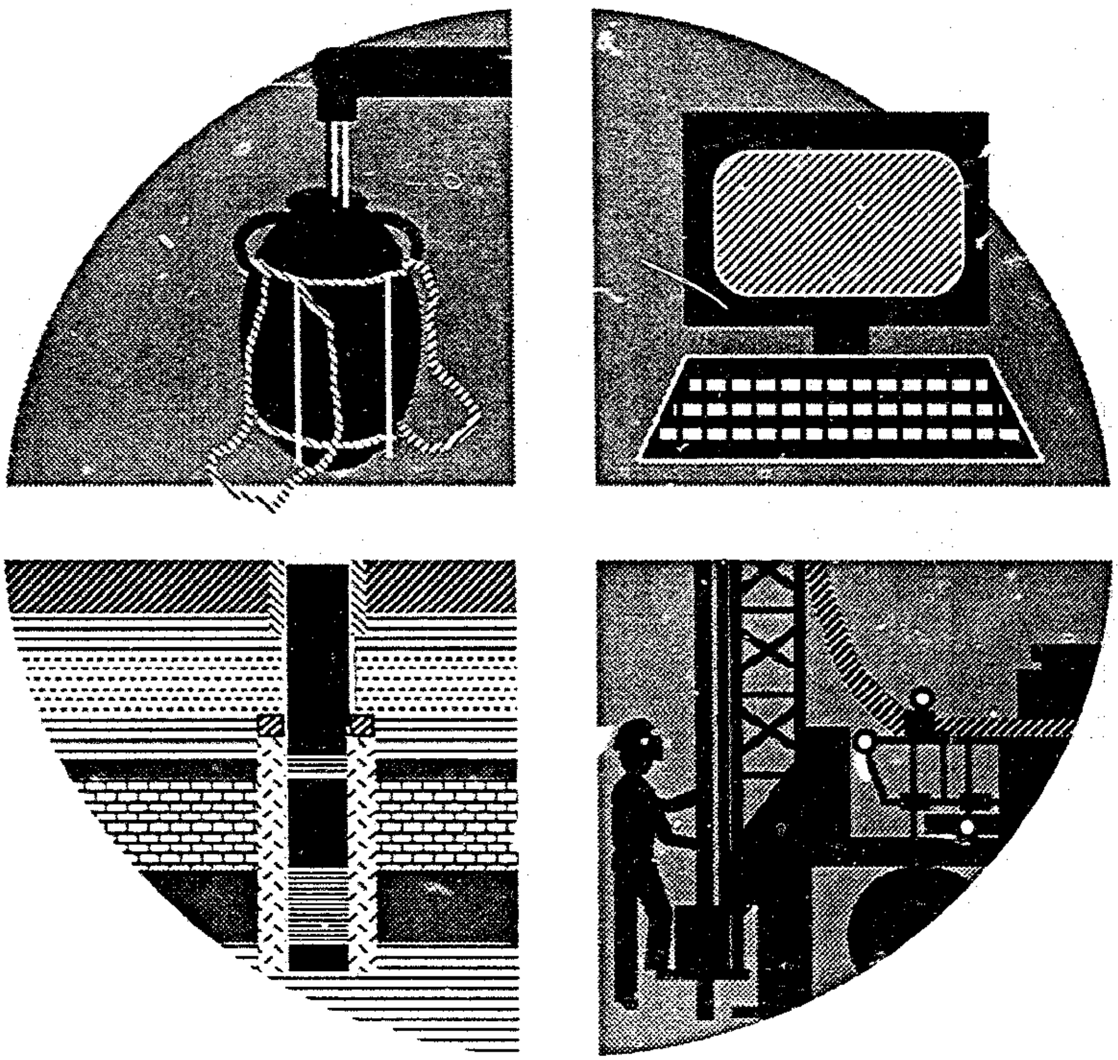
SOMALI DEMOCRATIC REPUBLIC

MINISTRY OF MINERALS AND WATER RESOURCES
WATER DEVELOPMENT AGENCY

Comprehensive Groundwater Development Project



Volume III

Hydrogeology

End of Project Report

LOUIS BERGER INTERNATIONAL, Inc.

ROSCOE MOSS Co.

END OF PROJECT REPORT

COMPREHENSIVE GROUNDWATER DEVELOPMENT PROJECT

VOLUME III

HYDROGEOLOGY

PREPARED FOR:	THE WATER DEVELOPMENT AGENCY MINISTRY OF MINERALS AND WATER RESOURCES SOMALI DEMOCRATIC REPUBLIC
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1.0 INTRODUCTION

During the course of the project a total of 118 boreholes were drilled in the Bay Region and Central Rangelands. Ninety five of these were in the Bay Region and twenty-three in the Central Rangelands. Fifty-three percent of those in the Bay Region and forty-one percent in the Central Range were completed as production wells equipped, or waiting to be equipped with either a motor pump or a hand pump. The data accumulated in this effort are the subject of this volume of the report. Well data are presented in Table 3.1.1.

An extensive discussion of the hydrogeology was originally presented in the CGDP Phase I Final Report that summarized activities for the first three years of the project. Additional hydrogeologic data were presented in the Interim Report, that described activities from July 1984 through July 1985. During the past twelve months, additional data have been collected and reviewed. It is the intent of this report to present an in-depth discussion and graphic illustration of hydrogeologic conditions in the two areas. Some information, for example Methods of Investigation is somewhat repetitive for the two regions, however, this was done to provide separable reports for the respective areas.

The establishment of a hydrogeologic data collection, storage and retrieval system was one of the major objectives of the CGDP. The initial program of data collection dealt mainly with the Bay Region. Hydrogeologic data from all available sources were collected and filed for reference in planning groundwater exploration activities. These data were useful, but not definitive as the distances between locations of data points were too great for correlation, and the quality of some older data was judged to be not suitable.

Published documents, mainly technical papers in scientific bulletins and investigative reports by governmental and international agencies, have been prime sources of hydrogeologic data and other related information. Most of these sources are listed in the report under Selected References. As the exploratory phase of the CGDP progressed, hydrogeologic data from boreholes in the Bay Region and the Central Rangeland were accumulated, analyzed and appropriately filed in the storage and retrieval system.

All hydrogeologic data were filed in order of acquisition; boreholes were numbered consecutively with a B-prefix for the Bay Region holes and a CR-prefix for holes in the Central Rangeland. These data were extracted from the files and assembled in tabular form as a preliminary step in preparation

Table 5.4.1. List of All LCDP Boreholes

Refer. number	Location	Map Co-ord's Long. (hhmmss)	Map Co-ord's Latit. (hhmmss N)	Elevation (m)	Date Completed	Well Depth (m)	Screen depth 1: Start/end 2: Start/end (m)	(m)	Static Water Level (m)	Specific conductivity umhos/cm	Total dissolved solids mg/l	Yield CuM/hr	Specific capacity CuM/hr/M	Pump depth (m)	Pump type	Remarks	
SRO	Afgoi	450910	20625	95	15.04.85	158	96	114	70.2	1950		5.45	0.35		A	Awaiting Pump	PI CO GL
R 1	Bonkay 1	433900	30700	510	04.02.87	18									E	Aband. dry	
R 2	Bonkay 2	433900	30700	510	27.02.87	201	30	201	48.5	2300					E	Aband. observ. well	GL
R 3	Bonkay 3	433900	30700	510	13.04.82	160	78	160	30	2700	2216	6.6	0.33	114	M	In use	PI CO GL
R 4	Jugerew 1	434230	30701	390	10.06.82	42	6 26	12 32	3	1700	1348	1.7	0.21	29	M	In use	PI CO GL
R 5	Gasarta	434812	30736	350	21.03.82	42	6	42	12						E	Aband. low yield	GL
R 6	Waraji 1	433230	25448	475	28.03.87	80	6	80	67						E	Aband. low yield	GL
R 7	Waraji 2	433230	25312	430	29.03.87	39	1	39							E	Aband. dry	GL
R 8	Jugerew 2	434142	30654	400	29.03.87	48		48							E	Aband. dry	GL
R 9	Bur Halab	440612	30412	280	30.03.87	32		35							E	Aband. dry	GL
R 10	Sarman Dheere	432124	31636	450	10.04.82	85	30	50.4	12.9	3300	3000	26.6	140.2	50	M	In use	PI CO GL
R 11	Baidoa Aid Comp	433854	30718	460	02.06.82	137	48	140	7	1500	1360	13.3	28.9		E	Aband. surface seal	PI CO GL
R 12	Hareero Jiifo	432512	31354	478	09.07.87	166	51	73	29.5	3900	3544	11.4	0.53	77	M	In use	PI CO GL
R 13	Shabelle Dugsiil	431300	31712	420	14.07.87	172	44	172	11	24000	19772				E	Aband. exc. salinity	CO GL
R 14	Warta Jaffay	430830	31900	390	03.08.82	91	2	91	17.5	10000	9188				E	Aband. exc. salinity	CO GL
R 15	Oansax Omane	430224	31954	365	19.08.82	174		174	165	24000	16436				E	Aband. exc. salinity	CO GL

Table 5.3.5. List of All EGDF Boreholes

R 16	[illegible]	471174	30354	435	16.08.82	154	72	153	35.4	1580	1528	11.4	1.69	67 M	In use	FT CO GL
[illegible]	[illegible]	[illegible]	24417	440	27.08.82	142	48	88	22.7	1260	1024	11.4	0.2	88 M	In use	FT CO GL
R 18	[illegible]	471548	24730	430	29.09.82	73	16	64	23.5	3800	1932	11.4	0.7	50 M	In use	FT CO GL
R 19	[illegible]	430560	25718	435	20.09.82	94		94						E	Aband. dry	GL
R 20	[illegible] Galle	425554	24954	405	11.1[illegible].82	116	82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] M	In use	FT CO GL
R 21	Bar[illegible]	433942	30724	460	16.12.82	42	19.6	36.4	8.5	2500	1928	5.5		40 M	In use	CO GL
[illegible]	[illegible]	473824	20724	260	04.01.83	189		189						E	Aband. dry	GL
[illegible]	[illegible]	425118	[illegible]2954	350	10.01.83	149	39	54	[illegible]	2490	1868	5.6	0.12	40 M	In use	FT CO GL
[illegible]	[illegible]	471406	15700	160	24.01.83	10	5	10	1					E	Aband. low yield	GL
R 25	[illegible]	[illegible]	[illegible]5618	[illegible]	[illegible]	24	12	24	12	950	688			E	Aband. low yield	CO GL
R 26	[illegible] 1	441612	[illegible]	195	20.01.83	67	3	67	26	33000	12842			E	Aband. exc. salinity	CO GL
[illegible]	Shadallew 2	441612	25336	195	22.01.83	80	2	80	[illegible]	[illegible]	[illegible]			[illegible]	[illegible] salinity	CO GL
[illegible]	[illegible]	[illegible]	24836	200	25.01.83	54	1	54	22	14600				E	Aband. exc. salinity	GL
[illegible]	[illegible] 2	441136	24836	200	26.01.83	24	1.5	24	7	34000				E	Aband. exc. salinity	
[illegible]	Bur Akata 3	441136	24836	200	01.02.83	30	1	30	22	42000				E	Aband. exc. salinity	GL
R 31	Bur Akaba 4	440506	24730	200	02.02.83	63	1	63	20	49000				E	Aband. exc. salinity	GL
R 32	Bur Akaba 5	440506	24730	200	15.02.83	[illegible]	6 31	[illegible]	17	1140	916				[illegible]	CO GL
R 33	Bur Heibi 1	442954	25836	230	10.03.83	26			18					E	Aband. low yield	GL

Table [illegible]

B 34	Bur Heibi 2	442600	25848	230	23.07.83	73	8	20	16	1320	952			52 H	Low yield	CE GL
B 35	Bur Heibi 3	442654	25836	230	23.02.83	60	7	60						E	Aband. dry	GL
B 36	Bur Heibi 4	442654	25848	230	15.03.83	25	1	25						E	Aband. dry	
B 37	Bur Heibi 5	442654	25848	230	15.03.83	26	1	26						E	Aband. dry	
B 38	Bur Heibi 6	442654	25848	230	16.03.83	26	[illegible]	26						E	Aband. dry	GL
B 40	Limestone Depres	441524	31112	360	23.02.83	32	1.5	32						E	Aband. dry	GL
B 41	Colondole	441412	31666	400	02.03.83	166	5.4 10.8	10.8 166	1.9	1040	564			E	Well destroyed	CD GL
B 42	Boulo four 2	430500	25348	435	03.05.83	130	64.5 98	98 130	56.2	2050	1640	11.4	1.35	92 M	In use	PT CD GL
CR43	Abrey 1	465112	35730	435	03.09.83	130	2	120						E	Not deep enough	GL
CR44	Afar Irdood	465124	35930	204	21.05.83	174	37.8	81						E	Not deep enough	GL
B 45	Baidoa AID Comp.	433854	30718	460	20.07.83	120	65	117	6.5	1770		10.9	0.22	E	Aband. defect. seal	PT GL
B 46	Quansaxdheere	425718	25530	405	11.05.83	103	60	103	30.2	1900	1722	11.4	0.87	92 M	In use	PT CD GL
B 47	Gwshiol	432330	31212	475	30.06.83	143	56 90	86 143	29.8	3100	2740	11.4	0.72	89 M	In use	PT CD GL
CR48	More Ari	460212	35130	180	23.06.83	102	60	96	36	3700				E	PVC casing rupt 45m	GL
CR49	Mavaas Jeejo 1	461006	44006	200	09.09.83	190	9	190						E	Dry, not deep enough	GL
CR49	Mavaas Jeejo 2	461036	44036	200	15.10.83	180	6	180						E	dry, not deep enough	GL
B 50	Bonlay seed farm	433636	31148	510	22.09.83	200			30.1	11400		11.4	0.21	E	Aband, high salinity	PT GL
B 51	Mintano	433312	32048	490	02.10.83	132	51 99	97 132	40.2	1400	1164	11.3	0.7	60 H	In use	PT CD GL

Table 3.1.1. List of All CGDP Boreholes

R 52	Maleel	433512	32612	495	07.12.83	130	51 99	93 130	48.5	670	608	25.2	23.77	92 M	In use	PT CD GL
CR53	Aboorey 2	455048	35054	285	11.12.83	133	3	133						E	Aband. dry	GL
R 54	Isqeed	433312	32648	490	19.12.83	150	90 120	114 150	37.1	1350	992	17	0.76	92 M	In use	PT CD GL
R 55	Martimoog	432848	33400	490	23.01.84	147	76 120	114 147	32.8	1150	964	22.7	0.83	91 M	In use	PT CD GL
R 56	Jimcada Dheen	442124	24542	175	03.03.84	41								E	Aband. dry	
R 57	Hagarlaa	431842	25342	470	09.03.84	154	54	114						E	Aband. dry	PT CD GL
R 58	Dour Hakaba 6	440848	24430	190	20.03.84	27			20	48000				E	Aband. saline	
R 59	Shawla	433148	30030	485	18.03.84	138	45.8 91.6	51.6 132	30	13500	10224	11.4	0.27	P	Awaits investigation	PT CD GL
R [illegible]	Fannadar	432400	21224	200	27.03.84	15	9	15	8.6					E	Aband. low yield	GL
R 61	Hubay	425848	23818	405	05.04.84	152	60 108	100 152	17	2550	1348	3.56	0.1	E	Low yield	PT CD GL
R 62	War Caasha	433236	30236	485	29.04.84	201		201	120	1250	1200			E	Aband. low yield	CD GL
R 63	Bonkay extension	433636	31348	510	30.04.84	153	117	147	25.6	2200	1476	9.1	0.1	W	Experim. windmill	PT CD GL
R 64	Buulo Yuusuf	432748	30342	480	15.05.84	95	58.5	85	18.7	2900	2456	15.9	3.6	55 M	In use	PT CD GL
CR65	Aboorey 3	455040	35854	285	19.05.84	210	3	210						E	Aban.not deep enough	GL
R 66	Buulo Haawo	430636	30342	435	07.06.84	142	66.2 83	77.4 142	33.5	1825	1408	14.5	0.43	76 M	In use	PT CD GL
CR67	Wargaloh	473112	61548	205	25.07.84	252	165 178	177 252	100	3200	3156	11.4		134 M	In use	PT CD GL
R 68	Dhaabaal AAlin	432654	30536	475	26.06.84	126	49 98.5	71 126	17.7	1675	1456	14.1	0.18	96 M	In use	PT CD GL
R 69	Ir,aal	435536	33124	625	18.07.84	72	37	64.5	18.7	970	576	15.3		E	Low yield	PT CD

Table 3.1.1. List of All LGDP Boreholes

R 70	Barismay	435212	33854	600	16.09.84	135	60 90	72 114	60	1420	964			H		0 PT CD
R 71	Uisle	43300(	32342	465	19.08.84	102	50	80	36	1420	1252			H		0 PT CD GL
CR72	Afqaduudle	435812	55730	125	17.11.84	204			17	12000	5245			E	Aband. exc. salinity	CD
R 73	Fasir-Lowger	435506	34148	605	12.09.84	4								E	Aband. as directed	
R 74	Migdalow	435030	33674	605	13.10.84	130	58 70	64 88	74.7	1700	1088			A		0 PT CD
R 75	1 Labaatan Jiro	435054	33135	595	18.10.84	132	60 90	72 108	40.1					E	Aband. low yield	PT CD
R 75	2 Ufurow	425306	24536	395	28.12.84	85	49	73	49.5	2200	2068	4.7	0.24	H	Replac. well for WDA	PT CD
R 76	Dhuuboy	435300	24130	375	28.12.84	124	52 88	64 100	19.2	3500	2344	15.9	0.51	90 H		0 PT CD
R 77	Dhorhabay	425548	23354	390	28.12.84	200			46.5					50 H		0
CR78	Dajimaale	481300	61830	110	19.01.85	177	56.8 86.8	68.8 176	69.6	4800	6720	12.5	8.33	90 H	In use	PT CD
R 79	2. Buulo Caddey	424806	30030	315	11.02.85	50	3 18	26 50						E	Aban.	
R 79	1. Buulo Caddey	424806	25912	315	27.12.84	26								E	Aband. dry	
R 80	Tugere Hoosle	425436	23800	395	04.03.85	212			57	3900	2246			90 H		0 CD GL
CR81	Budbud	484042	61036	70	11.03.85	60	24	60	25.9	12000	10128	0.65	0.03	40 H	In use	PT CD
CR82	Saadaal	473048	40642	50	25.04.85	75	46	73	40.1	6100	<352	10.3	0.93	54 H	In use	PT CD
R 83	Misra	432418	23512	390	17.04.85	170	62 152	74 170	21.1	9400	6640	5.8	0.14	50 H	T = 3M²/day step	PT CD
CR84	Cagacadde	472260	42442	360	02.06.85	133								E	Aband.	GL
R 85	Bullaabow	432418	30112	490	30.05.85	130	88	106	14	2900	2232			P		0 CD

Table 3.1.1. List of All CBDP Boreholes

CR86	Xasan Afrax	470736	40742	290	30.05.85	290								E	Aband. dry	GL
CR87	Calsabaal	470560	35818	229	09.07.85	250	216	240	220					E	Low yield,obser.well	GL
R 88	Toobain Heegan	430400	24000	395	16.06.85	294			28	4800	3540	4.7		E	Aband. constr.supply	CD GL
CR89	Xarardheere	475118	43918	235	20.07.85	28	15	21	13.5	2800				21 H		CD GL
R 90	BRADP CMPD	433954	30718	460	27.06.85	30	6	18	5.6	790	639	23.2	34.8	A		0 PT CD GL
R 91	Yaarre	433348	33048	500	13.07.85	115	44 72	50 83	42	1100	876	18.2	1.57	P	Needs retest	PT CD GL
R 92	Caasha Fartow	433400	31560	505	18.07.85	120	54 84	72 102	46.4	1400	899	15.3	0.96	A		0 PT CD GL
CR93	Calvton	471842	44654	185	23.10.85	114	78	113	82.6	6600	3996	6	0.35	108 H	Backfilled from 122m	PT CD
R 94	Baqalley	431312	31418	470	18.07.85	66	48	66	18	1300	980	21.5	0.35	A		0 PT CD GL
R 95	Fortin	431242	30100	470	05.08.85	130	76 100	100 130	34	2400		1.78	0.05	50 H	Low yield	PT CD GL
R 96	Qansaxdheere 2	425718	25530	405	08.08.85	136	82 124	100 130	48	1900	1760	4.1	0.05	A		0 PT CD GL
R 97	Toosilow	431112	30812	445	22.08.85	140	68 92	80 110	32	2250	1550	12.2	0.34	50 H		0 PT CD GL
R 98	Ouralow	431605	30200	477	11.09.85	120	41.6	69.6	39	3320	2092	2.59	0.05	A	Low yield - handpump	PT CD GL
R 99	Hareero Jiifo 2	432512	31354	478	11.09.85	120	63.8 103	80.6 114	35					P		0 GL
CR100	Darr Shadoor	471512	35542	55	00.01.00	50				32900	23192			E	Aband. high salinity	CD
R 101	Hobishole	432100	25848	482	02.10.85	120	36	114	26.5	1520	1112	2	0.09	A	Aquifer 40-90m	PT CD GL
R 102	Caliyo Marayle	431954	25554	478	12.10.85	88	20.8 37.6	32 54.4	14.3	3500	2390	8.3	2.32	A	Screen 65.6 - 71.2	PT CD GL
R 103	Gras Mood	431624	25230	455	27.11.85	94	26.8 49.2	43.6 54.8	25.4	1500	912	18.2	0.69	A	Screen 60.4 - 66.0	PT CD GL

Table 3.1.1. List of All CGDP Boreholes

R 104	Ceel Jaalle	434900	30236	300	27.11.85	30			15.4	21800	14080		E	Aband. high salinity		CD	
R 105	Coorar	430754	31306	398	12.12.85	102	30	34	11.7	6900	4940		P		0	CD	
R 106	Asha Gab St	433800	31518	510	07.01.86	96			38.4				E	Low yield			GL
R 107	Hartiqanle	433110	31724	525	30.12.85	84	40 60	52 72	24.2	910	140		P	Screen 70 - 84		CD	
CR109	Guraley	471148	50342	160	18.01.86	230							E	Aband. dry			GL
CR109	Hore Arie 2	460236	35130	180	10.03.86	110	74	104	69			90	M		0		
R 110	Dhejiile	430800	30700	420	18.03.86	90	54 72	66 78	37				A		0		
CR111	Hobbio NGA	483130	52042	12	04.03.86	11	7	11	7				A	Saline water			
R 112	Bottis	432342	25142	462	22.03.86	96	34 62	46 74	35				P		0		
CR113	Hobbio 2	433106	52112	17	22.03.86	19	13	19	17				A		0		
R 114	Eeg	432712	30206	0	00.01.00	0							D		0		
CR115	Bulo Burde Nurse	453448	35000	140	00.01.00	54							D		0		

Total: 118

Key:

M	Wells with diesel pump	20	17%
H	Wells with hand pump	16	14%
W	Wells with windmill	1	1%
A	Wells awaiting pump	15	13%
P	Wells awaiting pump test	7	6%
E	Exploratory boreholes	57	48%
D	Under construction	2	2%

PT - Pumptest Data Available
CD - Chemical Data Available
GL - Geophysical Log Available

of hydrogeologic data for computer processing, storage, and retrieval, (Table 3.1.1.) The completion dates indicate that the boreholes were not finished in order of well number. The borehole locations are shown in Plates 1 and 2. The contents of Table 3.1.1 are briefly described below.

Well Name: The well name is generally the name of the nearest community, small geographical area, or grazing locality. Where more than one borehole was located near a community, the name was followed by a number in suffix in order of construction. Well name spellings may differ between publications, however, an attempt has been made to standardize in this document.

Well Coordinates. Well coordinates were in some cases determined by satellite navigation methods, which although more accurate, were found to be time-consuming and subject to equipment malfunction or failure. Well coordinates alternatively were determined from 1:250 000-scale and 1:1 000 000-scale base maps of the Bay Region and Central Rangelands, (HTS, 1982). Coordinates are given by degrees, minutes and tenths of minutes north latitude and east longitude, Greenwich reference. One minute of longitude or one minute of latitude is about 1.85 kilometers.

Borehole Elevation: Elevations of borehole sites are given in meters above mean sea level. In the absence of physical surveys for elevations, these were determined from 1:100 000 -scale series topographic maps of Somalia; elevations of borehole sites were estimated to the nearest 5 meters. Completion date of the borehole is the date when the well was ready for pump testing.

Depths of Wells: Total depth of the bored well was given in meters and was determined by the number of drill rods of known length used to reach the total depth. Total depth is accurate to plus or minus 1 meter.

Screened Interval: Intervals completed with screen, perforated casing or left as open hole, refers to the section of borehole open to that interval of the aquifer determined to be most productive . All depths and intervals are given in meters.

Static Water Level: Static water level in the bored well was determined by measurement with an electrical-contact sounder, or with a steel survey tape, and is accurate to $\pm$ 0.05 meter. The measurements recorded were made after the well had been developed, but before it had been tested.

Specific Conductivity: Specific conductivity is a determination of the electrical conductivity of water expressed as the reciprocal of resistance in micromhos per centimeter at 25°C. This measurement is an indication of the dissolved mineral content of water.

Well Yield: Well yields were determined by pump testing the well at a constant rate while measuring the decline or drawdown of water level in the well. The yield is expressed in cubic meters per hour (m^3/hr).

Specific Capacity: Specific capacity of a bored well is an expression of the yield of the well per meter of drawdown. It is expressed as cubic meters per hour per meter ($m^3/hr/m$) or, simplified, as square meters per hour (m^2/hr). It is obtained by the ratio of well yield to drawdown.

Pump Type: The types of pumps used for bored wells were determined by well yields. Generally, bored wells that yielded 10 m^3/hr or more were equipped with diesel-powered Mono pumps. The installation depth of the pump in the well is expressed in meters and was predetermined by the pumping test.

Remarks: The remarks column indicates the use or abandonment of the well and any other information that may contribute to the basic data. Abbreviated notations indicate additional data or information available with respect to that well:

PT - Pump-test data available. These data include pumping rates, water-level drawdown with time, recovery of water level with time after pumping, and plots of water level versus time for determination of aquifer characteristics.

CD - Chemical data available. Laboratory analysis of water includes:

pH	Sodium ion
Specific conductivity	Potassium ion
Total dissolved solids	Calcium ion
Total hardness	Magnesium ion
Alkalinity (as mg/l HCO_3)	Chloride ion
	Sulfate ion

These are minimal data that determine the usefulness of the water; more detailed analyses were not practical.

GL - Geophysical log available. Whenever possible, downhole geophysical logs consisting of gamma ray, single-point resistivity, caliper and flowmeter were taken. These data were useful in determination of rock types, presence of potential aquifers, and relative quality of formation water.

2.0 BAY REGION

The Bay Region located in the southern part of Somalia, was selected as one of the priority areas for the exploration and development of groundwater supplies (Figure 3.2.1.). This designation was based primarily on the needs of an existing project in that region. The Bay Region Agricultural Development Project (BRADP), designed primarily to increase the efficiency of animal and rainfed crop production, has been in operation since April, 1980. Development of the physical resource potential of the area required that an assessment be made of the available water resources from drilled wells: the water source least affected by drought. The objective of the CGDP in the Bay Region was to explore and develop groundwater by drilled wells.

This section of the report was prepared in a format that will allow the interested reader to extract hydrogeologic information pertaining only to the Bay Region.

2.0.1 Physiography

The Bay Region comprises 40000 km^2 of an area between the Jubba and Shabelle Rivers (Figure 3.2.1). Slightly more than half of the region, 20700 km^2, is underlain by the igneous and metamorphic rock complex of the Bur area. The Bur area is separated from a limestone plateau in the west and north of the Bay Region by an escarpment that may rise above the Bur area as much as 100 m in a 3 km distance. The limestone plateau attains an altitude of about 640 m above sea level in the northeastern part of the Bay Region and the Bur area descends to about 80 m above sea level in the southeastern part of the region.

The drainage divide of the Jubba and Shabelle Rivers lies generally northwest of the escarpment, but also passes through the western-most part of the Bur area (HTS base topo. maps, 1:250000). About 28 per cent of the Bay Region drains to the Jubba River and about 72 per cent to the Shabelle River by dry wadis; there are no perennial streams in the Bay Region. Small intermittent streams resulting from a few springs at the limestone escarpment flow for short distances.

Drainage courses are absent on most of the limestone plateau indicating probable karst development that permits infiltration of rainfall. In the western and northwestern parts of the region, drainage courses have developed on less permeable geologic formations not susceptible to karst development: they drain to the Jubba River. Wadis on the Bur area drain southeastward and disappear in nearly flat alluvial fans at the southeast side of the area. Average gradient of these wadis is

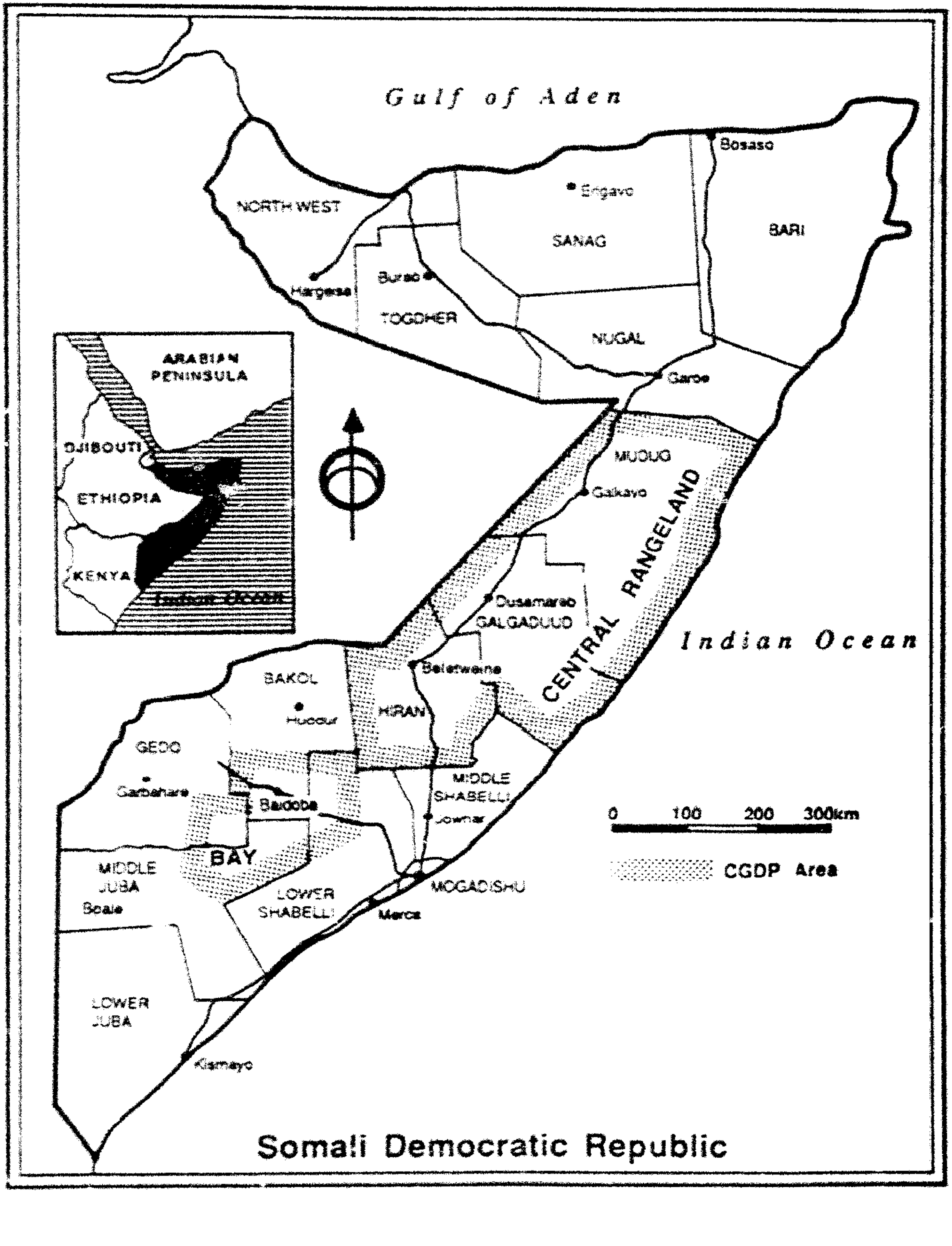


Figure 3.2.1 PROJECT LOCATION MAP

about 3 m/km. During rainfall seasons, a few random storms of high intensity may produce floods that reach the Shabelle River; most wadi runoff is of short duration and distance.

2.0.2 Climate

The climate of southern Somalia is described as arid with some years of no rainfall, and rainfall insufficient for regular dry-farm crop production; this climate is classified as Continental-Steppe (Ven Te Chow, 1964). Climatic conditions described below are taken primarily from the Hunting Technical Services (HTS) report of 1982.

Temperature: The mean annual temperature at Baidoa is 26.3°C with only slight variation about 2°C in mean monthly temperature. . The highest daily mean temperatures occur in March, before the Gu' season of rainfall, and the lowest daily mean temperatures follow the Gu' season in July.

Humidity: In the Bay Region, humidity is least at Bur Akaba, increasing toward Baidoa and southeastward toward the coast. Humidity ranges during the year from about 65 to 75 per cent; the lowest is from January through March and the highest is during the Gu' and Dayr rainfall seasons.

Rainfall: Most rainfall in Somalia occurs as randomly dispersed advective storms of high intensity and short duration during two wet seasons. The Gu' season, April through May, provides about 58 per cent of seasonal rainfall in 3 of 4 years and is less variable than the Dayr season of October through November. A small amount of rainfall, less than 10 per cent of mean annual, may occur between the Gu' and Dayr seasons, June through September. Mean annual rainfall is about 590 mm at Baidoa and 442 mm at Bur Akaba. Isohyets of Gu' and Dayr rainfall seasons are given in Figure 3.2.2 (HTS, 1982). Locally, droughts are common owing to the random distribution of storms. There are insufficient data to forecast widespread, large-scale droughts that may have a cyclic recurrence.

Wind: Wind speed at Baidoa ranges from a recorded annual mean of 1.2 m/sec in 1954 to 4.4 m/sec in 1959. For the periods 1954-74 and 1978-80, the mean annual wind speed was 3.1 m/sec (11.1 km/hr, 6.9 mi/hr), ranging from 2.3 m/sec in November to 4.0 m/sec in July (standard deviation 0.52), (Statistical Asbstracts, Ministry of National Planning). The average wind speed, 3.1 m/sec, is sufficient to power some windmill-driven water pumps for bored wells.

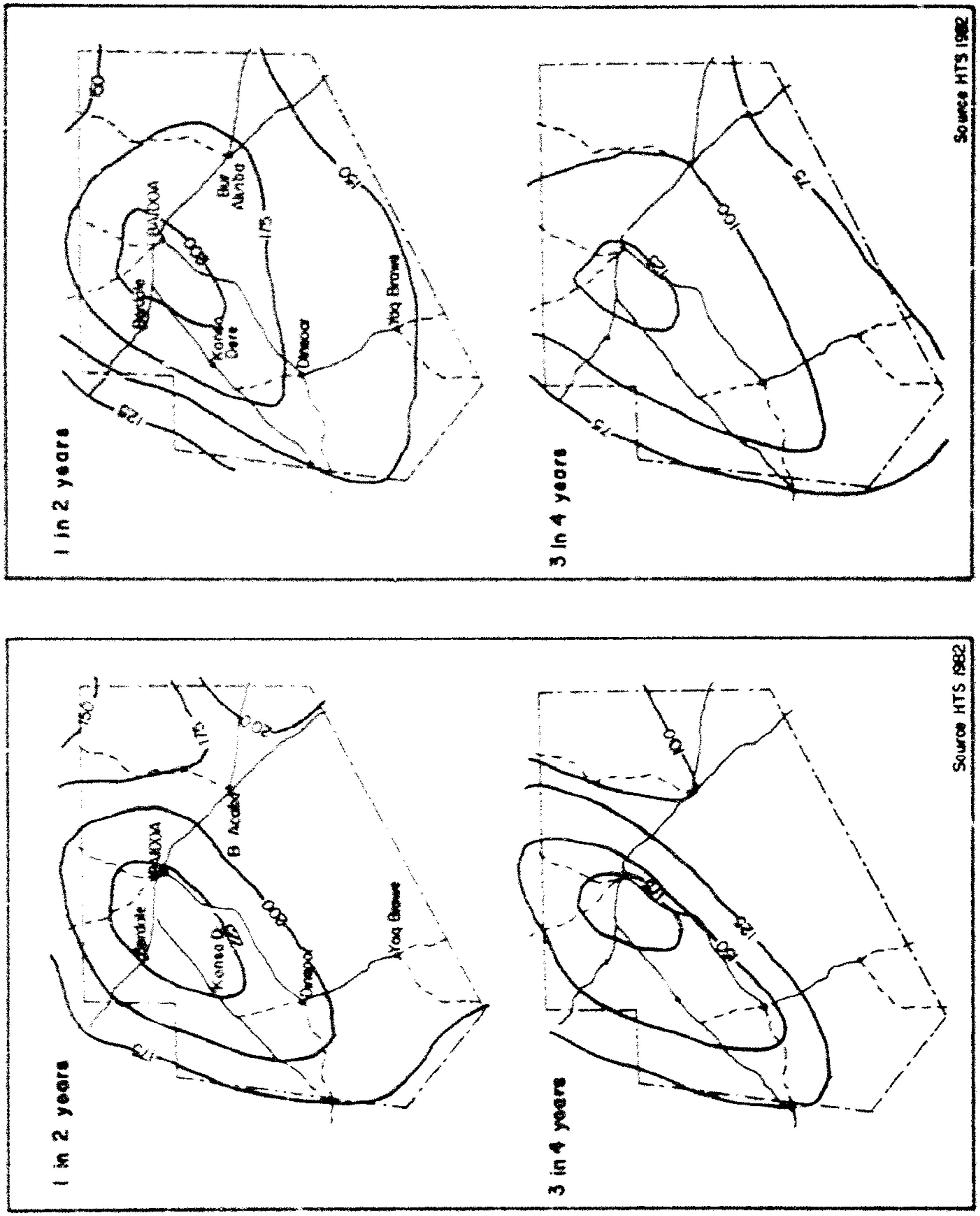


Figure 3.2.2 DISTRIBUTION OF RAINFALL IN THE BAY REGION.

Evapotranspiration: Potential evapotranspiration in the Bay Region is greatest during the period January through March with a monthly peak of about 290 mm. At Baidoa, mean annual evapotranspiration by the corrected Penman method is about 2300 mm; a potential water deficiency of about 1700 mm annually.

2.0.3 Land Use

Land capability in the Bay Region has been classified according to the USDA system, but with some modifications to meet local range conditions (HTS, 1982). The BRADP has divided the Bay Region into land suitable for grazing, land with a potential for rainfed cultivation, and land potentially suitable for irrigation; pending water availability. USDA-system Class I land, suited to a wide range of cultivated crops, is not present in the Bay Region. Classes II through IV, suitable for cultivation, limited cultivation, and potentially reclaimable land, cover about 54.7 per cent, 21880 km^2, of the Bay Region. Classes V through VIII, capable of some very limited cultivation but mostly suitable only for rangeland or limited grazing cover 45.3 per cent, 18120 km^2, of the Bay Region (HTS, 1982).

Irrigation of cropland must coincide with suitable soils and availability of chemically suitable water in sufficient quantities. At the present time the cost of pumping water from bored wells probably makes this type of irrigation economically unfeasible. Some experimental plots using this type of irrigation are recommended in order to determine accurately the costs and effects on soils of the use of groundwater for irrigated cultivation. There are some bored wells on the limestone plateau capable of producing sufficient water for experimental irrigation; they are:

No. 10, Sarman Dheere	No. 71, Usle
No. 16, Taflow	No. 74, Migdaloo
No. 42, Buulo Fuur	No. 91, Hare
No. 52, Maleel	No. 92, Asha Fartow
No. 64, Buulo Yusuuf	

2.1 Previous Investigations

There have been many studies dealing with the hydrogeology of the Bay Region and adjacent areas. Some of these are listed by author under Select References of this report. Those studies dealing more directly with the hydrogeology of the Bay Region and adjacent areas are briefly described here. Reference is made to others throughout the text.

Stefanini, G. and Paoli, G., 1913. One of the earliest studies of hydrogeology in the central and southern parts of

Somalia, this report gives general observations on the occurrence of shallow groundwater, and the potential for deeper bored wells in the area. The initial exploratory work for the project was basad in part on the findings of this report.

