.
	Offensive Odor	C	C	・Foul odor of H_2S from the discharge test may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown. ・Foul odor of H_2S from the power plant during operation, may temporarily affect surrounding areas. Since the population density in the area is low, the extent of the impact is still unknown.
	Accident	C	C	・The possibility of accidents caused by H_2S gas from the discharge test is low but not negligible. ・Accidents during construction and operation (H_2S gas leakage) are possible.

Rating

A：Serious negative impacts are expected.

B：Some negative impacts are expected.

C：Extent of impact is unknown.

D：No significant impact. IEE/EIA is not necessary.

APPENDIX

9. Economic Evaluation of Wellhead Generator

Economic Evaluation of Wellhead Generator

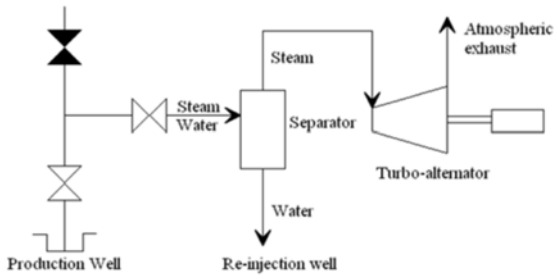
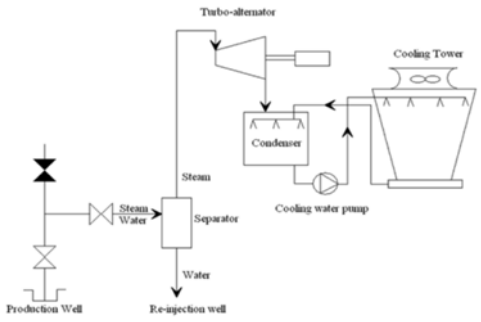
1. Introduction

In general, large-scale geothermal power plants are economically favorable due to the economy-of-scale effect in construction costs. However, small-scale wellhead generators (WHG) are recently drawing attention because of their quick start-up and early cash earning. In Kenya, KenGen has built two 6 MW small WHGs to utilize standby production wells in parallel to the construction of large-scale geothermal power plants in Olkaria. KenGen plans to expand wellhead generation up to 75 MW in total in the future. Triggered by KenGen's success in WHG, GDC is also considering to introduce 5 MW-class WHGs in order to start early generation in Menengai field. With these background, this chapter discusses the economic aspect of small-scale WHG.

2. Technical options of WHG

Wellhead generator has several technical options such as backpressure type, condensing type, binary cycle type and so on. In this chapter, however, backpressure type and condensing type are discussed based on an assumption that production wells produce large volume of steam with high temperature adequately enough for both types. The technical system and comparison is as shown in Table-2.1.

Table-2.1 Technical options of WHG

Type	System diagram (Joel Sutter, et al (2012))	Characteristics
Backpressure		- Suitable for small capacity generation - No need of condenser - Construction cost is low - Large steam consumption rate - Suitable for steam with high gas contents - Need noise measures
Condensing		- Suitable for large capacity generation - Construction cost is high - Small steam consumption rate

3. Classification of WHG's utilization

There are several possible utilizations of small-scale WHGs.

3.1 Temporarily utilization during construction stage

Geothermal power plants are developed step by step, as shown in Fig.-3.1, from drilling necessary number of production wells to constructing power plant. In general, it takes several years and the start of power generation should wait for the completion of all production well drilling and power plant construction. During this construction period, no cash comes in from sales of electricity. The first possible and promising usage of WHG is to utilize waiting steam for power generation during construction stage to obtain early cash flows (Fig.-3.2). The WHGs should be portable type in this use because they would be removed once the main power plant is completed and transferred to another project site for reuse. This type of use is suitable for a developer who has several developing fields.

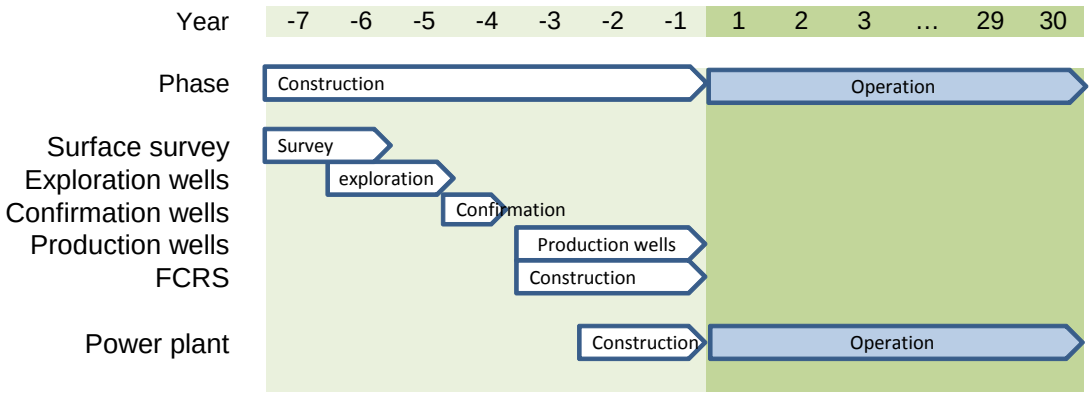


Fig-3.1 Process of geothermal power plant construction

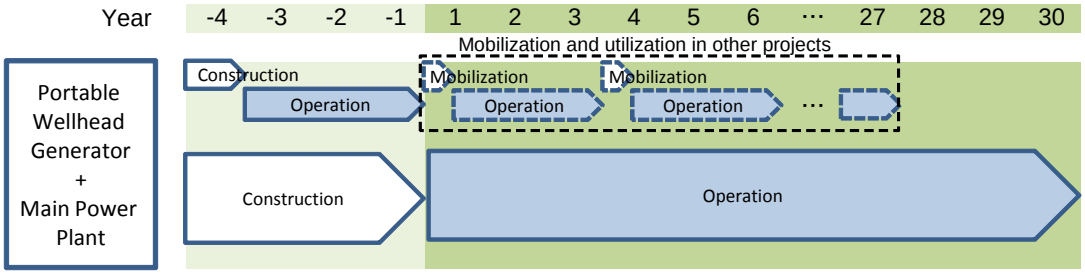


Fig.-3.2 Utilization of WHG (Temporarily utilization during the construction stage)

3.2 Permanent utilization in parallel with main power plant

The second possible utilization of WHGs is to use them not only during construction stage but also during operation stage of main power plant (Fig.-3.3). The purpose of this utilization is to obtain early cash flow, to save construction costs of steam pipeline, and to make use of the advantage of installing different design pressure of power plants according to the difference of production well pressure. On the other hand, however, the permanent use of WHGs reduces the steam volume that could have been used in the main power plant. Therefore, there is a problem that the capacity of main power plant becomes smaller than the case without WHGs and therefore the main power plant loses the advantage of scale-of-economy in construction costs. This permanent utilization of WHG could be possible when the profit of the former exceeds the losses of the latter.

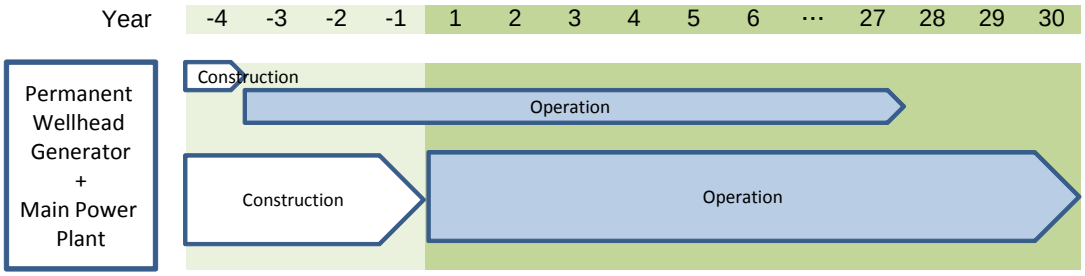


Fig.-3.3 Utilization of WHG (Permanent utilization)

3.3 Utilization of disconnected production wells

The third possible utilization of WHGs is to use them for the disconnected production wells, which are released from the steam gathering system due to the reduction of steam pressure below the designed pressure. The pressure and steam flow rate of production wells are slowly reduced during the service period. Once the pressure becomes below the designed pressure, such wells are released from the system and abandoned. This utilization of WHGs is to use these disconnected wells to recover remaining steam (Fig.-3.4). In this case, the WHG becomes smaller capacity than the two cases previously mentioned in section 3.1 and 3.2, because the turbines designed pressure becomes low. The feasibility of this utilization is decided by the balance of the amount of the investment in WHG and the amount of the steam value recovered from the disconnected wells.

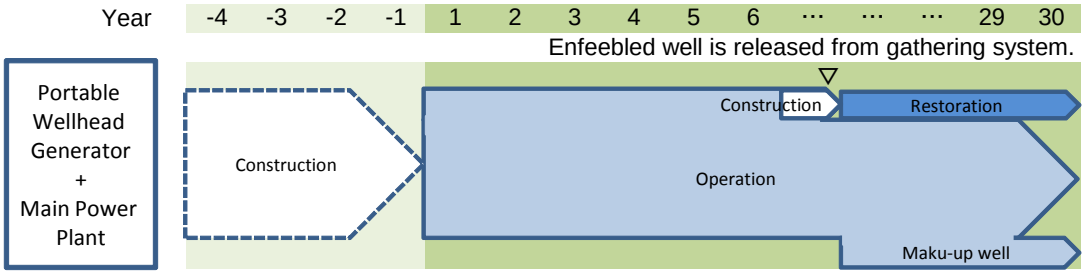


Fig.-3.4 Utilization of WHG (Utilization of disconnected production wells)

Table-3.1 summarizes utilization of WHG.

Table-3.1 Utilization of WHG

Utilization	Explanation	Economical gains	Economical losses
Temporarily utilization during construction stage (Portable type)	To generate power during the construction stage by setting portable type WHG at the waiting wells. This utilization is subject to the existence of other developing fields where WHGs are reused after operation of the main plant.	Early cash flows during construction stage using waiting steam.	Investment in WHG
Permanent utilization in parallel with main power plant (Permanent type)	To generate power in parallel with main power plant.	Early cash flows during construction stage using waiting steam. Reduction in construction costs of steam pipeline.	Investment in WHG Loss of scale-of-economy in construction costs of main power plant
Utilization of disconnected production wells (Portable type)	To generate power by setting low pressure type WHG at the disconnected production wells of which pressure becomes below the designed pressure of steam gathering system.	Recovery of remaining steam from the disconnected wells	Investment in WHG

4. Assumptions of economic evaluation of WHG

4.1 Model field considered

A geothermal model field that has three well pads which is equally located away from the center by the distance of L_1 [km] is considered as a Model filed, as shown in Fig.-4.1. This Model field has three production wells in each pad, totaling 9 production wells. The steam-brine separator is installed by each production well, and only steam is transported to the main power plant in the center through steam pipeline. Separated brine is transported to reinjection wells through water pipeline. When a geothermal power plant is constructed in such a way to consolidate steam of all wells in the main power plant, let's call this power plant as a "centralized PP".

On the other hand, let's consider a power plant that has WHGs in several wells of nine production wells, like the one shown in Fig.-4.2. Steam of wells that has no WHGs is collected by steam pipeline and transferred to the main power plant. Let's call this power plant as a "hybrid PP", which is a combination of WHGs and the main power plant. Moreover, let's call a power plant, which is consisted of WHGs alone and all power is transferred to the central substation by transmission line, as a "decentralized PP". The decentralized PP is an extreme case of a hybrid PP (Fig.-4.3).

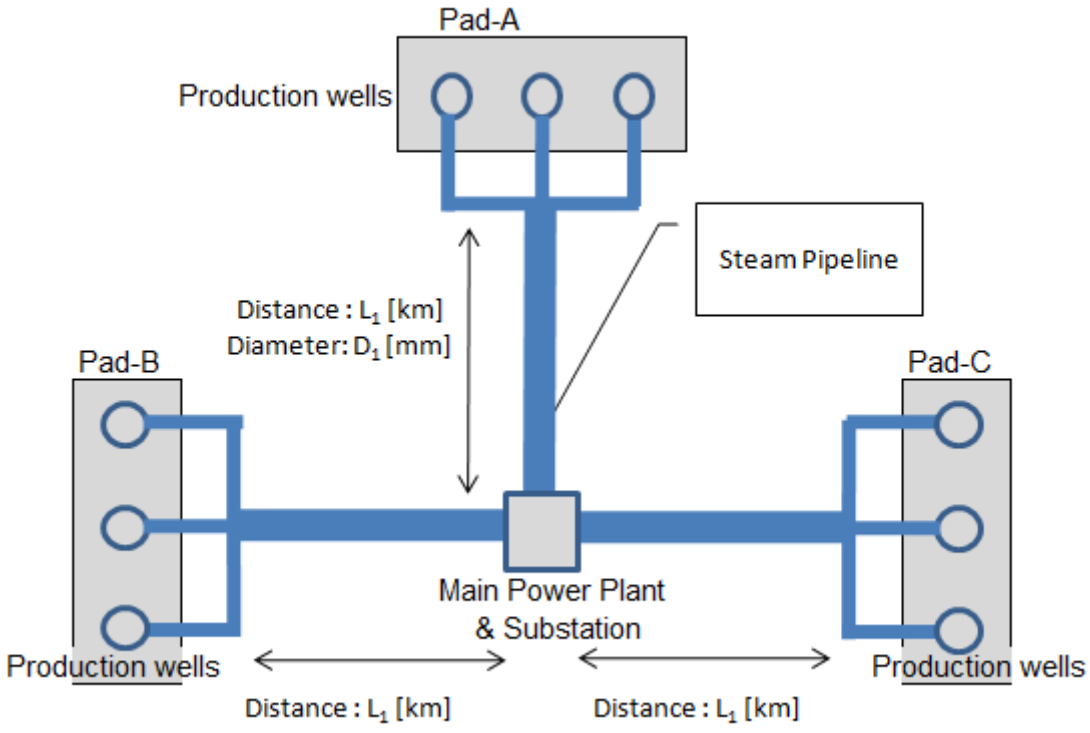


Fig.-4.1 Centralized Power Plant

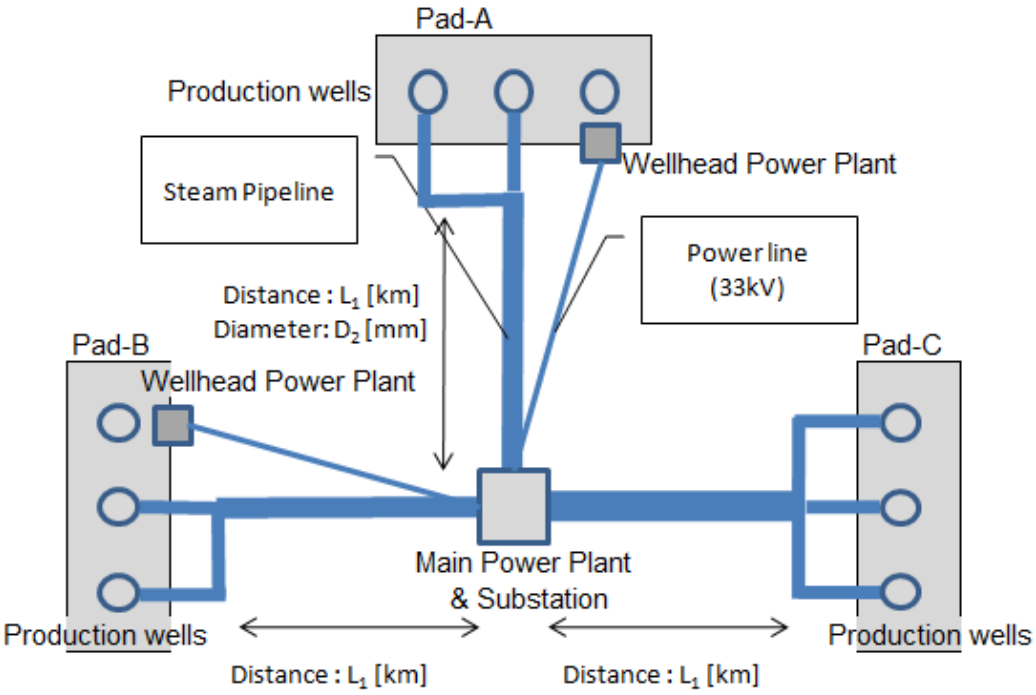


Fig.-4.2 Hybrid Power Plant

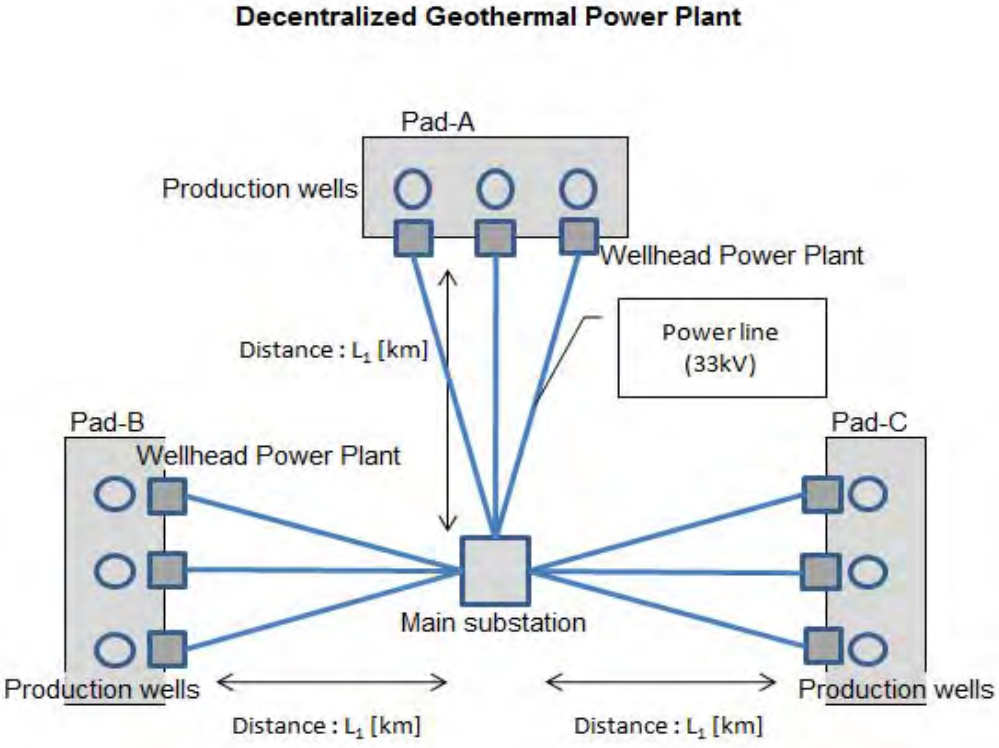


Fig.-4.3 Decentralized Power Plant

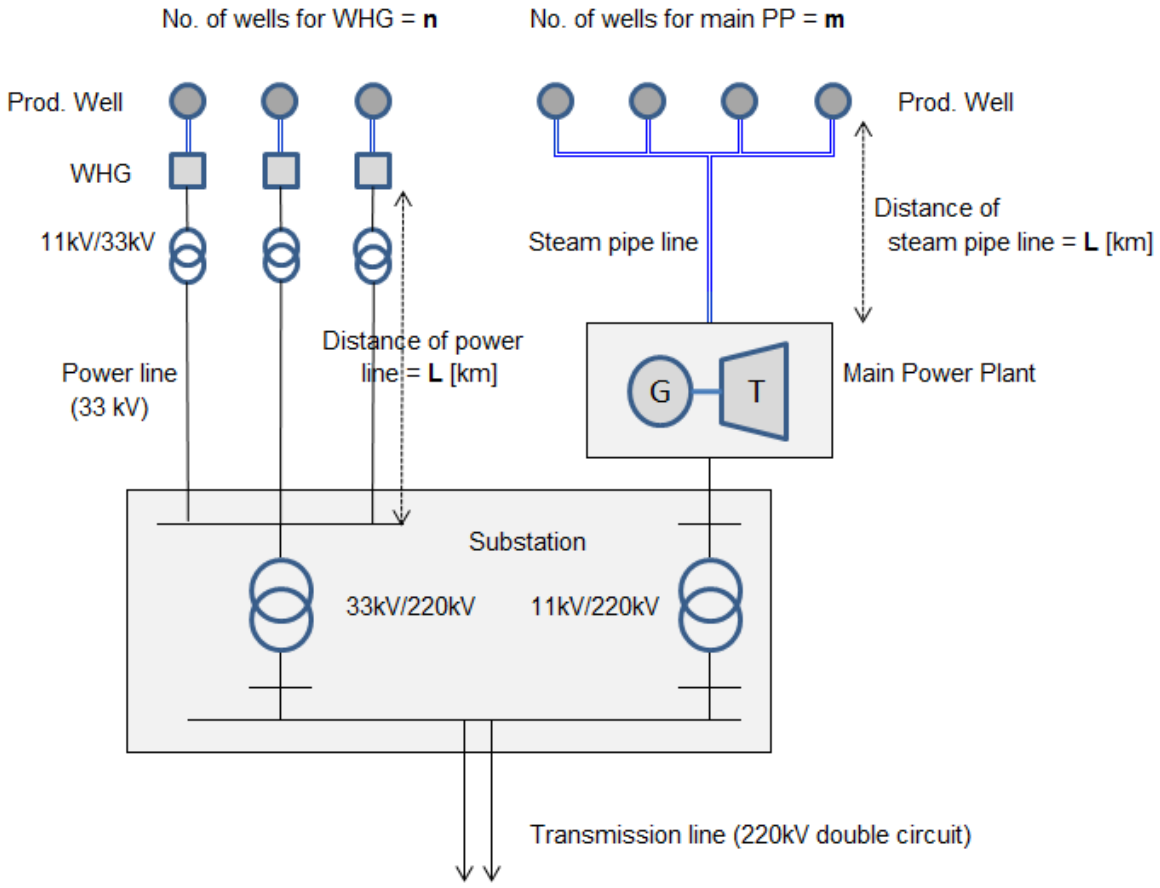


Fig.-4.4 System configuration of hybrid power plant

The system configuration of a hybrid PP is shown in Fig.-4.4. There are n wellhead generators installed in n of nine (9) production wells. Steam of the remaining (9-n) wells is transferred to the main power plant. The output of main power plant becomes less than that of a centralized PP that uses steam of all wells, because some steam is consumed by WHGs. The less volume of steam flow makes the steam pipeline construction costs of the hybrid PP less than that of the centralized PP. If all wells have WHG, the construction costs of steam pipeline becomes null. On the other hand, the electricity generated in WHGs is boosted to 33kV by wellhead transformers and transferred to the main substation by n transmission lines (33 kV). Therefore, the hybrid PP needs the extra installation costs of such equipments as WHGs, wellhead booster transformer (11kV/33kV), 33 kV transmission lines, switch gears, bays and a main transformer (33kV/220kV).

In this hybrid PP model, the case of n=0 represents a centralized PP, and the case of n=9 represents a decentralized PP. Our interest is what value of n presents the highest economic return in this hybrid PP model.

4.2 The output of hybrid PP

This Model assumes that each production well produces 50 t/h of steam and 450 t/h of steam is available in total. In the case that the steam consumption rate of steam turbine in the main power plant is 7.5 t/h/MW, the output of the centralized PP becomes 60 MW (the case of n=0). In the case that the steam consumption rate of WHG is 8.0 t/h, the output of one (1) set of WHG becomes 6.25 MW. However, the amount of steam for the main power plant reduces to 400 t/h and the output of it also decreases to 53.3 MW. Therefore, the combined output of the hybrid PP becomes 59.6 MW when one (1) set of WHG is installed (the case of n=1).

Similarly, the output of n sets of WHGs becomes 6.25n MW, and the output of the main power plant becomes (450-50n)/7.5 = (60-6.67n) MW. Therefore, the combined output of the hybrid PP becomes (60-0.42n) MW. As this example shows, the output of the hybrid PP decrease slightly from the centralized PP. However, this is the case that the steam consumption rate is 7.5 t/h/MW for the main power plant and it is 8.0 for WHGs. In this Model, the steam consumption rate is determined from the pressure at the turbine inlet, as explained later. As a result, the output of the hybrid PP differs the case by case.

4.3 The construction costs of hybrid PP

Next, let's see the construction costs of the hybrid PP. The construction costs of power plant differs according to its capacity. However, it does not always become double even if the capacity becomes double. This is attributed to the so-called scale-of-economy effect. In general, the construction costs (CC) of a power plant can be described in the following formula with the scale-of-economy factor of "κ".

$$\text{CC of power plant with capacity } P_2 = \text{CC of power plant with capacity } P_1 \times \left(\frac{P_2}{P_1}\right)^{\kappa} \quad (4.1)$$

Since the scale-of-economy factor is generally in the range of 0.7-0.8, the construction costs of a power plant becomes 1.6-1.7 times more even if the capacity doubles twice. On the contrary, the construction costs falls only up to around 60 percent level even if the capacity becomes half (1/2).

Here, let's assume that the unit construction costs of a centralized PP with capacity of 60 MW is 1,600 US$/kW and that of 5 MW WHG is 2,600 US$/kW. From these two costs, κ=0.805 is obtained. Using this κ, the construction costs of each plant can be calculated as follows.

Construction costs of a centralized PP with 60 MW capacity: 60 MW×1,600 US$/kW = 96 M$

Construction costs of a WHG with 5 MW capacity: 5 MW×2,600 US$/kW = 13 M$

Construction costs of a main PP with 53.3 MW capacity: $96\text{ M\$} \times \left(\frac{53.3}{60}\right)^{0.805} = 87.3\text{ M\$}$

Construction costs of a WHG with 6.25 MW capacity: $13\text{ M\$} \times \left(\frac{6.25}{5}\right)^{0.805} = 15.6\text{ M\$}$

Therefore, the construction costs of a 59.6 MW hybrid PP (with a set of WHG) are US$ 102.9 million, while that of 60 MW centralized PP are US$ 96 million. Similarly, the construction costs of a hybrid PP with n sets of WHG are sum of the following two costs.

Construction costs of a main PP with capacity of (60-6.67n) MW: $96\ \text{M\$} \times \left(\frac{60-6.67n}{60}\right)^{0.805}$

Construction costs of n sets of WHG with capacity of 6.25 MW: $13\ \text{M\$} \times \left(\frac{6.25}{5}\right)^{0.805} \times n$

From this example, you may see that the construction costs of power plant increase largely when a WHG is installed. This is attributed to the fact that the plant loses the scale-of-economy advantage in construction costs by dividing the output of the power plant (Fig.-4.5).

Table-4.1 Output and construction costs of Hybrid PP

Item	Main power plant	WHG
Number of wells	9-n	n
Output （P)	$P_{MAIN} = Q_{MAIN}/\eta_{MAIN}$ P_{MAIN}: Output of main PP [MW] Q_{MAIN}: Steam consumed by main PP [t/h] η_{MAIN}: Steam consumption rate of main PP [t/h/MW]	$n * P_{WHG} = n * (Q_{WHG}/\eta_{WHG})$ P_{WHG}: Output of WHG [MW]) Q_{WHG}: Steam consumed by WHG [t/h] η_{WHG}: Steam consumption rate of WHG [t/h/MW]
Construction costs (CC)	$CC_{MAIN} = CC_{60} * (P_{MAIN}/60)^{\kappa}$ CC_{MAIN}: Construction costs of main PP [M$] CC_{60}: Construction costs of 60 MW PP[M$] P_{MAIN}: Output of main PP [MW] κ: Factor of scale-of-economy	$n * CC_{WHG} = n * CC_5 * (P_{WHG}/5)^{\kappa}$ CC_{WHG}: Construction costs of WHG [M$] CC_5: Construction costs of 5 MW WHG [M$] P_{WHG}: Output of WHG [MW]) κ: Factor of scale-of-economy

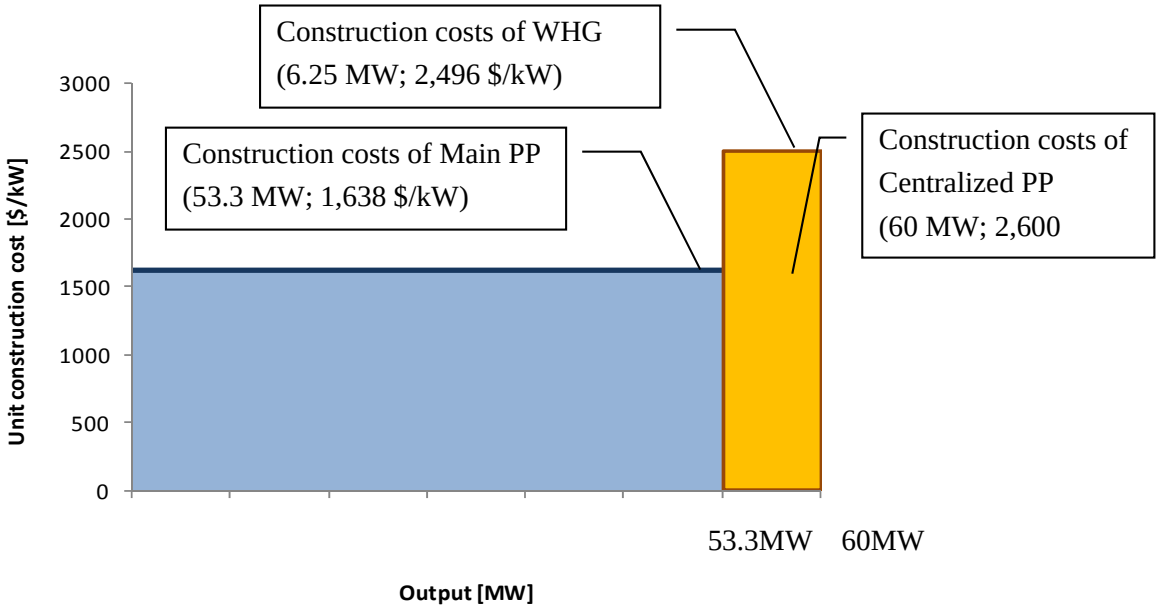


Fig.-4.5 Loss of scale-of-economy in construction costs

4.4 Construction costs of steam pipeline and power distribution line

When steam flows in a steam pipeline with diameter of d [m], there is a following relation of (4.2) among steam flow rate Q [t/h], steam velocity v [m/s] and steam density ρ [kg/m$^{3]}$. From this formula, the diameter is expressed by formula of (4.3) .

$$\frac{\pi}{4} d^2 v\rho = \frac{Q}{3.6} \qquad (4.2)$$

$$d = \sqrt{\frac{4Q}{3.6\pi v\rho}} \qquad (4.3)$$

Here, when v = 40 m/s and ρ = 4.90 kg/m^3 (at 9.5 bar(a) saturated steam pressure), the formula of (4.3) becomes (4.4).

$$d = 0.0425\sqrt{Q} \qquad (4.4)$$

The construction costs of steam pipeline are approximately proportional to the diameter and the length of pipe. Since the unit construction cost of pipeline is around 2.0 M$/mφ-km, the unit construction cost of pipeline (c_{PL} [M$/km]) is expressed by (4.5) formula.

$$c_{PL} = 0.0850\sqrt{Q} \qquad (4.5)$$

Therefore, when steam of three (3) production wells is transported to the main power plant, the steam flow rate (Q) is 150 t/h and the diameter (d) becomes 0.521 m. Therefore, unit construction cost (c_{PL}) becomes 1.04 M$/km. In such a circumstance, when one WHG is set on one of three wells, the steam flow rate (Q) reduces to 100 t/h. By this reduction, the diameter (d) reduces to 0.425 m and the unit construction cost (c_{PL}) decreases to 0.85 M$/km. As a result, the saving of the steam pipeline construction costs is 0.19 M$/km. Thus, the reduction of steam pipeline diameter is proportional to the square root of steam flow rate ($\sqrt{Q}$), and the reduction of construction costs is only 18% when steam flow rate reduces to two-thirds (2/3) of original state. Further, when WHGs are set on two of three production wells, the reduction of flow rate reduces to one-thirds (1/3) of original flow rate, and the unit construction costs reduces to only 58% of original costs. However, if all three wells have WHGs, then the steam pipeline costs becomes null (Fig.-4.6).

On the other hand, WHG requires power transmission line from WHG to the main substation that locates adjacent to the main power plant. The voltage of transmission line is around 33 kV of which transmission loss is less than that of 11 kV which is output voltage of WHGs. The construction costs of power transmission line is around 0.05 M$/km.

When WHGs are installed on each well of three pads in the numerical order as shown in Fig.-4.7, the construction costs of steam pipeline and power transmission line of a hybrid PP with n WHGs are expressed as shown in Fig.- 4.8 in case of distance (L_1) between the main power plant and the pads is 1 km.

Table-4.2 Unit construction cost of steam pipeline and power line in a hybrid PP

Item	Main power plant	WHG
Unit construction cost of steam pipeline (c_{PL})	$c_{PL} = 0.0850\sqrt{Q}$ c_{PL}: Unit construction cost of steam pipeline [M$/km] Q: Steam flow rate [t/h]	-
Unit construction cost of 33kV power line (c_{DL})	-	$c_{DL} = 0.05$ c_{DL}: Unit construction cost of 33kVpower line [M$/km]

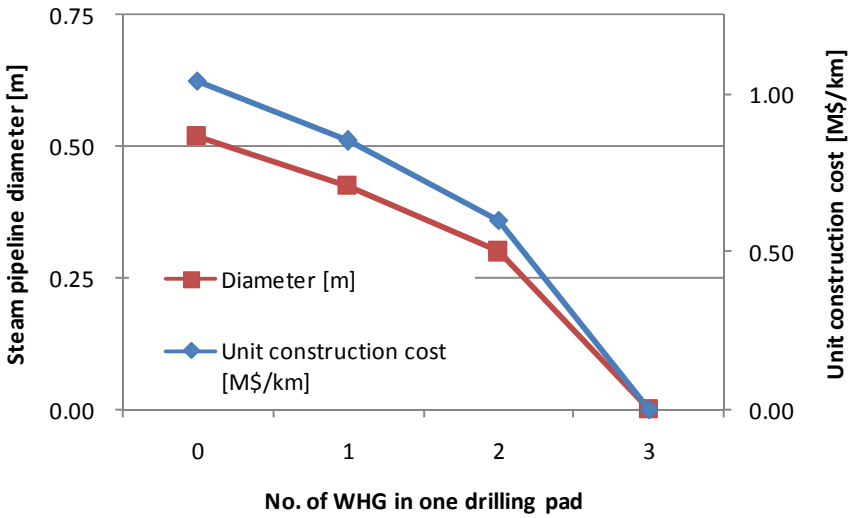


Fig.-4.6 Reduction of steam pipeline diameter and unit construction cost by WHGs

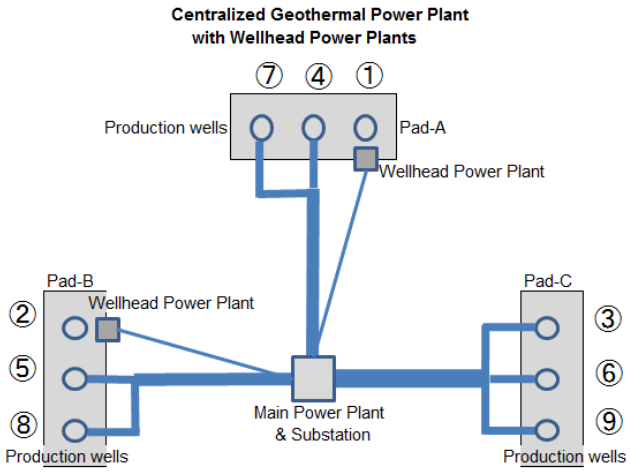


Fig.-4.7 Installation order of WHGs

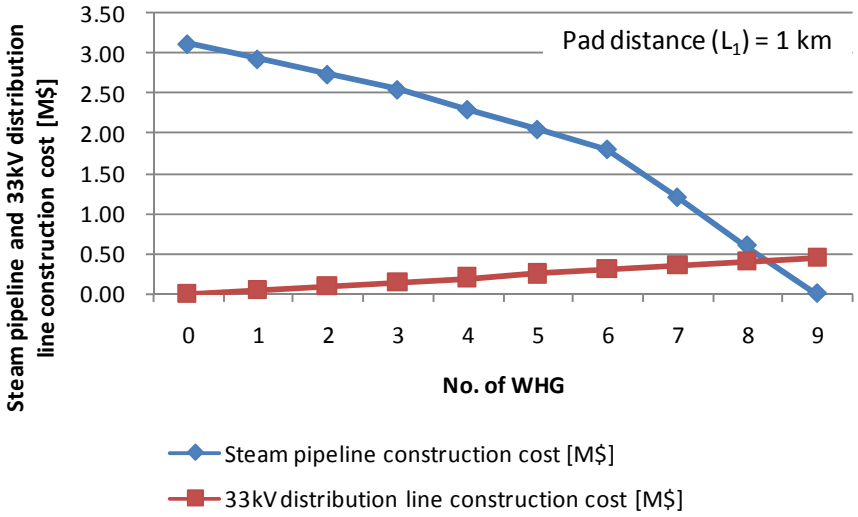


Fig.-4.8 Number of WHGs installed vs. unit construction cost of steam pipeline and 33 kV power line（in case of L_1=1km)

4.5 Other electric equipment costs needed to install WHGs

When n WHGs are installed, the following electric equipment costs are necessary in addition to power lines.

Table-4.3 Other electric equipment costs needed to install WHGs

Item	Unit cost	Quantity	In case of n=1
Wellhead booster transformer (11kV/33kV)	30,000 $/MVA/unit	n	0.24 M$
Adaptation work in main substation	0.74 M$/unit	n	0.74 M$
Switch gears	0.09 M$/unit	n	0.09 M$
Main transformer in main substation (33kV/220kV)	30,000 $/MVA	1	0.24 M$
Bay expansion (220kV)	1.28 M$/bay	4 bays × (n/9)	0.57 M$
Total			1.88 M$

Table-4.4 Electric equipment costs in hybrid PP

Item	Main power plant	WHG
Electric equipment costs	-	Costs of Table-4.3

4.6 Steam consumption rate of turbine, pressure loss and power transportation loss

In subsection 4.2, it is written that the output of main power plant and the output of WHGs are calculated by dividing the steam flow rate by the steam consumption rate of turbine. In fact, the steam consumption rate of turbine is not a constant number but a function of steam pressure at turbine inlet. Here, the steam consumption rate of turbine is obtained on the assumption that the turbine efficiency of the main power plant is 0.8 and that of WHG is 0.75. In addition, it is also assumed that the condenser pressure is 0.1 [bar(a)] in both the main power plant and the condensing type WHG case, while the back pressure is 1.1 [bar(a)] in case of the backpressure type WHG. The density of non-condensation gas in steam is assumed to be 2%. The steam consumption rate of turbine, which is obtained from these assumptions is shown in Fig.-4.9 and Table-4.5.

