Hydrogeology And Groundwater Resources Of The North-West Frontier Province Pakistan

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HYDROGEOLOGY AND GROUNDWATER RESOURCES OF THE NORTH-WEST FRONTIER PROVINCE PAKISTAN

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UNITS AND CONVERSIONS

Length	*units:* metre: m; foot: ft; inch *conversions:* 1 m = 100 cm = 3.28 ft 1 ft = 30.48 cm = 0.3048 m 1 cm = 0.39 inch 1 inch = 2.54 cm
Area	*units:* square metre: m^2; hectare: ha; square foot: ft^2; acre *conversions:* 1 m^2 = 10.76 ft^2 1 ft^2 = 0.093 m^2 1 ha = 10,000 m^2 = 2.47 acres = 107,573 ft^2 1 acre = 0.4046 ha = 4046 m^2 = 43,552 ft^2
Volume	*units:* cubic metre: m^3; litre: l; cubic foot: ft^3; (US)gallon: gal; acrefoot *conversions:* 1 m^3 = 1000 (l) = 260 g 1 gal = 3.79 l = 0.00379 m^3 1 ft^3 = 28.32 l 1 l = 0.0353 ft^3 1 Mm^3 = 10^6 m^3 = 811.7 acrefeet 1 acrefoot = 43,552 ft^3 = 1232 m^3
Time	*units:* year: yr; day: d; hour: h; minute: min.; second: s *conversions:* 1 yr = 365 d = 8760 h = 525,600 min = 31.563 x 10^3 s 1 d = 1440 min = 86400 s
Flow rate	*units:* cubic metre per hour: m^3/h; litre per second: l/s; (US)gallon per minute: gpm; cubic feet per second: ft^3/s or cusec; acrefeet per year *conversions:* 1 m^3/h = 0.277 l/s = 4.405 gpm = 0.00970 ft^3/s or cusec 1 gpm = 0.227 m^3/h 1 cusec = 101.9 m^3/h (appr. 100 m^3/h) = 0.893 Mm^3/yr = 724.8 acrefeet/yr
Transmissivity	*conversions:* 1 m^2/d = 80.4 gpd/ft
Specific capacity	*conversions:* 1 m^3/hr per m drawdown = 1.340 gpm/ft dd. 1 gpm/ft dd. = 0.746 m^3/h per m dd.
Mass	*units and conversions:* 1 ton = 1000 kilogram (kg) = 2222 pound (lb) = 26.80 maund
Prefixes:	m: milli = one-thousanth c: centi = one-hundredth k: kilo = thousand M: mega = million

LIST OF ABBREVIATIONS

app.	appendix(ces)
BADP	Buner Agricultural Development Project
CGG	Compagnie General de Geophysique
cm	centimetre
cusec	cubic foot per second
d	day
dd.	drawdown
EC	Electrical Conductivity
FAO	Food and Agriculture Organization of the United Nations
FATA	Federally Administered Tribal Areas
FATA-DC	FATA-Development Corporation
fig(s)	figure(s)
ft	foot, feet
gpm	US gallons per minute
h	hour
hp	horse power
m	metre
meq/l	milliequivalent per litre
mg/l	milligram per litre
min.	minutes
mm	millimetre
mS	milliSiemens
msl	metres above sea level
Myr	million years
NBP	National Bank of Pakistan
NWFP	North-West Frontier Province
P and D Dept.	Planning and Development Department
PATA	Provincially Administered Tribal Areas
PHED	Public Health Engeneering Department
pl.	plate(s)
PMD	Pakistan Meteorological Department
PNCB	Pakistan Narcotics Control Board
p(p).	page(s)
ppm	parts per million
PWD	Public Works Department
s	second
SAR	Sodium Adsorpion Ratio
SCARP	Salinity Control and Reclamation Project
TDS	Total Dissolved Solids
UNFDAC	United Nations Fund for Drug Abuse Control
UNOPE	United Nations Office for Project Executi on
USAID	United States Agency for International Development
w	week
WAPDA	Water and Power Development Authority, Pakistan
WAPDA-HDP	WAPDA Hydrogeology Directorate Peshawar
WMO	World Meteorological Organization
WASID	Water and Soil Investigations Division of WAPDA
yr	year

PREFACE

Groundwater studies that were started by WAPDA's Water And Soil Investigations Division and continued by WAPDA Hydrogeology Directorate received new momentum, when in 1979 the Project "Groundwater Investigations in North-West Frontier Province" was started. In the framework of the bilateral development cooperation between the Governments of Pakistan and The Netherlands this project linked TNO Institute of Applied Geoscience from The Netherlands with WAPDA Hydrogeology Directorate Peshawar. Together they have studied most of the alluvial plains in NWFP (insofar as these are not commanded by surface water irrigation systems) and one plain in FATA. The purpose of the studies was to assess the exploitable groundwater resources and to establish where public sector tubewells with a yield of at least 100 m^3/hour or 1 cusec can be drilled. The senior project staff prepared 18 Technical Reports in which the results of the investigations were described areawise. These reports have been submitted to the Government of the North-West Frontier Province and also distributed to other interested parties.

Given the large number of reports on the groundwater conditions of NWFP it was felt that the conclusions should be consolidated in a document, which, although dealing with a technical subject, could be understood by the non-specialist too. The result is this book, compiled and edited on behalf of WAPDA Hydrogeology Directorate and TNO Institute of Applied Geoscience by Dr. G.P. Kruseman, TNO's Project Supervisor since 1983, who was assisted by Mr S.A.H. Naqavi, Project Director until December 1986.

The book is divided into two parts: Chapters 1 - 7 contain general information on the North-West Frontier Province and its geological formation and on aspects of the groundwater investigations, development and management; Chapters 8 - 15 comprise the description of the regional groundwater basins and their groundwater development potential, with an annotated bibliography for each area.

The book is based on the documents available; no additional field investigations were made. When the conclusions of the editors deviate from those of the authors of the reports referred to, this is clearly stated. The editors recognize that this book could not have been written without the hydrogeological work previously carried out by the staff of WAPDA-WASID, WAPDA Hydrogeology Directorate, TNO Institute of Applied Geoscience, and others. In this respect we wish to mention Mr. Abdul Qadir, Project Director at WAPDA Hydrogeology Directorate Peshawar, Mr Itrat Hussain Qureshi, superintending geophysicist, Mr. A.H. Mirza, superintending hydrogeologist, Mr. Mukhtiar Ahmad and Mr Muhammmad Ibrahim Khan, superintending engineers of the drilling section, the senior geophysicists Mohammad Akram Faiz and Abdullah Mir Khan, the senior hydrogeologists, Malik Muhammad Yousuf, Abdul Ghaffar Sheikh (deceased), Sajjad Ali Muhammad, Muhammad Yasin Malik, the executive engineer drilling Akhtar Jamal, the junior geophysicists, junior hydrogeologists, sub-engineers, plant superintendents and other staff of WAPDA Hydrogeology Directorate Peshawar; G. Jousma and W.P.G. Ewalts, TNO teamleaders, the TNO geophysicists: T. Stavenga and W. van Dalfsen, the TNO hydrogeologists: S. Bloemendaal and Dr H. Uil, and the visiting experts from TNO. The editors are very grateful to Mr. R.A. Shamsi, WAPDA Director General Hydrogeology, Mr. Khalid Moatullah, WAPDA General Manager (Planning) and Mr. F. Walter, Director TNO Institute of Applied Geoscience, for their continuous encouragement and guidance. They acknowledge gratefully the assistance and cooperation extended by WAPDA and the Provincial Government and also the permission given by the Governments of Pakistan and The Netherlands to use project funds for the preparation and publication of this book. Last but not least, they thank all the others, not mentioned here by name, who have contributed directly or indirectly to the production of this book.

The Editors

1 INTRODUCTION

1.1 THE PURPOSE AND SCOPE OF THIS BOOK

Groundwater has been used in the area that is now called the North-West Frontier Province (NWFP) of Pakistan since time immemorial. The climate is semi-arid, and therefore the people living some distance away from the perennial rivers depend on groundwater for their domestic use and to water their livestock and crops.
Systematic groundwater investigations in NWFP only started some 20 years ago. They were undertaken with the aim to develop means of producing groundwater for public water supply and irrigation, or to reclaim waterlogged areas in surface-water irrigation schemes. Most of NWFP's groundwater basins have been studied since then and the results of these studies have been presented in technical reports, which are however, not always easy for non-specialists to understand. With this in mind this book has been written and it is intended for the user, the development planner and the manager of the groundwater resources. At the same time it will provide the hydrogeologist with a ready overview and with references to the technical documentation.
The book is divided into two parts: Chapters 1 - 7 and Chapters 8 - 15. Chapter 1 contains a brief description of the relevant features and statistics of NWFP and Chapters 2 and 3 comprise the background knowledge required to understand the occurrence, the dynamics and the development potential of groundwater. The first part continues with a brief account of the methodology of groundwater investigations, and of the groundwater development carried out so far (Chapters 4 and 5). Chapter 6 summarizes our knowledge of the groundwater development potential in NWFP and Chapter 7 presents the actions required to achieve full use of this potential through scientific management of the groundwater resources. In Chapters 8 - 15 the groundwater basins or groups of basins are discussed in more detail. For each basin a brief general description precedes a description of the present water development situation, of the groundwater conditions and of the groundwater development potential. An annotated bibliography concludes each chapter; detailed data sheets are not included. A hydrogeological map of NWFP is not included because it will be prepared by WAPDA Hydrogeological Directorate in the framework of the Hydrogeological Map of Pakistan Project.

1.2 THE NORTH-WEST FRONTIER PROVINCE

The Province is situated on the northwest frontier of Pakistan. In the north and west it borders on Afghanistan; in the south and southeast it is bounded by Baluchistan and the Punjab, respectively, and in the east by Gilgit Agency and the territories of Jammu and Kashmir. It lies between latitudes 31°40' and 36°57'N and longitudes 69°16' and 74°70'E. Its maximum north-south extent is 657 km and its maximum east-west extent 449 km. It is approximately 100,220 km^2 in area, of which 74,521 km^2 are under provincial administration. The remainder covers the Federally Administered Tribal Areas (FATA), which are under the political control of the Federal Government Agent.
The North-West Frontier Province was created in 1901, and came under the jurisdiction of a Chief Commissioner and Agent to the Governor-General of India. At that time, the northern part of the province consisted of a number of princely states under the political control of a Political Agent. In 1931 the NWFP was upgraded to a fully-fledged province under a Governor in Peshawar. Between 1955 and 1970 the NWFP was merged with Punjab, Sind and Baluchistan into a single province: West Pakistan. In 1970 this decision was reversed and the pre-1955 provinces were restored. In the meantime, the princely states had lost their autonomy. Their former area is still known as Provincially Administered Tribal Area (PATA). At present, the only difference between the PATA and the "settled areas" is the absence of a "land ownership survey" in the former.
The territory of NWFP, excluding FATA, has five Divisions (Figure 1):

- Malakand Division, consisting of the Malakand Agency, and the Districts of Dir, Chitral and Swat;
- Peshawar Division, covering the Districts of Peshawar and Mardan;
- Harara Division on the left bank of the Indus river, covering the Districts of Abbottabad, Mansehra and Kohistan;
- Kohat Division covering the Kohat and Karak Districts;
- Dera Ismail Khan Division, which encompasses the Bannu District and the D.I. Khan District.

Each District is subdivided into a number of Tehsils.
FATA is subdivided into the Agencies of Bajaur, Mohmand, Orakzai, Khyber, Kurram, North Waziristan and South Waziristan, and the small Tribal Territories of Peshawar, Kohat and Bannu.

1.3 CLIMATE

The climatic conditions of the North-West Frontier Province are extremely diverse. The District of Dera Ismail Khan in the south is one of the hottest of Pakistan, with maximum temperatures between 46° and 50°C, while in the mountain-

Figure 1: Map of the North-West Frontier Province

ous region in the north, summers are temperate and winters often intensely cold. The air is generally dry, hence the difference in daily and annual temperatures can be very large (Table 1). Also there is a wide variation in precipitation, both in amounts and in distribution over the year.

In the mountains in the north of Mansehra District the annual

Table 1: Data from some meteorological stations in NWFP

A. PRECIPITATION (in mm)

Station		Period	Fall			Winter			Spring			Summer			Year
Latt. N	Long. E.	Alt. m	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Chitral		69/85	14	19	27	35	58	83	65	44	2	3	7	8	365
35°51'	71°47'	1475	4%			56%			30%			5%			
Saidu Shariff		66/80	64	10	45	35	112	107	104	46	23	110	113	48	817
34°41'	72°22'	975	9%			37%			18%			36%			
Chakdarra		30/80	21	17	43	86	82	114	64	30	13	91	104	46	711
33°39'	72°20'	670	5%			46%			13%			36%			
Daggar		71/83	32	25	31	73	94	46	87	42	55	148	190	85	908
34°30'	72°28'	720	6%			27%			14%			53%			
Tarbela		69/86	40	19	28	43	63	85	58	33	43	170	216	70	868
34°08'	72°50'	457	7%			25%			10%			57%			
Dir		72/75,77/80	32	50	52	71	74	175	128	72	41	120	122	82	1019
35°12'	71°05'	1375	8%			37%			20%			36%			
Shinkiari		61/79	40	33	46	63	110	130	120	59	81	246	231	89	1248
34°28'	73°16'	991	6%			28%			14%			52%			
Oghi		71/79	19	38	57	91	126	107	89	57	119	129	169	66	1067
34°30'	73°21'	975	5%			36%			14%			45%			
Bala Kot		71/79	20	47	56	97	130	121	88	63	106	329	275	94	1426
34°33'	73°21'	1128	5%			14%			11%			57%			
Mardan		33/65	10	16	42	44	38	109	76	33	12	109	85	61	635
34°11'	72°03'	305	4%			37%			17%			42%			
Risalpur		(?) 30/60	24	33	62	71	36	72	38	20	5	86	104	55	606
34°04'	71°59'	305	9%			40%			10%			41%			
Peshawar		??/??	10	10	15	39	41	65	42	40	7	39	41	14	363
34°01'	71°35'	359	5%			44%			23%			28%			
Cherat		??/??	25	29	79	84	85	109	67	62	22	110	125	51	848
33°50'	71°34'	1320	6%			42%			15%			36%			
Kohat		61/81	39	9	14	24	48	73	56	38	23	69	112	41	546
33°32'	71°28'	466	9%			29%			17%			45%			
Hangu		64/72	34	13	20	19	43	68	74	56	32	88	120	57	624
32°32'	71°04'	815	8%			24%			21%			48%			
Fort Lockhart		63/67	41	32	4	44	37	108	135	99	25	125	96	80	826
33°33'	71°55'	1905	9%			23%			28%			39%			
Parachinar		31/60	17	13	31	81	76	135	103	64	46	122	112	54	854
33°52'	70°05'	1748	4%			38%			20%			39%			
Bannu		40/79	9	6	13	20	30	43	40	18	10	70	52	20	331
33°00'	70°37'	381	5%			32%			18%			46%			
Sarai Naurang		49/66	8	7	9	20	18	38	37	19	8	64	47	20	295
32°50'	70°47'	306	5%			29%			19%			47%			
Lakki		49/66	4	7	9	17	18	30	30	15	12	53	41	23	258
32°36'	70°55'	274	4%			29%			17%			50%			
Miranshah		31/66	5	6	21	18	36	60	50	24	22	65	36	13	356
32°58'	70°05'	918	3%			38%			21%			38%			
Tank		61/76	1	4	14	9	22	28	25	24	14	59	50	11	261
32°12'	70°22'	250	2%			28%			19%			51%			
Dera Ismail Khan		47/81	3	11	9	8	21	24	21	17	20	55	55	15	259
31°50'	70°55'	174	5%			24%			15%			56%			