UNDP, 1968, 1970, 1973. The United Nations Development Programme (UNDP) supported a national inventory of water resources from 1968-1973. These reports contain an inventory of dug wells, bored wells and springs in the Bay Region and adjacent areas. Although no longer current, these reports contain physical and chemical data for numerous locations in the Bay Region.

Faillace, C., 1960, 1962, 1964, 1983, and 1984. For a number of years and for numerous entities, important hydrogeological studies have been made by Mr. C. Faillace in areas within and adjacent to the Bay Region. These publications provide valuable physical and chemical data of bored wells, the potential for additional groundwater development, and recommendations for water resource development. Although mostly in areas adjacent to the Bay Region, the hydrogeology is in part related to that of the Bay Region.

IDROTECNECO, 1973. A hydrogeological study of the Bur area in the Bay Region was undertaken by IDROTECNECO. The report deals mainly with geophysical methods for detecting groundwater and near surface permeable zones in the metamorphic rock complex. The report includes data on chemical quality of shallow groundwater in the Bur area complex.

Hunting Technical Services, Ltd., 1982. A comprehensive study of soils and agricultural potential of the Bay Region was made for the BRADP. This report includes information and data about water resources in the Bay Region; availability, use, and chemical quality. Some of the data from this report served as a guide for exploratory borehole locations in the Bay Region.

2.2 Methods of Investigation

Prior to beginning the production well drilling program in the Bay Region a literature search was conducted, and maps and aerial photos were studied. On the basis of this data an exploratory drilling program of 25 wells was initiated in the limestone plateau area and in the "limestone depression" which appeared to offer the highest possibility for finding significant quantities of water. These areas were also documented as having the highest population and water demand.

The Bur area or area containing igneous metamorphic rocks was not expected to yield significant quantities of water. Water in these rocks occurs only in joints and fissures, and data from one borehole cannot be extrapolated areally.

The methods of investigation used in the Bay Region are briefly described in the sections that follow. These include well site selection process, drilling methods, geophysical logging, development and testing, and water quality sampling and analysis.

2.2.1 Well Site Selection

The site selection process after the exploratory drilling was completed became more of a verification process. The BRADP personnel selected well sites on the basis of need and on the basis of potential for expanding agricultural production. The BRADP staff met with commissioners from the four political districts, Baidoa, Quansa Dhere, Dinsoor, and Bur Akaba, to develop a list of proposed sites. Staff of the CGDP then visited the sites, and in conjunction with the village elders selected a drilling site.

Beginning in September 1985 the hydrogeologist of the CGDP in collaboration with the BRADP technical manager drafted a list of wells based on geographic distribution. The list was then presented to the Bay Region Council for its approval. Thereafter, villages were visited to determine their desire for, and their ability to manage, a groundwater supply. Generally, the villagers were found to have a water committee in place. A few villages had no desire for such a water supply. Other villages were adamant about a specific location and were accommodated when possible.

The use of aerial photos, became less important as additional knowledge was gained from each borehole completed, however, the photos assisted in identifying major structural features. Maps prepared by the CGDP hydrogeologist were more useful tools in verifying the potential for successful wells.

2.2.2 Drilling

With few exceptions, all drilling conducted during the project in the Bay Region was done with Ingersoll Rand TH-60 rotary drilling rigs. These rigs were equipped with a 600 cfm two-stage screw-type compressor, and with Gardner-Denver 5 1/2 X 8 mud pumps. Early drilling techniques consisted of drilling 6-inch diameter pilot holes with a 6-inch air-hammer bit, and then reaming the hole to accommodate an 8-inch steel or PVC well casing. As confidence was developed in site selection, and in an effort to conserve time and fuel, 6 meters of 12 or 14-inch surface casing was set and grounted, followed by drilling to total depth with a 10-inch air-hammer bit. Removal of cuttings was in all cases assisted by circulating drilling foam.

Given the site logistics, fuel constraints, and equipment provided, this was found to be the best available technique. It was, however, not totally satisfactory. The effectiveness of downhole geophysical logging was minimized, the collection of drill cuttings was less accurate, loss of circulation occurred from time to time, and the drill site was perpetually under a sea of foam. Some of these problems were solvable, but the lost circulation problem was not. An auxillary compressor or the completion of smaller-diameter holes may have solved the problem. Unfortunately, additional compressors were not available, and the completion of smaller-diameter wells was unacceptable to WDA.

A Dando cable-tool rig of British manufacture was initially utilized on a few holes, but not effectively. The early uses were in the Bur area that consists of igneous and metamorphic rocks. When utilized on the limestone plateau under constant supervision by consultant's staff, the cable rig performed satisfactorily. It is recommended that cable-tool drilling be utilized in the limestone plateau area. This rig requires less fuel to operate, less water, and no drilling additives. In addition, maintenance costs are generally less on the cable rig than on the rotary rig. The time for well completion, assuming knowledgeable operators, should not be significantly different than that required for a rotry rig.

2.2.3 Geophysical Logging

Whenever possible geophysical logs were run prior to setting casing in the hole. The project was equipped with three Mineral Logging Systems geophysical logging units. Two of these were mounted in four wheel drive suburban-type vehicles. Logging tools provided were 1 3/8-inch diameter except for a long normal resistivity/gamma probe which is 2 inches in diameter. Other tools included a caliper probe, gamma/resistivity probe, flow meter, and a temperature probe. An operator's manual was prepared by consultant's staff to assist counterparts in operating the equipment. This manual was in addition to that provided by the manufacturer.

The geophysical logs were used to determine lithologies and water-bearing zones. No well-defined marker bed was noted on the logs for areawide geologic correlation of stratigraphic units. Some correlations were possible in localized areas.

Resistivity and spontaneous-potential logs were the most useful in identifying potential aquifer zones. The natural gamma-ray logs were most useful in determining the clay horizons of the formations. In limestone formations the caliper log was the most useful in delineating zones of secondary permeability and fracturing.

As more wells are drilled and logged in the Bay Region the usefulness of the geophysical logs for stratigraphic correlation should improve.

2.2.4 Development and Testing

Well development, regardless of drilling technique was minimal. When using the rotary rig, development consisted of blowing the hole with air until the water being discharged was free from sediment. This method was satisfactory for wells drilled in limestone.

Development methods with the cable tool rig consisted of bailing the hole until no cuttings could be recovered. Because a bailer tends to a limited degree to surge the hole, this procedure was adequate in the types of formations drilled.

After a well was drilled, cased, and developed, it was pumped using air lift techniques to obtain a rough approximation of its potential yield. In some instances a well was able to be blown "dry" and recovery measurements made. Based on these preliminary data, the pump installation and test crew would install a submersible pump in preparation for further testing.

In those wells selected for long-term, 24-hour testing a 1-inch diameter PVC pipe was installed in the well with the lowering of the submersible pump. This pipe, referred to as a water-level tremie pipe, allowed drawdown and recovery of water level readings to be taken without interference from cascading water or entanglement with the pump electrical cable.

A 2-inch diameter continuous-roll PVC pipe was used to carry the discharge water away from the immediate area of the well. In most cases this was 200 meters. In limestone areas where the surface contained numerous open joints, the discharge distance from the well was made greater than 200 meters.

A gate valve and an accumulating flowmeter were installed in the discharge line for controlling and measuring the flow. Discharge was also measured with a 55-gallon drum and a stop watch to insure that the flowmeter was operating properly.

When conditions warranted, a step-drawdown test was conducted to determine the optimum rate at which to conduct the constant-rate 24-hour test. The well was allowed to fully recover from the step-drawdown tests before beginning the constant-rate discharge tests. Drawdown and recovery data were recorded and plotted on semi-log and/or log-log paper for analysis. Section 2.4.4 describes well hydraulics.

2.2.5 Water Quality Sampling and Analysis

Electrical conductivity meters were provided to the hydrogeologist for monitoring water quality during the drilling of wells. Because water quality was found to be highly variable from one area to another, periodic measurement of conductivity was important. This measurement provided a rapid means of determining whether or not a well should be completed.

During the testing of a well, conductivity measurements were also taken. The objective was to determine if water quality significantly deteriorated or improved with pumping. In addition, two water samples were collected during a pumping test; one about midway through the test and another at the end of the test.

Water samples were taken to the MMWR laboratory and analyzed for the major ions. Microbiologic testing was conducted for a short period on a selected number of wells to monitor any changes in quality due to use. Results of all analyses are discussed in section 2.5.

2.3 Geology

Somalia rests on a shelf of the Precambrian basement complex underlying the Horn of Africa. Jurassic and younger strata cover the shelf to thicknesses of about 5000 m in the Hobbio basin, but leave basement complex exposed in the Bur Akaba and Nogal uplifts and along the coast of the Gulf of Aden. Northwest of the Bur Akaba uplift is another structural depression, the Lugh-Mandera basin, (Figure 3.2.3). These regional structural features affect the general regional occurrence and flow of groundwater; flow directions are away from uplifts and toward basins. Locally, groundwater occurrence, quality, and movement may be subject to restricted geologic conditions, such as facies changes or karst development. Geology of the Bay Region is shown in Plate 3.

2.3.1 Geomorphology

The largest part of the Bay Region is the Bur area underlain by the Precambrian metamorphic and intrusive complex. The Bur area has probably been at or near land surface since at least Jurassic time and it lies exposed or obscured by only a thin cover of alluvial or aeolian sediment of Recent origin. Geomorphologically, the Bur area is at a mature stage of development; it is a peneplain with isolated inselbergs of resistant intrusive granitic rock that may rise more than 300 m above the plain. There are no perennial streams in the Bur area, however, southeastward-coursing wadis with dendritic to

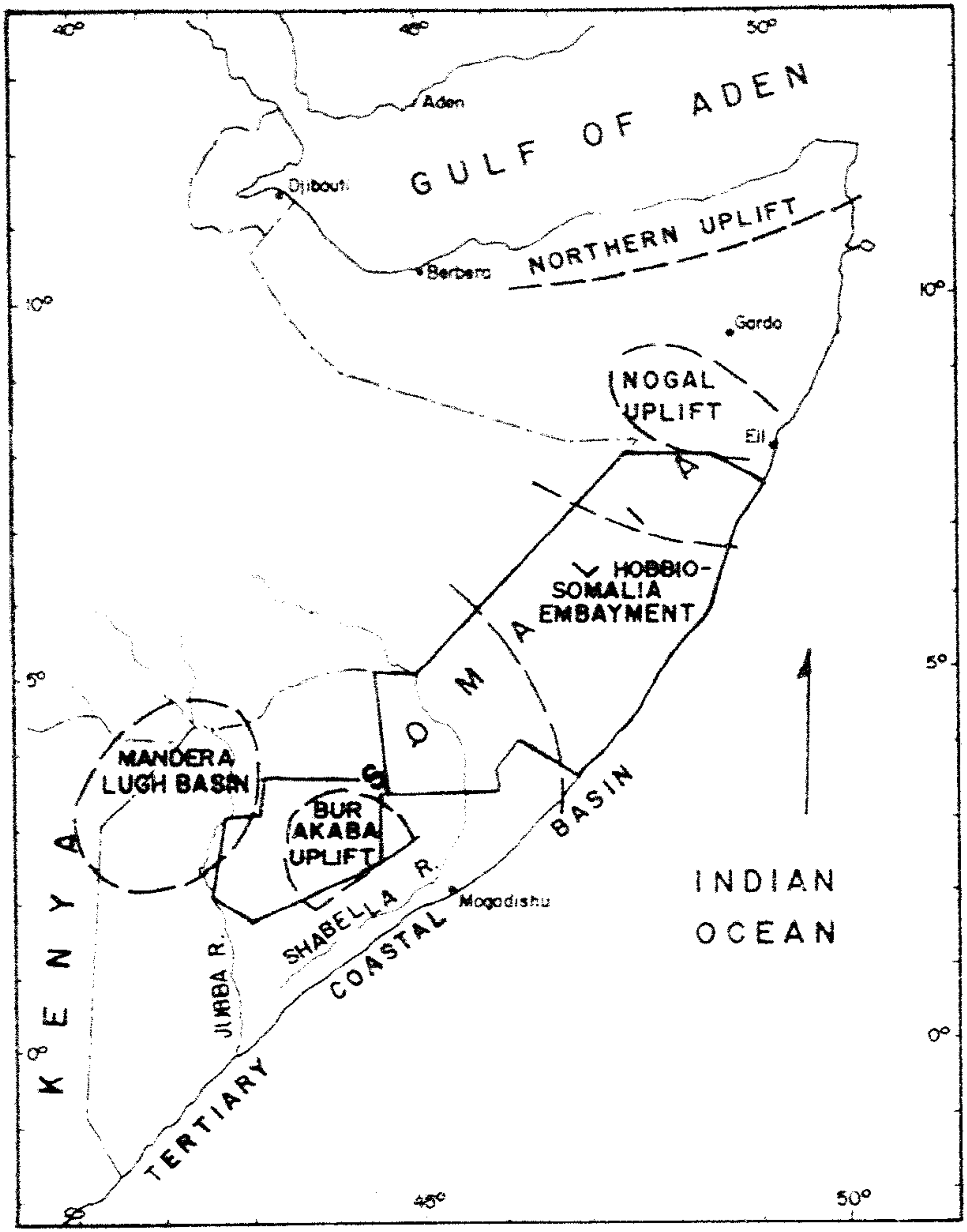


Figure 3.2.3 GENERALIZED STRUCTURAL BASINS AND UPLIFTS OF SOMALIA.

pinnate tributaries cross the Bur area. Joints and fractures in the Bur complex relate to the pinnate tributaries, (Plate 4).

The limestone plateau northwest of the Bur area, is at a submature stage of development, showing little or no drainage development over "karst" areas, but containing some wadis on the northwest slope coursing to the Jubba River. Drainage on the northwest slope is fairly rapid owing to gradients of 6 m/km or more toward the Jubba River.

Widespread topographic features commonly associated with true karst development are not found anywhere in the Bay Region. The lack of perennial streams and limited rainfall prevent rapid karst development. Small sink holes and enlarged joint patterns are fairly common. In a recent investigation by Dr. George Brooks, University of Georgia, no caves or sinks were found that exceeded 2 meters in depth, (Brooks,G., 1985, Personal Communication). Significant karst development, discovered during drilling operations, generally occurred at depths of less than 50 meters. Relatively few holes drilled actually encountered cavities large enough for the drill string to drop. The term karst development must henceforth be used with caution when referring to the limestones of the Bay Region.

2.3.2 Stratigraphy

Geologic units of the Bay Region and nearby areas and their water-bearing characteristics are given in Table 3.2.1. The areal distribution of the geologic units with their stratigraphic and structural relationships are shown in the generalized geologic map of the area, Plate 3. Inferred stratigraphic contacts and structural features from Landsat imagery of the Bay Region are shown in Plate 4.

The most important stratigraphic unit containing groundwater in the Bay Region is the Iscia Baidoa Suite of Jurassic age; it has a well-developed secondary permeability and limited karst development that furnishes water to bored wells on the limestone plateau and to springs at the escarpment that faces the Bur area. The Iscia Baidoa Suite reflects several depositional environments. It began with a continental and deltaic environment, and continued into a reducing, closed-basin, and lagoonal environment that was followed by a littoral and finally a shallow (<200 m) facies phase. This suite consists mainly of crystalline (micritic) limestone with oolitic intervals and coquinas. The lowermost part is conglomerate and sandstone followed by limestones, marls, shales and sandstone with lateral facies changes over short distances. Trace hydrocarbons are present in the closed-basin facies.

TABLE [illegible] BAY REGION GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

EPOCH	NAME OF SERIES AND SYMBOL	APPROXIMATE MAXIMUM THICKNESS, M	OCCURRENCE, LITHOLOGY AND WATER BEARING CHARACTERISTICS
	Jubba and Shabelle Rivers alluvium, also alluvium of the Bur area: Qal	[illegible]	In the valleys or flood plains of the Jubba and Shabelle Rivers, the wadis of the Bur area: clay, silt, sand and coarser alluvium yield water to shallow (less than [illegible] m) wells. Water of less than [illegible] micromhos/cm specific conductivity is found in about [illegible] percent of the wells.
RECENT - PLEISTOCENE	Aeolian sand, sand stone, and reef deposits of the eastern coastal zone: [illegible]	[illegible]	Active and inactive dunes on the eastern coast, of well sorted aeolian sands yield water of [illegible] quality to shallow (less than 7 m) wells. Bored wells in this zone yield saline water.
	Fluvial, alluvial clay, silt, sand, and gravel in flood deposits of the lower Jubba River: [illegible]	[illegible]	Fluvial sediments of the lower Jubba River flood plain mostly of clay, silt, and sand with lenticular gravel near the river; yields water of useable quality to shallow (less than [illegible] m) wells. There are no bored wells of record in this unit east of the Jubba River.
PLIOCENE	Mudug Merka [illegible]	[illegible]	Mostly in the Central Rangeland, but extends westward to the near vicinity of the Bay Region: limestone, marl, gypsum, clay, sandstone, calcrete and related rocks not important to the Bay Region as an aquifer, but yields water to shallow (less than [illegible] m) wells.

[illegible]	[illegible]		Near the rivers and in the north-western Juba-Shabelle interfluve: olivine basalt with layers of scoria and with columnar jointing. Yields water to a few small springs.
[illegible]	Main Gypsum and Marl Subunit of [illegible]	[illegible]	North of the Bay Region between the Juba and Shabelle rivers: gypsum, anhydrite, dolomite, marl, clay and siltstone. Yields water of marginally useable quality to a few hand-dug wells.
	[illegible]	[illegible]	North of Bay Region between the Juba and Shabelle rivers: limestone, dolomite, marl and siltstone yield water of marginally useable quality to hand-dug wells.
[illegible]	[illegible]		In the northwest part of the Bay Region also northern and eastern part of the interfluve of the Juba and Shabelle rivers: limestone, dolomite, and marl. Hand-dug and bored wells yield water of useable quality. The project well [illegible] penetrates but does not yield water from the Uegit Suite.
	[illegible]	[illegible]	Extends through the northwestern part of the Bay Region, also the northern and eastern part of the interfluve of the Juba and Shabelle rivers. Limestone, marl and clay. Project wells 514 and 5[illegible] yield unuseable saline water from this suite.

[illegible]	[illegible]	[illegible]	Occupies part of the Bay Region adjacent to the northwest side of the Bur area. Clastic limestone, marl, clay, and sandstone yield water of generally good chemical quality to most project wells in the Bay Region. Average depth of the wells is [illegible] m.
PRECAMBRIAN, UNDIFFERENTIATED	Metamorphic and igneous massif, undifferentiated	Undetermined	Occupies a large part of the central Bay Region forming the Bur area. Granitic gneiss, schist, amphibolite gneiss and schist, quartzite, marble, and related siliceous metamorphic complex with intrusive stocks and dikes of granitic to gabbroid composition and pegmatites. Fractured areas of the massif yield water of usable quality but also some highly saline water in other places, not all [illegible].

The Iscia Baidoa Suite is underlain by metamorphic and intrusive rocks of the Bur massif of Precambrian age; part of the crystalline basement beneath the Horn of Africa. The Bur metamorphic complex consists of gneiss, schist, quartzite, marble, amphibolite schist, pegmatites and intrusive plugs of granite. The intrusive granite is resistant to erosion and forms inselbergs above a plain that represents the metamorphic complex.

The Iscia Baidoa Suite is overlain by the Anole Suite, (Plate 3), (Table 3.2.1). The Anole Suite of Jurassic age extends through the northwestern part of the Bay Region with a generally northeast strike and northwest dip of 2 to 4 degrees, in common with the underlying Iscia Baidoa Suite. The Anole Suite consists of black marl and shale with interlayers of compact blue limestone representing a neritic environment of deposition. Evaporites are present in the marl and shale facies and lateral facies changes occur over short distances. Where groundwater is found in the Anole, as in boreholes No. 14 and No. 105, it is too saline to be of use. Borehole No. 105 found unuseable water in the Anole Suite, but penetrated to the underlying Iscia Baidoa Suite where groundwater of useable chemical quality was found.

The Anole Suite is overlain by the Jurassic Uegit Suite in the northwestern corner of the Bay Region. The Uegit Suite consists mainly of biogenic limestone with marl, shale, and calcareous conglomerate. There are some evaporites with the shale beds. The depositional environment was neritic to littoral and restricted littoral. Much of the limestone has been recrystallized and altered to dolomite. The Uegit Suite was penetrated by borehole No. 15, which produced saline water of unuseable quality.

The Uegit Suite is overlain by the Gabbra Harre Suite of Jurassic and Cretaceous age which consists of the Busul and Mao Subsuites, part of a regressive marine depositional environment. The Busul Subsuite consists mainly of micritic limestone, dolomite and sandstone, and the overlying Mao Subsuite consists of gypsum and anhydrite alternating with dolomite, limestone and sandstone. Crossbedding is common, indicating a littoral environment with restricted circulation for deposition and accumulation of evaporites. The evaporites contribute to the salinity of groundwater.

All of these stratigraphic units dip gently, 2 to 4 degrees, away from the Bur complex as indicated in the generalized geologic map of the Bay Region and its surrounding area (Plate 3).

No detailed lithologic correlation has been attempted between boreholes. Gross lithologic data from well cuttings in boreholes only short distances apart were not adequate for definitive correlation. Lithologic data correlation with borehole geophysical logs was equally unsupportive of more detailed stratigraphic correlation. Drill cuttings from wells in the Bay Region were sent to the Somalia University for more detailed lithologic work. (This work will be carried out over an extended period of time). Detailed studies of stratigraphic correlation should be undertaken to provide for stratigraphic and structural synthesis of the Bay Region limestone plateau. Analysis of drill core for coefficients of permeability, presence of microfossils, and microlithic units or unconformities, may establish criteria for correlation.

2.3.3 Structural Geology

A major fault strikes about north 60-degrees east, crosses the southeast corner of the Bay Region, and separates the metamorphic complex of the Bur area from the sedimentary strata underlying the Shabelle River valley, (Plate 3). This fault is not exposed at land surface, but is covered by Recent alluvium; it has been located and defined by seismic geophysical exploration. Displacement of the fault is not known accurately, but is on the order of hundreds of meters (UNDP, 1973).

The Bur area has the aspect of a structural uplift between the Lugh-Mandera basin on the northwest and the Hobbio basin on the northeast (Figure 3.2.3). Strata of Jurassic age overlie the Bur area complex in the west, northwest, north and northeast parts of the Bay Region and dip gently, 2 to 4 degrees, away from the exposed Bur complex. Lineaments that may be seen and traced from Landsat imagery in the sedimentary strata are interpreted as faults (Plate 4). Determination of the width or displacement of these probable faults is beyond the scope of this investigation, but they most likely represent a parallel series of faults or fault zones. Because their displacement is not known, they are not shown in the cross-sections (Plate 5). Within the exposed Bur-area complex, joint sets and fractures may be traced from lineation on Landsat imagery; there are prominent west and northwest-trending joint sets and subordinate sets trending nearly north. Possible faults in the Bur complex also trend northerly. Faults at the southwest end of the Bay Region in the Iscia Baidoa Suite probably prevent southwest-flowing groundwater from reaching the area east of Bardera; borehole No. 27 at Buulo Gaduud about 45 km southeast of Bardera was dry at 189 m total depth, all in limestone of the Iscia Baidoa Suite (Plate 1).

2.4 Hydrogeology of the Bay Region

The hydrogeology of the Bay Region was first addressed in the Exploratory Report for the Bay Region (LBII, 1983). Data in that report were based in part on literature survey and to a greater degree upon the completion of 25 boreholes. Recommendations were made as to the most promising areas for groundwater development. These recommendations took into account lithology and structure.

There evolved basically one water-producing area in the Bay Region; the limestone plateau. Within the limestone plateau, the Iscia Baidoa Suite was found to contain the major aquifer. Contours on top of the main aquifer are shown in Plate 6. It extends southwestward and is approximately coincident with topography. Average depth of wells drilled on the limestone plateau is 123 m. The main aquifer of the Iscia Baidoa Suite is developed from karstic limestone and is irregular in thickness and transmissivity, but yields water of useable chemical quality. Diagrammatic cross-sections projected through selected boreholes of the Bay Region indicate the probable generalized configuration of the aquifer (Plate 5). Borehole geophysical records of resistivity and gamma logs show no basis for correlation between boreholes, probably owing to rapid facies changes over short distances. Locations of the cross-sections in Plate 5 are shown on the bored-well location map (Plate 1).

Occurrence of groundwater in the Bur area metamorphic complex is within joints or fractures, or in overlying alluvium. There is little circulation of groundwater in the Bur complex and dissolved solids in groundwater are concentrated by evaportion loss through capillary rise into overlying alluvium. Bored wells in the Bur complex have small yields of generally saline water, but a few wells produce useable water. Groundwater near the base of the Iscia Baidoa Suite immediately above the Bur complex may also be saline, as in well No. 50 at Bonkay, owing to restricted groundwater circulation.

The so-called "limestone depression" of earlier reports (Johnson, 1978, and HTS, 1982) was evidently inferred from a conceptual analysis of the northern part of the Bur area. This part of the Bur area, however, is not a topographic or structural basin; wadis course southeastward over it without interruption. The area is not everywhere underlain by limestone. A thin cover of colluvium and alluvium with aeolian sand as shown from borehole Nos. 4,5,9,40 and 104, overlie the metamorphic complex east of the escarpment. The potential for development of groundwater from bored wells in this area is poor, as the geologic materials consist of mixed silts, sands, clay and weathered limestone.

The igneous and metamorphic rocks of the Bur area were not expected to yield large quantities of water, however, it was hoped that small quantities of good water would be available. Unfortunately, most exploratory wells had small yields of highly saline water. Potential for water development in this area is discussed in Section 2.7.

The discussion that follows considers the three main elements of groundwater systems; recharge, movement, and discharge. Most information provided relates to the Iscia Baidoa aquifer.

2.4.1 Recharge

The main aquifer in the limestone of the Iscia Baidoa Suite receives recharge from direct infiltration of rainfall during the Gu' and Dayr seasons. Recharge to the limestone takes place mostly by direct runoff into enlarged joint and fracture systems that are passageways to the aquifer. The absence of surface drainage courses on the limestone plateau indicates that there are abundant openings and sinkholes that readily accept rainfall. The aquifer response, as observed in well water levels, was observed to be from rapid, (within hours) to as much as one month. Observation of water levels in well No. 21 showed a rapid response to intense precipitation events and a delayed response to those of lower magnitude (Figure 3.2.4).

Minimal recharge to the main aquifer takes place from infiltration through soils or alluvium. These materials are clay, or contain relatively large percentages of clay. Two soil infiltration tests were performed in the Baidoa area by Hunting Technical Services, Ltd. at 1.5 km southeast of Baidoa in Asharow Valley and at 7 km east of Baidoa adjacent to the limestone escarpment. Infiltration rates were 18.2 cm/hr (for 6:30 hrs) at Asharow Valley in "sandy clay loam", and 7.5 cm/hr (for 7:00 hrs) on the limestone escarpment in "light clay loam". These rates are greater than average infiltration rates for similar materials given by USDA Technical Bulletin 729, but negligible in comparison to the rate of direct rainfall runoff into sinkholes.

Infiltration studies conducted by the BRADP on soils overlying the aquifer in the vicinity of Bonkay wells No. 2 and 3, yielded rates from 13.56 cm/hr to 0.2 cm/hr with a mean of 4.6 cm/hr, (BRADP, 1985) soil in the area ranges in thickness from 3 to 20 meters. At the mean infiltration rate, water would transit the soil profile in 3 to 18 days under saturated conditions.

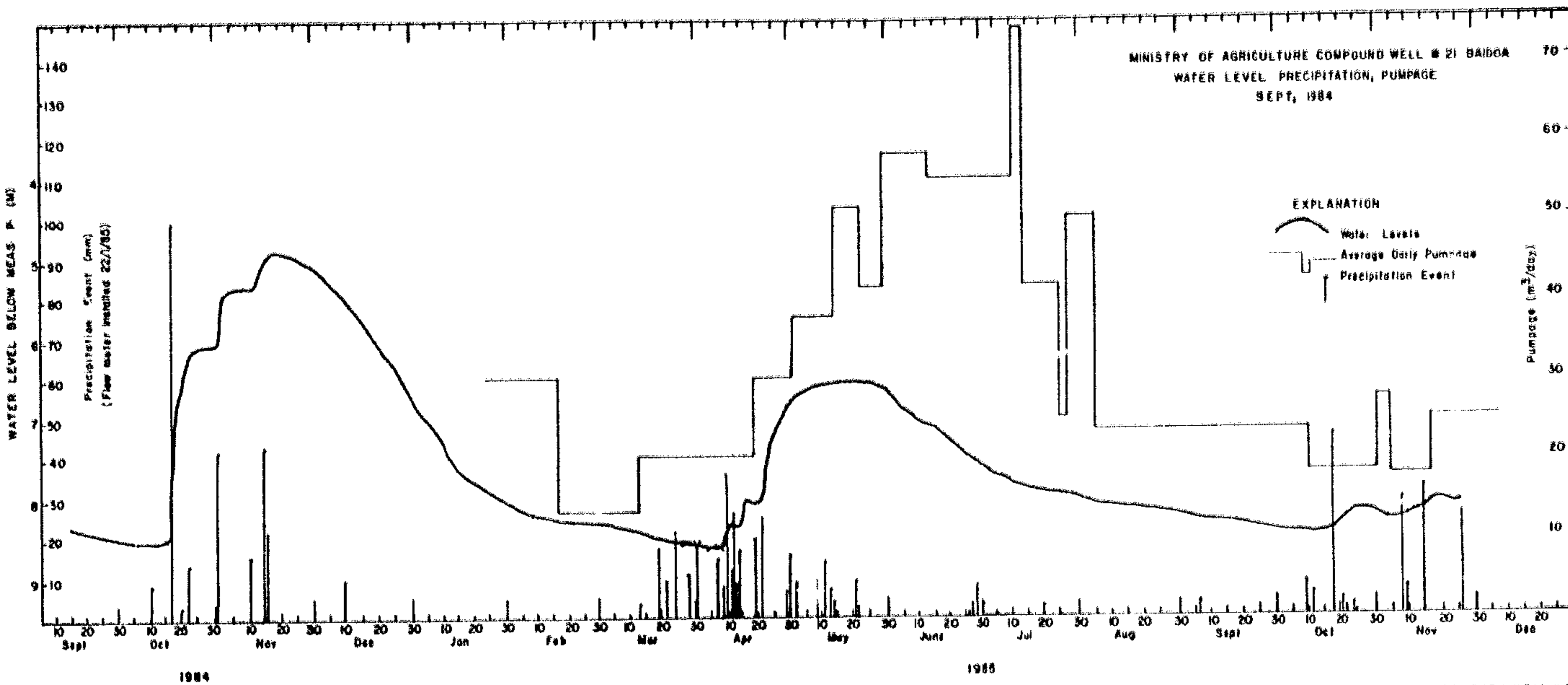


FIGURE: 3.2.4 HYDROGRAPH WELL #2
BAY REGION

Because the water quality from wells completed in areas of thick soil cover does not reflect the high salinity of the soils, it is suspected that most recharge occurs early in the precipitation event when fractures in the dry soil are open.

An estimate of groundwater recharge in the Bay Region was made only for that area 9320 km^2 underlain by the Iscia Baidoa Suite. The estimate was calculated by assuming that 5 percent of the average annual rainfall goes directly to groundwater recharge. Rainfall estimates were obtained from isohyetal maps of the Bay Region (Figure 3.2.2).

During the Gu' season, about 70 million cubic meters of recharge occurs to the aquifer in 3 of 4 years, and 100 million cubic meters in 1 of 2 years. During the Dayr season, recharge amounts to about 50 million cubic meters in 3 of 4 years, and 80 million cubic meters in 1 of 2 years. Estimated pumped withdrawal from the aquifer annually is about 1.3 million cubic meters, or only about 1 percent of annual estimated recharge in 3 of 4 or 1 of 2 years.

It is recommended that a concerted effort be made to measure and record water levels of observation wells for a base period of at least 5 years. These data will permit a more accurate estimate of the volume of groundwater recharge, and the amount of groundwater available for use. Measurement of the conductivity will provide an indication of quality of groundwater, and will provide warning of any significant changes that may result from drought or other alterations of the hydrogeologic regime.

2.4.2 Movement

The movement, or flow of groundwater in general terms is from areas of recharge to areas of discharge. In the limestone plateau of the Bay Region, groundwater flows through karst zones, along bedding planes, through open joint sets, and fractures of the Iscia Baidoa Suite. Plate 7 shows contours on the undifferentiated groundwater elevations of the limestone plateau in the Bay Region. The flow of groundwater is normal to the contours from higher to lower elevations. A groundwater divide is indicated that coincides approximately with the topographic divide of the Jubba and Shabelle Rivers. Most of the groundwater in the Iscia Baidoa Suite flows northwestward toward the Jubba River, but some flows toward the limestone escarpment where it emerges as springs or enters alluvium of the Bur area wadis, becoming underflow. Groundwater flow rates are variable with the extent of karst development of the aquifer;

transmissivity values of the Iscia Baidoa Suite may range widely over very short distances. Plate 8 shows isopleths of the natural logs of transmissivity values. The lack of uniformity indicates typically uneven karst development. Transmissivity is discussed in more detail in Section 2.4.4.

2.4.3 Discharge

Groundwater discharge may be observed at springs along the escarpment of the limestone plateau and inferred as underflow in alluvium of the Bur area wadis that rise at the escarpment. Nearly all groundwater discharge to the springs and wadies is ultimately dissipated as evapotranspiration. Groundwater that flows toward the Jubba and Shabelle Rivers is discharged as base flow to these streams; this is indicated by the hydraulic gradient and direction of groundwater flow shown in Plate 7. The volumes of groundwater discharged to the springs, wadi alluvium, and to the rivers cannot be quantified separately, but in total, should approximate the estimated recharge to the main aquifer. This is true only because there are no significant manmade withdrawals from the system. Groundwater pumped from bored wells was estimated to be about 1 percent of the estimated volume of recharge.

2.4.4 Well Hydraulics

A well is simply a "...hydraulic structure which, when properly designed and constructed, permits the economic withdrawal of water from a water-bearing formation." (Johnson, 1975). The hydraulic characteristics that are essential to the understanding and solution of aquifer problems and to the proper evaluation and utilization of groundwater resources are transmissivity, storativity, and boundary conditions. Analyses of these characteristics are dependent upon many factors including an appreciation of the hydrologic and geologic setting of the aquifer. Although many of the conditions precedent that influence an aquifer test are known, deviations from the ideal on which analyses are based and the limitations of testing procedures generally prohibit precise results. This paradox may be stated another way. Although numerous assumptions are made to enable a mathematical solution to an understanding of flow conditions, some of the assumptions are never met, while others are only rarely observed. Nonetheless, formulas can be applied with success and the resultant calculated hydraulic characteristics can be useful for most purposes.

The information provided is presented in a format that will hopefully be understandable to the casual reader, and yet maintain enough detail to be of use to the professional. A glossary of terms has been provided, and only a brief, if any, description is provided in the text for terminology used.

Because of the emphasis on exploration and exploitation, less emphasis was placed on the collection of data for the determination of detailed aquifer characteristics. Wells were located sufficiently far apart and surface-water bodies were so few, that concerns for interference between wells or from surface-water bodies was nonexistent. Time and cost constraints were such that no observation wells were drilled to enable detailed aquifer tests to be attempted. Thirty-seven well tests were conducted, however, throughout the Bay and Central Range Regions. Twenty-two of these were tests of 24 hours duration. Storativity data were assumed or determined on the basis of water level data taken in completed wells not yet equipped with pumps.

Boundary effects were localized and appeared to be related to structure or changes in stratigraphy. Although not apparent from the aquifer-test data, water quality data indicate some regional boundary effects (Section 2.5).

Aquifer characteristics are described in the following sections in general terms. This approach is in deference to describing the results of each and every well test conducted.

2.4.4.1 Transmissivity

Transmissivity (T) is a measure of the volume rate of flow through an aquifer. It provides a means to evaluate the potential contribution of the aquifer to a well. If one envisions a rectangular sponge sandwiched between two glass plates, the amount of water able to move through a unit width of that sponge would be a measure of its transmissivity. Transmissivity is obtained by graphical means utilizing semi-log or log-log graph paper. All test data were therefore plotted on semi-log and/or on log-log paper. Semi-log plots were analyzed using Jacob straight-line methods, and log-log plots were analyzed using matching-curve methods. (Detailed descriptions of these methods can be found in a number of texts on groundwater hydrology). Log-log plots yield curves that are characteristic of aquifer conditions. Three types of log-log curves were found; those that approximated a true confined aquifer condition, those that reflected leaky artesian conditions, and those that indicated delayed yield conditions.

Aquifer conditions, or types, can also be described on the basis of the permeability of the overlying materials, if it is assumed that the bottom of the aquifer is impermeable. No distinction between horizontal and vertical permeability will be made, but in general horizontal permeability will be two to ten times greater than vertical. On the basis of these criteria an aquifer that has overlying materials with relatively the same permeability can be referred to as unconfined. If the overlying materials are less pervious than the main aquifer, but horizontal flow cannot be neglected, the aquifer is semi-unconfined. Often overlying materials have some permeability, but horizontal flow can be neglected. In this case the main aquifer is considered semi-confined. Where the overlying materials can be considered impermeable, the aquifer is referred to as confined. In reality no material is totally impervious, but for all practical purposes the amount passing through is negligible.

It will be noted that while referring to conditions within the overlying materials, the aquifer is actually being defined. Although the overlying materials are used for descriptive purposes, underlying beds may exhibit similar characteristics. These references are given other descriptions, such as leaky artesian for semi-confined, and unconfined with delayed yield for semi-unconfined. Delayed yield may also result from storage within an unconfined aquifer.

In the Bay Region, a qualitative appreciation for transmissivity can be obtained by relating the aquifer's potential to supply water for domestic use. A transmissivity range for a 50-meter thick limestone aquifer can be from 4×10^{-1} to 4.0×10^{4} m^2/d. If the aquifer potential is described according to the following divisions;

4.0×10^{-1} to 4.0	Poor
4.0 to 4.0×10^{1}	Fair
4.0×10^{1} to 4.0×10^{2}	Good

nearly 50 percent of the wells reflect poor aquifer conditions, and only 17 percent good aquifer conditions. Only four wells, Nos. 10, 11, 52, and 71 had T's greater than 1.0×10^{2} (Table 3.2.2.). These wells could be considered for small-scale irrigation use.

Because of the many variables involved, determination of the transmissivity using only the producing well, must be viewed with caution. The water producing zone is not always completely open to a well, and the formation is definitely not homogeneous. Collectively, the transmissivity values indicate a highly heterogeneous and complex aquifer system of low-yielding wells.