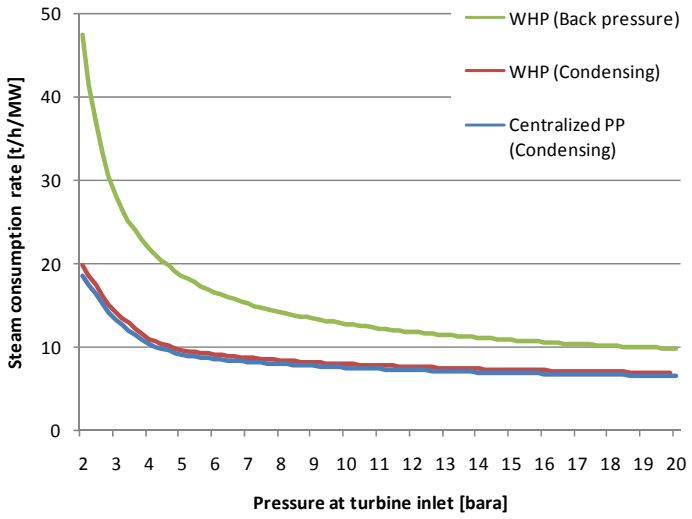


Fig.-4.9 Steam consumption rate of turbine at turbine inlet pressure

Table-4.5 Steam consumption rate of turbine at turbine inlet pressure

Turbine inlet pressure (p_t) [bar(a)]	Main power plant (condensing type) (η_{MAIN}) [t/h/MW]	WHG (condensing type) (η_{WHG}) [t/h/MW]	WHG (backpressure) (η_{WHG}) [t/h/MW]
3.0	13.2	14.1	28.1
4.0	10.3	11.0	21.8
5.0	8.98	9.58	18.6
6.0	8.51	9.08	16.6
7.0	8.16	8.70	15.2
8.0	7.88	8.40	14.2
9.0	7.65	8.16	13.4
10.0	7.45	7.95	12.8

By the way, in the case of WHG, the turbine inlet pressure is equal to the wellhead pressure because the WHG is set up in the neighborhood of the steam separator of the wells. On the other hand, in the case of the main power plant, the turbine inlet pressure is less than the wellhead pressure because there is pressure drop in the steam pipeline. Therefore, the turbine inlet pressure is expressed by the following.

Steam pressure at turbine inlet =
Steam pressure at the separator - Pressure loss in the steam pipeline (4.6)

The pressure loss in the steam pipeline is simply assumed as 1.0 [bar(a)] per one kilo-meter.

On the other hand, there is the power transmission loss between WHG and the main substation in the WHG case. This power transmission loss is assumed to be 0.15% of the amount of the electricity transmitted per one kilo-meter.

Table-4.6 Steam consumption rate of turbine, pressure loss and power transmission loss in hybrid PP

Item	Main power plant	WHG
Steam consumption rate of turbine	η_{MAIN}: see Fig.-4.9 where, $p_t=p_s-\Delta p$ η_{MAIN}: Steam consumption rate of main PP [t/h/MW] p_t : Steam pressure at turbine inlet [bar(a)] p_s : Steam pressure at separator [bar(a)] Δp : Steam pressure loss ($=p_s-p_t$) [bar(a)]	η_{WHG}: see Fig.-4.9 where, $p_t=p_s$ η_{WHG}: Steam consumption rate of WHG [t/h/MW] p_t : Steam pressure at turbine inlet [bar(a)] p_s : Steam pressure at separator [bar(a)]
Steam pressure loss in pipeline	$\Delta p=1.0*L_1$ Δp : Steam pressure loss in pipeline [bar(a)] L_1 : Distance between well pad and power plant [km]	-
Power transmission loss	-	$\Delta E = 0.0015*L_1*E$ ΔE : Power transmission loss [MWh] E : Amount of power transmitted [MWh] L_1 : Distance between well pad and power plant [km]

4.7 Costs of steam field development

The development of steam field is done to obtain 9 successful wells which produces 50 t/h steam each and 450 t/h in total. It is correspondent to a 60 MW power plant development. It is assumed that the steam field development is carried out over 7 years from surface survey, exploration drillings, resource confirmation, production/reinjection well drillings to the construction of steam/brine pipeline. Other assumptions are: 15 wells are drilled and 9 wells of them are successful. The drilling costs of production wells are US$ 5 million per well. As for reinjection wells, 13 wells are drilled and the drilling costs of reinjection wells are US$ 3.5 million/well. The total development costs are assumed as US$ 147.6 million (2,460 US$/kW). These costs does not include construction cost of steam pipeline because this cost is separately calculated and added according to the steam flow rate which varies with the number of WHGs installed in the hybrid PP.

As a result of this development activity, the successful wells are assumed to be obtained as shown in Table-4.7. WHGs are to be installed along this schedule on the first-drilled-first-installed basis.

Table-4.7 Steam field development costs (Unit: M$)

Item	-7 Yr	-6 Yr	-5 Yr	-4 Yr	-3 Yr	-2 Yr	-1 Yr	Total
Surface survey and Exploration	10.0	5.0						15.0
Resource confirmation			21.5	35.1				56.6
Production drillings, etc					17.0	27.2	24.8	69.0
Administration (5%)	0.5	0.3	1.1	1.8	0.9	1.4	1.3	7.0
Total	10.5	5.3	22.5	36.9	17.9	28.6	26.0	147.6
No. of successful well		1	1	1	3	3	0	9

This report assumes three kinds of WHG usage; (a) Temporarily utilization during construction stage, (b) Permanent utilization in parallel with main power plant, and (c) Utilization of disconnected production wells. In case (a) and in case (c), steam field development costs are originally paid by the main power plant, and therefore WHGs don't bear the steam field development costs. In case (b), however, the steam field development costs are allocated between the main power plant and the WHGs in proportion according to the number of wells each party uses, because this usage is long-term one and each party equally receives the benefit of steam field development (Table-4.8).

Table-4.8 Allocation of steam field development costs

WHG utilization	Main power plant	WHG
Temporarily utilization during construction stage	Pay all costs (100%)	Pay no costs (0%)
Permanent utilization in parallel with main power plant	Allocate proportionally according to the number of wells each party uses	
Utilization of disconnected production wells	Pay all costs (100%)	Pay no costs (0%)

4.8 Other assumptions

Other assumptions used in this report are as shown in Table-4.9.

Table-4.9 Other assumptions

Item	Main power plant (Condensing)	WHG	
		Condensing	Back pressure
Steam flow from separator	50 t/h/well		
Separator pressure	10 bar(a)（10~5 bar(a) sensitivity analysis is done）		
Distance of well pad	1.0 km		
Unit construction cost (*)	1,600 US$/kW (@ 60MW)	2,600 US$/kW (@ 5MW)	1,700 US$/kW (@ 5MW)
Auxiliary use ratio	6%	10%	2%
Annual O&M costs	3% of total const. costs	ditto	ditto
Turbine degradation rate	-	0.5% a.n.	ditto
Demobilization costs（**)	-	5% of const. costs	ditto
Annual plant factor	90%		
Operation years	30 years		
Depreciation years	Steam field equipment: 15years, Power plant: 25 years		
Depreciation method	Straight line method		
Selling price of electricity	8.5 US¢/kWh		
Tax rate	30%		
Capital source	Equity		

(*) Unit construction cost is adjusted from the value in the table and the output by the formula of (4.1).

(**) For the temporary utilization during construction period and for the utilization of disconnected production wells

4.9 Economic evaluation Model

An economic evaluation model of the hybrid PP, which includes the above-mentioned element, is built in Excel sheet (the Model). The main input data are steam flow rate from separator (Q_s [t/h]) of each well and the separator pressure (p_s [bar(a)]). The parameters which can be changed are: number of WHGs (n), distance between well pad and main power plant (L_1 [km]), turbine type of WHG (condensing type or backpressure type), construction costs, auxiliary use ratio, the selling price of electricity, tax rate, and annual O&M costs, etc. The main output are: the construction costs (CC_{HYB} [M$]) and an internal rate of return (IRR_{HYB} [%]) of the hybrid PP, the construction costs (CC_{WHG} [M$]) and an internal rate of return (IRR_{WHG} [%]) of WHGs, the construction costs (CC_{MAIN} [M$]) and an internal rates of return (IRR_{MAIN} [%]) of the main power plant as the breakdown of the hybrid PP (Fig.-4.10).

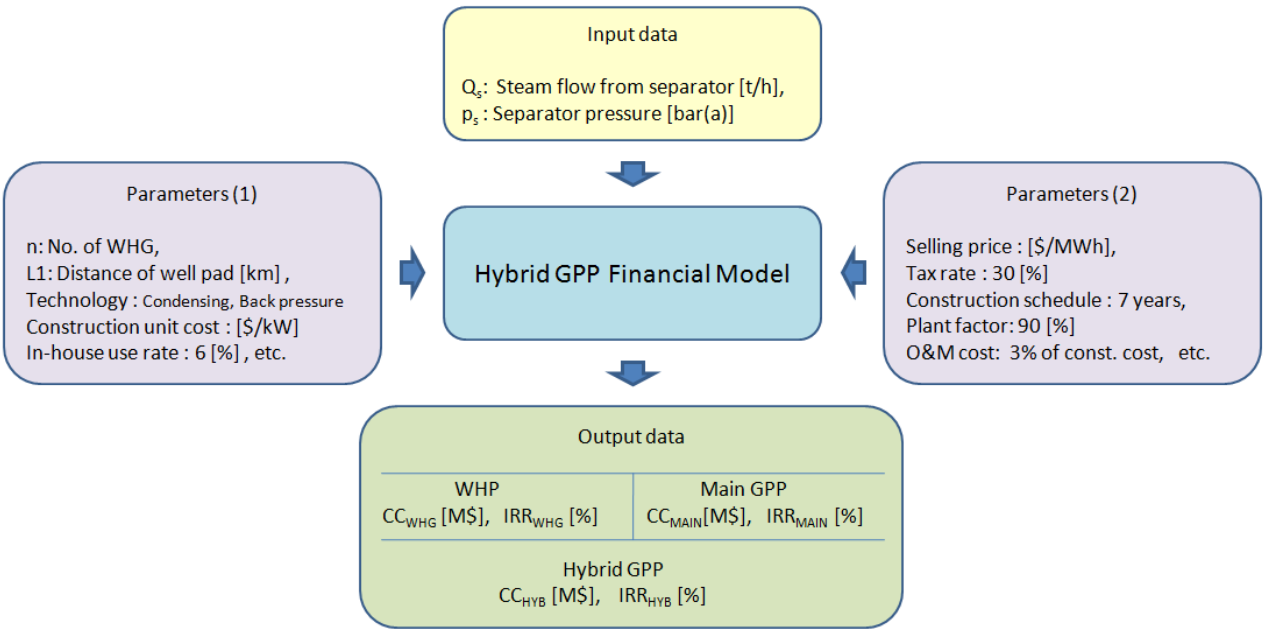


Fig.-4.10 Outline of economic evaluation model for hybrid PP

5. Economic evaluation of WHG temporarily utilized during construction period

5.1 Output, construction costs and returns

This chapter discusses the economic evaluation of WHG that is temporarily utilized during construction period of a centralized PP. Let's suppose that the centralized PP has a layout arrangement as shown in Fig.-4.1. Nine (9) production wells in three pads are supposed to produce 450 t/h of steam in total. The centralized PP can produce 60 MW output using all the steam (it is actually 58.8 MW in strict terms because of the pressure loss in pipeline). The production wells remain capped until all construction work finishes. However, it is waste of resource to keep all the production wells waiting until start of power plant operation. The usage of WHGs in this chapter is to utilize this waiting steam effectively for power generation by installing WHGs one by one to the production wells after their drilling is completed. .

None (9) production wells are supposed to be drilled in the order shown in Table-4.7. Therefore WHGs are utilized as shown in Fig.-5.1. Once the centralized PP start operation, WHGs are transferred to other project and are reused there. At this relocation, WHGs are to be sold to other project at the price of remaining book value.

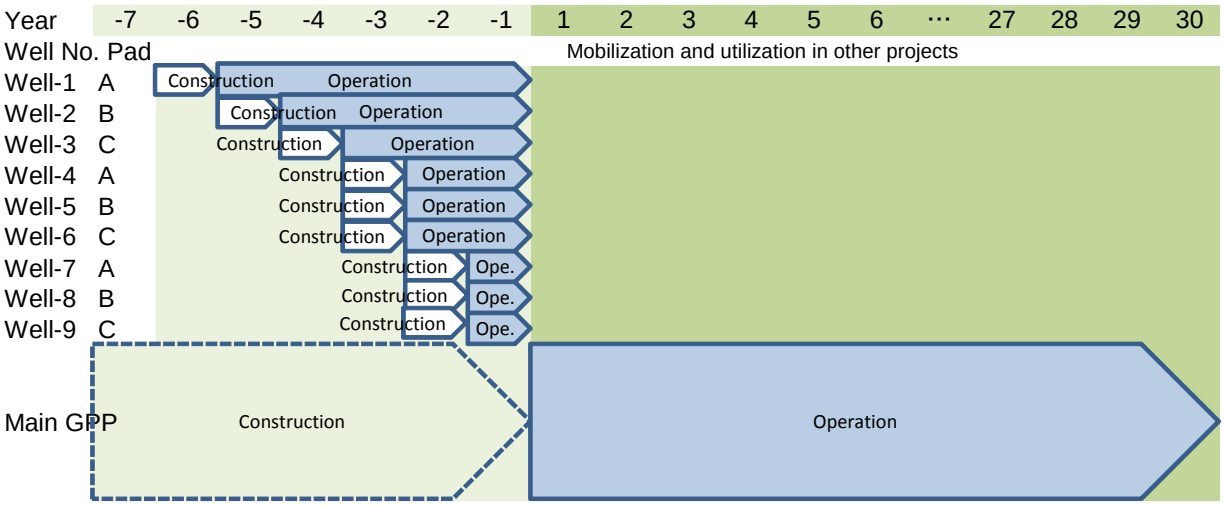


Fig.-5.1 Temporarily utilization of WHG during construction period

Both the condensing WHG and the back pressure WHG can be used for this purpose. Since the steam consumption rate of the condensing WHG is 7.95 t/h/MW, the output of the WHG becomes 6.3 MW for one unit, when the steam pressure is 10.0 bar(a) and the flow rate is 50 t/h. In case of back pressure WHG, the steam consumption rate is 12.8 t/h/MW and the output of the WHG becomes 3.9 MW. The amount of generation of the condensing type is 44.3 GWh in the first operation year, and it is 30.1 GWh of the back pressure type. The construction costs of condensing WHG is US$ 18.4 million and that of back pressure WHG is US$ 9.2 million respectively. The construction costs of centralized PP, of which output is 58.8 MW, is US$ 261.1 million including steam field development.

From these results, the internal rate of return (IRR) of the condensing WHG is 12.5%, that of the back pressure WHG is 18.0%, and that of the main power plant is 7.12% (Table-5.1, Table-5.2).

Table-5.1 Results of calculation
(Temporarily use during construction period; one unit of condensing WHG)

Item		WHG（construction period）	Main PP（after operation）	Total/Remarks
Steam flow rate (separator pressure10 bar(a))		50 t/h	450 t/h	-
Steam consumption rate (@ turbine inlet)		7.95 t/h/MW (@ 10.0 bar(a))	7.65 t/h/MW (@ 9.0 bar(a))	-
Output (gross)		6.3 MW	58.8 MW	-
Unit construction cost		2,486 $/kW	1,606 $/kW	-
Construction costs	Steam field development (a)	-	147.6 (M$)	Main PP bears
	WHG	15.6	-	-
	Power line, main substation	1.9	-	-
	Subtotal of WHG（incl. 5% administration cost） (b)	18.4 (M$)	-	-
	Main power plant	-	94.5	-
	Steam pipeline	-	3.1	-
	Main substation	-	10.5	-
	Subtotal of main PP（incl. 5%administration cost) (c)	-	113.5 (M$)	-
	Total (d)=(a)+(b)+(c)	18.4 (M$)	261.1 (M$)	279.6 (M$)
Generation（net）（1st year）		44.3 GWh	435.9 GWh	-
Internal rate of return（IRR)		12.5%	7.12%	

Table-5.2 Results of calculation

(Temporarily use during construction period; one unit of back pressure WHG)

Item		WHG (construction period)	Main PP (after operation)	Total/Remarks
Steam flow rate (separator pressure10 bar(a))		50 t/h	450 t/h	-
Steam consumption rate (@ turbine inlet)		12.8 t/h/MW (@ 10.0 bar(a))	7.65 t/h/MW (@ 9.0 bar(a))	-
Output (gross)		3.9 MW	58.8 MW	-
Unit construction cost		1,783 $/kW	1,606 $/kW	-
Construction costs	Steam field development (a)	-	147.6 (M$)	Main PP bears
	WHG	7.0	-	-
	Power line, main substation	1.8	-	-
	Subtotal of WHG (incl. 5% administration cost) (b)	9.2 (M$)	-	-
	Main power plant	-	94.5	-
	Steam pipeline	-	3.1	-
	Main substation	-	10.5	-
	Subtotal of main PP (incl. 5%administration cost) (c)	-	113.5 (M$)	-
	Total (d)=(a)+(b)+(c)	9.2 (M$)	261.1 (M$)	270.3 (M$)
Generation (net) (1st year)		30.1 GWh	435.9 GWh	-
Internal rate of return (IRR)		18.0%	7.12%	

5.2 Effect of early utilization

One of the benefits of WHG is that it can obtain the cash flow from early stage of construction period. To see this effect, the IRR of the WHG and the main PP combined is calculated for different usage period of WHG. Fig.-5.2 shows the combined IRR of one unit of WHG and the main PP when the WHG is used for 1 -5 years. Back pressure WHG is more profitable than condensing WHG and shows higher IRR if it is used from earlier year. Condensing WHG provides returns if it is used for more than two years.

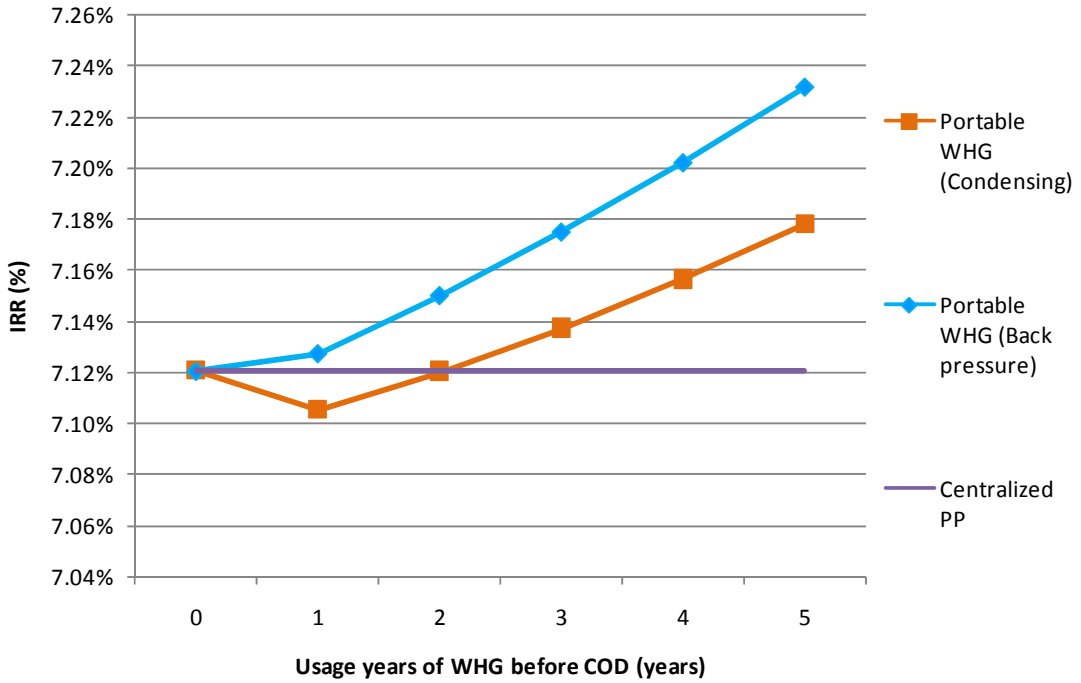


Fig.-5.2　Effect of usage years of WHG（Temporarily use during construction period）(n=1)

5.3 Optimal number of WHGs

Next, let's search whether there is an optimal number of WHGs installed. The WHGs are installed in the order shown in Table-4.7. Since the WHG that is installed in later stage provides smaller returns, the effect of WHG installation becomes gradually lower as the number of WHGs increases as shown in Fig.-5.3. Fig.-5.3 shows that the effect of back pressure WHG becomes the maximum when WHGs are installed in nine (9) wells. As for condensing WHG, the effect of WHG becomes the maximum when WHGs are installed in three (3) wells.

As discussed, the back pressure WHG is more suitable for the temporarily use during construction period. This is attributed to the relatively lower cost of the back pressure WHG than that of the condensing one. Table-5.3 compares the output, the power generation and the construction costs between a back pressure WHG and a condensing WHG. The reason why the cost of a back pressure WHG is lower than that of a condensing one is that the both WHGs bear their own equipment costs only and not bear steam field development costs. The steam field development costs are born by the main power plant. If the WHGs should also bear some of steam field development costs, then the costs and the power generation balance may change and the cost advantage of a back pressure WHG against a condensing WHG may disappear. In many cases, the condensing WHG may have cost advantages against back pressure WHG on the contrary. From technical view point, back pressure WHG is easy to installation and dismantling for short term use. Therefore back pressure WHG is recommendable for temporarily use during construction period.

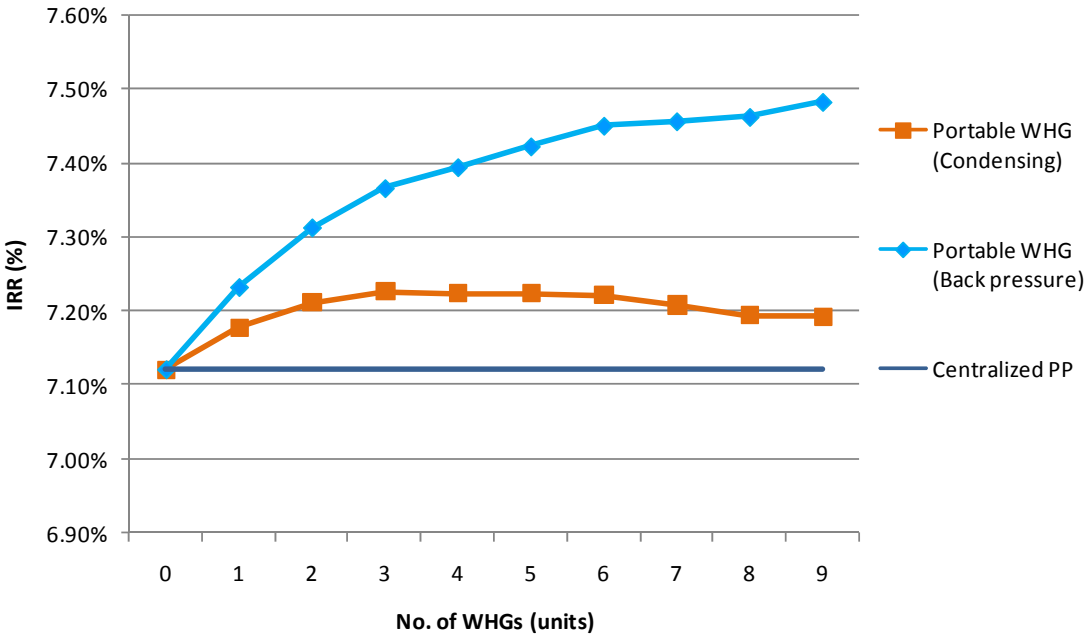


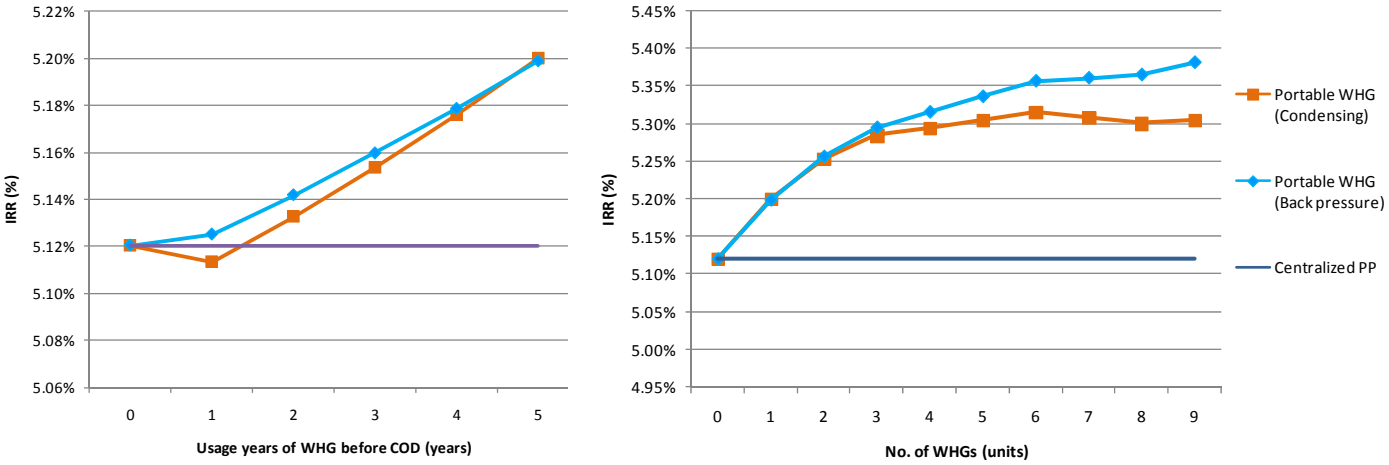
Fig.-5.3 Effect of numbers of WHGs (Temporarily use during construction period)

Table-5.3 Comparison between a condensing WHG and a back pressure WHG

Item	Condensing WHG	Back pressure WHG
Output	6.3 MW (1.00)	3.9 MW (0.62)
Power generation amount (1st year)	44.3 GWh (1.00)	30.1 GWh (0.68)
Construction costs per one WHG	18.4 M$ (1.00)	9.2 M$ (0.50)

5.4 Low steam pressure field

Above discussion is based on the assumption that the wells produce steam of 50 t/h flow rate and of 10 bar(a) pressure. Here, let's change this assumption and suppose that the steam pressure becomes 5 bar(a) instead of 10 bar(a). The result is shown in Fig.-5.4. The IRRs of both a back pressure WHG and a condensing WHG become lower and come to the almost same level. It is because the steam consumption rate of back pressure WHG deteriorates larger than condensing WHG in a low steam pressure range. This means that the back pressure WHG is not necessarily advantageous in the low steam pressure field.



(a) Effect of usage years of WHG (b) Effect of numbers of WHGs

Fig.-5.4 Effect of WHGs in case of 5 bar(a) steam pressure

5.5 Summary of temporarily use during construction period

From these results, the economic returns of the WHGs which are used temporarily during construction period can be summarized as follows.

(a) The temporarily use of WHGs during construction period can obtain cash flows from the early stage and has an effect of enhancing returns of the project. Therefore it is highly recommendable. However this analysis assumes that the WHGs will be effectively recycled and reused in other construction fields after the original construction field starts operation. This is an important condition and is necessary to note.

(b) The effect appears from the first year of usage for a back pressure WHG and appears from the second year of the usage for a condensing WHG. The effect becomes higher, if it is used longer or is installed earlier.

(c) It can be recommended to install WHGs to all the wells in case of back pressure WHG. In case of condensing WHG, there is an optimal number to install.

(d) The backpressure WHG is advantageous in the field where the steam pressure is high. Since the backpressure WHG is easy to transfer and is not costly, it is recommendable for temporarily use. However, the noise control measures is necessary for back pressure WHGs. It needs to take note that the back pressure WHG is not necessarily advantageous in the field where steam pressure is low, because the efficiency of back pressure turbine becomes low.

(e) Since Kenya has some geothermal development projects and steam pressure is usually high, it is recommendable for GDC to hold an appropriate number of back pressure WHG units for geothermal development projects, taking the GDC's development plan into consideration.

The calculation table of the IRR for the main PP project in Appendix Table-1, and the calculation table of the IRR for nine (9) sets of the back pressure WHGs which are used during construction period of the main PP is shown in Appendix Table-2.

6. Economic evaluation of WHG permanently utilized in parallel with main power plant

6.1 Output, construction costs and returns

The temporarily usage of WHGs during construction period is based on the condition that there are other development fields where the WHGs are recycled and reused. If such a condition is not met, the possibility of the permanent use of WHGs could be considered. This chapter discusses the economic evaluation of WHG that is permanently utilized in parallel with the main power plant.

Let's suppose that the hybrid PP has a layout arrangement as shown in Fig.-4.1. N sets of WHG are installed in n wells and the steam of the remaining (9-n) wells is transferred to the main power plant. the production wells are supposed to be drilled in the order shown in Table-4.7. Therefore WHGs are utilized as shown in Fig.-6.1. In the case of n=9, the power plant is consisted of all WHGs and is called a decentralized PP (Fig.-6.2).

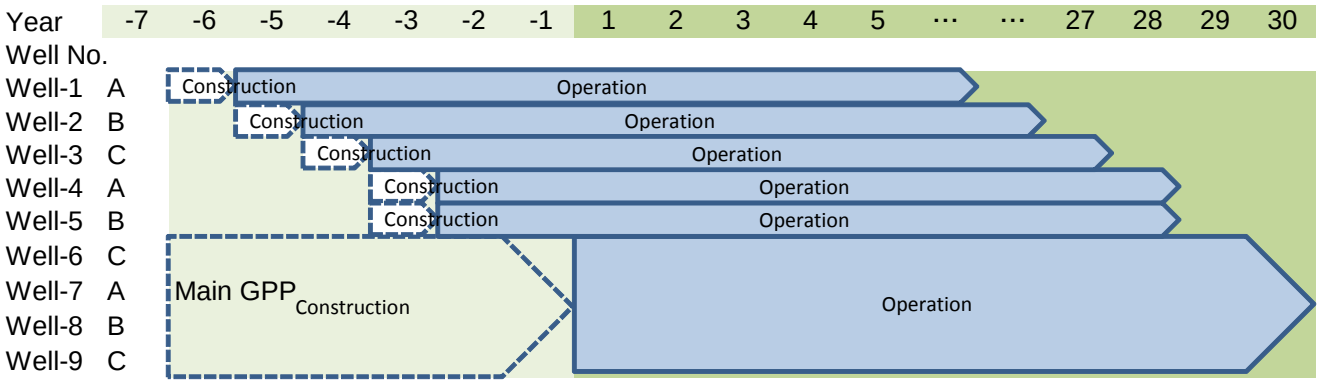


Fig.-6.1 Permanent utilization of WHG in parallel with main power plant (Hybrid PP (n=5))

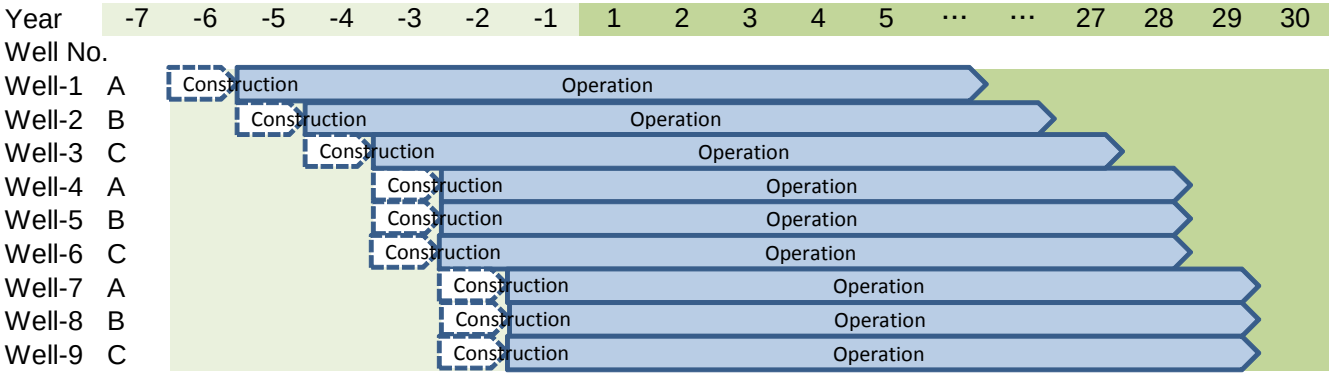


Fig.-6.2 Permanent utilization of WHG (Decentralized PP (n=9))

Table-6.1 Results of calculation (Hybrid PP with one unit of condensing WHG)

Item		WHG	Main PP	Hybrid PP Total
Steam flow rate (separator pressure10 bar(a))		50 t/h	400 t/h	450 t/h
Steam consumption rate (@ turbine inlet)		7.95 t/h/MW (@10.0 bar(a))	7.65 t/h/MW (@ 9.0 bar(a))	-
Output (gross)		6.3 MW	52.3 MW	58.6 MW
Unit construction cost		2,486 $/kW	1,644 $/kW	-
Construction costs	Steam field development (a)	16.4 (M$)	131.2 (M$)	147.6 (M$)
	WHG	15.6	-	15.6
	Power line, main substation	1.9	-	1.9
	Subtotal of WHG（incl. 5% administration cost） (b)	18.4 (M$)	-	18.4 (M$)
	Main power plant	-	85.9	85.9
	Steam pipeline	-	2.9	2.9
	Main substation	-	10.5	10.5
	Subtotal of main PP（incl. 5%administration cost) (c)	-	104.3 (M$)	104.3 (M$)
	Total (d)=(a)+(b)+(c)	34.8 (M$)	235.5 (M$)	270.3 (M$)
Generation（net） （1st year）		44.3 GWh	387.5 GWh	431.8 GWh
Internal rate of return（IRR)		5.8%	7.0%	6.9%

Table-6.2 Results of calculation (Hybrid PP with one unit of back pressure WHG)

Item		WHG	Main PP	Hybrid PP Total
Steam flow rate (separator pressure10 bar(a))		50 t/h	400 t/h	450 t/h
Steam consumption rate (@ turbine inlet)		12.8 t/h/MW (@10.0 bar(a))	7.65 t/h/MW (@ 9.0 bar(a))	-
Output (gross)		3.9 MW	52.3 MW	56.2 MW
Unit construction cost		1,783 $/kW	1,644 $/kW	-
Construction costs	Steam field development (a)	16.4 (M$)	131.2 (M$)	147.6 (M$)
	WHG	7.0	-	7.0
	Power line, main substation	1.8	-	1.8
	Subtotal of WHG（incl. 5% administration cost） (b)	9.2 (M$)	-	9.2 (M$)
	Main power plant	-	85.9	85.9
	Steam pipeline	-	2.9	2.9
	Main substation	-	10.5	10.5
	Subtotal of main PP（incl. 5%administration cost) (c)	-	104.3 (M$)	104.3 (M$)
	Total (d)=(a)+(b)+(c)	25.6 (M$)	235.5 (M$)	261.1 (M$)
Generation（net） （1st year）		30.1 GWh	387.5 GWh	417.6 GWh
Internal rate of return（IRR)		5.4%	7.0%	6.9%

Both the condensing WHG and the back pressure WHG can be used for this purpose. The calculation results of hybrid PP with one set of condensing WHG is shown in Table-6.1. Since the steam consumption rate of the condensing WHG is 7.95 t/h/MW, the output of the WHG becomes 6.3 MW

for one unit, when the steam pressure is 10.0 bar(a) and the flow rate is 50 t/h. As the main power plant is located 1.0 km away from well pads, the steam pressure decreases to 9.0 bar(a) at the turbine inlet and the steam consumption rate becomes 7.65 t/h. The steam available for the main power plant is 400 t/h, and then the output of the main PP becomes 52.3 MW, which makes the total output of the hybrid PP as 58.6 MW.

As for the construction costs, WHG needs to bear one ninths (1/9) of the steam field development costs. As a result, the construction costs of WHG is US$ 34.8 million and that of the main PP is US$ 235.5 million. The total construction costs of the hybrid PP becomes US$ 270.3 million. The IRRs from these investment are 5.8% for WHG, 7.0% for the main PP, and 6.9% as a whole for the hybrid PP.

The calculation table of the IRR for the hybrid PP, which uses one condensing WHG for 6 years, in Appendix Table-3.

Similarly, the calculation results of hybrid PP with one set of back pressure WHG is shown in Table-6.2. Since the steam consumption rate of the back pressure WHG is 12.8 t/h/MW, the output of the WHG becomes 3.9 MW for one unit. The output of the main power plant is as same as the condensing WHG case and is 52.3 MW, which makes the total output of the hybrid PP as 56.2 MW.

As for the construction costs, that of WHG is US$ 25.6 million and that of the main PP is US$ 235.5 million. The total construction costs of the hybrid PP becomes US$ 261.1 million. The IRRs from these investment are 5.4% for WHG, 7.0% for the main PP, and 6.9% as a whole for the hybrid PP.

6.2 Disadvantage of dividing power plant

As seen in section 6.1, the IRR of the hybrid PP is less than 7.1% of the IRR of the centralized PP which uses all steam of production wells (see the main power plant in Table-5.1).

This reduction is attributed to the fact that the first three loss factors of WHG ((a), (b), (c)) outweigh the last two benefits of WHG ((d), (e)), as shown in Table-6.3.