Table 1: (continued)

B. TEMPERATURE (in °C)

Station	Fall Oct	Fall Nov	Winter Dec	Winter Jan	Winter Feb	Winter Mar	Spring Apr	Spring May	Summer Jun	Summer Jul	Summer Aug	Summer Sep	Winter ave*	Winter min**	Summer ave	Summer max***
Saidu Sharif	19	13	9	8	10	14	20	24	29	28	27	23	8	2	28	36
Chakdarra	21	14	9	8	11	15	19	24	30	30	29	26	11	1	29	38
Daggar	20	14	9	7	9	14	20	25	29	29	28	26	10		29	
Tarbela	25	19	14	12	14	16	24	30	25	34	32	29	14		35	
Dir	16	11	7	4	5	11	14	18	25	27	25	22	7	-2	25	33
Shinkiari	20	15	9	7	9	14	21	24	28	28	27	24	10	****	27	
Oghi	17	12	7	5	7	13	18	22	25	25	25	23	8		25	
Bala Kot	19	14	9	6	10	14	20	24	28	27	26	24	10		26	
Mardan	21	14	10	8	13	18	21	26	31	31	29	27	12	0	30	39
Risalpur	23	16	11	10	13	17	23	29	34	33	32	30	13		32	
Peshawar	24	18	12	11	13	17	23	29	33	33	31	29	13	4	32	40
Kohat	25	19	14	12	15	19	24	30	34	33	32	30	15		32	
Parachinar	17	12	7	4	5	10	15	20	25	25	24	22	6	-2	24	31
Bannu	25	19	12	12	14	19	25	31	34	33	32	30	14	5	32	41
Miranshah	22	15	11	9	11	16	21	27	31	31	29	27	12	3	30	37
Tank	27	20	15	12	14	21	28	32	36	34	33	32	15		34	
D.I. Khan	26	19	14	12	15	22	26	31	34	33	32	30	16		32	

* ave = average daily temperature
** min = average daily minimum of coldest month
*** max = average daily maximum of hottest month
**** = below freezing

C. EVAPOTRANSPIRATION (in mm)

Station		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Chakdarra	T	83	33	11	8	19	39	83	163	221	220	190	113	1213
Daggar	A	64	35	21	21	26	48	81	120	132	132	102	85	867
Tarbela	A	167	99	61	60	71	120	175	269	328	245	176	168	1939
Shinkiari	T	82	39	15	10	15	39	98	142	179	182	158	124	1083
	A	118	88	55	48	43	84	132	165	193	165	125	120	1236
Mardan	A	80	39	25	27	40	74	111	171	203	201	169	124	1264
Risalpur	T	92	27	10	7	15	43	96	182	215	216	190	167	1260
Kohat	T	115	40	21	11	19	48	110	199	217	221	205	168	1374
Parachinar	T	65	27	10	5	9	29	57	114	147	155	137	102	857
Bannu	A	133	84	50	50	60	102	139	200	223	200	186	160	1587
Tank	T	134	43	14	8	13	57	159	205	220	220	206	176	1455
	A	178	128	88	62	61	109	156	258	207	307	258	234	1946
D.I. Khan	T	121	41	13	9	18	78	143	198	214	213	198	168	1414

Method: T = Thornthwaite
A = Application of $\alpha = 0.7$ to pan-evaporation, E_0

precipitation exceeds 1000 mm, while in the arid areas of north Chitral it is only 150 mm and in south Dera Ismail Khan it is less than 250 mm (Figure 2).

Geographical factors control the climatic elements:
Precipitation
There are two wet seasons: one, the monsoon, is in summer when moisture is brought up by the winds from the Arabian Sea and the Bay of Bengal; and the other in winter, November through April, when storms from Iraq, Iran and the Caspian basin bring widespread rain in the plains and snowfall in the mountains. Both sources of supply are precarious and not infrequently either the winter or the summer rainfall fails almost entirely. The average summer and winter precipitation has approximately the same magnitude; however, in summer rains come as brief, high intensity thunderstorms, while winter rains may be persistent but of low intensity. In combination with the low air temperatures and the corresponding low evapotranspiration, the rain in winter provides sufficient moisture for a barani crop. Snowfall

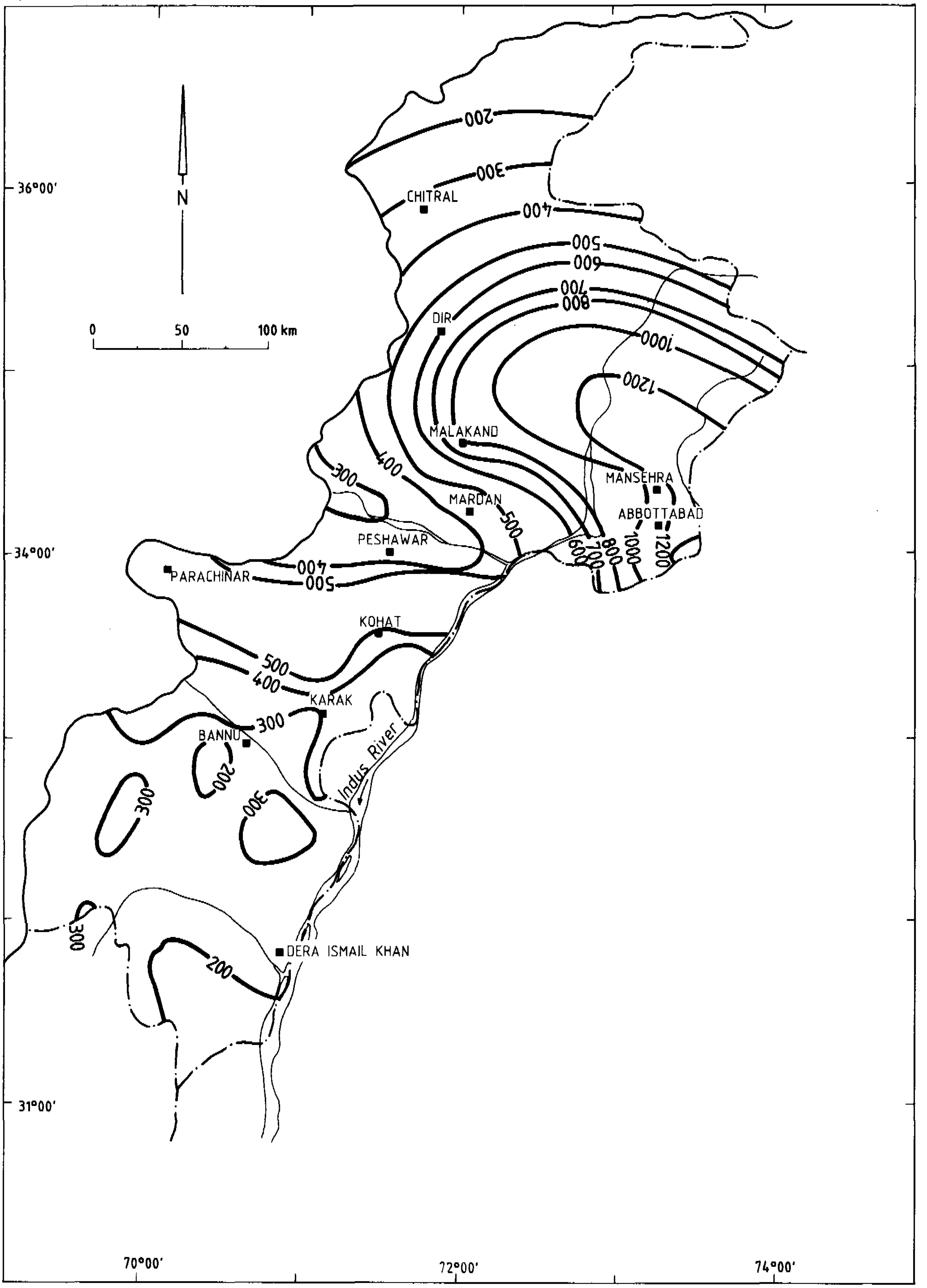


Figure 2: Isohyetal map of the North-West Frontier Province

occurs in all mountainous areas from the Hindu Kush in the north to the Suleiman range in the south.

Temperature

In the plains summers are very hot. The temperature begins to rise rapidly in April and peaks in late May or early June. The daily maximum temperature normally exceeds 40° C and seldom drops below 24° C. During this period winds are strong, hot and dry. Occasionally, such a spell is interrupted by dust storms and by thunderstorms that may bring light showers.

When the monsoon breaks in July the temperature falls and the relative humidity rises, again causing unpleasant conditions.

In the mountains, the higher altitude tempers the summer heat, and therefore the weather is pleasantly warm.

The Himalayas and the Hindu Kush block the influx of really cold air from Central Asia in winter. Nevertheless, the winters are severe in the mountainous area, where the temperature regularly drops below freezing point. In the plains it is warmer, temperatures averaging 4°C although ground frost is common. No part of NWFP is completely frost-free.

Humidity

The relative humidity is moderate during most of the year. However, during May and June, midday values often fall below 10 per cent in the plains. There is a general rise in humidity in the monsoon season, notably during July and August.

Evapotranspiration

Potential evapotranspiration is high in summer because of high temperatures and low relative humidity. In NWFP it is common practice to calculate the annual potential evapotranspiration with Thornthwaite's method (Thornthwaite, 1948) or to derive it from class-A pan evaporation observations by applying a correction factor of 0.7. It ranges from 850 mm in Swat District to 2000 mm in Dera Ismail Khan. Highest monthly values are reached in May and June, with values between 200 and 300 mm/month. Such harsh conditions prevent germination of crops, even if irrigation water is supplied.

Climatic regions

The important regional variations in climate in Pakistan and particularly in NWFP warrant a regional classification based on relative severity of the climatic elements. The method adopted here is an adaptation by Ashraf Ali (1973) of the classification introduced by Ahmad (1951).

Nine main climatic regions are distinguished for Pakistan as a whole. They are described below in relation to their relevance for the NWFP, and shown in Figure 3. Note that in this account the word "rainfall" stands for mean annual precipitation, "maximum temperature" for the mean temperature of the hottest month, and "minimum temperature" for the mean minimum temperature of the coldest month.

Region 1: Arid marine tropical coastland

This region is characterized by a steady sea breeze throughout the summer; high humidity; rainfall exceeding 150 mm; mean annual temperature above 32°C and no major variation in seasonal and diurnal temperatures.

Position in NWFP: not applicable.

Region 2: Arid subtropical continental lowland

This region comprises large plains and is characterized by great annual and daily variations in temperature; maximum temperature about 41° C; minimum temperature from 3 to 8° C; a few frosty days, generally low humidity; mainly late summer monsoon rains and rainfall between 90 and 200 mm.

Position in NWFP: Ashrif Ali (1971) puts the Dera Ismail Khan basin in this category. However, the rainfall there is about 250 mm, ranging from 200 mm in Ramak in the extreme south to 290 mm in Pezu on the northern fringe of the basin. Consequently, the D.I.Khan plain belongs to region 3 and no part of NWFP falls in this category.

Region 3: Semi-arid subtropical continental lowland

A region with rainfall between 80 and 500 mm, maximum temperature about 41°C and minimum temperature 4.5°C; otherwise, same as region 2.

Position in NWFP:

Subregion 3a: Western zone of the Peshawar Vale: rainfall is 340 mm, of which about 60 per cent falls in winter; thunderstorms are common in summer.

Subregion 3b: Bannu basin: rainfall is about 275 mm, about 45 per cent occurring in winter.

Subregion 3c: Dera Ismail Khan: rainfall about 250 mm; about 37 per cent falls in winter.

Region 4: Sub-humid subtropical continental lowland

The rainfall in this region is 500 to 1000 mm, increasing sharply towards the hills: at least two months are humid; winters are distinctly colder and summers cooler than in region 3; otherwise, like the previous region.

Position in NWFP: Buner area in Swat District, The Talash and Adinzai valleys in Dir District, part of Abbottabad District, and Nizampur area as well as the eastern part of the Peshawar Vale belong to this category.

Region 5: Humid subtropical continental highland

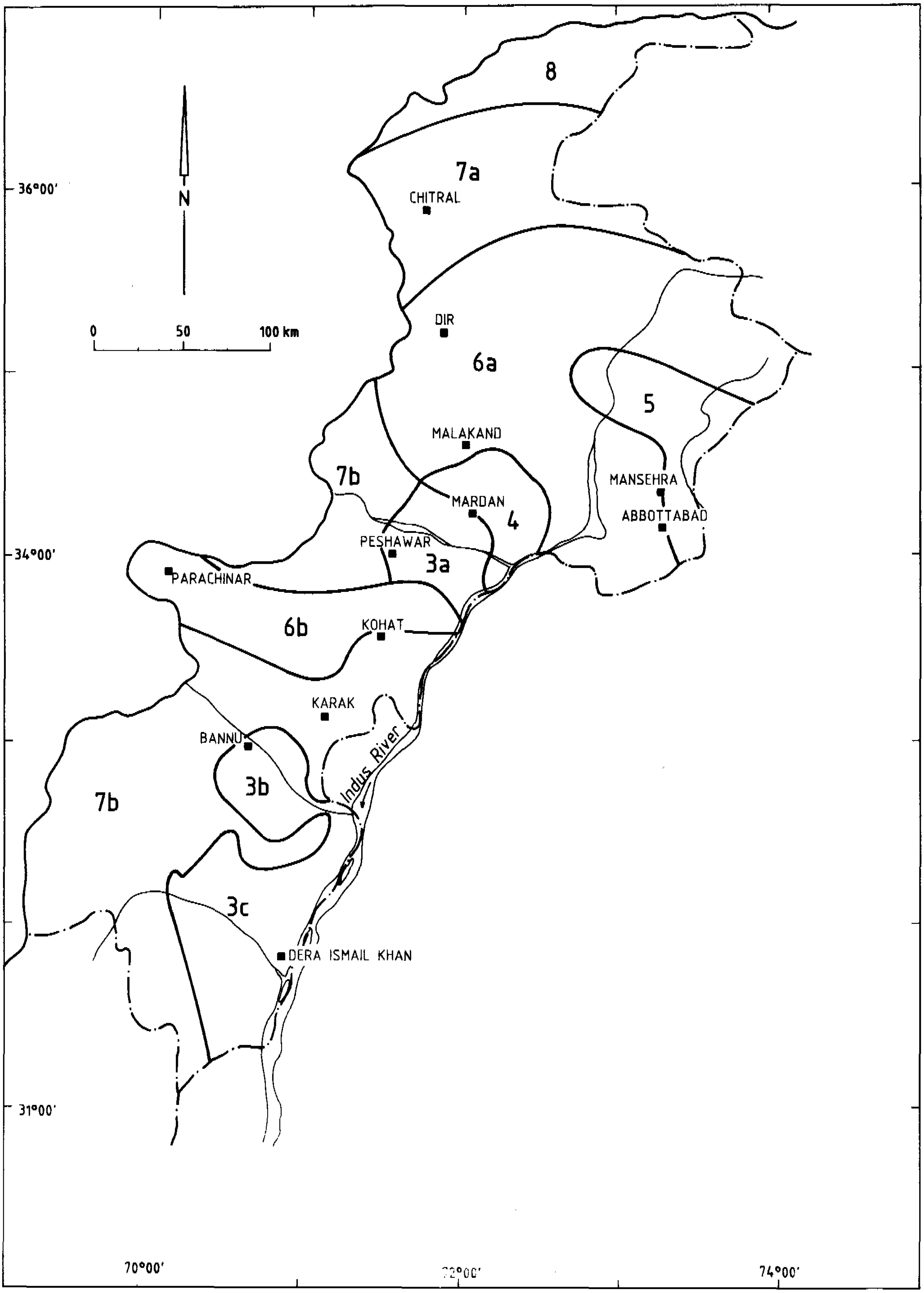
This region comprises mountainous areas, including the narrow intervening valleys. The maximum temperature occurs in June or July and is less than 38°C; winters are cold, snowy and foggy; rainfall exceeds 1250 mm; late winter and summer rains are common. The climatic elements vary over short distances in relation to altitude and aspect.