The natural logs of transmissivity values were plotted and contoured, Plate 8. These contours, although somewhat tenuous, show increasing transmissivity away from the groundwater divide. This is especially true in the northwestern part of the area. Toward the southwest no interpretable trend exists. The reason for the increase in the northwest area is not known with

Table 3.2.2. Aquifer Test Data for Wells in the Bay Region

Well	Number	Location	Date Tested	Pumping Rate (CuM/d)	Duration (hrs)	T (SqM/d)	Analytical Method	T (SqM/d)	Analytical Method	Spec. Capacity (SqM/min)
B	10	Sarmaan Dheere	23-Jun-82	639.4	24	414	Delayed yield	200	Jacob	1.1
B	11	Baidoa Compound	11-Oct-82	319.2	32.2	480	Jacob	430	Theis	0.49
B	12	Heero Jeefo	03-Jan-84	273.6	5	2	Theis	2	Jacob	0
B	16	Taflow	05-Jan-84	272.2	24	16	Theis	19	Jacob recovery	0.03
B	18	Gaduudo Dhunte	14-Mar-84	272.2	24	13	Theis	15	Jacob	0.02
B	20	Durai Ali Galle	29-Apr-84	272.2	79.3	2	Jacob			0.01
B	23	Kurman	07-Oct-85	86.4	0.6	0.2	Theis			0.005
B	42	Buulo Fur	16-Apr-84	272.2	24	40	Theis		Jacob	0.03
B	46	Qansax Dheere	16-May-84	272.2	24	10	Theis		Jacob	0.01
B	47	Awshini	10-Apr-84	273.6	24	17	Theis	22	Jacob	0.01
B	51	Mintaano	08-Dec-83	272.2	.12	27	Theis	25	Jacob	0.02
B	52	Maleel	21-Dec-83	604.8	11.5	300	Jacob	240	Theis	0.42
B	54	Isgeed	25-Jan-84	408.2	24	3	Walton LKy Art	5	Theis	0.01
B	55	Marti moog	22-Feb-84	544.2	24	1	Theis	11	Jacob	0.01
B	59	Shawka	03-Apr-84	272.2	0.6	4	Jacob			0
B	61	Hubay	08-Jul-85	196.5	1.3	3	Jacob			0.002
B	63	Bonkay	06-May-84	217.7	1.3	0.4	Theis	0.5	Jacob	0
B	64	Buulo Yuusuf	10-Aug-84	391.9	24	98	Theis	84	Jacob	0.01
B	66	Buulo Hawa	28-Aug-84	354.1	24	18	Theis	21	Jacob	0.01
B	69	Tagaal	12-Dec-84	370.1	0.3	2	Jacob			0
B	70	Garimay	15-Sep-85	528	24	2	LKy Artesian			0.01
B	71	Usle	26-Dec-85	555.7	24	200	LKy Artesian	280	Jacob	0.39
B	76	Dhubei	27-Jun-85	384	3.2	3	Jacob			0.01
B	83	Misra	07-Jul-85	216	7.85	2	Theis		Jacob	0.002
B	92	Asha Farto	06-Sep-85	386.3	24	9	Theis		Jacob	0.02
B	94	Bakale	01-Jan-86	564.2	24	10	Theis	6	Delayed yield	0.07
B	95	Kurtin	04-Nov-85	42.7	24	1	Theis			0.001
B	97	Toosilow	25-Nov-85	296.8	24	3	Theis		Jacob	0.01
B	98	Kuralow	08-Nov-85	61.5	3.3	1	Theis		Jacob	0.001
B	99	Heero Jifto	28-Dec-85	260	24	2	Theis			0.01
B	101	Hobishole	29-Nov-85	48	24	0.8	Theis		Jacob	0.002
B	102	Caliyow Marayle	03-Dec-85	198.7	24	11.3	Theis	36.4	Jacob	0.05
B	103	Garasmood	07-Dec-85	34.6	3.2	0.5	Theis			0.001

certainty, but may be due to the greater number of faults in that area. Faults have one of two effects on groundwater movement in an area; barriers to flow or conduits of flow. In the Iscia Baidoa formation both conditions occur at different locations. In the northwest the faults and related fractures appear to have increased transmissivity. In the southwest, faulting has inhibited groundwater movement. This is reflected in the water quality as well as in the transmissivity, (Section 2.5).

Although karst conditions, sinkholes and solution cavities, were noted in some areas at the surface, well-developed subsurface karst conditions were not everywhere defined. Less than 40 percent of the wells drilled contained sections described as karst, and some of these are suspect. Where karst conditions were described it was, with few exceptions, within the first 100 m and in many instances within the first 50 m of hole. Water movement in the limestone is predominately horizontal along bedding planes and vertically through fractures and joint sets. The three types of aquifer curves previously mentioned are a reflection of the areal heterogeneity of these conditions. Figure 3.2.5 after Davis and De Wiest (1966) clearly demonstrates the potential for the resultant Theis-type curve, and delayed-yield type curve. The leaky artesian curves are reflecting conditions similar to well C in Figure 3.2.5, but with a semi-confined or leaky unit overlying the screened zones. Shale layers or dense limestones were found overlying the water producing zones in those wells where a leaky artesian type curve occurred; wells No. 46, 54, 70, and 97.

Most shales, based on drill cuttings, were brittle, suggesting thin horizontal bedding and the potential for vertical fracturing that could permit movement of water between beds. It is likely that any contribution from these layers is strongly diminished in the areas adjacent to the well where dewatering will cause compression of the beds.

Specific capacity values, calculated using Walton's equation, (Walton, 1970 p. 315), were plotted versus transmissivity, Figure 3.2.6. Twelve transmissivity values, covering the range of those measured in the field, and two storage values, one for confined conditions, 0.003, and one for unconfined conditions, 0.015, were used in the equation. Specific capacity and transmissivity values derived from field measurements were then plotted on the graph for comparison. The number of wells that reflected confined aquifer conditions were only slightly more than those that reflected water-table aquifer conditions. The vertical scatter of data points above the confined aquifer plot for the same specific capacity reflects

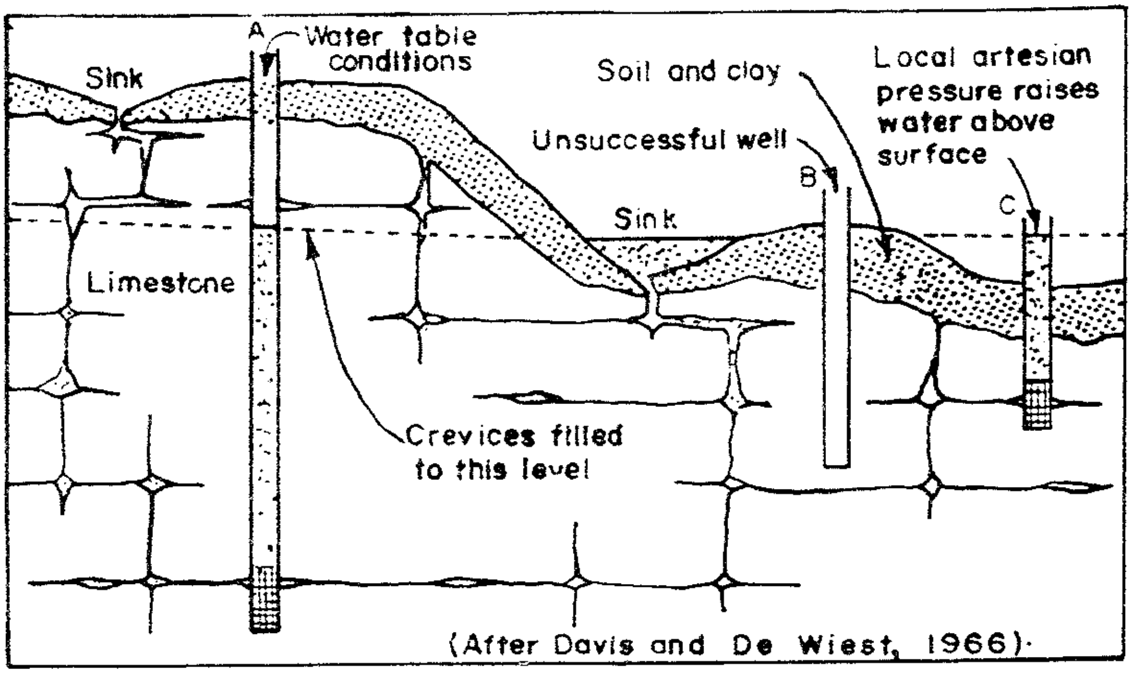


Figure 3.2.5 GENERALIZED DIAGRAM OF GROUNDWATER OCCURRENCE IN KARSTIC LIMESTONE.

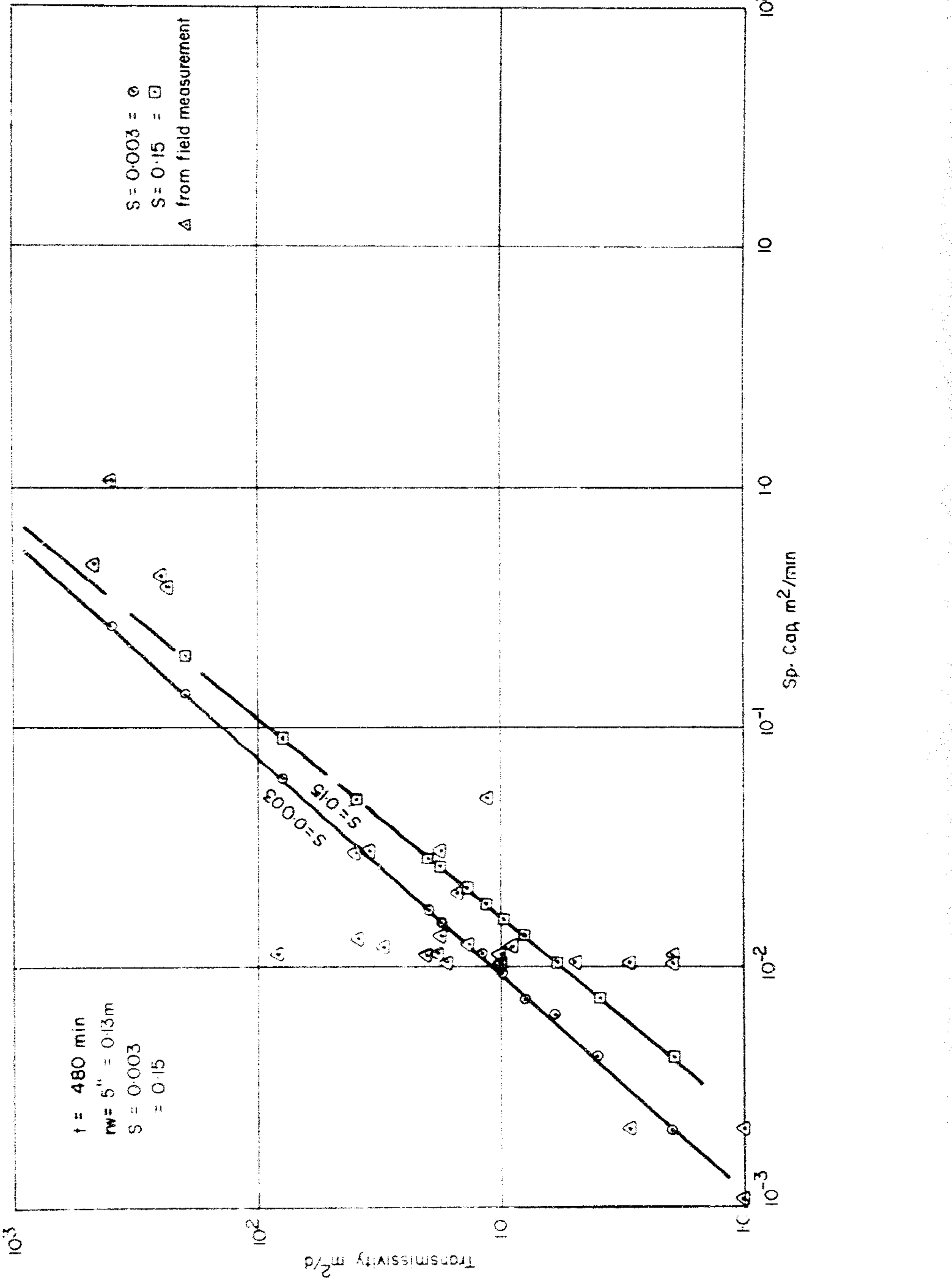


Figure 3.2.6 TRANSMISSIVITY VERSUS SPECIFIC CAPACITY

wide variation in transmissivity with depth. This is typical of areas where secondary permeability is dominant. Secondary permeability invariably declines with depth.

An excellent example of varying transmissivity with depth are the wells within the BRADP compound, and those relatively close to the escarpment. These wells had a fairly well-developed karst zone to depths of 20 to 30 m, but simply bedded and fractured limestone below this depth. If pumped during or shortly after the rainy season, these wells will appear to have a very high T and a very high specific capacity. This is because of the shallow karst development. Other times of the year, when the karst zone has drained, T's are very much lower. This factor should be noted when reviewing transmissivity data. The time of year during which the test was conducted should be noted as carefully as the geologic log of the well.

2.4.4.2 Storativity

Because observation wells were not drilled in conjunction with the exploration/production well program, values of storativity could not be calculated using pump test data.

Estimates of storage were made based on changes in water level. Water level measurements were made in a number of wells, Table 3.2.3, and showed an average fluctuation of two meters. If the 590 mm average annual precipitation over the Iscia Baidoa formation is assumed to be uniform and 5 percent of this is recharged to groundwater, then 2.8 x 10^8 m^3 of water would be recharged. Recharge from direct infiltration of precipitation is affected by upon many factors, however, not the least of which is the fact that it is irregularly distributed in time and place. The character and thickness of soils, the depth to the water table, topography, vegetal cover, land use, intensity and duration of rainfall, air temperature, and other meterological factors all affect recharge.

Another approach to estimating storativity is assuming an average value for the type of aquifer, that is 0.2 for an unconfined aquifer or 10^{-4} for a confined aquifer, (Lohman, 1972). Using the confined aquifer storage coefficient would yield 1.9 x 10^7 m^3 of storage and using the unconfined would yield 3.7 x 10^9 m^3 of storage. Compared with the average annual precipitation, the required recharge is too low or too high to effect this volume of storage. Coincidentally, by using the average porosity of limestone, 0.015, as the storage coefficient, the volume of storage is approximately equal to 5 percent of the average annual precipitation. Coincidentlly must be emphasized, however, it falls within the realm of reality.

Table 3.2.3. Observation-well water levels, Bay Region

Observation well number and name	Measurement Periods			
	1. Pre-Gu	2. Post-Gu'	3. Pre-Dayr	4. Post-Dayr
	Water levels (m) and dates (day,month,year)			
B3 Bonkay Farm	38.55/19.3.85	36.60/3.7.85		
B18 Gaduudo Dhunte	26.8/19.3.85	30.45/18.6.85	33.26/29.9.85	24.90/17.2.86 (Probable -10 m error)
B21 Baidoa Compound	8.50/19.3.85	6.59/18.6.85		
B46 Qansaxdheere	30.89/12.4.85	31.16/18.6.85	30.97/29.9.85	31.10/17.2.86
B47 Awshiinle	33.26/20.3.85	29.61/18.6.85	29.28/29.9.85	29.44/17.2.86
B52 Maleel	48.68/4.2.85	48.27/22.6.85	48.25/29.9.85	48.83/17.2.86
B54 Isgeed	37.65/4.2.85	37.39/22.6.85	37.56/29.9.85	38.53/17.2.86
B63 Bonkay Ext.Farm	25.45/19.3.85	24.30/26.5.85	34.83/30.9.85	
B71 Usle		29.28/22.6.85	29.30/29.9.85	29.83/17.2.86
B- Ufurow	51.62/12.4.85	48.27/25.6.85	50.19/29.9.85	
B76 Dhuboi	20.20/12.4.85	19.16/16.6.85	19.65/29.9.85	20.16/17.2.86

In some areas the water level response to rainfall is almost immediate, Figure 3.2.4. This would suggest a higher storativity than 0.015, however, it also indicates the rapidity with which water moves out of the aquifer, and thus the limiting storage characteristics of the aquifer.

2.4.4.3 Boundary Effects

Boundary effects are commonly noted on semi-log plots of pump test data by a significant change in slope of the straight-line portion of the curve. Impermeable boundaries are marked by an increase in slope and recharge boundaries are marked by a decrease in slope. Wells No. 61, 66, and 98 indicate the presence of an impermeable boundary and well No. 76 suggests the presence of a recharge boundary, (Vol.V Appendix 3). Wells No. 61 and 66 are potentially affected by the proximity to faults. The cause of a boundary at well No. 98 is unknown. Neither structural nor lithologic differences are readily apparent from available data. As the number of wells increases, the presence of significant areal boundaries will become known.

In all likelihood, the indication of an impermeable boundary is simply the result of drawdown passing from a zone containing larger solution cavities to one where the limestone is fairly competent. The recharge boundary effect may be attributable to the opposite circumstance described above, or to contribution from a zone with storage.

2.5 Quality of Water

The predominant water types from bored wells in the Bay Region are calcium-bicarbonate and sodium-chloride. These are shown in Stiff diagrams in Plate 9. Other water types, calcium-sulfate, calcium-chloride, sodium-sulfate, sodium-biocarbonate, and magnesium-chloride are present, but uncommon. Water quality data for all boreholes is provided in Volume V, Appendix 4.

The major sources of total dissolved solids in groundwater of the limestone plateau are the soluble mineral constituents of the limestone aquifer in the Iscia Baidoa Suite. Rainfall, because of carbon-dioxide in the air, is slightly acidic, containing small amounts of carbonic acid, H_2CO_3. This dilute weak acid is sufficient, however, to react with limestone and produce dissolved material. The total dissolved solids content of water from bored wells in the limestone plateau ranges from 640 mg/l (milligrams per liter) in well No. 90 at the BRADP Compound, to 6640 mg/l in well No. 83 at Misra. Isopleths of total dissolved solids concentrations are shown in Plate 10.

Concentrations of total dissolved solids in groundwater from bored wells in the limestone plateau are least in the area of recharge north of Baidoa at boreholes Nos. 51, 52, 54, 44, 61, 70,74,75, 92, and 94 (Plate 10). Groundwater has been in contact with the aquifer for the shortest length of time in this area. Groundwater from boreholes in the Anole Suite, where permeabilities are low and evaporites present, has high concentrations of total dissolved solids as in boreholes Nos. 13, 14, and 15. Where groundwater circulation is probably restricted by fault barriers as in boreholes Nos. 10 and 47, total dissolved solids concentrations in groundwater are moderately high.

There are slight variations in total dissolved solids concentrations throughout the other parts of the limestone plateau owing to mineral variations in facies of the Iscia Baidoa Suite, to restricted circulation by faults or other structural or stratigraphic barriers (boreholes Nos. 83 and 88), and to increasing distances of boreholes from the recharge areas north of Baidoa and along the topographic divide of the Jubba and Shabelle drainages. The high concentration of dissolved solids in groundwater from borehole No. 59 comes from a deeper aquifer with restricted groundwater circulation. One well, No. 104, drilled in the Bur area at Ceel Jaalle, had total dissolved solids of 14080 mg/l in a sodium-chloride type water. The probable source of the more saline water in bored wells of the Bur area is concentration of dissolved solids by evaporation through capillary rise from groundwater that is in restricted storage with no circulation.

Isopleths of chloride-ion concentrations, sulfate-ion concentrations and specific conductivity are shown in Plates 11, 12, and 13, respectively. Specific conductivity of groundwater is a measure of the dissolved mineral content. The relation of total dissolved solids to specific conductivity in the Bay Region is shown by a linear-regression analysis plot in Figure 3.2.7. The relation of chloride-ion concentration to specific conductivity is shown by a linear-regression plot in (Figure 3.2.8). The difference in the slope of the linear plots indicates the greater influence of the chloride ion on specific conductivity. The concentrations of chloride and sulfate ions generally follow the same pattern as that of total dissolved solids and specific conductivity; having the least values in recharge areas and greatest values in areas distant from recharge areas, or where groundwater circulation is restricted or in contact with evaporites.

2.5.1 Recommended Criteria

Water quality criteria for domestic and animal consumption, as established by WHO, have no validity in Somalia. The availability of water tends to outweigh any concerns for particular levels of specific constituents. The standards for

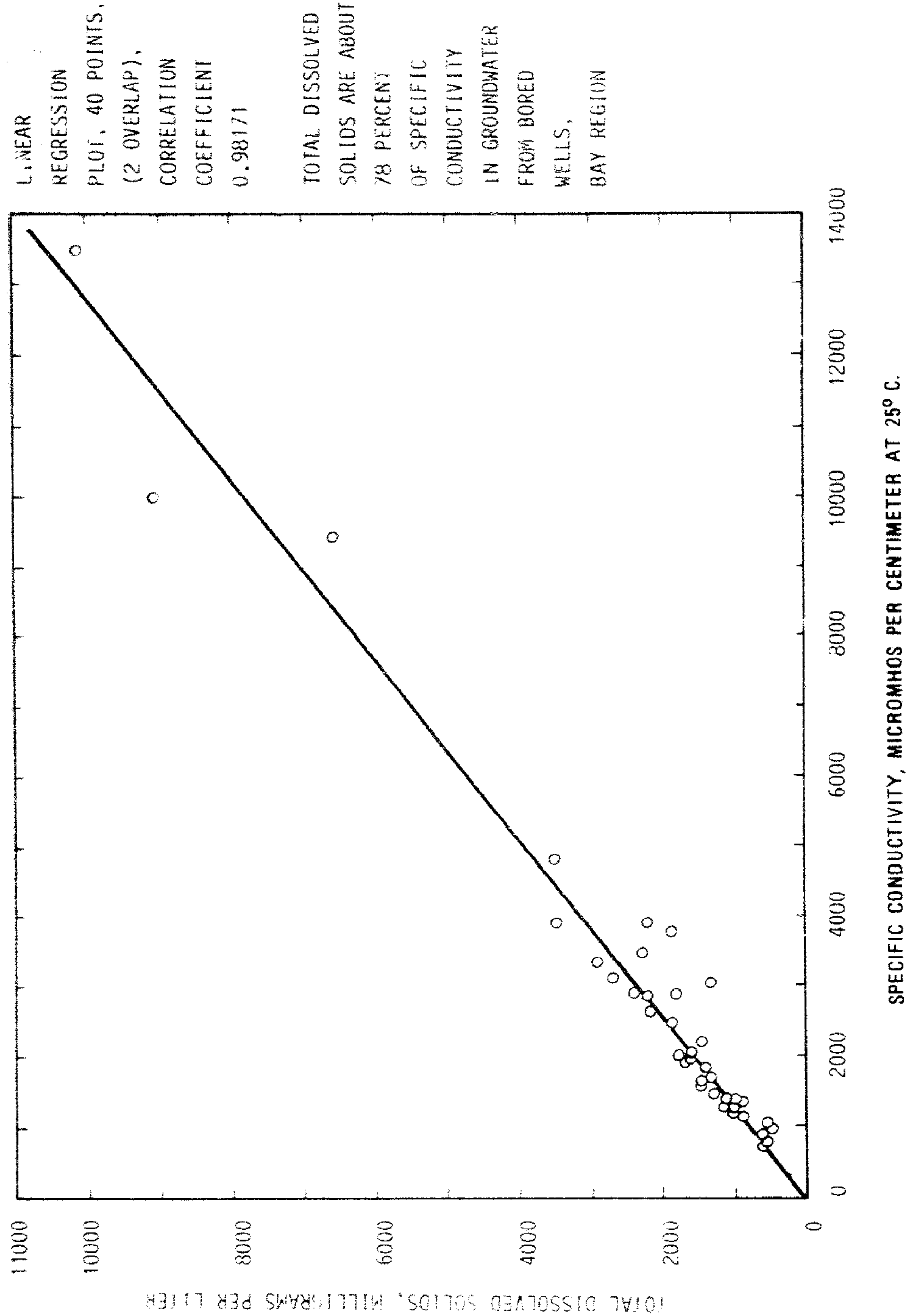


Figure 3.2.7 TOTAL DISSOLVED SOLIDS vs SPECIFIC CONDUCTIVITY, BAY REGION.

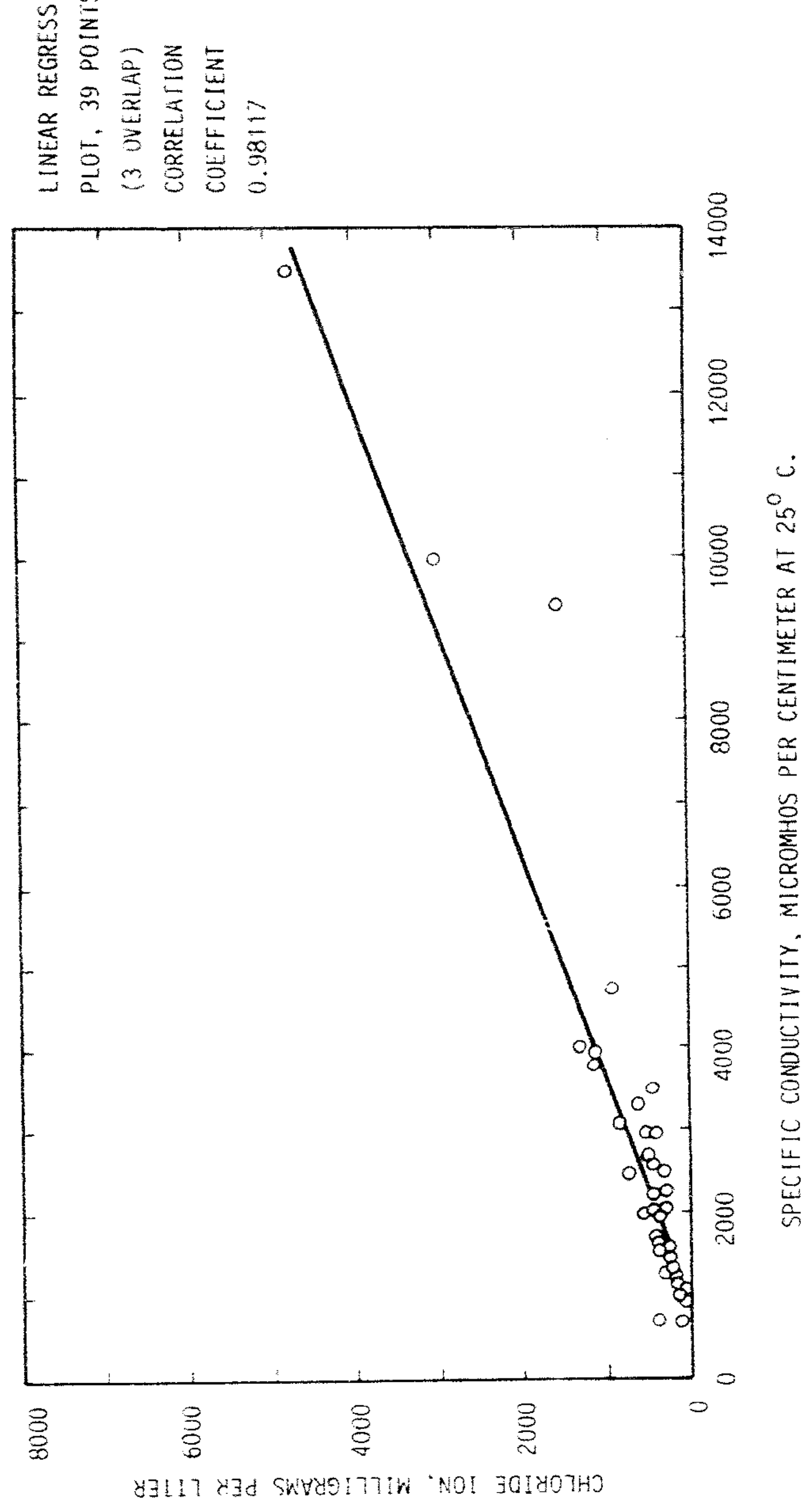


Figure 3.2.8 CHLORIDE - ION CONCENTRATION vs SPECIFIC CONDUCTIVITY IN GROUNDWATER FROM BORED WELLS, BAY REGION.

the chemical quality of water in the Bay Region are related to the tolerance levels of people and animals. An approximation of upper limits of salinity in terms of specific conductance of water, were established during this project to be as follows:

People < 3500 micromhos/cm at $25^{o}C$,
Cattle, goats, and sheep < 7500
Camels, < 10000

People and animals have been known to accept water of greater salinity than these arbitrary limits. It is recommended that the concentrations of chloride ion not exceed 800 mg/l and sulfate ion not exceed 500 mg/l in drinking water for people, but even these limits are known to be exceeded. The specific conductivity, chloride and sulfate- ion content of water from bored wells in the Bay Region are shown in Plate 14.

2.5.2 Special Problems

The occurrence of groundwater unsuitable for use or of limited use in boreholes No.14 and No.15 is due to their location in the Anole Suite, a geologic unit containing large amounts of evaporites. The poor-quality water from borehole Nos.10, 47, and 97 is attributed to restricted groundwater circulation caused by northwest-trending faults that serve as barriers (Plate 4). The saline water from boreholes No.50 and No.59 originates in a deeper aquifer than the main limestone aquifer of the Iscia Baidoa Suite. Groundwater of poor quality in borehole Nos.76, 80, 83 and 88 may also be due to restricted groundwater circulation by fault or stratigraphic barriers (Plate 4).

At Ufurow, No.75-2 and at Dhuboi, No.76, trace hydrogen-sulfide was reported in water from the boreholes. The trace hydrogen-sulfide results from the reaction of methane with the sulfate ion in groundwater: $CH_4 + SO_2 + 2H = H_2S + CO_2 + 2H_2O$. Sources of the methane are hydrocarbons in trace amounts in the Iscia Baidoa Suite. These boreholes were backfilled to eliminate the hydrocarbon-bearing strata from the wells. Trace amounts of hydrogen-sulfide may be eliminated from water by aeration if this water is to be used for human consumption.

Corrosion of steel well casing has not been observed to have been a problem in the Bay Region. The potential for groundwater to cause corrosion or incrustation of well screen or perforated casing may be calculated by a formula for the Ryznar Stability Index (Schafer and Moog, 1966). Data needed for the calculation are analyses of groundwater for total dissolved solids, calcium ion, bicarbonate ion, and pH. Groundwater having indices of less than 7 may cause incrustation, and indices of greater than 9 may cause corrosion. Ryznar indices of groundwater from most of the bored wells in the Bay Region limestone plateau range from 7 to 8. A few wells in the northern and northwestern part of the region have groundwater with Ryznar indices of less than 7 (Plate 15). Groundwater in these areas has a potential for incrustation of well screen or perforated casing. The highest Ryznar index is at well No.46, 8.21. Groundwater having a potential for corrosion, Ryznar index greater than 9, has not been found in the Bay Region.

2.6 Civil Works

Civil works consist of a storage tank, animal watering troughs, and domestic water distribution taps. These works were completed only at those sites where diesel powered pumps were installed. Civil works have been constructed at the following sites in the Bay Region:

- No. 10 Sarman Dheere
- No. 16 Taflow
- No. 42 Buulo Fuurow
- No. 52 Maleel
- No. 12 Hareero Jiifo
- No. 18 Gaduuda Dhunte
- No. 47 Awshiini

Initially the civil works were to be constructed by the projects, however, they did not have adequate staff or the means to carry on this task. The CGDP took on the task until July, 1984 when the project was extended. At this time civil works were again assigned to the respective projects for completion. An improved design for the storage and distribution system was completed in October 1985 after an inspection of existing facilities. The consultant's engineer in conjunction with the WDA engineer, revised all the structures to more closely meet the needs of the people. Revised drawings and specifications were prepared and given to the BRADP and CRDP managers. The features of these structures are described in sections that follow.

2.6.1 Storage Tank

In order to meet the requirements for a two-day reserve of water without pumping, the storage tank was designed for 45 m^3 capacity; this will supply about 1000 people at 20 liters per person per day. The tank was designed for gravity flow to the distribution system for people and for animals. With normal use the system may distribute about 70 m^3/d, and is capable of 84 m^3/d for peak periods. The improved storage tank design provides for an elevated structure of masonry, using locally available stone for the elevated foundation and tank. Cement and sand must still be transported to the site. The original design provided for rectangular tanks with no covers, but this allowed algae to grow in the tank and restrict drainage through the distribution systems. A circular tank was recommended in the revised design to reduce the cost of materials, and a cover was added to prevent the growth of algae.

2.6.2 Watering Troughs

The watering troughs originally designed were the same for all animals. The revised design changed the construction to prevent sheep and goats from entering the trough. The troughs were positioned sufficiently far from the domestic system and from the well head to reduce chances for contamination.

2.6.3 Domestic Standpipes and Washing Facilities

This part of the distribution system provides water for domestic containers and provides facilities for hand laundry. Domestic containers may average about 20 liters per person. At peak demand, it is assumed that ten of twelve taps will be on delivery at the same time, drawing 7 liters/minute each, or a total of 70 liters/minute while pumped water is available. Laundry washing facilities consist of large basins with an adjacent scrub board. These have been redesigned to be separate from the water distribution taps.

2.7 Pumping Systems

Under normal circumstances the selection of a pump for a well is based on the anticipated yield of the well and on the purpose for which the well was constructed. Normal circumstances are those where the items desired are readily available in a short period of time. Because project operations required advance purchases, decisions had to be made well in advance of intended use, and without benefit of firm data. The pumps ordered for installation in wells completed during this project were ordered on this basis. Four types of pumps were obtained; hand pumps, direct-drive diesel pumps, submersible pumps, and wind pumps. The discussion of pumps that follows has been divided into three main categories; hand pumps, motorized pumps and wind pumps.

2.7.1 Hand Pumps

Hand pumps, as the name implies, move water by manual operation. Hand pumps were sometimes referred to as reciprocating pumps because they involved an up-down motion. The hand pumps obtained for this project are, however, non-reciprocating. The principle of operation for these pumps, the Mono by Robbins and Myers, is the helical screw or rotor. This rotor turns inside a molded stator and causes water to move upward. The main advantage of this type of hand pump is that it requires virtually no maintenance.

The models ordered for the project were the 1v12, designed for single person operation for lifts up to 45 m, and the 2v12 for two person operation for lifts up to 90 m. Unfortunately, a factory defect in the shaft construction caused most of these pumps to fail shortly after installation. The company, after considerable delay, provided repair kits for these pumps.

Additional requirements of hand pumps led to the purchase of Mono pumps. Mono was the inventor of the helical rotor pump; however, until recently they were made only in England and were not eligible under USAID regulations. These pumps have the same lift capability characteristics as the Robbins and Myers pumps. At the time of report preparation these pumps were not yet delivered.

One other type of hand pump was installed during the project; the India Mark II. Two of these pumps were provided as demonstrators by Export Trading Co. of Nairobi. These pumps are the basic reciprocating type hand pump that has been successfully used in many other African countries. The main feature of these pumps is low cost, and potential for being locally manufactured. The disadvantages are a lower lift capacity, 60 m, and more frequent maintenance requirements. The maintenance reportedly can be conducted locally.

Hand pumps generally have not been well received in the project areas where users prefer motorized pumps. Reports from other water development projects, mostly refugee relief, indicate that hand pumps are being accepted. The early breakdowns on those installed by the project may account for the lack of user confidence. Hand pumps, and especially the helical rotor type, are recommended. Although more expensive initially, when properly received and installed these pumps should outlast all others. The main feature of these pumps, no maintenance, is a major reason for the recommendation. During the five years of the project, the general lack of maintenance on all equipment was found to be a critical problem.

2.7.2 Motorized Pumps

Two types of motorized pumps were purchased for the project, direct-drive diesel pumps and submersible pumps. The direct-drive diesel pumps are those manufactured by Mono pump and operated by Lister diesel engines. These pumps were purchased for permanent installation at selected well sites.

Stainless-steel Grundfos submersible pumps were purchased for use as test pumps on newly completed wells. These pumps could also be used as permanent pumps during an emergency situation.

2.7.2.1 Mono Diesel Pumps

Mono diesel-driven pumps were selected for installation at high-yield well sites with human and animal populations large enough to require one. These pumps have the same helical rotor/stator design as the Mono hand pumps, but are capable of producing more water at greater depths. Depending upon motor size, these pumps are capable of water lifts from 150 m.

The direct-drive diesel engine was selected for its ease of operation, low maintenance, and comparatively low cost. In many cases submersible pumps would have been preferable, however, power supplies are not available at most sites and diesel generators would be required. These are more expensive and require more maintenance to keep operating properly. Another advantage of the Mono pump is that it is interchangeable with the hand pump. By standardizing the motor pumps and hand pumps, parts requirements can be kept at a minimum.

2.7.2.2 Submersible Pumps

Two Grundfos stainless-steel pumps, a 40 hp and a 20 hp, were purchased for use primarily as test pumps. Submersible pumps were chosen over direct-drive deep-well turbine pumps because of the ease of installation. Deep-well turbine pumps require more care and handling in both transport and installation. The road conditions and the technical ability of the crews warrant installation of submersible pumps. In addition, deep-well turbine pumps require that the wells in which they are installed be plumb throughout the length of installation. Submersible pumps are more forgiving in this regard.

The Grundfos stainless steel pumps are three-phase having from 7 to 20 stages. The number of stages reflect the heads against which the pumps are capable of operating. This includes depth below water level to the highest point of discharge. Generators were mounted on each of the two pump installation rigs in conjunction with cable reels to enable these pumps to operate from one vehicle.

2.7.3 Wind Pumps

Wind pumps, or more commonly windmills, gained increasing interest as the project matured. This was due primarily to the realization that fuel to operate the diesel pumps was going to be a continual problem in Somalia. Windmills are not new to Somalia, but have suffered the same fate as most mechanical equipment; lack of spare parts to keep them maintained. Other deterrents to the widespread use of windmills have been the high cost to import, the difficulty in transporting and erecting at remote sites, and the inability to operate under low wind conditions.

Two windmills were obtained for installation and monitoring during the project. These were US-manufactured Wind Baron pumps. This particular windmill was selected on the basis of its ability to function at windspeeds as low as 8 kilometers per hour. Because of the high cost and advanced technology of these pumps, interest turned to the less expensive Kenya-manufactured Kijito pumps. These two pumps will be briefly discussed and compared.

2.7.3.1 Wind Baron Pump

The Wind Baron Pump (WBP) was selected for operation in Somalia because of its ability to produce water at low windspeeds, and to serve as an experimental system. The ability of this windmill to function at velocities as low as 8 kilometers per hour was believed to be important for research purposes. Conventional windmills generally require wind speeds of 24 kilometers per hour. Figure 3.2.9 shows the theoretical discharge of the Wind Baron Pump and the observed discharge as measured at the Bay Region installation. The erection of the windmill for the Bay Region was completed in February, 1985. Unfortunately, periodic operational problems with the system prevented the gathering of data as initially planned. Some data were able to be collected, however, and an evaluation made of the windmills performance.

An anemometer was installed on the windmill tower at nine meters above ground surface to measure wind velocity at the operating height. Data from this instrument were compared to data from an anemometer at the standard 2 meter height above ground surface. This anemometer was located at the Bonkay Seed Farm approximately 150 meters from the windmill tower. In an effort to insure that the two recording instruments were comparable, the anemometer/compilator used on the tower was positioned adjacent to the Seed Farm instrument and at the same height. A small correction factor of 0.92 was found to be necessary, that is 0.92 times anemometer (Seed Farm) readings would yield the same as the compilator (Figure 3.2.10).

The anemometer/compilator was then reinstalled on the tower at nine meters above ground level and readings taken were compared with the Seed Farm anemometer at two meters above ground level (Figure 3.2.11).