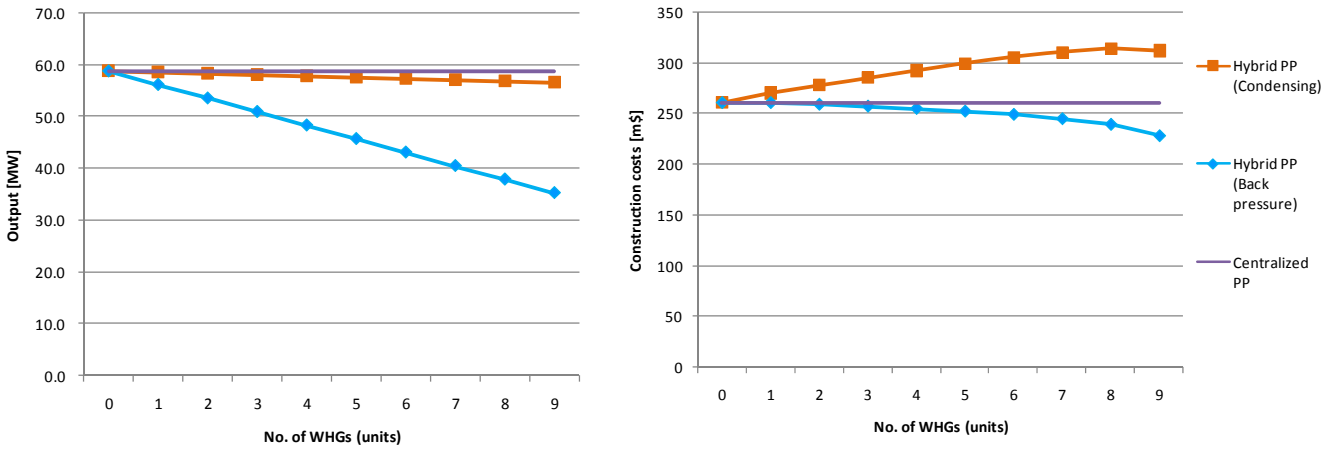
(a) Decrease in output (due to slightly higher steam consumption rate of WHGs than that of the main PP) (▲0.2MW)
(b) Increase in the construction costs by loss of scale-of-economy advantage (15.6 (A) - 8.5 (D) = 7.1 M$)
(c) Increase in electric equipment expense by WHG introduction (1.9 (B) M$)
(d) Decrease in the steam pipeline construction costs (0.2 M$ (E))
(e) Effect of early cash flows (1.7 M$ annually (cf. Appendix table-3))

Among these factors, the biggest one is an increase in the construction costs (b) (cf. Fig.-4.5).

Table-6.3　Comparison between a centralized PP and a hybrid PP with one set of condensing WHG

Item		Centralized PP (aa)	Hybrid PP (bb)	Difference (bb)-(aa)	
Output	WHG	-	6.3 MW		
	Main power plant	58.8 MW	52.3 MW		
	Total	58.8 MW	58.6 MW	▲ 0.2 MW	
Construction costs	Steam field development (a)	147.6 (M$)	147.6 (M$)	-	
	WHG	-	15.6	15.6	A
	Power line, main substation	-	1.9	1.9	B
	Subtotal of WHG（incl. 5% administration cost） (b)	-	18.4 (M$)	18.4 (M$)	C
	Main power plant	94.5	85.9	▲ 8.5	D
	Steam pipeline	3.1	2.9	▲ 0.2	E
	Main substation	10.5	10.5	▲ 0.0	F
	Subtotal of main PP（incl. 5%administration cost) (c)	113.5 (M$)	104.3 (M$)	▲ 9.2 (M$)	G
	Total　(d)=(a)+(b)+(c)	261.1 (M$)	270.3 (M$)	9.2 (M$)	H
Generation（net）（1st year）		435.9 GWh	431.8 GWh	▲ 4.1 GWh	
Internal rate of return（IRR)		7.1%	6.9%	▲ 0.27%	
Remarks		Table-5.1	Table-6.1		

As shown above, the permanent utilization of WHG brings the disadvantage of dividing a power plant scale into two parts. To confirm this phenomenon, the output, the construction costs and the IRRs of the hybrid PP are calculated for different number of WHGs. The result is shown in Fig.-6.3 and Fig.-6.4. The output of the hybrid PP decreases slightly in case of condensing WHGs and greatly in case of back pressure WHGs as the number of WHGs increases. The construction costs increases considerably in case of condensing WHGs and decreases slightly in case of back pressure WHGs as the WHG number increases. As a result, it is shown that the IRRs of the hybrid PP decreases gradually as the number of WHGs increases.



(a) Output　　(b) Construction costs

Fig.-6.3　Output and construction costs changes according to the number of WHGs

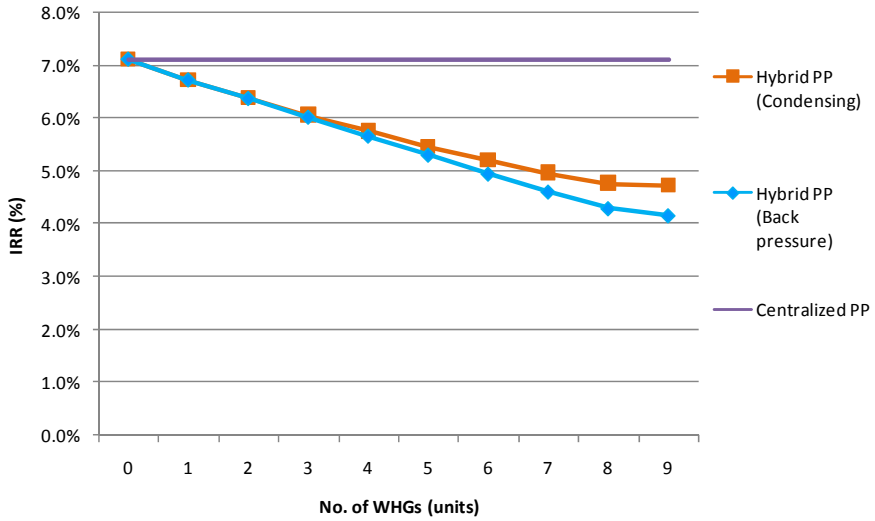


Fig.-6.4　IRR changes of hybrid PP according to the number of WHGs

6.3 Effect of early utilization

One of the benefits of WHG is that it can obtain the cash flow from early stage of construction period. To see this effect, the IRR of the hybrid PP is calculated for different usage period of WHG. Fig.-6.5 shows the IRR of the hybrid PP of which WHG is used for 1 - 5 years. The IRR with a condensing WHG and that with a back pressure WHG are almost same level, and increase as usage years increase. However, the IRRs with both WHG don't surpass the IRR of a centralized PP. The early utilization of WHGs don't come to cancel the disadvantage of dividing the power plant scale.

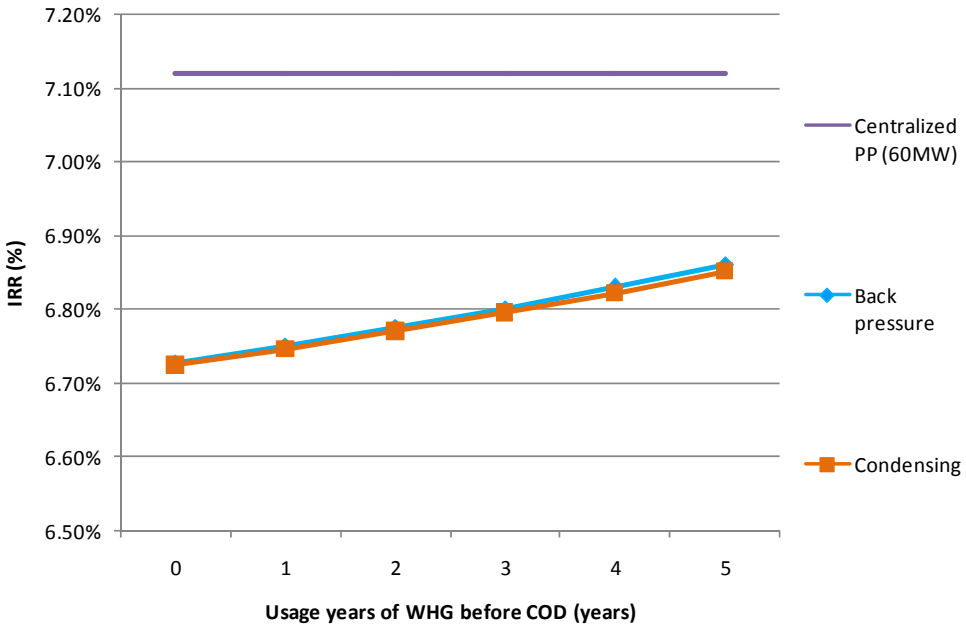


Fig.-6.5　Effect of usage years of WHG（Hybrid PP）(n=1)

6.4 Optimum number of WHGs

Next, let's examine whether there is an optimum number of WHGs in a hybrid PP. In this case, the production wells are supposed to be completed in the order shown in Table-4.7, and WHGs are installed in each well one by one in this order. Since the hybrid PP has a disadvantage of splitting plant scale, the IRR decreases as the number of WHGs increases within the steam pressure range of 10.0 - 5.0 bar(a) (Fig.-6.6).

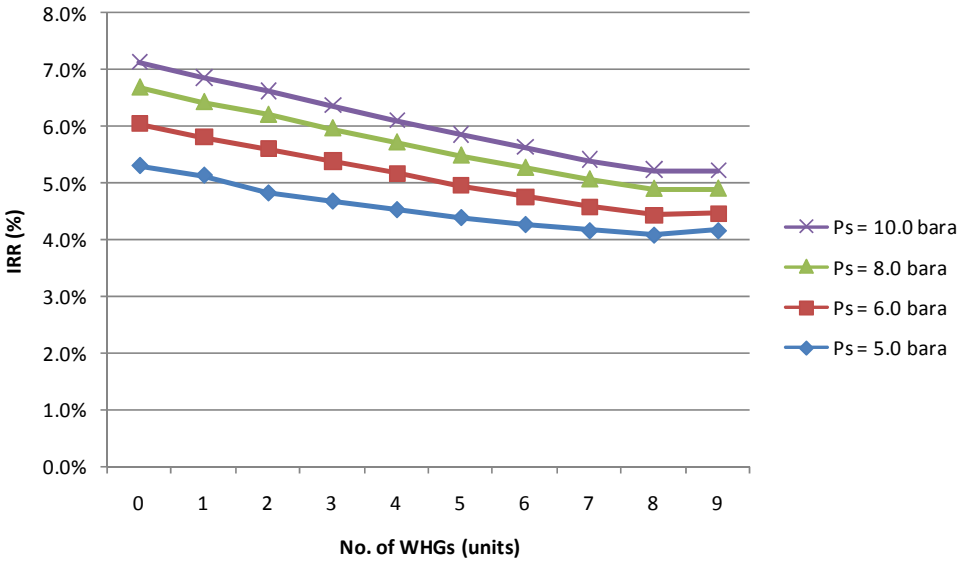


Fig.-6.6 Effect of numbers of WHGs (Hybrid PP with condensing WHG)

6.5 Randomization of steam production

6.5.1 Assumptions of randomization

The discussion in the previous sections is based on that all nine (9) wells equally produce steam with 10.0 bar(a) pressure at 50 t/h flow rate each and 450 t/h in total. Here, the following modifications are added to the assumptions of the economic evaluation Model so that the simulation reflects more reality.

<condition -1> Randomizing steam flow rate and pressure

Mass flow of geothermal fluid from the well (Q_w [kg/s]) is expressed by the second function of steam pressure at well head (p_w [bar(a)]) as shown in the formula of (6.1). Enthalpy (h_w [kJ/kg]) of the fluid is assumed to be constant as shown in expression of (6.2). From these Q_w and p_w, the steam flow rate from separator (Q_s) and separator pressure (p_s) are calculated that make the generation capacity maximum using the steam of each well.

$$Q_w = -ap_w^2+c \qquad (6.1)$$

$$h_w = e \text{ (constant)} \qquad (6.2)$$

Here, a, c, e are obtained by random numbers with the uniform probability assumption in the range of -0.001 ~ -0.03 for a, 10 ~ 50 for c, 1,000 - 2,500 for e. As a result, randomized Q_s and p_s are obtained.

When the steam flow rate is randomized like this, there might occur the cases that the total flow rate of nine (9) wells exceeds 450 t/h or less than 450 t/h. Therefore, to cope with such cases, the following conditions are also introduced. .

<Condition -2> Limitation of maximum output of the main power plant in hybrid PP

The turbine and generator in the main power plant must be ordered to manufacture at least three years before operation. Therefore even if more steam is obtained from the wells after the order of equipment, the maximum output of the plant is limited by the ordered specification. Here, the assumption is added that the output of the power plant is limited to 60 MW, or 60(1-n/9) MW in case of n sets of WHG are used, even if the total steam flow rate exceeds 450 t/h by randomization.

<Condition -3> Decrease in number of drilling wells

On the other hand, when the total steam flow rate of 450 t/h is obtained by less than 9 wells, no more wells are drilled to save construction costs.

On the other hand, the following two scenarios are considered for WHG.

<Scernario-1 WHGs are adjusted to the optimum condition for each well>

This scenario is the one that each WHG is individually adjusted to the optimum condition of each well so that the maximum power of wells can be driven from the WHGs.

<Scenario-2 Standard ready-made WHGs are used>

This scenario is the one that WHGs are obtained from the market as standard ready-made products and simply installed without adjusted to the wells. In such a case, the output of WHG is limited to that of standard ready-made machine. Therefore, even if the powerful steam is obtained from wells, the maximum output of WHGs is limited. The maximum power output of a standard product is assumed to be 10 MW here.

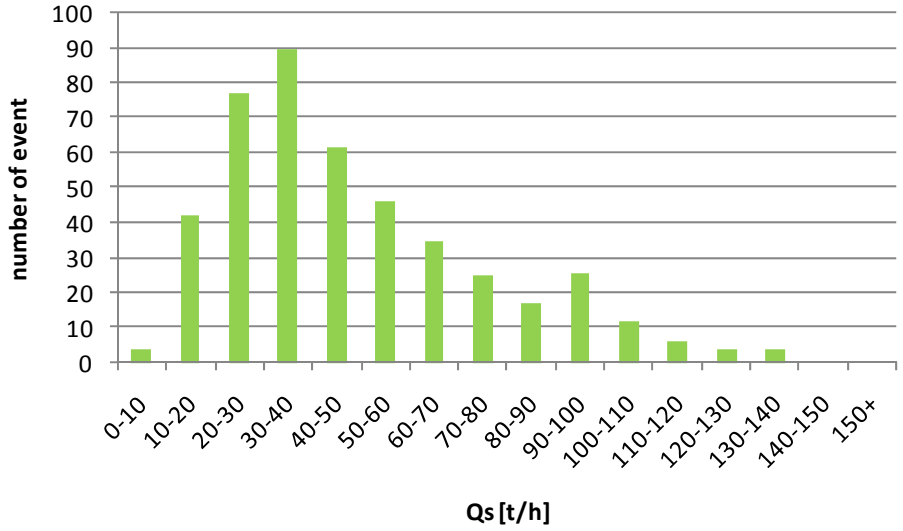
Randomization is done by Monte Carlo method. Fifty times trial are examined. In each trail, the IRR of hybrid PP is calculated with changing n (the number of WHGs) to find which n provides the maximum IRR.

6.5.2 Randomized steam flow rate and pressure

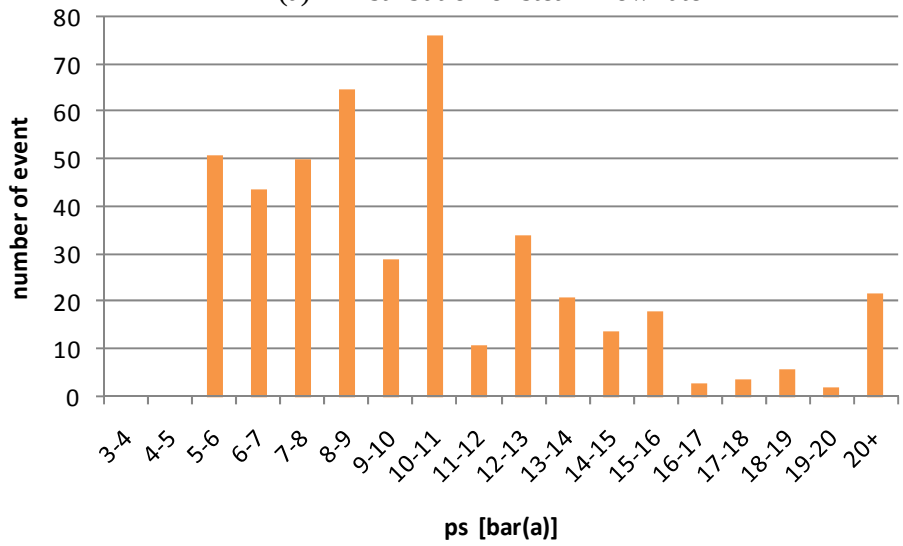
The distribution of steam flow rate (Q_s) and pressure (p_s) obtained in 50 trials (a total number of wells is 450) is shown in Table-6.4 and Fig.-6.7. The mean value of flow rate is 49.2 t/h and the mean value of pressure is 9.8 bar(a), which are roughly close to the uniform case.

Table-6.4 Distribution of randomized steam flow rate and pressure
(50 trials, total number of wells is 450)

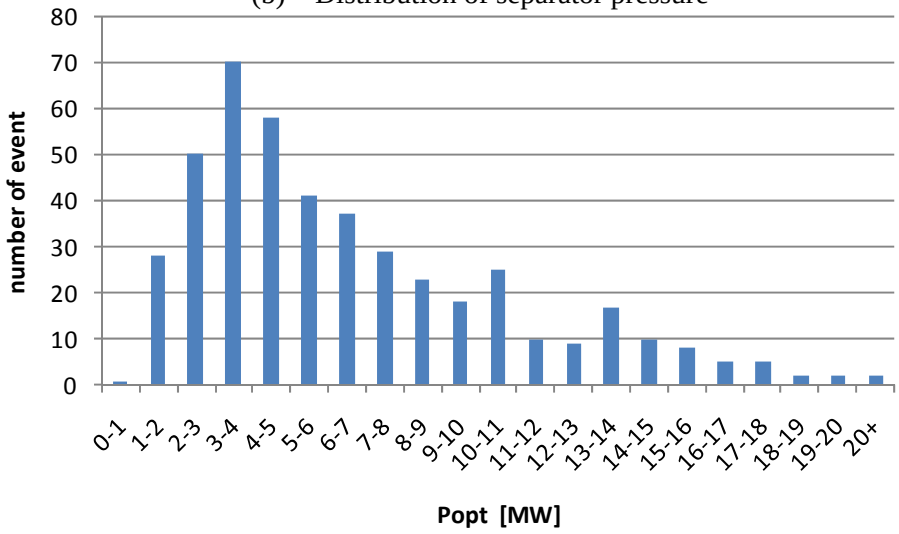
Item	Uniform case			Randomized case		
	Steam flow rate (Q_s)[t/h]	Separator pressure (p_s)[bar(a)]	Output (P_{opt})[MW]	Steam flow rate (Q_s)[t/h]	Separator pressure (p_s)[bar(a)]	Output (P_{opt})[MW]
Mean	50.0	10.0	6.7	49.2	9.8	6.7
Standard deviation	-	-	-	27.7	3.9	4.2
Maximum	-	-	-	138.8	20.0	20.6
Minimum	-	-	-	8.6	5.0	1.0



(a) Distribution of steam flow rate



(b) Distribution of separator pressure



(c) Distribution of well output Fig.-6.7 Distribution of randomized steam flow rate, pressure and output (50 trials, total number of wells is 450)

6.5.3 Results of calculation

The results of IRR calculation in 50 trials is shown in Table-6.5 (Scenario-1) and Table-6.6 (Scenario-2). In scenario-1, five (5) trials show the IRR becomes maximum when n=1, two (2) trials show the maximum IRR when n=2, one (1) trial shows the maximum IRR when n=3, and one (1) trial shows the maximum IRR when n=9. Other 41 trials show the maximum IRR when n=0.

From the results of this trials, a clear rule cannot be discovered, but the rough conclusion is as follows.

(a) Since n=0 represents the centralized PP, the centralized PP is most likely to obtain maximum return in principle. This observation is supported by Fig.-6.8,which shows the average IRR of 50 trials decreases as n, number of WHGs, increases. This means a concentrated PP is advantageous and it is corresponding to the discussions in the previous sections.

(b) However, if unusually large output wells are discovered in the early stage of exploration and WHGs are installed in such wells, the IRR becomes maximum. The degree of unusually large scale is around twice of expected output, around 13 MW in this trials (Table-6.5).

From the results of scenario-2, the number of cases that the IRR of hybrid PP with WHGs is the highest has decreased to four (4) times. This result can be interpreted that;

(c) When the WHGs are introduced, it is important to adjust WHGs to become the best design for each well.

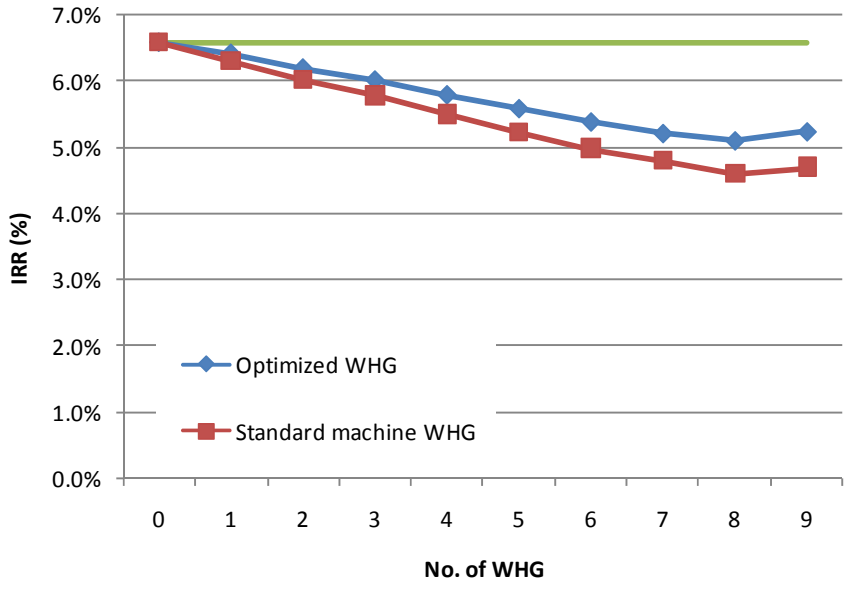


Fig.-6.8 Effect of numbers of WHGs (Hybrid PP with condensing WHG in randomized trials)

Table-6.5 Optimum number of WHGs under randomized steam flow rate and pressure (Scenario-1 Adjusted scenario)

	Output of Well										
Trial No.	Well-1 [MW]	Well-2 [MW]	Well-3 [MW]	Well-4 [MW]	Well-5 [MW]	Well-6 [MW]	Well-7 [MW]	Well-8 [MW]	Well-9 [MW]	MW of 9 wells are used to WHP	MW of 0 wells are used to WHP
1	13.7	14.2	3.0	8.6	13.3	5.7	7.0	11.5	4.1	**75.9**	**60.0**
2	2.4	8.7	8.4	4.8	6.0	4.0	4.7	2.7	11.7	**50.1**	**51.0**
3	6.0	2.6	6.5	15.9	12.9	10.1	5.7	8.1	4.1	**67.4**	**60.0**
4	10.4	4.5	3.8	9.7	9.6	3.5	1.3	2.3	3.1	**45.2**	**46.2**
5	3.1	3.3	1.8	7.7	17.0	7.8	9.5	4.9	4.6	**56.0**	**57.3**
6	3.4	7.5	13.4	4.5	16.0	6.8	1.5	4.1	4.9	**58.2**	**59.0**
7	7.3	13.5	10.9	6.8	4.7	8.4	5.5	1.1	13.9	**67.8**	**60.0**
8	1.4	7.0	5.3	2.8	4.1	5.2	6.8	5.3	5.2	**40.5**	**41.3**
9	5.9	3.3	14.6	17.1	9.8	5.2	2.9	8.5	13.4	**75.7**	**60.0**
10	3.2	3.1	11.6	1.4	3.4	10.5	4.4	5.1	10.2	**49.5**	**50.6**
11	5.1	13.8	9.4	4.4	7.6	5.6	10.7	1.1	2.0	**56.0**	**56.9**
12	10.0	2.6	10.9	15.5	13.2	4.6	1.7	6.4	2.8	**63.4**	**60.0**
13	6.2	3.7	8.4	2.6	9.3	5.7	2.0	6.6	4.7	**46.2**	**47.8**
14	5.8	7.3	6.2	2.8	4.2	6.5	12.1	13.0	3.6	**57.6**	**60.0**
15	2.5	10.5	15.3	3.4	8.5	3.1	4.0	1.3	6.7	**51.7**	**52.8**
16	12.6	10.9	5.0	2.4	11.7	6.6	4.8	5.3	3.6	**58.8**	**60.0**
17	1.2	11.8	1.9	2.1	5.0	8.7	9.0	13.5	4.1	**53.8**	**55.7**
18	4.5	7.9	5.5	2.8	12.7	14.1	4.9	9.3	4.6	**62.2**	**60.0**
19	8.1	6.1	14.3	7.0	2.5	1.9	8.6	15.5	4.0	**63.8**	**60.0**
20	11.0	14.0	1.0	3.7	4.8	2.5	10.6	10.2	8.9	**62.4**	**60.0**
21	4.0	17.4	2.7	6.7	3.3	4.5	4.5	7.6	7.4	**54.5**	**54.6**
22	18.7	10.6	8.3	3.1	2.0	8.3	13.0	11.9	4.3	**75.1**	**60.0**
23	9.5	3.9	12.8	3.2	2.3	10.5	10.2	15.4	2.6	**66.0**	**60.0**
24	3.7	3.8	11.6	5.0	4.2	3.2	1.4	15.5	5.6	**50.6**	**52.1**
25	9.0	5.5	1.0	3.6	7.0	13.6	2.6	14.2	4.9	**57.5**	**58.1**
26	3.6	3.5	9.8	7.7	5.5	2.6	9.2	3.8	5.2	**47.7**	**49.1**
27	2.7	4.3	8.0	4.0	6.0	6.5	8.8	1.3	10.5	**48.9**	**50.5**
28	6.3	19.1	9.8	2.9	8.0	3.2	8.5	13.9	2.7	**69.6**	**60.0**
29	8.8	9.9	4.0	6.8	2.3	4.1	14.8	11.1	3.9	**61.6**	**60.0**
30	3.7	4.4	6.7	4.8	2.4	3.6	1.9	17.3	7.3	**48.7**	**48.8**
31	10.9	1.8	8.0	7.8	5.8	1.2	4.5	2.6	19.0	**57.7**	**58.5**
32	3.1	9.3	8.5	7.2	3.7	2.4	1.9	1.2	2.8	**37.6**	**39.0**
33	2.3	2.6	6.9	16.6	4.1	4.9	6.9	10.1	3.8	**54.6**	**55.8**
34	15.1	6.9	8.7	6.0	5.9	6.1	4.7	2.8	4.6	**57.0**	**58.4**
35	5.6	7.9	5.0	1.6	3.7	16.1	3.2	3.6	3.6	**47.2**	**48.0**
36	1.2	11.4	14.0	1.7	2.3	4.1	7.2	2.3	2.9	**44.2**	**44.9**
37	2.5	3.6	6.6	6.1	7.3	4.5	8.1	3.6	4.4	**43.7**	**44.9**
38	3.6	4.0	2.7	10.2	6.0	3.6	7.5	6.0	1.9	**42.7**	**44.3**
39	17.9	8.8	4.7	2.0	4.6	2.1	6.2	10.6	7.6	**60.5**	**60.0**
40	2.5	8.0	3.6	3.8	4.1	7.2	3.6	4.7	10.4	**44.8**	**46.1**
41	3.3	7.4	5.3	3.2	4.0	6.1	5.3	2.1	13.0	**46.6**	**47.6**
42	5.0	13.8	4.9	3.8	1.4	4.2	9.7	6.5	11.6	**57.2**	**59.3**
43	13.6	3.8	7.8	2.6	2.2	3.5	5.4	5.5	4.8	**46.1**	**47.8**
44	3.8	6.7	1.9	5.1	9.7	2.8	2.9	5.9	5.7	**41.6**	**43.5**
45	5.8	3.7	3.4	4.9	1.4	10.1	6.3	4.6	3.2	**40.8**	**41.4**
46	2.5	3.3	20.4	5.7	14.4	3.9	6.5	3.0	9.3	**64.8**	**60.0**
47	20.6	3.2	3.9	2.3	13.1	3.9	2.7	4.2	7.2	**57.2**	**56.6**
48	16.8	6.5	4.0	14.1	3.9	7.1	4.0	6.3	3.5	**62.1**	**60.0**
49	6.3	4.5	4.4	5.2	15.4	14.1	7.0	10.5	4.9	**67.7**	**60.0**
50	12.9	3.6	10.8	17.8	11.6	12.2	6.4	14.4	19.1	**101.3**	**60.0**
Average	**7.0**	**7.2**	**7.3**	**6.0**	**6.9**	**6.1**	**6.0**	**7.2**	**6.4**	**56.4**	**54.2**

	IRR when No. of wells are used to WHP									
	1	2	3	4	5	6	7	8	9	0
1	7.8%	8.2%	7.7%	7.6%	7.6%	7.4%	7.2%	7.1%	7.2%	7.6%
2	6.0%	5.8%	5.5%	5.3%	5.1%	4.8%	4.7%	4.1%	4.6%	6.2%
3	7.2%	6.6%	6.3%	6.7%	6.8%	6.7%	6.5%	6.3%	6.3%	7.4%
4	5.4%	5.2%	5.0%	4.7%	4.4%	4.3%	4.2%	4.1%	4.2%	5.5%
5	6.6%	6.2%	5.6%	5.4%	5.7%	5.6%	5.4%	5.2%	5.2%	6.9%
6	6.8%	6.5%	6.4%	6.1%	6.0%	5.8%	5.7%	5.6%	5.6%	7.1%
7	7.0%	7.4%	7.5%	7.2%	6.9%	6.7%	6.4%	5.9%	6.5%	7.2%
8	4.6%	4.4%	4.2%	4.0%	3.8%	3.6%	3.5%	3.3%	3.3%	4.8%
9	7.1%	6.8%	7.0%	7.4%	7.3%	7.0%	6.6%	6.5%	7.0%	7.4%
10	5.9%	5.7%	5.4%	5.3%	4.9%	4.9%	4.6%	4.2%	4.5%	6.1%
11	6.8%	6.4%	6.1%	5.9%	5.8%	5.6%	5.4%	5.4%	5.4%	7.1%
12	7.5%	6.9%	7.0%	6.9%	6.6%	6.4%	6.3%	6.1%	6.1%	7.4%
13	5.4%	5.2%	5.0%	4.8%	4.6%	4.5%	4.4%	4.2%	4.1%	5.7%
14	6.9%	6.7%	6.4%	5.9%	5.4%	5.1%	5.3%	5.4%	5.4%	7.3%
15	6.2%	5.9%	5.7%	5.6%	5.3%	5.2%	5.0%	5.0%	4.9%	6.4%
16	7.2%	6.9%	6.7%	6.5%	6.2%	6.0%	5.9%	5.7%	5.7%	7.3%
17	6.5%	6.3%	6.1%	5.5%	5.1%	5.0%	5.0%	5.1%	5.0%	6.7%
18	6.9%	6.8%	6.4%	5.8%	6.1%	6.1%	5.9%	5.8%	5.8%	7.4%
19	7.3%	7.0%	7.1%	6.8%	6.4%	5.9%	5.9%	6.0%	6.1%	7.4%
20	7.4%	7.2%	7.1%	6.6%	6.2%	5.8%	5.7%	5.8%	6.0%	7.3%
21	6.3%	6.3%	6.1%	5.9%	5.7%	5.6%	5.3%	5.1%	5.2%	6.6%
22	8.3%	8.2%	8.1%	7.7%	7.2%	7.1%	7.2%	7.2%	7.2%	7.6%
23	7.4%	6.9%	7.2%	6.6%	6.0%	6.1%	6.2%	6.2%	6.3%	7.4%
24	6.1%	5.8%	5.5%	5.2%	5.0%	4.8%	4.2%	4.7%	4.7%	6.3%
25	6.8%	6.6%	6.3%	5.7%	5.5%	5.7%	5.3%	5.5%	5.5%	7.0%
26	5.7%	5.5%	5.2%	4.9%	4.8%	4.6%	4.4%	4.3%	4.3%	5.9%
27	5.9%	5.7%	5.4%	5.2%	5.0%	4.7%	4.4%	4.0%	4.4%	6.1%
28	7.1%	7.8%	7.7%	7.5%	7.1%	6.8%	6.7%	6.7%	6.7%	7.4%
29	7.2%	7.1%	6.7%	6.5%	6.0%	5.5%	5.9%	5.8%	5.8%	7.4%
30	5.7%	5.4%	5.2%	4.9%	4.7%	4.2%	3.5%	4.4%	4.4%	5.9%
31	6.8%	6.7%	6.5%	6.2%	6.0%	5.4%	4.9%	4.3%	5.5%	7.1%
32	4.1%	3.9%	3.7%	3.5%	3.3%	3.2%	3.1%	3.1%	3.1%	4.4%
33	6.6%	6.1%	5.8%	5.8%	5.6%	5.4%	5.2%	5.0%	5.1%	6.8%
34	7.0%	6.8%	6.5%	6.2%	6.0%	5.8%	5.6%	5.5%	5.5%	7.1%
35	5.5%	5.3%	5.1%	5.0%	4.8%	4.7%	4.5%	4.4%	4.4%	5.8%
36	5.2%	5.0%	4.7%	4.6%	4.5%	4.3%	4.1%	4.1%	4.1%	5.3%
37	5.1%	4.9%	4.6%	4.4%	4.2%	3.9%	3.7%	3.7%	3.7%	5.3%
38	5.0%	4.7%	4.6%	4.3%	4.1%	3.8%	3.7%	3.6%	3.6%	5.2%
39	7.3%	7.1%	6.9%	6.7%	6.6%	6.0%	5.7%	5.9%	5.9%	7.3%
40	5.3%	5.2%	5.0%	4.8%	4.6%	4.3%	4.0%	3.5%	3.9%	5.5%
41	5.5%	5.2%	5.0%	4.8%	4.6%	4.4%	4.2%	3.4%	4.2%	5.7%
42	6.8%	6.7%	6.5%	6.2%	5.6%	5.1%	5.2%	5.0%	5.4%	7.2%
43	5.5%	5.3%	5.1%	4.9%	4.8%	4.7%	4.5%	4.3%	4.3%	5.7%
44	4.9%	4.7%	4.6%	4.3%	4.1%	4.0%	3.8%	3.6%	3.5%	5.1%
45	4.5%	4.3%	4.1%	4.0%	3.9%	3.7%	3.5%	3.4%	3.4%	4.8%
46	6.9%	6.3%	7.1%	6.7%	6.7%	6.5%	6.3%	6.0%	6.2%	7.2%
47	6.9%	6.7%	6.5%	6.3%	6.1%	5.9%	5.7%	5.6%	5.7%	6.9%
48	7.4%	7.1%	6.9%	6.7%	6.4%	6.2%	6.1%	6.0%	6.1%	7.4%
49	7.1%	6.6%	6.3%	5.9%	6.3%	6.5%	6.3%	6.3%	6.3%	7.4%
50	8.1%	7.6%	7.6%	7.9%	7.9%	8.0%	7.8%	8.0%	8.7%	7.8%
Average	6.4%	6.2%	6.0%	5.8%	5.6%	5.4%	5.2%	5.1%	5.2%	6.6%

Table-6.6 Optimum number of WHGs under randomized steam flow rate and pressure (Scenario-2 Ready-made product scenario)