Position in NWFP: the spurs of the outer Himalayas extending into Mansehra District.

Region 6: Sub-humid subtropical continental highland

Does not greatly differ from the previous region, except for the rainfall, which range from 500 to 1250 mm.

Figure 3: Climatic regions of the North-West Frontier Province modified after Ashraf Ali (1971): (2) arid subtropical conti nental lowland, (3) semi-arid subtropical continental lowland, (4) sub-humid subtropical continental lowland, (5) humid subtropical continental highland, (6) sub-humid subtropical continental highland, (7) arid subtropical continental high land. (For legend see fold-out at back of book)



8
7a
CHITRAL
36°00'
N
0
50
100 km
DIR
6a
5
MALAKAND
7b
MANSEHRA
MARDAN
4
ABBOTTABAD
PESHAWAR
34°00'
3a
PARACHINAR
6b
KOHAT
KARAK
BANNU
Indus River
3b
7b
3c
DERA ISMAIL KHAN
31°00'
70°00'
72°00'
74°00'

Position in NWFP:

Subregion 6a: The hills of Swat, Dir and Kohistan Districts with more than 875 mm rainfall, of which 60 per cent occurs in late summer. The maximum temperature ranges from 32 to 38°C (June) and the minimum temperature is less than 3°C.

Subregion 6b: The hills of Kohat and Karak Districts with a rainfall depth between 500 and 800 mm, and those of Kurram Agency between 500 and 1000 mm distributed throughout the year. October is the driest month and there is more rain in March and April than in July, the rainiest summer month. The maximum temperature is about 32° C and the minimum temperature is about -1°C.

Region 7: Semi-arid subtropical continental highland
Like region 5, but the rainfall varies from 200 to 500 mm.
Position in NWFP:

Subregion 7a: Northern part of Swat and southern part of Chitral Districts and Bajaur and Khyber Agencies. The rainfall is about 450 mm, of which 200 mm falls in March and April. The maximum temperature is 36°C and the minimum temperature is -0.5°C.

Subregion 7b: Waziristan and southern part of Kohat and Karak Districts, with not more and often less than 300 mm rainfall mainly in winter and spring; the amount of precipitation decreases towards the south. Maximum temperature about 40°C and minimum temperature around freezing point.

Region 8: Arid subtropical continental highland
This region is like the other subtropical continental highland regions except for the rainfall, which is less than 200 mm. Position in NWFP: northern part of Chitral District (Baltistan): March is the wettest month. Maximum temperature is 31°C and the minimum temperature -9°C. Winter precipitation occurs as snow.

Region 9: Very arid
This region is characterized by rainfall of about 50 mm, mostly occurring in January and February. The maximum temperature is 39°C in June and the minimum temperature is -3°C in January. Severe dust storms are frequent from May to September.
Position in NWFP: not applicable. This climate is restricted to the extreme western fringe of Baluchistan.

1.4 LAND AND WATER

Land

The North-West Frontier Province is a mountainous area. Its western area along the Afghan border belongs to the Pakistani fold belt and the north is part of the Himalayan-Hindu Kush Mountain system (Section 2.1). The highest point in the Province is the Tirich Mir, north of Chitral town, which rises 7690 m (25,230 ft) above sea level. The Districts of Swat and Dir are mountainous (mainly igneous rocks). The Malakand range and the Khyber hills encircle the Peshawar Vale on its northern and western sides. The southern boundary is formed by the east-west tending Safed Koh-Cherat range. Minor east-west tending ridges cover the Kohat and - partly - Karak Districts, as well as the Kurram Agency. They enclose small intermontane basins.
The Bannu basin (Bannu District) is enclosed by the Kurram range in the north and by mountains that belong to the Trans-Indus Salt range (Marwat range and Bhittanni range) along the eastern and southern boundaries. The Bhittanni range separates the Bannu basin from the Dera Ismail Khan basin. The Suleiman range forms the western boundary of both the Bannu basin and the D.I. Khan basin.
There are a great number of intermontane basins in the central and southern parts of the Province. Some are no more than flat-bottomed river valleys. Others, like the Peshawar Vale and the Bannu basin cover thousands of square kilometres. The Dera Ismail Khan basin is the northwestern corner of the Indogangetic plain, which runs in front of the Himalayas from the Sulaiman range in NWFP to the western mountain ranges of Burma in the east.
The relatively flat alluvial plains are the concentration points of economic activity, almost entirely in the form of agriculture. Most plains are crossed by one or more rivers, making it possible to irrigate some of the soils. Moreover, the plains are the sites with the best groundwater resources, for the coarse alluvial deposits make good aquifers.

Rivers

With the exception of the Kunhar river in Mansehra District which flows down the Kagan valley into the Jhelum River, the whole Province drains into the Indus. The Indus river, which rises on the Tibetan Plateau, passes through Gilgit Agency and forms the boundary with the Kohistan District of NWFP. It enters the province as it swings south and flows between the Swat and Mardan Districts on the right bank and the Districts of Kohistan, Mansehra and Abbottabad on the left bank. Near Tarbela the Indus is dammed by the world's largest earth-fill dam. The purpose of the reservoir is flood regulation and electricity production. Downstream from a point halfway between Tarbela and Attock the Indus forms the boundary between NWFP and the Punjab, down to the southern tip of the Dera Ismail Khan District. The only exception is the inlier of Isa Khel Tehsil of Mianwali District of the Punjab, which is located on the west bank of the river at the level of the Bannu basin.
The main tributaries of the west bank are the Kabul, Kurram and Gomal or Luni rivers. The Kabul river rises in Afghanistan and in that country near Jalalabad it receives the water from the Kunar river. The latter is called Chitral river in Pakistan, where it drains the District of that name. The Kabul river passes through the Khyber Agency and just before entering the Peshawar Vale near Warsak it is dammed by a multipurpose dam. The water from the reservoir is used for the production of 250,000 kW hydroelectric power and for irrigation in the Vale. Below the dam the river divides into three branches: the Sardargah, Naguman and Shah Alam rivers. Near Charsadda the Khiali river discharges into the northern branch, the three branches converge and are joined by the Bara river. The Khiali river is the continuation in the Peshawar Vale of the Swat river, which drains the Swat and

Dir Districts, the latter through its tributary the Panjkora river. The Bara river descends from the Khyber hills and enters the Vale from the southwest near Jhansi Post. Downstream of Charsadda the Kabul river is also known by the name Landai river. It passes through Nowshera town, where it receives the Kalpani Nala, and it discharges into the Indus near Attock.
The Kurram river rising in Afghanistan on the southern slopes of the Safed Koh, passes through the Kurram Valley and the lower Wazir hills and enters the Bannu basin through the Kurram Garhi gorge. Five kilometres downstream of Lakki it is joined by the Tochi/Gambila River, which drains North Waziristan. It leaves the plain at Darra Tang and it discharges into the Indus near Isa Khel.
The Gomal or Luni river has its origin in Baluchistan where it is called Zhob river. It discharges into the Indus south of the town of Dera Ismail Khan.
Besides the above-mentioned perennial rivers there are a large number of ephemeral rivers that only carry water during the rainy season and shortly afterwards, or even only after individual rainstorms.

Canals
In the North-West Frontier Province the use of river water for the irrigation of crops is an age-old practice (Ahmad, 1974, Appendix A). The oldest method is the construction of small diversions, kathas, that carry water when the river is high. Canal irrigation started in the period of Moghul rule (16th and 17th centuries) and received a big boost at the end of the 19th and the beginning of the 20th centuries and again after the independence of Pakistan.
In the Peshawar Vale the Joi Sheikh, Joi Zardad and Doaba Canals date back to the Moghul period. After the British conquest, the first canal was taken out of the Kabul river in 1890. The canal's supply comes from a natural pool just downstream of the gorge at Warsak. The capacity of this canal is 11.75 m^3/sec (415 cusec). It feeds the Juri Sheikh Canal. At the same time (1872 - 1891) the Lower Swat Canal was constructed. The headworks, built in 1915 - 1917, are located near Alazi at Munda and consist of a barrage-type weir. The Upper Swat Canal was constructed around 1915. It takes off from Amandara in the upper reaches of the Swat river and crosses the Malakand hills in a tunnel that is 3424 m (11,234 feet) long and was designed to have a capacity of 68.5 m^3/sec (2420 cusec). The present full supply discharge of 51 m^3/sec (1800 cusec) produces 20,000 kW of electric power both at Jabban and Dargai. The culturable command area is 103,000 ha (255,000 acres).
The reservoir behind the multi-purpose dam completed in 1960 on the Kabul river at Warsak serves a culturable command area of 47,400 ha (117,140 acres). The water is distributed by the Right Bank Canal, which at "R.D. 20,130" bifurcates into a gravity flow canal with a capacity of 7.22 m^3/s (255 cusec) supplying a culturable command area of 24,303 ha (60,067 acres) and a lift canal with a capacity of 5.66 m^3/s (200 cusec) supplying a culturable command of 18,660 ha (46,120 acres). The water is lifted into the canal over a height of 49 m (160 feet). The Left Bank Canal has a designed discharge of 1.27 m^3/s (45 cusec) and a culturable command area of 4,448 ha (10,993 acres).
The Pehur Main Canal, inaugurated in 1956, has a culturable command area of 17,870 ha (44140 acres) along the eastern border of the Peshawar Vale. It takes off from the right bank of the Indus river 8 km downstream of the Tarbela Dam.
In Bannu area the water from the Kurram river that enters the basin through the Kurram Garhi gorge is used for irrigation. The irrigation system dates back to the 16th century when the Kurram-Gambila Doab was irrigated by private "Zamindari" canals, which diverted water from the river by temporary bunds. The main artery of this age-old system is the still functioning Katchkot Canal. The distribution system gave priority rights to the upstream users, who fiercely opposed any later plans for redistribution of the water supply that would curb their unlimited rights to river water. Not until 1954 was a steady irrigation system on 43,300 ha (107,000 acres) established after a weir had been constructed across the river at Kurram Garhi gorge. The reallocation of the water permitted the increase of the irrigated area on the left bank of the Kurram river to 10,520 ha (26,000 acres). In 1962 a storage reservoir of 114 Mm^3 was completed on Barran Nullah to control flood water supplies, to enlarge the irrigated area and to generate 4000 kW electricity. The Barran Nullah reservoir receives the runoff from the nullah and the surplus supplies from the Kurram through the Baran Feeder Channel at a maximum rate of 85 m^3/sec (3000 cusec). The water from the reservoir - which is now seriously silted up - is distributed through the Marwat Canal that was designed to provide a safe supply to 60,690 ha (150,000 acres) on the Marwat plain.
Water from the Baran Nullah downstream of the dam is diverted by three canals that were built between 1890 and 1958 and are known as the Barran Lohra system. They command a gross culturable area of 7560 ha (18,684 acres).
The Paharpur Canal in Dera Ismail Khan District has functioned since 1934. It takes off from the Indus at Chasma and flows in the Bilot creek where the old head of the canal was located. As part of the Indus Basin Works a barrage was built in the 1960s. The canal's present headworks are at the barrage. In 1974 the culturable command was 39,650 ha (98,000 acres).
The Chasma Right Bank Canal (C.R.B.C.) is presently under construction. The first phase of the project aims at bringing an area of 52,000 ha (128,000 acres) under the command of a canal with a length at 83 km (52 miles). This area includes the command area of the Paharpur canal which will become a branch of the CRBC. In the second phase of the construction the canal will be extended by 38 km and the irrigated area will thus increase by 38,000 ha (94,000 acres). During the last phase the canal will be continued to Taunsa in Dera Ghazi Khan District (Punjab). The total irrigable area of the project in D.I. Khan District will then be 142,000 ha (350,000 acres).

1.5 POPULATION

At the beginning of this century the estimated population of NWFP was 4 million and Peshawar town was inhabited by nearly 100,000 persons. At present, 15.7 per cent of Pakistan's population lives in NWFP and FATA, approximately 13.7 million in NWFP and 2.6 million in FATA (see also Table 2). The annual growth rate is about 3.3 per cent. About 14 million people or 85 per cent of the population live in the

rural areas and only 2 million in the urban centres, with approximately 1.5 million in Peshawar. These figures do not include the several million Afghan refugees who have temporarily settled in NWFP.
The Pathans are the predominant ethnic group. Their language is Pashtu which has two main dialects: a harder northeastern Pakhto and a softer southwestern Pashtu. The differences in language seem to correspond with a broad difference in tribal custom. In the urban centres the Urdu language has gained some prominence and many people are bilingual. Ethnically, the Pathans of the North-West Frontier Province are closely related to the tribes of eastern Afghanistan.
Many of the amenities of modern life such as a safe water supply, gas and electricity are available to only part of the population.
Table 3 gives a breakdown of the housing units by source of drinking water, lighting and cooking fuel, in the urban and rural areas of NWFP in 1980.

1.6 ECONOMIC ACTIVITY

The statistics given in this section have been compiled from data published by the Bureau of Statistics of the NWFP (B.o.S., 1986a, 1986b and 1986c) and by the Department of Agriculture of NWFP (Ullah Khan and Ullah Khan, 1986). During the year 1985/1986 the working population of 10 years and older was mainly employed in agriculture (B.o.S, 1986c) as can be seen in Table 4.