Data collected from both instruments were then plotted resulting in a linear correlation for the comparison period (Figure 3.2.10). Collection of comparative data will continue with the objective of being able to assess the potential for

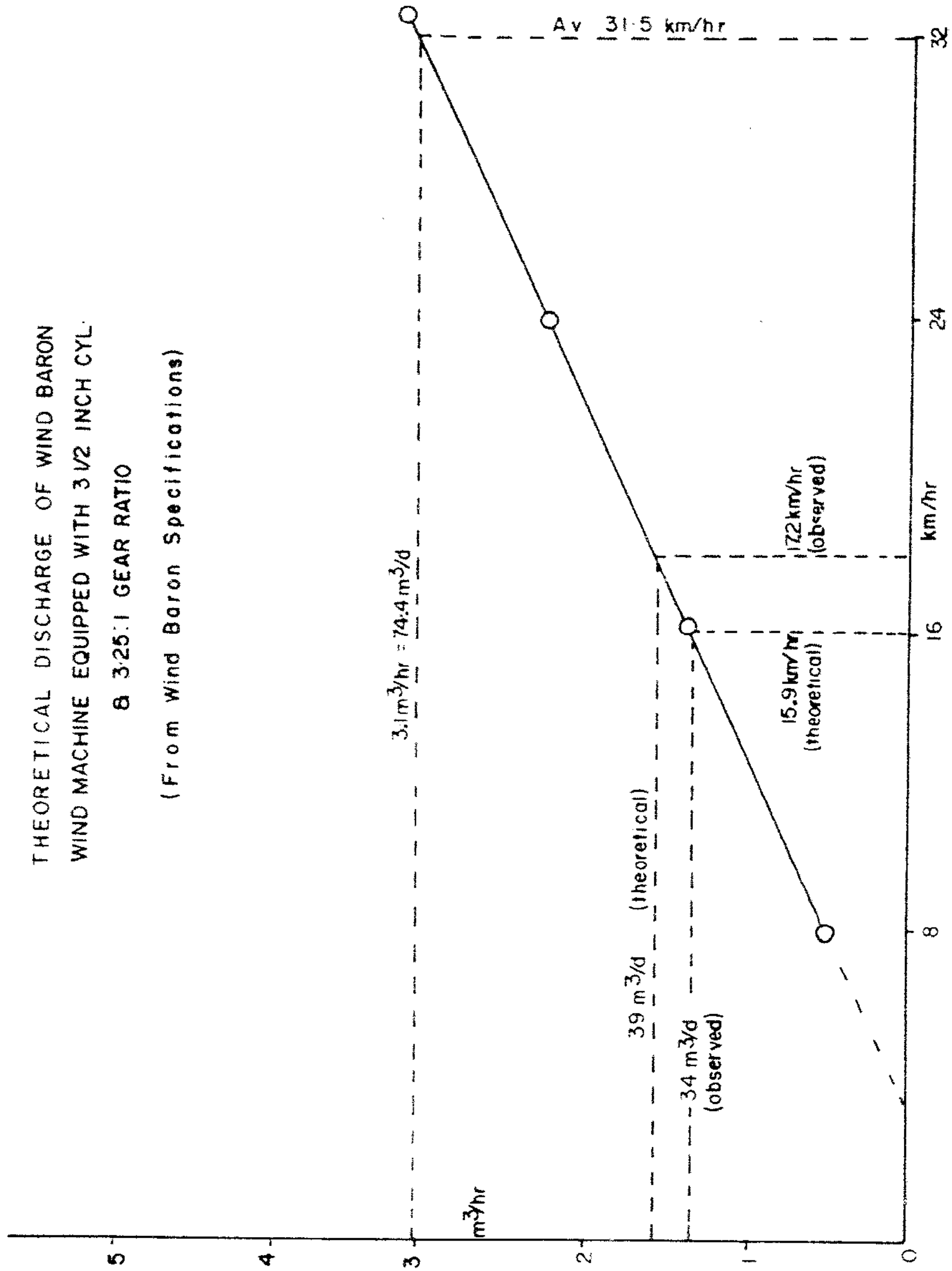


FIGURE 3.2.9 THEORETICAL DISCHARGE SYSTEM AS EQUIPPED

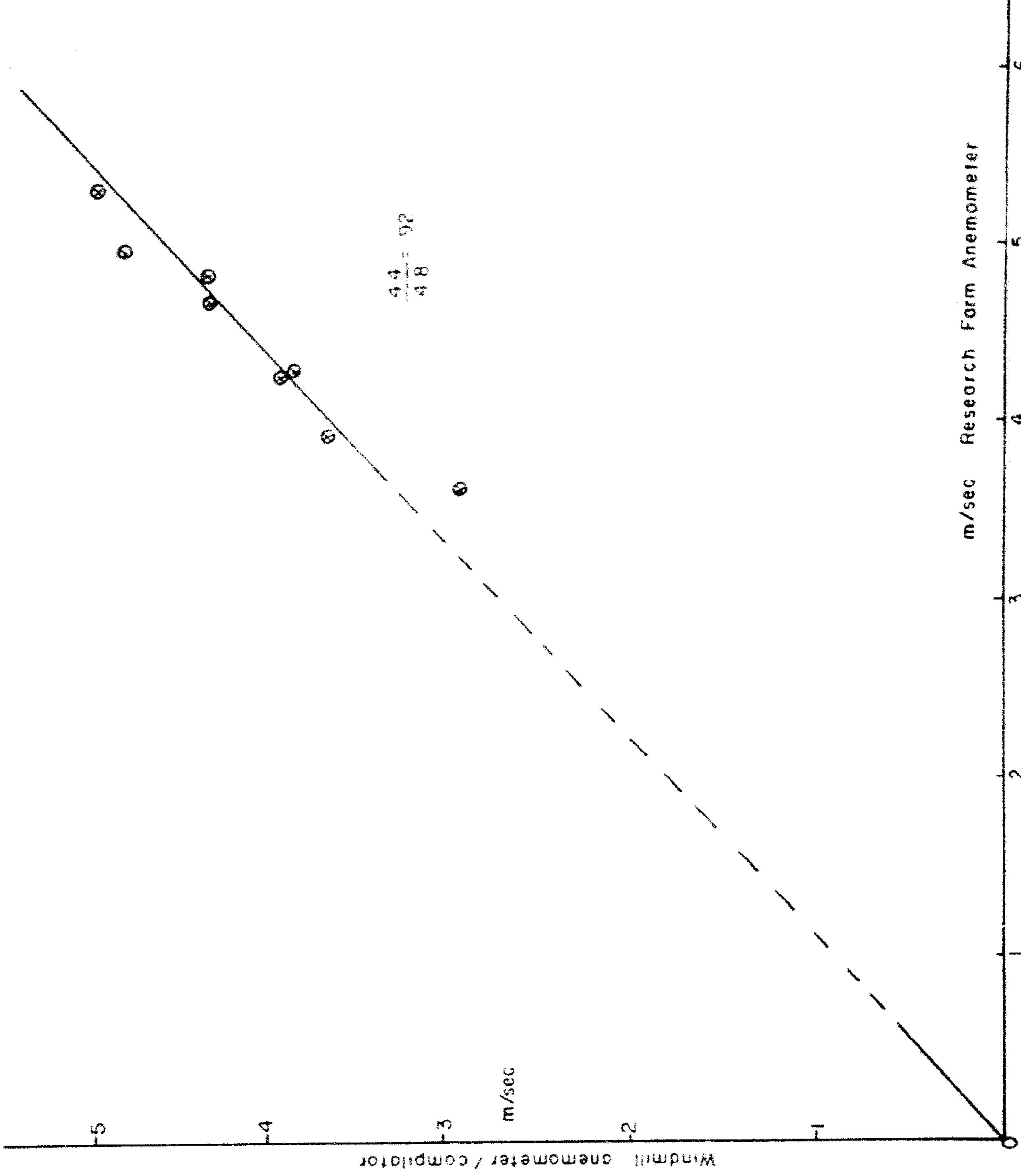


Figure 3.2.10 COMPARISON OF ANEMOMETERS AT 2m AGL.

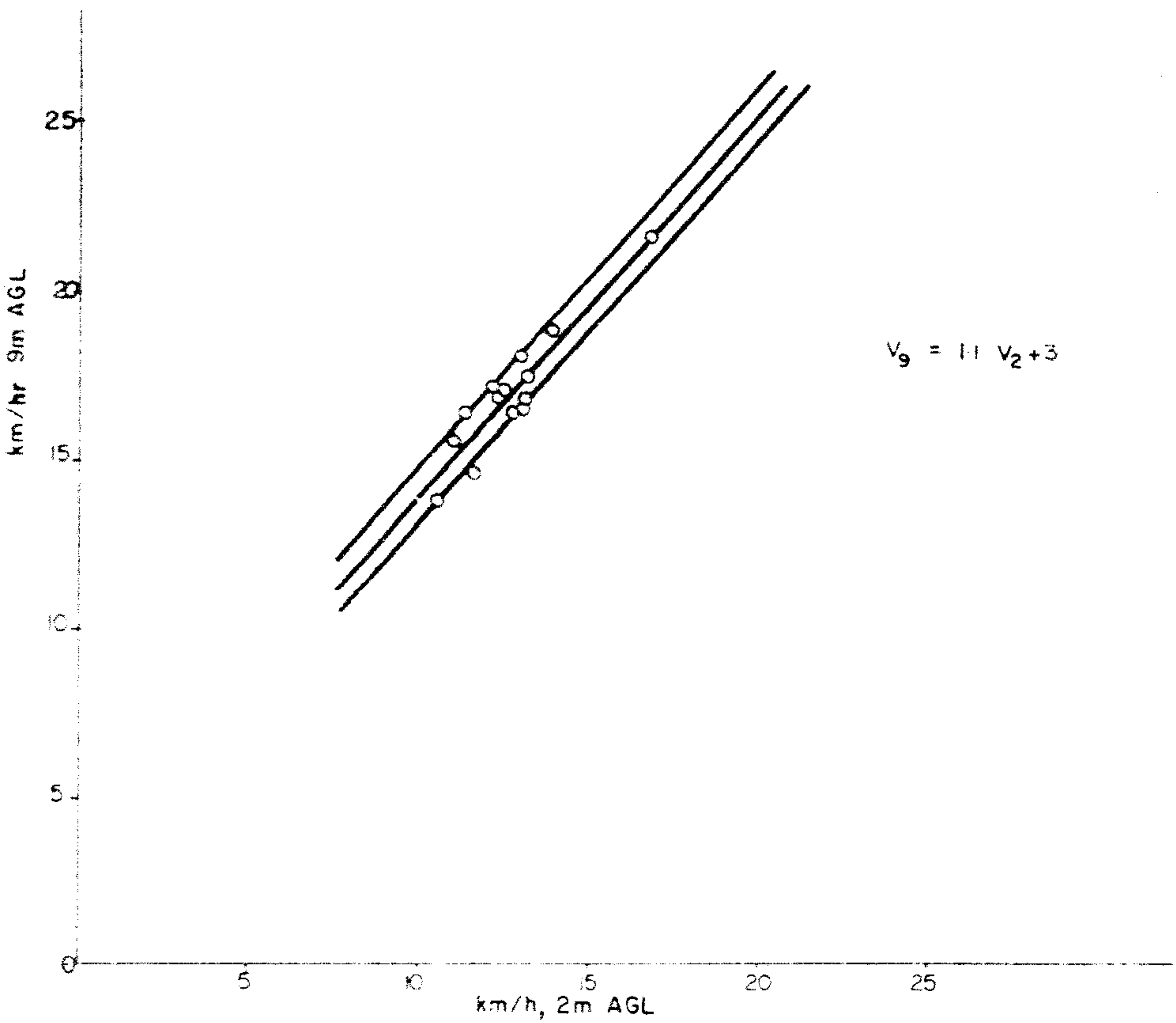


FIGURE 3.2.11 COMPARISON OF WINDSPEEDS AT 2m vs 9m AGL

windmill operations by collecting wind data from standard height meterological stations.

The data collected at the Bonkay Seed Farm for 1984, and 1985 was compared with the 24 years of record for Baidoa provided by the Ministry of National Planning (Table 3.2.4 and Figure 3.2.12). Very little difference exists between the 24-year average and that of the past 2 years. It is important to note that the months of minimum wind speed are during the wet season. Loss of yield because of low wind speeds would therefore not be a serious problem.

Flow data were also collected and compared to the theoretical data to evaluate the pumping performance of the system. The Wind Baron pump installed has a gear ratio of 3.25:1, that will allow pumpage of water at depths ranging from 300 to 400 hundred meters. At a wind speed of eighteen km/hr it should be capable of producing approximately 40 m^3/day, however, it only produced 34 m^3/d. This suggests that the system is operating at 85 percent efficiency; this is not unreasonable.

2.7.3.2 Kijito Pumps

Kijito windmills are manufactured in Nairobi, Kenya and have therefore gained considerable interest in East Africa. Additionally, these pumps have the potential to be manufactured in Somalia. Figure 3.2.13 shows the performance graph for the Kijito pump. If a rotor or wheel assembly of 7.3 m diameter is erected in the Bay Region it could potentially produce between 15 and 21 cubic meters per day during medium winds of 10.8 to 14 km/h. Below 10.8 km/h this potential yield drops off drastically. With the exception of the wet season months, the mean wind speeds are at or above these rates. This performance is only about 25 to 30 percent less than what the Wind Baron pump could produce at six times the cost.

There are numerous other wind pump manufacturers from whom comparative data could have been obtained, however, it is reasonably safe to say on the basis of data collected to date, that wind pumps are a viable means of producing domestic/stock watering needs in the Bay Region. Manufacturer's performance should be compared with area wind data prior to selection of specific pumps.

2.8 Recommendations for Future Water Development

During the course of this investigation, it became clear that water requirements in the Bay Region could not be totally satisfied by the addition of drilled wells. The area of the limestone plateau recommended for additional borehole drilling

Table 3.2.4. 24 Years of Wind Speed Data for Baidoa in meters/second.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1954	1.4	1.7	1.9	0.7	0.7	0.9	1.0	1.1	1.3	1.2	1.4	1.1	1.2
1955	1.6	1.4	1.9	1.2	0.5	0.8	1.0	1.2	1.3	1.3	1.4	1.4	1.3
1956	1.6	2.7	1.7	1.2	0.7	2.4	2.4	2.8	2.2	1.4	1.1	1.2	1.8
1957	1.4	1.6	1.2	1.4	1.3	2.0	2.0	2.3	1.9	1.1	1.0	1.0	1.5
1958	1.4	1.4	1.8	1.2	1.5	2.2	2.3	2.5	1.9	1.1	1.0	1.1	1.6
1959	4.5	4.4	4.8	3.6	3.9	5.4	5.3	5.3	4.5	3.7	2.8	4.1	4.4
1960	0.6	5.9	2.6	4.0	3.7	5.3	5.9	5.8	5.1	3.8	2.5	3.8	4.1
1961	4.0	5.3	7.3	3.1	3.2	4.2	4.8	5.8	4.7	2.4	1.7	2.7	4.1
1962	6.8	1.9	3.2	2.5	3.3	4.6	4.8	4.6	4.3	2.0	2.3	3.1	3.6
1963	3.7	3.9	3.2	2.4	2.8	3.8	5.1	5.0	4.2	2.8	1.4	2.2	3.4
1964	4.0	3.8	1.6	1.4	2.1	2.3	5.1	5.2	5.1	3.7	2.8	3.7	3.4
1965	4.0	4.0	4.0	3.0	3.7	4.6	4.8	5.4	4.8	3.5	2.1	3.5	4.0
1966	3.2	4.1	3.1	2.3	3.1	4.7	5.0	4.7	4.1	3.1	2.8	3.6	3.7
1967	4.0	3.4	3.5	2.6	3.0	4.0	5.2	2.2	2.7	3.4	3.4	2.5	3.3
1968	4.0	3.6	3.1	2.2	2.6	3.9	4.9	4.9	4.2	3.1	3.0	3.5	3.6
1969	3.7	2.9	3.9	3.3	2.9	3.7	4.6		4.0	2.8		3.8	3.6
1970	4.1	3.3	3.0	2.8	3.0	3.7	3.7	4.1	3.5	1.5	3.9		3.3
1971	4.1	3.3	3.5	3.2	3.6	4.7	4.9	4.7	4.4	3.2			4.0
1972	3.7	3.6	3.7	3.3	2.4	3.8	4.6	3.9	2.9	1.7	1.4	2.7	3.1
1973	3.6	3.2	3.0	2.9	2.8	3.9	4.1	3.2	2.7	3.7	3.2	4.5	3.4
1974	2.2	3.4		3.0	4.0	4.2	4.5	4.0	3.2	2.9			3.5
1975													
1976													
1977													
1978	4.5	3.0	3.5	3.5	4.5	4.0	3.5	4.0	3.5	3.0	3.0	4.5	3.7
1979	3.5	3.0	3.0	3.0	3.5	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.3
1980	2.5	1.5	2.5	1.5	1.5	2.5	2.5	1.5	1.5	2.5	3.0	2.0	2.1
Mean m/s	3.3	3.2	3.1	2.5	2.7	3.6	4.0	3.8	3.4	2.6	2.3	2.8	3.1
* m.p.h.	7.3	7.1	6.9	5.5	6.0	8.0	8.9	8.5	7.6	5.8	5.2	6.3	7.0
* km/hr	11.7	11.4	11.1	8.9	9.6	12.8	14.3	13.7	12.2	9.3	8.3	10.1	11.2

* 1 meter/second = 2.24 miles per hour = 3.6 kilometers/hour

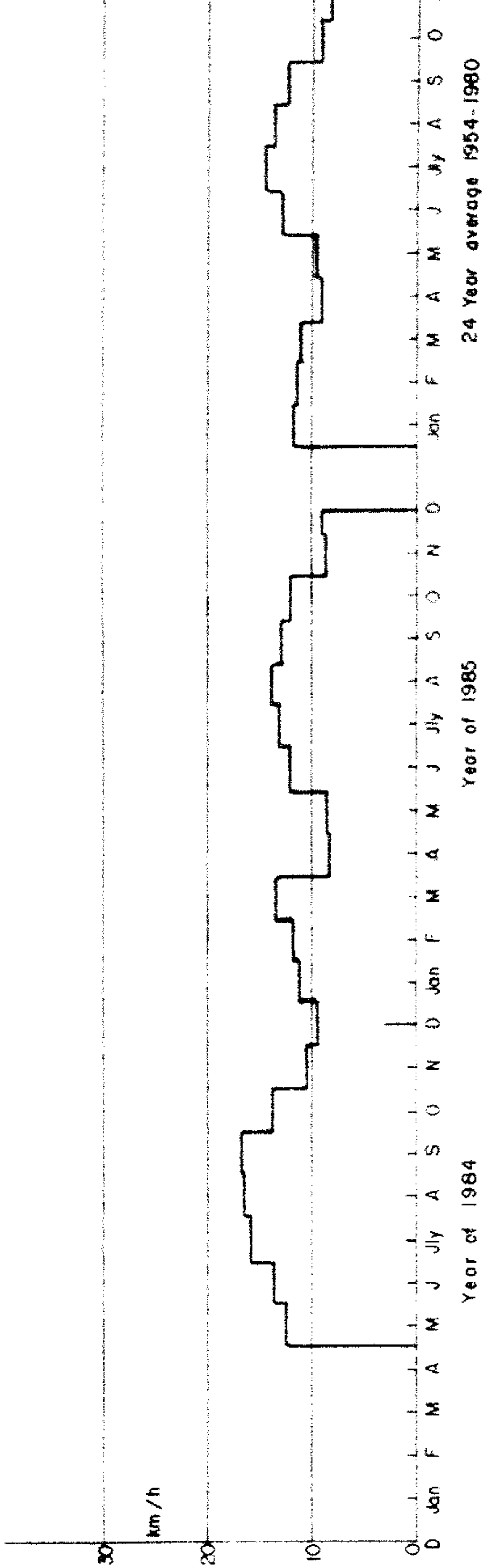


FIGURE 3.2.12 AVERAGE WIND SPEED OF BONKAY RESEARCH FARM AND 24 YEAR AVERAGE FOR BAIDOA

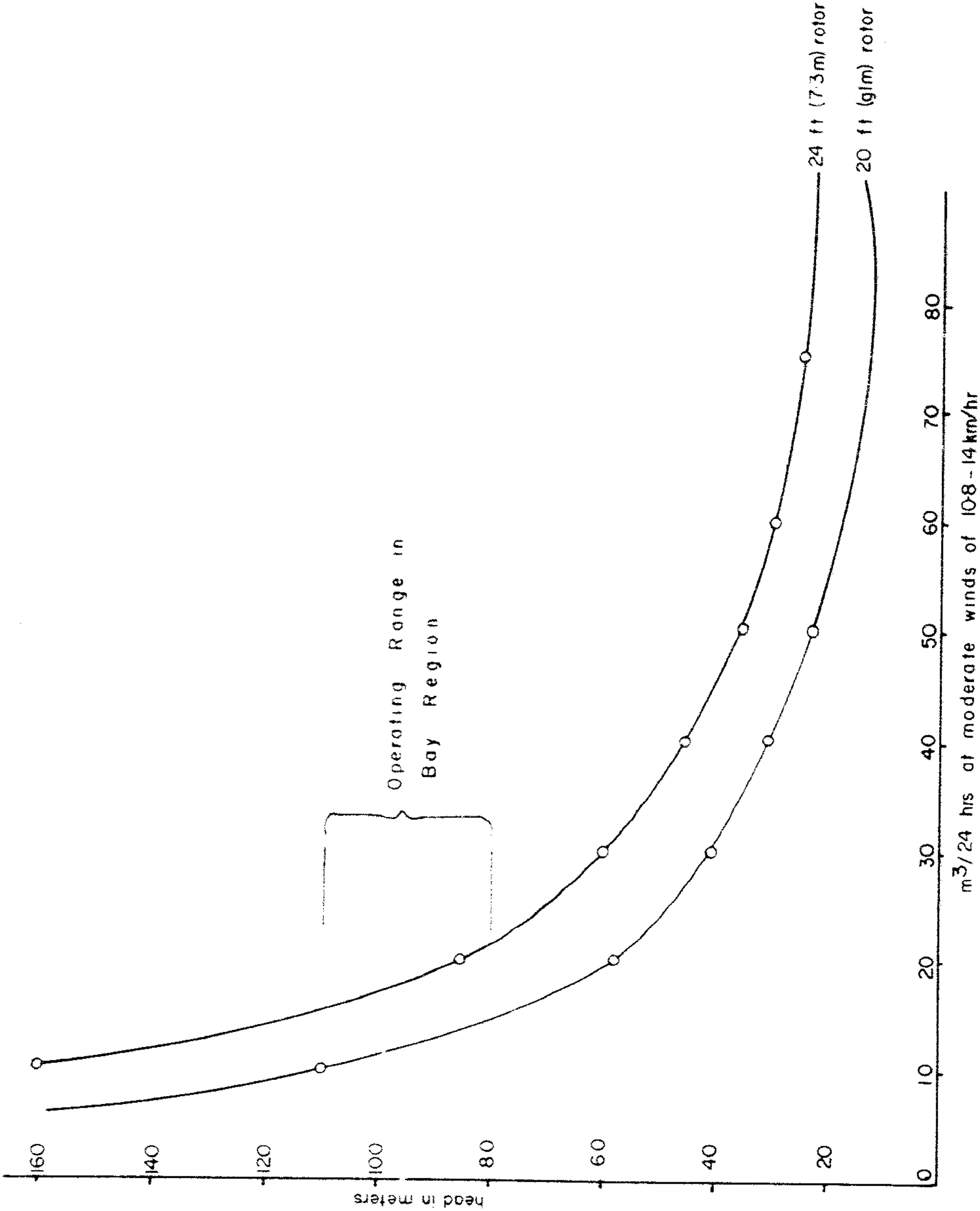


FIGURE 3.2.13 KIJITO PUMP PERFORMANCE GRAPH

is shown in Plate 16, based on drilling results and geology. There are large areas in the southern two-thirds of the Bay Region that will by necessity have to be satisfied by other means.

In addition, much was learned about the drilling techniques used. Recommendations for future water development are made regarding drilling methods, other structures such as galleries, catchments, and wars and in terms of monitoring programs and reports.

2.8.1 Drilling Methods

The drilling technique utilized almost exclusively in the Bay Region involved a rotary rig drilling with an air-hammer bit. While this method can continue to be utilized, some modifications to improve its efficiency should be made. One of the major problems was the loss of circulation that resulted in the inability to return drill cuttings to the surface. Utilization of commercially manufactured drilling foam helped to a large degree, however, the karstic nature of the main aquifer made this solution inadequate. One of the factors contributing to the problem was the necessity of having to drill 10 1/2-inch diameter holes to set 8-inch diameter casing. The drilling rigs used are not equipped with adequate compressor volumes to efficiently remove cuttings from this large-diameter borehole.

Two solutions are available; provide an additional compressor to operate in tandem with the rig compressor, and/or drill smaller diameter holes. An attempt was made during the project to change from wells completed with 8-inch casing, to wells completed with 6-inch casing. This recommendation was negated by the WDA administrators for fear that future pump installations would be a problem. Apparently the WDA experienced such difficulties in the past. Based on the potential yields of wells in the Bay Region and the types of pumps utilized during this investigation, 6-inch diameter holes would be more than adequate.

Another solution to the loss circulation problem would be to use cable-tool rigs instead of rotary rigs. One cable-tool rig was utilized in the Bay Region for a short period, however, not satisfactorily. The only problem with the operation of the cable-tool rig was the time required to drill a well. This problem would have been easily solved by changing the driller. The driller assigned to this rig was an older, experienced operator who was unwilling to change drilling habits. When under constant supervision by the consultant's drillers, wells could be completed in the same time frame as a rotary-drilled well. Cable-tool rigs require less water, less fuel, no additives, and generally require less maintenance than a rotary rig.

The main limitations to the cable-tool rig, at least for the rig made available to the project, were the depth it could drill and the requirement of a separate vehicle to move it from site to site. For most well completions in the Bay Region the depth limitation will not be critical. Increased mobility could be obtained by mounting the rig on a four-wheel drive truck; it is currently trailer mounted.

2.8.2 Infiltration Galleries

As previously mentioned, many areas of the Bay Region are not suitable for the construction of conventional water wells. Large parts of the Bur area, for example, provide little opportunity for drilled wells. Horizontal wells or infiltration galleries may, however, be feasible. Infiltration galleries are subsurface drains that intercept underflow in permeable materials. They are used most effectively to collect underflow in the alluvium of ephemeral wadis (Figure 3.2.14).

Infiltration galleries are most commonly constructed with the use of perforated ceramic or concrete drain pipe, but perforated PVC pipe or other perforated pipe may be used. Perforated PVC pipe is recommended for the Bay Region because of cost, ease of handling and local availability. Although 45 cm diameter pipe is generally recommended to reduce entrance velocities, smaller diameters can be used. The length of the pipe must depend on the depth of the alluvium that is to be trenched, and the width of the wadi that is to be intercepted. The pipe is usually buried in a trench well below the level of underflow. The pipe should be be backfilled with sized gravel or coarse sand if the material in the wadi is too fine or ill sorted.

Because deep scouring usually occurs during heavy rainfall events, a gallery not adequately buried or protected may be displaced or destroyed. A gabion constructed across a wadi a few meters downstream from the installation will restrict the depth of flood scour and protect a gallery system. A gabion will also cause alluvium to accumulate to the top of the structure, and result in retention of underflow, making more water available to the gallery.

Wadis heading at the escarpment and coursing southeast across the Bur area can be identified on aerial photos. Based on size and location, a select number of these should be investigated during the dry season for depth and character of alluvial material. Infiltration galleries could then be

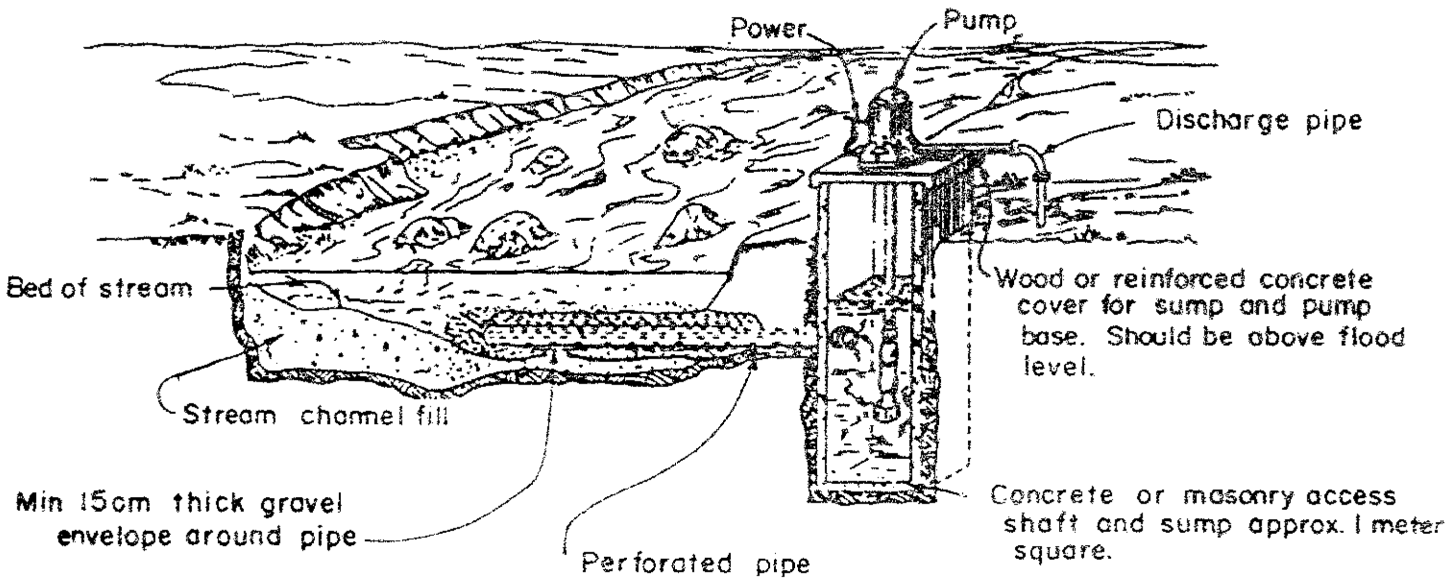


Figure 3.2.14 SCHEMATIC SECTION OF AN INFILTRATION GALLERY CONSTRUCTED TO INTERCEPT INFILTRATION FROM A STREAM OR WADI (U.S. Dept. 1981).

designed to fit the respective conditions. This recommendation holds even if wadis inspected are found to be dry over the entire depth investigated. The use of subsurface dams or gabions at the surface could make these useful watering points.

2.8.3 Surface Catchments

Surface catchments are small natural or man-made drainage basins modified for the collection of surface runoff and rainfall. Water captured is channeled for storage in berkeds, wars, or other reservoirs. Surface catchments are commonly developed where no other source of water is available.

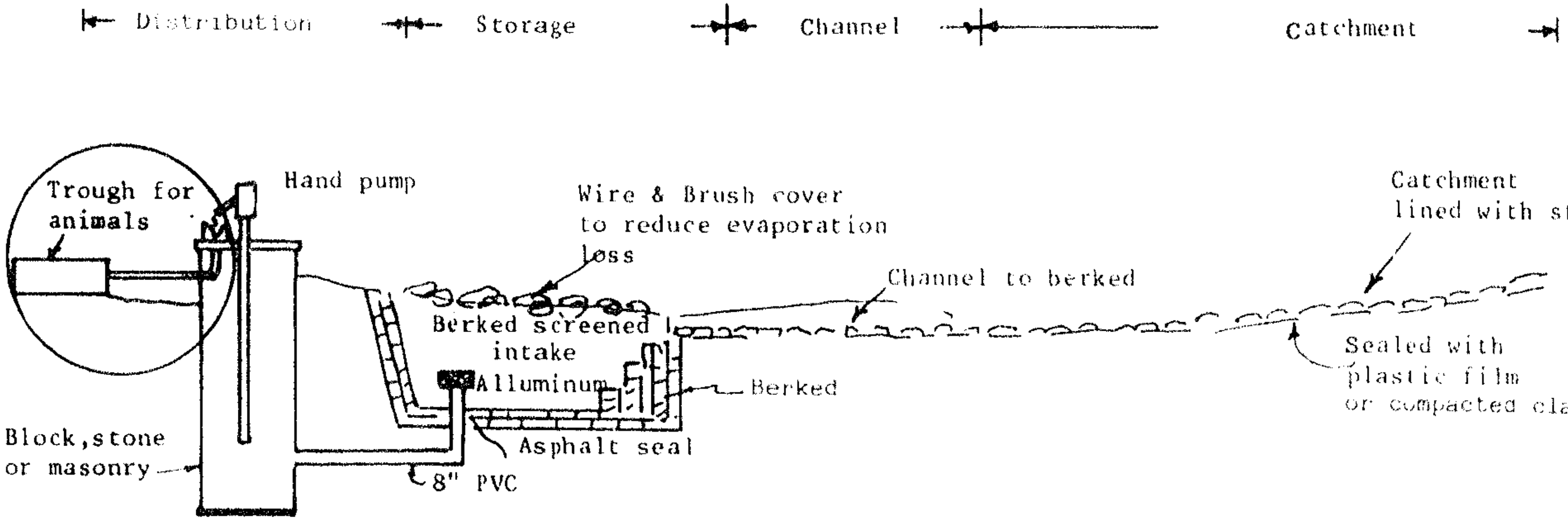
Generally, a minimum of development work is done to effect a catchment. This results in relatively large losses of rainfall to infiltration in sandy areas, and rapid accumulation of sediment in storage. By use of a small amount of labor-intensive development, surface catchments can be made to deliver more runoff with less sediment. A catchment paved with laid or rolled stone, concrete clay or plastic sheets, can be used to increase runoff and reduce sediment loads (Figure 3.2.15).

A catchment in roughly circular shape, of about 320 m diameter, capturing 5 mm of runoff will fill a berked of 20 x 20 m to 1 m; this is 400 m^3 of available water.

With some basic data on precipitation and runoff, catchments could be properly planned and designed. Existing catchments should be provided with a standard rain gage and some means of measuring the volume of runoff from each storm; a staff gage in the storage reservoir would be adequate. Records of rainfall and runoff kept on a regular basis by the catchment and reservoir supervisor would allow for improved surface catchments. Any catchment, improved or unimproved, must be fenced with thorn brush to prevent access and possible pollution by animals or people.

2.8.4 War Modification

Wars are storage reservoirs constructed by creating raised embankments or dikes of compacted earth. Wars are located such that all available runoff is collected from surface catchments or wadi diversions. The main problems with most wars, aside from erosion and siltation of entrance channels, are loss of water by evaporation and seepage, and destruction and contamination by people and animals.



NOTE:

- For catchments on sandy material with high infiltration losses pave catchments with plastic liner covered by stone or gravel.
- Size of catchment to be based on precipitation data vs. size of berked vs. anticipated use.
- Fence catchment area with thornbush.

Figure 3.2.15 CATCHMENT - BERKED MODIFICATION.

Evaporation losses are reduced somewhat by the raised embankment and by windbreaks of trees or brush. Seepage losses have been reduced by lining the war with packed clay or packed clay over a plastic liner. The plastic liner must be buried deeply enough so that it cannot be removed for other uses.

Destruction and contamination are concurrent problems caused by the movement of people and animals in and out of the wars. One solution to this combined problem is to modify the war such that water can be obtained outside the war. Figure 3.2.16 shows a recommended modification to existing or proposed wars that would help solve the problem.

2.8.5 Groundwater Monitoring Program

An observation-well network for the main aquifer of the Iscia Baidoa Suite was designed and implemented in February, 1985 for the collection of basic data. Measurements were to be made and water samples taken for chemical analysis from bored wells to determine what seasonal changes took place before and after the Gu' and Dayr seasons. Counterpart hydrogeologists were trained and have demonstrated their capability to measure and record the data. Observation well locations were selected in the aquifer area on the basis of accessibility and probable sensitivity to hydrologic and chemical change.

In order to determine hydrologic trends of any significance, at least 5 years of records are needed. Table 3.2.3 lists the wells and water-level data collected to date. Locations of the wells are shown in Plate 2. The period of measurements during this extension phase of the CGDP was too short to indicate any significant hydrologic changes. Measurements of water levels at the end of the dry season, and again at the end of the rainfall season will indicate the amount of recharge that has occurred for that season. Correlation of recharge between observation wells will allow a better estimate of seasonal and annual recharge to the aquifer. Estimates based on records for longer periods, more than 5 years, will more accurately indicate the availability of groundwater during seasons of rainfall and during dry periods. These data are essential for the effective planning and development of water resources.

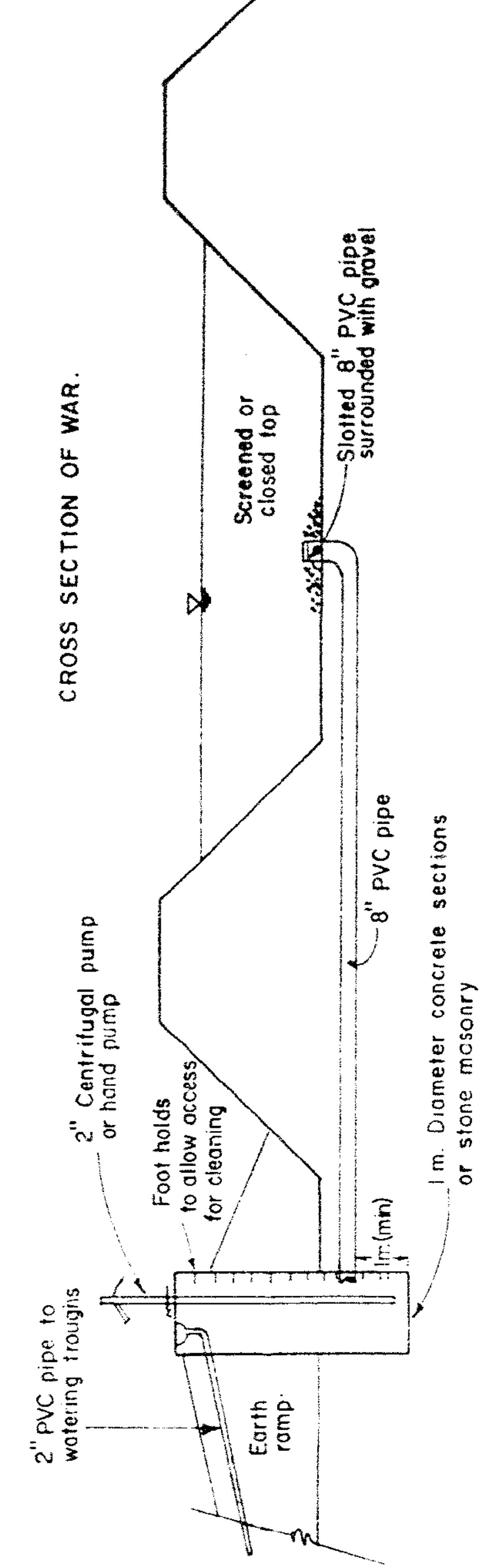


Figure 3.2.16 MODIFICATION TO WARS.

2.8.6 Publication of Basic Data

The hydrogeologic work begun during this project for the Bay Region and the three regions in the Central Rangelands should be continued for all of Somalia. Numerous donors are conducting various water projects throughout the country, however, most of the results of this work become buried in the files of that donor agency. The MMWR and perhaps more specifically the WDA, should plan a series of water-resource studies by region for the country. This work should begin in the most water short regions and continue until the entire country has been surveyed. Reports entitled, "Water Resources of _________ Region", should be completed and made available to those ministries, municipalities, and those in the private sector, involved in water-resource development.

The outline used for the hydrogeology section of this report could be used as a guide. In those areas where surface water can play a significant role, a section would be included to show drainage basin boundaries, gaging stations, current diversions and related parameters.

3.0 CENTRAL RANGELANDS

The Central Rangelands consists of the Mudugh, Galgadud, and Hiran Regions in central Somalia and covers an area of approximately 150,000 square kilometers (Figure 3.3.1). With the exception of a small area in the floodplain of the Shabelle River, the Central Rangelands is entirely arid to semi-arid. In many areas of the Central Rangelands the lack of an adequate water supply has been a serious constraint to bringing potentially productive rangelands into use for Somalia's livestock resources. Figure 3.3.2 shows accessibility to water sources and thus regions of water scarcity within the Central Rangelands.

According to the best available estimates there were approximately 35 boreholes operating in the Central Rangelands prior to 1979 (Resource Management and Research, 1979). The exact number and location of all boreholes operating in the Central Rangelands is unknown. Since 1979 additional boreholes have been drilled by this project, by the Water Development Agency, and by other development projects. Nonetheless, most watering points in the Central Rangelands consist of hand-dug wells constructed in shallow unconfined aquifers where the water table is subjected to significant seasonal variations and has a high potential for contamination. The majority of the hand-dug wells in the Central Rangelands are less than five meters in total depth and are constructed to a depth averaging 0.5 meters below the static water level (UNDP, 1973). It is clear that even in areas where adequate water is available the supply is highly vulnerable to drought.

The Comprehensive Groundwater Development Project has been working in close association with the Central Rangelands Development Project to improve the water supply for the pastoral population of the Central Rangelands. Development of groundwater resources is, and will continue to be an important aspect of the overall development of the Central Rangelands. Locations of all boreholes completed in the Central Rangelands during the Comprehensive Groundwater Development Project are presented on Plate 2.

3.0.1 Physiography

The Central Rangelands consists of a broad central plateau, a narrow coastal plain, and a portion of the drainage area of the Shabelle River. With the exception of the Shabelle River, which occurs in the extreme south of the Central Rangelands, there are no perennial streams or important watercourses in the area.