	Output of Well											IRR when No. of wells are used to WHP									
Trial No.	Well-1 [MW]	Well-2 [MW]	Well-3 [MW]	Well-4 [MW]	Well-5 [MW]	Well-6 [MW]	Well-7 [MW]	Well-8 [MW]	Well-9 [MW]	MW of 9 wells are used to WHP	MW of 0 wells are used to WHP	1	2	3	4	5	6	7	8	9	0
1	13.7	14.2	3.0	8.6	13.3	5.7	7.0	11.5	4.1	**66.5**	**60.0**	7.5%	7.6%	7.1%	7.0%	6.9%	6.6%	6.4%	6.3%	6.3%	7.6%
2	2.4	8.7	8.4	4.8	6.0	4.0	4.7	2.7	11.7	**49.1**	**51.0**	6.0%	5.8%	5.5%	5.3%	5.1%	4.8%	4.7%	4.1%	4.5%	6.2%
3	6.0	2.6	6.5	15.9	12.9	10.1	5.7	8.1	4.1	**60.4**	**60.0**	7.2%	6.6%	6.3%	6.2%	6.2%	6.0%	5.8%	5.6%	5.6%	7.4%
4	10.4	4.5	3.8	9.7	9.6	3.5	1.3	2.3	3.1	**45.2**	**46.2**	5.4%	5.2%	5.0%	4.7%	4.4%	4.3%	4.2%	4.1%	4.2%	5.5%
5	3.1	3.3	1.8	7.7	17.0	7.8	9.5	4.9	4.6	**50.1**	**57.3**	6.6%	6.2%	5.6%	5.4%	5.1%	4.9%	4.7%	4.5%	4.5%	6.9%
6	3.4	7.5	13.4	4.5	16.0	6.8	1.5	4.1	4.9	**50.7**	**59.0**	6.8%	6.5%	6.1%	5.9%	5.2%	5.0%	4.9%	4.7%	4.7%	7.1%
7	7.3	13.5	10.9	6.8	4.7	8.4	5.5	1.1	13.9	**61.7**	**60.0**	7.0%	7.1%	7.2%	6.9%	6.6%	6.5%	6.1%	5.5%	5.9%	7.2%
8	1.4	7.0	5.3	2.8	4.1	5.2	6.8	5.3	5.2	**40.5**	**41.3**	4.6%	4.4%	4.2%	4.0%	3.8%	3.6%	3.5%	3.3%	3.3%	4.8%
9	5.9	3.3	14.6	17.1	9.8	5.2	2.9	8.5	13.4	**63.4**	**60.0**	7.1%	6.8%	6.6%	6.5%	6.5%	6.1%	5.6%	5.6%	5.9%	7.4%
10	3.2	3.1	11.6	1.4	3.4	10.5	4.4	5.1	10.2	**48.7**	**50.6**	5.9%	5.7%	5.3%	5.2%	4.8%	4.8%	4.5%	4.1%	4.4%	6.1%
11	5.1	13.8	9.4	4.4	7.6	5.6	10.7	1.1	2.0	**53.0**	**56.9**	6.8%	6.1%	5.8%	5.6%	5.4%	5.2%	5.0%	5.0%	5.0%	7.1%
12	10.0	2.6	10.9	15.5	13.2	4.6	1.7	6.4	2.8	**56.3**	**60.0**	7.5%	6.9%	7.0%	6.4%	5.9%	5.7%	5.6%	5.3%	5.4%	7.4%
13	6.2	3.7	8.4	2.6	9.3	5.7	2.0	6.6	4.7	**46.2**	**47.8**	5.4%	5.2%	5.0%	4.8%	4.6%	4.5%	4.4%	4.2%	4.1%	5.7%
14	5.8	7.3	6.2	2.8	4.2	6.5	12.1	13.0	3.6	**54.2**	**60.0**	6.9%	6.7%	6.4%	5.9%	5.4%	5.1%	5.1%	5.0%	5.0%	7.3%
15	2.5	10.5	15.3	3.4	8.5	3.1	4.0	1.3	6.7	**47.3**	**52.8**	6.2%	5.9%	5.2%	5.0%	4.8%	4.6%	4.5%	4.4%	4.4%	6.4%
16	12.6	10.9	5.0	2.4	11.7	6.6	4.8	5.3	3.6	**55.8**	**60.0**	7.0%	6.6%	6.4%	6.3%	5.9%	5.7%	5.5%	5.4%	5.3%	7.3%
17	1.2	11.8	1.9	2.1	5.0	8.7	9.0	13.5	4.1	**50.0**	**55.7**	6.5%	6.2%	5.9%	5.4%	4.9%	4.9%	4.8%	4.7%	4.6%	6.7%
18	4.5	7.9	5.5	2.8	12.7	14.1	4.9	9.3	4.6	**57.1**	**60.0**	6.9%	6.8%	6.4%	5.8%	5.9%	5.6%	5.4%	5.3%	5.3%	7.4%
19	8.1	6.1	14.3	7.0	2.5	1.9	8.6	15.5	4.0	**55.8**	**60.0**	7.3%	7.0%	6.7%	6.4%	6.0%	5.6%	5.5%	5.2%	5.3%	7.4%
20	11.0	14.0	1.0	3.7	4.8	2.5	10.6	10.2	8.9	**59.0**	**60.0**	7.4%	6.9%	6.8%	6.3%	5.8%	5.4%	5.3%	5.5%	5.6%	7.3%
21	4.0	17.4	2.7	6.7	3.3	4.5	4.5	7.6	7.4	**48.2**	**54.6**	6.3%	5.5%	5.3%	5.1%	4.9%	4.8%	4.4%	4.3%	4.4%	6.6%
22	18.7	10.6	8.3	3.1	2.0	8.3	13.0	11.9	4.3	**64.2**	**60.0**	7.5%	7.5%	7.3%	6.9%	6.3%	6.2%	6.2%	6.1%	6.1%	7.6%
23	9.5	3.9	12.8	3.2	2.3	10.5	10.2	15.4	2.6	**59.5**	**60.0**	7.4%	6.9%	7.0%	6.4%	5.8%	5.9%	6.0%	5.6%	5.6%	7.4%
24	3.7	3.8	11.6	5.0	4.2	3.2	1.4	15.5	5.6	**45.1**	**52.1**	6.1%	5.8%	5.4%	5.1%	4.9%	4.7%	4.1%	4.0%	4.0%	6.3%
25	9.0	5.5	1.0	3.6	7.0	13.6	2.6	14.2	4.9	**51.5**	**58.1**	6.8%	6.6%	6.3%	5.7%	5.5%	5.4%	5.0%	4.8%	4.8%	7.0%
26	3.6	3.5	9.8	7.7	5.5	2.6	9.2	3.8	5.2	**47.7**	**49.1**	5.7%	5.5%	5.2%	4.9%	4.8%	4.6%	4.4%	4.3%	4.3%	5.9%
27	2.7	4.3	8.0	4.0	6.0	6.5	8.8	1.3	10.5	**48.9**	**50.5**	5.9%	5.7%	5.4%	5.2%	5.0%	4.7%	4.4%	4.0%	4.4%	6.1%
28	6.3	19.1	9.8	2.9	8.0	3.2	8.5	13.9	2.7	**58.7**	**60.0**	7.1%	7.0%	6.9%	6.7%	6.3%	6.0%	5.9%	5.5%	5.6%	7.4%
29	8.8	9.9	4.0	6.8	2.3	4.1	14.8	11.1	3.9	**57.3**	**60.0**	7.2%	7.1%	6.7%	6.5%	6.0%	5.5%	5.5%	5.4%	5.4%	7.4%
30	3.7	4.4	6.7	4.8	2.4	3.6	1.9	17.3	7.3	**42.5**	**48.8**	5.7%	5.4%	5.2%	4.9%	4.7%	4.2%	3.5%	3.6%	3.6%	5.9%
31	10.9	1.8	8.0	7.8	5.8	1.2	4.5	2.6	19.0	**49.7**	**58.5**	6.8%	6.7%	6.5%	6.2%	6.0%	5.3%	4.9%	4.2%	4.7%	7.1%
32	3.1	9.3	8.5	7.2	3.7	2.4	1.9	1.2	2.8	**37.6**	**39.0**	4.1%	3.9%	3.7%	3.5%	3.3%	3.2%	3.1%	3.1%	3.1%	4.4%
33	2.3	2.6	6.9	16.6	4.1	4.9	6.9	10.1	3.8	**49.0**	**55.8**	6.6%	6.1%	5.8%	5.2%	5.0%	4.8%	4.5%	4.4%	4.4%	6.8%
34	15.1	6.9	8.7	6.0	5.9	6.1	4.7	2.8	4.6	**52.9**	**58.4**	6.5%	6.3%	6.0%	5.7%	5.5%	5.2%	5.1%	5.0%	5.0%	7.1%
35	5.6	7.9	5.0	1.6	3.7	16.1	3.2	3.6	3.6	**42.1**	**48.0**	5.5%	5.3%	5.1%	5.0%	4.8%	4.0%	3.8%	3.7%	3.7%	5.8%
36	1.2	11.4	14.0	1.7	2.3	4.1	7.2	2.3	2.9	**40.4**	**44.9**	5.2%	4.9%	4.2%	4.1%	3.9%	3.8%	3.6%	3.5%	3.5%	5.3%
37	2.5	3.6	6.6	6.1	7.3	4.5	8.1	3.6	4.4	**43.7**	**44.9**	5.1%	4.9%	4.6%	4.4%	4.2%	3.9%	3.7%	3.7%	3.7%	5.3%
38	3.6	4.0	2.7	10.2	6.0	3.6	7.5	6.0	1.9	**42.7**	**44.3**	5.0%	4.7%	4.6%	4.3%	4.1%	3.8%	3.7%	3.6%	3.6%	5.2%
39	17.9	8.8	4.7	2.0	4.6	2.1	6.2	10.6	7.6	**53.7**	**60.0**	6.5%	6.3%	6.1%	5.9%	5.8%	5.1%	4.8%	5.0%	5.1%	7.3%
40	2.5	8.0	3.6	3.8	4.1	7.2	3.6	4.7	10.4	**44.8**	**46.1**	5.3%	5.2%	5.0%	4.8%	4.6%	4.3%	4.0%	3.5%	3.9%	5.5%
41	3.3	7.4	5.3	3.2	4.0	6.1	5.3	2.1	13.0	**44.4**	**47.6**	5.5%	5.2%	5.0%	4.8%	4.6%	4.4%	4.2%	3.4%	3.9%	5.7%
42	5.0	13.8	4.9	3.8	1.4	4.2	9.7	6.5	11.6	**53.3**	**59.3**	6.8%	6.4%	6.1%	5.9%	5.3%	4.7%	4.8%	4.6%	5.0%	7.2%
43	13.6	3.8	7.8	2.6	2.2	3.5	5.4	5.5	4.8	**43.4**	**47.8**	5.1%	4.9%	4.7%	4.5%	4.4%	4.3%	4.0%	3.9%	3.8%	5.7%
44	3.8	6.7	1.9	5.1	9.7	2.8	2.9	5.9	5.7	**41.6**	**43.5**	4.9%	4.7%	4.6%	4.3%	4.1%	4.0%	3.8%	3.6%	3.5%	5.1%
45	5.8	3.7	3.4	4.9	1.4	10.1	6.3	4.6	3.2	**40.8**	**41.4**	4.5%	4.3%	4.1%	4.0%	3.9%	3.7%	3.5%	3.4%	3.4%	4.8%
46	2.5	3.3	20.4	5.7	14.4	3.9	6.5	3.0	9.3	**52.2**	**60.0**	6.9%	6.3%	6.1%	5.7%	5.3%	5.2%	5.0%	4.5%	4.8%	7.2%
47	20.6	3.2	3.9	2.3	13.1	3.9	2.7	4.2	7.2	**45.6**	**56.6**	5.7%	5.5%	5.3%	5.1%	4.6%	4.3%	4.1%	4.0%	4.1%	6.9%
48	16.8	6.5	4.0	14.1	3.9	7.1	4.0	6.3	3.5	**53.1**	**60.0**	6.7%	6.5%	6.3%	5.6%	5.4%	5.2%	5.1%	5.0%	5.0%	7.4%
49	6.3	4.5	4.4	5.2	15.4	14.1	7.0	10.5	4.9	**60.1**	**60.0**	7.1%	6.6%	6.3%	5.9%	5.8%	5.8%	5.6%	5.6%	5.6%	7.4%
50	12.9	3.6	10.8	17.8	11.0	12.2	6.4	14.4	19.1	**79.3**	**60.0**	7.9%	7.3%	7.4%	7.1%	7.2%	7.2%	7.0%	6.9%	7.2%	7.8%
Average	**7.0**	**7.2**	**7.3**	**6.0**	**6.9**	**6.1**	**6.0**	**7.2**	**6.4**	**51.3**	**54.2**	6.3%	6.0%	5.8%	5.5%	5.2%	5.0%	4.8%	4.6%	4.7%	6.6%

The observation that an adjusted scenario (Scenario-1) is better than a ready-made product scenario (Scenario) is also seen in the comparison of the power plant outputs. Table-6.7 compares an average output of 50 trials in three kinds of power plant; (a) the centralized PP (n=0), (b) the decentralized PP (n=9) with adjusted WHGs (Scenario-1), and (c) the decentralized PP (n=9) with unadjusted WHGs (Scenario-2).

Table-6.7 shows that the average output of the decentralized PP with adjusted WHGs is 56.2 MW and is larger than 54.2 MW of the average output of the centralized PP, larger by 3.8%. However, when the WHGs are not adjusted, the average output decreases to 51.2 MW which is less than the centralized PP by 5.4%. Since one of the WHG's advantages is to make the best use of the output of each well, it is necessary to adjust WHGs to match the characteristic of each well.

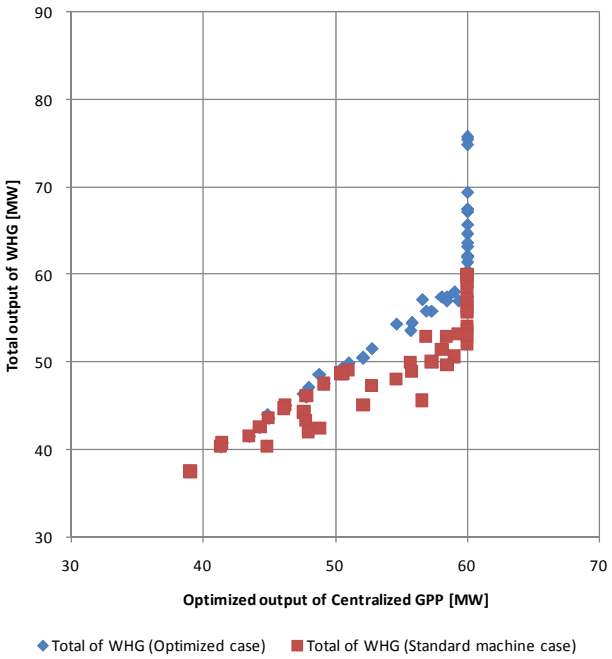


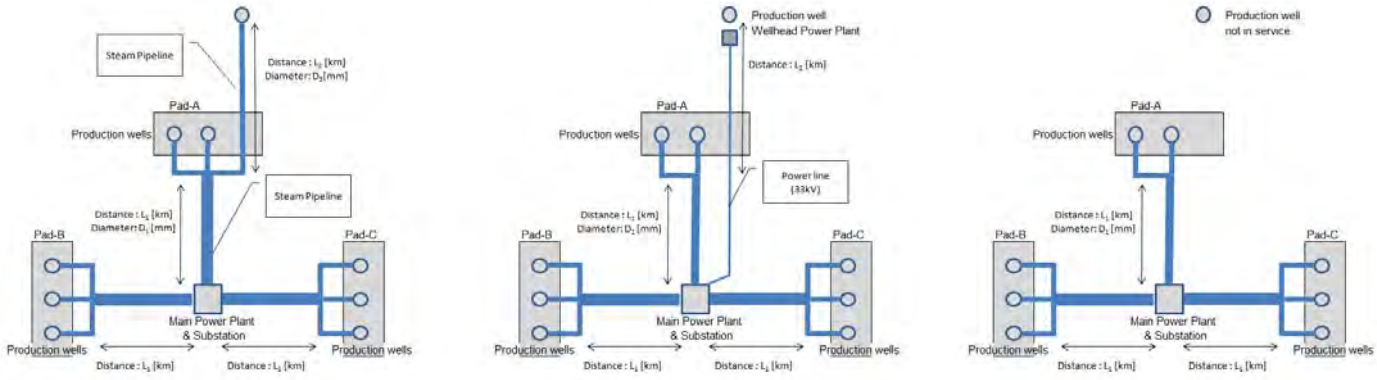
Fig-6.9 Output of decentralized PP (scenario-1 and scenario-2) against output of centralized PP (50 trials)

Table-6.7 Output of decentralized PP (scenario-1 and scenario-2) against output of centralized PP

Item	Centralized PP（a)	Decentralized PP with adjusted WHGs（b)	Decentralized PP with unadjusted WHGs（c)
Average output of 50 trials	54.2 MW (1.000)	56.2 MW (1.038)	51.2 MW (0.946)

6.6 Remote well

This section returns to the assumption of uniform steam flow rate and pressure again, and discusses an treatment of a well that is located in a remote area. Let's suppose that Well-1 alone is located at the distance of L_2 [km] from Pad-A. In this case, there are three kinds of treatment of Well-1; (a) Steam of Well-1 is transported to the main power plant by steam pipeline (Centralized PP with nine (9) wells), (b) a WHG is installed in Well-1 and remaining well are connected by steam pipeline (Hybrid PP with a WHG (n=1)), and (c) Well-1 is abandoned and eight (8) wells are used by the main power plant (Centralized PP with eight (8) wells) (Fig.-6.10).



(a) Centralized PP with 9 wells (b) Hybrid PP with a WHG (c) Centralized Pp with 8 wells

Fig-6.10 Development plan in case of geothermal field with a remote well

In case (a) of these three treatments, the wellhead pressure of Well-1 needs to be increased to more than 10.0 bar(a) to make up the pressure loss in pipeline. When wellhead pressure increases the steam flow rate from the well decreases. Here, the characteristic of Well-1 is assumed as shown in Table-6.8.

Table-6.8 Assumed characteristic of remote Well-1

Wellhead pressure (p_s)[bar(a)]	10	11	12	13	14	15	16	17	18	19	20
Steam flow rate (Q_s)[t/h]	50.0	48.8	47.6	46.3	45.0	43.6	42.1	40.6	39.2	37.3	35.6

(Note) Characteristic of Well-1is assumed as $Q_w = -0.017p_w^2+21.135$ [kg/s] and $h_w = 2,200$ [kJ/kg]

The calculation results of three cases is shown in Fig.-6.11 which expresses the IRR and the distance of L_2. First of all, when the centralized PP with 9 wells (case (a)) and the centralized PP with 8 wells (case (c)) is compared, the IRR of the former is higher than that of the latter within the range of 10 km. It means that it is more advantageous to utilize 9 wells than abandon the

remote well (Well-1). Next, when the centralized PP with 9 wells (case (a)) and the hybrid PP (case (b)) is compared, the IRR of the former is higher than that of the latter until the distance becomes 7.5 km. The IRR of the hybrid PP with condensing WHG and with back pressure WHG are almost same level.

In short,

(i) It is desired to utilize wells even though they are located in remote area, because they are drilled using a certain development costs.

(ii) It is advantageous to transport steam by steam pipeline to a centralized PP if distance (L2) is less than 7.5km.

(iii) When distance (L2) exceeds 7.5km, a hybrid PP using a WHG in the remote well is advantageous.

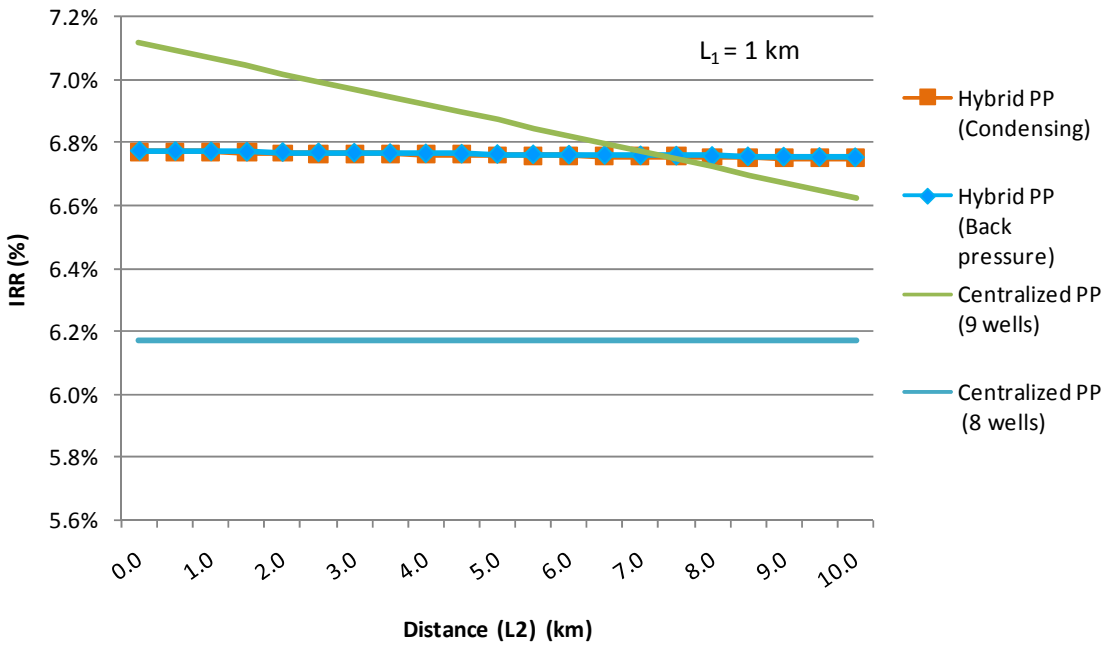


Fig.-6.11 The IRRs of three kinds of plant when one well is located in remote area

6.7 Effect of the construction costs reduction of WHG

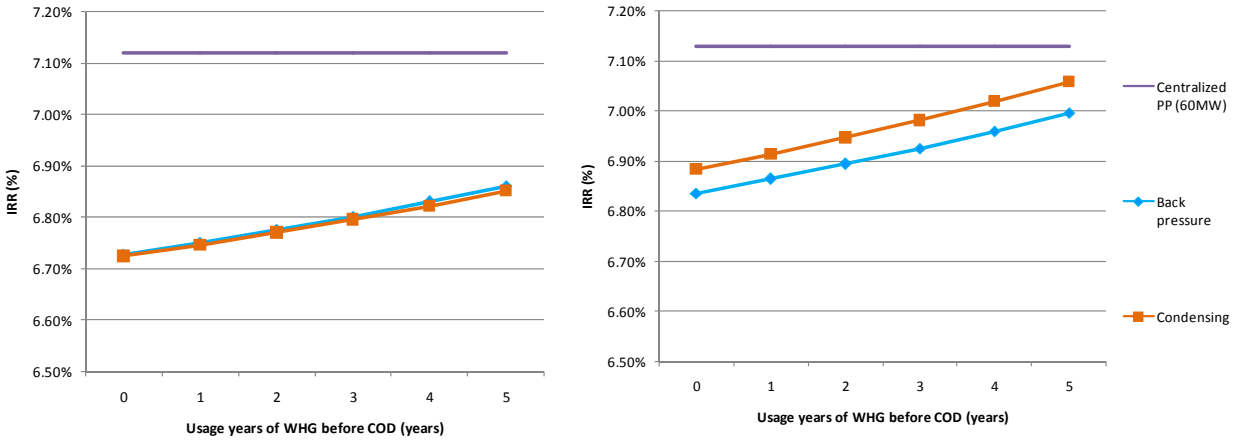
The analysis in the previous sections is based on the assumptions of the following unit construction costs: a condensing WHG of 5 MW is 2,600 US$/kW and a back pressure WHG of 5 MW is 1,700 US$/kW. This section studies the IRR of the hybrid PP when the unit construction costs decreases to 2,000 US$/kW for a condensing WHG and 1,300 US$/kW for a back pressure WHG.

First of all, the significant improvement is seen for the effect of WHG introduction at the early stage although the effect does not recover the disadvantage of splitting plant scale yet. (Fig.-6.12(b)). Next in the treatment of a remote well, when distance (L_2) becomes 4.0 km or more, the hybrid PP becomes advantageous in this case study (Fig.-6.13(b)).

The results tell us that a concentrated PP is still more advantageous than a hybrid PP. However, an interesting result is obtained in the low steam pressure field. That is, when steam pressure decreases to 5 bar(a), the IRR of a centralized PP, a hybrid PP and a decentralized PP become almost same level regardless of the number (n) of WHGs (Fig.-6.14(b)). Of course, the IRRs are low level of around 5% and it is rather difficult to start the project in general. However, if the project owner can obtain low interest rate finance like ODA, there is a possibility to approve the project. In such a case, a hybrid PP or a decentralized PP might be possible in the low steam pressure field.

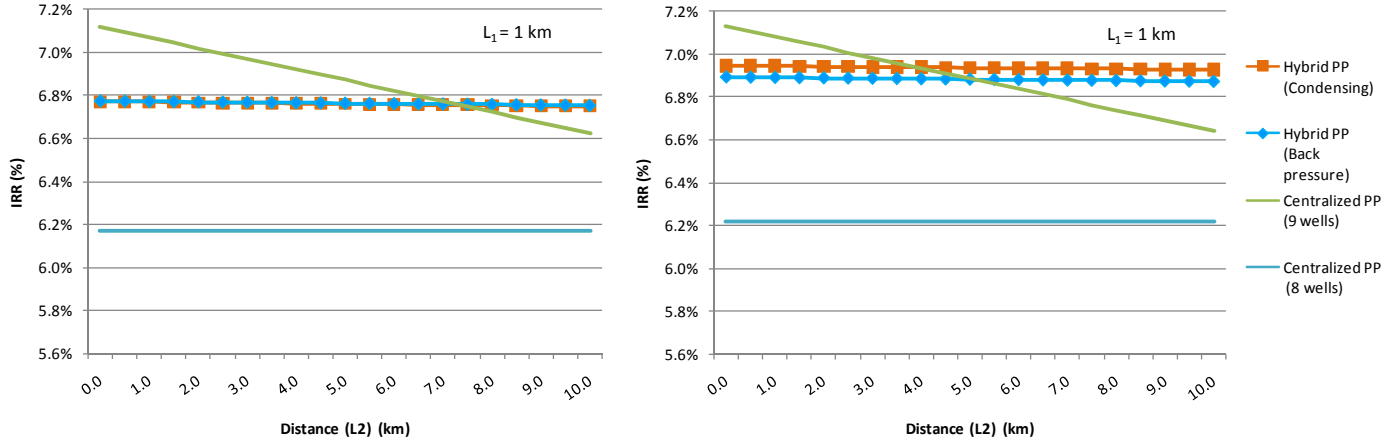
Moreover, when steam flow rate and pressure is randomized, 23 cases in scerario-1 (adjusted scenario) and 13 cases in scenario-2 (unadjusted scenario) among 50 trials show the IRR of a hybrid PP becomes maximum (Table-6.9 and Table-6.10).

Thus, when the costs of WHG becomes lower, the cases appear that a hybrid PP or a decentralized PP become advantageous than a centralized PP. This means we need to change our conventional design concept from the one putting preference on a conventional large-scale centralized PP to a new one of examining possibilities of all types of plant including a hybrid PP or a decentralized PP. For this purpose, we need to pay close attentions to the price trend and the technical performance trend of WHGs.



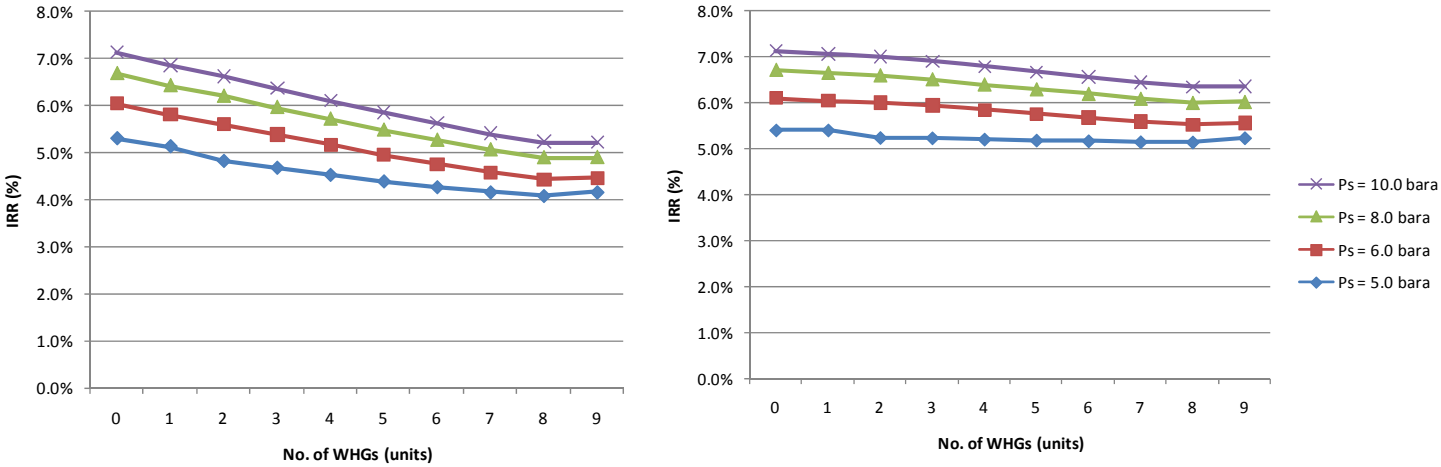
(a) Base case (b) Cost reduction case

Fig.-6.12 Effect of utilization period



(a) Base case (b) Cost reduction case

Fig.-6.13 The IRRs of three kinds of plant when one well is located in remote area



(a) Base case (b) Cost reduction case

Fig.-6.14 Effect of numbers of WHGs (Hybrid PP with condensing WHG)

Table-6.9 Optimum number of WHGs under randomized steam flow rate and pressure (Scenario-1 Adjusted scenario) <Condensing WHG at 2,000$/kW >

	Output of Well										
Trial No.	Well-1 [MW]	Well-2 [MW]	Well-3 [MW]	Well-4 [MW]	Well-5 [MW]	Well-6 [MW]	Well-7 [MW]	Well-8 [MW]	Well-9 [MW]	MW of 9 wells are used to WHP	MW of 0 wells are used to WHP
1	13.7	14.2	3.0	8.6	13.3	5.7	7.0	11.5	4.1	75.9	60.0
2	2.4	8.7	8.4	4.8	6.0	4.0	4.7	2.7	11.7	50.1	51.0
3	6.0	2.6	6.5	15.9	12.9	10.1	5.7	8.1	4.1	67.4	60.0
4	10.4	4.5	3.8	9.7	9.6	3.5	1.3	2.3	3.1	45.2	46.2
5	3.1	3.3	1.8	7.7	17.0	7.8	9.5	4.9	4.6	56.0	57.3
6	3.4	7.5	13.4	4.5	16.0	6.8	1.5	4.1	4.9	58.2	59.0
7	7.3	13.5	10.9	6.8	4.7	8.4	5.5	1.1	13.9	67.8	60.0
8	1.4	7.0	5.3	2.8	4.1	5.2	6.8	5.3	5.2	40.5	41.3
9	5.9	3.3	14.6	17.1	9.8	5.2	2.9	8.5	13.4	75.7	60.0
10	3.2	3.1	11.6	1.4	3.4	10.5	4.4	5.1	10.2	49.5	50.6
11	5.1	13.8	9.4	4.4	7.6	5.6	10.7	1.1	2.0	56.0	56.9
12	10.0	2.6	10.9	15.5	13.2	4.6	1.7	6.4	2.8	63.4	60.0
13	6.2	3.7	8.4	2.6	9.3	5.7	2.0	6.6	4.7	46.2	47.8
14	5.8	7.3	6.2	2.8	4.2	6.5	12.1	13.0	3.6	57.6	60.0
15	2.5	10.5	15.3	3.4	8.5	3.1	4.0	1.3	6.7	51.7	52.8
16	12.6	10.9	5.0	2.4	11.7	6.6	4.8	5.3	3.6	58.8	60.0
17	1.2	11.8	1.9	2.1	5.0	8.7	9.0	13.5	4.1	53.8	55.7
18	4.5	7.9	5.5	2.8	12.7	14.1	4.9	9.3	4.6	62.2	60.0
19	8.1	6.1	14.3	7.0	2.5	1.9	8.6	15.5	4.0	63.8	60.0
20	11.0	14.0	1.0	3.7	4.8	2.5	10.6	10.2	8.9	62.4	60.0
21	4.0	17.4	2.7	6.7	3.3	4.5	4.5	7.6	7.4	54.5	54.6
22	18.7	10.6	8.3	3.1	2.0	8.3	13.0	11.9	4.3	75.1	60.0
23	9.5	3.9	12.8	3.2	2.3	10.5	10.2	15.4	2.6	66.0	60.0
24	3.7	3.8	11.6	5.0	4.2	3.2	1.4	15.5	5.6	50.6	52.1
25	9.0	5.5	1.0	3.6	7.0	13.6	2.6	14.2	4.9	57.5	58.1
26	3.6	3.5	9.8	7.7	5.5	2.6	9.2	3.8	5.2	47.7	49.1
27	2.7	4.3	8.0	4.0	6.0	6.5	8.8	1.3	10.5	48.9	50.5
28	6.3	19.1	9.8	2.9	8.0	3.2	8.5	13.9	2.7	69.6	60.0
29	8.8	9.9	4.0	6.8	2.3	4.1	14.8	11.1	3.9	61.6	60.0
30	3.7	4.4	6.7	4.8	2.4	3.6	1.9	17.3	7.3	48.7	48.8
31	10.9	1.8	8.0	7.8	5.8	1.2	4.5	2.6	19.0	57.7	58.5
32	3.1	9.3	8.5	7.2	3.7	2.4	1.9	1.2	2.8	37.6	39.0
33	2.3	2.6	6.9	16.6	4.1	4.9	6.9	10.1	3.8	54.6	55.8
34	15.1	6.9	8.7	6.0	5.9	6.1	4.7	2.8	4.6	57.0	58.4
35	5.6	7.9	5.0	1.6	3.7	16.1	3.2	3.6	3.6	47.2	48.0
36	1.2	11.4	14.0	1.7	2.3	4.1	7.2	2.3	2.9	44.2	44.9
37	2.5	3.6	6.6	6.1	7.3	4.5	8.1	3.6	4.4	43.7	44.9
38	3.6	4.0	2.7	10.2	6.0	3.6	7.5	6.0	1.9	42.7	44.3
39	17.9	8.8	4.7	2.0	4.6	2.1	6.2	10.6	7.6	60.5	60.0
40	2.5	8.0	3.6	3.8	4.1	7.2	3.6	4.7	10.4	44.8	46.1
41	3.3	7.4	5.3	3.2	4.0	6.1	5.3	2.1	13.0	46.6	47.6
42	5.0	13.8	4.9	3.8	1.4	4.2	9.7	6.5	11.6	57.2	59.3
43	13.6	3.8	7.8	2.6	2.2	3.5	5.4	5.5	4.8	46.1	47.8
44	3.8	6.7	1.9	5.1	9.7	2.8	2.9	5.9	5.7	41.6	43.5
45	5.8	3.7	3.4	4.9	1.4	10.1	6.3	4.6	3.2	40.8	41.4
46	2.5	3.3	20.4	5.7	14.4	3.9	6.5	3.0	9.3	64.8	60.0
47	20.6	3.2	3.9	2.3	13.1	3.9	2.7	4.2	7.2	57.2	56.6
48	16.8	6.5	4.0	14.1	3.9	7.1	4.0	6.3	3.5	62.1	60.0
49	6.3	4.5	4.4	5.2	15.4	14.1	7.0	10.5	4.9	67.7	60.0
50	12.9	3.6	10.8	17.8	11.0	12.2	6.4	14.4	19.1	101.3	60.0
Average	**7.0**	**7.2**	**7.3**	**6.0**	**6.9**	**6.1**	**6.0**	**7.2**	**6.4**	**56.4**	**54.2**

	IRR when No. of wells are used to WHP									
	1	2	3	4	5	6	7	8	9	0
1	8.1%	8.7%	8.3%	8.3%	8.5%	8.4%	8.3%	8.3%	8.4%	7.6%
2	6.2%	6.1%	6.1%	5.9%	5.9%	5.7%	5.6%	5.1%	5.6%	6.2%
3	7.5%	7.0%	6.8%	7.4%	7.6%	7.6%	7.5%	7.4%	7.4%	7.4%
4	5.7%	5.6%	5.5%	5.4%	5.3%	5.2%	5.2%	5.2%	5.2%	5.6%
5	6.8%	6.5%	6.1%	6.0%	6.5%	6.4%	6.3%	6.2%	6.2%	7.0%
6	7.0%	6.8%	6.9%	6.8%	6.8%	6.8%	6.7%	6.7%	6.6%	7.1%
7	7.2%	7.8%	8.1%	8.0%	7.7%	7.7%	7.5%	7.0%	7.6%	7.2%
8	4.8%	4.7%	4.7%	4.6%	4.5%	4.4%	4.4%	4.3%	4.3%	4.9%
9	7.3%	7.2%	7.5%	8.1%	8.2%	8.0%	7.6%	7.6%	8.1%	7.4%
10	6.1%	6.0%	5.9%	5.9%	5.6%	5.7%	5.5%	5.2%	5.6%	6.2%
11	7.0%	6.9%	6.8%	6.7%	6.6%	6.5%	6.5%	6.4%	6.5%	7.1%
12	7.7%	7.2%	7.5%	7.6%	7.5%	7.4%	7.3%	7.2%	7.2%	7.4%
13	5.7%	5.6%	5.5%	5.5%	5.3%	5.4%	5.3%	5.2%	5.2%	5.8%
14	7.1%	7.0%	6.9%	6.6%	6.2%	6.0%	6.3%	6.5%	6.5%	7.3%
15	6.3%	6.3%	6.4%	6.3%	6.2%	6.1%	6.0%	6.0%	6.0%	6.4%
16	7.4%	7.4%	7.3%	7.2%	7.1%	7.0%	6.9%	6.8%	6.8%	7.3%
17	6.6%	6.6%	6.5%	6.1%	5.7%	5.8%	5.9%	6.1%	6.0%	6.8%
18	7.1%	7.2%	6.9%	6.4%	6.9%	7.0%	7.0%	6.9%	6.9%	7.4%
19	7.5%	7.4%	7.7%	7.5%	7.2%	6.9%	6.9%	7.1%	7.2%	7.4%
20	7.6%	7.7%	7.7%	7.3%	7.0%	6.7%	6.7%	6.9%	7.1%	7.3%
21	6.5%	6.7%	6.7%	6.6%	6.5%	6.5%	6.2%	6.2%	6.3%	6.7%
22	8.6%	8.7%	8.7%	8.5%	8.0%	8.1%	8.2%	8.3%	8.4%	7.6%
23	7.7%	7.3%	7.8%	7.3%	6.8%	7.1%	7.2%	7.3%	7.4%	7.4%
24	6.3%	6.1%	6.0%	5.9%	5.8%	5.6%	5.1%	5.7%	5.7%	6.4%
25	7.1%	7.0%	6.8%	6.3%	6.2%	6.6%	6.3%	6.5%	6.5%	7.0%
26	5.9%	5.9%	5.7%	5.6%	5.5%	5.5%	5.4%	5.3%	5.3%	6.0%
27	6.0%	6.0%	5.9%	5.8%	5.7%	5.6%	5.4%	5.0%	5.4%	6.1%
28	7.3%	8.3%	8.3%	8.2%	8.0%	7.8%	7.8%	7.8%	7.8%	7.4%
29	7.4%	7.5%	7.3%	7.2%	6.8%	6.4%	6.9%	6.9%	6.9%	7.4%
30	5.9%	5.8%	5.7%	5.6%	5.4%	5.0%	4.4%	5.4%	5.4%	5.9%
31	7.1%	7.1%	7.0%	6.9%	6.8%	6.2%	5.9%	5.3%	6.6%	7.1%
32	4.4%	4.3%	4.3%	4.2%	4.1%	4.1%	4.0%	4.0%	4.0%	4.5%
33	6.7%	6.4%	6.3%	6.4%	6.3%	6.2%	6.1%	6.0%	6.1%	6.8%
34	7.3%	7.3%	7.2%	7.0%	6.9%	6.8%	6.7%	6.7%	6.7%	7.1%
35	5.7%	5.7%	5.7%	5.6%	5.5%	5.6%	5.5%	5.4%	5.4%	5.8%
36	5.3%	5.4%	5.3%	5.3%	5.2%	5.2%	5.1%	5.0%	5.0%	5.4%
37	5.3%	5.2%	5.1%	5.0%	4.9%	4.8%	4.7%	4.7%	4.8%	5.4%
38	5.2%	5.1%	5.1%	4.9%	4.8%	4.7%	4.7%	4.6%	4.6%	5.3%
39	7.6%	7.6%	7.5%	7.4%	7.4%	6.9%	6.7%	7.0%	7.0%	7.3%
40	5.5%	5.6%	5.5%	5.4%	5.3%	5.2%	4.9%	4.5%	4.9%	5.6%
41	5.7%	5.6%	5.5%	5.4%	5.3%	5.2%	5.1%	4.4%	5.2%	5.8%
42	7.0%	7.2%	7.0%	6.9%	6.4%	6.0%	6.1%	6.0%	6.5%	7.2%
43	5.9%	5.8%	5.7%	5.7%	5.6%	5.5%	5.4%	5.3%	5.3%	5.8%
44	5.1%	5.1%	5.0%	4.9%	4.9%	4.8%	4.7%	4.6%	4.5%	5.2%
45	4.8%	4.7%	4.6%	4.6%	4.6%	4.5%	4.5%	4.4%	4.4%	4.9%
46	7.1%	6.6%	7.6%	7.3%	7.5%	7.4%	7.3%	7.0%	7.2%	7.2%
47	7.2%	7.2%	7.1%	7.0%	6.9%	6.8%	6.7%	6.7%	6.8%	6.9%
48	7.7%	7.6%	7.5%	7.4%	7.3%	7.2%	7.2%	7.2%	7.2%	7.4%
49	7.3%	7.0%	6.8%	6.5%	7.1%	7.5%	7.4%	7.4%	7.4%	7.4%
50	8.4%	8.0%	8.2%	8.6%	8.8%	9.1%	9.0%	9.2%	9.9%	7.8%
Average	6.6%	6.6%	6.6%	6.5%	6.4%	6.3%	6.2%	6.2%	6.3%	6.6%