Agriculture
The cultivated area of NWFP is only 23 per cent of the total land area and forest covers 13 per cent. The remaining area is range lands, barren lands, high mountains, glaciers, built-up areas, etc. Irrigated land and land currently fallow account for 43 and 17 per cent of the cultivated area, respectively. Figures are presented districtwise in Table 5.

Farms range in size from less than 0.4 ha (1 acre) to more than 60 ha (150 acres). According to the Census of Agricul-

Table 2: Population of NWFP (excl. Afghan refugees) (Source: Bureau of Statistics, Govt. NWFP)

	area km^2	1981 total pop (x 1000)	1981 urban pop (x 1000)	1981 rural pop (x 1000)	1987[1] total x1000
Peshawar Division					
Peshawar	4 001	2 282	849	1 433	2 810
Mardan	3 137	1 507	225	1 282	1 780
Kohat Division					
Kohat	3 057	509	122	387	620
Karak	3 955	250	14	236	300
Hazara Division					
Abbottabad	3 565	1 169	152	1 017	1 340
Mansehra	5 957	1 067	37	1 029	1 220
Kohistan	7 581	465	-	465	860
D.I. Khan Division					
Bannu	9 005	710	62	649	840
D.I. Khan	4 391	635	117	519	790
Malakand Division					
Malakand Agency	952	258	-	258	330
Dir	5 282	767	-	767	1 010
Chitral	14 850	209	-	209	260
Swat	8 788	1 203	88	1 145	1 580
Subtotal NWFP	74 521	11 061	1 165	9 396	13 740
Subtotal FATA	27 220	2 199	-	2 199	2 630
Grand total	101 741	13 260	1 165	11 595	16 370
Pakistan total	796 095	84 235	23 841	60 394	
NWFP (incl. FATA) as percentage of total Pakistan	12.8	15.7	4.9	19.2	

[1]Estimated

ture of 1980, there are 725,454 farms in NWFP and 132,948 in FATA. Details are given in Table 6.

The annually cropped area of NWFP (excl. FATA) was around 1.4 million ha (3.5 million acres) in 1970/1971. Since then it has increased to its present level of 1.76 million ha (4.4 million acres). The irrigated area varied interannually between 46 and 50 per cent of the cultivated land and is at present about 825, 000 ha (2.1 million acres). During the Kharif season the irrigated area is about 475,000 ha (1.2 million acres) or 66 per cent of the cropped area and during the Rabi season these figures are 345,000 ha (860,000 acres) and 33 per cent. The statistics on FATA do not mention barani (unirrigated) crops during Kharif, when 37,000 ha (90,000 acres) are irrigated. The cropped area in the Rabi season consists of approximately 30,000 ha (75,000 acres) irrigated and 80,000 ha (200,000 acres) barani land.
The major crop sown in the Kharif season is maize, both on irrigated and on barani land. Other important crops are sugar cane, rice, tobacco, fruits, vegetables and pulses on irrigated

Table 3: Housing units by source of water and energy supply (1980) (Source: Bureau of Statistics, Govt. NWFP)

Housing Facility	Total		Rural		Urban	
	Housing units	per cent	Housing units	per cent	Housing units	per cent
NWFP:						
Source of drinking water inside						
Pipe	128 414	8	48 932	4	79 482	34
Handpump	45 292	3	34 983	3	10 309	4
Well	317 516	20	268 236	19	59 280	21
Source of drinking water outside						
Pipe	146 938	9	91 692	7	55 246	24
Handpump	11 392	1	10 425	1	967	-
Well	285 890	18	254 624	18	31 266	13
Pond	56 776	4	56 123	4	653	-
Spring, River, Stream, etc.	623 398	39	615 525	45	6 873	3
	1 615 616	100	1 381 540	100	234 076	100
Source of Lighting						
Electricity	540 974	34	352 503	26	188 471	81
Kerosene Oil	987 913	61	944 631	68	43 282	18
Other	86 729	5	84 406	6	2 323	1
	1 615 616	100	1 381 540	100	234 076	100
Cooking fuel used						
Wood	1 167 888	72	1 053 349	76	114 539	49
Coal	5 078	-	3 048	-	2 030	1
Kerosene Oil	80 781	5	14 911	1	65 870	28
Gas	25 021	2	2 409	-	22 612	10
Electricity	4 939	-	4 070	-	869	-
Cow Dung, etc.	331 909	21	303 753	22	28 156	12
TOTAL	1 615 616	100	1 381 540	100	234 076	100

Source: Housing Census of Pakistan, 1980, Census Bulletin No. 6

Table 4: Employment of the working population of 10 years and older in different economic sectors in 1985/1986 (Source: Bureau of Statistics, Govt. NWFP)

		number (x 1000)	%
1.	Agricultural sector (including agriculture forestry, hunting and fishing)	2 065	62.1
2.	Industrial sector (including mining and quarrying, manufacturing and construction)	237	7.1
3.	Utilities (electricity, gas and water)	28	0.8
4.	Commerce (including wholesale and retail trade, restaurants and hotels)	251	7.6
5.	Services (including transport, storage, communications, financing, insurance, real estate and business services, community services and personnel services)	607	18.3
6.	Miscellaneous	135	4.1
	Total NWFP	3 323	100.0

Table 5: Land use in NWFP (excl. FATA) (Source: Bureau of Statistics, Govt. NWFP)

District	Cultivated area as % of total area	Forest area as % of total area	Irrigated area as % cultivated area	Current fallow as % cultivated area
Peshawar	48.8	2.3	72.4	17.2
Mardan	64.7	1.1	57.3	7.9
Kohat	25.3	1.9	30.8	43.1
Karak	18.4	-	1.8	21.8
Abbottabad	39.6	34.6	11.6	3.2
Mansehra	17.6	10.3	22.0	19.4
Kohistan	4.8	28.6	65.9	21.5
Bannu	57.9	-	32.0	19.1
D.I.Khan	33.4	5.5	35.0	26.0
Swat	17.2	32.6	60.0	1.2
Dir	18.0	30.7	61.9	22.9
Chitral	1.2	2.8	91.2	7.2
Malakand Agency	47.9	3.7	74.8	20.4
NWFP	22.8	12.9	43.2	17.3

land, and jowar and bajra/ millet on barani land; minor crops are cotton, sesame and groundnuts.

Wheat takes the place of maize during the Rabi season. Additional crops grown on irrigated land are barley, gram, potato, onion, rapeseed and mustard, fruits, vegetables and pulses. Gram and barley are fairly important unirrigated crops, followed by mustard, rapeseed and potatoes.

The yields per hectare of irrigated crops are about one to two times higher than those of the same crops under barani conditions (Table 7).

Nevertheless, yields of irrigated crops are still relatively low and it may be expected that the introduction of modern technology with regard to improved soil preparation, plant distances, new varieties, appropriate inputs and good farm water management, could bring wheat yields up to 3 t/ha, maize

Table 6: Districtwise number of farms and farm size distribution (Source: Bureaus of Statistics NWFP and FATA)

District	number	ha : 0.4 acre: 1.0	0.4–1 1–2.5	1–2 2.5–5	2–3 5–7.5	subtotal small farms	3–5 7.5–12.5	5–10 12.5–25	10–20 25–50	20 50	subtotal larger farms
		Percentage:									
Peshawar	85 421	13.2	30.6	25.7	14.5	84.0	11.1	3.8	1.0	0.2	16.0
Mardan	8 470	12.4	29.2	26.4	14.9	82.9	10.8	5.0	1.0	0.2	17.0
Kohat*	52 217	10.7	21.2	25.4	17.8	75.1	15.0	8.1	1.4	0.3	24.8
Abbottabad	125 297	16.0	31.3	25.1	12.5	84.9	9.3	4.4	1.0	0.3	15.0
Mansehra	82 714	11.0	24.9	27.9	14.7	78.5	12.4	6.5	1.8	0.9	21.5
Kohistan	11 694	3.2	17.4	28.3	16.0	64.9	13.9	12.8	5.0	3.4	35.1
Bannu	45 376	12.8	17.3	15.6	10.6	56.3	13.6	18.9	8.5	2.7	43.7
D.I. Khan	40 453	2.4	5.4	7.9	11.7	27.4	15.6	21.6	18.4	16.9	72.5
Swat	110 068	16.0	38.8	24.4	10.4	89.6	6.7	2.5	0.7	0.4	10.3
Dir	57 078	19.7	50.8	15.6	7.2	93.3	4.2	1.7	0.4	0.3	6.6
Chitral	23 078	26.9	37.0	21.3	7.0	92.2	4.0	1.9	1.2	0.6	7.7
Malakand A.	7 318	6.6	28.8	23.5	16.5	75.4	14.6	7.1	2.0	0.8	24.5
Subtotal NWFP	725 426	13.6	29.8	23.2	12.7	79.3	10.2	6.3	2.6	1.5	20.6
Subtotal FATA	132 938	17.9	26.5	23.6	13.6	81.6	11.2	5.3	1.3	0.6	18.4
Grand total	858 364	14.3	29.3	23.3	12.8	79.7	10.4	6.2	2.4	1.4	20.4

*including Karak District

Table 7: Crop production in NWFP (Source: Agricultural Statistics of NWFP)

Crop	Irrigated area 1000 ha	%	Production 1000 ton	ton/ha	Barani 1000 ha	%	Production 1000 ton	ton/ha	ton/ha irr./bar.
Kharif crops 1983/84									
Maize	225.90	45.80	360.70	1.60	213.50	86.30	190.20	0.89	1.80
Rice	72.20	14.60	115.80	1.60	-	-	-	-	-
Jowar	5.02	1.02	3.35	0.67	11.17	4.51	5.20	0.47	1.43
Bajra/Millet	0.98	0.20	0.54	0.55	43.48	5.45	5.97	0.44	1.25
Sugar cane	102.20	20.70	4010.90	39.20	24.48	1.00	544.70	21.90	1.79
Tobacco	26.40	5.35	52.50	1.99	-	-	-	-	-
Cotton	2.22	0.45	0.47	0.21	0.28	0.11	0.045	0.16	1.31
Sesamum	0.07	0.01	0.027	0.36	0.76	0.31	0.24	0.32	1.12
Groundnuts	0.93	0.19	1.93	2.08	5.77	2.33	8.96	1.55	1.34
Fruits*	16.00	3.25	180.00	11.28	?		?		
Vegetables*	18.50	3.75	247.00	13.35	?		?		
Pulses*	22.60	4.58	14.80	0.66	?		?		
Total	493.02	99.90			269.80	100.01			
Rabi crops 1983/84									
Wheat	292.60	87.80	497.10	1.70	500.90	73.00	392.70	0.72	2.36
Gram	4.01	1.20	1.03	0.26	72.10	10.51	33.40	0.46	0.57
Barley	12.80	3.85	15.20	1.18	72.40	10.56	46.90	0.65	1.82
Potato	1.60	0.48	18.30	11.47	0.045	-	0.35	7.89	1.45
Onion	2.65	0.79	327.8	32.80	0.007	-	0.05	7.14	4.59
Rape and mustard seed	2.38	0.71	1.31	0.55	40.60	5.92	16.80	0.42	1.31
Fruits*	5.46	1.64	47.10	8.62	?		?		
Vegetables*	5.89	1.77	76.70	13.00	?		?		
Pulses*	5.88	1.76	3.00	0.51	?		?		
Total	333.27	100.00			686.00	99.99			

* possibly partly not irrigated

Table 8: Percentage of the area in NWFP (incl. FATA) irrigated with water from various sources (1970/1971 - 1983/1984) (Source: Bureau of Statistics of NWFP)

Source / Year	Canals: government	Canals: private	Canals: total	Groundwater: tube-wells	Groundwater: dug wells	Groundwater: total	Unspecified
1970/1971	38.54	45.36	83.90	5.36	4.37	9.73	6.36
/1972	43.33	42.09	85.42	4.05	5.81	9.86	4.73
/1973	40.01	42.55	82.56	5.27	4.40	9.67	7.77
/1974	40.94	45.78	86.72	5.65	5.45	11.10	2.23
/1975	41.03	45.38	86.41	4.98	4.23	9.21	4.37
/1976	43.29	41.91	85.20	3.94	5.31	9.25	5.54
/1977	42.82	43.27	86.09	4.45	4.83	9.28	4.64
/1978	43.36	43.36	86.71	2.81	4.26	7.07	6.22
/1979	41.70	43.99	85.69	2.68	4.73	7.41	6.90
/1980	42.17	44.51	86.68	2.75	5.18	7.93	5.39
/1981	39.79	45.25	85.04	4.92	4.60	9.52	5.34
/1982	38.74	45.56	84.30	7.66	3.87	11.53	4.15
/1983	39.18	41.35	80.53	6.27	3.99	10.26	7.80
/1984	38.52	39.58	78.10	5.82	4.67	10.49	11.38

Table 9: Livestock in NWFP (in millions) (Bureau of Statistics, Govt. NWFP)

	1980 (census)			1986 (estimates)		
	NWFP	FATA	TOTAL	NWFP	FATA	TOTAL
Cattle	2560	722	3382	2950	850	3800
Buffaloes	864	76	940	1030	90	1120
Sheep	1078	1027	2105	1290	860	2150
Goats	1901	1653	3554	2150	1390	3540
Camels	49	22	71	78	21	99
Equines*	293	119	412	345	103	448
Poultry	9031	3129	12 160	11 420	3960	15 380

* Horses, mules and donkeys

Table 10: Electricity consumption by industry (Source: Bureau of Statistics, Govt. NWFP)

	1970/71	1973/74	1977/78	1980/81	1983/84
Connections (1000 numbers)	5.1	6.7	10.2	12.5	15.5
Units sold (million kWh)	235.5	426.5	354.1	370.2	587.3

and rice up to 4 t/ha and sugar cane yields up to 80 to 100 t/ha.

Table 8 shows a breakdown of the irrigated area according to the source of the irrigation water supply. Although this irrigated area increased by 30 per cent between 1970/1971 and 1983/1984 there is little variation in the importance of each source and there is certainly no trend. Nearly 85 per cent of the irrigated land in NWFP (incl. FATA) receives canal water supplied to an equal degree by government and private canals. The remaining 15 per cent is divided into: 10 per cent supplied with groundwater and 5 per cent water source unspecified.
Table 9 gives an indication of the number of cattle, buffaloes, sheep and goats in the province.

Industry and Mining
The level of industrial development in the NWFP is still very low. In 1985/1986 only 289 large industrial units with 46,000 employees were registered. Nearly half of the units are located in Peshawar. Few statistical data are available on the unorganized small-scale manufacturing sector and the cottage industry. The employment in this sector is probably as important as that in the large industries. The number of electrical connections for industrial purposes grew from 5000 in 1970/1971 to 15,500 in 1983/1984. Table 10 indicates the growth of the small scale industrial sector. Industry uses water mainly for washing and cooling; the amount of process water is negligible.

Mining is of limited importance. There are quarries for limestone, dolomite, feldspar, marble, phosphate, soapstone, coal and Fuller's earth. Emeralds are found in Swat.