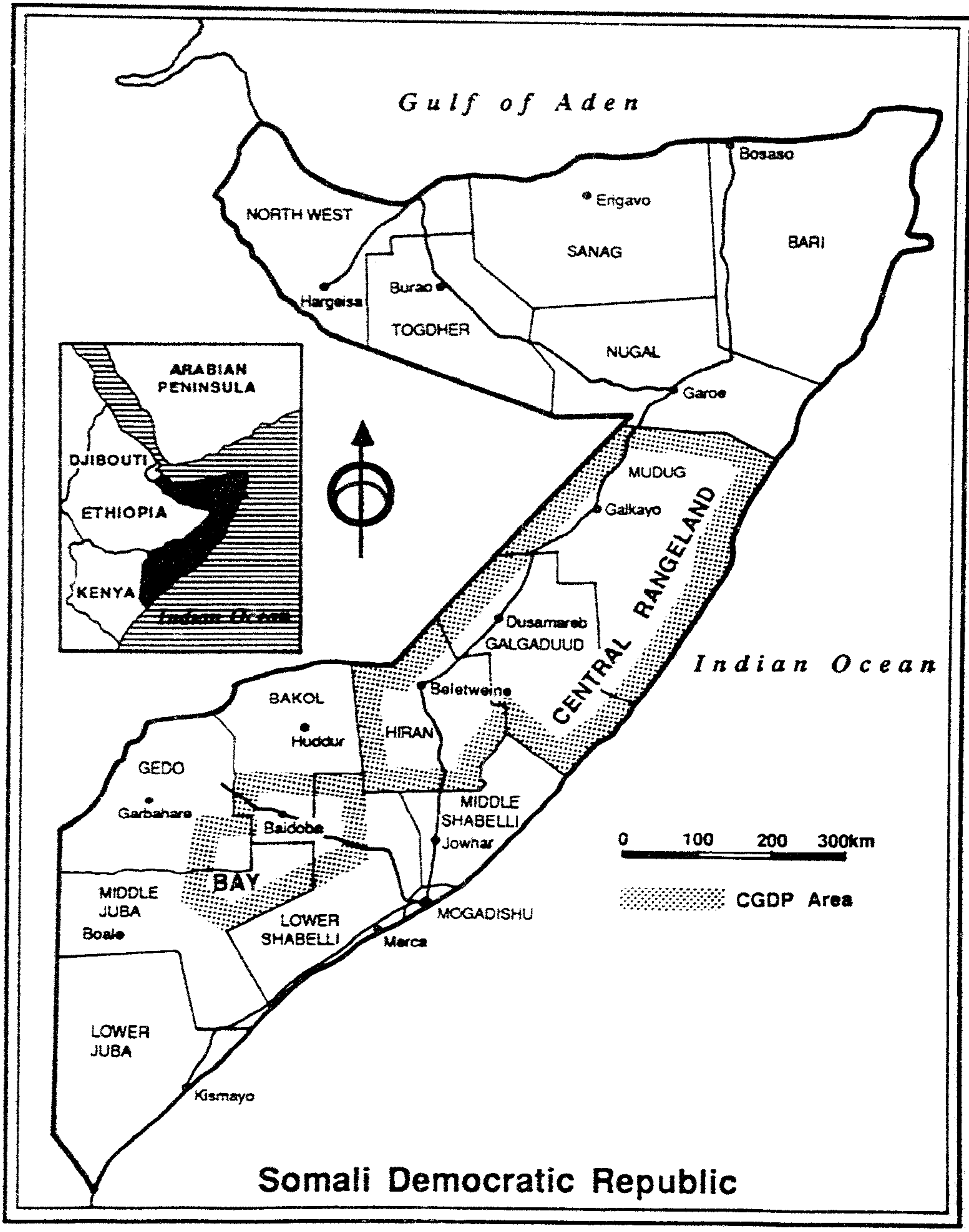


Figure 3.3.1 PROJECT LOCATION MAP

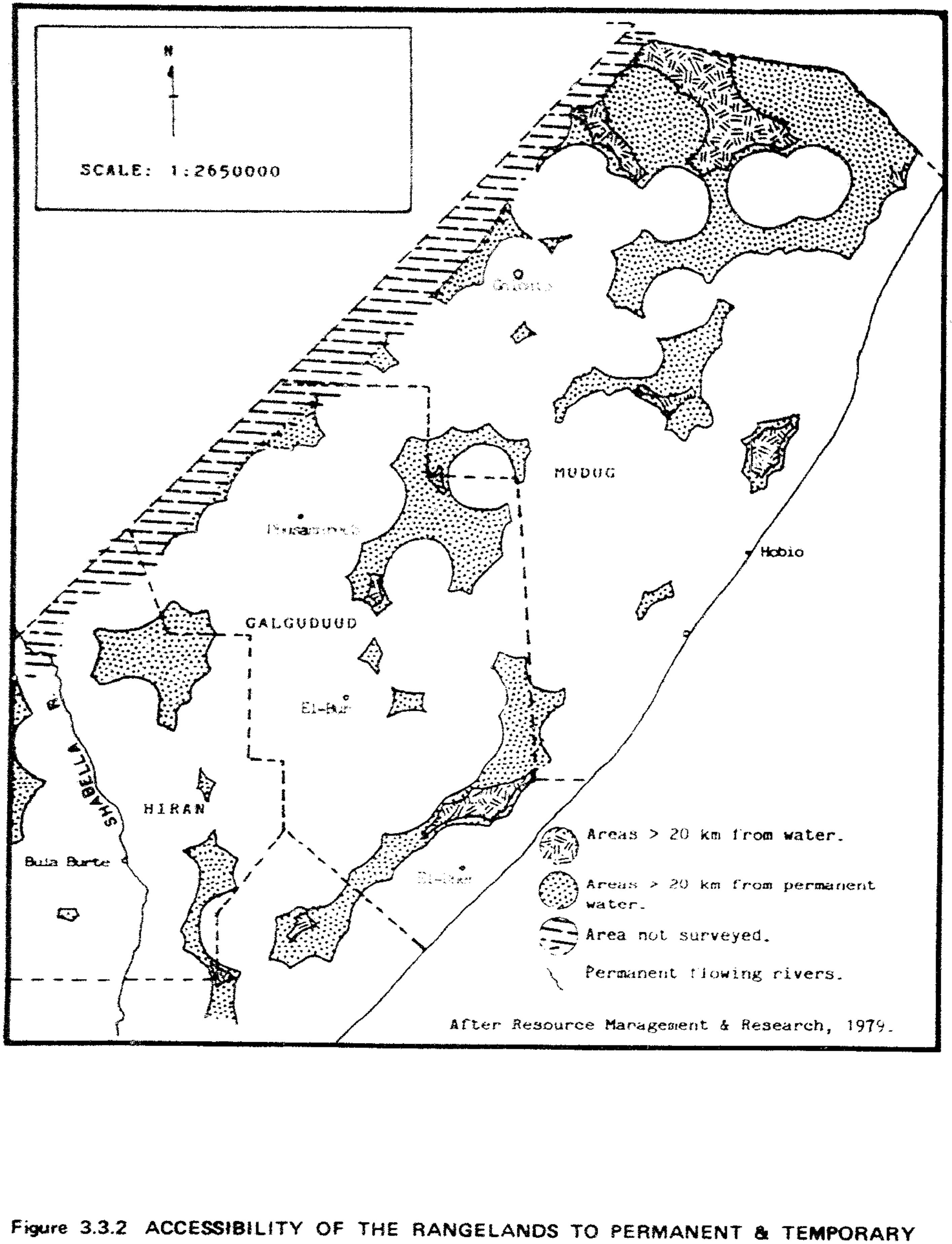


Figure 3.3.2 ACCESSIBILITY OF THE RANGELANDS TO PERMANENT & TEMPORARY WATER SOURCES.

The central plateau ranges in elevation from 50 to 700 meters above mean sea level and is covered by sand, caliche and evaporites. It is characterized by gentle slopes with micro-relief associated with caliche bands and sand drifting.

Between the central plateau and the coastal plain is an area of hummocks and stabilized dune fields grading into a transition zone of small gulleys and steep escarpments.

The coastal plain ranges in elevation from sea level to 50 meters and is covered by recent aeolian deposits with active barchan and seif sand dunes. Adjacent to the coast it is characterized by gentle slopes and low limestone cliffs.

The Shabelle floodplain, in the southern portion of the Central Rangelands, ranges in elevation from 100 to 200 meters above mean sea level. The Shabelle floodplain is covered by recent alluvial sediments with essentially flat terrain.

3.0.2 Climate

The Central Rangelands has an arid to semi-arid climate with a range in mean annual precipitation from approximately 100 mm in the north to 300 mm in the south (Resource Management and Research, 1979). The extremely irregular rainfall patterns in the Central Rangelands are typical of arid regions . Tremendous variations in precipitation occur both spatially and temporally. A map of mean-annual precipitation for the Central Rangelands is presented in Figure 3.3.3.

Precipitation is generally concentrated into a minor rainy season, the Dayrr which occurs from October to December, and the main rainy season, the Gu, which lasts from April to June. Storms tend to be concentrated in small geographic areas and it is not uncommon for an area to receive no rain during one or more rainy seasons. The rainy seasons are separated by the dry monsoons. The southern monsoon, the Hagai, occurs from July through August and is generally dry except for slight rains on the southern coast. The northern monsoon, the ilaal, occurs from December through February.

The temperature throughout the Central Rangelands varies from 20°C to 35°C throughout the year. Maximum temperature occur in April 40°C and minimum temperature in July 15°C as measured at Belet Weyne.

The potential evapotranspiration in the Central Rangelands has been estimated at 2225 mm/year (McGowan, et al, 1979). This relatively high potential evapotranspiration rate is the result of the high winds, high temperatures, dense thornbush cover, and of the phreatophytes which occur in the wadis. A potential

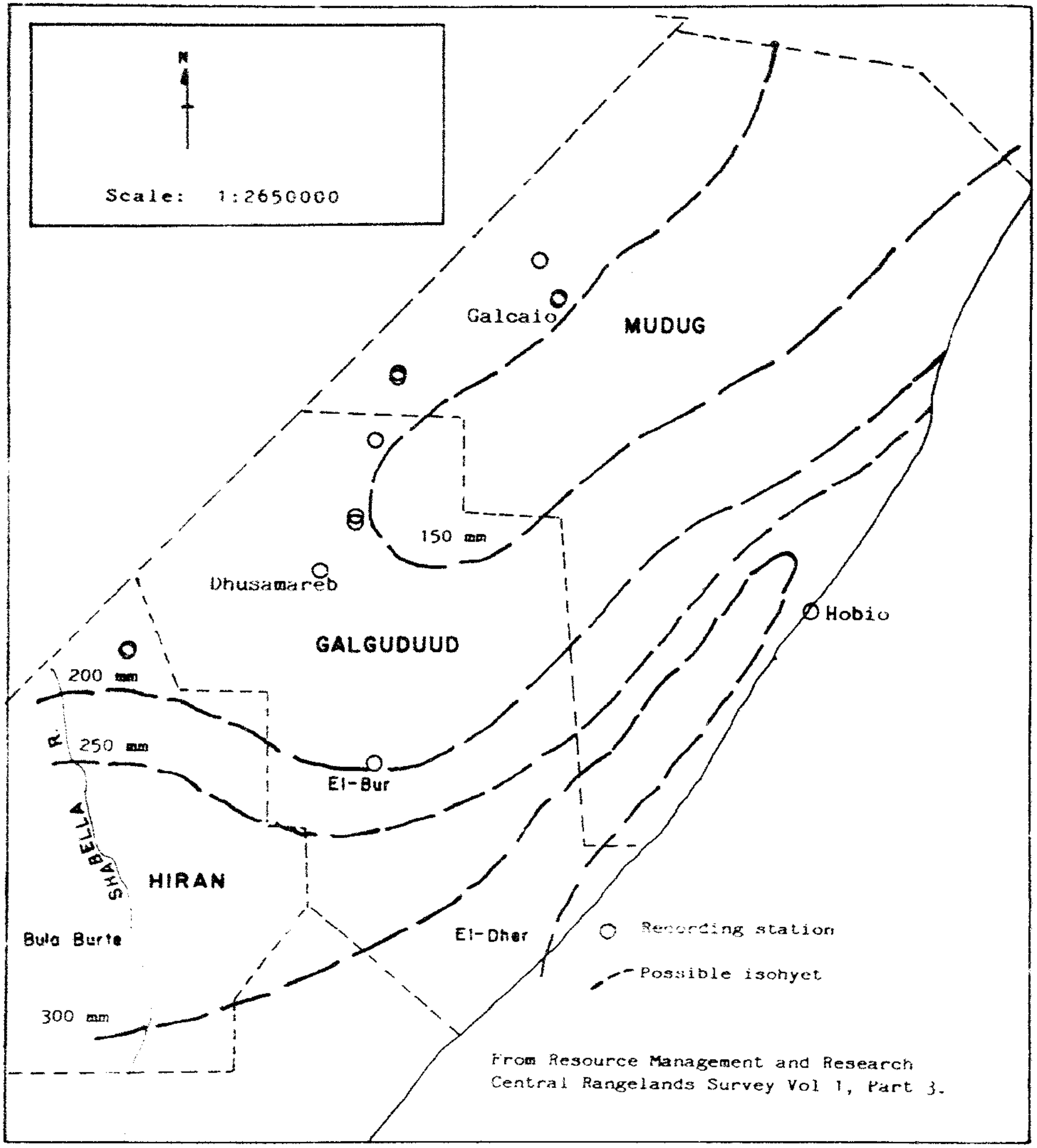


Figure 3.3.3 DISTRIBUTION OF RAINFALL IN THE CENTRAL RANGELANDS.

annual water deficit of over 2000 mm/year exists throughout the Central Rangelands.

Winds are generally constant on the coastal plains, decreasing somewhat inland. Although wind speed information is scant and of questionable quality the average coastal winds are estimated at over 10 m/s. Inland wind velocities are estimated

to range from 7 to 10 m/s in the Mudugh and Galgaduud regions (Pallabazzer, 1983). Winds are generally lower during the rainy seasons and higher during the dry monsoon seasons.

3.0.3 Land Use

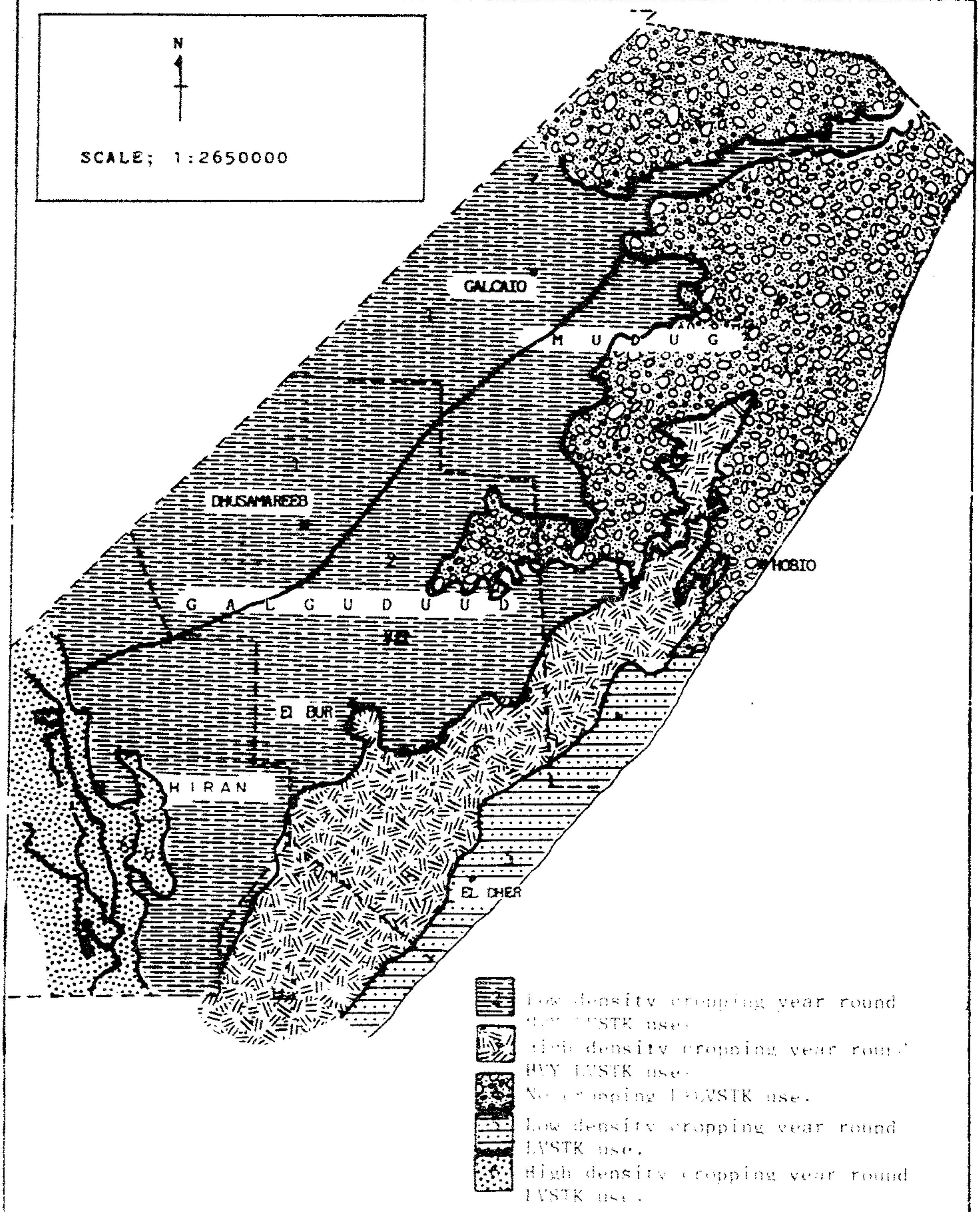
Land use in the Central Rangelands generally consists of opportunistic cropping by settled people in the towns and villages, and of year-round heavy grazing by livestock, (RMR, 1979).

The western portion of the CR is characterized by low densities of opportunistic cropping and by heavy livestock use (Figure 3.3.4). The central plateau is characterized by low density opportunistic cropping by nomadic families and by year round livestock grazing that is concentrated in the wet seasons. The transition zone between the central plateau and the coastal plain in the northern portion of the CR is characterized by high densities of opportunistic cropping by nomadic and settled families, and by year round livestock use that is concentrated during the wet seasons. The northern portion of this zone receives no cropping and light livestock use; chiefly in the wet season. The southern coastal plain is generally used by livestock year round and is only occasionally used for opportunistic cropping. The Shabelle floodplain is characterized by high density regular cropping, and by year round livestock utilization that is concentrated in the dry season.

3.1 Previous Investigations

Several investigations of the water resources in the Central Rangelands have been conducted, however, only those investigations found useful to this study are summarized below.

UNDP, 1973. This report offers a comprehensive review of the groundwater resources throughout Somalia. The conclusions reached are generally reliable and do not substantially differ from the conclusions of this report. The inventory of boreholes, hand dug wells, and springs, though out of date, is relatively accurate and was extremely useful. A list of well



Modified from Resource Management and Research, 1979.

Figure 3.3.4 LAND USE SYSTEMS IN THE CENTRAL RANGELANDS.

lithologies and chemical analyses is included and was found to be helpful. A serious drawback to the chemical data presented in the report is that sodium and chloride were apparently derived by ion differences rather than by analyses. Therefore, any evaluation of the accuracy of the data was impossible. Many of the sampled wells were resampled during the CGDP, and the correlation between results was found to be very poor. This may be due, in part, to the difficulties in positive well identification, but it does suggest some doubt concerning the quality of these data. For reconnaissance level investigations, however, these data are useful.

The geologic data presented in this report are extremely general. Although the stratigraphy appears essentially correct, the 1:1,000,000 geological map is not of sufficient quality to be useful in field work.

Resource Management and Research, 1979. This report is comprehensive and is useful in any work undertaken in the Central Rangelands. Data concerning the climate, land use, geomorphology, and water sources throughout the Central Rangelands are presented.

German Agency for Technical Development, 1981. This is a comprehensive hydrological report covering the well installation at the town of Dhusa Mareeb. Complete data are reported covering the hydrology, lithology, production tests, and water quality of the wells.

GKW, 1983. These reports detail the well installations at Bulo Berti, Ceel Bur, and Beled Weyn. They contain data on well installations, lithology, production tests, and water quality. The report on Beled Weyne, Vol. 7, also contains an analysis of the hydrologic connection between the Shabelle River and the alluvial aquifer.

Pozzi, et al, 1983. Pozzi's report contains valuable information on the stratigraphy and water quality of the central portion of the Central Rangelands. The presentation, organization, and English translation, however, are confusing. Place names are difficult to locate due to unusual spellings. The 1:1,000,000 geologic map presented in this report is particularly useful and is the most detailed geologic map available for the Central Rangelands.

Pozzi, et al, 1984. This report contains valuable information on the water resources and stratigraphy of the northern portion of the Central Rangelands. Potassium-argon age determinations from the Trap Series basalts are particularly useful for interpreting the Central Rangelands stratigraphy.

The specific conductance map of the shallow groundwater should be useful in future planning of shallow wells. The organization and English translation are, however, confusing.

Louis Berger International, Inc., 1981-1986. The Comprehensive Groundwater Development Project has been operating since July, 1981. Several reports including a final report on the first phase of the project have been completed. Because the main thrust of the CGDP for the first three years of the project was in the Bay Region, little data relevant to the Central Rangelands were generated. All relevant data, conclusions, and recommendations from these previous reports have been summarized in this report.

3.2 Methods of Investigation

Previous groundwater development in the Central Rangelands has consisted of "... an inefficient program of poking holes throughout Somalia in the hope of finding sufficient potable water to sustain the population." (AID, Project Paper, 1979). The CGDP has attempted to inject some degree of rationale in planning for water resources development and to establish a reliable data base.

Because of the limited amount of borehole data in the Central Rangelands, the efforts of the CGDP were mostly exploratory. Methods of investigation consisted of well-site selection, drilling, geophysical logging, development and testing, and water-quality sampling and analysis.

3.2.1 Well Site Selection

Borehole sites were selected by the CRDP personnel based on extensive sociological surveys, water requirements, and on a careful consideration of the ecological implications of the site. The proposed sites were then investigated by the CGDP for hydrogeologic suitability and, in some cases, were "vetoed" or relocated as appropriate.

Water is an intensely political issue in arid Somalia. This issue has caused occasional disagreements and frequent delays over proposed borehole locations. Because a great deal of random drilling has been done throughout Somalia, the areas which experience the most intense water shortages are frequently areas in which previous drilling has indicated that there are no useable aquifers at exploitable depths. Boreholes were attempted at Cagacade, Xasan Afra, and Quralai due to intense local pressure, but against hydrogeological recommendations. All of these wells were unsuccessful. The success ratio of wells completed by this project was lowered by the political necessity of drilling wells at hydrogeologically doubtful locations.

Record keeping during most previous drilling in the Central Rangelands was so poor that most drilling in the area should be considered exploratory. In this sense, even the unsuccessful boreholes are valuable for the understanding of Somalia's groundwater resources.

As has been noted by all previous investigations, the primary problem with developing the groundwater resources of Somalia, and the Central Rangelands in particular, is one of water quality rather than quantity. Borehole locations have been considered largely on this criterion. While the tolerance of the local population to saline water is remarkably high, much of the water encountered in the Central Rangelands is still unusable for domestic purposes.

The regional geology, geomorphology, and previous drilling experience have all been examined when locating boreholes. One great and recurring difficulty has been the lack of reliable information concerning previous drilling. Many wells which produced unusable water were backfilled with rocks by the local population without chemical analyses having been performed, lithologic logs taken or static water levels recorded. These wells were essentially forgotten. A typical experience in investigating proposed borehole sites was to find a previously attempted, and subsequently, abandoned borehole on the site. A variety of conflicting rumors were heard concerning the depth, water level, and water quality of the well. Proposed sites at War Shupo, Haji Imam, Dhalwa, Xindheere, and Godin Midgod were rejected because borehole attempts at these sites would have merely duplicated previous unsuccessful attempts.

In all cases, physical well site inspections were performed by the CGDP hydrogeologist in the accompaniment of representatives from the CRDP. Following the site inspection all available information on the hydrology, geology, and previous drilling in the area were reviewed. A decision to drill or not drill was then made.

3.2.2 Drilling

The majority of the wells drilled in the Central Rangelands have been drilled with an Ingersol Rand TH-60 drilling rig utilizing mud-rotary techniques. Surface casing, generally 16-inch diameter, was cemented to a minimum depth of 3 meters. In areas where a relatively good chance of success was anticipated, 12-inch diameter boreholes were drilled followed by completion with 8-inch diameter casing. Washed samples of the borehole cuttings were collected and examined at each lithologic change or at a maximum of 3 meter intervals. In exploratory boreholes a 6 or 7 7/8-inch diameter pilot hole was drilled, and then reamed to a 12-inch diameter hole if usable water was encountered. In some instances, the long time required to provide the desired casing neccessitated the utilization of casing at hand. On occasion, 6-inch diameter slotted casing was used for well completion. For the same reasons, slotted 8-inch diameter casing was set above the static water level in instances when blank casing was not readily available.

In boreholes where saline water was encountered at relatively shallow depths, 8, 10, or 12-inch diameter casing was used to seal off the bad water, and the borehole was advanced with a 7 7/8-inch bit to the target depth. Boreholes were abandoned by removing all casing, when possible, and backfilling the borehole with grout. Where it was not possible to remove the casing, a steel cap was welded onto the well casing.

In addition to the rotary-drilling rig, one British made Dando cable-tool rig was used in the Central Rangelands. This rig completed two boreholes in the Ceel Bur District one in Xaradheere and two in Hobbio. Boreholes drilled with the cable-tool rig were drilled to a diameter of approximately 12 inches. Samples of the drill cuttings were collected and examined at 3-meter intervals or change of formation. After the hole was drilled, it was completed with 8-inch diameter plastic casing or 8-inch steel casing. The plastic casing was perforated with handsawn slots spaced at 4-inch intervals along a length corresponding to the aquifer thickness.

Drilling in the Central Rangelands most frequently encountered unconsolidated sands, sandstones, and limestone. A recurring drilling problem was the collapse of boreholes when drilling was interrupted for unreasonably long periods; generally due to lack of fuel or serious mechanical problems. Lost circulation in porous limestone was another problem. It was not usually possible to regain circulation with conventional lost-circulation materials. In several instances, the utilization of a "diesel squeeze" (a mixture of diesel fuel and bentonite) was required to regain circulation and enable drilling to continue.

Another frequently encountered problem was the difficulty of mixing bentonite drilling mud with high-saline makeup water. Mud additives made especially for utilization with saline makeup waters should be made available for future drilling projects in the Central Rangelands.

3.2.3 Geophysical Logging

Whenever possible geophysical logs were run prior to setting casing in the hole. The project was equipped with three

Mineral Logging Systems geophysical logging units. Two of these were mounted in four-wheel drive suburban-type vehicles. Logging tools provided are 1 3/8-inch diameter except for a long-normal resistivity and gamma probe which is 2 inches in diameter. Other tools included a caliper probe, gamma/resistivity probe, a flow meter, and a temperature probe. An operators manual was prepared by consultant's staff to assist counterparts in operating the equipment. This manual was in addition to that provided by the manufacturer.

The geophysical logs were used to determine lithologies, and water-bearing zones. The boreholes in the Central Rangelands were not spaced sufficiently close to provide an opportunity for stratigraphic correlation on the basis of geophysics.

Resistivity and spontaneous-potential logs were the most useful in identifying potential aquifer zones. The natural gamma-ray logs were most useful in determining the clay horizons of the formations. In limestone formations the caliper log was the most useful in delineating zones of secondary permeability and fracturing. As more wells are drilled and logged in the Central Rangelands the usefulness of the geophysical logs for stratigraphic correlation will increase.

3.2.4 Development and Testing

When drilling with mud, it was frequently difficult to be sure when water was encountered, and even more difficult to evaluate the quality of the water. Whenever suspected zones of water production were found the boreholes were cleaned by thinning or removing the mud and blowing with air. The water was then tested for quantity and quality. Poor-quality water zones were sealed off with casing and drilling continued.

After casing was set, the wells were developed by blowing with air until the sand production, as measured with an Imhoff Cone, was less than 0.2 mg/l. When possible, a step-drawdown test was conducted to estimate the production capacity of the well. If determined to be significant, a 24-hour constant discharge-pumping test was conducted. In some instances, when the well discharge could be estimated from the well development activities, or when the fuel supply was critical, the step-drawdown test was neglected.

An aquifer test was attempted on every well, and whenever possible a 24-hour pumping test was conducted. Wells were pumped with a 19-stage submersible pump, and discharges were measured with a flowmeter or with a barrel and a stopwatch. All water-level data were measured with an electric well sounder. In low-discharge wells, a bailer test was conducted to estimate the well production. Water temperature and specific conductance were periodically measured throughout the test.

Predicted drawdowns and sustained yields were estimated using the Jacob and/or Theis approaches. Aquifer test analyses for each well are presented in Volume V. It should be noted that the perforated intervals do not necessarily correspond to aquifer thicknesses in wells completed in the Central Rangelands. Occasionally, material logistics, such as the lack of blank or perforated casing on site, rather than aquifer thicknesses determined well-completion details. Any rigorous hydrogeologic computations involving aquifer thickness should therefore be based on the lithologic logs, rather than on perforated intervals for estimates of aquifer thickness.

3.2.5 Water Quality Sampling and Analyses

Water quality samples were collected from each borehole completed in the Central Rangelands following well development activities. Additionally, samples were collected from many of the existing operating wells in the Central Rangelands. Water samples were generally delivered within five days of collection to the MMWR laboratory in Mogadishu. No field preservation of samples was practiced.

Chemical analyses of samples included all major ions. Analytical techniques developed during this project were used to analyze the samples. Results were evaluated on the basis of the ion balances. Ion balances that were within 10 percent, were regarded as acceptable. Any analyses considered to be questionable were rejected from the data base and repeated when possible. Results of the water-quality analyses performed for samples collected in the Central Rangelands are presented in Volume V.

3.3 Geology

The Central Rangelands consists of a sequence of marine and continental sediments with minor, but hydrologically important, intraformational basalt flows. The geology is poorly mapped and published interpretations of the stratigraphic sequence are not always in agreement.

The Central Rangelands extends northeast of the Shabelle River to the Nogal Valley in northeastern Somalia. Marine sediments of mostly Tertiary age, and sub-recent continental sediments cover the surface as part of a wide basin. The basin extends through the Ogaden region, east of Beled Weyne to Johar. The deepest part of the basin, the Hobyo Embayment, is located near Hobyo on the coast of the Indian Ocean (Barnes, 1976). There have been several transgressive and regressive phases of the sea over the Horn of Africa and sedimentation thicknesses generally decrease inland. Plate 17 presents the regional geology of the Central Rangelands.

3.3.1 Geomorphology

The geomorphic map of the Central Rangelands modified from Resource Management and Research (Central Rangelands Survey, 1973) is presented in Figure 3.3.5. Five basic geomorphic types were identified; the flood plain, the plateaus and basins, and areas of stable and unstable dunes. The shallow groundwater occurring in these geomorphological units bears the chemical signature of the associated lithotypes. A brief descriptio of the five geomorphic types are described below.

Flood Plains. The Webi Shabelle Valley floodplain region is dominated by recent alluvial sediments consisting of sand, silt, clay, and gravel. The Shabelle landforms have been created by normal valley cutting through the limestone plateau and by alternate cycles of deposition and erosion.

Plateau Areas. The major portion of the central plateau is composed of limestones which have experienced erosion by sheet flow and wind-driven abrasive sands. Weathering of the carbonate rocks generally produces a dense carbonate-caliche layer from a few centimeters to several meters thick. Oolitic and concretionary forms with iron-oxide coatings are common. Coverings of terra rosa sand are also common. The terra rosa is a friable bright-red ferruginous soil consisting of clay minerals, iron oxides and hydroxides, fine quartz grains, and small amounts of carbonate and hygroscopic moisture (Mikhailov, 1971). A thin veneer of sand covering limestone is common throughout the plateau region.

Basins. Large complexes of evaporite minerals, primarily gypsum and anhydrite, have filled two ancestoral drainage zones which have stagnated in the vicinity of the coastal fault. These areas cut the central plateau from northwest to southeast beginning from approximately Galcayo and Dhuusa Mareeb. These evaporite deposits have experienced karst weathering and are, in places, overlain by limestone and sand sheets. Drilling results from Dhuusa Mareeb, Ceel Bur, and Wargaloh suggest that these ancestoral drainages may have controlled the flow of basalts in the Central Rangelands.

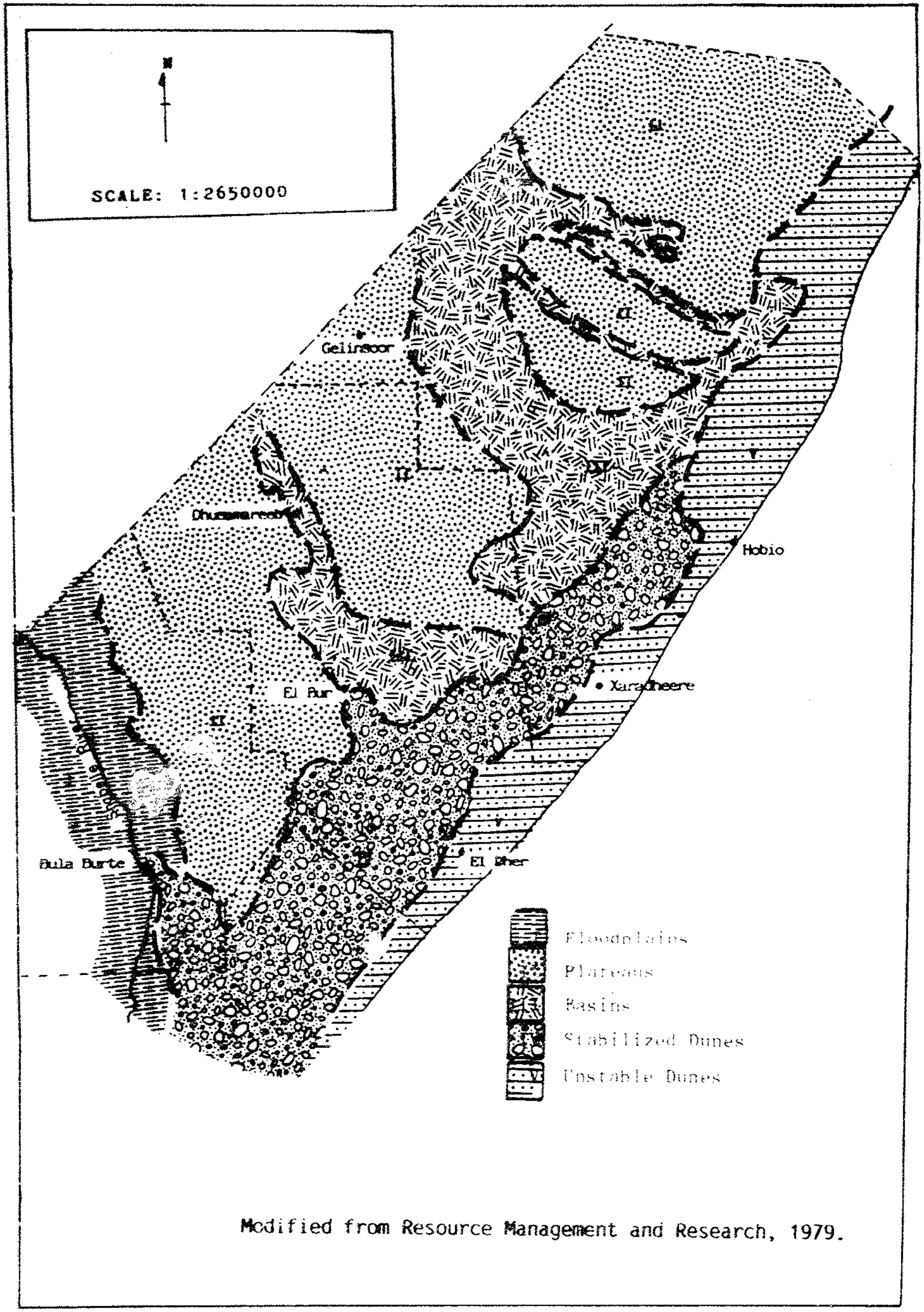


Figure 3.3.5 GEOMORPHOLOGICAL TYPES IN THE CENTRAL RANGELANDS.

Stabilized Sand Dunes. Large semi-stabilized sand dunes are found in the transition zone between the central plateau and the coastal plain. These dunes are generally composed of fine Pliocene sands from formerly mobile dunes which have been recently stabilized. The stabilized dunes formerly provided much of the source material for the sand sheets in the central plateau (Resource Management and Research, 1979).

Unstable Sand Dunes. In the southern portion of the coastal plain there are rows of large sand dunes, predominately barchan and seif dunes, and sandy grasslands. These dunes which are still mobile overlie coastal limestones east of the coastal fault.

3.3.2 Stratigraphy

The stratigraphic units and their water bearing properties are presented below in tabular form in Table 3.3.1. Opinions concerning the stratigraphic sequence in the Central Rangelands vary. In this report the sequence proposed by Pozzi, et al, (1983) is considered to be the most probable. Drilling during the course of this project further delineated the extent of the Trap Series basalts. No distinction was made in the more recent stratigraphic units, such as the Mudugh-Merca, the Upper Daban, and the Taleh Suites. Distinctions between these suites must be made from paleontological or other age-dating techniques which are beyond the scope of this project.

Belet Uen Suite (Upper Cretaceous). The Belet Uen Suite is the oldest formation considered in the groundwater exploration effort in the Central Rangelands. It outcrops in the southern portion of the Central Rangelands east of the Shabelle River and reaches a maximum thickness of 200 meters. The lower portion of the Belet Uen Suite is composed of interlayered limestone and gypsum beds, overlain by limestones with sandy and marly beds. The upper portion of the Belet Uen Suite is composed of alternating gypsiferous limestones, marls, sandstones, and gypsum beds. Due to the presence of high-solubility evaporites, the water contained in the Belet Uen Suite is generally highly mineralized.

Jessoma Suite (Paleocene). The Jessoma Suite outcrops in a north-south trend east of the Shabelle and south of Ceel Bur. The Jessoma Suite consists of varicolored, quartzitic, well-cemented, hard sandstone beds. Cross bedding of fluvial origin is common. Limestone layers may occur and the top weathered zone of uncemented sandstone contains subsurface calcareous concretions. The Jessoma Suite supplies relatively fresh water (EC = 3500 micromhos/cm) to wells and springs.

TABLE 3.3.1. CENTRAL RANGELANDS GEOLOGIC UNITS AND WATER BEARING CHARACTERISTICS

EPOCH	SUITE OR SERIES	APPROXIMATE MAXIMUM THICKNESS	OCCURENCE, LITHOLOGY, AND WATER BEARING CHARACTERISTICS
RECENT PLEISTOCEN	Stream Alluvium Qal	100 m	In the flood plain of the Shebelle River and along wadis throughout the Central Rangelands; clay, silt, sand, and coarse alluvium; yields water to shallow (less than 35 m) wells; water specific conductance of less than 3500 umhos/cm found in approximately 10 percent of wells.
	Aeolian sand, sandstone and reef deposits, Qeolts	120 m	Active and inactive dunes on the eastern coast consisting of well-sorted aeolion sand. Yields small amounts of fresh water to shallow (less than 10 m) wells.
PLIOCENE-MIOCENE	Upper Daban Series, $N_1 - N_2$ md	120 m	Possible in the eastern portions of Central Rangelands; sandstone, and ;conglomerate; yields water of variable quality from pore spaces and along bedding planes.
MIOCENE	Mudugh-Merca Suite, N_1 md	500 m	Continental sediments covering much of the northern Central Rangelands; limestone, marl, sand, sandstone, gypsum, clay calcrete, and related rocks. Yields varying quantities of water from pore spaces, bedding planes, and karst formations water quality is variable with specific conductance from 3,000 to 30,000 umhos/cm, sulfate conccentrations are generally high; water with specific conductance of less than 3,000 umhos/cm is found in less than 15 percent of wells.

MIOCENE PALEOCENE	Trap Series; B P_g-N_1	80 m	Forms intraformational flow extending from Dhusamareeb to El-Bur and north to Wargaloh. Basalt and tuff, may be related to the existence of fesh water found during this project.
OLIGOCENE	Middle Daban series Pg_3 mdu	800 - 2000 m	Sandstone, siltstone, lenses of boulder conglomerate; generally contains highly mineralized
EOCENE	Lower Daban series Pg_2ld	245 m	Sandstone, siltstone, marl, lenses of gypsum and conglomerate; generally contains highly mineralized water.
	Karkar Suite Pg_2Kr	230 m	Limestone, minor marl, clayey dolomite, siltstone; may contain small amounts of water but not an aquifer of regional importance.
	Taleh Suite Pg_2tl	350 m	Anhydrite, gypsum, interbedded dolomite and marl; generally contains highly mineralized water in karstified zones.
	Auradu series Pg_2ar	400 m	Outcrops in a band extending through the western part of Galgudud region; massive limestone, dolomitic limestone, dolomite, marl, siltstone; limestone beds are commonly fractured and offer good potential for groundwater storage and development; frequently yields large quantities of fresh water.

PALEOCENE	Jessoma Suite	200 m	In a north-south section east of the Shabelle River and west of El-Bur. Inequigranular crossbedded sandstone, minor siltone, and compacted clay; supplies water with specific conductance of less than 3500 umhos/cm to wells and springs but frequently yields only small amounts of water due to low effective porosity.
UPPER CRETACEOUS	Beled Weine Suite Cr_2bl	200 m	East of the Shabelle River, limestone, marl, gypsiferous shaley clay. Generally contains highly mineralized water at depth.
CRETACEOUS	Mustahil Suite Cr_1	180 m	West of Shabelle River, gypsiferous siltstone, mudstone, interbedded limestone; karst formations supply water which is generally highly mineralized, specific contuctance is rarely below 3500 umhos/cm.
CRETACEOUS	Marehan Suite Cr_{1-2}-mr	300 m	Occurs only at southwestern border of Central Rangeland. Generally supplies small amounts of fresh water to wells.

From: UNDP, 1971, Pozzi etal, 1983, Pozzi etal, 1984.

Transmissivities are, however, frequently low (UNDP, 1973). Outcrops examined during the course of this project appeared to possess low porosities and permeabilities. More test drilling is required to evaluate the potential of the Jessoma Suite as an important regional aquifer.