Table-6.10 Optimum number of WHGs under randomized steam flow rate and pressure (Scenario-2 Unadjusted scenario) <Condensing WHG at 2,000$/kW >

	Output of Well										
Trial No.	Well-1 [MW]	Well-2 [MW]	Well-3 [MW]	Well-4 [MW]	Well-5 [MW]	Well-6 [MW]	Well-7 [MW]	Well-8 [MW]	Well-9 [MW]	MW of 9 wells are used to WHP	MW of 0 wells are used to WHP
1	13.7	14.2	3.0	8.6	13.3	5.7	7.0	11.5	4.1	66.5	60.0
2	2.4	8.7	8.4	4.8	6.0	4.0	4.7	2.7	11.7	49.1	51.0
3	6.0	2.6	6.5	15.9	12.9	10.1	5.7	8.1	4.1	60.4	60.0
4	10.4	4.5	3.8	9.7	9.6	3.5	1.3	2.3	3.1	45.2	46.2
5	3.1	3.3	1.8	7.7	17.0	7.8	9.5	4.9	4.6	50.1	57.3
6	3.4	7.5	13.4	4.5	16.0	6.8	1.5	4.1	4.9	50.7	59.0
7	7.3	13.5	10.9	6.8	4.7	8.4	5.5	1.1	13.9	61.7	60.0
8	1.4	7.0	5.3	2.8	4.1	5.2	6.8	5.3	5.2	40.5	41.3
9	5.9	3.3	14.6	17.1	9.8	5.2	2.9	8.5	13.4	63.4	60.0
10	3.2	3.1	11.6	1.4	3.4	10.5	4.4	5.1	10.2	48.7	50.6
11	5.1	13.8	9.4	4.4	7.6	5.6	10.7	1.1	2.0	53.0	56.9
12	10.0	2.6	10.9	15.5	13.2	4.6	1.7	6.4	2.8	56.3	60.0
13	6.2	3.7	8.4	2.6	9.3	5.7	2.0	6.6	4.7	46.2	47.8
14	5.8	7.3	6.2	2.8	4.2	6.5	12.1	13.0	3.6	54.2	60.0
15	2.5	10.5	15.3	3.4	8.5	3.1	4.0	1.3	6.7	47.3	52.8
16	12.6	10.9	5.0	2.4	11.7	6.6	4.8	5.3	3.6	55.8	60.0
17	1.2	11.8	1.9	2.1	5.0	8.7	9.0	13.5	4.1	50.0	55.7
18	4.5	7.9	5.5	2.8	12.7	14.1	4.9	9.3	4.6	57.1	60.0
19	8.1	6.1	14.3	7.0	2.5	1.9	8.6	15.5	4.0	55.8	60.0
20	11.0	14.0	1.0	3.7	4.8	2.5	10.6	10.2	8.9	59.0	60.0
21	4.0	17.4	2.7	6.7	3.3	4.5	4.5	7.6	7.4	48.2	54.6
22	18.7	10.6	8.3	3.1	2.0	8.3	13.0	11.9	4.3	64.2	60.0
23	9.5	3.9	12.8	3.2	2.3	10.5	10.2	15.4	2.6	59.5	60.0
24	3.7	3.8	11.6	5.0	4.2	3.2	1.4	15.5	5.6	45.1	52.1
25	9.0	5.5	1.0	3.6	7.0	13.6	2.6	14.2	4.9	51.5	58.1
26	3.6	3.5	9.8	7.7	5.5	2.6	9.2	3.8	5.2	47.7	49.1
27	2.7	4.3	8.0	4.0	6.0	6.5	8.8	1.3	10.5	48.9	50.5
28	6.3	19.1	9.8	2.9	8.0	3.2	8.5	13.9	2.7	58.7	60.0
29	8.8	9.9	4.0	6.8	2.3	4.1	14.8	11.1	3.9	57.3	60.0
30	3.7	4.4	6.7	4.8	2.4	3.6	1.9	17.3	7.3	42.5	48.8
31	10.9	1.8	8.0	7.8	5.8	1.2	4.5	2.6	19.0	49.7	58.5
32	3.1	9.3	8.5	7.2	3.7	2.4	1.9	1.2	2.8	37.6	39.0
33	2.3	2.6	6.9	16.6	4.1	4.9	6.9	10.1	3.8	49.0	55.8
34	15.1	6.9	8.7	6.0	5.9	6.1	4.7	2.8	4.6	52.9	58.4
35	5.6	7.9	5.0	1.6	3.7	16.1	3.2	3.6	3.6	42.1	48.0
36	1.2	11.4	14.0	1.7	2.3	4.1	7.2	2.3	2.9	40.4	44.9
37	2.5	3.6	6.6	6.1	7.3	4.5	8.1	3.6	4.4	43.7	44.9
38	3.6	4.0	2.7	10.2	6.0	3.6	7.5	6.0	1.9	42.7	44.3
39	17.9	8.8	4.7	2.0	4.6	2.1	6.2	10.6	7.6	53.7	60.0
40	2.5	8.0	3.6	3.8	4.1	7.2	3.6	4.7	10.4	44.8	46.1
41	3.3	7.4	5.3	3.2	4.0	6.1	5.3	2.1	13.0	44.4	47.6
42	5.0	13.8	4.9	3.8	1.4	4.2	9.7	6.5	11.6	53.3	59.3
43	13.6	3.8	7.8	2.6	2.2	3.5	5.4	5.5	4.8	43.4	47.8
44	3.8	6.7	1.9	5.1	9.7	2.8	2.9	5.9	5.7	41.6	43.5
45	5.8	3.7	3.4	4.9	1.4	10.1	6.3	4.6	3.2	40.8	41.4
46	2.5	3.3	20.4	5.7	14.4	3.9	6.5	3.0	9.3	52.2	60.0
47	20.6	3.2	3.9	2.3	13.1	3.9	2.7	4.2	7.2	45.6	56.6
48	16.8	6.5	4.0	14.1	3.9	7.1	4.0	6.3	3.5	53.1	60.0
49	6.3	4.5	4.4	5.2	15.4	14.1	7.0	10.5	4.9	60.1	60.0
50	12.9	3.6	10.8	17.8	11.0	12.2	6.4	14.4	19.1	79.3	60.0
Average	**7.0**	**7.2**	**7.3**	**6.0**	**6.9**	**6.1**	**6.0**	**7.2**	**6.4**	**51.3**	**54.2**

	IRR when No. of wells are used to WHP									
	1	2	3	4	5	6	7	8	9	0
1	7.8%	8.1%	7.7%	7.7%	7.7%	7.5%	7.4%	7.4%	7.5%	7.6%
2	6.2%	6.1%	6.1%	5.9%	5.9%	5.7%	5.6%	5.1%	5.5%	6.2%
3	7.5%	7.0%	6.8%	6.9%	7.0%	7.0%	6.8%	6.7%	6.7%	7.4%
4	5.7%	5.6%	5.5%	5.4%	5.3%	5.2%	5.2%	5.2%	5.2%	5.6%
5	6.8%	6.5%	6.1%	6.0%	5.8%	5.8%	5.7%	5.5%	5.6%	7.0%
6	7.0%	6.8%	6.6%	6.5%	6.0%	5.9%	5.9%	5.8%	5.8%	7.1%
7	7.2%	7.6%	7.8%	7.7%	7.4%	7.4%	7.2%	6.7%	7.0%	7.2%
8	4.8%	4.7%	4.7%	4.6%	4.5%	4.4%	4.4%	4.3%	4.3%	4.9%
9	7.3%	7.2%	7.1%	7.2%	7.3%	7.1%	6.6%	6.7%	7.0%	7.4%
10	6.1%	6.0%	5.8%	5.8%	5.5%	5.6%	5.4%	5.1%	5.4%	6.2%
11	7.0%	6.5%	6.4%	6.3%	6.3%	6.2%	6.1%	6.1%	6.1%	7.1%
12	7.7%	7.2%	7.5%	7.1%	6.7%	6.6%	6.6%	6.4%	6.5%	7.4%
13	5.7%	5.6%	5.5%	5.5%	5.3%	5.4%	5.3%	5.2%	5.2%	5.8%
14	7.1%	7.0%	6.9%	6.6%	6.2%	6.0%	6.1%	6.1%	6.1%	7.3%
15	6.3%	6.3%	5.8%	5.7%	5.6%	5.5%	5.5%	5.4%	5.4%	6.4%
16	7.2%	7.1%	7.0%	7.0%	6.8%	6.6%	6.6%	6.5%	6.5%	7.3%
17	6.6%	6.5%	6.4%	5.9%	5.6%	5.7%	5.8%	5.7%	5.6%	6.8%
18	7.1%	7.2%	6.9%	6.4%	6.7%	6.5%	6.4%	6.4%	6.4%	7.4%
19	7.5%	7.4%	7.3%	7.2%	6.9%	6.5%	6.5%	6.3%	6.3%	7.4%
20	7.6%	7.3%	7.3%	6.9%	6.6%	6.2%	6.3%	6.5%	6.7%	7.3%
21	6.5%	5.9%	5.9%	5.8%	5.7%	5.7%	5.4%	5.3%	5.4%	6.7%
22	7.8%	7.9%	7.9%	7.7%	7.2%	7.2%	7.2%	7.3%	7.3%	7.6%
23	7.7%	7.3%	7.6%	7.1%	6.6%	6.8%	7.0%	6.7%	6.7%	7.4%
24	6.3%	6.1%	5.9%	5.8%	5.7%	5.5%	5.0%	5.0%	5.0%	6.4%
25	7.1%	7.0%	6.8%	6.3%	6.2%	6.3%	5.9%	5.9%	5.9%	7.0%
26	5.9%	5.9%	5.7%	5.6%	5.5%	5.5%	5.4%	5.3%	5.3%	6.0%
27	6.0%	6.0%	5.9%	5.8%	5.7%	5.6%	5.4%	5.0%	5.4%	6.1%
28	7.3%	7.5%	7.5%	7.4%	7.2%	6.9%	6.9%	6.7%	6.7%	7.4%
29	7.4%	7.5%	7.3%	7.2%	6.8%	6.4%	6.5%	6.5%	6.5%	7.4%
30	5.9%	5.8%	5.7%	5.6%	5.4%	5.0%	4.4%	4.6%	4.6%	5.9%
31	7.1%	7.0%	7.0%	6.9%	6.8%	6.2%	5.8%	5.2%	5.7%	7.1%
32	4.4%	4.3%	4.3%	4.2%	4.1%	4.1%	4.0%	4.0%	4.0%	4.5%
33	6.7%	6.4%	6.3%	5.8%	5.7%	5.6%	5.4%	5.4%	5.4%	6.8%
34	6.8%	6.7%	6.6%	6.5%	6.3%	6.2%	6.1%	6.1%	6.1%	7.1%
35	5.7%	5.7%	5.7%	5.6%	5.5%	4.9%	4.8%	4.7%	4.7%	5.8%
36	5.3%	5.3%	4.8%	4.7%	4.6%	4.6%	4.5%	4.4%	4.4%	5.4%
37	5.3%	5.2%	5.1%	5.0%	4.9%	4.8%	4.7%	4.7%	4.8%	5.4%
38	5.2%	5.1%	5.1%	4.9%	4.8%	4.7%	4.7%	4.6%	4.6%	5.3%
39	6.8%	6.8%	6.7%	6.6%	6.6%	6.0%	5.8%	6.1%	6.2%	7.3%
40	5.5%	5.6%	5.5%	5.4%	5.3%	5.2%	4.9%	4.5%	4.9%	5.6%
41	5.7%	5.6%	5.5%	5.4%	5.3%	5.2%	5.1%	4.4%	4.9%	5.8%
42	7.0%	6.8%	6.7%	6.5%	6.0%	5.6%	5.8%	5.6%	6.0%	7.2%
43	5.5%	5.4%	5.3%	5.2%	5.2%	5.1%	5.0%	4.9%	4.9%	5.8%
44	5.1%	5.1%	5.0%	4.9%	4.9%	4.8%	4.7%	4.6%	4.5%	5.2%
45	4.8%	4.7%	4.6%	4.6%	4.6%	4.5%	4.5%	4.4%	4.4%	4.9%
46	7.1%	6.6%	6.6%	6.3%	6.1%	6.0%	5.9%	5.6%	5.8%	7.2%
47	6.0%	5.9%	5.8%	5.7%	5.3%	5.2%	5.1%	5.1%	5.2%	6.9%
48	7.0%	6.9%	6.8%	6.4%	6.2%	6.1%	6.1%	6.1%	6.1%	7.4%
49	7.3%	7.0%	6.8%	6.5%	6.6%	6.7%	6.6%	6.7%	6.7%	7.4%
50	8.1%	7.7%	8.0%	7.8%	8.0%	8.2%	8.1%	8.1%	8.4%	7.8%
Average	6.5%	6.4%	6.3%	6.2%	6.0%	5.9%	5.8%	5.6%	5.8%	6.6%

6.7 Summary of permanently utilization in parallel with main power plant

From these results, the economic returns of the WHGs which are used permanently in parallel with main power plant can be summarized as follows.

(a) Although the permanently use WHGs has the advantages in obtaining cash flows in earlier stage before start of operation and in saving the construction costs of steam pipeline, it splits the scale of a power plant and loses the scale-of-economy in construction costs. As a result, the construction costs increases and the IRR becomes less than that of a centralized PP which uses all steam of well in the main power plant in principle. It could be said to each type of backpressure WHG and condensing WHG.

(b) Therefore, it can be said, based on the current costs of WHGs, that utilization of WHGs permanently is not a good policy in principle.

(c) However, the permanent usage of condensing WHGs are acceptable in a certain conditions such that an unusually large output wells are drilled in the early stage of exploration. The degree of unusually large size is around twice output or more than an expected one.

(d) In addition, WHGs are also acceptable when some wells are located in a remote area. In such case, hybrid PP becomes competitive against a centralized PP that collects all steam by pipeline. The threshold distance is around 8 km. For this case, it is recommendable to compare the economic returns of both cases.

(e) When WHGs are introduced, it is important to adjust WHGs to each well's characteristics so that the wells capacity is fully reflected to in the WHG. Otherwise, the advantageousness of WHGs cannot be demonstrated.

(f) When the construction costs of WHGs decreases in the future, there is possibilities that a hybrid PP or a decentralized PP could be advantageous in fields where steam pressure is low. Therefore, we need to pay close attention to the price trend and the technical performance tend of WHGs in the future.

7. Economic evaluation of WHG used in disconnected wells

7.1 Output, construction costs and returns

In the previous chapters, we have looked at the economic aspect of WHG that is used in a newly drilled production well. In this section, we take a short glance at the economic return of WHG that is used in disconnected production wells. There are some disconnected wells of which pressure becomes lower than the designed pressure of steam gathering system in a geothermal power plant. Such wells are usually disconnected from the system and abandoned. One of the possible usages of WHG is to take out remaining steam from such disconnected wells (Fig.-7.1). Here, we assume that the steam flow rate reduces to 25 t/h and the pressure declines to 4 bar(a). Even though, the steam production is assumed to continues for a certain period.

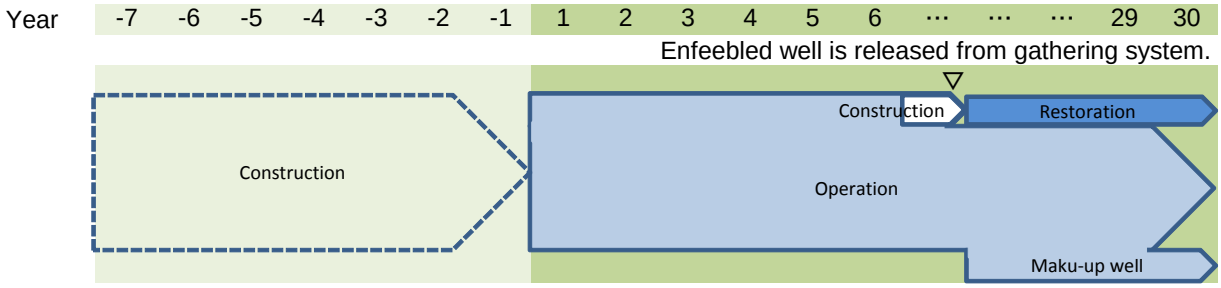


Fig. 7.1 Utilization of retire well

In this analysis, we can assume that the disconnected wells can be obtained at free of charge. Therefore our attention goes to whether the initial costs of a WHG could be recovered by the cash flows to be obtained in the operational years of the WHG. Both the condensing WHG and the back pressure WHG can be used for this purpose. Since the steam consumption rate of the condensing WHG is 11.0 t/h/MW at the pressure of 4.0 bar(a), the output of the WHG becomes 2.3 MW for one unit. The unit construction cost is estimated to 3,031 US$/kW and the construction costs become US$ 9.0 million. From these data, the IRR is calculated as 0.2% for 5 years utilization, 3.4% for 8 years utilization, and 4.6% for 10 years utilization.

In case of a back pressure WHG, the steam consumption rate deteriorates to 21.8 t/h/MW at the pressure of 4.0 bar(a) and the output of the WHG reduces to 1.1 MW for one unit. The unit construction cost is estimate to 2,267 US$/kW and the construction costs become US$ 4.3 million. The IRRs based on these assumptions is 1.9% for 5 years utilization, 5.1% for 8 years utilization and 6.3% for 10 years utilization.

Table-7.1 Results of calculation (Utilization of retires well) (one set of WHG)

Item			WHG (Condensing)	WHG (Back pressure)
Steam flow rate (separator pressure10 bar(a))			25 t/h	25 t/h
Steam consumption rate (@ turbine inlet)			11.0 t/h/MW (@ 4.0 bar(a))	21.8 t/h/MW (@ 4.0 bar(a))
Output (gross)			2.3 MW	1.1 MW
Unit construction cost			3,031 $/kW	2,267 $/kW
Construction costs	Steam field development (a)		-	-
	WHG		6.9	2.6
	Power line, main substation		1.6	1.5
	Subtotal of WHG（incl. 5% administration cost） (b)		9.0 (M$)	4.3 (M$)
	Main power plant		-	-
	Steam pipeline		-	-
	Main substation		-	-
	Subtotal of main PP（incl. 5%administration cost) (c)		-	-
	Total (d)=(a)+(b)+(c)		9.0 (M$)	4.3 (M$)
Generation（net） （1st year）			16.1 GWh	8.8 GWh
Internal rate of return（IRR）		5 years use	0.2%	1.9%
		8years use	3.4%	5.1%
		10years use	4.6%	6.3%

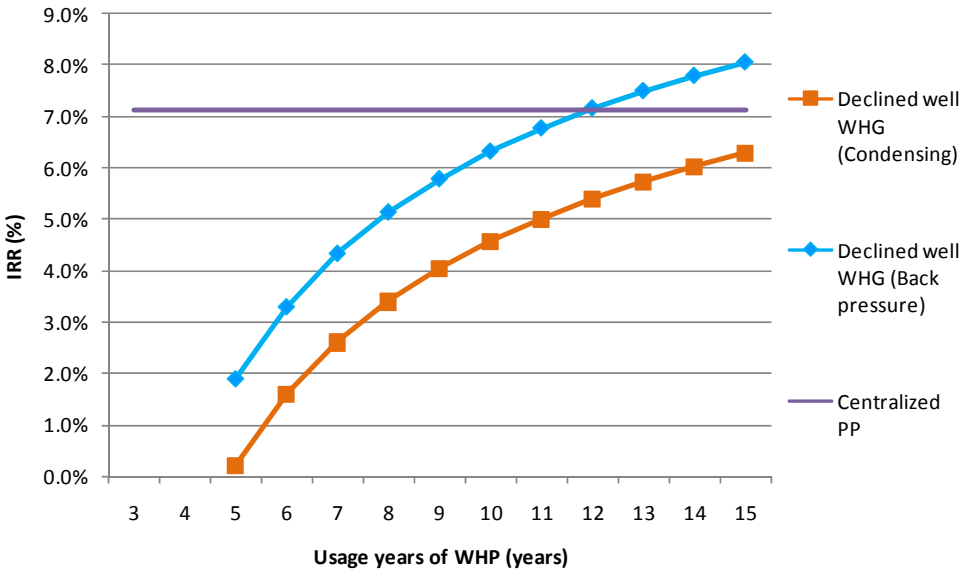
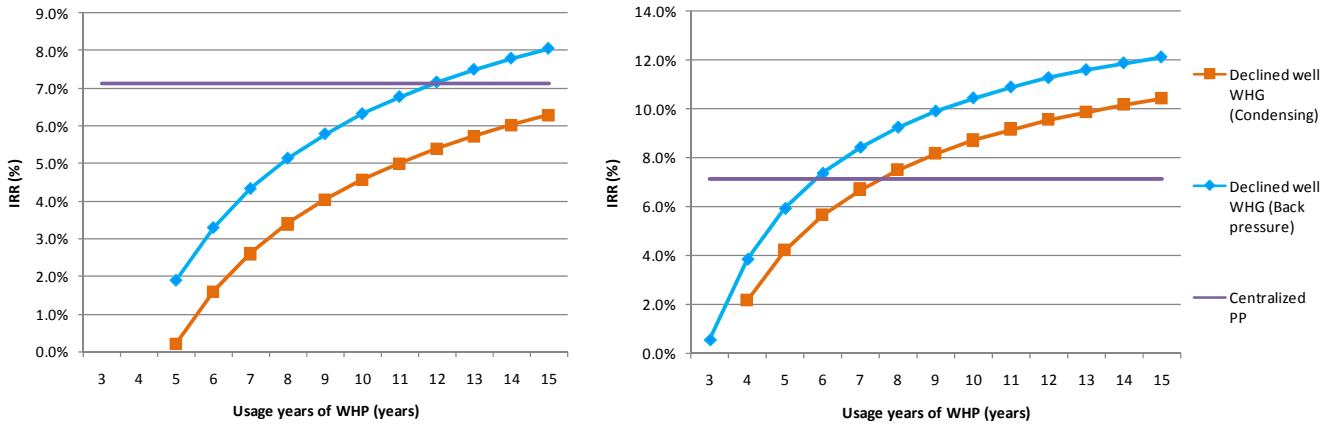


Fig.-7.1 Effect of usage years on the IRR (utilization of disconnected well)

The relations between the IRR and a period of WHG utilization are shown in Fig.-7.1. From this chart, it is understood that a back pressure WHG is more advantageous than a condensing WHG. The level of the IRRs is considerably low. However, if the project owner can use low interest rate fund and the threshold IRR for investment is 5%, then a back pressure WHG could be feasible if it is used for 8 years or more and a condensing WHG could be feasible if it is used for 11 years or more. This means the WHG needs to be used for considerably long period. Therefore, the judgment of life expectancy of the disconnected well becomes very important.

7.2 Effect of the construction costs reduction of WHG

The analysis in the previous sections is based on the assumptions of the following unit construction costs: a condensing WHG of 5 MW is 2,600 $/kW and a back pressure WHG of 5 MW is 1,700 $/kW. If the unit construction costs decreases to 2,000 $/kW for a condensing WHG and 1,300 $/kW for a back pressure WHG, the IRR of WHGs increases as shown in Fig.-7.2 (b). As a result, the back pressure WHG could be feasible if it is used for 5 years or more, and the condensing WHG could be feasible if it is used for 6 years or more in case that the threshold IRR is 5%. Here again, it can be confirmed that the cost reduction has a great impact on the utilization of WHGs.



(a) Base case (b) Cost reduction case

Fig.-7.2 Effect of utilization period

From these results, the economic returns of the WHGs which are used in a disconnected well can be summarized as follows.

(a) When a WHG is used in a pressure-declined well to exploit remaining steam, it is necessary for the WHG to use the well for a certain period to collect capital investment. Therefore, the evaluation of life expectancy of the well becomes very important.

(b) In Kenya, a lot of pressure-declined wells will appear as geothermal development progresses in the future. When such a situation comes, it is worthwhile consideration for GDC to hold some sets of back pressure WHG and to exploit remaining steam energy by setting them to disconnected wells because of pressure decline.

The calculation table of the IRR for a back pressure WHG, which is used in a disconnected well, is shown in Appendix Table-4.

8. Conclusion

This chapter studied the economic evaluation of WHGs which are used in three kinds of forms; (i) temporarily use during a main power plant's construction period, (ii) permanent use in parallel with a main power plant, and (iii) use in a disconnected well to exploit remaining steam.
The results are summarized as follows.

(1) The temporarily use of WHGs during construction period has an effect of enhancing returns of the project. Therefore it is highly recommendable in such a situation that the WHGs will be effectively recycled and reused in other construction fields after the original construction field start operation.

(2) A back pressure WHG is recommendable for the temporarily use during construction period, provided that the wells holds certain steam pressure.

(3) The permanent use of WHGs is not recommendable in principle, because the parallel use of WHGs and the main power plant splits the development scale and loses the scale-of-economy advantage.

(4) However, the permanent use of condensing WHGs is acceptable in a certain conditions such that unusually large-scale output wells are drilled in the early stage of exploration or that some wells are located in a remote area.

(5) The usage of WHGs in disconnected pressure-declined wells depends on the length of the life expectancy of the wells. Therefore, the evaluation of life expectancy of the well becomes very important.

(6) The above-mentioned conclusion holds under the situation that the project owner has a necessary fund for a large-scale development and has a certain prospect of the amount of the resources. If either capital fund or the prospect of the resources is uncertain, an approach to develop a small-scale WHG for reconnaissance to observe the resource behavior is realistic. This report does not deny such approach.

Appendix Table-1 The calculation table of the IRR for a centralized PP

Type	**Total Power Plant (Field + MainPP + WHGs)**						
Technology	**Condensing**						
No of WHGs	0	units		Well production		ton/h	
WHG capacity (gross)	0.0	MW					
Main Power Plant (gross)	58.8	MW					
Total Capacity (gross)	**58.8**	**MW**		WHG pattern	B		
Total Capacity (net)	55.3	MW		WHG utilization years	-	0≤ N ≤5	
Plant factor	90%						
				Electricity tariff	0.085	$/kWh	
Field dev. costs	147.58	M$		Tax rate	30%		
WHG Const. costs	0.00	M$	OK				
Main PP Const. costs	113.53	M$					
WHG Power Line Length	0.0	km (total)		Field O&M costs (annual)	0.00	M$	
Steam Pipeline Length	3.0	km (total)		WHP O&M costs (annual)	0.00	M$	
Total const. costs	**261.1**	**M$**	OK	Main PP O&M costs (annua	3.41	M$	
Total unit costs	4,439	$/kW	OK				Discount rate 10.00%

Profits and Losses Table

No	Year	Investment [M$] 1	Generation [GWh] 2	Revenue [M$] 3	Depreciation [M$] 4	O&M costs [M$] 5	Mobilization [M$] 6	Other costs [M$] 7	Income [M$] 8=3-4-5-6-7	Tax [M$] 9	Income af. Tax [M$] 10=8-9	Free Cash Flows (FCF) [M$] 11=10+4-1	Present Value
1	-7	-10.50										-10.50	-19.51
2	-6	-5.25										-5.25	-8.87
3	-5	-22.52			0.00				-0.00		-0.00	-22.52	-34.58
4	-4	-36.86			0.00				-0.00		-0.00	-36.86	-51.45
5	-3	-19.49			0.00				-0.00		-0.00	-19.49	-24.73
6	-2	-85.33			0.00				-0.00		-0.00	-85.33	-98.44
7	-1	-81.17			0.00				-0.00		-0.00	-81.17	-85.13
8	1	0.00	435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	23.62
9	2		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	21.47
10	3		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	19.52
11	4		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	17.74
12	5		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	16.13
13	6		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	14.66
14	7		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	13.33
15	8		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	12.12
16	9		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	11.02
17	10		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	10.02
18	11		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	9.10
19	12		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	8.28
20	13		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	7.52
21	14		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	6.84
22	15		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	6.22
23	16		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.98
24	17		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.53
25	18		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.12
26	19		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.74
27	20		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.40
28	21		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.09
29	22		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.81
30	23		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.56
31	24		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.32
32	25		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.11
33	26		435.92	37.05	0.00	7.83			29.22	8.77	20.45	20.45	1.80
34	27		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.64
35	28		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.49
36	29		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.35
37	30		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.23
	Total	-261.11	13,077.54	1,111.59	261.15	235.00	0.00	0.00	615.45	184.64	430.81	430.85	-83.96
												IRR	NPV=
	OK											7.12%	-83.96

Appendix Table-2 The calculation table of the IRR for temporarily use of back pressure WHGs

Type	**Total Power Plant (Field + MainPP + WHGs)**						
Technology	**Back pressure**						
No of WHGs	9	units		Well production		ton/h	
WHG capacity (gross)	35.3	MW					
Main Power Plant (gross)	58.8	MW					
Total Capacity (gross)	**94.1**	**MW**		WHG pattern	B		
Total Capacity (net)	89.8	MW		WHG utilization years	-	0≤ N ≤5	
Plant factor	90%						
				Electricity tariff	0.085	$/kWh	
Field dev. costs	147.58	M$		Tax rate	30%		
WHG Const. costs	81.16	M$	OK				
Main PP Const. costs	113.53	M$					
WHG Power Line Length	9.0	km (total)		Field O&M costs (annual)	2.43	M$	
Steam Pipeline Length	3.0	km (total)		WHG O&M costs (annual)	2.43	M$	
Total const. costs	**342.3**	**M$**		Main PP O&M costs (annua	3.41	M$	
Total unit costs	3,638	$/kW				Discount rate	10.00%

Profits and Losses Table

No	Year	Investment [M$] 1	Generation [GWh] 2	Revenue [M$] 3	Depreciation [M$] 4	O&M costs [M$] 5	Mobilization [M$] 6	Other costs [M$] 7	Income [M$] 8=3-4-5-6-7	Tax [M$} 9	Income af. Tax [M$] 10=8-9	Free Cash Flows (FCF) [M$] 11=10+4-1	Present Value
1	-7	-10.50										-10.50	-19.51
2	-6	-14.27										-14.27	-24.10
3	-5	-31.54	30.07	2.56	0.36	0.27			1.93	0.58	1.35	-29.83	-45.81
4	-4	-45.87	60.00	5.10	0.72	0.54			3.84	1.15	2.69	-42.47	-59.28
5	-3	-46.54	89.77	7.63	1.08	0.81			5.74	1.72	4.02	-41.45	-52.60
6	-2	-112.38	179.55	15.26	2.16	1.62			11.47	3.44	8.03	-102.18	-117.89
7	-1	-11.64	268.87	22.85	3.25	2.43			17.17	5.15	12.02	3.63	3.81
8	1	0.00	435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	23.62
9	2		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	21.47
10	3		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	19.52
11	4		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	17.74
12	5		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	16.13
13	6		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	14.66
14	7		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	13.33
15	8		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	12.12
16	9		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	11.02
17	10		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	10.02
18	11		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	9.10
19	12		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	8.28
20	13		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	7.52
21	14		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	6.84
22	15		435.92	37.05	14.38	7.83			14.84	4.45	10.39	24.77	6.22
23	16		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.98
24	17		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.53
25	18		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	4.12
26	19		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.74
27	20		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.40
28	21		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	3.09
29	22		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.81
30	23		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.56
31	24		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.32
32	25		435.92	37.05	4.54	7.83			24.68	7.40	17.27	21.82	2.11
33	26		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.80
34	27		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.64
35	28		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.49
36	29		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.35
37	30		435.92	37.05		7.83			29.22	8.77	20.45	20.45	1.23
	Total	-272.74	13,705.81	1,164.99	268.68	240.68	0.00	0.00	655.63	196.69	458.94	454.88	-76.63
												IRR	NPV=
												7.48%	-76.63

Appendix Table-3 The calculation table of the IRR for a hybrid PP with a condensing WHG

Type	**Total Power Plant (Field + MainPP + WHGs)**						
Technology	**Condensing**						
No of WHGs	1	units		Well production		ton/h	
WHG capacity (gross)	6.3	MW					
Main Power Plant (gross)	52.3	MW					
Total Capacity (gross)	**58.6**	**MW**		WHG pattern	B		
Total Capacity (net)	54.8	MW		WHG utilization years	-	0≤ N ≤5	
Plant factor	90%						
				Electricity tariff	0.085	$/kWh	
Field dev. costs	147.58	M$		Tax rate	30%		
WHG Const. costs	18.44	M$	OK				
Main PP Const. costs	104.33	M$					
WHG Power Line Length	1.0	km (total)		Field O&M costs (annual)	0.55	M$	
Steam Pipeline Length	3.0	km (total)		WHP O&M costs (annual)	0.55	M$	
Total const. costs	**270.3**	**M$**	OK	Main PP O&M costs (annua	3.13	M$	
Total unit costs	4,615	$/kW	OK			Discount rate	10.00%

Profits and Losses Table

No	Year	Investment [M$] 1	Generation [GWh] 2	Revenue [M$] 3	Depreciation [M$] 4	O&M costs [M$] 5	Mobilization [M$] 6	Other costs [M$] 7	Income [M$] 8=3-4-5-6-7	Tax [M$} 9	Income af. Tax [M$] 10=8-9	Free Cash Flows (FCF) [M$] 11=10+4-1	Present Value
1	-7	-10.50										-10.50	-19.51
2	-6	-23.69										-23.69	-40.01
3	-5	-22.52	44.34	3.77	0.74	0.55			2.48	0.74	1.73	-20.05	-30.79
4	-4	-36.86	44.12	3.75	0.74	0.55			2.46	0.74	1.72	-34.40	-48.02
5	-3	-19.39	43.90	3.73	0.74	0.55			2.44	0.73	1.71	-16.94	-21.50
6	-2	-80.72	43.68	3.71	0.74	0.55			2.42	0.73	1.70	-78.29	-90.32
7	-1	-76.66	43.46	3.69	0.74	0.55			2.40	0.72	1.68	-74.24	-77.87
8	1	0.00	430.73	36.61	13.66	7.62			15.34	4.60	10.74	24.39	23.26
9	2		430.51	36.59	13.66	7.62			15.32	4.60	10.72	24.38	21.13
10	3		430.30	36.58	13.66	7.62			15.30	4.59	10.71	24.37	19.20
11	4		430.08	36.56	13.66	7.62			15.28	4.58	10.70	24.35	17.45
12	5		429.87	36.54	13.66	7.62			15.26	4.58	10.68	24.34	15.85
13	6		429.66	36.52	13.66	7.62			15.25	4.57	10.67	24.33	14.40
14	7		429.45	36.50	13.66	7.62			15.23	4.57	10.66	24.32	13.09
15	8		429.24	36.49	13.66	7.62			15.21	4.56	10.65	24.30	11.89
16	9		429.03	36.47	13.66	7.62			15.19	4.56	10.63	24.29	10.80
17	10		428.82	36.45	13.66	7.62			15.17	4.55	10.62	24.28	9.82
18	11		428.62	36.43	13.66	7.62			15.16	4.55	10.61	24.27	8.92
19	12		428.41	36.41	13.66	7.62			15.14	4.54	10.60	24.25	8.11
20	13		428.21	36.40	13.66	7.62			15.12	4.54	10.59	24.24	7.36
21	14		428.00	36.38	13.66	7.62			15.10	4.53	10.57	24.23	6.69
22	15		427.80	36.36	13.66	7.62			15.09	4.53	10.56	24.22	6.08
23	16		427.60	36.35	4.91	7.62			23.82	7.14	16.67	21.58	4.93
24	17		427.40	36.33	4.91	7.62			23.80	7.14	16.66	21.57	4.48
25	18		427.20	36.31	4.91	7.62			23.78	7.13	16.65	21.56	4.07
26	19		427.00	36.29	4.91	7.62			23.76	7.13	16.64	21.55	3.70
27	20		426.80	36.28	4.91	7.62			23.75	7.12	16.62	21.54	3.36
28	21		426.60	36.26	4.17	7.62			24.47	7.34	17.13	21.30	3.02
29	22		426.41	36.24	4.17	7.62			24.45	7.34	17.12	21.29	2.74
30	23		426.21	36.23	4.17	7.62			24.44	7.33	17.10	21.28	2.49
31	24		426.02	36.21	4.17	7.62			24.42	7.33	17.09	21.27	2.26
32	25		425.83	36.20	4.17	7.62			24.40	7.32	17.08	21.26	2.06
33	26		387.48	32.94	0.00	7.07			25.87	7.76	18.11	18.11	1.59
34	27		387.48	32.94		7.07			25.87	7.76	18.11	18.11	1.45
35	28		387.48	32.94		7.07			25.87	7.76	18.11	18.11	1.32
36	29		387.48	32.94		7.07			25.87	7.76	18.11	18.11	1.20
37	30		387.48	32.94		7.07			25.87	7.76	18.11	18.11	1.09
	Total	-270.34	12,862.72	1,093.33	253.98	228.55	0.00	0.00	610.80	183.24	427.56	411.20	-94.22
												IRR	NPV=
	OK											6.85%	-94.22

Appendix Table-4 The calculation table of the IRR for a back pressure WHG used in disconnected well

Type	**1 set of Wellhead PP Unit <Base Table>**							
Technology	Back pressure							
				Welll No.	1			
				Installation year	-1			
Capacity (gross)	1.1	MW						
In-house use ratio	2%			No. of WHP units	*1*	units		
Capacity (net)	1.1	MW		WHP Usage Years	*1*	years	0≤ N ≤5	
Efficiency gradation	0.5%	/year	Decline	Well WHP usage years	8	years		
Plant factor	90%							
Construction unit costs		$/kW @ 5MW		Electricity tariff	0.085	$/kWh		
				Tax rate	30%			
Power loss rate / km	0.15%	%/km						
Pad location	1.0	km		Mobilization cycle	14	years	Mobilization cost ratio	
Power loss ratio	0.15%			Mobilization costs	0.00	M$	5.0%	
WHP const. costs	4.34	M$		Mobilization months	0	months		
Total const. costs	**4.34**	M$		O&M costs (annual)	0.13	M$	O&M Rate	3%
							Discount rat	10.00%

<Base Table>

No	Year	Investment [M$] 1	Generation [GWh] 2	Revenue [M$] 3	Depreciation [M$] 4	O&M costs [M$] 5	Mobilization [M$] 6	Other costs [M$] 7	Income [M$] 8=3-4-5-6-7	Tax [M$} 9	Income af. Tax [M$] 10=8-9	Free Cash Flows (FCF) [M$] 11=10+4-1	Present Value
1	-7												
2	-6												
3	-5												
4	-4												
5	-3												
6	-2												
7	-1	-4.34										-4.34	-4.55
8	1		8.80	0.75	0.17	0.13			0.44	0.13	0.31	0.48	0.46
9	2		8.75	0.74	0.17	0.13			0.44	0.13	0.31	0.48	0.42
10	3		8.71	0.74	0.17	0.13			0.44	0.13	0.31	0.48	0.38
11	4		8.67	0.74	0.17	0.13			0.43	0.13	0.30	0.48	0.34
12	5		8.62	0.73	0.17	0.13			0.43	0.13	0.30	0.47	0.31
13	6		8.58	0.73	0.17	0.13			0.43	0.13	0.30	0.47	0.28
14	7		8.54	0.73	0.17	0.13			0.42	0.13	0.30	0.47	0.25
15	8		8.49	3.67	0.17	0.13	0.22		3.15	0.95	2.21	2.38	1.16
16	9												0.00
17	10												0.00
18	11												0.00
19	12												0.00
20	13												0.00
21	14												0.00
22	15												0.00
23	16												0.00
24	17												0.00
25	18												0.00
26	19												0.00
27	20												0.00
28	21												0.00
29	22												0.00
30	23												0.00
31	24												0.00
32	25												0.00
33	26												0.00
34	27												0.00
35	28												0.00
36	29												0.00
37	30												0.00
	Total	-4.34											-0.95

IRR	NPV=
5.14%	-0.95

<Reference>

Joel Sutter, et al (2012), The use of portable geothermal wellhead generators as small power plants to accelerate geothermal development and power generation in Kenya, GHC bulletin, February 2012

Carlos Atli Cordova Geirdal et al (2013), Economic comparison between a well-head geothermal power plant and a traditional geothermal power plant, Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 11-13, 2013

Sachio Ehara, Tetsuro Noda, Wellhead power generation in the early stage of geothermal development, Journal of Geothermal resource society vol. 36, No. 4 (2014), P.143-148

APPENDIX

10. GDC Corporate Financial Model - User's Manual

PROJECT FOR REVIEWING GDC'S
GEOTHERMAL DEVELOPMENT STRATEGY
IN THE REPUBLIC OF KENYA

GDC Corporate Financial Model (2015US$) (16.6) (Basic)

User's Manual

GDC Corporate Financial Model (2015US$) (16.6) (Basic)
User's Manual

Contents

Author and Model creator: Masahiko Kaneko
Certified Management Consultant for Small and Medium-size Enterprises
West Japan Engineering Consultants, Inc.