2 HYDROGEOLOGY

2.1 INTRODUCTION

Hydrogeology can be defined as the study of groundwater, with particular emphasis on its chemistry, mode of migration and relation to the geological environment (Davis and DeWiest, 1966). The basic principles of hydrogeology must be understood if the groundwater resources of NWFP are to be efficiently explored and rationally exploited. In this and the following chapter, aspects of the hydrogeology of NWFP will be explained, so that the non-specialist reader will understand the groundwater conditions in the province.
The geological evolution of NWFP on the northwestern corner of the collision zone between the Indian and the Eurasian tectonic plates is depicted in Section 2.2. During the youngest epoch of the earth's long history, intermontane basins were formed and filled with alluvial deposits, which contain the major groundwater resources. This aspect of the Quaternary geology, together with some aspects of the lithology and

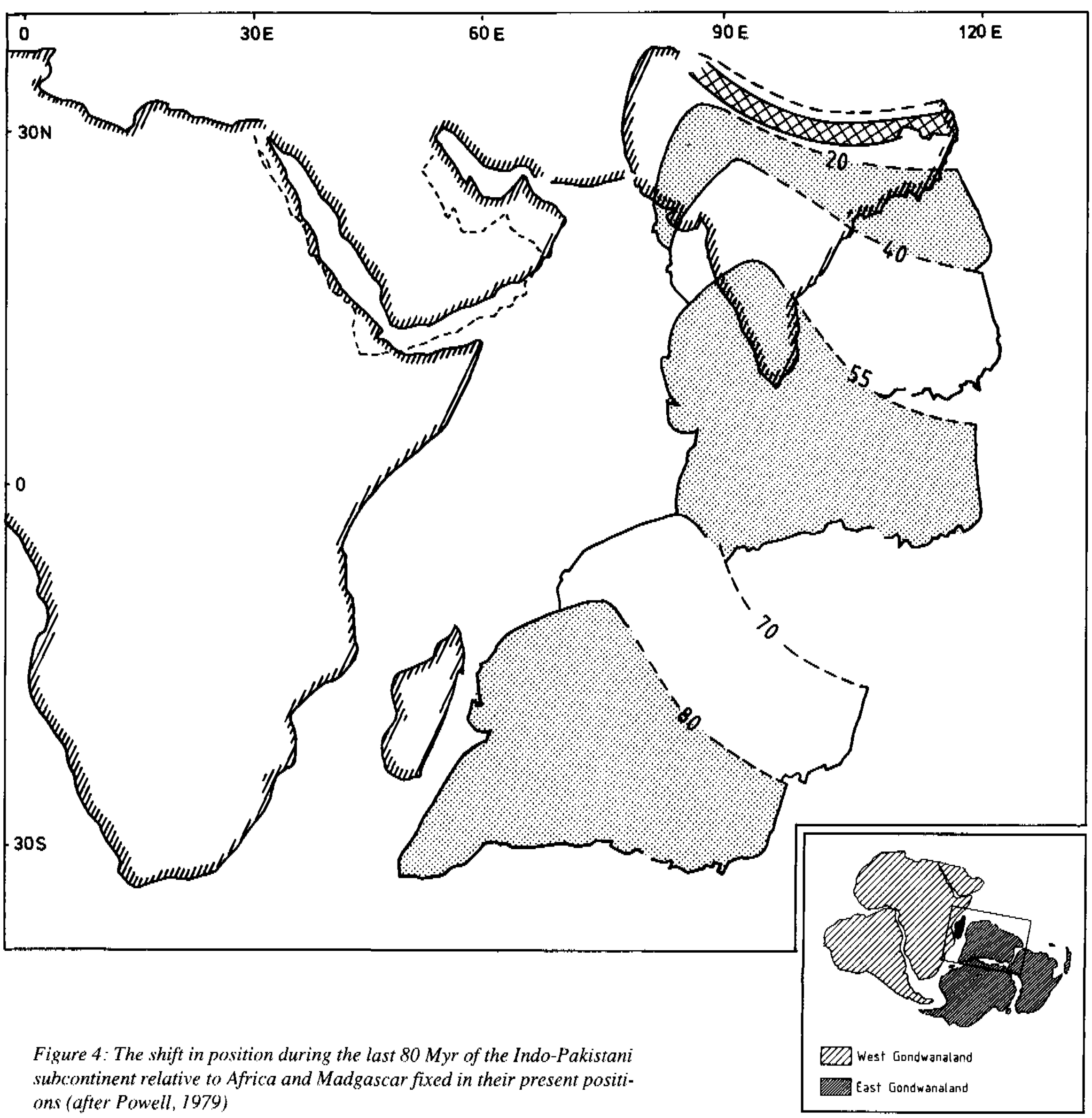


Figure 4: The shift in position during the last 80 Myr of the Indo-Pakistani subcontinent relative to Africa and Madgascar fixed in their present positions (after Powell, 1979)

stratigraphy of the older formations are described in Section 2.3.

Section 2.4 deals with the occurrence of groundwater and explains when and where groundwater may be found in exploitable quantities. The concepts and terms used in describing groundwater conditions are also discussed.

In Section 2.5 the properties of groundwater are discussed, with special emphasis on the chemical properties and their relation to the quality criteria of different water users. Attention is also given to the origin of the dissolved matter in water (natural processes or by pollution caused by human activity).

The movement of groundwater, its relation to surface water, the hydrological cycle and the related water budget are discussed in Section 3.1; the groundwater flow and the related aquifer parameters in Section 3.2, and groundwater storage and flow to wells in Sections 3.3 and 3.4, respectively.

2.2 GEOLOGICAL HISTORY OF NWFP

The North-West Frontier Province is located in the extreme northwest of the Indo-Pakistani subcontinent where it merges with the Eurasian continent. This merging is the consequence of the collision of two tectonic plates: the Laurasian plate and the Greater Indian plate (Powell, 1979). Originally, the latter formed with Africa, South America, Australia and Antarctica a single continent named "Gondwanaland" (Figure 4).

Some 130 million years (Myr) ago the Gondwana tectonic plate broke up and the different parts drifted slowly across the Tethys Ocean, which at that time was several thousand kilometres wide, to their present position. This drifting was possible because the 35 km thick "solid" earth crust is lighter than the "liquid" mantle below. Figures 5 to 2.6 show the gradual displacement of "Greater India".

Figure 5 shows the situation at the end of the Cretaceous about 70 Myr ago. The Indo-Pakistani subcontinent had separated from Madagascar but still lay south of the northern edge of the African continent. Two major convergence zones are indicated: the Alborz-Hindu convergence zone marking the southern boundary of the Turan Block which is part of the Eurasian continent, and the southern Zagros-Chitral convergence zone. An island arc is postulated south of Chitral; its remains are preserved in the Kohistan rock sequence (Tahirkheli, 1979). The Tethys Ocean east of the Owen fracture was probably still 2000 km wide but rapidly shrinking as India moved north relative to Africa at rates between 15 and 20 cm/yr.

The rapid northward drift ended about 55 Myr ago. Geologically this time is very important because the Indo-Pakistani subcontinent had probably already made initial contact with the island arc, or the continental margin at the southern edge of Eurasia (Figure 6). This event was accompanied by igneous rock being formed on the edges of the continental plates before and during the time the Tethys Ocean was closing up. Following the closure, terrestrial sediments developed within and on either side of the suture zone. Powell (1979) concludes that collision of the subcontinent with the Zagros-Chitral convergence zone and the closure of the Indus suture were completed before the Middle Eocene.

Between 55 Myr and 40 Myr ago the movement of the plates was restricted to a small counter-clockwise rotation that turned the Indo-Pakistani subcontinent by about 9°. In this 15 Myr period it converged not only northward with Eurasia but also westward with the Arabian shield and the various tectonic elements of the Iran-Afghanistan orogenic belt. The subcontinent's twist during the Eocene was responsible for the first major bend in the Zagros-Chitral convergence zone (Figure 7).

From the late Eocene onwards the northward movement relative to Africa took place at a more leisurely pace. The anticlockwise rotation continued. By 20 Myr ago, the subcontinent had moved 500 to 600 km northward from its 40 Myr position. This slow northward advance was made possible partly by the development of a new convergence zone within the Indo-Pakistani subcontinent. This deep crustal dislocation, now expressed as the Central Crystalline Axis of the High Himalaya, developed 100 to 200 km south of the Indus suture zone (Figure 8). To the northwest, the Pakistani edge of the subcontinent converged further with the Central Iran and Afghanistan micro-continents. By 20 Myr ago it had moved much closer to the present location of the Turan continental block, so that a pincer-like squeeze was being applied on all sides of the Central Iran and Afghanistan micro continents.

From 20 Myr ago to the present, the leading edge of the Indo-Pakistani shield, underthrusting along the Central Crystalline Axis, moved 300 to 500 km northward and the subcontinent rotated further counter-clockwise. The main effects

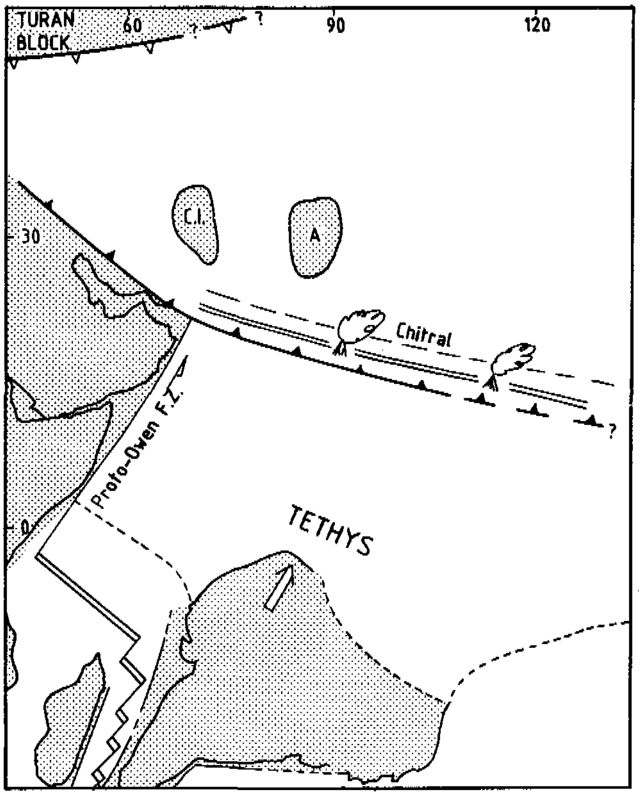


Figure 5: Sketch of the Indo-Pakistani subcontinent 70 Myr ago relative to Africa in its present position. Barbed heavy lines represent the convergence zones bordering Eurasia. The thin double line north of the Tethys ocean represents a postulated island arc with volcanic activity, whose remains are now found in a zone extending east from Baluchistan through Chitral. C.I = Central Iran, A = Afghanistan (after Powell, 1979)

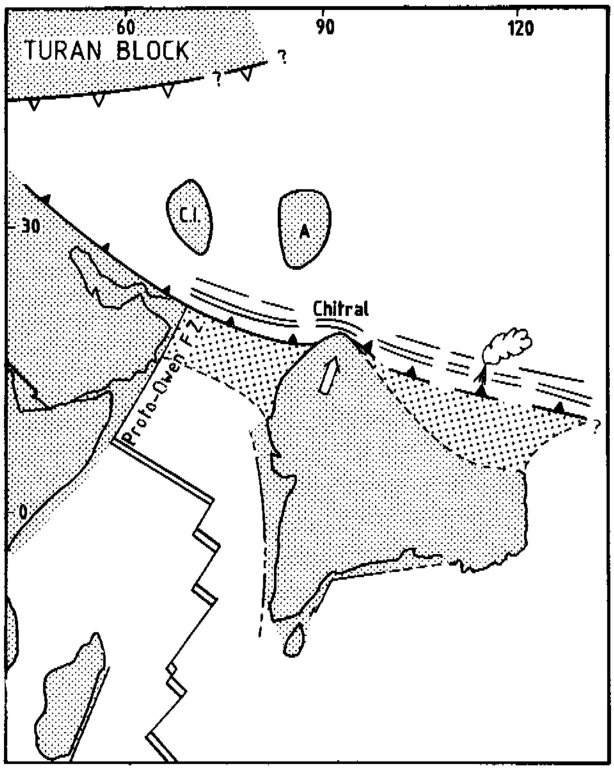


Figure 6: As Figure 5 but 55 Myr ago (after Powell, 1979)

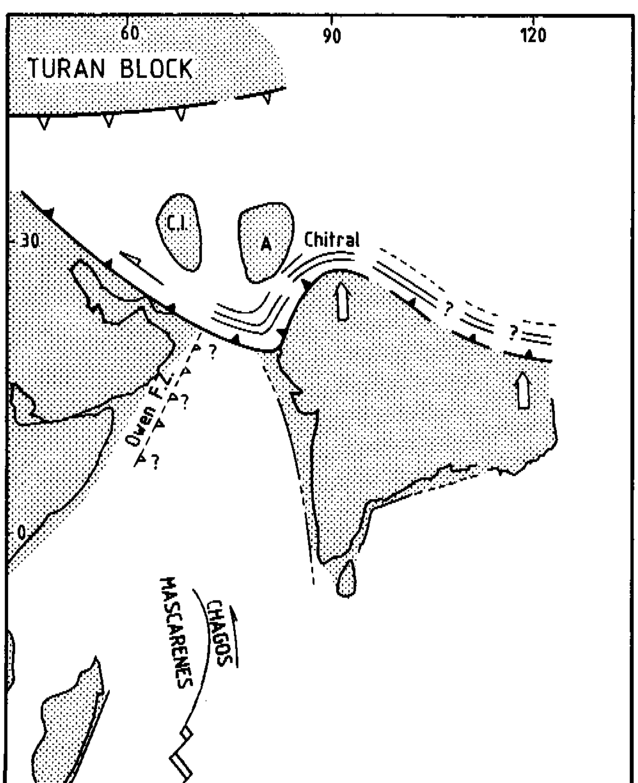


Figure 7: As Figure 5 but 40 Myr ago (after Powell, 1979)

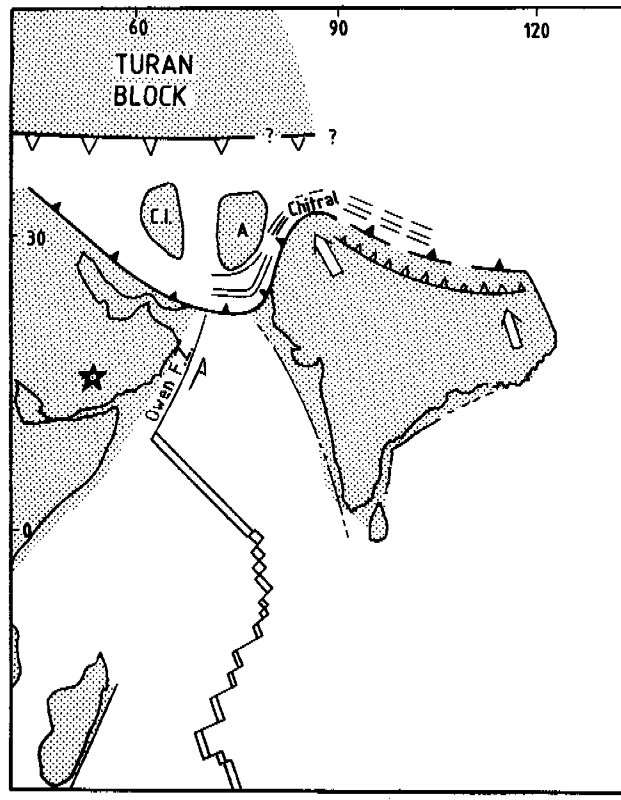


Figure 8: As Figure 5 but 20 Myr ago. The line with small closely spaced open barbs is the intracontinental convergence zone on which the Himalayas subsequently rose. The star indicates the position of the rotation pole of the subcontinent relative to Africa (after Powell, 1979)