Auradu Suite (Eocene). The Auradu limestone was deposited conformably over the Jessoma Suite during marine transgression. Outcrops of the Auradu are found in a band extending through the western portion of the Galgadud region from Dhusa Mareeb to the coastal fault. The lower section consists of a dark-brown, fine, crystalline, coarsely banded limestone. The limestone in the upper portions contains a finer and clearer banding with lighter colors.

The outcrops of the Auradu limestone show some karstification and the beds are frequently fractured. The artesian wells in Ceel Bur and Dhusa Mareeb may be tapping a confined aquifer in the Auradu Suite. Generally, the water produced from the Auradu Suite is relatively fresh (EC = 3500 micromhos/cm).

Taleh Suite (Eocene). The evaporite sediments of the Taleh Suite were deposited during a regression of the sea from the Horn of Africa. The Taleh Suite consists of gypsum and anhydrite interbedded with dolomite and marl. The Taleh Suite reaches a maximum thickness in the Nogal Valley, north of the Central Rangelands of approximately 350 meters. The Taleh Suite was previously thought by some researchers (Altichieri et al,1981) to be pervasive in the Central Rangelands. Recent work by Pozzi et al, (1983) indicates that the Taleh Suite is missing entirely from several sections in the western portion of the Central Rangelands and that the surficial beds in the Central Rangelands are considerably younger than the Eocene.

The Taleh Suite often displays intense karstification in its outcrops. Groundwater is found in the fractures and solution cavities in the Taleh Suite, but it is generally highly mineralized and unusable.

Karkar Suite (Eocene). The Karkar Suite consists of limestone, marly limestone, and gypsum. The Karkar Suite reaches its maximum thickness, 230 meters, in the Nogal Valley, north of the Central Rangelands. The Karkar Suite is the uppermost marine deposit in the Central Rangelands but is not known to outcrop in the area. The Karkar Suite is not an important aquifer in the Central Rangelands. It contains small amounts of water that is generally highly mineralized.

Lower Daban Series (Eocene). The Lower Daban Series is characterized by sandstones, siltstone, marl, and lenses of gypsum and conglomerate. The lower Daban Series is not known to outcrop in the Central Rangelands, and is not an important regional aquifer. Water encountered in the Lower Daban Series is generally highly mineralized.

Middle Daban Series (Oligocene). The Middle Daban Series consists of sandstones, siltstone, and boulder conglomerates. The Middle Daban Series reaches its maximum thickness in the northern regions of Somalia and is not known to outcrop in the Central Rangelands. The middle Daban Series is not an important regional aquifer and generally contains highly mineralized water.

Trap Series (Paleocene-Miocene). The Trap Series consists of basalt and tuff which occurs as intraformational flows in the Central Rangelands. The Trap Series occurrences appear to be related to the ancestral drainages in the Central Rangelands. Boreholes have encountered basalt at Dhuusa Mareeb, Ceel Bur, Afwayne, Wargaloh, and Quracley. In most instances, boreholes penetrating basalt have encountered fresh water. It is unclear at present whether the fresh water is being transmitted within the basalt, or whether the basalt is simply separating the fresh water in the deposits below from the highly mineralized waters above.

The Trap Series, in any case, is highly important in the groundwater resources of the Central Rangelands. A high priority should be placed on refining the mapping of this suite in any future groundwater investigations in the Central Rangelands. Locations, depths, and estimated elevations of the basalt are shown in Plate 17.

Mudugh-Merca Suite (Miocene). The Mudugh-Merca Suite consists of a variety of continental sediments that cover the majority of the central and northern portions of the Central Rangelands. The Mudugh-Merca Suite consists of limestone, marl, sand, sandstone, gypsum, clay, calcrete, and related rocks. In the ancestoral drainages sediments of continental lacustrine conglomerates, fluvial sandstone, clay, and marl were deposited as the climate dried. These " Mudugh beds" are frequently karstified near the surface and may provide relatively highly mineralized but easily accessible water.

The Mudugh-Merca Series produces water of highly variable quality and quantity from pore spaces, fractures, bedding planes, and karst zones. Specific conductivities of water produced from the Mudugh-Merca Suite vary from 3000 to 30,000 micromhos/cm and are frequently high in sulfate. Measured transmissivities in the Mudugh-Merca Suite are highly variable and range from 10 to over 350 m^2/day. The Mudugh-Merca Suite is, by default, an important regional aquifer in the Central

Rangelands.

Upper Daban Series (Miocene-Pliocene). The Upper Daban Series occurs in the central and eastern portions of the Central Rangelands and consists of sandstones and conglomerates. The Upper Daban Series produces water of highly variable quality. The delineation between the Upper Daban and the Mudugh-Merca Suites is unclear at present. Depending on the interpretation of the extent of these formations, the Upper Daban may be considered an important aquifer in the Central Rangelands.

Aeolian Sand and Reef Deposits (Pleistocene-Recent). The active and inactive dunes along the eastern coast in the Central Rangelands consist of well sorted aeolian sand. The high infiltration rate of these sands allows for the accumulation of shallow deposits of fresh water at the base of these sand dunes. Shallow wells in the vicinity of the sand dunes frequently produce small amounts of fresh water.

Stream Alluvium (Recent-Quarternary). Stream alluvium occurs along the floodplain of the Shabelle River and along wadis throughout the Central Rangelands. The alluvium consists of fine gravel, sand, silt, and clay. Shallow wells frequently produce relatively fresh water from the alluvium. Stream alluvium is an important, but very limited source of groundwater in the Central Rangelands. Transmissivities in the stream alluvium measured near Beled Weyne are on the order of 225 m^2/day (GKW, 1983).

3.3.3 Structural

The main structural feature in the Central Rangelands is the coastal fault interpreted from geophysical exploration (UNDP, 1973), which may affect the underflow regimes of the regional aquifers in the Central Rangelands (Johnson, 1978; Pozzi et al, 1983). Exploration records suggest that the fault zone could be 50 to 150 kilometers wide, (Johnson, 1978). A second fault system, also defined by geophysical exploration, is located in the Jessoma sandstone which outcrops in a northwest to southeast strip in the southern portion of the Central Rangelands (UNDP, 1973; Pozzi et al, 1983). A third fault system, also interpreted from geophysical exploration, runs approximately parallel to the coastal fault but approximately 100 kilometers inland (Plate 17). Both of these faults appear to be coincident with the occurrence of fresh water (Pozzi, et at, 1983).

3.4 Hydrogeology

Hydrogeological data in the Central Rangelands were found to be sparse. No direct measurements of infiltration, recharge, or discharge were carried out in most areas. No precise horizontal and vertical control of potentiometric levels and sampling locations exists. Because most boreholes are inexactly located on a 1:1,000,000 scale topographic map, surface elevations can be only poorly estimated. All discussions of groundwater recharge, movement, and discharge are therefore subject to change as additional data becomes available.

3.4.1 Recharge

The major source of recharge to the exploited aquifers (Mudugh-Merca and Upper Daban) in the Mudugh and northern Galgadud regions appears to be direct infiltration from precipitation. Mean annual precipitation in this area is approximately 100 mm. The infiltration is assumed to be very low. Measured infiltration rates in areas with similar climatic conditions indicate that direct recharge from precipitation would be slightly less than 5 percent of the total precipitation (Chow, 1964). The remaining portion of the precipitation would be lost to recharging the soil moisture deficit and, eventually, to evapotranspiration.

Due to the high soil moisture deficits and to the depth of the water table in the Central Range, recharge to the deeper aquifers is probably limited to exceptional precipitation events if at all. There may be some additional component of recharge to the deeper artesian aquifers in the Eocene Suites which receive recharge from their highland outcrops, but the extent of this recharge is unknown.

Water levels in the numerous hand-dug wells in the area frequently fluctuate more than 1 meter between the wet and dry seasons (Johnson, 1979). Most of the samples collected from these shallow hand-dug wells indicate that the quality of the water is already degraded by the soluble evaporites in the area. The majority of the water samples from the Mudugh and northern Galgadud regions, showed chloride or sulfate to be the dominant anions. This indicates that recharge is poor, and that groundwater movement is sluggish.

In contrast, the samples collected from shallow wells located at the base of sand dunes, such as the wells at Dumaye in the Xarrardheere area, were very fresh (EC = 600 micromhos/cm). Bicarbonate was the dominant ion, indicating direct recharge from precipitation (Domenico, 1972). The majority of the soluble minerals were presumably leached from the source material prior to the formation of the dunes.

In addition to frequently being very poor quality, the water sampled from the Mudugh and northern Galgaduud regions is highly variable. In most of the water samples from the

Mudugh-Merca and Upper Daban aquifers, there was good correlation between the samples collected from the shallow wells and the samples from the boreholes. The most significant control in the water quality appeared to be geomorphic, rather than depth. Therefore, recharge to these areas was believed to be localized.

Recharge to the aquifers of the Jessoma and Auradu Suites is probably substantially more than to the Mudugh-Merca and Upper Daban aquifers. The Jessoma and Auradu Suites have extensive outcrop areas in the southern portion of the Central Rangelands where the mean annual precipitation is slightly higher, approximately 200 mm. In addition, these aquifers presumably outcrop in the Ethiopian highlands where substantial recharge from much higher precipitation levels is available. The water quality from samples collected from these aquifers was generally signifigantly better (EC's of approximately 2000 to 4000 micromhos/cm). Although sparse, data indicated greater consistency.

Annual recharge to the Mudugh-Merca and Upper Daban aquifers, assuming a five percent infiltration rate and a 150 mm mean annual precipitation rate, is approximately 7,500 cubic meters per square kilometer. This indicates that approximately 20 cubic meters per square kilometer per day could be removed without disturbing the groundwater balance. Because most of the recharge in these aquifers appeared to be localized, and groundwater in these aquifers occurs in isolated lenses, this type of regional analysis may be invalid for specific wells.

In the region of the Shabelle floodplain there is significant connection between the riv_ and the groundwater in the shallow alluvium. Recharge from t e river to the alluvial aquifer occurs during the wet seasc s and drainage from the alluvial sediments to the river occurs during the dry seasons.

3.4.2 Movement

Due to the paucity of data, and the poor state of geologic mapping in the Central Rangelands, only a general conceptual model of the groundwater movement in the Central Rangelands may be attempted.

The coastal fault appears to have a significant effect on the regional flow patterns. The lack of water in wells drilled below sea level in the area between Aliyabal and Xarrardheere, less than 40 kilometers from the coast, suggests that the coastal fault acts as a groundwater barrier. The extent of this effect, or even if the fault is the cause, was not able to be verified during this project. Work to better delineate the fault, and to explore along its length could prove beneficial to future water-development planning.

Groundwater in most of the Central Rangelands occurs in unconfined aquifers of the Miocene to Recent sediments, or in confined aquifers in the deeper Eocene sediments. The upper unconfined aquifers consist of limestone, sandstone, and clay, with evaporite sections. Although their overall lithology is fairly uniform, individual strata grade and pinch out laterally. Infiltration from heavy rains forms discontinuous lenses of groundwater in these unconfined aquifers. Groundwater in the deeper confined aquifers, which originates from recharge at distant outcrops, can be expected to move down dip through the aquifers. Movement in the unconfined lensed aquifers tends to be toward playas and basins. Based on the high salinities of water samples from these aquifers, movement must be relatively slow, and residence times long.

Movement in the confined aquifers, such as the Jessoma and the Auradu, is expected to be down dip toward the north-northeast. Insufficient data prevents any guesstimates of the rate of movement in these formations.

Groundwater movement in the alluvium of the Shabelle valley can be expected to coincide with river-stage conditions. During high flow periods, movement would be toward the alluvial aquifer and during low or dry flow periods it would be from the alluvium toward the river.

3.4.3 Discharge

Discharge from aquifers identified in the Central Range was not able to be quantified, however, based on the few operative wells, it must be minimal. Some water is discharged to playas and basins from the shallow unconfined aquifers. This water is quickly evaporated.

There are not many springs or known discharge points along the coastal cliff areas. The spring near Jessoma discharges into a thin alluvial channel that surfaces downstream only to disappear after a relatively short distance as a result of evaporation and seepage.

In summary, discharge from aquifers in the CR can be regarded as minimal. It takes place through wells, evaporation from playas, and evaporation and seepage from springs.

3.4.4 Well Hydraulics

A well is simply a "...hydraulic structure which, when properly designed and constructed, permits the economic withdrawal of water from a water-bearing formation." (Johnson, 1975). The hydraulic characteristics that are essential to the understanding and solution of aquifer problems and to the proper evaluation and utilization of groundwater resources are transmissivity, storativity, and boundary conditions. Analysis of these characteristics are dependent upon many factors including an appreciation of the hydrologic and geologic setting of the aquifer. Although many of the conditions precedent that influence an aquifer test are known, deviations from the ideal on which analyses are based and the limitation of testing procedure generally prohibit precise results. This paradox may be stated another way. Although numerous assumptions are made to enable a mathematical solution to an understanding of flow conditions, some of the assumptions are never met, while others are only rarely observed. Nonetheless, formulas can be applied with success and the resultant calculated hydraulic characteristics can be useful for most purposes.

The information provided is presented in a format that will hopefully be understandable to the casual reader, and yet maintain enough detail to be of use to the professional. A glossary of terms has been provided for the uninitiated, and only a brief, if any, description is provided in the text.

Because of the emphasis on exploration and exploitation, less emphasis was placed on the collection of data for the determination of detailed aquifer characteristics. Wells were located sufficiently far apart and surface-water bodies were so few, that concerns for interference between wells or from surface-water bodies was non-existent. Time and cost constraints were such that no observation wells were drilled to enable detailed aquifer tests to be attempted. Thirty-seven well tests were conducted, however, throughout the Bay and Central Range Regions. Twenty-two of these were tests of twenty-four hours duration.

3.4.4.1 Transmissivity

Transmissivity is a measure of the volume rate of flow through an aquifer. It provides a means to evaluate the potential contribution of the aquifer to a well. If one envisions a rectangular sponge sandwiched between two glass plates, the amount of water able to move through a unit width of that sponge would be a measure of its transmissivity. Transmissivity is obtained by graphical means utilizing semi-log or log-log graph paper.

All test data were plotted on semi-log and/or on log-log paper. Semi-log plots were analyzed using Jacob straight line methods, and log-log plots were analyzed using matching curve methods. (Detailed descriptions of these methods can be found in a number of texts on groundwater hydrology). Log-log plots yield curves that are characteristic of aquifer conditions. Three types of log-log curves were found; those that approximated a true confined aquifer condition, those that reflected leaky artesian conditions, and those that indicated delayed yield conditions.

Aquifer conditions, or types, can also be described on the basis of the permeability of the overlying materials, if it is assumed that the bottom of the aquifer is impermeable. No distinction between horizontal and vertical permeability will be made, but in general horizontal permeability will be two to ten times greater than vertical. On the basis of this criterion, an aquifer that has overlying materials with relatively the same permeability can be referred to as unconfined. If the overlying materials are less pervious than the main aquifer, but horizontal flow cannot be neglected, the aquifer is semi-unconfined. Often, overlying materials have some permeability, but horizontal flow can be neglected. In this case the main aquifer is considered semi-confined. Where the overlying materials can be considered impermeable, the aquifer is referred to as confined. In reality no material is totally impervious, but for all practical purposes the amount passing through is negligible.

It will be noted that while referring to conditions within the overlying materials, the aquifer is actually being defined. Although the overlying materials are used for descriptive purposes, underlying beds may exhibit similar characteristics. These references are given other descriptions, such as leaky artesian for semi-confined and unconfined with delayed yield for semi-unconfined. Delayed yield may also result from storage within an unconfined aquifer. Because of the many variables involved, determination of the transmissivity using only the producing well must be viewed with caution. The water-producing zone is not always completely open to a well, and the formations are definitely not homogeneous.

Although tests were performed on all potentially useable wells in the CR, not all tests resulted in good data. Table 3.3.2 lists those wells for which data are available. The test at Wargaloh was conducted with the Mono/Lister diesel pump that was to remain in the well. This pump did not have enough capability to stress the aquifer sufficiently to obtain additional time-drawdown values. After five minutes of pumping, the water level stayed constant. This was for a pumping rate of 11.4 m^3/hr.

The aquifer test at Dhajimale resulted in a test curve that could fit either a delayed yield type curve or a leaky artesian curve, Volume V. An argument could be made for either situation.

Table 3.3.2. Aquifer Test Data for Wells in the Central Rangelands

Well Number	Location	Date Tested	Pumping Rate (CuM/d)	Duration (hrs)	T (SqM/d)	Analytical Method	Spec. Capacity (SqM/min)
CR 78	Dhajimale	25-Feb-85	392	8.3	10	Lky Artesian	0.18
CR 81	Bud Bud	12-Mar-85	432	2.2	18	Jacob	0.01
CR 82	Saddel	26-May-85	246	12.5	8	Jacob	0.02
CR 93	Cali Tue	02-Oct-85	144	24	3	Delayed yield	0.01

The well is open to alternating beds of sand and clayey sand. Depending upon the permeability of the clayey sands, these may be contributing flow to the well. A calculation of transmissivity using the leaky artesian curves resulted in a T value an order of magnitude higher than when determined from delayed yield type curves. Geologic conditions would suggest that the combination of events could occur, namely there could be delayed yields from the sand layers and there could be some contribution from the overlying sands.

The resulting test curve from the test at Bud Bud suggests the presence of an impermeable boundary. Closer examination of the gelogy would indicate that dewatering of the limestone aquifer was responsible for the sudden decline in water level.

The Saddel well test results indicated just the opposite effect; a recharge boundary. Again examination of the well log helped to clarify the situation. The aquifer at the Saddel site appears to be the limestone unit. The overlying sands are the materials through which recharge must pass, and no doubt provide storage when the limestone aquifer is full. These conditions would normally result in a delayed yield type of aquifer test curve. It is therefore suspected that there was some residual recovery taking place later in the test period. There are no geologic conditions that would cause rapid recharge response at this well site.

The well at Cali Tun displayed similar characteristics to that at Saddel; a delayed yield type curve resulted from the plotted test data. The geology differs, but the hydrogeology is similar, namely a water producing zone overlain by deposits capable of transmitting some flow. The T value for both wells is of the same order of magnitude, (Table 3.3.2). It is possible that the fractured limestone aquifer is the same for both wells, however, additional borehole data would be required for verification.

The well at Xaradhere was only tested with the bailer on the drill rig. Because this well was quite shallow and planned only for a hand pump, the pump-testing crew was not mobilized. The bailer test indicated that the well was capable of producing 9 m^3/hr.

3.4.4.2 Storativity

No data existed, nor were sufficient data able to be collected, from which to calculate storativity for aquifers in the Central Rangeland. The average storativity for confined and unconfined aquifers of 10^{-4} and 0.2 respectively (Lohman, 1972) are adequate for any required estimates. The sparsity of wells in the Central Range renders this parameter somewhat academic at this time.

Storativity may be of concern for the basalt aquifer if and when it receives more intense development. The same applies to the coastal dune aquifers if a program of horizontal wells or infiltration galleries is implemented.

3.4.4.3 Boundary Conditions

With the exception of the well at Bud Bud, none of the wells tested exhibited any boundary effects. Likewise none of the observed hydrogeologic conditions would suggest the presence of boundary conditions in the Central Range. The data from the well test at Bud Bud indicates the presence of an impermeable boundary, but this is more likely a result of water level being drawn down below the producing zone.

3.5 Water Quality

The water quality in the Central Rangelands, as is typical of arid lands throughout the world, is generally very poor. The poor quality of the groundwaters in the Central Rangelands is due to a variety of reasons. One reason is the slow circulation times in the groundwater regime, and the resultant increase in the exposure time of the groundwater to soluble minerals in the formations. A second reason is the high evaporation rates which tend to concentrate salts on the soil surface. These salts are eventually flushed into the groundwater. A third reason is the exposure of the groundwater to the extensive soluble evaporite deposits; these are prevalent in the Central Rangelands.

In the deeper aquifers, the high salinity levels are the result of dissolution of soluble evaporite deposits. In the shallower aquifers salinities probably result from the concentration of salts in the aerated zone of the soil profile. Salts are leached downward during the rains, and are "pumped" back upwards by capillary action during the dry seasons; thus concentrating the salts in the aerated zone. Shallow hand-dug wells tapping aquifers in these zones frequently encounter saline water.

Generally, it is the quality rather than the quantity of available groundwater in the Central Rangelands which limits its utilization. The little water-quality data available in the Central Rangelands are poor. A significant problem in understanding water quality in the Central Rangelands on a regional basis is that the available data are strongly biased in the direction of favorable water. This is because, historically, when boreholes have encountered saline water, the wells have been abandoned and frequently backfilled before any data are recorded.

Although there are insufficient data to conduct statistical analyses of the water quality in the Central Rangelands, an attempt was made to define water-quality regions. This information is presented in Plates 18 and 19. The regions are preliminary, and should be adjusted as more wells are drilled and data collected. A high priority should be placed on collecting water-quality data in any future groundwater-development work in the Central Rangelands.

The CGDP concentrated activities in the priority districts established by the CRDP. These districts are; Hobyo, Ceel Dheere, and Ceel Bur, located in the Mudugh and Galgadud regions. Additionally, samples were collected from existing boreholes throughout the Central Rangelands. Results of the water-quality sampling are discussed by region below.

Water Quality in the Mudugh Region. Four geomorphological conditions occur in the Mudugh region, (Figure 3.3.5). The main plateau consists of limestone and sand sheets or evaporite deposits. The coastal plain consists of active sand dunes and the transition zone between the coastal plain and the central plateau consists of stabilized sand dunes. With the exception of the few wells in the Mudugh region which penetrate to the Eocene formations, the water quality appears to be related to these geomorphological areas.

Groundwater occurring in the plateau area between Galcayo and Hobyo is generally moderately saline. Specific conductivities from borehole samples range from approximately 1,200 to 9,000 micromhos/cm with an increase towards the boundaries of the geomorphological unit. Sulfate concentrations are generally above 1,500 mg/l, but appear to decrease in the northern portions of this region (indicated by the lower sulfate concentrations at Jerriban, Bali Busle, and Bitale). The controlling factor in water quality for this region appears to be the presence/absence of soluble evaporite deposits. The area between Galcayo and Hobyo, outside the limits of the evaporite units, will produce, locally, marginal-quality water. Good prospects for fresher water occur to the north of this region.

Groundwater occurring in the evaporite area in the Mudugh region appears, from the scant information available, to degrade as the water moves from the western boundary towards the east. The three boreholes in the eastern portion of this region, Colgula, Afgaduudle, and Yamaarugle, all contain poor water with high concentrations of sulfates and/or chlorides (Plate 18). The abundance of evaporite deposits in this region will make it difficult to locate usable water. Relatively fresh water has been found in the western portions of this region.

Groundwater occurring in the coastal plain and the transition zones is of highly variable quality and appears to be controlled by locally occurring conditions of evaporite deposits and proximity to the coast. Salt-water intrusion occurs in the coastal wells when they are overproduced. Sodium and chloride are the dominant ions in all of the water samples collected from the coastal plain.

The best-quality water in the Mudugh region is the water produced at the base of sand dunes (such as Damaye). The development of this resource, however, presents ecological problems with mobilization of the sand dunes potentially resulting from overgrazing. The other consistent source of good- quality water in the Mudugh region is beneath the Trap Series basalts. Only one well in the Mudugh region is known to have tapped this aquifer; the well at Wargaloh. A high priority should be placed on mapping this aquifer in order to plan a groundwater development strategy for the Mudugh region.

Water Quality in the Galgaduud Region. The water quality in the Galgaduud region follows the same patterns as in the Mudugh. There are four geomorphological types in the Galgaduud. The central and western portions of the Galgaduud are covered by evaporite deposits which are surrounded to the north and south by limestone and sand sheets. In the eastern portion of the Galgaduud are the stable sand dunes of the transition zone and the active dunes of the coastal plain. Water quality of the broad plateau of sand and limestone in the northern portion of the Galgaduud is essentially unknown.

Water in the evaporite region around Ceel Bur is very saline, and dominated by sulfate and chloride. Fresh water can be developed in this area beneath the basalt in confined aquifers occurring in the Jessoma and Auradu formations. Water occurring in the upper unconfined aquifers is frequently very saline (specific conductivities frequently above 6,000 micromhos/cm) with sulfates and chlorides being the dominant anions. Water from the confined aquifers below the basalts (sampled at Dhusa Mareeb and Ceel Bur) had specific conductivities below 3,000 micromhos/cm and sulfate levels below 500 mg/l.

The water quality in the transition zone between the coastal plain and the central plateau is relatively good. Specific conductivities range from 2,500 to 6,000 micromhos/cm and sulfate levels are generally below 1,000 mg/l. Relatively fresh water is generally found in this region at depths between 60 and 90 meters.

The water quality on the coastal plain in the Galgaduud region is variable, but usable at depths of approximately 50 meters. The water is generally below 6,000 micromhos/cm specific conductance and is dominated by sodium and chloride. Gypsum deposits are present in the small cliffs at the edge of the coastal plain and water produced near the boundries of the plain may be adversely affected by soluble evaporites.

Essentially no data are available from the southern portion of the Galgaduud. Only one well, Moqokori, has been sampled from this region. The water from this well was relatively fresh with chloride being the dominant anion. It is presumed that this well, and the nearby well at More Ari are producing water from the Jessoma Sandstone. It is probable that relatively fresh water may be found in the Jessoma and Auradu formations at relatively shallow depths in the southern portion of the Galgaduud.

Water Quality in the Hiran Region. The Hiran region is composed of two geomorphological units, the broad sand and limestone sheet in the northern portion and the Shabelle floodplain in the southern region.

The water quality in the northern portion of the Hiran region appears good with a slight tendency, as in the other regions, to degrade towards the east. The water is dominated by sodium and chloride, and sulfate levels are generally below 1,000 mg/l. The Jessoma and Auradu formations outcrop in this region and are considered to be a good target for water development in the future. A spring occurring in the Jessoma Sandstone near the village of Jessoma produces water with a specific conductance of 2,000 micromhos/cm and only 200 mg/l sulfate. Artesian water produced from the Auradu Limestone at Ceel Bur was relatively fresh (specific conductance of 1,950 micromhos/cm) and contains less than 200 mg/l sulfates.

The water occurring in the floodplain of the Shabelle river is generally good with a slight tendency to degrade downstream. This aquifer is probably in communication with the Shabelle river and is a reliable source of good water. The naturally occurring groundwater, neglecting river infiltration in this area, is poor due to the presence of gypsiferous sediments; specific conductances are approximately 6,000 micromhos/cm. The specific conductance of the water from the Shabelle River measured near Beled Weyne ranges from 500 micromhos/cm to 2,000 micromhos/cm from the wet to the dry seasons respectively (GKW, 1983). Mineralization in the groundwater increases with the distance away from the river and exploitation of the groundwater should be planned accordingly. Generally the alluvium in the floodplain of the Shabelle may be considered as a reliable source of good-quality water.

3.5.1 Water Quality Criteria

International Water Quality Criteria, as established by the WHO (World Health Organization, 1971) are frequently exceeded in the Central Rangelands. These criteria are, however, primarily aesthetic rather than health-related for the major ions analyzed. The currently accepted water-quality criteria adopted by the WDA for utilization by the CGDP are listed below:

Utilization	Specific Conductance micromhos/cm	Chloride mg/l	Sulfate mg/l
Human Consumption	3,500 (64)[1]	800(54)	600(46)
Livestock	7,500 (96)		
Camels	10,000 (96)		

[1](percentage of currently utilized wells in the Central Rangelands which meet the stated criteria, based on 28 samples).

Field observations have shown that the pastoral population of the Central Rangelands will partially accept water for domestic utilization with specific conductance of up to 8,500 micromhos/cm. Taste, the primary criteria in local usage is affected most strongly by sulfate content. At levels exceeding 500 mg/l, sulfates impart a bitter taste to the water.

Specific conductance, while an easily measured field parameter, is not a very useful criterion for water quality in the Central Rangelands. Total dissolved solids do not correlate well with specific conductance. Water in which sulfate is a dominant ion will have a much higher specific conductance than a sodium-chloride water containing the same amount of total dissolved solids. Figures 3.3.6 and 3.3.7 show the relationship between specific conductance and total dissolved solids for sulfate and sodium-chloride waters respectively. The numerical relationships are as follows:

Dominant Anion

Sulfate $TDS = 628 + 1.2\ EC$

Chloride $TDS = 491 + 0.82\ EC$

In practice it is difficult, if not impossible, to control water utilization in the Central Rangelands. Water utilization is related to water availability more than to anything else. In Gal Harreri (Ceel Dheere District) water with a specific conductance of 4,200 micromhos/cm and a sulfate content of 882 mg/l is not used for drinking due to its bitter taste. Wells containing sweeter water located 18 and 30 kilometers distant, at Garable and Jacar respectively, are preferred. In Bud Bud

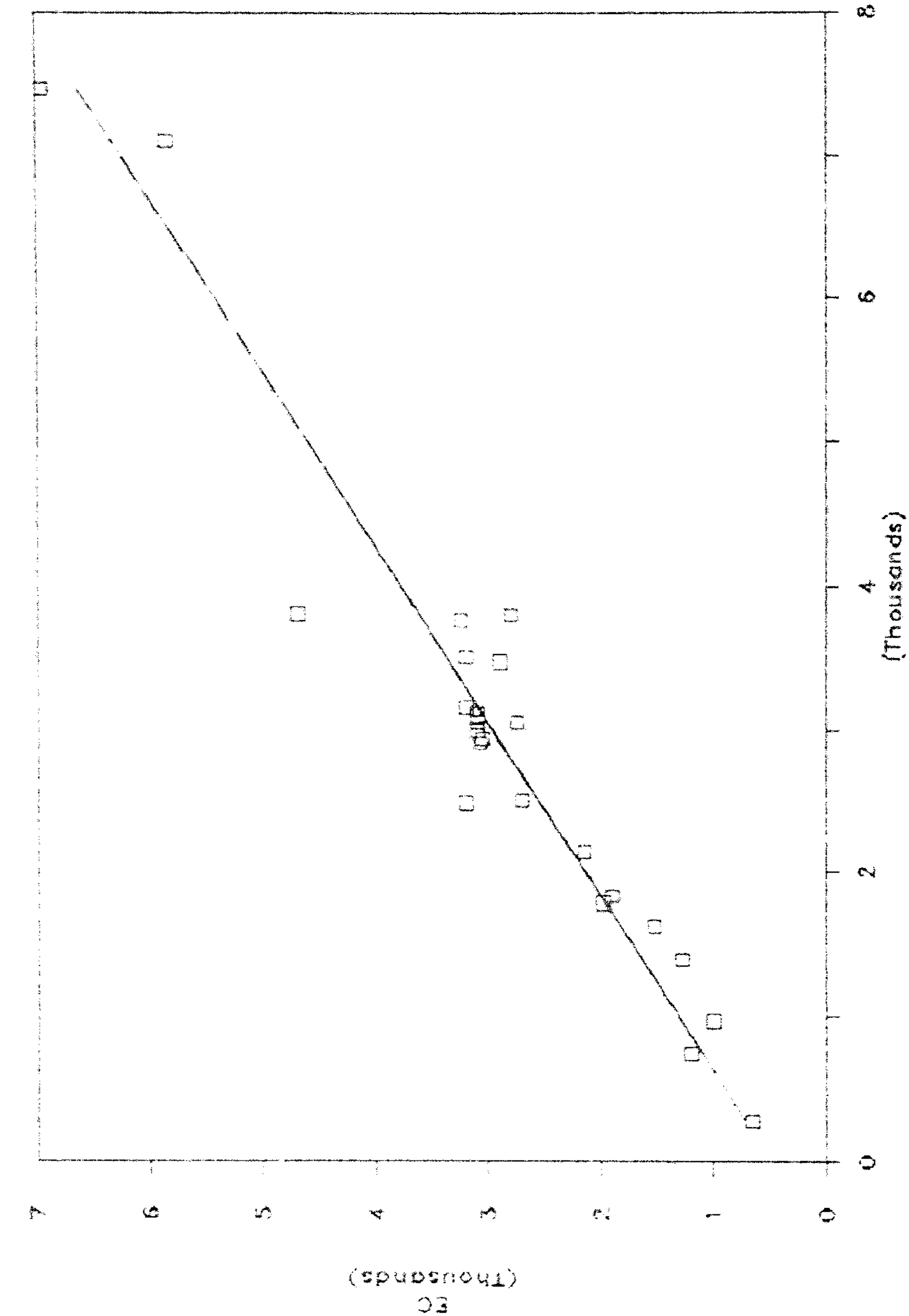


Figure 3.3.6 TDS vs SULFATE - DOMINANT ANION.

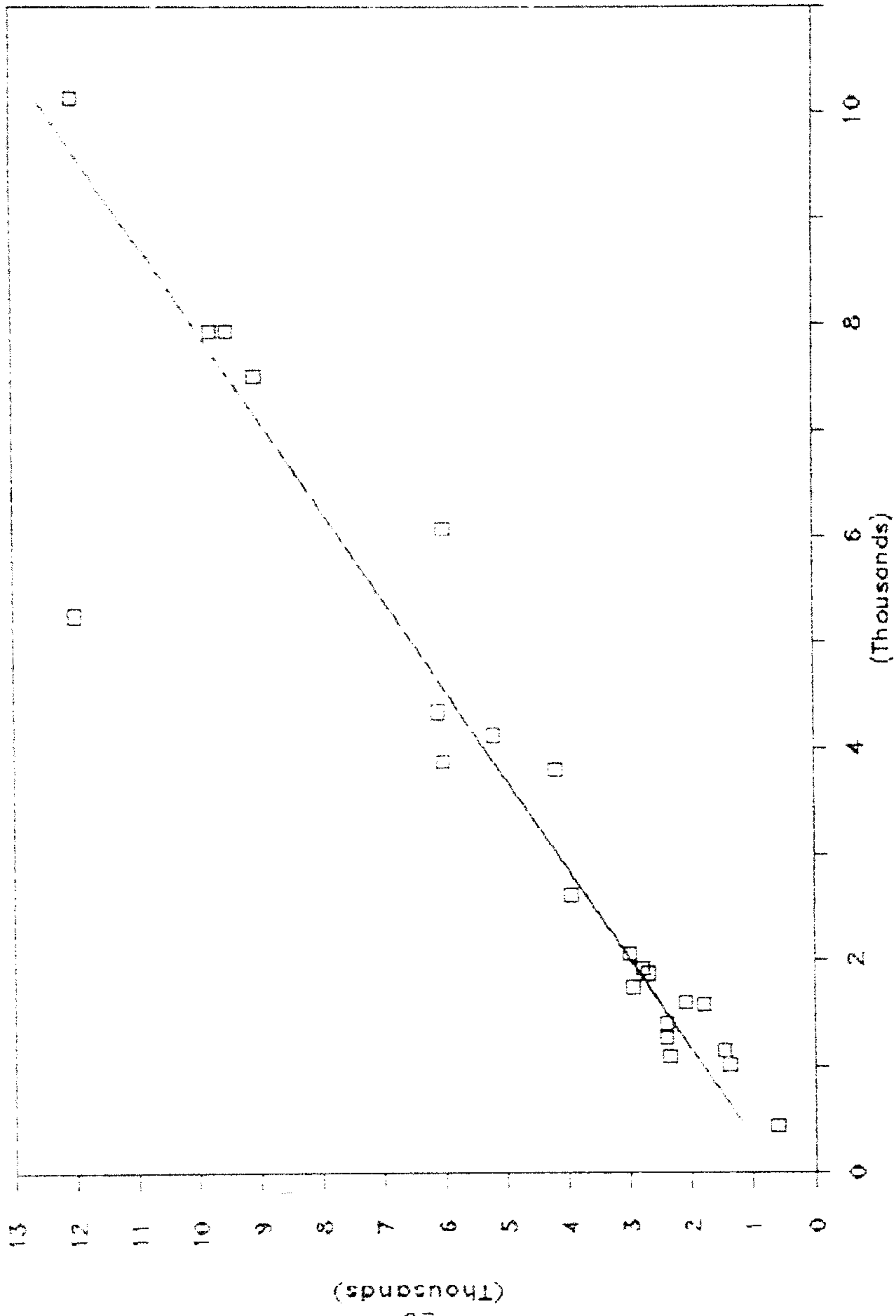


Figure 3.3.7 TDS vs EC CHLORIDE - DOMINANT ANION.

(Hobyo District) water with a specific conductance of over 9,000 micromhos/cm, a sulfate concentration of over 2,500 mg/l, and a very bitter taste is commonly consumed due to the unavailability of an alternative water supply. At Xindheere (Ceel Bur District) water from a WDA borehole with a specific conductance of 16,000 micromhos/cm is occasionally utilized for livestock watering in the dry seasons. The criterion utilized for water consumption in the Central Rangelands will continue to be local acceptance.

The decision to complete or abandon a borehole in the Central Rangelands should be made on a site specific basis. In general, any boreholes in areas where water is in short supply encountering water with specific conductance of less than 10,000 micromhos/cm should be completed.

It was beyond the scope of this project to investigate the resulting health effects of the groundwater encountered in the Central Rangelands. No data were found in the available literature that indicate adverse health effects would result from long-term consumption of high TDS waters. It is reasonable to assume, however, that some exist. Further research into the effects of long-term consumption of high TDS water, and in particular high sulfates, should be conducted. Known health effects of some constituents are described in Section 3.5.2.

3.5.2 Special Problems

The extremely poor water quality frequently encountered in the Central Rangelands presents several specific problems. These include; screen incrustation/corrosion, drilling, construction, and health problems.

Incrustation/Corrosion. Metal screens and pumps used in wells may be subjected to deterioration resulting from poor quality water. Incrustation, the deposition and accumulation of minerals on the well screen openings, and corrosion, the dissolving of metal materials, are two common problems. Both cause reduced well efficiency or total failure of the well. One widely used method of evaluating incrustation or corrosion potential is by use of the Ryznar Saturation Index (RSI) (Campbell, M.D and Lehr, J.H. 1973). The RSI is based on the calcium-carbonate saturation and is dependent on the total dissolved solids, the hardness, and the pH of the water. In general, a RSI of less than 7.0 indicates that the water has a tendency to be incrusting, and a RSI of greater than 9.0 indicates a tendency for corrosion. Ryznar Index values were calculated for all of the samples collected from boreholes completed by this project in the Central Rangelands. These values are presented in Table 3.3.3.

Table 3.3.3. Ryznar Index Values for Central Range Wells

Well No.	Well Name	Ryznar Index	Casing Type
CR67	Wargaloh	7.10	Steel
CR72	Afgaduudle	6.88	None
CR78	Dhajimale	6.70	Steel
CR81	Bud Bud	6.74	PVC
CR82	Saddal	7.25	PVC
CR89	Xarrardheere	8.01	PVC
CR93	Cali-Tun	6.61	Steel

The use of plastic (PVC) well casing in waters which have a corrosive tendency should alleviate the corrosion problem and increase the life of the well. (This was not done at Wargaloh due to the depth of the well which was beyond the limits at which plastic casing can be safely used). Corrosion problems in the Central Rangelands will tend to be amplified by the relatively high temperatures of the groundwater, (over 30°C in all samples collected). The high temperatures reduce the viscosity, and thus increase the diffusion rate of oxygen.

Plastic well casing should be used, where possible, in boreholes completed in the Central Rangelands. Incrustation problems may result even with plastic casing but, can be alleviated somewhat by proper well management. Due to the pressure change (drawdown) which is necessary to make water flow into a well, dissolved carbon-dioxide is released from the water causing carbonates, primarily calcium-carbonate, to be deposited around the well intake area. Proper well development and well management, i.e. minimizing drawdown, are the most effective measures in preventing incrustation.

Drilling Makeup Water and Concrete. Much of the water available in the Central Rangelands is of substandard quality for efficient utilization as makeup water for mixing drilling fluids. High total dissolved solids and relatively low pH values will result in excessive amounts of bentonite required to achieve proper drilling-mud viscosities. Water which contains more than 5000 mg/l of total dissolved solids should be avoided when possible. When it is necessary to use saline water for mixing drilling fluids special drilling muds designed for saline water, such as Quik-Trol or Quik-Mud, should be provided rather than conventional bentonite. In addition, soda ash should be routinely used to reduce the hardness, and to eleviate the pH of the makeup water. Sufficient soda ash should be routinely mixed to keep the pH of the drilling mud between 8.0 and 9.0.

The high total dissolved solids and particularly the high sulfate content will have an adverse effect on the strength of cement made with this water. Saline borehole water should be avoided when constructing pump bases and civil works at boreholes in the Central Rangelands.