Chapter 1 Introduction ～ Characteristics of Model ～

The GDC Corporate Financial Model(2015US$), hereinafter "Model", is a financial model that simulates GDC's financial position when certain projects are implemented. This model has two functions (Fig.-1.1). The first function is to predict GDC's three financial statements (the statement of Profits & Losses(P/L), the statement of Cash flows (C/F) and the statement of Balance sheet (B/S)) when a certain project development schedule is given as My Plan. The second function is to search for the maximum development plan that the GDC's financial situation allows. The constrains are; (i) the required number of drilling rigs does not exceed the number of rigs that GDC would hold, and (ii) the GDC's reserved cash amount does not become less than a minimum limitation for a certain period. The Model could find the maximum development plant under these constraints using Macro function of Microsoft Excel sheet. It is expected that readers could use this Model as one of the simulation tools to discuss geothermal development plan of GDC.

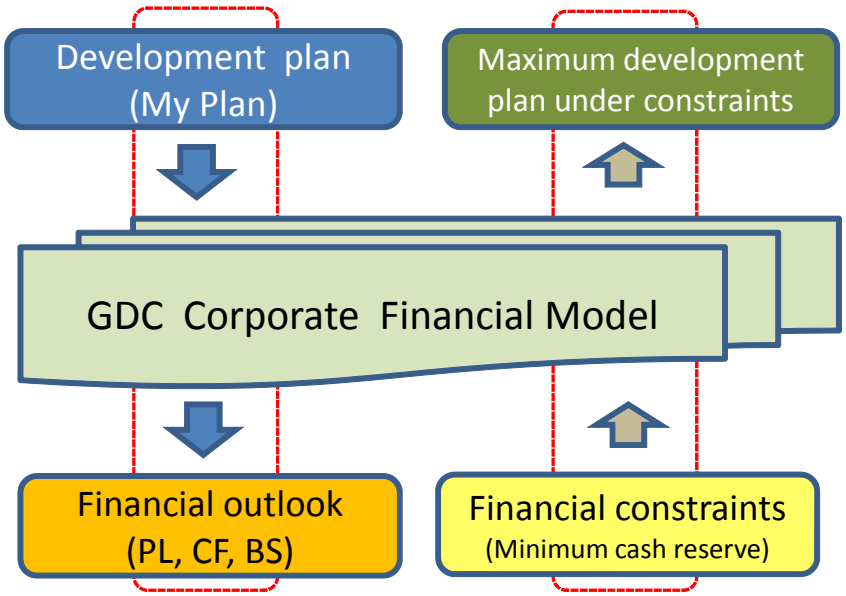


Fig. -1.1 Two functions of this Model

Chapter 2 Structure of Model

This Model is composed of six (6) sheets, "Olkaria_280MW", "Menengai_105MW", "Headquarter", "Project", "GDC_Total", and "GDC_Total(Summary)".

Four sheets of "Olkaria_280MW", “Menengai_105MW", “Headquarter", and “Project" have a similar structure. These sheets output the statement of Profits & Losses (P/L), the statement of Cash flows (C/F) and the statement of Balance sheet (B/S) of each project for 30 years.

The three sheets of "Olkaria_280MW", "Menengai_105MW" and "Headquarter" represent the project of Olkaria 280 MW, the project of Menengai 105 MW and administration costs respectively. These three projects are "fixed projects" and the first year of calculation is 2015. The total cash flows of revenue and expenditure from these three projects are assumed as Fig.-2.2 though the detail assumptions of calculation are described later (Chapter 7).

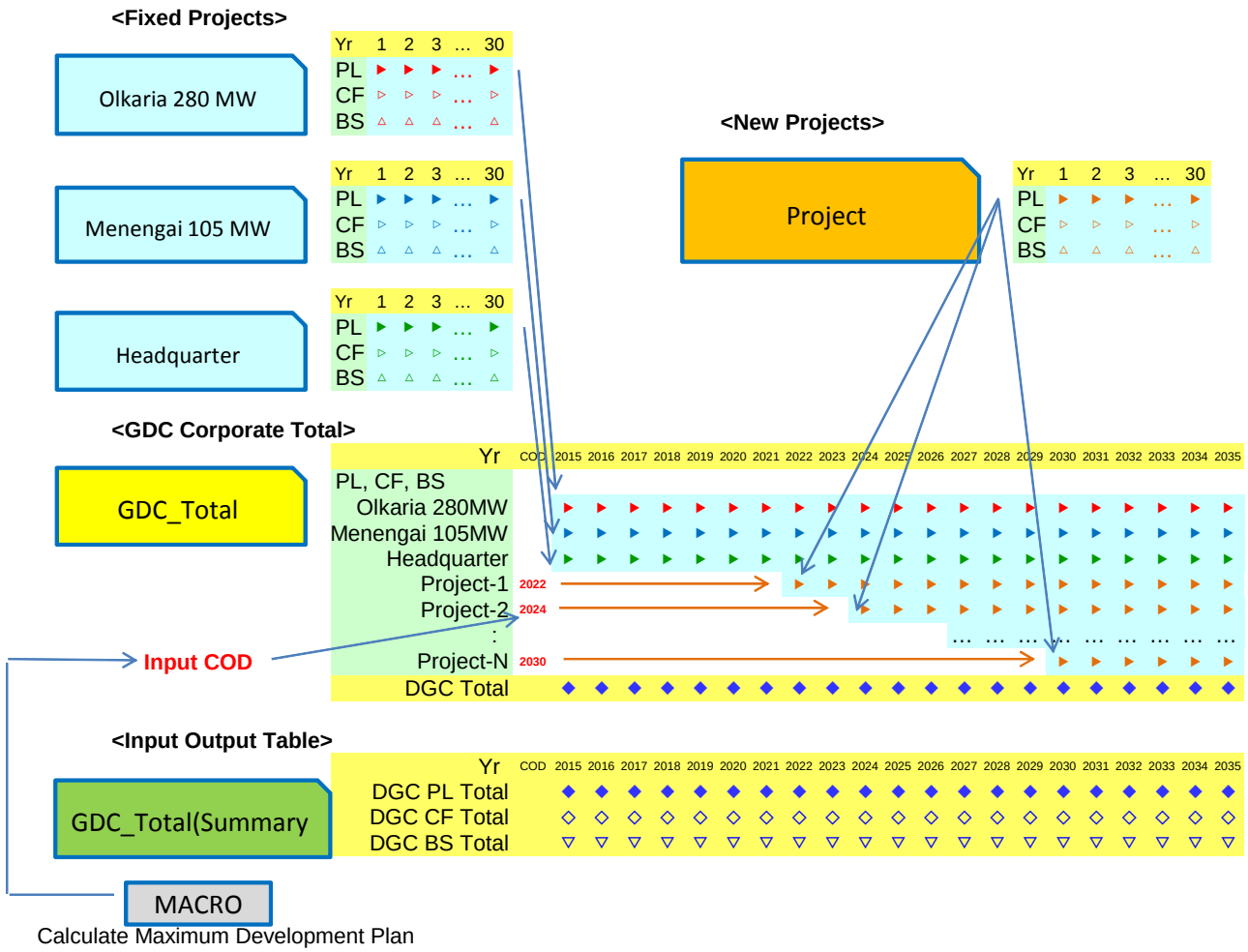


Fig.-2.1 Structure of GDC Corporate Financial Model

On the other hand, the Model assumes that new projects are same scale and are represented by "Project" sheet. The "Project" sheet generates the stream of cash flows that are out-flows in construction stage and are in-flows in operation stage. When the year of the commercial operation date (COD) is given to the "Project" sheet, the cash flow steam is adjusted according to the COD year. The scale and the conditions of the project are changeable. As default conditions, new projects are of 70 MW scale with total development costs of US$ 145 million (steam section) in seven (7) year development period. This project produces US$ 8-10 million annual cash flows in each operation year when the steam selling price is US$ 5.2 cents/kWh which provides steam developer with 10% return (Fig.-2.3). This Model can handle 30 new "projects."

The “GDC_Total" sheet totals the financial statements (P/L, C/F and B/S) of three fixed projects and 30 new "projects" to create GDC's corporate financial statements (Fig.-2.4).

The “GDC_Total_(Summary)" sheet summarizes the “GDC_Total" sheet and works a function of input and output table of the Model.

This Model is written in the price of 2015 US dollars. This means that the inflation of the costs and the sales price hike of steam or electricity is not considered. It is partly because to simplify the Model and partly because it is very difficult to forecast a certain rate of inflation or price hike for a very long time.

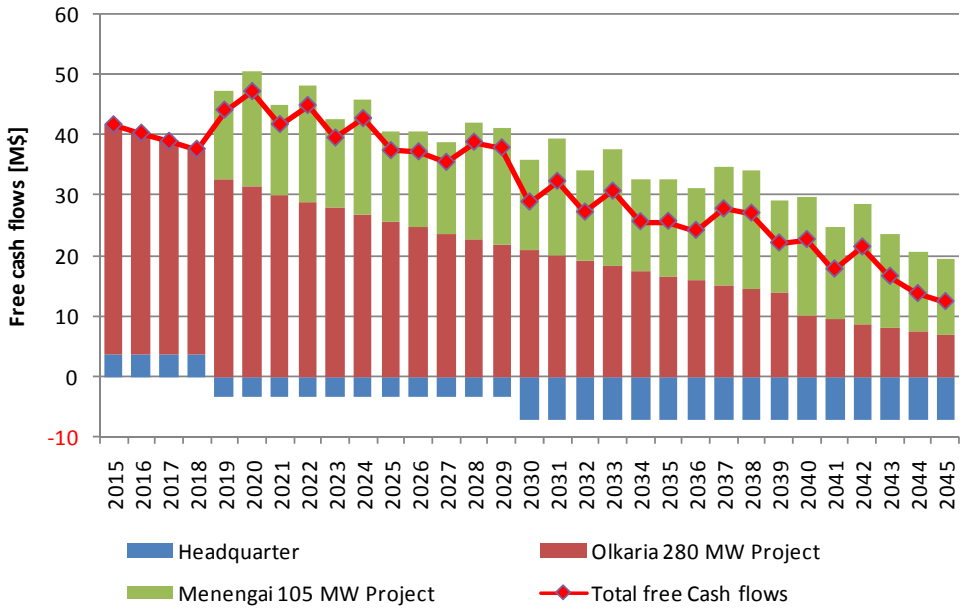


Fig.-2.2 Cash flows forecast form three fixed projects

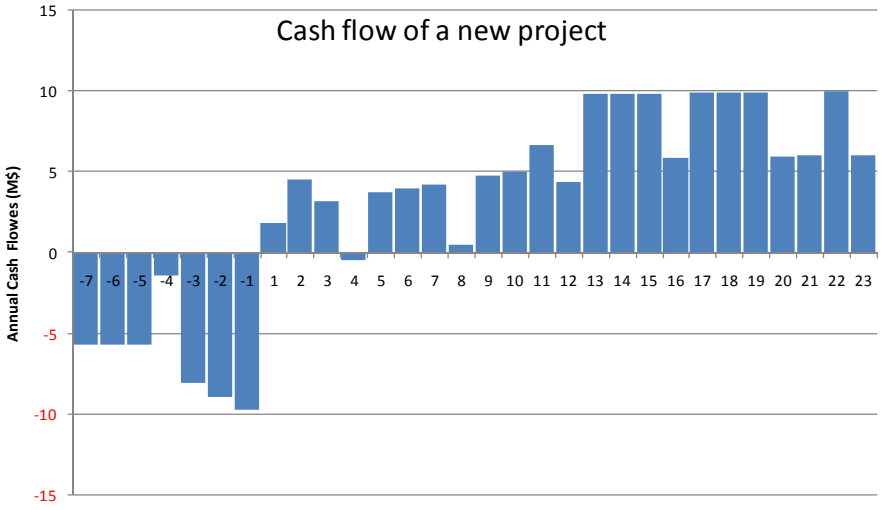


Fig.-2.3 Cash flows forecast from a new project (70MW)

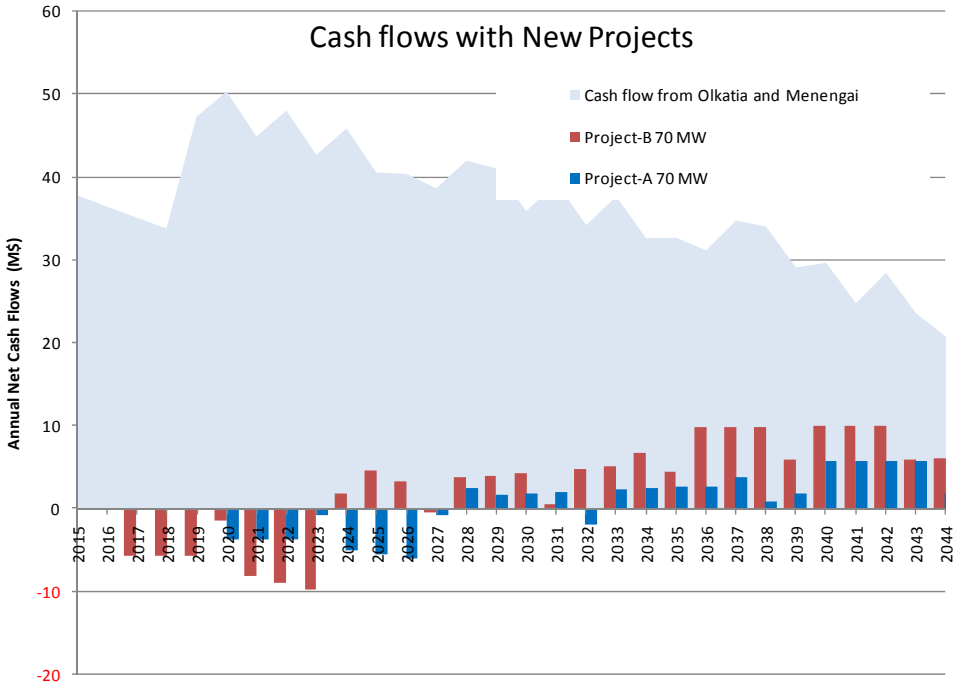


Fig.-2.4 Combination of cash flows from fixed and new projects
（An example of Project-A with COD of 2022 and Project-B with COD of 2030）

Chapter 3 Structure of "Project" sheet

The “Project" sheet is a large table as shown in Fig.-3.1. It consists of mainly six pats of (i) Project assumptions, (ii) Construction costs estimation, (iii) Construction schedule & depreciation, (iv) Financial Statements, (v) Repayment schedule, and (vi) Make-up well schedule.

The "Project assumptions" part is a part where several assumption data is input, as shown in Fig.-3.2, such as Field Assumption, Turbine Assumption, Field Activities, Calculation Table of Development Stage Scheduling, Finance Arrangement, Selling Price, and Tax and so on. **The cells written in red letters are changeable. The cells displayed in blue letters are quotations from other sheets**, and **the cells displayed in black letters have numerical formula. These cells are not changeable.** **The cells displayed in the gray letters are not used to calculate in this Model.**

The "Construction costs estimation" part is a part where the construction cost estimation is input for steam development and power plant. as shown in Fig.-3.3.

The "Construction schedule & depreciation" part is a part where Drilling Schedule, Construction Costs Disbursement Schedule, and the Calculation of Equity & Debt results are displayed as shown in Fig.-3.4.

The part of "Financial statements" is a part where the results of P/L, C/F and B/S of two sections of steam development and power plant are displayed as shown in Fig.-3.5.

The part of "Repayment schedule" is a part where the repayment plan of loans for two sections of steam development and power plant is displayed as shown in Fig.-3.6.

The part of "Make-up well schedule" is a part where the calculation results of drilling schedule of make-up wells and their depreciation expenses and book values are displayed as shown in Fig.-3.7.

Project Assumptions

Construction Costs Estimation

Construction Schedule & Depreciation

Financial Statements

Repayment Schedule

Make-up Well Schedule

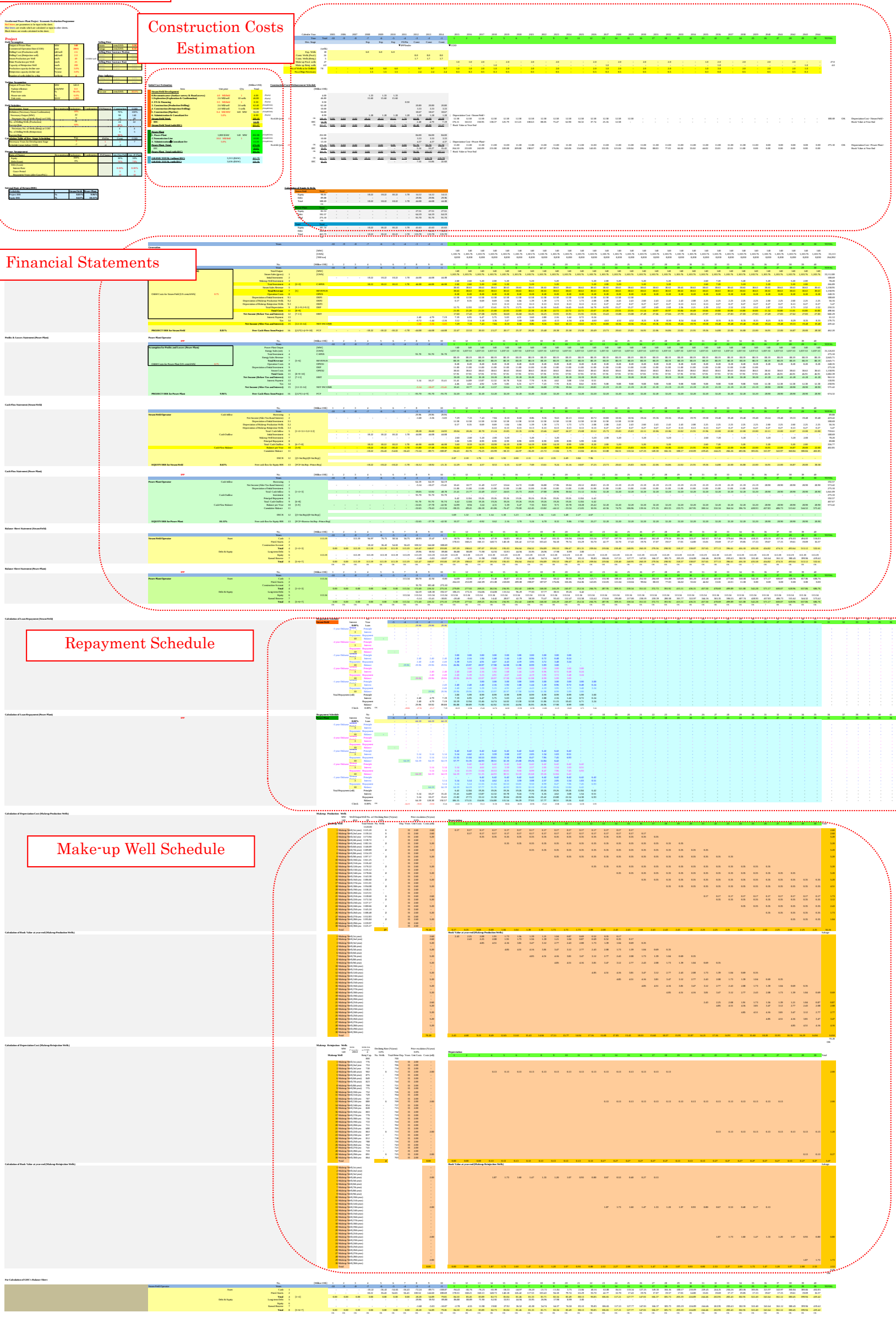


Fig.-3.1 Bird-view of "Project" sheet

Geothermal Power Plant Project Economic Evaluation Programme
Red letters are parameters to be input in this sheet.
Blue letters are results which are calculated or input in other sheets.
Black letters are results calculated in this sheet.

Project

Field Assumption Drilling 100 days

Output of Power Plant	MW	**70**		
Commercial Operation Date (COD)	year	**2015**		
Drilling Cost (Production well)	m$/well	**3.5**	4.0	
Drilling Cost (Reinjection well)	m$/well	2.9		
Steam Production per Well	ton/h	62	8.9 MW/well	
Brine Production per Well	ton/h	45		
Capacity of Reinjection Well	ton/h	200		
Production capacity decline rate	%/year	3.0%		
Reinjection capacity decline rate	%/year	3.0%		
Number of wells drilled by a Rig	wells/rig	**4.0**	3.5	

Turbine Assumption

Output of Power Plant	MW	70.0
Turbine efficienct	(t/h)/MW	7.0
Plant factor	%	90.0%
House use ratio	%	6.0%
Unit costs	$/kW	1,550

Selling Price

Steam	cents/kWh	**5.22**
Energy	cents/kWh	**11.88**

Selling Price Increase Portion

Steam	%	20.0%
Energy	%	20.0%

Selling Price Increase Rate

Steam	%/year	0.0%
Energy	%/year	0.0%

Price Inflation

Drilling well	%/year	0.0%
O&M costs	%/year	0.0%

Tax

Tax rate	cents/kWh	30.0%

Field Activities

Development Stage	Reconnaissa	Exploratory	Confirmatio	FS/Financce	Construction	COD
Definition (Necessary Steam Confirmatio		48%			52%	100%
Necessary Output (MW)		33.6			36	70
Necessary No. of Wells (Prod.) at COI		4			4	8
No. of Drilling Wells (Production)		7			5	12
Success Rate		66%			90%	
Necessary No. of Wells (Reinj) at COI					2	2
No. of Drilling Wells (Reinjection)					3	3
Success Rate					90%	
Calculation Table of Dev. Stage Schedulin		Exp		FS/Fin	Const	COD
Necessary Years for Development Stage		**3**		1	3	7
Schedule (years before COD)		-7		-4	-3	

Finance Arrangement

Ratio of Finance	Reconnaissa	Exploratory	Confirmatio	FS/Finance	nst.(Stm Fiel	Cnst. (P.Plant)
Equity		100%			30%	30%
Debt (Loan)		0%			70%	70%
Debt (Loan)						
Interest Rate					8.00%	8.00%
Grace Period					3	3
Repayment Years (after GracePrd.)					10	10

Equity cost	**Steam**	**P. Plant**
	10.00%	20.00%

Internal Rate of Return (IRR)

Profitability		Steam	Power
Project IRR	%	**9.92%**	**15.66%**
Equity IRR	%	**9.98%**	**20.00%**
Equity IRR difference from target IRR		0.0%	0.0%

Target IRR

	Steam	P. Plant
WACC	9.08%	11.60%
WACE	10.00%	20.00%

Fig.-3.2 Project Assumptions part of "Project" sheet

Initial Cost Estimation			(Million US$)	Construction Costs Disbu
Item	Unit price	Q'ty	Total	
Steam Field Development				
0.Reconnaissance (Surface survey & Road access)	5.0 M$/field	1	5.00	*(Equity)*
1.Exploration (Exploration & Confirmation)	3.5 M$/well	7 wells	24.50	*(Equity)*
2. F/S & Financing	10.0 M$/field	1	10.00	*(Equity)*
3. Construction (Production Drilling)	3.5 M$/well	5 wells	17.50	*(Euity&Debt)*
4. Construction (Reinjection Drilling)	2.9 M$/well	3 wells	8.59	*(Euity&Debt)*
5. Construction (Pipeline)	0.90 M$/MW	70 MW	63.07	*(Euity&Debt)*
6. Administration & Consultant fee	5.0%		6.43	*(Equity)*
Steam Field Total			135.09	EcoLife (yrs) 25
IDC			9.99	
Steam Field Total (with IDC)			145.08	
Power Plant				
1. Power Plant	1,550 $/kW	70 MW	108.50	*(Euity&Debt)*
2.Transmission Line	2.0 M$/field	1	2.00	*(Euity&Debt)*
3. Administration&Consultant fee	5.0%		5.53	*(Euity&Debt)*
Power Plant Total			116.03	EcoLife (yrs) 25
IDC			12.99	
Power Plant Total (with IDC)			129.02	
GRAND TOTAL (without IDC)	3,587 ($/kW)		251.12	
GRAND TOTAL (with IDC)	3,916 ($/kW)		274.10	

Fig.-3.3 Construction Costs Estimation part of "Project" sheet

Calender Year			2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Year		Total	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5
Dev. Stage						Exp	Exp	Exp	FS/Fin	Const	Const	Const					
									▼IPPTender				▼COD				
Drilling Schedule		(wells)															
Own rig	Exp. Wells	7				2.3	2.3	2.3									
Own rig	Const. Wells (Prod.)	5								1.7	1.7	1.7					
Own rig	Const. Wells (Reinj.)	3								1.0	1.0	1.0					
	Make up Prod. wells	8											1.0	-	-	1.0	-
	Make up Reinj. wells	2.0											-	1.0	-	-	-
	No.of Wells to be Drillded	25	-	-	-	2.3	2.3	2.3	-	2.7	2.7	2.7	1.0	1.0	-	1.0	-
	No.of Rigs Necessary		-	-	-	1.0	1.0	1.0	-	1.0	1.0	1.0	1.0	1.0	-	1.0	-
	Rig Working efficiency	67%	0%	0%	0%	58%	58%	58%	0%	67%	67%	67%	25%	25%	0%	25%	0%

Construction Costs Disbursement Schedule

(Million US$)

(Equity)			5.00				1.67	1.67	1.67								
(Equity)			24.50				8.17	8.17	8.17								
(Equity)			10.00							10.00							
(Euity&Debt)			17.50								5.83	5.83	5.83				
(Euity&Debt)			8.59								2.86	2.86	2.86				
(Euity&Debt)			63.07								21.02	21.02	21.02				
(Equity)			6.43				0.92	0.92	0.92	0.92	0.92	0.92	0.92	↓ Depreciation Cost <Steam Field>			
EcoLife (yrs)	25	OK	135.09	0.00	0.00	0.00	10.75	10.75	10.75	10.92	30.64	30.64	30.64	5.40	5.40	5.40	5.40	5.40
		IDC	9.99						-	-	1.66	3.33	4.99	129.69	124.29	118.88	113.48	108.08
		OK	145.08	0.00	0.00	0.00	10.75	10.75	10.75	10.92	32.30	33.97	35.63	↑ Book Value at Year End				
(Euity&Debt)			108.50								36.17	36.17	36.17				
(Euity&Debt)			2.00								0.67	0.67	0.67				
(Euity&Debt)			5.53								1.84	1.84	1.84	↓ Depreciation Cost <Power Plant>			
EcoLife (yrs)	25	OK	116.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.68	38.68	38.68	4.64	4.64	4.64	4.64	4.64
		IDC	12.99						-	-	2.17	4.33	6.50	111.38	106.74	102.10	97.46	92.82
		OK	129.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.84	43.01	45.17	↑ Book Value at Year End				
		OK	251.12	0.00	0.00	0.00	10.75	10.75	10.75	10.92	69.31	69.31	69.31					
		IDC	22.98						-	-	3.83	7.66	11.49					

Calculation of Equity & Debt

Steam Field	Total										
Equity	72.68	-	-	-	10.75	10.75	10.75	10.92	9.84	9.84	9.84
Debt	62.41	-	-	-	-	-	-	-	20.80	20.80	20.80
Total	135.09	-	-	-	10.75	10.75	10.75	10.92	30.64	30.64	30.64
	OK										
Power Plant	Total										
Equity	34.81	-	-	-	-	-	-	-	11.60	11.60	11.60
Debt	81.22	-	-	-	-	-	-	-	27.07	27.07	27.07
Total	116.03	-	-	-	-	-	-	-	38.68	38.68	38.68
	OK										
Total	Total										
Equity	107.49	-	-	-	10.75	10.75	10.75	10.92	21.44	21.44	21.44
Debt	143.63	-	-	-	-	-	-	-	47.88	47.88	47.88
Total	251.12	-	-	-	10.75	10.75	10.75	10.92	69.31	69.31	69.31
	OK										

Fig.-3.4 Construction Schedule & Depreciation part of "Project" sheet

Years	No.	Formula	Unit	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
Generation																																												
Power Plant			[MW]											70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	
Generation (gross)			[GWh]											551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	16,556
Steam Sales			['000 ton]											3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	3,863	115,895

Steam Field Operator

Assumption for Profits and Losses (Steam Field)

O&M Costs for Steam Field [US cents/kWh] 0.75

Years	No.	Formula	Code	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.			[Million US$]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Total Output			[MW]											70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	
Steam Sales (gross)	1		[GWh]											551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	551.88	16,556.40
Initial Investment	2			-	-	-	10.75	10.75	10.75	10.92	30.64	30.64	30.64																															135.09
Makeup Well Investment	3													3.50	2.86		3.50				3.50				3.50				3.50	2.86			3.50			3.50				3.50				33.73
Total Investment	4	[2+3]	CAPEX				10.75	10.75	10.75	10.92	30.64	30.64	30.64	3.50	2.86		3.50				3.50				3.50				3.50	2.86			3.50			3.50				3.50				168.82
Steam Sales Revenue	5													28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	864.81
Total Revenue	7	[5]	REVENUE											28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	864.81
Operation Costs	8		OPEX											4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	124.17
Depreciation of Initial Investment	9.1		DEP1											5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40						135.09
Depreciation of Makeup Production Wells	9.2		DEP2											0.14	0.14	0.14	0.28	0.28	0.28	0.28	0.42	0.42	0.42	0.42	0.56	0.56	0.56	0.56	0.70	0.70	0.70	0.70	0.84	0.84	0.84	0.98	0.98	0.98	0.84	0.98	0.98	0.84	0.84	18.20
Depreciation of Makeup Reinjection Wells	9.3		DEP3												0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.11	0.11	0.11	0.11	4.47
Total Depreciation	9	[9.1+9.2+9.3]	DEP											5.54	5.66	5.66	5.80	5.80	5.80	5.80	5.94	5.94	5.94	5.94	6.08	6.08	6.08	6.08	6.22	6.33	6.33	6.33	6.47	6.47	6.47	6.61	6.61	6.61	1.07	1.09	1.09	0.95	0.95	157.76
Total Costs	11	[8+9]												9.68	9.80	9.80	9.94	9.94	9.94	9.94	10.08	10.08	10.08	10.08	10.22	10.22	10.22	10.22	10.36	10.47	10.47	10.47	10.61	10.61	10.61	10.75	10.75	10.75	5.21	5.23	5.23	5.09	5.09	281.93
Net Income (Before Tax and Interest)	12	[7-11]	EBIT											19.14	19.03	19.03	18.89	18.89	18.89	18.89	18.75	18.75	18.75	18.75	18.61	18.61	18.61	18.61	18.47	18.36	18.36	18.36	18.22	18.22	18.22	18.08	18.08	18.08	23.62	23.59	23.59	23.73	23.73	582.88
Interest Payment	13										1.66	3.33	4.99	4.99	4.83	4.49	3.99	3.50	3.00	2.50	2.00	1.50	1.00	0.50	0.17																			42.44
Tax	14								-	-	-0.50	-1.00	-1.50	4.25	4.26	4.36	4.47	4.62	4.77	4.92	5.03	5.18	5.33	5.48	5.53	5.58	5.58	5.58	5.54	5.51	5.51	5.51	5.46	5.46	5.46	5.42	5.42	5.42	7.09	7.08	7.08	7.12	7.12	162.13
Net Income (After Tax and Interest)	15	[12-13-14]	NET INCOME								-1.17	-2.33	-3.50	9.91	9.94	10.18	10.43	10.78	11.13	11.48	11.73	12.08	12.43	12.78	12.91	13.03	13.03	13.03	12.93	12.85	12.85	12.85	12.75	12.75	12.75	12.65	12.65	12.65	16.53	16.52	16.52	16.61	16.61	378.31
PROJECT IRR for Steam Field 9.92% — **Free Cash Flows from Project**	16	[(12*(1-t)+9+10]	FCF	-	-	-	-10.75	-10.75	-10.75	-10.92	-30.64	-30.64	-30.64	15.44	16.12	18.98	15.52	19.02	19.02	19.02	15.56	19.06	19.06	19.06	15.61	19.11	19.11	19.11	15.65	16.32	19.18	19.18	15.72	19.22	19.22	15.77	19.27	19.27	17.60	14.11	17.61	17.57	28.63	408.01

Power Plant Operator

IPP

Assumption for Profits and Losses (Power Plant)

O&M Costs for Power Plant [US cents/kWh] 0.75

Years	No.	Formula	Code	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.			[Million US$]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Power Plant Output			[MW]											70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	
Energy Sales (net)	1		[GWh]											518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	518.77	15,563.02
Total Investment	4		CAPEX								38.68	38.68	38.68																															116.03
Energy Sales Revenue	5													61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	1,848.55
Total Revenue	7	[5+6]	REVENUE											61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	61.62	1,848.55
Operation Costs	8		OPEX1											4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	124.17
Depreciation of Initial Investment	9		DEP											4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64						116.03
Steam Costs	10		OPEX2											28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	28.83	864.81
Total Costs	11	[8+9+10]												37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	37.61	32.97	32.97	32.97	32.97	32.97	1,105.01
Net Income (Before Tax and Interest)	12	[7-11]	EBIT											24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	24.01	28.65	28.65	28.65	28.65	28.65	743.54
Interest Payment	13										2.17	4.33	6.50	6.50	6.28	5.85	5.20	4.55	3.90	3.25	2.60	1.95	1.30	0.65	0.22																			55.23
Tax	14													5.25	5.32	5.45	5.64	5.84	6.03	6.23	6.42	6.62	6.81	7.01	7.14	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	8.60	8.60	8.60	8.60	8.60	210.39
Net Income (After Tax and Interest)	15	[12-13-14]	NET INCOME								-2.17	-4.33	-6.50	12.26	12.41	12.71	13.17	13.62	14.08	14.53	14.99	15.44	15.90	16.35	16.66	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	20.06	20.06	20.06	20.06	20.06	477.92
PROJECT IRR for Power Plant 15.66% — **Free Cash Flows from Project**	16	[(12*(1-t)+9]	FCF	-	-	-	-	-	-	-	-38.68	-38.68	-38.68	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	20.06	20.06	20.06	20.06	20.06	520.48
Sales price of Energy			[$/MW]											8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	8.314	
Sales price of Steam			[$/MW]											3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	3.656	