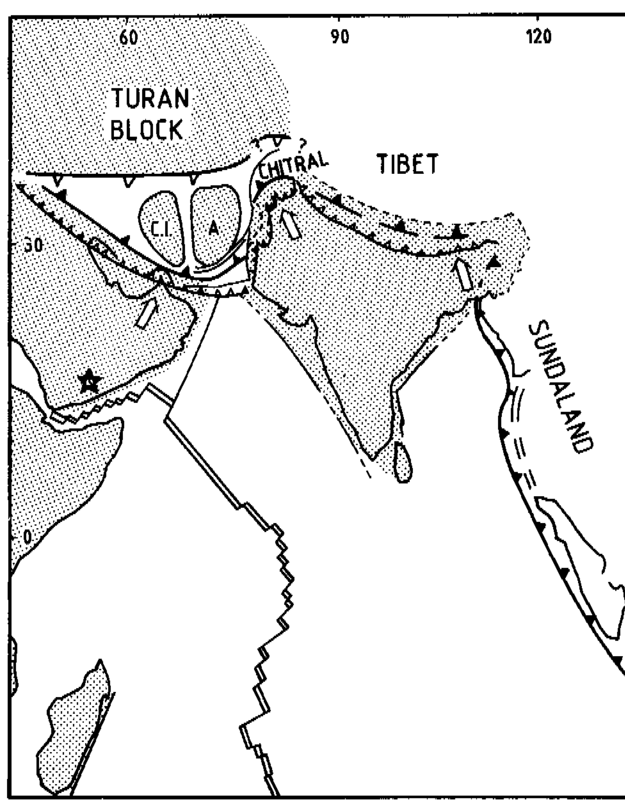


Figure 9: As Figure 5 but at present. The thin line of solid barbs within the NW part of the subcontinent represents the thrust-fold front of the Pakistani fold belt (after Powell, 1979)

of this rotation were the continued convergence of the micro-continental blocks of Central Iran and Afghanistan, the formation of the Pamir "knot", the rise of the Tibetan plateau and the growth of the Himalayas, with the accompanying formation of the Indogangetic basin (foredeep). The Plio-Pleistocene was also the climax of the main uplift and folding in the Pakistani fold belt (Auden, 1974). The accelerated uplift of most of the present high mountain ranges during the Plio-Pleistocene can be related to the continuing convergence between the Indo-Pakistani subcontinent and Eurasia. A comparison of the distribution of the present tectonic elements (Figure 9) with their configuration 20 Myr ago (Figure 8) illustrates the intense compression that has occurred in the Hindu Kush-Karakoram-Pamir region. The structural trends and the old convergence zone, on the southern margin of the Turan continental block, have been bent ahead of the advancing northwestern margin of the Indo-Pakistani subcontinent.

Based on the above picture it may be concluded that the Iran-Afghanistan belt has been progressively squeezed between the converging Indo-Pakistani, Arabian and Eurasian continental shields, and this has resulted in the rise of the Pakistan fold belt. One of its most distinctive features is its scalloped outline in plane. The major fold festoon is the 250 km wide Sulaiman lobe, and to the north the Salt range and the Trans-Indus Salt range structures also form marked protuberances. They are probably thin-skinned wedges of material that were either driven by a push from the rear or spread or slid under their own gravitational potential in a south-southeastern direction.

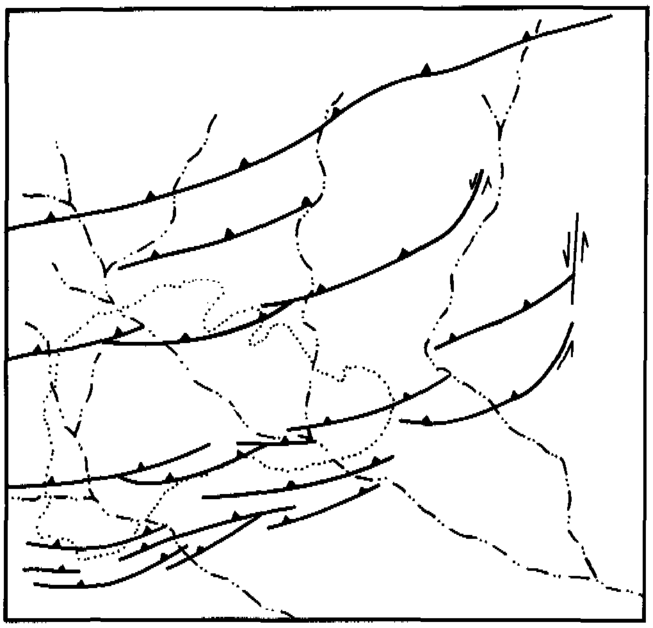


Figure 10: The Peshawar basin and its surroundings 8-10 Myr ago (after Burbank, 1983).

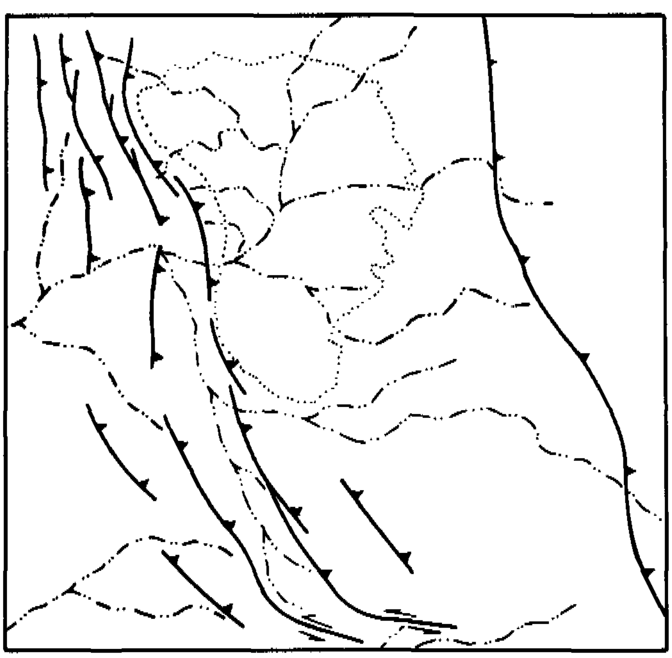


Figure 11: As figure 10 but 2-4 Myr ago. In this period thrust-faulting activity began to migrate southward (after Burbank, 1983)

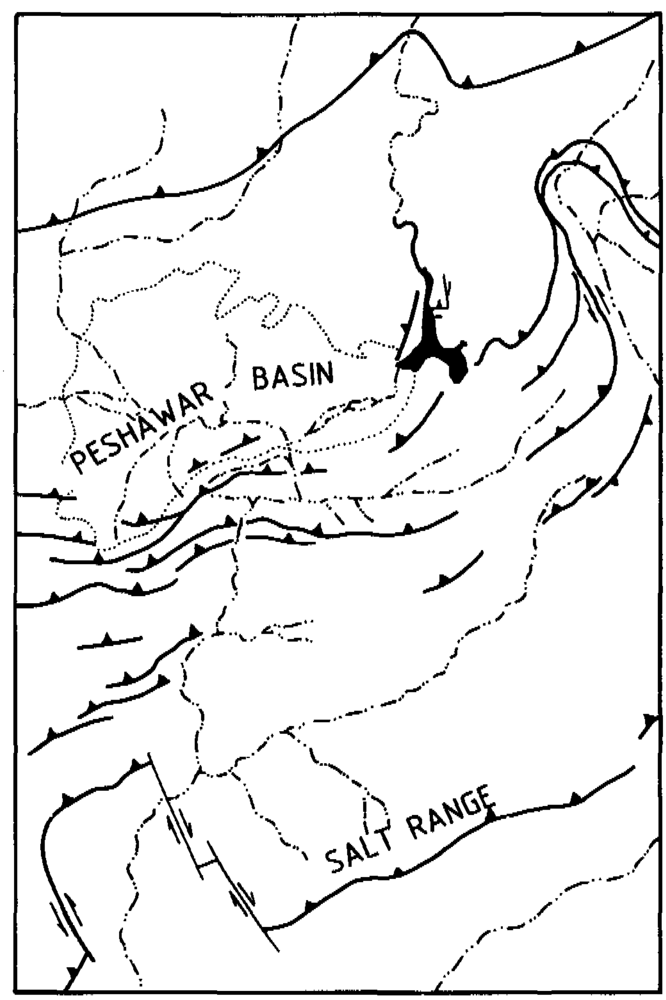


Figure 12: Present situation of the Peshawar and Campbellpore basins. Diminution of thrusting in the north and differential uplift of the southern margins initiates sedimentation in the intermontane basin. Widespread sedimentation is halted by renewed uplift and faulting during the past 0.5 Myr (after Burbank, 1983)

The Basins
The orogenesis of the mountain ranges was accompanied by the formation of basins. The most famous is the Indogangetic foredeep that stretches in the north of the Indo-Pakistani subcontinent from the Sulaiman range in the west to the mountains of Nagaland and Manipur in the east. The Dera Ismail Khan basin is the western extremity of the Indogangetic plain and the Peshawar Vale was part of it during an early stage of its formation. Evidence for this is provided by deformed early molasse deposits (Murree Formation of the Oligocene and early Miocene), which have been found in the Peshawar basin.
According to Burbank (1983), the major uplift and concomitant thrusting began to the south of the Main Mantle Thrust by late Oligocene to early Miocene. This deformation spread at least as far south as the Attock range by middle Miocene, some 8 to 10 Myr ago (Figure 10).
Intermontane basin development did not begin while uplift was still active throughout the region. Hence, Burbank (1983) suggests that in the early to middle Pliocene, when major deformation began to shift southwards, an equilibrum between uplift and erosion was attained in the Peshawar area. By the late Pliocene, 2-4 Myr ago, intermontane basin sedimentation had begun in the Peshawar basin (Figure 11). It continued until the morphotectonic emergence of the modern Attock range some 0.5 Myr ago (Figure 12).
The filling of the Bannu basin probably dates from the period after the emerging Trans-Indus Salt range had cut off the Peshawar and the Bannu basins from the Indogangetic foredeep some 2 (?) Myr ago.
Not much is known about the formation of the other intermontane basins, but most, if not all, are young to very young and filled with Pleistocene and Holocene alluvial deposits.

2.3 STRATIGRAPHY AND QUATERNARY GEOLOGY

The North-West Frontier Province can be subdivided into four broad geological units:
- the metamorphic and igneous rocks of the northern mountains
- the Mesozoic rocks of the southern and southwestern part
- the Tertiary rocks of the central and southeastern part
- the Upper Tertiary and Quaternary fill of the intermontane basins.

The metamorphic and igneous rocks of the northern mountains
The area north and west of the Peshawar Vale consists of metamorphic rocks associated with intrusions of igneous rock (Tahirkhelli, 1979). They can be divided into the Kohistan sequence north of the Main Mantle Thrust (MMT) and the metasediments associated with alkaline intrusions south of the MMT.
The bulk of the Kohistan sequence consists of black amphibolites of the Upper Swat Hornblendic group. Before the closure of the Tethys these rocks were part of the Kohistan island arc. They are found in the catchment of the Talash and Adinzai valleys, in the southern part of the Bajaur Agency, and in the Nikpikhel area (Kazmi et al., 1984). Associated with the amphibolites are dioritic rocks, peridotites, and quartzdiorites. The dioritic rocks are widespread in Bajaur Agency, and in the south of the Jandool area in Dir District (Kakar et al.,1971).
Further to the north, (e.g. in the north of the Jandool area) Tertiary volcanic rocks are present in the form of a very thick series of andesite and dacite tuffs interbedded with fossiliferous metasedimentary rocks.
Kempe and Jan (1980) defined the area south of the MMT as the "Peshawar plain alkaline igneous province". It extends from Mansehra in the east to the Afghan border and includes the Warsak granite on the edge of the Peshawar Vale, the Malakand granite south of the Talash and Adinzai valleys, the Ambela granite in Buner, and the Mansehra granite of the Pakhli plain. The associated rocks are metasediments, generally of Lower Palaeozoic age. They include:
- the slates and phyllites with interbedded metamorphosed limestones, tentatively dated as Siluro-Devonian of the southern part of the Bajaur (Ahmad and Khan, 1980) and Mohmand Agencies (Aslam et al., 1981);
- the massive grey limestone with sand and clay beds that makes up the Carboniferous Khyber Formation and the slate, phyllites and schists with minor limestone and quartzite beds of the Ordovician-Silurian Landi Kotal Formation in the eastern part of the Khyber Agency;
- the schists and calcareous (marble) rocks of the southern part of the Talash and Adinzai areas;
- weathered quartz-muscovite schists, often rich in garnet and tourmaline, associated with marbles and quartz biotite schists of the Lower Swat-Buner schistose group, found in the southwest of the Nikpikhel area (Jalil-ur-Rehman and Zeb, 1970) and in the Buner area (Martin et al.,1962);
- the Swabi-Chamla sedimentary group which is made up of quartzites overlying shales and which frequently form the tops of scarp faces and dip slopes in the Totali area (Martin et al.,1962);
- the metamorphic slates and quartzite of the Cambrian Tanawal Formation and the phyllites and slates of the left bank of the Indus river;
- the Permian phyllite, slate, quartzite and limestone of the Attock ridge (Hussain, 1977).

The Mesozoic rocks of the southern and southwestern part of NWFP
Mesozoic sediments occur in the western part of the Khyber Agency, the Orakzai area, the Kurram Agency, North Waziristan, and South Waziristan. They also extend into the Kohat range. This area is located at the western end of the Indo-Pakistani plate, where it collided with the Afghan continental block. As a result of the collision a belt of northsouth trending Jurassic and Cretaceous marine shelf deposits was uplifted. The east-west trending Safed Koh range that blocks the belt in the north also comprises Jurassic and Cretaceous limestones; its crest is formed by Cretaceous quartzites. In North Waziristan a thrust fault along the line Thal - Mir Ali separates Cretaceous rocks in western facies (see Section 15.6) from the Tertiary formations of the Kohat and Karak districts. South of Mir Ali, the thrust fault separates the Cretaceous rocks of North Waziristan from the Tertiary rocks along the western border of the Dera Ismail Khan basin.
The Kurram Agency consists mainly of overthrust Jurassic

and Cretaceous rocks (Meissner et al., 1975). On the right bank of the Kurram river Cretaceous rocks are predominant. They are developed in the so-called western facies, which is represented by the Kurram Formation. The latter consists of variegated red-brown and green shale, light grey, in places mottled, very thin bedded to platy limestone and brown or grey, conglomeratic sandstone. On the left bank of the Kurram river grey to dark grey, thin to thick bedded oolitic Jurassic limestones are found. They are interbedded with dark green sandstone and shale. Subordinate Cretaceous rocks are represented by undifferentiated sandstones of the Lumshiwal Sandstone and Chichali Formations, which are dark green to dark grey and glauconitic; locally, they are white and quartzose. North and northeast of Parachinar is a narrow ridge of Cretaceous quartzite that forms the border with Afghanistan.