Adverse Health Effects. As previously mentioned, the adverse effects of long term consumption of high TDS water are unknown. The effects of sulfates, flourides and nitrates are, however, fairly well documented. Sulfate imparts a bitter taste to water at concentrations in excess of 500mg/l, and tends to have a laxative effect at concentrations greater than 1,000mg/l. Although it appears that the local population has been able to adjust to sulfate levels as high as 2,900 mg/l, further research should be conducted on the long term effects of consuming waters with high concentrations of sulfate.

Flouride was not one of the ions routinely analyzed in the Central Rangeland sampling program, but during the initial phases of this project 19 samples were analyzed for flouride. An additional 19 samples were analyzed for flouride by GTZ in 1982 (Table 3.3.4). Flouride concentrations above 1.5 mg/l have been reported to cause mottling of the teeth, and flouride concentrations above 3.0 mg/l have been reported to cause skeletal fluorosis, (WHO, 1970). Fifty percent of the samples analyzed contained flouride concentrations above the 1.5 mg/l level recommended as the maximum permissible concentration by WHO. Because the water consumption of the rural population of Somalia is relatively low, a higher concentration may be acceptable. Further investigation into the flouride concentrations of groundwater in the Central Rangelands should be conducted.

Nitrates were not routinely analyzed, but 31 samples from the Central Rangelands were analyzed during the early phases of the project (Table 3.3.4). Seven of the samples contained nitrate levels in excess of the 10 mg/l level recommended by WHO. Nitrates are a direct result of contamination from domestic or animal excrement.

Table 3.3.4. Nitrates and Flourides In The Central Rangelands

Location	Date	NO_3-N mg/l	F mg/l	Source
Qardo 1	14.2.81	7	2.3	Drilled Well
Qardo 2	14.2.81	7	2.4	Drilled Well
Qardo 3	14.2.81	10	2.4	Drilled Well
Halin	14.2.81	nd.	2.8	Spring
Garowe	15.2.81	nd.	3.0	Drilled Well
Garowe	15.2.81	7	1.5	Hand Dug Well
Burtinle	16.2.81	2	2.6	Drilled Well
Buriqap	16.2.81	0.2	2.7	Drilled Well
Galcayo	16.2.81	2	2.7	Drilled Well
Hotel Bulsho	16.2.81	16	3.0	Hand Dug Well
Ghelinsor 1	16.2.81	6	1.8	Drilled Well
Ghelinsor 2	16.2.81	5	1.7	Drilled Well
Cadado	16.2.81	4	1.9	Drilled Well
Godinlabe	16.2.81	nd.	1.1	Drilled Well
Dhusa Mar'b 1	16.2.81	8	0.8	Drilled Well
Dhusa Mar'b 2	16.2.81	4	1.2	Drilled Well
Awsweyne	17.2.81	0.2	2.2	Drilled Well
Galacad	17.2.81	5	1.6	Drilled Well
Mareer-Gur	5.4.82	7	0.5	Drilled Well
Godinlabe	5.4.82	7	0.3	Hand Dug Well
Cadado	5.4.82	5	0.8	Drilled Well
Ghelinsor	5.4.82	20	-	Drilled Well
Gowlallo	6.4.82	16	0.8	Drilled Well
Qargoie	6.4.82	7	1.8	Hand Dug Well
Gana Falle	8.4.82	8	1.4	Hand Dug Well
Balli Busle	8.4.82	0.2	0.8	Drilled Well
Jiriban	9.4.84	13	0.2	Hand Dug Well
Ceel Hammer	9.4.84	1	0.3	Hand Dug Well
Garcado	9.4.82	43	0.5	Hand Dug Well
Hobyo	10.4.82	51	1.7	Hand Dug Well
Xarrardheere	10.4.82	4	0.4	Hand Dug Well
Moqokori	9.2.83	-	0.4	Drilled Well
Shebelli R.	9.2.83	-	0.5	Surface Water
Bugda 1	10.2.83	-	2.7	Hand Dug Well
Bugda 2	10.2.83	-	2.5	Hand Dug Well
Aborey	9.2.83	-	0.1	Drilled Well
Bulo Berti	9.2.83	-	0.4	Drilled Well

Nitrates are considered to be a health hazard to infants, and possibly to older children, if they are present in drinking water at concentrations greater than 45 mg/l, (WHO, 1971). Samples collected from hand-dug wells at Garcado and Hobyo contained 43 and 51 mg/l respectively. Rehabilitation of these wells and the implementation of health standards should be imposed. As in the case of sulfates, higher concentrations of nitrates may be tolerated but are definitely not recommended.

3.6 Civil Works

No construction of civil works was started in the Central Rangelands during the project period. The CRDP with assistance from the CGDP, completed a design for civil works to be constructed at well sites having motorized pumps. Plans and specifications with a materials list were provided to the CRDP. The plans called for construction of 48 cubic meter storage tanks in addition to domestic and animal watering facilities.

Without benefit of completed civil works, the current practice is for utilization of the mud pits, constructed during the drilling operation, as water storage and distribution facilities. The watering is accomplished relatively efficiently but pollution problems are rampant. It is recommended that all boreholes completed with diesel pumps be fitted with civil works as soon as possible.

An additional objective of the civil-works construction is to provide some storage in the event of pump failures or fuel shortages. An assessment of the amount of time required to service equipment, and/or to supply fuel to the remote locations in the Central Rangelands, renders this purpose absolete. Civil-works construction in the Central Rangelands should therefore concentrate on providing a hygenic system of water supply.

Any civil-works construction undertaken for hand pumps should be minimal. The primary consideration should be to provide sanitary conditions around the well site.

3.7 Pump Systems

Under normal circumstances the selection of a pump for a well is based on the anticipated yield of the well and on the purpose for which the well was constructed. Normal circumstances are those where the items desired are readily available in a short period of time. Because project operations require advance purchases, decisions had to be made well in advance of intended use, and without benefit of firm data. The pumps ordered for installation in wells completed during this project were ordered on this basis. Four types of pumps were obtained; hand pumps, direct-drive diesel pumps, submersible pumps, and wind pumps. The discussion of pumps that follows has been divided into three main categories, hand pumps, motorized pumps and wind pumps.

3.7.1 Hand Pumps

Hand pumps, as the name implies, move water by manual operation. Hand pumps were sometimes referred to as reciprocating pumps because they involved an up-down motion. The hand pumps obtained for this project are, however, non-reciprocating. The principle of operation for these pumps, the Moyno by Robbins and Myers, is the helical screw or rotor. This rotor turns inside a molded stator and causes water to move upward. The main advantage of this type of hand pump is that it requires virtually no maintenance.

The models ordered for the project were the 1v12, designed for single person operation for lifts up to 45 m, and the 2v12 for two person operation for lifts up to 90 m. Unfortunately, a factory defect in the shaft construction has caused most of these pumps to fail shortly after installation. The company, after considerable delay, has provided repair kits for these pumps.

Additional requirements of hand pumps led to the purchase of Mono pumps. Mono was the inventor of the helical rotor pump, however, until recently they were made only in England and were not eligible under USAID regulations. These pumps have the same lift capability characteristics as the Robbins and Myers pumps. At the time of report preparation, these pumps were not yet in country.

One other type of hand pump was installed during the project; the India Mark II. Two of these pumps were provided as demonstrators by Export Trading Co. of Nairobi. These pumps are the basic reciprocating-type hand pump that has been successfully used in many other African countries. The main feature of these pumps is low cost, and potential for being locally manufactured. The disadvantages are a lower lift capacity, 60 meters, and more frequent maintenance requirements. The maintenance reportedly can be conducted locally. The two pumps provided were installed in the Bay Region.

Hand pumps generally have not been well received in the project areas where users prefer motorized pumps. Reports from other water development projects, mostly refugee relief, indicate that hand pumps are being accepted. The early breakdowns on those installed by the project may account for the lack of user confidence.

Hand pumps, and especially the helical rotor type, are recommended. Although more expensive initially when properly received and installed, these pumps should outlast all others. The main feature of these pumps, no maintenance, is a major reason for the recommendation. During the five years of the project, the general lack of maintenance on all equipment was found to be a critical problem. There would not appear to be much prospect for change in the near future.

3.7.2 Motorized Pumps

Two types of motorized pumps were purchased for the project, direct-drive diesel pumps and submersible pumps. The direct-drive diesel pumps are those manufactured by Mono pump and operated by Lister diesel engines. These pumps were purchased for permanent installation at selected well sites.

Stainless-steel Grundfos submersible pumps were purchased for use as test pumps on newly completed wells. These pumps could also be used as permanent pumps during an emergency situation.

3.7.2.1 Mono Diesel Pumps

Mono diesel-driven pumps were selected for installation at high-yield well sites with human and animal populations large enough to require one. These pumps have the same helical rotor/stator design as the Mono hand pumps, but are capable of producing more water at greater depths. Depending upon motor size, these pumps are capable of water lifts from 150 m.

The direct-drive diesel engine was selected for its ease of operation, low maintenance, and comparatively low cost. In many cases submersible pumps would have been preferable, however, power supplies are not available at most sites and diesel generators would be required. These are more expensive and require more maintenance to keep operating properly. Another advantage of the diesel-operated Mono pump is that the rotor/stator assembly is interchangeable with that of the mono hand pump. By standardizing the motor pumps and hand pumps, maintenance of spare parts can be kept at a minimum.

3.7.2.2 Submersible Pumps

Two Grundfos stainless-steel pumps, a 40 hp and a 20 hp were purchased for use primarily as test pumps. Submersible pumps were chosen over direct-drive deep-well turbine pumps because of the ease of installation. Deep-well turbine pumps require more care and handling in both transport and installation. The road conditions and the technical ability of the crews warrant installation of submersible pumps. In addition, deep-well turbine pumps require that the wells in which they are installed be plumb throughout the length of installation. Submersible pumps are more forgiving in this respect.

The Grundfos stainless-steel pumps are three-phase having from 7 to 20 stages. The number of stages reflects the heads against which the pumps are capable of operating. This includes depth below water level to the highest point of discharge. Generators were mounted on each of the two pump installation rigs in conjunction with cable reels to enable these pumps to be operated from one vehicle.

3.7.3 Wind Pumps

Wind pumps, or more commonly windmills, gained increasing interest as the project matured. This was due primarily to the realization that fuel to operate the diesel pumps was going to be a continual problem in Somalia.

Windmills are not new to Somalia, but have suffered the same fate as most mechanical equipment, namely, lack of spare parts to keep them maintained. Other deterrents to the widespread use of windmills have been the high cost to import, the difficulty in transporting and erecting at remote sites, and the inability to operate under low wind conditions.

Two windmills were obtained for installation and monitoring during the project. These were US-manufactured Wind Baron pumps. This particular windmill was selected on the basis of its ability to function at windspeeds as low as eight kilometers per hour. Because of the high cost and advanced technology of these pumps, interest turned to the less expensive Kenya-manufactured Kijito pumps. These two pumps will be briefly discussed and compared.

3.7.3.1 Wind Baron Pump

The Wind Baron Pump (WBP) was selected for operation in Somalia because of its ability to produce water at low windspeeds and to serve as an experimental system. The ability of this windmill to function at velocities as low as eight kilometers per hour was believed to be important for research purposes. Conventional windmills generally require wind speeds of twenty-four kilometers per hour to function. One windmill was to be erected in the Bay Region and one in the Central Rangelands.

Unfortunately, the windmill earmarked for the Central Rangelands was not erected during the project. The extremely long distances over poor roads, combined with the unavailability of a suitable site prevented the culmination of the effort.

Windspeed data were obtained for three areas in the Central Range, and all three were found to have sufficient winds to warrant consideration of wind pumps, (Tables 3.3.5 to 3.3.7, and Figure 3.3.8). Figure 3.3.8 shows a strong correlation between high and low wind months, and it demonstrates the increasing intensity of wind from the interior to the coast. Selection of wind pumps should not be made without comparison of these data with the manufactures performance curves.

3.7.3.2. Kijito Pumps

Kijito windmills are manufactured in Nairobi, Kenya and have therefore gained considerable interest in East Africa. Additionally, these pumps have the potential to be manufactured in Somalia. Figure 3.3.9 shows the performance graph for the Kijito pump. If a rotor, or wheel assembly, of 7.3 m diameter is erected on a Kijito pump in the Central Rangelands it could potentially produce between 15 to 21 cubic meters per day during medium winds of 10.8 to 14 K/hr. Below 10.8 K/hr this potential yield drops off drastically. With the exception of the wet season months, however, the mean windspeed is at or above these levels. This performance is only about 25 to 30 percent less than what the Wind Baron pump could produce at six times the cost.

3.8 Recommendations for Future Water Development.

During the course of this investigation, much has been learned about the water resources of the Central Rangelands. It is hoped that this experience will be incorporated into the future water resource development of the area. The single most important recommendation is that information collected during water development activities be collected and retained for future use.

More realistic recommendations pertain to drilling methods, hand-dug wells, water lifts, infiltration galleries and surface-water catchments. These are discussed in the following sections.

3.8.1 Drilling Methods

Rotary drilling and cable-tool drilling have been utilized throughout the CGDP While local conditions, such as lack of trained mechanics, the incessant fuel shortages, and the great distances to a drilling-water supply favor cable tool drilling in some areas of the CR, rotary drilling will be required to reach potable water depths in most areas. The cable-tool rigs

Table 3.3.5. 26 Years of Wind Speed Data for Hobio in meters/second.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1954	5.0	5.4	7.0	5.6	7.0	5.2	5.5	6.2	6.4	8.2	5.7	7.1	6.2
1955	5.8	6.3	6.4	6.8	6.8	6.5	5.4	6.0	5.8	6.6	7.0	6.0	6.3
1956	6.2	5.0	5.6	7.1	5.6	6.0	5.6	7.2	5.3	5.6	5.5	7.2	6.0
1957	8.2	6.7	8.2	6.4	7.5	7.3	6.4	8.0	4.6	4.9	6.5	5.2	6.7
1958	5.6	8.1	7.7	8.0	8.2	7.0	6.8	6.6	5.5	5.7	8.3	6.5	7.0
1959	7.7	7.0	6.0	8.0	8.5	6.6	7.0	5.6	6.0	6.3	7.1	5.0	6.7
1960	4.8	6.8	8.8	7.7	8.8	5.1	6.8	6.2	7.5	7.0	7.5	6.5	7.0
1961	5.8	5.5	5.8	5.4	6.1	8.0	5.1	4.8	8.1	6.0	5.7	5.8	6.0
1962	7.0	6.2	7.5	6.9	7.4	7.0	5.4	7.2	5.6	5.6	4.6	7.3	6.5
1963	8.0	7.0	6.7	7.5	5.6	6.1	4.8	10.2	4.6	5.2	4.6	7.1	6.5
1964	8.2	7.4	6.9	7.0	5.2	4.6	4.3	4.9	8.7	6.2	4.8	4.6	6.1
1965	6.0	7.1	6.0	5.8	5.4	7.0	5.2	6.5	5.5	6.4	4.6		6.0
1966	5.8	6.4	4.6	4.4	6.0	6.4	6.8	7.2	5.9	4.0	4.2	5.2	5.6
1967	4.8	4.2	5.6	2.5	4.1	5.5	5.8	6.1	6.6	3.2	4.1	6.1	4.9
1968	6.1	4.3	5.5	3.8	9.8	6.8		6.9	6.3	4.5	4.0	5.3	5.8
1969	6.4	3.1	5.7	3.9	5.5	6.5	7.1	5.6	6.3	2.0	4.5	6.3	5.2
1970	6.4	5.9	4.7	8.1	5.5	5.0	11.0	10.9	5.2	6.5	6.5	9.3	7.1
1971	9.2	7.9	6.3	4.0	8.0	10.9	10.0	7.6	10.0	5.0	5.8	7.3	7.7
1972	8.3	8.3	4.0	4.5	5.2	11.6	10.7	11.1	9.6	4.4	5.8		7.6
1973	7.6	6.0	4.8	5.0	7.4	11.5	10.6	5.9	10.1	6.7	6.6	7.5	7.5
1974	9.9	7.5	7.8	5.0	7.9	11.6	12.8	11.5	10.8	6.2	5.2	5.8	8.5
1975	6.5	6.0	2.0	3.0	4.0	10.5	10.0	9.6	9.5	7.5	5.3	5.4	6.6
1976	6.5	6.0	6.0			9.0	8.5	8.0	7.0	5.6	6.0	8.0	7.1
1977	7.5			6.0	8.5	10.5	10.0	12.0	10.0	5.0	6.0	7.0	8.3
1978	7.5	6.0	6.0	4.0				11.0	6.5		6.0	6.5	6.7
1979	6.0	6.0	4.0	3.0	5.0	6.5	6.0	3.5	4.5	3.5	4.0		4.7
1980	8.8	6.0	4.5	4.0	7.5	11.0	9.5	9.5	6.5	8.5	5.0	7.5	7.4
Mean m/s	6.9	6.2	5.9	5.5	6.7	7.7	7.5	7.6	7.0	5.6	5.6	6.5	6.6
* m.p.h.	15.4	14.0	13.3	12.4	14.9	17.2	16.8	17.1	15.6	12.6	12.5	14.5	14.7
* km/hr	24.7	22.4	21.3	19.9	24.0	27.7	26.9	27.4	25.1	20.3	20.1	23.3	23.6

* 1 meter/second = 2.24 miles per hour = 3.6 kilometers/hour

Table 3.3.6. 16 Years of Wind Speed Data for Ceel Buur in meters/second.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1953													
1954	6.9	5.9	4.9	9.0	5.4	8.2	7.4	7.4	9.7	3.8	5.0	5.7	6.6
1955	6.3	7.5	3.3	3.5	4.5	6.5	6.9	6.9	5.9	2.7	2.6	5.0	5.1
1956	5.9	5.1	4.4	4.6	5.0	7.0	6.7	6.3	6.5	3.6	4.9	5.4	5.5
1957	5.0	5.2	4.3	4.0	4.4	6.0	6.0	6.4	5.4	3.7	3.9	5.3	5.0
1958	5.5	5.4	4.9	3.4	5.7	6.3	6.0	6.9	6.0	3.7	4.7	5.4	5.3
1959	5.5	5.3	5.0	3.3	4.6	5.7	5.5	6.1	5.2	3.6	4.1	5.7	5.0
1960	5.4	4.8	3.8	3.4	5.2	5.7	7.1	6.6	5.8	2.2	1.0	4.2	4.6
1961	5.0	4.2	2.3	6.3	5.1	6.1	6.3	6.9	5.6	2.6	3.3	5.4	4.9
1962	6.[illegible]	5.5	4.2	3.0	6.0	7.6	5.1	9.5	6.3	2.3		3.9	5.5
1963		4.0	2.6	2.3	5.3	7.4	7.7	7.1	5.5	2.0	1.8	4.5	4.6
1964													
1965	7.7			3.6	7.0	11.4	12.3	12.0	6.7	1.8	2.2	1.4	6.6
1966	6.3	5.0	2.5	3.4	1.5	6.0	8.8	9.3	6.2	2.7	3.7	4.6	5.0
1967	6.4	4.3	3.1	2.4	5.4	4.4	5.3	3.6	7.8	2.1	2.6	6.4	4.5
1968	7.1	5.1	3.8	2.1	3.0	5.0	6.8	6.7					5.0
1969													
1970													
1971	9.4	6.8	5.8	4.6	6.3	8.9	9.1	8.2	7.1	4.4	4.5	5.6	6.7
1972	5.8	6.0	2.4	2.9	3.0	5.6	6.1	5.4	5.5	3.2	3.3	5.8	4.6
1973	5.5	4.8	4.0	5.4	6.4			6.1	6.5	5.8	2.6	5.5	5.3
1974	5.7	5.4	3.8			5.7	7.7	5.6	6.6	4.3	5.6		5.6
Mean m/s	6.3	5.3	3.8	4.0	4.9	6.7	7.1	7.1	6.4	3.2	3.5	5.0	5.3
* m.p.h.	14.0	11.9	8.6	8.9	11.0	15.0	15.9	15.8	14.3	7.2	7.8	11.2	11.9
* km/hr	22.5	19.1	13.8	14.2	17.7	24.0	25.6	25.4	23.0	11.5	12.6	17.9	19.0

* 1 meter/second = 2.24 miles per hour = 3.6 kilometers/hour

Table 3.3.7. 26 Years of Wind Speed Data for Beletweyn
in meters/second.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1954	3.1	2.1	1.9	0.9	3.4	5.1	4.9	4.3	3.8	1.4	2.3	3.8	3.1
1955	3.1	3.7	2.0	1.7	3.8	5.2	4.7	4.0	4.6	1.6	2.1	3.4	3.3
1956	4.0	3.6	1.9	2.0	3.6	4.5	4.5	4.9	5.2	3.2	3.8	4.3	3.8
1957	4.8	3.9	2.5	1.9	2.6	6.0	5.5	6.4	4.3	2.0	1.2	3.3	3.7
1958	3.5	4.5	3.5	2.4	4.5	5.8	5.5	6.1	4.2	2.2	2.9	3.7	4.1
1959	4.1	4.3	4.1	2.4	4.4	7.1	6.6	6.7	5.4	2.3	2.7	4.4	4.5
1960	4.8	3.8	2.5	2.1	3.6	5.2	5.1	5.8	3.4	1.8	1.2	3.2	3.5
1961	3.0	3.0	2.9	2.1	3.0	3.7	5.1	2.1	3.4	1.7	9.0	3.1	3.5
1962	3.4	3.4	2.5	1.8	3.0	4.1	5.1	4.3	3.6	2.2	2.2	2.8	3.2
1963	4.2	3.2	2.5	1.7	2.3	4.3	5.5	5.7	4.1	3.2	1.5	2.8	3.4
1964	4.5	2.9	2.4	1.5	3.5	4.5	5.3	5.1	4.5	2.2	1.7	3.3	3.5
1965	3.2	3.5	2.7	2.2	2.9	4.1	4.8	4.5	3.7	2.0	1.7	2.9	3.2
1966	2.9	2.8	2.8	2.0	3.0	5.1	5.3	4.5	3.8	2.4	2.4	3.4	3.4
1967	3.4	2.8	2.2	1.9	2.1	4.2	4.4	4.3	3.8	2.1	2.0	2.0	2.9
1968	2.8	2.3	2.1	1.7	2.1	2.9	3.9	3.6	3.1	2.5	2.1	2.5	2.6
1969	3.7	4.2	2.5	2.6	2.5	4.3	5.0	5.2	3.9	2.0	5.1	3.6	3.6
1970	2.3	2.6	2.0	1.4	2.3	4.3	4.6	5.4	4.2	2.7	2.7	3.6	3.2
1971	4.9	4.9	3.7	2.8	3.2	5.8	5.0	5.7	4.8	2.4	2.5	4.0	4.1
1972	3.3	4.5	3.8	3.5	2.8	4.9	6.0	5.8	5.0	2.5	2.5	3.5	4.0
1973	4.9	4.1	2.7	2.5	3.0	5.2	5.6	6.0	4.3	2.5	2.5	3.5	3.9
1974	4.1	4.4	3.1	2.3	3.2	5.1	5.5	5.5	5.0	2.9	2.9	4.0	4.0
1975	3.8	3.9	3.8	2.5	3.6	5.2	5.2	5.6	5.5	3.3	3.0		4.1
1976	5.0	3.5	4.0	4.0		6.0	6.0	6.0	6.0	4.0	4.5	4.5	4.9
1977	6.0	4.0	3.5	2.5	2.5	5.0	5.5	5.5	4.0	2.5	2.5	3.5	3.9
1978			3.5	3.5	4.5	7.5	6.0	6.0	6.0	2.5	3.5	4.5	4.8
1979	5.0	4.5	4.0	2.5	3.0	4.5	6.0	6.0	4.5	4.5	3.0	3.0	4.2
1980	4.0	4.0	4.0	3.0	4.5	5.5	8.0	5.6	6.0	3.5	3.0	4.1	4.6
Mean m/s	3.9	3.6	2.9	2.3	3.2	5.0	5.4	5.2	4.4	2.5	2.8	3.5	3.7
* m.p.h.	8.8	8.1	6.6	5.1	7.1	11.2	12.0	11.7	10.0	5.6	6.3	7.7	8.4
* km/hr	14.1	13.1	10.5	8.2	11.5	18.0	19.3	18.7	16.0	9.1	10.2	12.4	13.5

* 1 meter/second = 2.24 miles per hour = 3.6 kilometers/hour

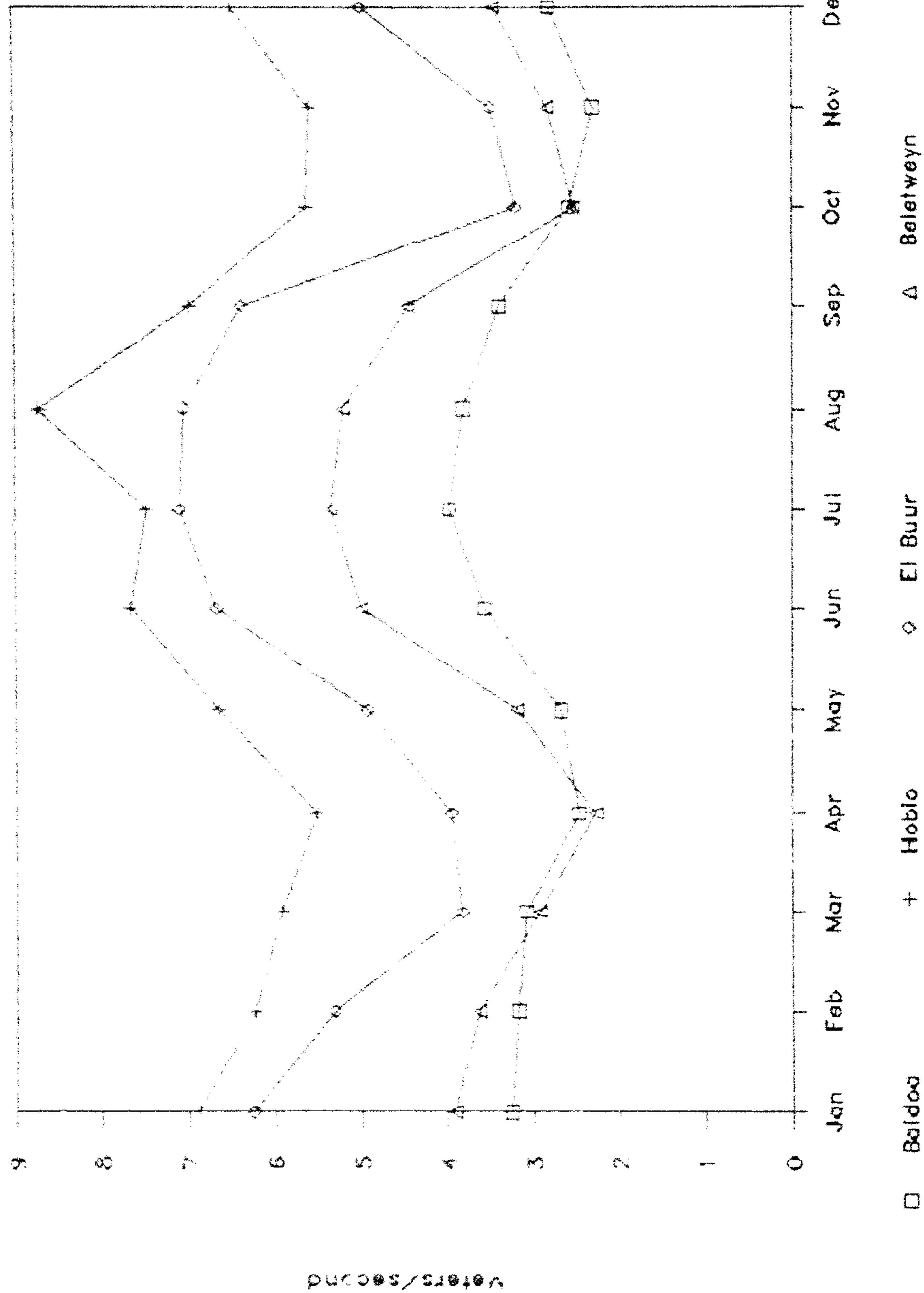


Figure 3.3.8 WIND SPEEDS FOR SELECTED STATIONS

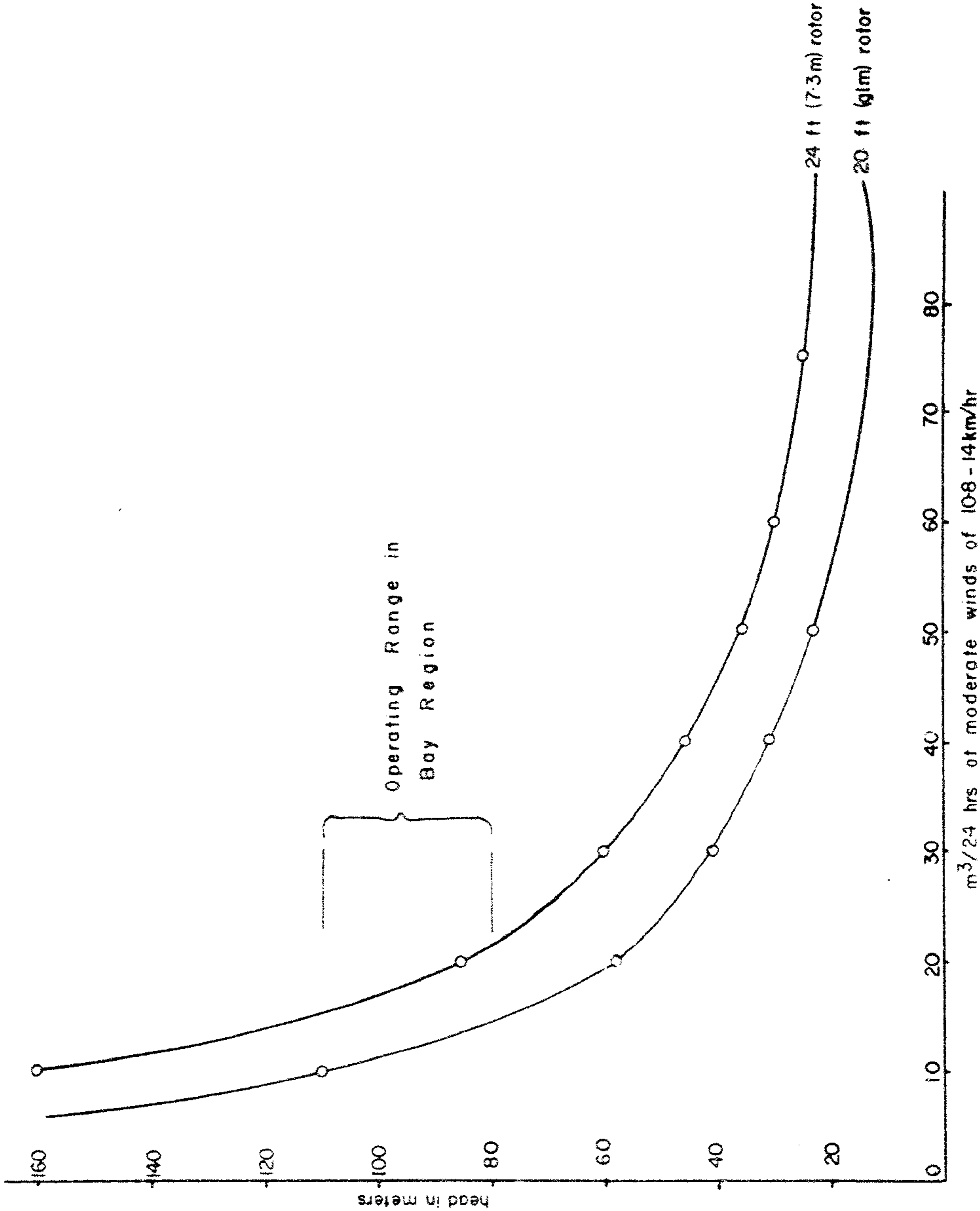


FIGURE 3·3·9 KIJITO PUMP PERFORMANCE GRAPH currently operated by WDA, and for which there are many qualified operators in Somalia, should be given preferance for all drilling in areas where reliable information indicates aquifers of less than 100 meters. (The depth capability of currently available cable-tool rigs in Somalia is approximately 125 meters). Productive drilling at these depths could include, for example, drilling along the coastal plain or in the Shabelle River floodplain. Exploratory boreholes as well as production wells in many regions of the Central Rangelands will continue to require rotary drilling.

In most of the Central Rangelands the presence of unconsolidated or weakly cemented sands makes the utilization of mud-rotary techniques preferable to air-rotary drilling. It is recommended that special drilling muds or additives be made available that can be used with the available saline makeup water. Soda ash should be made available for reducing the hardness and for raising the pH of the drilling fluid. The next most frequently encountered problem in mud-rotary drilling was lost-circulation zones. Lost circulation material should be made available whenever mud-rotary drilling is planned.

Whenever possible plastic well casing should be utilized to alleviate anticipated corrosion/incrustation problems. Care should be taken to insure that the pipe manufacturer's depth limitations are observed.

In most areas of the Central Rangelands, drilling will continue to be on an exploratory basis for the foreseeable future. Exploratory wells should be drilled with a small-diameter, 4 to 6-inch, pilot hole that can be better utilized for geophysical logging, well testing and design. In most cases, a significant amount of surface casing will have to be set to seal-off the shallow saline groundwater.

Reaming bits, roller bits, and rock bits should all be available to any drilling program operating in the Central Rangelands. Drilling in the basalts was accomplished during this project with a downhole hammer bit, but tricone button bits are recommended for future drilling.

One frequently encountered problem with mud drilling in the Central Rangelands is the extreme distances which must be traversed for makeup water. A minimum of two 10,000 liter-capacity water trucks should be available for remote sites.

All support vehicles operating in the Central Rangelands should be four-wheel drive equipped with flotation tires. Loose blowing sand is the predominate surface material.

3.8.2 Hand Dug Wells

Hand-dug wells are, and will continue to be, the most important water source for the nomadic population of the Central Rangelands. The most significant beneficial impact on the overall water supply in the area would be the rehabilitation of the existing hand-dug wells. The majority of the existing hand-dug wells in the Central Rangelands are simply unstructured holes. Providing some sort of borehole support, such as culvert rings or other masonry construction, would alleviate some of the maintenance problems associated with these wells. Concrete rims with aprons that slope away from the wells would prevent the entrance of polluted water and significantly improve the sanitary conditions of the water. A typical hand-dug well design which could be easily constructed by local labor in the Central Rangelands is presented in Figure 3.3.10. Rehabilitation or hand-dug wells was successfully accomplished by the CRDP and should be encouraged and continued (Figure 3.3.11). Additional modifications to improve sanitary conditions adjacent to the well are shown in Figure 3.3.12.

The most widespread method of lifting water from the hand-dug wells is by manually hauling a bucket attached to a rope. This method is labor intensive and time consuming, but it involves no payments. There is no indication that the local population is interested in utilizing animal power to accomplish water lifting, even in wells from which the water must be lifted 25 meters. Although animal power has been utilized for water lift in Mogadishu and Merca, it is not thought to be appropriate for widespread utilization in the Central Rangelands. Curiously, the local population has shown little interest in hand pumps. This seems to be due to the fact that water can generally be produced quicker by manual bailing than by hand pumps. The main benefit of hand pumps over bailing is in sanitation, which is an intangible benefit not appreciated by the rural population.

Diesel pumps are the most favored method of water lift by the local population. The required maintenance for the pumps, casing, and motors, however, makes for extremely short operational life at most wells. The lack of resources available for well maintenance results in costly situations where replacement wells are drilled instead of maintenance being performed on an existing system. It is our observation, however, that the local population puts an extremely high value on wells and will do anything possible to keep a well operable. It is difficult to conceive of any rigorous economic evaluation that would demonstrate the economic viability of diesel-powered pumps in the Central Rangelands.

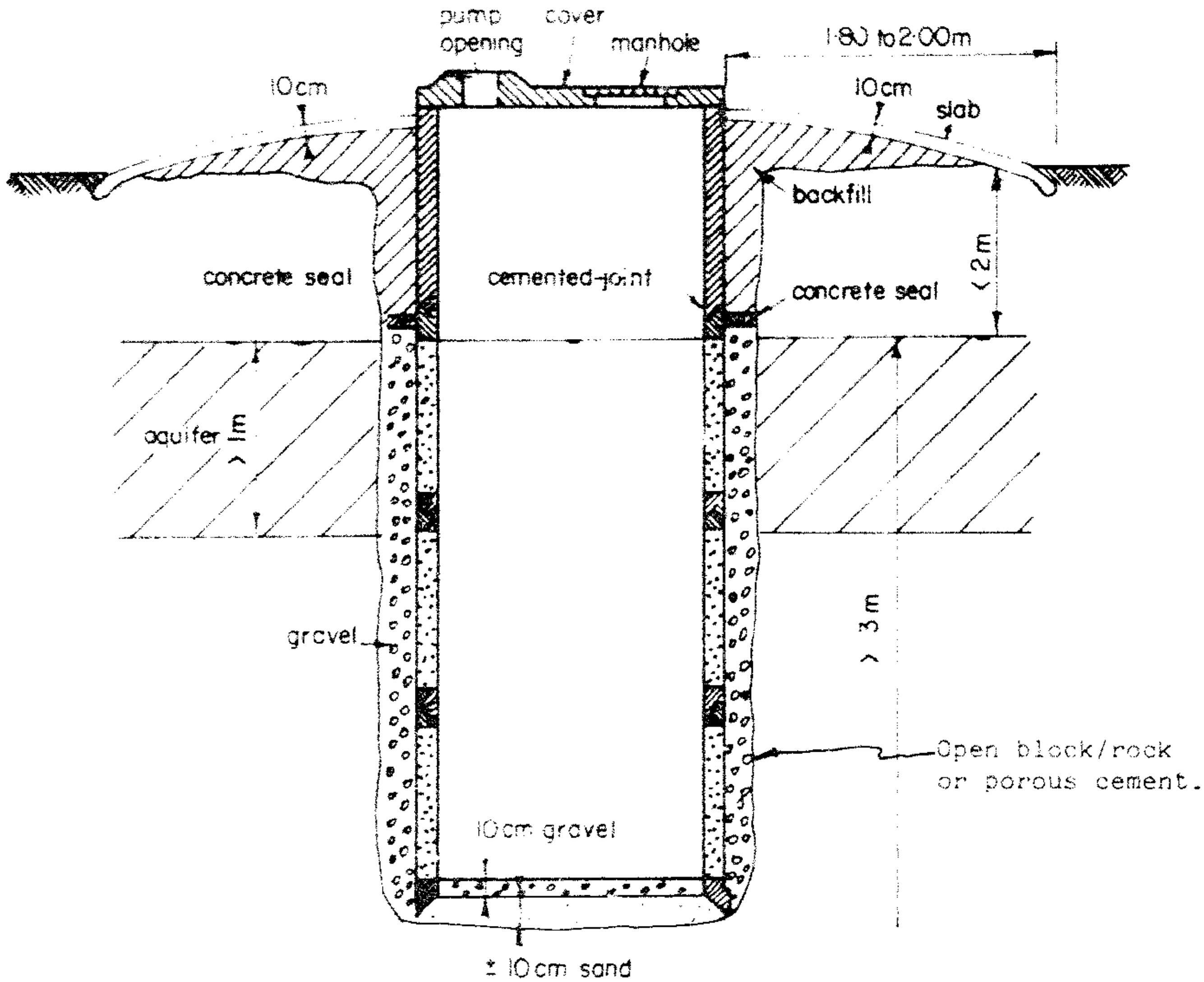


Figure 3.3.10 TYPICAL HAND DUG WELL CONSTRUCTION.