Steam Field Operator

Years	No.	Formula	Unit	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.			[Million US$]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Cash Inflow: Borrowing	1										20.80	20.80	20.80																															62.41
Net Income (After Tax &and Interest)	2			-	-	-	-	-	-	-	-1.17	-2.33	-3.50	9.91	9.94	10.18	10.43	10.78	11.13	11.48	11.73	12.08	12.43	12.78	12.91	13.03	13.03	13.03	12.93	12.85	12.85	12.85	12.75	12.75	12.75	12.65	12.65	12.65	16.53	16.52	16.52	16.61	16.61	378.31
Depreciation of Initial Investment	3.1													5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40						135.09
Depreciation of Makeup Production Wells	3.2													0.14	0.14	0.14	0.28	0.28	0.28	0.28	0.42	0.42	0.42	0.42	0.56	0.56	0.56	0.56	0.70	0.70	0.70	0.70	0.84	0.84	0.84	0.98	0.98	0.98	0.84	0.98	0.98	0.84	0.84	18.20
Depreciation of Makeup Reinjection Wells	3.3														0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.11	0.11	0.11	0.11	4.47
Total Cash Inflow	5	[1+2+3.1+3.2+3.3]		-	-	-	-	-	-	-	19.64	18.47	17.31	15.45	15.60	15.83	16.22	16.57	16.92	17.27	17.66	18.01	18.36	18.71	18.99	19.11	19.11	19.11	19.15	19.18	19.18	19.18	19.22	19.22	19.22	19.27	19.27	19.27	17.60	17.61	17.61	17.57	17.57	598.48
Cash Outflow: Initial Investment	6			-	-	-	10.75	10.75	10.75	10.92	30.64	30.64	30.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	135.09
Makeup Well Investment	7			-	-	-	-	-	-	-	-	-	-	3.50	2.86	-	3.50	-	-	-	3.50	-	-	-	3.50	-	-	-	3.50	2.86	-	-	3.50	-	-	3.50	-	-	-	3.50	-	-	-	33.73
Principal Repayment	8													2.08	4.16	6.24	6.24	6.24	6.24	6.24	6.24	6.24	6.24	4.16	2.08																			62.41
Total Cash Outflow	9	[6+7+8]					10.75	10.75	10.75	10.92	30.64	30.64	30.64	5.58	7.02	6.24	9.74	6.24	6.24	6.24	9.74	6.24	6.24	4.16	5.58				3.50	2.86			3.50			3.50				3.50				231.23
Cash Flow Balance: Balance per Year	10	[5-9]		-	-	-	-10.75	-10.75	-10.75	-10.92	-11.00	-12.17	-13.33	9.87	8.58	9.59	6.48	10.33	10.68	11.03	7.92	11.77	12.12	14.55	13.41	19.11	19.11	19.11	15.65	16.32	19.18	19.18	15.72	19.22	19.22	15.77	19.27	19.27	17.60	14.11	17.61	17.57	17.57	367.25
Cumulative Balance	11				-	-	-10.75	-21.50	-32.26	-43.18	-54.18	-66.34	-79.67	-69.80	-61.23	-51.63	-45.15	-34.82	-24.13	-13.10	-5.18	6.59	18.72	33.27	46.68	65.78	84.89	103.99	119.64	135.96	155.14	174.32	190.04	209.27	228.49	244.26	263.52	282.79	300.39	314.50	332.11	349.68	367.25	
DSCR	12	[(5+Int.Rep)/(8+Int.Rep)]												2.89	2.27	1.89	1.98	2.06	2.16	2.26	2.39	2.52	2.67	4.12	8.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
EQUITY IRR for Steam Field 9.98% — Free cash flow for Equity IRR	13	[FCF-Int.Rep -Prince.Rep]					-10.75	-10.75	-10.75	-10.92	-11.50	-13.16	-14.83	8.37	7.13	8.24	5.29	9.28	9.78	10.28	7.32	11.32	11.82	14.40	13.36	19.11	19.11	19.11	15.65	16.32	19.18	19.18	15.72	19.22	19.22	15.77	19.27	19.27	17.60	14.11	17.61	17.57	28.63	

IPP

Power Plant Operator

Years	No.	Formula	Unit	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.			[Million US$]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Cash Inflow: Borrowing	1										27.07	27.07	27.07																															81.22
Net Income (After Tax &and Interest)	2			-	-	-	-	-	-	-	-2.17	-4.33	-6.50	12.26	12.41	12.71	13.17	13.62	14.08	14.53	14.99	15.44	15.90	16.35	16.66	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	16.81	20.06	20.06	20.06	20.06	20.06	477.92
Depreciation of Initial Investment	3													4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64						116.03
Total Cash Inflow	5	[1+2+3]		-	-	-	-	-	-	-	24.91	22.74	20.58	16.90	17.05	17.36	17.81	18.27	18.72	19.17	19.63	20.08	20.54	20.99	21.30	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	20.06	20.06	20.06	20.06	20.06	675.16
Cash Outflow: Investment	6			-	-	-	-	-	-	-	38.68	38.68	38.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116.03
Principal Repayment	8													2.71	5.41	8.12	8.12	8.12	8.12	8.12	8.12	8.12	8.12	5.41	2.71																			81.22
Total Cash Outflow	9	[6+8]									38.68	38.68	38.68	2.71	5.41	8.12	8.12	8.12	8.12	8.12	8.12	8.12	8.12	5.41	2.71																			197.24
Cash Flow Balance: Balance per Year	10	[5-9]		-	-	-	-	-	-	-	-13.77	-15.93	-18.10	14.19	11.64	9.23	9.69	10.14	10.60	11.05	11.51	11.96	12.42	15.58	18.59	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	20.06	20.06	20.06	20.06	20.06	477.92
Cumulative Balance	11				-	-	-	-	-	-	-13.77	-29.70	-47.80	-33.61	-21.97	-12.74	-3.05	7.09	17.69	28.75	40.25	52.22	64.63	80.21	98.80	120.25	141.70	163.15	184.60	206.05	227.50	248.94	270.39	291.84	313.29	334.74	356.19	377.64	397.69	417.75	437.81	457.86	477.92	
DSCR	12	[(5+Int.Rep)/(8+Int.Rep)]												2.54	2.00	1.66	1.73	1.80	1.88	1.97	2.07	2.19	2.32	3.57	7.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
EQUITY IRR for Power Plant 20.00% — Free cash flow for Equity IRR	13	[FCF+Borrow-Int.Rep -Prince.Rep]					-	-	-	-	-13.77	-15.93	-18.10	12.24	9.75	7.48	8.13	8.78	9.43	10.08	10.73	11.38	12.03	15.38	18.52	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	20.06	20.06	20.06	20.06	20.06	

Steam Field Operator

Years	No.	Formula	[Million US$]	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Asset: Cash	1		82.67	-	-	82.67	71.91	61.16	50.41	39.49	28.49	16.33	3.00	12.86	21.44	31.03	37.52	47.85	58.53	69.56	77.49	89.26	101.38	115.94	129.35	148.45	167.56	186.66	202.31	218.63	237.81	256.99	272.71	291.93	311.16	326.92	346.19	365.45	383.06	397.17	414.78	432.34	449.91	
Fixed Assets	2													133.05	130.26	124.60	122.30	116.50	110.70	104.90	102.47	96.53	90.59	84.65	82.07	75.99	69.92	63.84	61.12	57.65	51.32	44.98	42.01	35.54	29.07	25.95	19.34	12.73	11.66	14.06	12.97	12.01	11.06	
Construction Account	3			-	-	-	10.75	21.50	32.26	43.18	73.82	104.45	135.09																															
Total	4	[1+2+3]		0.00	0.00	82.67	82.67	82.67	82.67	82.67	102.31	120.78	138.09	145.92	151.70	155.63	159.82	164.35	169.23	174.47	179.95	185.79	191.97	200.59	211.42	224.44	237.47	250.50	263.43	276.28	289.12	301.97	314.72	327.47	340.22	352.88	365.53	378.18	394.72	411.23	427.75	444.36	460.97	
Debt & Equity: Long-term Debt	5								-	-	20.80	41.61	62.41	60.33	56.17	49.93	43.69	37.45	31.21	24.97	18.72	12.48	6.24	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Equity	6		82.67	-	-	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	82.67	
Earned Reserve	7			-	-	-	-	-	-	-	-1.17	-3.50	-6.99	2.92	12.86	23.03	33.46	44.24	55.36	66.84	78.56	90.64	103.07	115.84	128.75	141.78	154.80	167.83	180.76	193.61	206.46	219.31	232.06	244.81	257.56	270.21	282.86	295.51	312.05	328.56	345.08	361.69	378.31	
Total	8	[5+6+7]		0.00	0.00	82.67	82.67	82.67	82.67	82.67	102.31	120.78	138.09	145.92	151.70	155.63	159.82	164.35	169.23	174.47	179.95	185.79	191.97	200.59	211.42	224.44	237.47	250.50	263.43	276.28	289.12	301.97	314.72	327.47	340.22	352.88	365.53	378.18	394.72	411.23	427.75	444.36	460.97	
				OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	

IPP

Power Plant Operator

Years	No.	Formula	[Million US$]	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	TOTAL
No.				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
Asset: Cash	1		47.80	-	-	-	-	-	-	47.80	34.03	18.10	-	14.19	25.83	35.06	44.75	54.90	65.49	76.55	88.06	100.02	112.44	128.01	146.60	168.05	189.50	210.95	232.40	253.85	275.30	296.75	318.19	339.64	361.09	382.54	403.99	425.44	445.50	465.55	485.61	505.66	525.72	
Fixed Assets	2													111.38	106.74	102.10	97.46	92.82	88.18	83.54	78.90	74.26	69.61	64.97	60.33	55.69	51.05	46.41	41.77	37.13	32.49	27.85	23.20	18.56	13.92	9.28	4.64	-	-	-	-	-	-	
Construction Account	3			-	-	-	-	-	-	-	38.68	77.35	116.03																															
Total	4	[1+2+3]		0.00	0.00	0.00	0.00	0.00	0.00	47.80	72.71	95.45	116.03	125.58	132.57	137.17	142.21	147.72	153.67	160.09	166.95	174.27	182.05	192.99	206.94	223.75	240.55	257.36	274.17	290.98	307.78	324.59	341.40	358.21	375.02	391.82	408.63	425.44	445.50	465.55	485.61	505.66	525.72	
Debt & Equity: Long-term Debt	5								-	-	27.07	54.15	81.22	78.51	73.10	64.97	56.85	48.73	40.61	32.49	24.37	16.24	8.12	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Equity	6		47.80	-	-	-	-	-	-	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	47.80	
Earned Reserve	7			-	-	-	-	-	-	-	-2.17	-6.50	-12.99	-0.74	11.68	24.39	37.56	51.18	65.26	79.80	94.78	110.23	126.13	142.48	159.14	175.94	192.75	209.56	226.37	243.17	259.98	276.79	293.60	310.41	327.21	344.02	360.83	377.64	397.69	417.75	437.81	457.86	477.92	
Total	8	[5+6+7]		0.00	0.00	0.00	0.00	0.00	0.00	47.80	72.71	95.45	116.03	125.58	132.57	137.17	142.21	147.72	153.67	160.09	166.95	174.27	182.05	192.99	206.94	223.75	240.55	257.36	274.17	290.98	307.78	324.59	341.40	358.21	375.02	391.82	408.63	425.44	445.50	465.55	485.61	505.66	525.72	
				OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	

Fig.-3.5 Financial Statements part of "Project" sheet

Repayment Schedule		No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
Steam Field		Year	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	Total		
	8.00%	Loan	-	-	*20.80*	*20.80*	*20.80*																																													-		
-5 year Disburse	Grace	Principle		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	3	Interest		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	Repayme	Repaymen		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	10	Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-4 year Disburse	Grace	Principle			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	3	Interest			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	Repayme	Repaymen			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	10	Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-3 year Disburse	Grace	Principle				-	-	-	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.80		
	3	Interest				1.66	1.66	1.66	1.66	1.50	1.33	1.17	1.00	0.83	0.67	0.50	0.33	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.15		
	Repayme	Repaymen				1.66	1.66	1.66	3.74	3.58	3.41	3.25	3.08	2.91	2.75	2.58	2.41	2.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.95		
	10	Balance			20.80	20.80	20.80	20.80	18.72	16.64	14.56	12.48	10.40	8.32	6.24	4.16	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-2 year Disburse	Grace	Principle					-	-	-	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.80		
	3	Interest					1.66	1.66	1.66	1.66	1.50	1.33	1.17	1.00	0.83	0.67	0.50	0.33	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.15		
	Repayme	Repaymen					1.66	1.66	3.74	3.58	3.41	3.25	3.08	2.91	2.75	2.58	2.41	2.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.95		
	10	Balance				20.80	20.80	20.80	20.80	18.72	16.64	14.56	12.48	10.40	8.32	6.24	4.16	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-1 year Disburse	Grace	Principle					-	-	-	-	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.80		
	3	Interest					1.66	1.66	1.66	1.66	1.50	1.33	1.17	1.00	0.83	0.67	0.50	0.33	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.15		
	Repayme	Repaymen					1.66	1.66	1.66	3.74	3.58	3.41	3.25	3.08	2.91	2.75	2.58	2.41	2.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.95		
	10	Balance					20.80	20.80	20.80	18.72	16.64	14.56	12.48	10.40	8.32	6.24	4.16	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Total Repayment (m$)		Principle	-	-	-	-	-	2.08	4.16	6.24	6.24	6.24	6.24	6.24	6.24	6.24	6.24	6.24	4.16	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	62.41	*62.41*	OK
		Interest	-	-	1.66	3.33	4.99	4.99	4.83	4.49	3.99	3.50	3.00	2.50	2.00	1.50	1.00	0.50	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42.44	*42.44*	OK
		Repaymen	-	-	1.66	3.33	4.99	7.07	8.99	10.73	10.24	9.74	9.24	8.74	8.24	7.74	7.24	4.66	2.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104.85	*104.85*	OK
		Balance	-	-	20.80	41.61	62.41	60.33	56.17	49.93	43.69	37.45	31.21	24.97	18.72	12.48	6.24	2.08	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
		Check	8.00%	OK	-20.80	-19.14	-17.48	4.99	7.07	8.99	10.73	10.24	9.74	9.24	8.74	8.24	7.74	7.24	4.66	2.25																																	42.44	*42.44*	OK

Repayment Schedule		No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50			
Heat Plant		Year	-5	-4	-3	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	Total		
	8.00%	Loan	-	-	*27.07*	*27.07*	*27.07*																																													-		
-5 year Disburse	Grace	Principle		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	3	Interest		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	Repayme	Repaymen		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	10	Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-4 year Disburse	Grace	Principle			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	3	Interest			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	Repayme	Repaymen			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
	10	Balance		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-3 year Disburse	Grace	Principle				-	-	-	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.07		
	3	Interest				2.17	2.17	2.17	1.95	1.73	1.52	1.30	1.08	0.87	0.65	0.43	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.41		
	Repayme	Repaymen				2.17	2.17	2.17	4.87	4.66	4.44	4.22	4.01	3.79	3.57	3.36	3.14	2.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.48		
	10	Balance			27.07	27.07	27.07	27.07	24.37	21.66	18.95	16.24	13.54	10.83	8.12	5.41	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-2 year Disburse	Grace	Principle					-	-	-	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.07		
	3	Interest					2.17	2.17	2.17	1.95	1.73	1.52	1.30	1.08	0.87	0.65	0.43	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.41		
	Repayme	Repaymen					2.17	2.17	4.87	4.66	4.44	4.22	4.01	3.79	3.57	3.36	3.14	2.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.48		
	10	Balance				27.07	27.07	27.07	24.37	21.66	18.95	16.24	13.54	10.83	8.12	5.41	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
-1 year Disburse	Grace	Principle					-	-	-	-	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.07		
	3	Interest					2.17	2.17	2.17	1.95	1.73	1.52	1.30	1.08	0.87	0.65	0.43	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18.41		
	Repayme	Repaymen					2.17	2.17	4.87	4.66	4.44	4.22	4.01	3.79	3.57	3.36	3.14	2.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.48		
	10	Balance				27.07	27.07	27.07	24.37	21.66	18.95	16.24	13.54	10.83	8.12	5.41	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Total Repayment (m$)		Principle	-	-	-	-	-	2.71	5.41	8.12	8.12	8.12	8.12	8.12	8.12	8.12	8.12	8.12	5.41	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	81.22	*81.22*	OK
		Interest	-	-	2.17	4.33	6.50	6.50	6.28	5.85	5.20	4.55	3.90	3.25	2.60	1.95	1.30	0.65	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.23	*55.23*	OK
		Repaymen	-	-	2.17	4.33	6.50	9.20	11.70	13.97	13.32	12.67	12.02	11.37	10.72	10.07	9.42	6.06	2.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	136.45	*136.45*	OK
		Balance	-	-	27.07	54.15	81.22	78.51	73.10	64.97	56.85	48.73	40.61	32.49	24.37	16.24	8.12	2.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
		Check	8.00%	OK	-27.07	-24.91	-22.74	6.50	9.20	11.70	13.97	13.32	12.67	12.02	11.37	10.72	10.07	9.42	6.06	2.92																																	55.23	*55.23*	OK

Fig.-3.6 Repayment Schedule part of "Project" sheet

Makeup Production Wells

MW	Well Outp	Well No. at	Declining Rate (%/year)	Price escalation (%/year)
70	62.0	8	3.0%	0.0%

Makeup Well	Total Steam	No. Wells	Dep. Year	Unit Costs	Costs (m$)
	496.00				
1 Makeup Well (1st ye	541.26	**1**	25	3.50	3.50
2 Makeup Well (2nd y	525.02	-	25	3.50	-
3 Makeup Well (3rd ye	509.27	-	25	3.50	-
4 Makeup Well (4th ye	554.13	**1**	25	3.50	3.50
5 Makeup Well (5th ye	537.51	-	25	3.50	-
6 Makeup Well (6th ye	521.38	-	25	3.50	-
7 Makeup Well (7th ye	505.74	-	25	3.50	-
8 Makeup Well (8th ye	550.71	**1**	25	3.50	3.50
9 Makeup Well (9th ye	534.19	-	25	3.50	-
10 Makeup Well (10th y	518.16	-	25	3.50	-
11 Makeup Well (11th y	502.62	-	25	3.50	-
12 Makeup Well (12th y	547.68	**1**	25	3.50	3.50
13 Makeup Well (13th y	531.25	-	25	3.50	-
14 Makeup Well (14th y	515.31	-	25	3.50	-
15 Makeup Well (15th y	499.85	-	25	3.50	-
16 Makeup Well (16th y	545.00	**1**	25	3.50	3.50
17 Makeup Well (17th y	528.65	-	25	3.50	-
18 Makeup Well (18th y	512.79	-	25	3.50	-
19 Makeup Well (19th y	497.40	-	25	3.50	-
20 Makeup Well (20th y	542.62	**1**	25	3.50	3.50
21 Makeup Well (21th y	526.34	-	25	3.50	-
22 Makeup Well (22th y	510.55	-	25	3.50	-
23 Makeup Well (23th y	555.38	**1**	25	3.50	3.50
24 Makeup Well (24th y	538.72	-	25	3.50	-
25 Makeup Well (25th y	522.55	-	25	3.50	-
26 Makeup Well (26th y	506.88	-	25	3.50	-
27 Makeup Well (27th y	551.81	**1**	25	3.50	3.50
28 Makeup Well (28th y	535.26	-	25	3.50	-
29 Makeup Well (29th y	519.20	-	25	3.50	-
30 Makeup Well (30th y	503.62	-	25	3.50	-
Total		**8**			28.00

Depreciation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
1 Makeup Well (1st ye	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14						3.50
2 Makeup Well (2nd y																															-
3 Makeup Well (3rd ye																															-
4 Makeup Well (4th ye				0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14				3.50
5 Makeup Well (5th ye																															-
6 Makeup Well (6th ye																															-
7 Makeup Well (7th ye																															-
8 Makeup Well (8th ye								0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	3.22
9 Makeup Well (9th ye																															-
10 Makeup Well (10th y																															-
11 Makeup Well (11th y																															-
12 Makeup Well (12th y												0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	2.66
13 Makeup Well (13th y																															-
14 Makeup Well (14th y																															-
15 Makeup Well (15th y																															-
16 Makeup Well (16th y																0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	2.10
17 Makeup Well (17th y																															-
18 Makeup Well (18th y																															-
19 Makeup Well (19th y																															-
20 Makeup Well (20th y																				0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1.54
21 Makeup Well (21th y																															-
22 Makeup Well (22th y																															-
23 Makeup Well (23th y																							0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1.12
24 Makeup Well (24th y																															-
25 Makeup Well (25th y																															-
26 Makeup Well (26th y																															-
27 Makeup Well (27th y																											0.14	0.14	0.14	0.14	0.56
28 Makeup Well (28th y																															-
29 Makeup Well (29th y																															-
30 Makeup Well (30th y																															-
Total	0.14	0.14	0.14	0.28	0.28	0.28	0.28	0.42	0.42	0.42	0.42	0.56	0.56	0.56	0.56	0.70	0.70	0.70	0.70	0.84	0.84	0.84	0.98	0.98	0.98	0.84	0.98	0.98	0.84	0.84	18.20

	Total Steam	No. Wells	Dep. Year	Unit Costs	Costs (m$)
1 Makeup Well (1st year)					3.50
2 Makeup Well (2nd year)					-
3 Makeup Well (3rd year)					-
4 Makeup Well (4th year)					3.50
5 Makeup Well (5th year)					-
6 Makeup Well (6th year)					-
7 Makeup Well (7th year)					-
8 Makeup Well (8th year)					3.50
9 Makeup Well (9th year)					-
10 Makeup Well (10th year)					-
11 Makeup Well (11th year)					-
12 Makeup Well (12th year)					3.50
13 Makeup Well (13th year)					-
14 Makeup Well (14th year)					-
15 Makeup Well (15th year)					-
16 Makeup Well (16th year)					3.50
17 Makeup Well (17th year)					-
18 Makeup Well (18th year)					-
19 Makeup Well (19th year)					-
20 Makeup Well (20th year)					3.50
21 Makeup Well (21th year)					-
22 Makeup Well (22th year)					-
23 Makeup Well (23th year)					3.50
24 Makeup Well (24th year)					-
25 Makeup Well (25th year)					-
26 Makeup Well (26th year)					-
27 Makeup Well (27th year)					3.50
28 Makeup Well (28th year)					-
29 Makeup Well (29th year)					-
30 Makeup Well (30th year)					-
Total					28.00

Book Value at year end (Makeup Production Wells)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Salvage
1 Makeup Well (1st year)	3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28	0.14							
2 Makeup Well (2nd year)																															
3 Makeup Well (3rd year)																															
4 Makeup Well (4th year)				3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28	0.14				
5 Makeup Well (5th year)																															
6 Makeup Well (6th year)																															
7 Makeup Well (7th year)																															
8 Makeup Well (8th year)								3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28	0.28
9 Makeup Well (9th year)																															
10 Makeup Well (10th year)																															
11 Makeup Well (11th year)																															
12 Makeup Well (12th year)												3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.84
13 Makeup Well (13th year)																															
14 Makeup Well (14th year)																															
15 Makeup Well (15th year)																															
16 Makeup Well (16th year)																3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.82	1.68	1.54	1.40	1.40
17 Makeup Well (17th year)																															
18 Makeup Well (18th year)																															
19 Makeup Well (19th year)																															
20 Makeup Well (20th year)																				3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10	1.96	1.96
21 Makeup Well (21th year)																															
22 Makeup Well (22th year)																															
23 Makeup Well (23th year)																							3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.38
24 Makeup Well (24th year)																															
25 Makeup Well (25th year)																															
26 Makeup Well (26th year)																															
27 Makeup Well (27th year)																											3.36	3.22	3.08	2.94	2.94
28 Makeup Well (28th year)																															
29 Makeup Well (29th year)																															
30 Makeup Well (30th year)																															
Total	3.36	3.22	3.08	6.30	6.02	5.74	5.46	8.54	8.12	7.70	7.28	10.22	9.66	9.10	8.54	11.34	10.64	9.94	9.24	11.90	11.06	10.22	12.74	11.76	10.78	9.94	12.46	11.48	10.64	9.80	9.80

28.00
OK

Fig.-3.7 Make-up Well Schedule part of "Project" sheet (Production well part)

Chapter 4 Structure of "Olkaria_280MW" sheet, "Menengai_105MW" and "Headquarter" sheet

The sheets of “Olkaria_280MW", “Menengai_105MW" and “Headquarter" have basically a same structure as the “Project" sheet as shown in Fig.-4.1.

The input data in the "Project Assumptions" part of the “Olkaria_280MW" are as shown in Fig.-4.2, and the input data in the "Construction Costs Estimation" part of the “Olkaria_280 MW" are as shown in Fig.-4.3.

The input data in the "Project Assumptions" part of the “Menengai_105MW" are as shown in Fig.-4.4, and the input data in the "Construction Costs Estimation" part of the “Menengai_105MW" are as shown in Fig.-4.5.

The “Headquarter" is not a project but an expenditure of administration department. Therefore the input data in the "Project Assumptions" part of the “Headquarter" sheet are as shown in Fig.-4.6, and the input data in the "Construction Costs Estimation" part of the “Headquarter" are as shown in Fig.-4.7.

The details of these assumptions are described in Chapter 7.

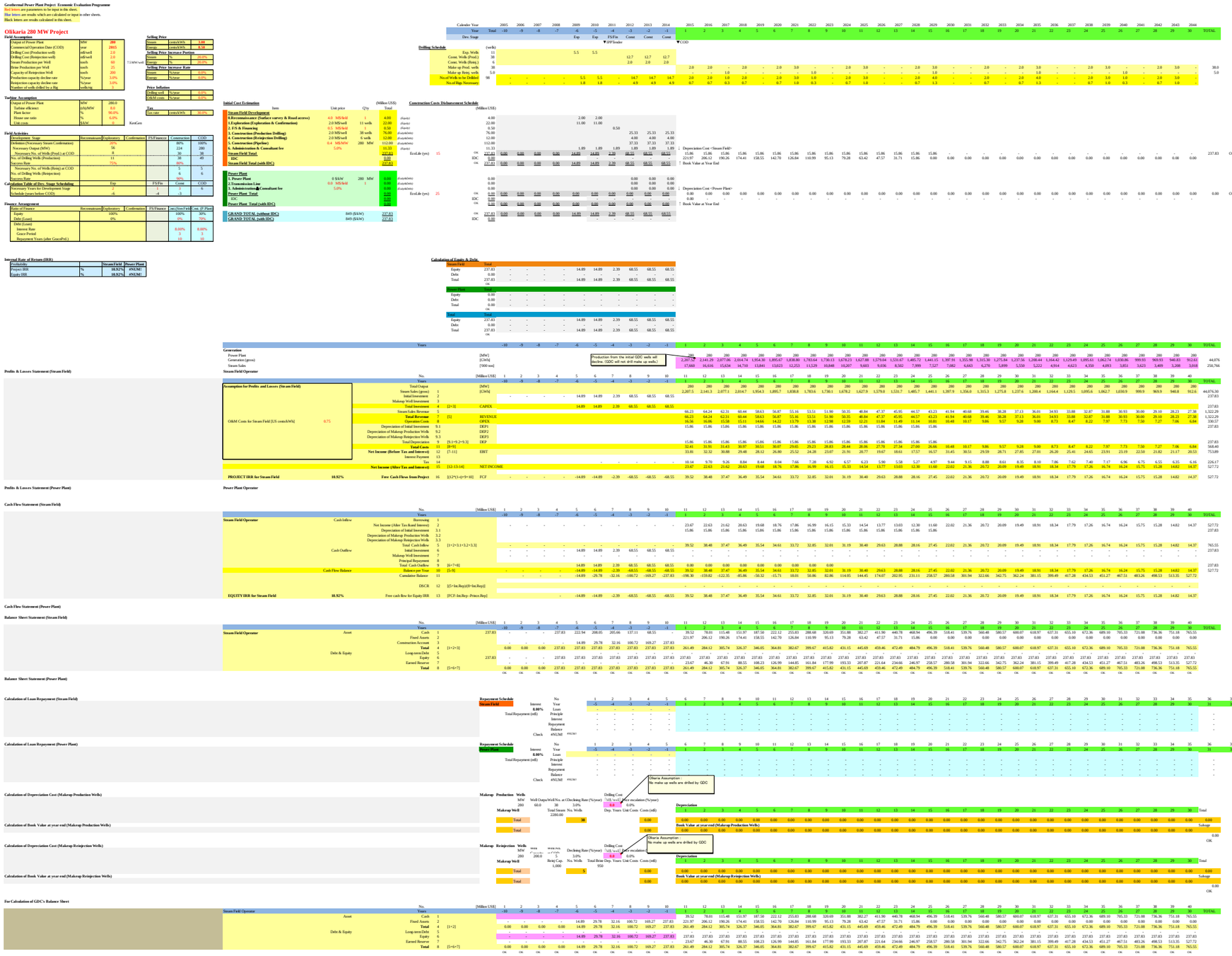


Fig.-4.1 Bird-view of "Olkaria_280MW" sheet

Olikaria 280 MW Project

Field Assumption

Output of Power Plant	MW	**280**
Commercial Operation Date (COD)	year	**2015**
Drilling Cost (Production well)	m$/well	2.0
Drilling Cost (Reinjection well)	m$/well	2.0
Steam Production per Well	ton/h	60
Brine Production per Well	ton/h	60
Capacity of Reinjection Well	ton/h	200
Production capacity decline rate	%/year	3.0%
Reinjection capacity decline rate	%/year	3.0%
Number of wells drilled by a Rig	wells/rig	3

7.5 MW/well

Turbine Assumption

Output of Power Plant	MW	280.0
Turbine efficienct	(t/h)/MW	8.0
Plant factor	%	90.0%
House use ratio	%	6.0%
Unit costs	$/kW	0

KenGen

Selling Price

Steam	cents/kWh	**3.00**
Energy	cents/kWh	**8.50**

Selling Price Increase Portion

Steam	%	20.0%
Energy	%	20.0%

Selling Price Increase Rate

Steam	%/year	0.0%
Energy	%/year	0.0%

Price Inflation

Drilling well	%/year	0.0%
O&M costs	%/year	0.0%

Tax

Tax rate	cents/kWh	30.0%

Field Activities

Development Stage	Reconnaissa	Exploratory	Confirmation	FS/Financce	Construction	COD
Definition (Necessary Steam Confirmatic		20%			80%	100%
Necessary Output (MW)		56			224	280
Necessary No. of Wells (Prod.) at COI		8			30	38
No. of Drilling Wells (Production)		11			38	49
Success Rate		75%			80%	
Necessary No. of Wells (Reinj) at COI					12	12
No. of Drilling Wells (Reinjection)					14	14
Success Rate					90%	
Calculation Table of Dev. Stage Schedulin		Exp		FS/Fin	Const	COD
Necessary Years for Development Stage		2		1	3	6
Schedule (years before COD)		-6		-4	-3	

Finance Arrangement

Ratio of Finance	Reconnaissa	Exploratory	Confirmation	FS/Finance	nst.(Stm Fiel	Cnst. (P.Plant
Equity		100%			100%	30%
Debt (Loan)		0%			0%	70%
Debt (Loan)						
Interest Rate					8.00%	8.00%
Grace Period					3	3
Repayment Years (after GracePrd.)					10	10

Fig.-4.2 Project Assumptions part of "Olkaria_280MW" sheet

Initial Cost Estimation (Million US$) **Construction Costs Disbu**

Item	Unit price	Q'ty	Total	
Steam Field Development				
0.Reconnaissance (Surface survey & Road access)	4.0 M$/field	1	4.00	*(Equity)*
1.Exploration (Exploration & Confirmation)	2.0 M$/well	11 wells	22.00	*(Equity)*
2. F/S & Financing	0.5 M$/field	1	0.50	*(Equity)*
3. Construction (Production Drilling)	2.0 M$/well	38 wells	76.00	*(Euity&Debt)*
4. Construction (Reinjection Drilling)	2.0 M$/well	14 wells	28.00	*(Euity&Debt)*
5. Construction (Pipeline)	0.4 M$/MW	280 MW	112.00	*(Euity&Debt)*
6. Administration & Consultant fee	5.0%		12.13	*(Equity)*
Steam Field Total			254.63	EcoLife (yrs) 25
IDC			0.00	
Steam Field Total (with IDC)			254.63	
Power Plant				
1. Power Plant	0 $/kW	280 MW	0.00	*(Euity&Debt)*
2.Transmission Line	0.0 M$/field	1	0.00	*(Euity&Debt)*
3. Administration&Consultant fee	5.0%		0.00	*(Euity&Debt)*
Power Plant Total			0.00	EcoLife (yrs) 25
IDC			0.00	
Power Plant Total (with IDC)			0.00	
GRAND TOTAL (without IDC)		909 ($/kW)	254.63	
GRAND TOTAL (with IDC)		909 ($/kW)	254.63	

Fig.-4.3 Construction Costs Estimation part of "Olkaria_280MW" sheet

Menengai 105 MW Project

Field Assumption

Output of Power Plant	MW	**105**
Commercial Operation Date (COD)	year	**2019**
Drilling Cost (Production well)	m$/well	4.3
Drilling Cost (Reinjection well)	m$/well	3.5
Steam Production per Well	ton/h	60
Brine Production per Well	ton/h	45
Capacity of Reinjection Well	ton/h	200
Production capacity decline rate	%/year	3.0%
Reinjection capacity decline rate	%/year	3.0%
Number of wells drilled by a Rig	wells/rig	3

7.5 MW/well

Turbine Assumption

Output of Power Plant	MW	105.0
Turbine efficienct	(t/h)/MW	8.0
Plant factor	%	90.0%
House use ratio	%	6.0%
Unit costs	$/kW	

IPP

Selling Price

Steam	cents/kWh	**3.50**
Energy	cents/kWh	**8.50**

Selling Price Increase Portion

Steam	%	20.0%
Energy	%	20.0%

Selling Price Increase Rate

Steam	%/year	0.0%
Energy	%/year	0.0%

Price Inflation

Drilling well	%/year	0.0%
O&M costs	%/year	0.0%

Tax

Tax rate	cents/kWh	30.0%

Field Activities

Development Stage	Reconnaissa	Exploratory	Confirmatior	FS/Financce	Construction	COD
Definition (Necessary Steam Confirmatic		100%			0%	100%
Necessary Output (MW)		105			0	105
Necessary No. of Wells (Prod.) at COI		14			0	14
No. of Drilling Wells (Production)		28			0	28
Success Rate		50%			80%	
Necessary No. of Wells (Reinj) at COD					4	4
No. of Drilling Wells (Reinjection)					5	5
Success Rate					90%	
Calculation Table of Dev. Stage Schedulin		Exp		FS/Fin	Const	COD
Necessary Years for Development Stage		3		0	3	6
Schedule (years before COD)		-6		-3	-3	

Finance Arrangement

Ratio of Finance	Reconnaissa	Exploratory	Confirmatior	FS/Finance	nst.(Stm Fiel	Cnst. (P.Plant
Equity		100%			100%	30%
Debt (Loan)		0%			0%	70%
Debt (Loan)						
Interest Rate					8.00%	8.00%
Grace Period					3	3
Repayment Years (after GracePrd.)					10	10

Fig.-4.4 Project Assumptions part of "Menengai_105MW" sheet

Initial Cost Estimation (Million US$) **Construction Costs Disbu**

Item	Unit price	Q'ty	Total	
Steam Field Development				
0.Reconnaissance (Surface survey & Road access)	15.0 M$/field	1	15.00	*(Equity)*
1.Exploration (Exploration & Confirmation)	4.3 M$/well	28 wells	120.40	*(Equity)*
2. F/S & Financing	0.5 M$/field	0	0.00	*(Equity)*
3. Construction (Production Drilling)	4.3 M$/well	0 wells	0.00	*(Euity&Debt)*
4. Construction (Reinjection Drilling)	3.5 M$/well	5 wells	17.50	*(Euity&Debt)*
5. Construction (Pipeline)	0.85 M$/MW	105 MW	89.25	*(Euity&Debt)*
6. Administration & Consultant fee	5.0%		12.11	*(Equity)*
Steam Field Total			254.26	EcoLife (yrs) 25
IDC			0.00	
Steam Field Total (with IDC)			254.26	
Power Plant				
1. Power Plant	0 $/kW	105 MW	0.00	*(Euity&Debt)*
2.Transmission Line	0.0 M$/field	1	0.00	*(Euity&Debt)*
3. Administration&Consultant fee	5.0%		0.00	*(Euity&Debt)*
Power Plant Total			0.00	EcoLife (yrs) 25
IDC			0.00	
Power Plant Total (with IDC)			0.00	
GRAND TOTAL (without IDC)	2,422 ($/kW)		254.26	
GRAND TOTAL (with IDC)	2,422 ($/kW)		254.26	

Fig.-4.5 Project Assumptions part of "Menengai_105MW" sheet

Headquarter

Field Assumption

Output of Power Plant	MW	
Commercial Operation Date (COD)	year	2014
Drilling Cost (Production well)	m$/well	
Drilling Cost (Reinjection well)	m$/well	
Steam Production per Well	ton/h	1
Brine Production per Well	ton/h	1
Capacity of Reinjection Well	ton/h	1
Production capacity decline rate	%/year	
Reinjection capacity decline rate	%/year	
Number of wells drilled by a Rig	wells/rig	3

Turbine Assumption

Output of Power Plant	MW	0.0
Turbine efficienct	(t/h)/MW	
Plant factor	%	
House use ratio	%	
Unit costs	$/kW	

Selling Price

Steam	cents/kWh	
Energy	cents/kWh	

Selling Price Increase Portion

Steam	%	20.0%
Energy	%	20.0%

Selling Price Increase Rate

Steam	%/year	0.0%
Energy	%/year	0.0%

Price Inflation

Drilling well	%/year	0.0%
O&M costs	%/year	0.0%

Tax

Tax rate	cents/kWh	30.0%

Field Activities

Development Stage	Reconnaissanc	Exploratory	Confirmation	FS/Financce	Construction	COD
Definition (Necessary Steam Confirmation)		40%			60%	100%
Necessary Output (MW)		0			0	0
Necessary No. of Wells (Prod.) at COD		0			0	0
No. of Drilling Wells (Production)		0			0	0
Success Rate		50%			80%	
Necessary No. of Wells (Reinj) at COD					0	0
No. of Drilling Wells (Reinjection)					0	0
Success Rate					90%	
Calculation Table of Dev. Stage Scheduling		Exp		FS/Fin	Const	COD
Necessary Years for Development Stage		3		1	2	6
Schedule (years before COD)		-6		-3	-2	

Finance Arrangement

Ratio of Finance	Reconnaissanc	Exploratory	Confirmation	FS/Finance	Cnst.(Stm Field	Cnst. (P.Plant)
Equity		100%			100%	30%
Debt (Loan)		0%			0%	70%
Debt (Loan)						
Interest Rate					8.00%	8.00%
Grace Period					3	3
Repayment Years (after GracePrd.)					10	10

Fig.-4.6 Project Assumptions part of "Headquarter" sheet

Initial Cost Estimation (Million US$) **Construction Costs Disbu**

Item	Unit price	Q'ty	Total	
Steam Field Development				
Headquarter Assets	190.0 M$/field	1	190.00	*(Equity)*
1.Exploration (Exploration & Confirmation)	0.0 M$/well	0 wells	0.00	*(Equity)*
2. F/S & Financing	0.5 M$/field	0	0.00	*(Equity)*
3. Construction (Production Drilling)	0.0 M$/well	0 wells	0.00	*(Euity&Debt)*
4. Construction (Reinjection Drilling)	0.0 M$/well	0 wells	0.00	*(Euity&Debt)*
5. Construction (Pipeline)	0.4 M$/MW	0 MW	0.00	*(Euity&Debt)*
6. Administration & Consultant fee	0.0%		0.00	*(Equity)*
Steam Field Total			190.00	EcoLife (yrs) 15
IDC			0.00	
Steam Field Total (with IDC)			190.00	
Power Plant				
1. Power Plant	0 $/kW	0 MW	0.00	*(Euity&Debt)*
2.Transmission Line	0.0 M$/field	0	0.00	*(Euity&Debt)*
3. Administration&Consultant fee	5.0%		0.00	*(Euity&Debt)*
Power Plant Total			0.00	EcoLife (yrs) 25
IDC			0.00	
Power Plant Total (with IDC)			0.00	
GRAND TOTAL (without IDC)	#DIV/0!	($/kW)	190.00	
GRAND TOTAL (with IDC)	#DIV/0!	($/kW)	190.00	

Fig.-4.7 Project Assumptions part of "Headquarter" sheet

Chapter 5 Structure of "GDC_Total" sheet

“GDC_Total" sheet has a structure as shown in Fig.-5.1. The annual financial figures of all projects are totaled for 50-year period from 2014 to 2064 for the following items.