Cretaceous shales with interbedded limestone and sandstone are the dominant formations in North Waziristan and South Waziristan.

In the Kohat range Jurassic limestones are strongly represented.

The Tertiary rocks of the central and southeastern part of NWFP

The rocks of Tertiary age are mainly found in the centre and south of the Province.

Dark grey Palaeocene shale and limestone are found along the crest of the Kohat range between the Peshawar Vale and the Kohat plain and in the adjacent part of Orakzai Agency. South of the Kohat range, between Kohat town and Banda Daud Shah is a broad belt of Eocene and Miocene formations. The Eocene sequence comprises limestone, clay, salt and gypsum, and the Miocene sequence purple sandstone, siltstone, shale, and clay. These rocks have been tightly folded and form narrow ridges 1000-1500 m (3300-4000 ft) high, separating broad flat valleys. Recumbent folds and overthrusts are common along the southern flanks of the anticlines. A belt of Pliocene strata lies immediately south of the Eocene - Miocene belt and stretches to the Bannu basin. The Pliocene layers are composed of sandstone, siltstone and clay with conglomerate lenses. They form a rugged mountain terrain that has about the same elevation as the Eocene-Miocene belt.

The (Waziristan) Sulaiman range that forms the western boundary of the alluvial basins of Dera Ismail Khan and Bannu is largely made up of Tertiary rocks. Consolidated or semi-consolidated sandstone with thick clay or shale beds of the Siwalik Group unconformably overlie Eocene clays. To the west a thrust fault separates the Tertiary rocks from the Cretaceous rocks of Waziristan.

The thick semi-consolidated sandstones and subordinate claystones of the upper part of the Siwalik group (Pliocene and lower Pleistocene) form the Bhittanni, Marwat and Shinghar mountains along the southern and eastern boundaries of the Bannu basin.

The Upper Tertiary and Quaternary fill of the intermontane basins

The intermontane basins are filled with deposits, mainly alluvium, consisting of sand, gravel, boulders, silt and clay. These are erosion products of the surrounding mountains and have been transported by the streams and rivers both from the hills and from more distant source areas. Not only river water but also wind is an active transport medium and has deposited thick layers of loess, which is well-sorted, fine, windblown silt.

The coarse alluvial deposits are found along the mountain fronts where each river or stream deposits its own alluvial fan by losing its coarse material when entering the plain. When the individual alluvial fans merge, the result is called a coalescing fan. The lower slopes of the fans that are dissected by hill torrents are called piedmont plains. The "hinterland" is still rising, and therefore there is no equilibrium between erosion and sedimentation; consequently, the plains are often dissected by these torrents.

Many of the basins may have been lakes at some time in their "recent" history. Consequently, the central parts of the large basins (Bannu, Peshawar) are filled with clayey lacustrine deposits with sandy intercalations and overlain with very young alluvial deposits. Floodplain deposits are present along the rivers in the central parts of the basins. These deposits consist of sandy streambed material that interfingers with clayey sediments spread out by rivers overflowing their banks during high floods. Typical features are the meander scars left behind by the shifting pattern of stream channels. Away from the floodplain the surface is covered with sheet flood deposits consisting of fine erosion material transported by the overland runoff after rainstorms.

In the larger basins, i.e. Peshawar Vale, Bannu basin, and Dera Ismail Khan basin, which are related to the Indogangetic plain, Upper Pliocene deposits are found as well. Burbank and Tahirkhelli (1985) concluded that in the Peshawar depression intermontane-basin sediments began to accumulate at least 2.8 Myr ago. Since that time more than 300 m of sediments have settled unconformably over the folded and faulted Murree Formation of Miocene age. Beginning approximately 2.5 Myr ago alluvial fans derived from the uplifting Attock range crept slowly into the Peshawar basin as witnessed by sections near Dag that were studied by the Pakistan Geological Survey. At the same time, floodplain and floodpond deposits formed on the western side of the basin near Garhi Chandan. Subsequently, the quiet water environment was invaded by braided rivers, representing the downstream, fluvial component of the alluvial fans. They left behind coarse-grained gravels fining upwards into silt. Towards the centre of the basin the gravel deposits thin out and are eventually replaced by lacustrine sediments, which aggraded in shallow lakes on extensive floodplains. Intercalated volcanic ash deposits date from 2.5 and 1.6-1.8 Myr ago. They probably originated in the Dasht-e-Nawar volcanic complex in east-central Afghanistan. Accelerated uplift of the Attock range during the Middle Pleistocene, some 0.6 Myr ago, caused folding and dissection of the sediments filling the Peshawar Vale. According to Nizami (1973), at that time the Peshawar area was transformed into a lake several times whenever the outflow of the Indus river was blocked. The lake must have been quite extensive, since its deposits are even found near Matanni, high up the southern piedmont. The lake deposits show alternating sandy and silty strata. At some places loess is found between different lacustrine layers, indicating a dry period between two lake periods. When the area was properly drained, sand to silty alluvial deposits were formed by the shifting rivers and by the sheetfloods that brought the runoff to the rivers. Several erosion cycles since the Middle Pleistocene have been recognized. During these cycles much of the loess cover was removed.

Since then, catastrophic floods have periodically inundated the basin.

The Bannu basin is younger than the Peshawar Vale, but it was formed in a comparable way when the Bhittanni, Marwat and Shinghar ranges emerged and cut off the Bannu basin from the Indogangetic foreland (Section 2.2). The young and not very high (usually less than 1200 m above msl), narrow ridges are of the same only partially consolidated Late Tertiary molasse deposits as the bedrock of the basin which gradually filled up with younger alluvial sediments.

The Dera Ismail Khan plain is part of the western fringe of the Indogangetic plain (Section 2.2). On the west side it is bordered by mountains that largely consist of consolidated or semi-consolidated sandstone with thick clay or shale beds (molasse deposits) of the late Tertiary Siwalik Group. Hood et al. (1970) assumed that these rocks extend as basement rock at relatively shallow depth below the alluvial fill. This is debatable because fault zones, now mostly buried under young sediments, separate the mountains from the basin. The basement of the unconsolidated Quaternary sediments is formed by a hard clay layer at a depth of more than 200 m below the surface, which may well belong to the molasse deposits of the Plio-Pleistocene period and not to those of the older Siwalik Group.The alluvial fill consists of two types of sediment: (a) piedmont deposits that have their source in the nearby mountains and (b) the floodplain deposits of the Indus river lowlands.

The Quaternary fill of the other intermontane basins and valleys is supposedly much younger and consists of fluviatile sediments forming piedmont and floodplain deposits. Remains of older loess sediment may be present. The character of the sediments is strongly related to the nature of the surrounding mountains.

2.4 OCCURRENCE OF GROUNDWATER

By definition, groundwater occurs below the land surface in the soil and rock. It may fill the pores in between the soil or rock particles, as well as cracks and solution cavities. Voids that are formed during the sedimentation of loose particles such as sand, gravel, etc., are called pores. The volume of the pores compared with the total rock volume is the primary porosity. The voids that originate as a result of post-depositional or post-crystallization processes such as faulting, fracturing and dissolving make up the secondary porosity. The porosity of the weathered mantle of an igneous rock complex is also considered primary porosity.

Consolidated sediments may show both primary and secondary porosity. The primary porosity is usually smaller than in the unconsolidated layers, because of the compaction and cementation that occur during the consolidation process. Open fractures in consolidated sediments may provide secondary porosity.

In crystalline rocks such as igneous and metamorphic complexes and lava flows, the primary porosity is usually negligible, except when the rock is completely weathered on the spot. Secondary porosity may be prominent either as isolated fractures and fault zones or as more or less dense joint patterns caused by tectonism or by cooling (e.g. basalt).

Secondary porosity by solution only occurs in easily soluble rocks that are rigid enough to support the solution channels from being closed by the pressure inside the rock. Hence, solution porosity is restricted to carbonate rocks such as limestone and dolomite.

Porosity, n, is defined as the ratio of the volume of pores, V_n, to the total volume of the rock or soil, V_t.

$$n = V_n/V_t$$

and expressed as a decimal fraction or a percentage.

Pores are filled with a fluid (e.g. water) or with a gas (e.g. air) or with a combination of both. When the pores are completely filled with water (or another fluid) the rock is said to be saturated. The upper boundary of the saturated groundwater zone is the water table. At the water table the fluid pressure is equal to the atmospheric pressure. Below the water table the fluid pressure is greater than the atmospheric pressure. Hence, when a well is constructed to a point below the water table the water will freely enter it. Flow in the saturated zone usually has a large horizontal component.

The unsaturated zone occurs above the water table and above the capillary fringe; the soil pores are only partially filled with water and the fluid pressure is less than atmospheric. Flow in the unsaturated zone is predominantly vertical.

The capillary fringe or tension-saturated zone (Freeze and Cherry, 1979) has an intermediate position: the pores are completely filled with water but the fluid pressure is less than atmospheric. There is no natural outflow to the atmosphere (e.g. through wells or springs) from the capillary zone.

Aquifers are best defined as saturated permeable geological units that can transmit significant quantities of water under ordinary hydraulic gradients. The term aquitard is used to describe the less permeable beds in a stratigraphic section. An aquitard is permeable enough to transmit water in quantities that are significant when viewed over large areas and long periods, but is not permeable enough to allow the completion of production wells (Freeze and Cherry, 1979). An aquiclude is a sequence of strata that does not transmit water at all. These definitions are often used in a relative sense e.g. an "aquifer" that can satisfy the domestic requirements of a small village may not be an "aquifer" when groundwater-based irrigation is considered.

Most sedimentary rocks are classified as either aquifers or aquitards, but only a small fraction of most saturated zones can be classified as aquifers. The most common aquifers are unconsolidated sand and gravels, permeable sedimentary rocks such as sandstone and limestone, and heavily fractured or weathered volcanic and crystalline rocks. Clays and shales are typical aquitards, and dense unfractured igneous or metamorphic rocks can often be classified as aquicludes.

It will be clear that the thick series of unconsolidated sediments of the alluvial basins contain the best aquifers in the North-West Frontier Province. Obviously, the aquifers are usually only a fraction of the total thickness of the sequence.

Aquifers are divided into confined, unconfined and semi-confined or leaky aquifers. A confined aquifer is confined

along top and bottom by aquicludes. The water in a well that is sunk in a confined aquifer will usually rise to a "level" above the top of the aquifer. In some cases the water level even rises above the land surface, in which case the well is known as "free flowing" or "artesian".
The use of the latter term is discouraged, because it is also used to denote a well in a confined aquifer in general. If at least one of the confining layers of an aquifer is an aquitard instead of an aquiclude, the aquifer is said to be semi-confined or leaky. An unconfined aquifer has the water table as its upper boundary. The base of an unconfined aquifer is an aquiclude or an aquitard.
When a well is constructed in a confined or semi-confined aquifer in such a way that it receives water from this aquifer only, the water in the well will usually rise to a level above the top of the aquifer. This level is called the piezometric or potentiometric surface. If the elevation of the piezometric level measured in all wells tapping the particular aquifer is plotted on a map and contoured, the isohypses of the piezometric or potentiometric surface emerge. A potentiometric map provides an indication of the directions of groundwater flow in the aquifer.
In an unconfined aquifer, the water-struck level coincides with the water table, in a confined aquifer the water-struck level is lower, sometimes by tens of metres, than the piezometric level.
The water-struck level gives an idea of the minimum depth a well needs to be, and the water table and piezometric level give an indication about the minimum pumping lift.
In the North-West Frontier Province, the aquifer conditions vary considerably. The Parachinar basin, for example, contains a single unconfined aquifer with a deep water table that is more than 100 m below the land surface near the mountains and intersects the land surface close to the Kurram river. On the other hand, in the centre of the Peshawar Vale there are very thick lacustrine clay layers with only relatively thin confined or semi-confined aquifers.

2.5 GROUNDWATER PROPERTIES

Water is made up of two chemical elements: hydrogen and oxygen, and has the chemical formula H_2O. Its density is 1 ton/m^3 which it reaches at a temperature of 4°C. At higher and lower temperatures the density is less. At sea level water freezes at 0°C and boils at 100°C. The resistance of a liquid to flow is called viscosity; its value varies with variations in temperature. The viscosity of water at 20°C is 1 centipoise and for water at 100°C: 0.28 centipoise.
In addition to water molecules, pure water also contains dissociated $H^+$and OH^- ions in very low concentrations. The symbol pH is used to designate the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. Thus, if there are 10^{-7} moles per litre of H^+, then the pH of pure water at 25°C is 7.0. Material going into solution may change the pH value. The influence of sodium chloride on the pH value is slight, but in the case of calcium carbonate going into solution the equilibrium shifts in the direction of few H^+ ions or a basic reaction: hence the pH value increases. Most groundwater has pH values btween 5.0 and 8.0. In general, water from clay-rich sediments has a lower pH than water from limestone.
The amount of total dissolved solids (TDS) in water is expressed in mg/l or in parts per million (ppm). Fresh water has a specific gravity close to 1, hence for fresh water, ppm and mg/l are nearly equivalent. In this book mg/l will be used. Another convenient unit is milligram equivalents per litre (meq/l). This is calculated by dividing mg/l by the equivalent

Table 11: Relative tolerance of plants to boron (after Richards, 1954)

	Sensitive	Semi-tolerant	Tolerant
Excellent water:	Less than 0.3 mg/1	Less than 0.7	Less than 1.0
Unsuitable water:	More than 1.3 mg/1	More than 2.5	More than 3.8
	Lemon	Bean (Lima)	Carrot
	Avocado	Pepper	Cabbage
	Orange	Pumpkin	Onion
	Apricot	Oat	Alfalfa
	Peach	Maize	Date palm
	Apple	Wheat	
	Walnut	Barley	
		Tomato	
		Cotton	
		Sunflower	

weight of the ion under consideration. This unit is helpful in picturing the true chemical character of the water. As the sum of the meq/l of the anions must equal the sum of the meq/l of the cations in the chemical analysis of a water sample, this provides a method for checking that the the chemical analysis is correct. TDS of natural waters varies between as little as 0.1 mg/l in arctic snow to more than 100 000 mg/l in oil-field brines; for comparison: seawater has a TDS of 30 000 mg/l.