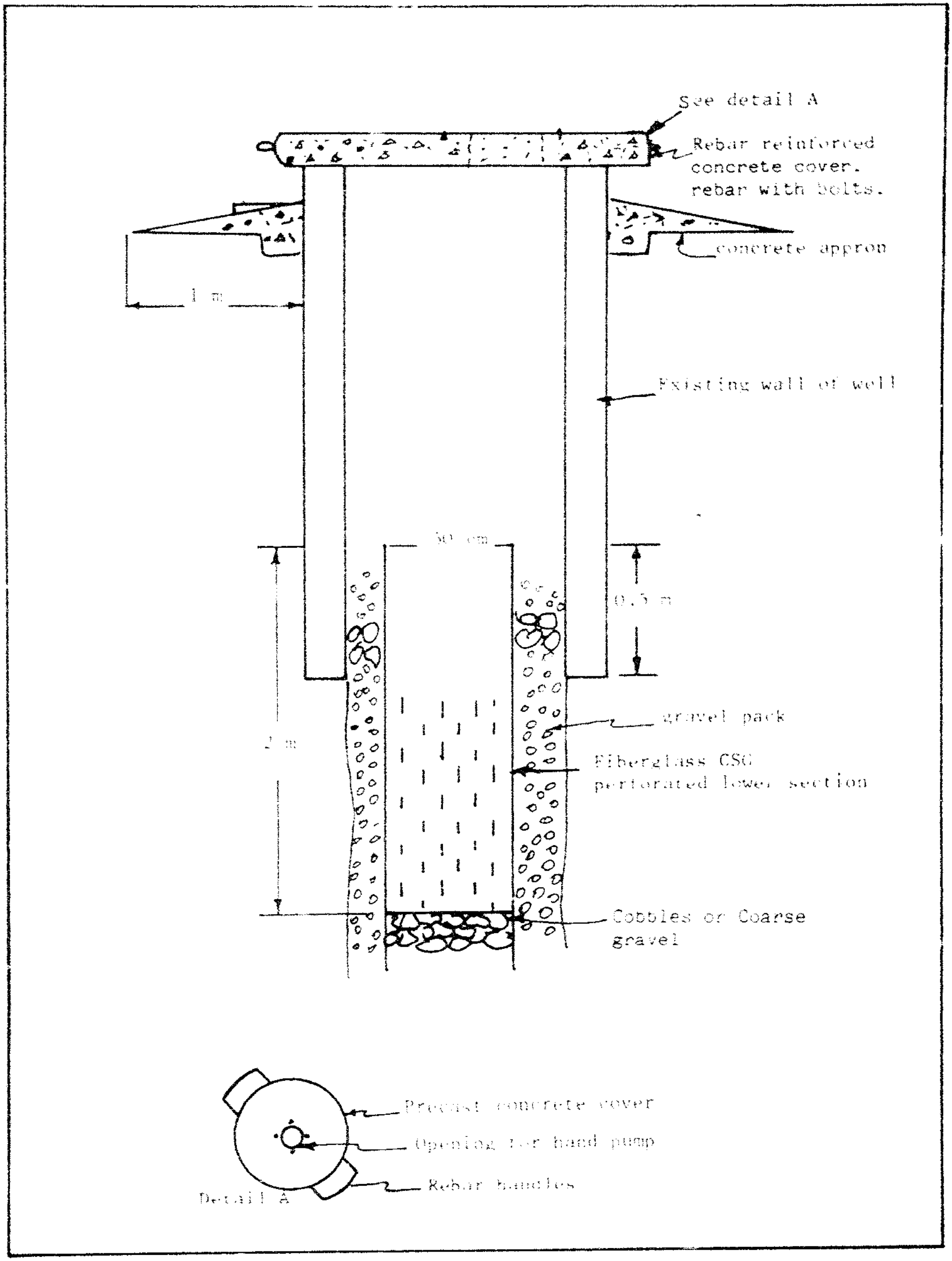


Figure 3.3.11 PROPOSED REHABILITATION FOR DUG WELLS IN SANDS.

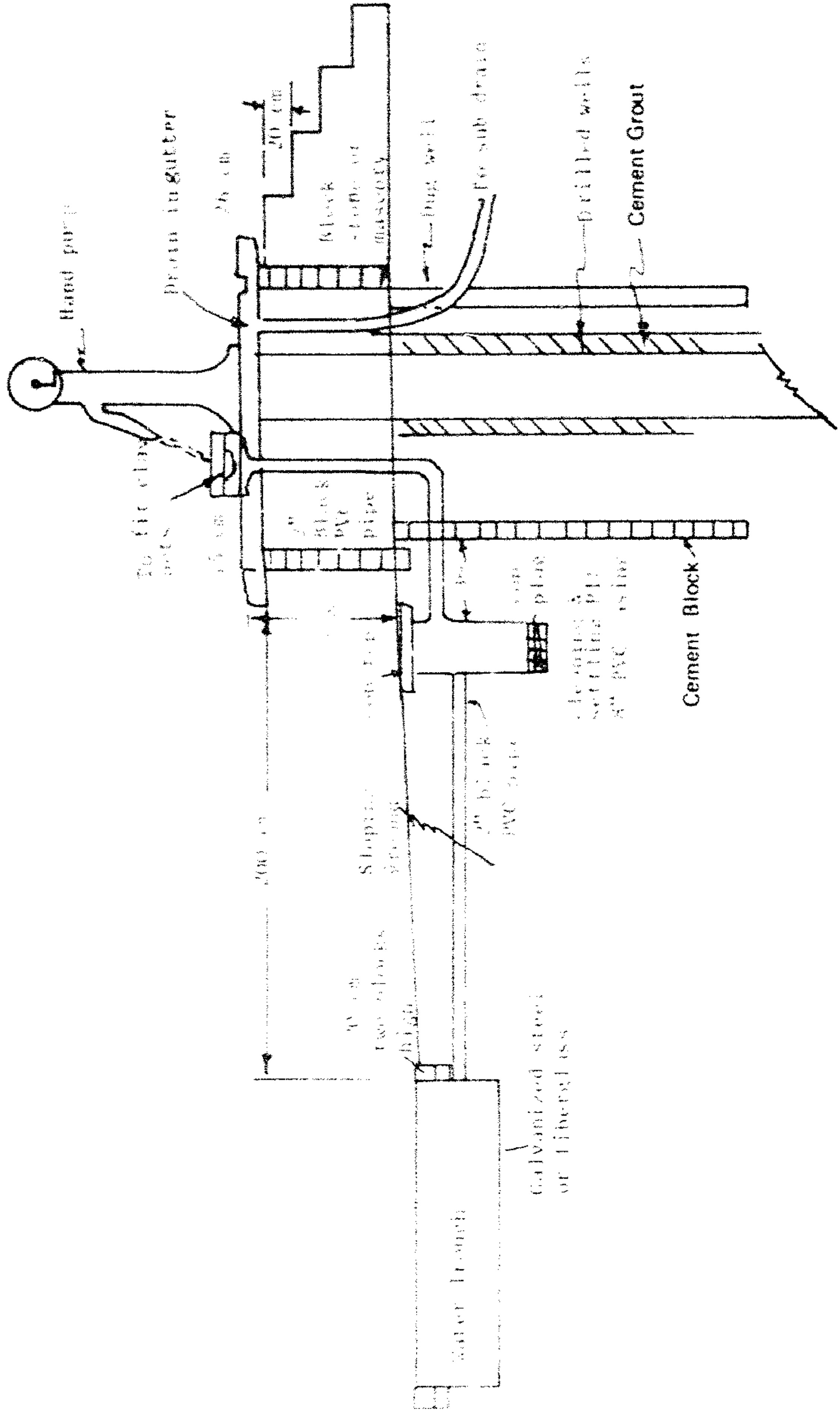


Figure 3.3 12 PROPOSED MODIFICATION TO DUG WELLS AND DESIGN FOR DRILLED WELLS.

3.8.3 Water Lift

It is thought that the Central Rangelands would be more economically, and perhaps more practically, served by the utilization of wind-driven pumps. The majority of the pumping water levels encountered are less than 100 meters and are well within the limitations of commercially available windmills. Windmills do require maintenance, however, and the presence of several inoperable windmills suggests that it does not get done. Nevertheless, it is recommended that wind-driven pumps be considered in the future water development of the Central Rangelands.

3.8.4 Infiltration Galleries

An infiltration gallery is a horizontal well or subsurface drain that intercepts underflow in permeable materials. This type of system allows for development of groundwater resources in areas where conditions, such as a thin aquifer underlain by saline water, preclude groundwater development by normal wells. This type of groundwater development would be uniquely suitable for areas along the coastal plain in the Central Rangelands.

In many areas along the coastal plain of Somalia shallow hand-dug wells, often placed in wadis, tap the thin layer of fresh water which "floats" on the more saline water below. These wells produce a small amount of fresh water, but quickly become saline when overproduced. Numerous wells of this type can be seen along the coast between Ceel Dhere and Hobyo. The installation of infiltration galleries to skim the fresh water off the saline water could greatly increase the water available in these areas.

The galleries should be constructed normal to the direction of flow by excavating a trench and placing a perforated plastic pipe horizontally. This pipe should not be less than eight inches in diameter, and should feed into a sump which could be fitted with a hand pump. The pipe should be completely surrounded with permeable gravel. A typical infiltration gallery for use along the coastal plain is presented in Figures 3.3.13 and 3.3.14. Design equations for infiltration galleries are presented in Groundwater Manual (U.S. Dept. of the Interior, 1981).

Another application of the infiltration gallery could be in the development of springs. While springs are not abundant in the Central Rangelands they are an important water source in some locales. Near the village of Jessoma, for example, a perennial spring from the Jessoma Sandstone produces on the

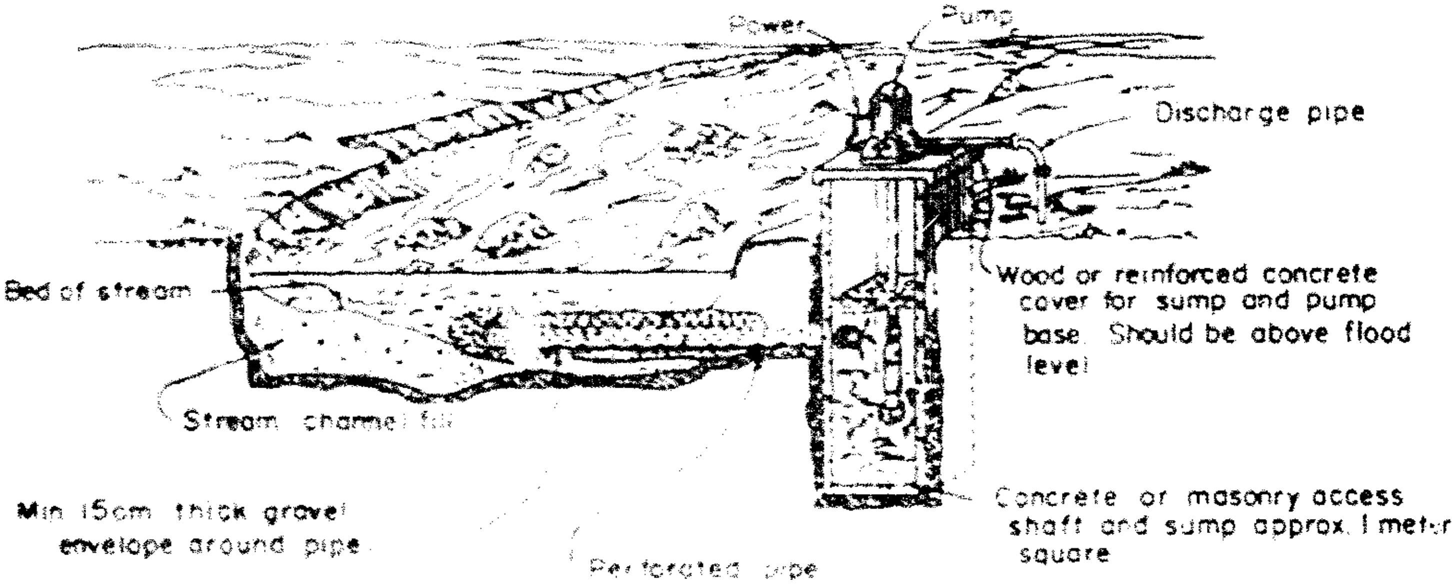


Figure 3.3.13 SCHEMATIC SECTION OF AN INFILTRATION GALLERY

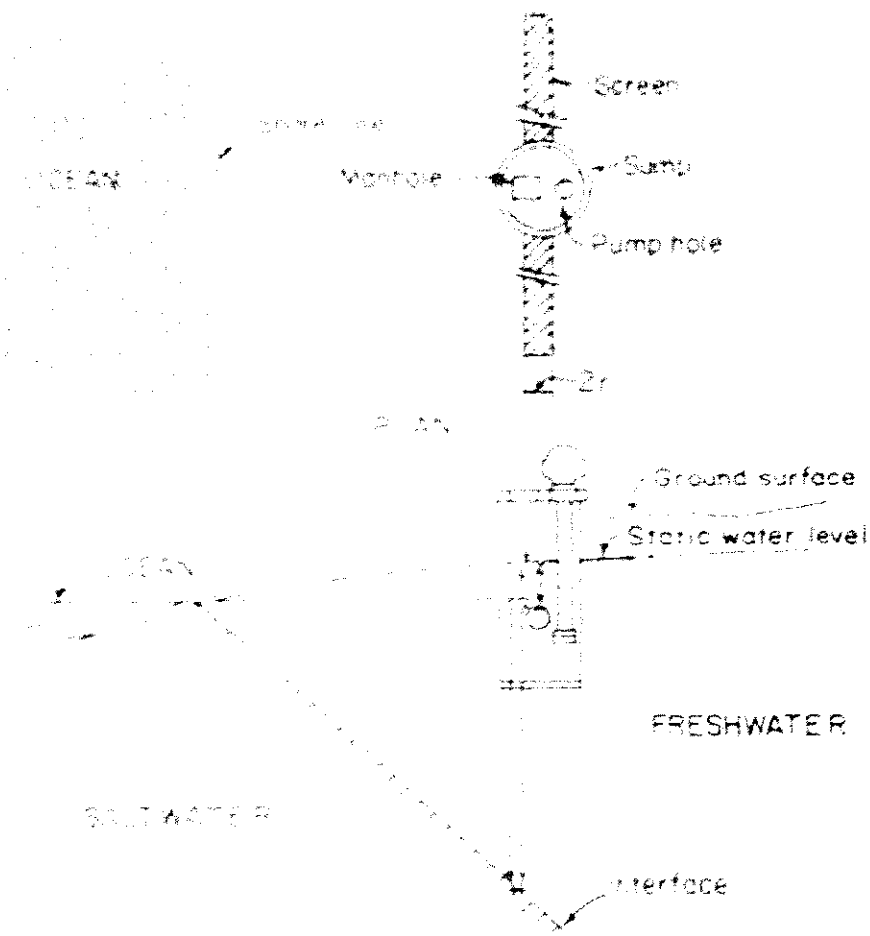


Figure 3.314 SCHEMATIC SECTION OF AN INFILTRATION GALLERY CONSTRUCTED TO OBTAIN FRESH WATER NEAR A COAST.

order of 20 liters per minute and provides a reliable source of water to the local population. This spring discharges into a thin alluvial channel in which an infiltration gallery could be constructed and equipped with a pump and water storage facilities. This would greatly improve the efficiency and the sanitation of this water supply.

3.8.5 Surface Water Catchments

Surface-water catchments provide a large portion of the water utilized in the Central Rangelands. In some regions of the Central Rangelands, especially in the eastern portions of the Mudugh and Galgadud regions where groundwater is frequently saline, surface-water catchments are the most viable alternative. The surface water catchments usually consist of three-sided dugouts termed "wars". These wars are sited by local experience to collect and store surface runoff. Local knowledge concerning the placement of wars is relatively sophisticated but improvements in the construction could be achieved.

The main problems observed at the wars are erosion of the feeder channels and inlets, excessive sedimentation, and seepage losses. Although there are generally insufficient meteorological data to justify detailed design of optimum war capacities, some improvements to the wars could be realized with relatively simple measures (Figure 3.3.15).

Most wars collect water from several drainage channels that come together at a narrow inlet of the war. As the water is concentrated into a narrow channel, the flow energy increases and causes soil erosion. Two simple solutions to the inlet erosion problem are; increasing the channel width, and utilizing cobble-sized stones for armour.

Most surface catchments experience excessive seepage losses when first constructed. After the war has been filled several times, however, a layer of fine silt builds up in the bottom of the war and reduces these losses. These initial and any subsequent seepage losses could be reduced in several ways. In some instances, native clays could be used as liner material. Where native clays were not available, additives, such as bentonite could be mixed in with the soil to reduce permeability. Plastic liners could be installed, but are expensive and require semi-skilled labor. Figure 3.3.16 shows typical catchment-berked modifications.

The most practical and economical technique would be to mix bentonite with the soil as the war is excavated. Subsequent compaction of the soil with the construction equipment, or with

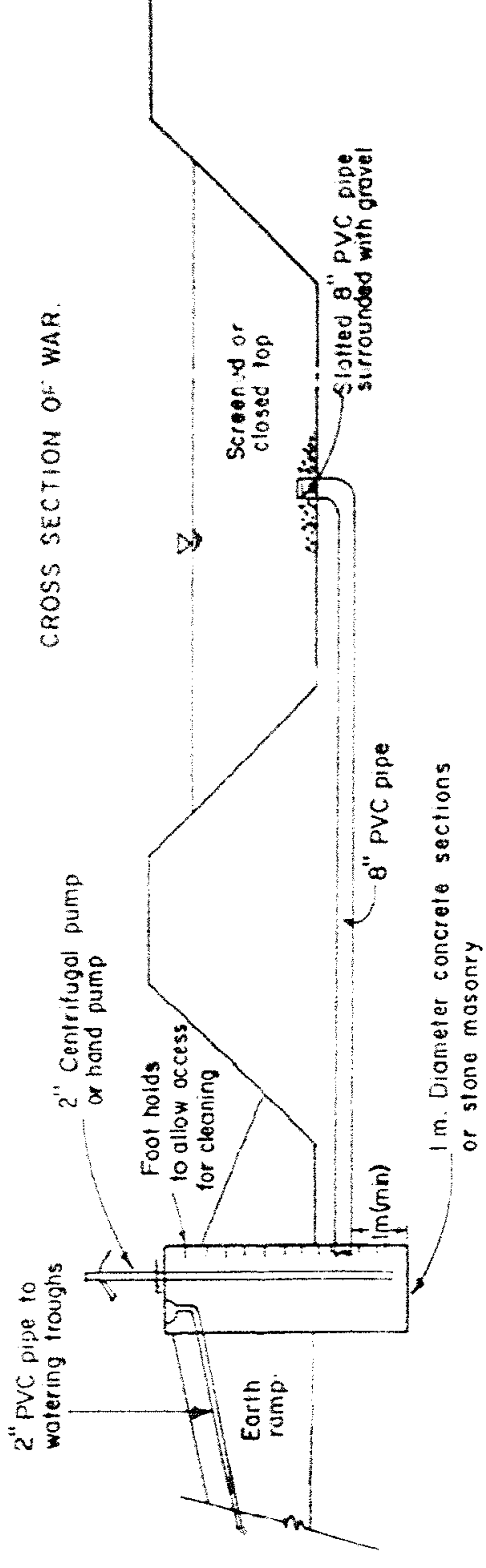


Figure 3.3.15 MODIFICATION TO WARS TO PREVENT DESTRUCTION OF BANKS AND CONTAMINATION OF SOURCE.

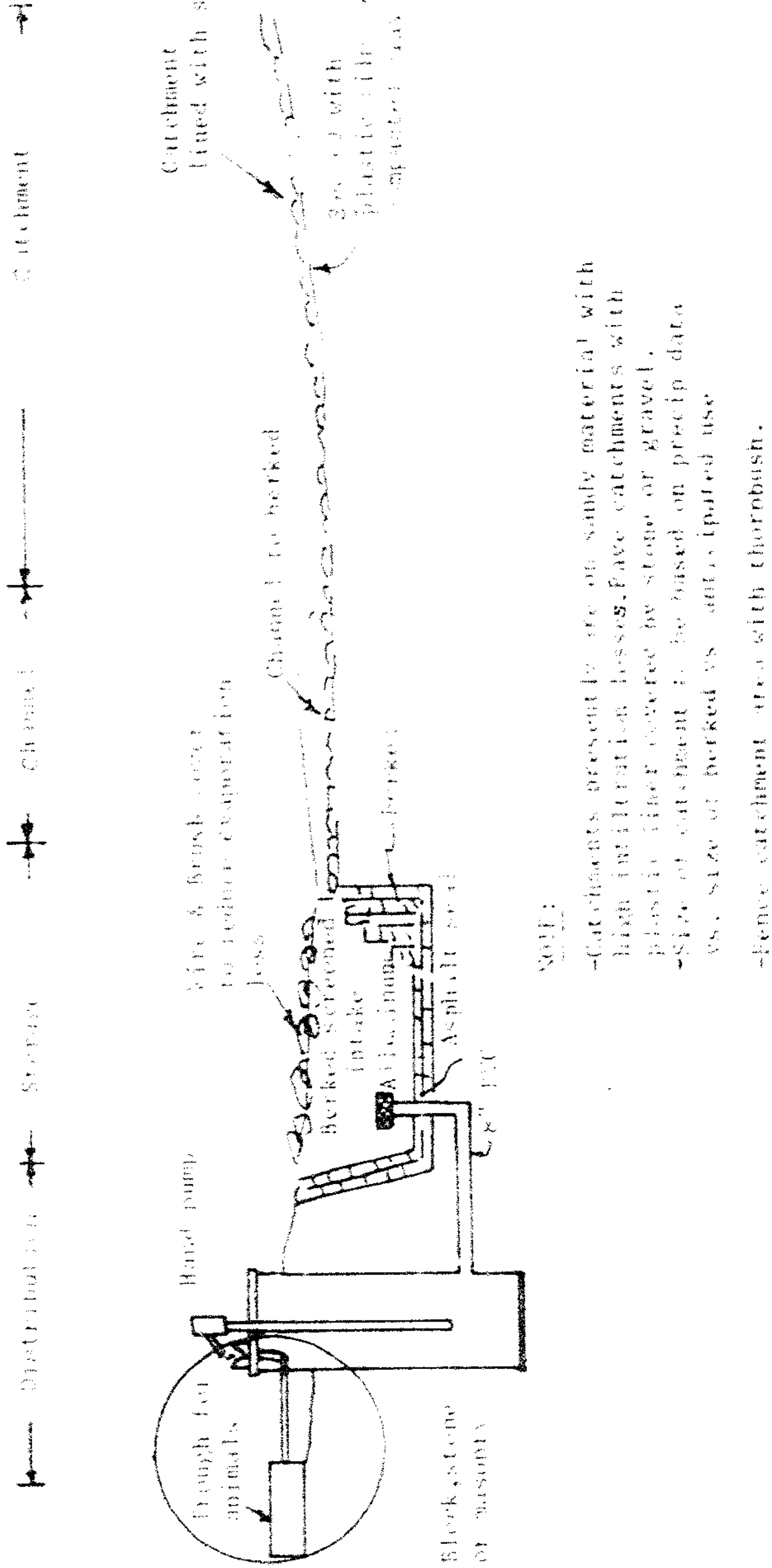


Figure 3.3.16 CATCHMENT - BERKED MODIFICATION.

animals would increase the effectiveness of the bentonite-soil mixture. A map of potential sites for surface-water catchments has been prepared by Resource Management and Research (1984). This map is shown as Figure 3.3.17. A program to collect meteorological data would facilitate the rational planning of surface-water facilities in the Central Rangelands. At minimum, rain-gauge stations should be established throughout the area and maintained indefinitely.

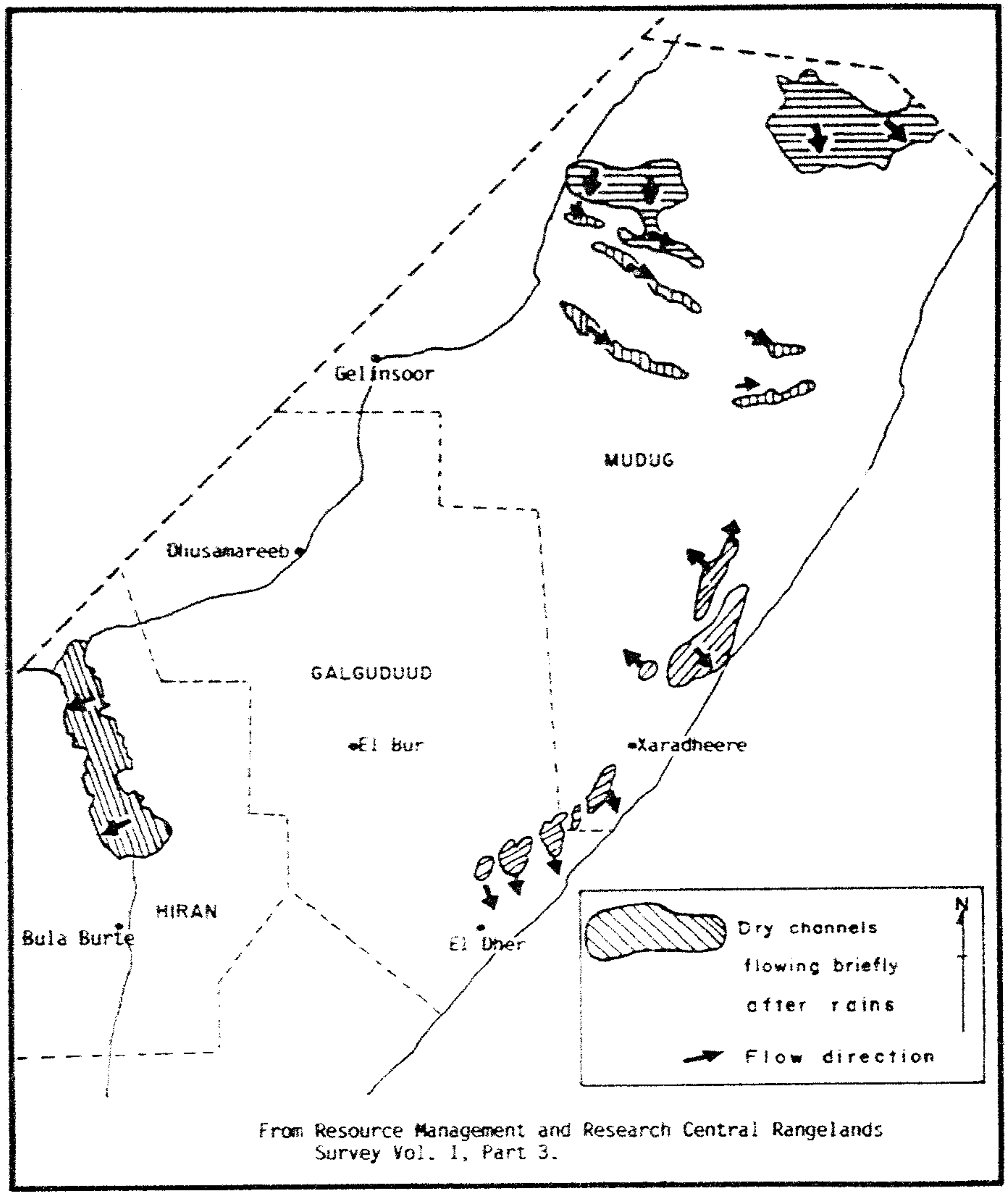


Figure 3.3.17 LOCATIONS OF SURFACE DRAINAGE CHANNELS WITH A POSSIBLE DEVELOPMENT POTENTIAL.

GLOSSARY OF TERMS
Adapted, with modifications, from "Water Well Technology"

by Campbell and Lehr, 1973, McGraw-Hill, New York. Additional terms by consultant noted with asterisk.

Anion. A negatively charged ion or radical.

Annular Space. The space between the casing referred to and the well bore or casing surrounding it.

Aquiclude. A formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish a useable supply for a well or spring.

Aquifer. An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield useable quantities of water to wells and springs.

Aquifuge. A rock without inter-connected openings which neither absorbs nor transmits water.

Area of Influence. The area beneath groundwater or pressure-surface contours modified by pumping.

Artesian. Artesian is synonymous with confined. Artesian water and artesian water body are equivalent respectively to confined groundwater and confined water body. An artesian well is a well deriving its water from an aquifer bounded above and below by impermeable materials. The level in an artesian well stands above the top of the water body it taps.

Artesian Well. A well tapping a confined or artesian aquifer in which the static water level stands above the aquifer. The term is sometimes used to include all wells tapping confined water, in which case those wells with water level above the water table are said to have positive artesian head (pressure) and those with water level below the water table, negative artesian head.

Basalt. A fine-grained basic rock usually occurring in volcanic flows, dikes, and sills.

Bed. Layer in sedimentary rock; stratum.

Bedding, Bedding Plane. Plane of stratification; the surface marking the boundary between a bed and the bed above or below it.

Bentonite. A highly plastic, colloidal clay composed largely of montmorillonite.

Bridge. An obstruction to circulation of drilling fluids in a borehole.

Calcium. Ca. The most frequent cause of hardness. Affects the scale-forming and corrosive properties of water.

Capillarity. The property of tubes with minute openings which, when immersed in a fluid, raise or depress the fluid in the tubes above or below the surface of the fluid in which they are immersed.

Capillary Fringe. The zone immediately above the water table, in which all or some of the interstices are filled with water, that is under less than atmospheric pressure and that is continuous with the water below the water table. The water is held above the water table by interfacial forces (surface tension).

Casing Shoe. A heavy-walled steel coupling or band at the lower extremity of the casing.

Cation. A positively charged ion or radical.

Cement Slurry. A pumpable mixture of cement and water.

Chert. Cryptocrystalline variety of quartz. SiO_2 G. 2.65, H. 7.

Chloride. The chlorides of calcium, magnesium, sodium, iron, etc. normally found in water are extremely soluble. In natural waters high chloride usually is from salt formations in the earth or from sea-water intrusion. A salty or brackish taste may be imparted to water by sodium-chloride.

Chlorination. The process of introducing a chlorine solution into a well for sterilization. Process used for well development where bacteria are found to be a major problem.

Circulation (Drilling). The drilling fluid movement from the mud pit, through the pump, standpipe, hose, drill pipe, annular space in the hole, and circulating ditch back to the mud pit.

Clay. A soft, plastic, variously colored earth composed largely of hydrous silicate of alumina, formed by the decomposition of feldspar and other aluminum silicates.

Clay Minerals. A family of minerals, most of them hydrous aluminum silicates and all either finely crystalline or amorphous. All those which crystallize are monoclinic. Species are indistinguishable except by laboratory methods.

Conductance (Specific). A measure of the ability of the water to conduct an electric current. It is related to the total concentration of ionizable solids in the water. It is inversely proportional to electrical resistance.

Conductivity, Hydraulic. Replaces the term "field coeficient of permeability." If a porous medium is isotropic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Confined Groundwater. A body of groundwater overlain by material sufficiently impervious to sever free hydraulic connection with overlying groundwater except at the intake. Confined water moves in conduits under the pressure due to difference in head between intake and discharge areas of the confined water body.

Confining Bed. Is a term which may now supplant the terms "aquiclude," "aquitard," and "aquifuge" and is defined as a body of "impermeable" material stratigraphically adjacent to one or more aquifers.

Connate Water. Water entrapped in the interstices of a sedimentary rock at the time it was deposited.

Contact. Bounding surface between two rock units, especially the boundary between an intrusive and its host-rock.

Contamination. Denotes impairment of water quality by chemical or bacterial pollution to a degree that creates an actual hazard to public health.

Dip. The inclination of a bed or fault measured from the horizontal; thus the angle between a line in the bed perpendicular to the strike and the horizontal plane.

Dolomite. $CaMg(CO_3)_2$. Rhombohedral. G. 2.85. H. 3 1/2-4. A sedimentary rock similar to limestone, but containing magnesium. Perfect rhombohedral cleavage. Does not effervesce in dilute HCl (difference from calcite).

Dry Hole or Duster. A well drilled which produces no water of significant quantity.

Evaporite. Sediments deposited from aqueous solution as a result of extensive or total evaporation of the solvent.

Filtration Rate. Water loss per unit time.

Fissure. An extensive crack, break, or fracture in rock.

Formation. An assemblage of rock units grouped together into a single unit that is convenient for description or mapping.

Fracture. A break. Fracture is a general term to include any kind of discontinuity in a body of rock if produced by mechanical failure, whether by shear stress or tensile stress. Fractures include faults, shears, joints, and planes of fracture cleavage.

Fracture System. Group of fractures, faults or joints, consisting of one or more sets, usually intersecting or interconnected. System usually implies contemporaneous age for all of the sets.

Geomorphology. (1) That department of physical geography which deals with the form of the earth, the general configuration of its surface, the distribution of land and water, and the changes that take place in the evolution of land forms. (2) (Geol.) The investigation of the history of geologic changes through the interpretation of topographic forms.

Groundwater. Water in the zone of saturation.

Groundwater (Confined). Under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lower hydraulic conductivity than that of the material in which the confined water occurs.

Groundwater Divide. The boundary of the cone of pumping depression which separates the area of influence and the area outside. The boundary between groundwater flow directions as delineated on water table or potentiometic maps.

Groundwater (Unconfined). Water in an aquifer that has a water table. Water surface is open to atomospheric pressure.

Gypsum. $CaSO_4.2H_2O$. A soft mineral found in sedimentary deposits most commonly in large evaporite basins.

Hydraulic Gradient (Dimensionless). Is the change in static head per unit of distance in a given direction.

Hydrograph. A graphic plot of changes in flow of water or in elevation of water level against time.

Igneous Rock. Rock made by the solidification of molten matter that originated within the earth. Examples: solidified lava; intrusive granite.

Intrusive. Igneous rock, having while fluid, penetrated into or between other rocks but solidifying before reaching the surface.

Isohyetal Map. A map on which precipitation is plotted by connecting points of equal precipitation (isohyetal lines) showing rainfall distribution in an area.

Isopleth. A line on a map drawn through points of equal value, composition or concentration; similar to contours of contour maps.

Joint. A divisional plane or surface that divides a rock and along which there has been no visible movement parallel to the plane or surface.

Lateritic. Extreme type of weathering common in tropical climates. Iron and aluminum silicates are decomposed and silica (along with most other elements) removed by leaching. The product, laterite, is characterized by high content of alumina and/or ferric oxide.

Lattoral*. The near shore zone between high and low tide.

Loss of Circulation. The loss of drilling fluid into formation pores or crevices.

Metamorphism. Throughgoing change in texture or mineralogical composition of rock, usually brought about by heat, pressure, or chemically active solutions.

Methane. CH_4. A colorless, odorless, tasteless, combustible gas found in some groundwaters.

Neritic*. The sea-floor zone extending from low tide to 200 m.

Perched Groundwater. Groundwater in a saturated zone which is separated from the main body of groundwater by unsaturated rock.

Permeability. The capacity of water-bearing material to transmit water, measured by the quantity of water passing through a unit cross section in a unit time under 100 percent hydraulic gradient.

pH. A measure of the acidity or alkalinity of water; the negative logarithm of the hydrogen-ion concentration. Values less than 7.0 are acid, and greater than 7.0 are alkaline or basic.

Phreatophytes. Plants that inherently send their roots to the capillary fringe and deplete groundwater by transpiration.

Physiography. Physical geography; more specifically, the study or description of present land-surface features. Includes cultural aspects.

Porosity (Effective). The amount of interconnected pore space available for fluid transmission. It is expressed as a percentage of the total volume occupied by the interconnecting openings.

Potentiometric Surface. Replaces the term "piezometric surface," is a surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is then required to describe the distribution of head. The water table is a particular potentiometric surface.

Pyrite. FeS_2. Isometric. Commonly cubes and pyritohedrons; less commonly octahedrons. G. 5.02. H. 6-6 1/2. Brassy yellow with metallic lustre. A mineral found in sedimentary and igneous rocks.

Quartz. SiO_2. Hexagonal. G. 2.65. H. 7. Colorless to white but some varieties smoky, reddish, brown or amethystine. A very hard mineral commonly found in igneous/metamorphic rocks and sand.

Regolith. The mantle of loose soils, sediments, broken rock, etc. overlying the solid rock of the earth.

Regressive*. Emerging land area as a result of receding sea level.

Residue. The material left in the container after evaporating a sample of water and drying in an oven at a definite temperature; a measure of total dissolved solids.

Sedimentary Rock. Rock which originated as a sediment. The sediment may have been transported by wind, water, or ice and carried in the form of solid particles (sand, gravel, clay) or in solution (rock salt, gypsum, some calcareous sediments). Sedimentary rocks (unless still unconsolidated) have been indurated by cementation or by recrystallization.

Seepage. Seepage is used in this text in two distinct and different meanings: (1) The accepted usage up to the present time; (i.e., the appearance and disappearance of water at the ground surface. (2) As proposed in this text seepage (verb, to seep) designates the type of movement of water in unsaturated material. It is to be distinguished from percolation, which is the predominant type of movement of water in saturated material.

Soda Ash. (Washing soda, sodium-carbonate Na_2CO_3) Used to remove hardness from water by precipitating calcium and magnesium salts, to raise the pH of acidic waters, and to treat anhydrite-contaminated drilling mud.

Sodium. Na. Present in most natural waters. A high sodium to total cations ratio can be detrimental to soil permeability in agriculture.

Soil. The layer or mantle of mixed mineral and organic material penetrated by roots. It includes the surface soil (horizon A), the subsoil (horizon B), and the substratum (horizon C) which is the basal horizon and is limited in depth by root penetration.

Solids, Total, Dissolved and Suspended. Suspended solids are those which are not in true solution and can be removed by filtration. Dissolved solids are in true solution and cannot be removed by filtration. Total solids represent the sum of dissolved and suspended solids.

Specific Capacity. The rate of discharge of water from the well divided by the drawdown of water level within the well. It varies slowly with duration of discharge which should be stated when known. If the specific capacity is constant except for the time variation, it is roughly proportional to the transmissivity of the aquifer. The relation between discharge and drawdown is affected by the construction of the well, its development, the character of the screen or casing perforation, and the velocity and length of flow up the casing. If the well losses are significant, the ratio between discharge and drawdown decreases with increasing discharge; it is generally possible to roughly separate the effects of the aquifer from those of the well by step-drawdown tests. In aquifers with large tubular openings the ratio between discharge and drawdown may also decrease with increasing discharge because of a departure from laminar flow near the well, or in other words, a departure from Darcy's law.

Specific Conductance. The electrical conductivity of a water sample at 25°C expressed in micromhos per centimeter. (Also expressed as E.C. or electrical conductivity.)

Specific Yield. Is the ratio of (1) the volume of water which the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock of soil. The definition implies that gravity drainage is complete. In the natural environment, specific yield is generally observed as the change that occurs in the amount of water in storage per unit area of unconfined aquifer as the result of a unit change in head. Such a change in storage is produced by the draining or filling of pore space and is therefore dependent upon particle size, rate of change of the water table, time, and other variables. Hence, specific yield is only an approximate measure of the relation between storage and head in unconfined aquifers. It is equal to porosity minus specific retention.

Static Level. The water level in a nonpumping well outside the area of influence of any pumping well. This level registers one point on the water table in a water-table well or one point on the pressure surface in a confined-water well.

Storage Coefficient or Storativity, S. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined water body the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer. In an unconfined water body, the amount of water derived from or added to the aquifer by these processes generally is negligible compared to that involved in gravity drainage or filling of pores; hence, in an unconfined water body the storage coefficient is virtually equal to the specific yield.

Stratigraphy. Study of strata of sedimentary rocks, particularly with reference to correlation or determination of age. Adj. stratigraphic.

Stream (Gaining). A gaining stream, which replaces the term "effluent stream," is a stream or reach of a stream whose flow is being increased by inflow of groundwater.

Stream (Losing). A losing stream, which replaces the term "influent stream," is a stream or reach of a stream that is losing water to the ground.

Strike. The bearing of a horizontal line in the plane of a bed or fault.

Sulfate (Sulphate), SO_4. Relatively abundant in hard waters, sulfate is widely distributed in nature. Its ability to combine with calcium forms calcium-sulfate.

Suite. An assemblage of rock units grouped together into a single unit convenient for description or mapping.

Surface Runoff. The runoff of rainfall which flows to stream channels over the surface of the ground.

Transgressive *. Submergence of land area by rising sea level.

Transmissibility. The hydraulic conductivity multiplied by the thickness of an aquifer.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It replaces the term "coefficient of transmissibility" because by convention it is considered a property of the aquifer, which is transmissive, whereas the contained liquid is transmissible. However, though spoken of as a property of the aquifer, it embodies also the saturated thickness of the aquifer and the properties of the contained liquid. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

Water-Cement Ratio. The amount of mixing water in liters used per sack of cement.

Water Spreading. Retention of water behind dams or in basins, maintenance of flow in ditches or stream channels, or feeding water down wells and shafts in order to develop influent seepage.

Water Table. That surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells which penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of groundwater flow exists.

Water-table Depression, Cone of. A cone of depression in the water table developed around a pumping well, the periphery of which (groundwater divide) delimits the groundwater moving toward the well.

Zone of saturation. That part of the water-bearing material in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric. The saturated zone may depart from the ideal in some respects. A rising water table may cause entrapment of air in the upper part of the zone of saturation, and the lower part may include accumulations of other natural fluids. The saturated zone has been called the phreatic zone by some.

Zone (Unsaturated). The unsaturated zone, which replaces the terms "zone of aeration" and "vadose zone," is the zone between the land surface and the water table. It includes the capillary fringe. Characteristically this zone contains liquid water under less than atmospheric pressure, and water vapor and air or other gases generally at atmospheric pressure. In parts of the zone, interstices, particularly the small ones, may be temporarily or permanently filled with water. Perched water bodies may exist within the unsaturated zone.

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