(a) Development plan
- Output (MW)
- RIGs needed
- Wells to be drilled

(b) Profits & Losses statement
- Revenue
- OPEX
- Total Depreciation
- EBIT
- Interest Payment
- Tax
- Net Income (after Tax)

(c) Cash flows statement
- Long-term Loan for Construction
- Cash Inflows
- CAPEX
- Loan Repayment (Principal)
- Cash Outflows
- Net Cash Flows

(d) Balance sheet statement
- Cash
- Fixed Asset
- Asset Total
- Long-term Debt
- Equity
- Earned Reserve
- Debt & Equity Total

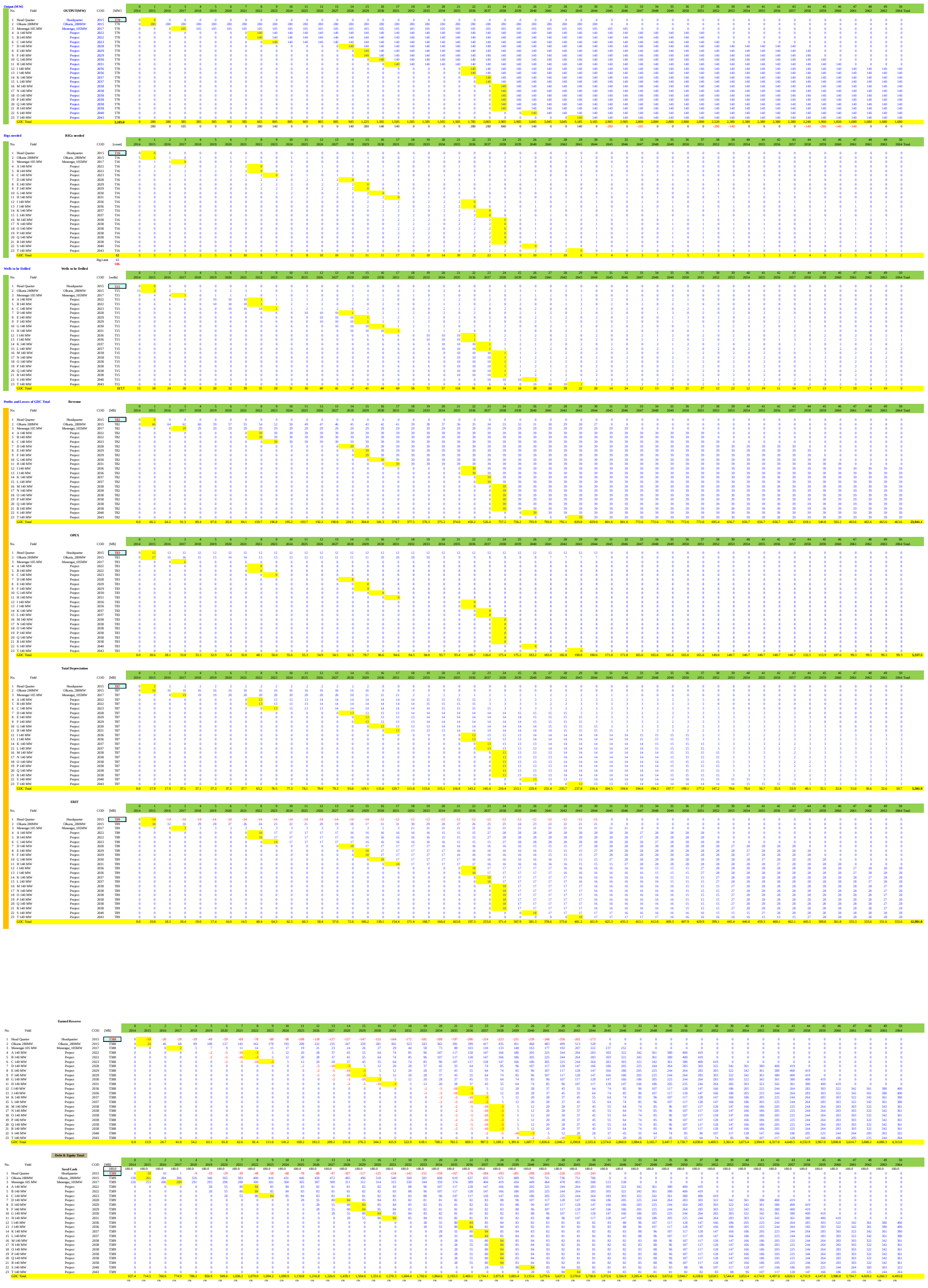


Fig.-5.1 Bird-view of "GDC_Total" sheet

Chapter 6 Structure of “GDC_Total_(Summary)” sheet

“GDC_Total_(Summary)" sheet is a summary of “GDC_Total” sheet and has a structure as shown in Fig.-6.1. The following items are displayed in total value for the period of 50 years from 2014 to 2064.

(a) Development plan
- Output (MW)
- RIGs needed
- Wells to be drilled

(b) Profits & Losses statement
- Revenue
- OPEX
- Total Depreciation
- EBIT
- Interest Payment
- Tax
- Net Income (after Tax)
- Net Income (after Tax) (cumulative)

(c) Cash flows statement
- Cash Inflows
  - Net Income (after Tax)
  - Borrowings for Construction
  - Total Depreciation
- Cash Outflows
  - CAPEX
  - Loan Repayment (Principal)
- Net Cash Flows
- Net Cash Flows (cumulative)

(d) Balance sheet statement
- Asset Total
  - Cash
  - Fixed Asset
- Debt & Equity Total
  - Long-term Debt
  - Equity
  - Earned Reserve

(e) Financial Analysis
- Return on Sales (ROS)
- Return on Asset (ROA)

- Return on Equity (ROE)
- Debt to Capital [D/(D+E)]
- Debt Service Coverage Ratio

(f) Break down of Net Cash Flows by Project (re-posted)

In the upper part of the "GDC_Total_(Summary)" sheet, there is a Macro button which searches for the maximum development plan under certain constraints. The constraints are to be input in the cells of the right side of this Macro button. The constraints are;

(a) The number of rigs until 2030. The default value is twelve (12).

(b) The number of maximum years which allow the cash reserve (the cumulative cash flows) to be less than minimum limitation. The default number is one (1) year. (The input number should be one (1), two (2) or three (3).)

(c) The minimum limitation of the cash reserve (the cumulative cash flows). The default number is minus US$ 0.0 million.)

After inputting these constraints, click the Macro button to start a search for the maximum development plan under the constraints.

Click the Macro button to calculate the maximum development plan under given constraints.

Constaints
- - Upper limit of number of Rigs untill the year of 2030 [count]
- 0 Upper limit for number of consecutive years that show negative Net Cash Flows (cum.) [years] <This number should be less than three (3).>
- -0.0 Lower limit of negative Net Cash Flows (cum.) [M$] <This number should be negative.>

Conditions
- 3.5 Drilling costs [M$/well]
- 3,916 Construction Costs with IDC [$/kW]
- 4 Number od wells drilled by a rig [wells/year]

Date 2/1/17
Time 4:54:31 PM

GDC TOTAL (Summary) [2015US$]

Output (MW)

No.		Field	COD	[MW]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
					2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1		Headquarter	2015		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2		Olkaria_280MW	2015	280	0	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	0	0	0	0	0
3		Menengai_105MW	2019	385	0	0	0	0	0	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	0	0
4	4	Project -1	2024	455	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
5	5	Project -2	2024	525	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
6	6	Project -3	2024	595	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
7	7	Project -4	2024	665	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
8	9	Project -5	2028	735	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
9	10	Project -6	2031	805	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
10	12	Project -7	2031	875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
11	14	Project -8	2031	945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
12	16	Project -9	2033	1,015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
13	18	Project -10	2033	1,085	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
14	1	Project -11	2033	1,155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
15	2	Project -12	2036	1,225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
16	3	Project -13	2038	1,295	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70
17	8	Project -14	2038	1,365	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70
18	11	Project -15	2038	1,435	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70
19	13	Project -16	2038	1,505	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70	70
20	15	Project -17	2039	1,575	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70
21	17	Project -18	2039	1,645	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70	70
22	19	Project -19	2040	1,715	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
23	20	Project -20	2040	1,785	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
24	21	Project -21	2040	1,855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
25	22	Project -22	2040	1,925	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
26	23	Project -23	2040	1,995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
27	24	Project -24	2040	2,065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70	70	70
28	25	Project -25	2042	2,135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70	70
29	26	Project -26	2043	2,205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70
30	27	Project -27	2043	2,275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70	70
31	28	Project -28	2044	2,345	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70
32	29	Project -29	2044	2,415	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70	70
33	30	Project -30	2045	2,485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	70	70	70	70	70
		GDC Total Capacity [MW]			0	280	280	280	280	385	385	385	385	385	665	665	665	665	735	735	735	945	945	1,155	1,155	1,155	1,225	1,225	1,505	1,645	2,065	2,065	2,135	2,275	2,415	2,485	2,205	2,205	2,205	2,100	2,100

Rigs needed and Wells to be drilled [count]

Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
RIGs needed	9	4	1	4	4	5	0	6	5	6	7	9	8	9	7	5	8	16	13	16	16	18	14	18	20	23	19	16	11	19	10	9	12	13	5	8	12
Wells to be Drilled	24	10	3	9	9	10	0	14	13	14	11	15	18	15	16	11	19	28	26	34	28	36	28	45	40	39	25	24	19	24	12	9	12	13	5	8	12

Profits and Losses of GDC Total [M$]

No.	Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1	**Revenue**	0	155	119	64	62	88	86	84	82	81	165	193	162	190	188	216	185	300	299	384	383	382	410	409	523	580	752	751	779	836	892	920	894	894	894	865	865
2	**OPEX**	0	27	27	27	27	33	33	33	33	33	49	49	49	49	53	53	53	66	66	78	78	78	82	82	99	107	132	132	136	145	153	157	130	130	130	124	124
3	**Depreciation**	0	23	23	23	23	33	33	33	33	34	56	56	56	57	63	63	50	68	68	85	86	87	93	93	115	128	152	154	160	173	175	181	183	184	185	162	163
4	**EBIT**	0	106	70	15	13	22	20	18	16	15	60	87	56	84	71	100	81	167	165	221	219	217	235	233	309	344	467	465	483	518	565	582	581	579	578	579	578
5	**Interest Payment**	0	0	0	0	0	0	0	7	13	20	20	21	21	21	24	27	34	37	39	37	34	38	44	60	70	77	77	78	78	75	68	60	51	42	32	24	17
6	**Tax**	0	32	21	4	4	6	6	3	1	-2	12	20	10	19	14	22	14	39	38	55	55	54	57	52	72	80	117	116	121	133	149	157	159	161	164	166	168
7	**Net Income (after Tax)**	0	74	49	10	9	15	14	8	2	-4	28	47	24	44	33	51	33	91	88	129	129	125	133	121	167	187	273	271	283	310	348	366	371	376	382	388	393
8	**Net Income (after Tax) (Cum.)**	0	74	123	133	142	157	171	179	181	178	205	252	276	320	353	404	437	528	616	745	874	1,000	1,133	1,254	1,421	1,608	1,882	2,153	2,436	2,746	3,094	3,460	3,831	4,207	4,589	4,978	5,370

Cash flows of GDC Total [M$]

No.	Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1	**Cash Inflows**	0	97	72	33	32	48	47	125	119	113	83	124	101	122	158	177	208	221	219	235	236	316	351	464	449	461	488	529	547	546	543	547	554	561	567	550	556
2	**Net Income (after Tax & Interest)**	0	74	49	10	9	15	14	8	2	-4	28	47	24	44	33	51	33	91	88	129	129	125	133	121	167	187	273	271	283	310	348	366	371	376	382	388	393
3	**Borrowing for Construction**	0	0	0	0	0	0	0	83	83	83	0	21	21	21	62	62	125	62	62	21	21	104	125	250	166	146	62	104	104	62	21	0	0	0	0	0	0
4	**Depreciation**	0	23	23	23	23	33	33	33	33	34	56	56	56	57	63	63	50	68	68	85	86	87	93	93	115	128	152	154	160	173	175	181	183	184	185	162	163
5	**Cash Outflows**	110	89	55	45	45	47	44	138	133	138	65	95	124	139	155	167	230	211	224	226	238	323	346	472	390	379	263	299	282	250	166	141	156	158	122	118	109
6	**CAPEX**	110	89	55	45	45	47	44	138	133	138	57	79	99	114	128	138	199	174	180	170	184	271	300	424	334	312	173	200	174	148	60	31	41	44	18	26	42
7	**Loan Repayment (Principal)**	0	0	0	0	0	0	0	0	0	0	8	17	25	25	27	29	31	37	44	56	54	52	46	48	56	67	89	100	108	102	106	110	114	114	104	92	67
8	**Net Cash Flows**	-110	8	17	-12	-13	1	3	-13	-15	-25	18	28	-22	-17	4	9	-22	10	-5	8	-2	-7	5	-8	59	82	225	229	265	296	377	406	398	403	445	432	447
9	**Net Cash Flows (cum.)** Seed cash **160**	50	58	75	63	50	51	55	42	27	3	21	49	27	10	13	23	0	10	5	13	12	4	9	1	59	141	367	596	861	1,156	1,533	1,939	2,337	2,740	3,184	3,617	4,064

Balance Sheet of GDC Total [M$]

No.	Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1	**Asset Total**	652	726	775	785	794	809	823	914	999	1,079	1,098	1,149	1,169	1,209	1,277	1,362	1,488	1,604	1,711	1,804	1,900	2,078	2,290	2,613	2,890	3,157	3,403	3,678	3,957	4,228	4,491	4,746	4,482	4,744	5,022	5,049	5,375
2	**Cash**	100	108	125	113	100	101	105	92	77	52	70	99	77	60	63	72	50	60	55	63	61	54	59	51	109	191	417	646	911	1,206	1,583	1,989	1,866	2,269	2,714	2,904	3,351
3	**Fixed Asset**	551	617	650	672	693	708	718	822	922	1,026	1,028	1,050	1,092	1,149	1,214	1,289	1,438	1,544	1,656	1,741	1,839	2,024	2,231	2,562	2,781	2,965	2,986	3,032	3,047	3,022	2,907	2,757	2,616	2,475	2,308	2,145	2,024
4	**Debt & Equity Total**	652	726	775	785	794	809	823	914	999	1,079	1,098	1,149	1,169	1,209	1,277	1,362	1,488	1,604	1,711	1,804	1,900	2,078	2,290	2,613	2,890	3,157	3,403	3,678	3,957	4,228	4,491	4,746	4,482	4,744	5,022	5,049	5,375
5	**Debt**	0	0	0	0	0	0	0	83	166	250	241	245	241	237	273	306	399	424	443	408	374	426	506	707	818	897	870	874	870	830	745	635	520	406	302	210	144
6	**Equity**	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	652	207	207	207	207	207
7	**Earned Reserve**	0	74	123	133	142	157	171	179	181	178	205	252	276	320	353	404	437	528	616	745	874	1,000	1,133	1,254	1,421	1,608	1,882	2,153	2,436	2,746	3,094	3,460	3,755	4,131	4,513	4,632	5,024

Financial Analysis

No.	Item	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1	Return on Sales (ROS)	0%	48%	41%	16%	14%	17%	16%	9%	3%	-5%	17%	24%	15%	23%	18%	24%	18%	30%	29%	34%	34%	33%	33%	30%	32%	32%	36%	36%	36%	37%	39%	40%	42%	42%	43%	45%	45%
2	Return on Asset (ROA)	0%	10%	6%	1%	1%	2%	2%	1%	0%	0%	3%	4%	2%	4%	3%	4%	2%	6%	5%	7%	7%	6%	6%	5%	6%	6%	8%	7%	7%	7%	8%	8%	8%	8%	8%	8%	7%
3	Return on Equity (ROE)	0%	10%	6%	1%	1%	2%	2%	1%	0%	0%	3%	5%	3%	5%	3%	5%	3%	8%	7%	9%	8%	8%	7%	6%	8%	8%	11%	10%	9%	9%	9%	9%	9%	9%	8%	8%	8%
4	Debt to Capital [D/(D+E)]	0%	0%	0%	0%	0%	0%	0%	9%	17%	23%	22%	21%	21%	20%	21%	22%	27%	26%	26%	23%	20%	21%	22%	27%	28%	28%	26%	24%	22%	20%	17%	13%	12%	9%	6%	4%	3%
5	Debt Service Coverage Ratio	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.7	9.9	6.7	3.7	3.8	2.7	3.1	3.6	3.6	3.7	3.5	3.1	2.9	3.1	3.9	4.4	4.8	4.1	3.7	3.4	3.4	3.4	3.5	3.5	3.6	3.7	3.9	4.4	5.0	6.9

<Break down of Net Cash Flows by Project> [M$]

No.		Field	COD	[MW]	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1		Headquarter	2015	[MW]	0	59	35	-2	-2	-3	-3	-3	-3	-3	-24	-3	-24	-3	-24	-3	-28	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	0	0	0	0	0
2		Olkaria_280MW	2015	280	-74	38	36	35	34	33	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	17	16	15	14	14	10	9	9	8	8	7	0	0	0	0	0
3		Menengai_105MW	2019	105	-36	-89	-55	-2	-2	15	19	15	19	15	19	15	16	15	19	19	15	19	15	19	15	16	15	20	20	15	20	15	20	15	13	12	17	17	12	0	0
4	4	Project -1	2024	70	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16	19	19	16	19	19	18	14
5	5	Project -2	2024	70	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16	19	19	16	19	19	18	14
6	6	Project -3	2024	70	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16	19	19	16	19	19	18	14
7	7	Project -4	2024	70	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16	19	19	16	19	19	18	14
8	9	Project -5	2028	70	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16	19	19	16
9	10	Project -6	2031	70	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16
10	12	Project -7	2031	70	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16
11	14	Project -8	2031	70	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19	19	16
12	16	Project -9	2033	70	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19
13	18	Project -10	2033	70	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19
14	1	Project -11	2033	70	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19	16	16	19
15	2	Project -12	2036	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19	19	19
16	3	Project -13	2038	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19
17	8	Project -14	2038	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19
18	11	Project -15	2038	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19
19	13	Project -16	2038	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13	19
20	15	Project -17	2039	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13
21	17	Project -18	2039	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15	13
22	19	Project -19	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
23	20	Project -20	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
24	21	Project -21	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
25	22	Project -22	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
26	23	Project -23	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
27	24	Project -24	2040	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12	12	15
28	25	Project -25	2042	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8	12
29	26	Project -26	2043	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8
30	27	Project -27	2043	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11	8
31	28	Project -28	2044	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11
32	29	Project -29	2044	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11	11
33	30	Project -30	2045	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-11	-11	-11	-11	-11	-12	-13	10	9	10	6	10	11
		Net Cash Flows			-110	8	17	-12	-13	1	3	-13	-15	-25	18	28	-22	-17	4	9	-22	10	-5	8	-2	-7	5	-8	59	82	225	229	265	296	377	406	398	403	445	432	447
		Net Cash Flows (Cum.)	Seed cash	**160**	50	58	75	63	50	51	55	42	27	3	21	49	27	10	13	23	0	10	5	13	12	4	9	1	59	141	367	596	861	1,156	1,533	1,939	2,337	2,740	3,184	3,617	4,064

Item	Unit	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Average Energy Price	[UScent/kW	0.00	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	9.92	9.92	9.92	9.92	10.11	10.11	10.11	10.50	10.50	10.75	10.75	10.75	10.82	10.82	11.01	11.09	11.25	11.25	11.27	11.31	11.34	11.35	11.72	11.72	11.72	11.88	11.88
Average Steam Price	[UScent/kW	0.00	3.00	3.00	3.00	3.00	3.14	3.14	3.14	3.14	3.14	4.02	4.02	4.02	4.02	4.13	4.13	4.13	4.37	4.37	4.53	4.53	4.53	4.57	4.57	4.69	4.73	4.83	4.83	4.85	4.87	4.89	4.56	5.14	5.14	5.14	5.22	5.22

Fig.-6.1 Bird-view of “GDC_Total_(Summary)” sheet

Chapter 7 Assumptions of “Olkaria_280MW” sheet, “Menengai_105MW” sheet and “Headquarter” sheet

The “Olkaria_280MW" sheet, the “Menengai_105MW" sheet and the “Headquarter" sheet have the following general assumptions:

(a) There will be no support from the government to GDC after 2015 because GDC will obtain the steam sales revenue from Olkaria 280MW since 2015.

(b) Menengai 105MW will be able to obtain the steam sales revenue from IPP from 2019. However, the additional investment of drilling four (4) more steam production wells and of constructing the steam gathering system is needed in 2015 and 2016. While GDC has already some stocks of materials and will receive some assistance from the government in 2015 and in 2016 for the additional investment, this Model assumes that GDC holds "seed cash", that is worth the value of additional investment. The amount of the seed cash is assumed to be US$ 160 million.

(c) GDC has the assets of US$ 650 million as of the end of 2014. The breakdown of the GDC’s assets by the projects is assumed as follows:

Table-7.1 Assumptions of GDC’s current assets by projects (as of end of 2014) [US$ million]

Section	Head quarter	Olkaria	Menengai	Total
Exploration Assets		250	110	360
Equipment	190			190
Inventories			50	50
Cash & Receivables	50			50
Total	240	250	160	650

The detail assumptions of Olkaria_280MW project are as follows:

(a) Olkaria has 60 production wells. The value of the assets is assumed to be US$ 250 million.

(b) 280MW worth of steam is obtained from these well assets.

(c) The annual revenue of US$ 66 million can be expected based on the steam sales at US$ 3.0 cents/kWh of the steam price from 2015. However, it is assumed that the sales revenue will decrease by 3% a year due to the natural decrease of steam production. (It is thought that make-up well drilling will be done by KenGen and not GDC.)

(d) As a result, the annual cash inflows from the Olkaria_280MW project is assumed between US$ 40 and 15 million when the O&M costs are considered.

The detail assumptions of Menengai_105MW project are as follows:

(a) The steam sales to IPPs begins in 2019 due to the delay of power plant construction by IPPs.

(b) GDC has already developed 21 production wells. However, it is assumed that 12 more production/reinjection wells are necessary before starting steam supply. Moreover, the steam gathering system is also necessary.

(c) The value of assets as of the end of 2014 is assumed to be US$ 110 million. The additional investment of wells and steam gathering system in 2015 and 2016 is assumed to be US$ 145 million.

(d) The steam sales price is US$ 3.5 cents/kWh after 2019, and GDC will obtain annual revenue of about US$ 30 million

(e) GDC will drill necessary make-up wells and supply the same amount of steam production to keep the 105 MW power production.

(f) As a result, the annual cash inflows from the Menengai_105MW project is assumed to be around US$ 20 million when the O&M costs and the make-up well drilling costs are considered.

The detail assumptions of headquarter are as follows:

(a) The headquarter holds US$ 190 million equipment and US$ 50 million of cash and receivables. The headquarter expends US$ 10 million every year as administration costs.

(b) This administration costs are assumed as constant every year.

Table-7.2 summarizes these assumptions.

Table-7.2 Forecast of revenue and expenditure from the fixed projects

Olkaria [280MW]	Dec. 2014	
Existing Wells	60	wells
Assets	250	M$
Capacity	280	MW
Generation	2,200	GWh/year
Tariff	3.0	UScents/kWh
Revenue	66	M$/year
Revenue decline	3	%/year
Net Cash Flows	40-15	M$/year

Menengai [105 MW]	Dec. 2014		2015-2018		Jan. 2019 -	
Existing Wells	21	wells	12	wells	33	wells
Assets	110	M$	145	M$	255	M$
Capacity	-	MW			105	MW
Generation	-	GWh/year			830	GWh/year
Tariff	-	UScents/kWh			3.5	UScents/kWh
Revenue	-	M$/year			29	M$/year
Revenue decline	-	%/year			-	%/year
Net Cash Flows	-	M$/year	-	M$	apr. 20	M$/year

Headquarter	Dec. 2014	
Assets	190	M$
Cash & Receivables	50	M$
Expenditure	▲ 10	M$/year
Net Cash Flows	▲ 10	M$/year

Chapter 8 Search of maximum development plan under constraints

This Model can search for the maximum development plan under certain constraints. The constraints built-in are as follows:

(a) The number of rigs until 2020. The default value is seven (7).

(b) The number of maximum years which allow the cash reserve (the cumulative cash flows) to be less than minimum limitation. The default number is one (1) year. (The input number should be one (1), two (2) or three (3).)

(c) The minimum limitation of the cash reserve (the cumulative cash flows). The default number is minus US$ 0.0 million.)

The reason why the rig number constraint is limited until 2030 is that the financial situation would improve rapidly after 2030 and GDC could buy new rigs if necessary.

The search of the maximum development plan is done by Macro function. After inputting the constraints, click the Macro button. Macro searches for the maximum development plan under the given constraints.

Fig. -8.1 and Fig.-8.2 shows the process of searching for the maximum development plan under certain constraints.

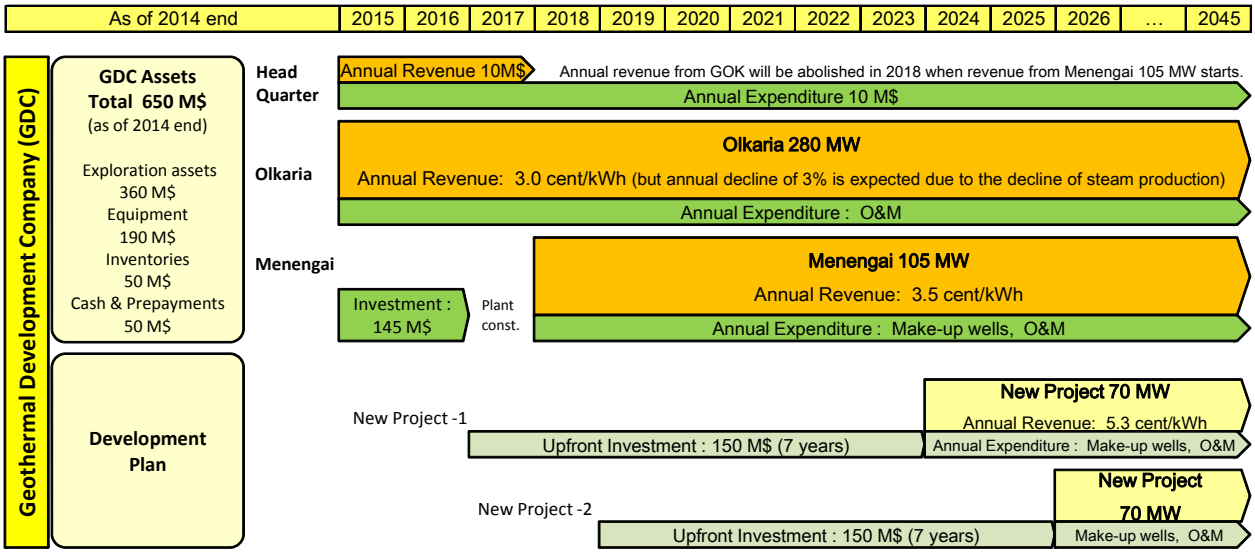
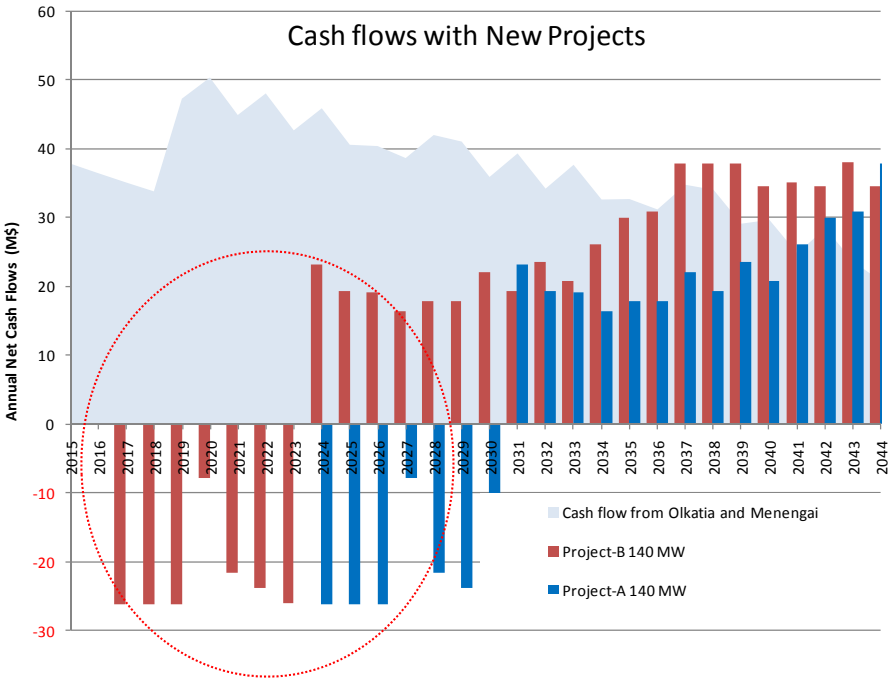


Fig.-8.1 Framework of searching maximum development plan under constraints



With keeping GDC's cash reserve in the allowable limitation, the Model searches for a plan that includes as many projects as possible.

Fig.-8.2 Process of searching maximum development plan under constraints

Chapter 9 Handling of multiple projects

This model handles future projects with one sheet of "Project" sheet only. However, there are cases where users want to consider multiple projects. For example, users may want to consider projects such as Arus (50 MW) and Korosi (70 MW).

In such a case, make a copy of "Project" sheet and name it as "Arus_50 MW" or "Korosi_70 MW" and input the characteristic values of each project (Fig.-9.1). Then input "Arus_50MW" and "Korosi_70MW" in the project field cells of the "GDC_Total (Summary)" sheet. Then, the values of these sheets are quoted on the "GDC_Total (Summary)" sheet (Fig. 9.2).

Then, by clicking the macro button on the "GDC_Total (Summary)" sheet, users can calculate the maximum development plan that includes these projects.

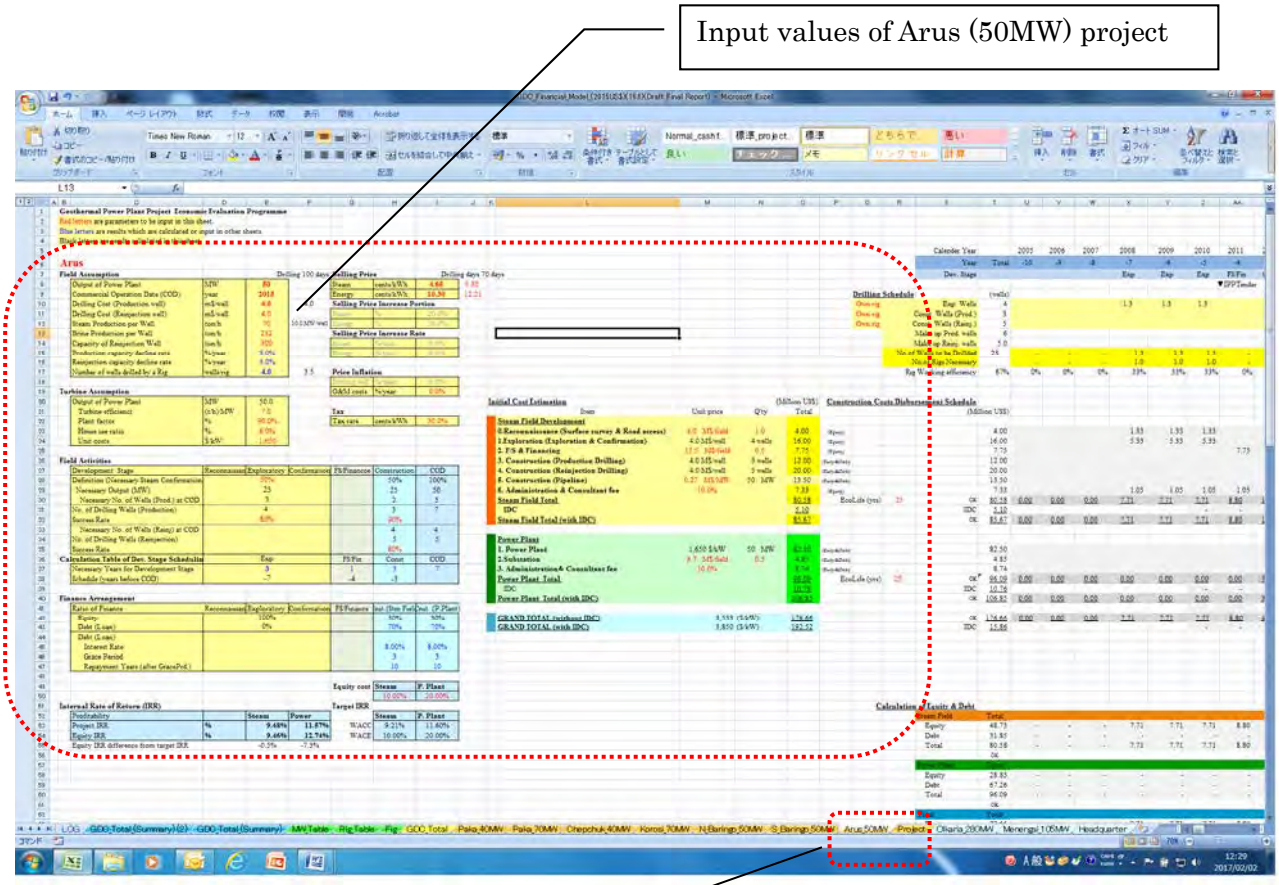


Fig.-9.1 Making "Arus_50MW" sheet by coping "Project" sheet

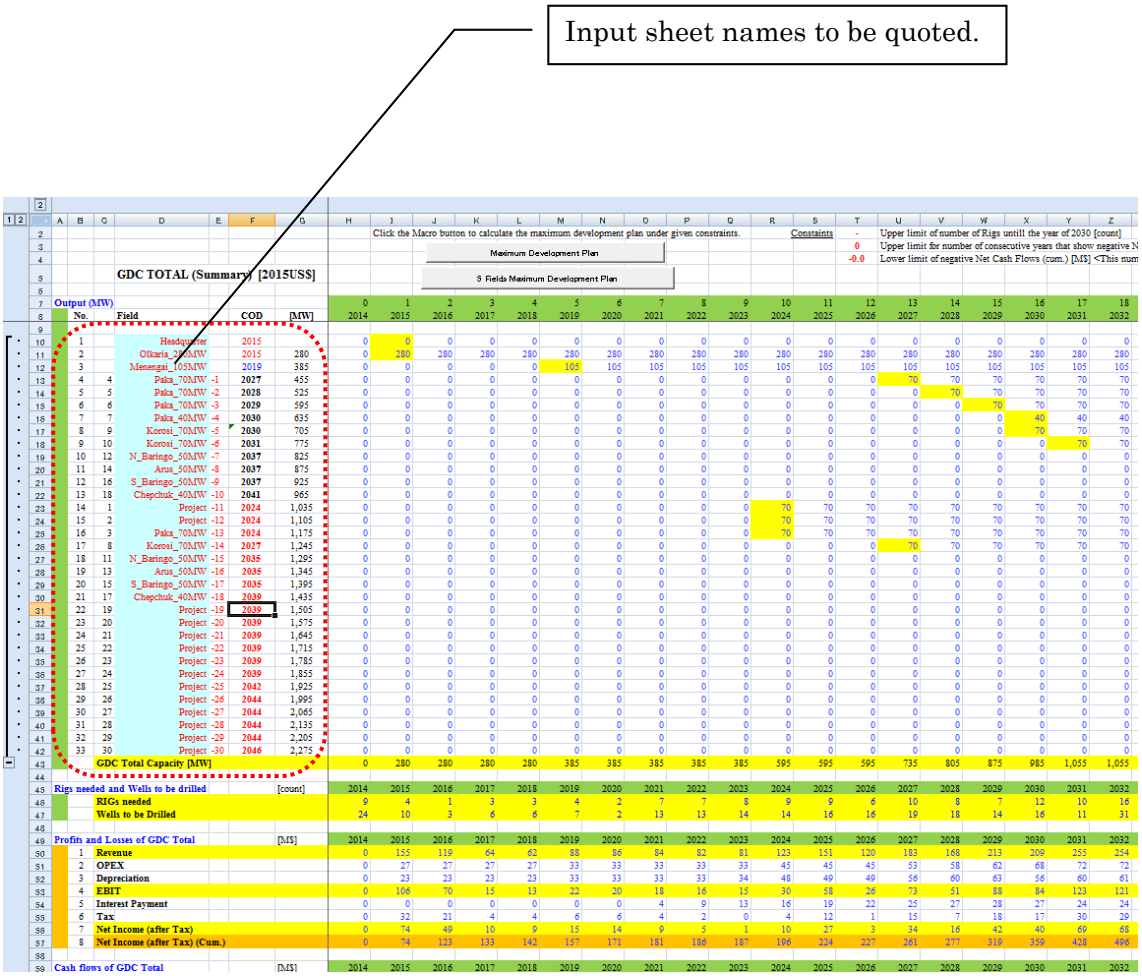


Fig.-9.2 Quotation of additional projects in "GDC_Total(Summary)" sheet

Chapter 10 Conclusion ~ Another advantage of Model ~

This Model is consisted of Microsoft EXCEL sheets. Therefore, users can easily modify the sheets for their own use once they understand the basic contents. This is another advantage of this Model. West JEC hopes that this Model is useful for person's related to GDC development strategy update work and that GDC will properly customize this Model to develop its business strategy.