A rough estimate of the total dissolved solids can be obtained by determining the capability of the water to conduct an electric current. This property is called the electric conductivity (EC) or the specific electrical conductance, and is the conductance of a cubic centimetre of water at a temperature of 25°C. It is the reciprocal of electrical resistance and it is expressed in the unit called siemens per centimetre (S/cm) formerly known as mho/cm (the reciprocal of ohm). The electric conductivty (EC) of groundwater is usually quite low so it is convenient to express it in millisiemens per centimetre (mS/cm).

The chemical composition of the dissolved constituents determines the chemical quality of a water and is often decisive in determining its usefulness. The major constituents are the cations calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K), and the anions: bicarbonate (HCO_3), chloride (Cl), sulphate (SO_4) and nitrate (NO_4). It is common practice to classify water by such terms as "calcium bicarbonate" water or "sodium chloride" water. These classifications represent the predominant cation and anion expressed in milliequivalents per litre. Water in which no one cation or anion constitutes at least 50 per cent of the totals is designated as water of a mixed type and identified by the names of all the important cations and anions (Hem, 1970).

Some of the minor constituents are of particular importance

Table 12: Water quality criteria for various uses. Numbers are maximum recommended concentrations in mg/l (after Davis and DeWiest, 1966)

	Drinking	General Household Use		Irrigation		Food Processing	Boiler water	
		Good	Poor	Good	Poor		High Pressure	Low Pressure
Antimony	0.05	...	...	...	...	0.05	...	...
Arsenic	0.05	...	...	...	...	0.05	...	...
Barium	1.00	...	...	...	...	1.00	...	...
Bicarbonate	500	150	500	200	500	300	5	50
Boron	20	...	...	0.3	3.0	...	...	...
Cadmium	0.01	...	...	...	...	0.1	...	...
Calcium	200	40	100	...	...	80	1	40
Chloride	250	...	...	100	300	300	...	...
Chromium	0.05	...	...	...	...	0.05	...	...
Copper	1.0	0.5	3.0	...	...	3.0	...	...
Cyanide	0.2	...	...	...	...	0.2	...	...
Fluoride	1.5	...	...	...	...	1.5	...	...
Hydrogen sulfide	1.0	0.05	2.0	...	...	0.5	0	5
Iron	1.0	0.2	0.5	...	...	0.2	...	...
Lead	0.05	...	...	...	...	0.05	...	...
Magnesium	125	20	100	...	...	40	1	20
Manganese	0.05	0.05	0.3	...	...	0.1	...	...
Nitrate	20	...	...	...	...	20	...	...
Phenol	0.001	...	...	...	...	0.001	...	...
Selenium	0.01	...	...	...	...	0.01	...	...
Silica	...	10	50	...	...	50	1	30
Silver	0.05	...	...	...	...	0.05	...	...
Sodium	200	100	300	50	300	300	...	50
Sulfate	250	100	300	200	500	...	...	...
Synthetic detergents	0.5	0.2	1.0	...	...	0.5	0	0
Total solids	1500	300	2000	500	3000	1000	100	2000
Zinc	5	...	...	...	...	5	...	...

Table 13: Substances and characteristics affecting the acceptability of water for domestic use (after PHED, Peshawar)

Substance or Characteristic	Undesirable effect	Highest desirable level	Maximum permissible level
Subtances causing discoloration	Discolaration	5 units	50 units
Substances causing odour	Odours	Unobjection-able	Unobjection-able
Substances causing taste	Taste	Unobjection-able	Unobjection-able
Suspended matter	Turbidity, possible gastrointestinal irritation	5 units	25 units
Total solids	Taste, gastrointestinal irritation	500 mg/1	1500 mg/1
pH	Taste, corrosion	7.0 to 8.5	6.5 - 9.2
Total hardness	Excessive scale formation	100 mg/1	500 mg/1
Calcium	Excessive scale formation	75 mg/1	200 mg/1
Chloride	Taste, corrosion	200 mg/1	600 mg/1
Magnesium	Hardness, taste, gastro-intestinal irritation in presence of sulfate	30 mg/1[1]	150 mg/1
Sulfate	Gastrointestinal irri-tation when magnesium or sodium are present	200 mg/1	400 mg/1
Iron (total)	Taste, discoloration, deposits and growth of iron bacteria, turbidity	0.1 mg/1	1.0 mg/1
Manganese	Taste, discoloration, deposits in pipes, turbidity	0.05 mg/1	0.5 mg/1
Zinc	Astringent taste, opalescence and sand-like deposits	5.0 gm/1	15 mg/1
Copper	Astringent taste, coloration, corrosion	0.05 mg/1	1.5 mg/1
Nitrate	Blue baby's desease		45 mg/1

[1]not more than 30 mg/1, if there are more than 250 mg/1 of sulfate; if there is less sulphate, 150 mg/1 may be allowed

Table 14: Crop tolerance to salt. Yield decrement to be expected for certain crops due to salinity of irrigation water when common surface irrigation methods are used (After Ayers and Westcot, 1976)

CROP	0% / ECw*	10% / ECw	25% / ECw	50% / ECw
Barley**	5.3	6.7	8.7	12.0
Cotton	5.1	6.4	8.4	12.0
Wheat**/***	4.0	4.9	6.4	8.7
Soybean	3.3	3.7	4.2	5.0
Sorghum	2.7	3.4	4.8	7.2
Groundnut	2.1	2.4	2.7	3.3
Rice (paddy)	2.0	2.6	3.4	4.8
Maize	1.1	1.7	2.5	3.9
Broadbean	1.1	1.8	2.0	4.5
Cowpea	0.9	1.3	2.1	3.2
Beans	0.7	1.0	1.5	2.4
Date palm	2.7	4.5	7.3	12.0
Pomegranate	1.8	2.6	3.7	5.6
Orange	1.1	1.6	2.2	3.2
Lemon	1.1	1.6	2.2	3.2
Apple	1.0	1.6	2.2	3.2
Walnut	1.1	1.6	2.2	3.2
Peach	1.1	1.4	1.9	2.7
Apricot	1.1	1.3	1.8	2.5
Almond	1.0	1.4	1.9	2.7
Plum	1.0	1.4	1.9	2.8
Tomato	1.7	2.3	3.4	5.0
Cucumber	1.7	2.2	2.9	4.2
Melon	1.5	2.4	3.8	6.1
Spinach	1.3	2.2	3.5	5.7
Cabbage	1.2	1.9	2.9	4.6
Potato	1.1	1.7	2.5	3.9
Pepper	1.0	1.5	2.2	3.4
Onion	0.8	1.2	1.8	2.9
Carrot	0.7	1.1	1.9	3.1
Beans	0.7	1.0	1.5	2.4
Crested Wheat grass	2.3	4.0	6.5	11.0
Sudan grass	1.9	3.4	5.7	9.6
Trefoil, big	1.5	1.9	2.4	3.3
Alfalfa	1.3	2.2	3.6	5.9
Maize (forage)	1.2	2.1	3.5	5.7
Clover, berseem	1.0	2.1	3.9	6.8
Orchard grass	1.0	2.1	3.7	6.4
Clover	1.0	1.6	2.4	3.8

* ECw means electrical conductivity of the irrigation water in millisiemen per cm at 25°C (mS/cm). This assumes about a 15-20% leaching fraction and an average salinity of soil water taken up by crop about three times that of the irrigation water applied (ECsw = 3ECw) and about two times that of the soil saturation extract (ECsw = 2ECe).

** Barley and wheat are less tolerant during germination and seedling stage. ECe should not exceed 4 or 5 mS/cm.

*** Tolerance data may not apply to semi-dwarf varieties of wheat.

because of their influence on the health and growth of living matter. Fluorine is required in small quantities for the proper development of teeth, in excessive quantities it causes mottled enamel and in a later stage bone deformation. Similarly, boron (B) is required in small quantities for plant growth, but is hazardous in large quantites (Table 11).

The stable isotopes deuterium (^2H or D) and oxygen 18 (^{18}O) and the radioactive isotopes tritium (^3H or T) and carbon 14 (^{14}C) occur in extremely small quantities in natural waters and can be used in groundwater research. The stable isotopes are used in investigations about the origin of the water and the radioactive isotopes are used in studies about the water's age. In NWFP these techniques have not yet been used.

Water should satisfy certain criteria to be classified as suitable for a specific purpose such as drinking water, irrigation, use in industrial process or cooling (Tables 12 and 13).

The water quality criteria should be used judiciously, because other environmental factors also play a role in the acceptability of a specific water source for a specific use. For example, in many parts of the world, the TDS of public water supplies is much higher than the recommended value because no other supply is available, and although the high TDS value affects the taste of the water it is, again within certain limits, not toxic. For irrigation use, the water quality criteria differ per crop; moreover, well-drained sandy soils permit the use of poorer quality water than poorly drained clay soils, because salt accumulations in the root zone are more easily leached out. Table 14 shows the relative tolerance of crops to salt. The salinity hazard can be estimated from the EC value of the water.

If the calcium and magnesium ions on the clays and colloids of the soil are replaced by sodium, soil permeability decreases and the soil hardens. The extent of the risk of a sodium hazard is estimated by the sodium adsorption ratio (SAR), which is expressed by the following formula:

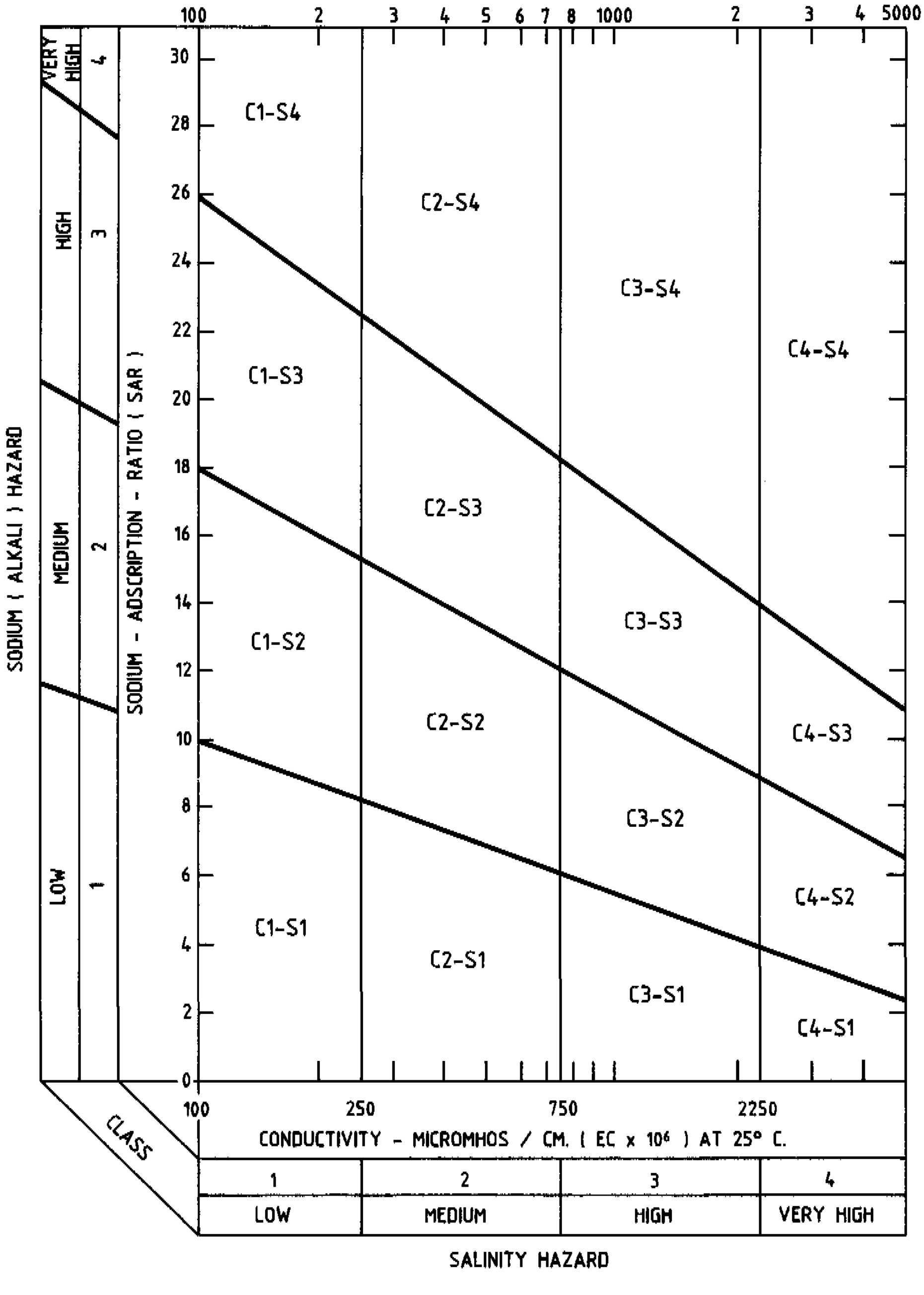


Figure 13: Diagram for the classification of irrigation waters (after Richards, 1954)

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

in which Na, Ca and Mg represent concentrations in meq/l of the respective ions. The diagram in Figure 13 indicates the relative hazard of various values of SAR and EC.

The salinity of NWFP's groundwater has different origins. Insofar as the deeper parts of the intermontane basins are filled with marine deposits, entrapped seawater may be present. The solution of evaporite deposits such as rock salt either by

Table 15: Summary of the EC value, water type and SAR value of the groundwater in the alluvial plains of NWFP

Area	EC in mS/cm	water type	SAR value
Groundwater quality good; EC less than 1.0 mS/cm:			
Dir and Swat Districts			
Talash and Adinzai	0.3 - 0.6	Ca / HCO_3	SAR < 1
Jandool area	(No data; quality probably good)		
Nikpikhel	0.6	Ca - Mg / HCO_3	SAR 0.2
Daggar valley	0.3 - 0.5	Ca - Mg / HCO_3	SAR < 2
Chamla valley	0.2 - 0.7	Ca - Mg / HCO_3	
Chingalai basin	(quality probably as in the Chamla valley)		
Totali area	(No data; quality probably good)		
Indus left bank			
Haripur area	0.3 - 1.0	Ca / HCO_3	SAR > 1
Pakhli plain	0.2 - 1.1	Ca / HCO_3	SAR < 2
Ghazi area	0.2 - 0.9	Ca / HCO_3	SAR 0.3 - 2.3
Mardan and Peshawar Districts			
Peshawar Vale tubewells:			
SW of Kabul r.	< 1.0	Ca-Mg / HCO_3	
N of Kabul r.	< 1.0	Na / HCO_3 - Cl	
Peshawar Vale shallow wells:			
SW of Kabul R.av.	1.35	Ca-Na / HCO_3	
Mardan District	av. 1.30	Ca-Na / HCO_3	
Nizampur tubewells	0.5 - 1.1	Ca / HCO_3	SAR 0.8 - 2.2
Gadoon	0.5 - 0.8		
"	exc. 0.6 - 4.6	high K / high SO_4 - high Cl	
Kohat and Karak Districts			
Kohat plain tubewells	0.4 - 1.1	Ca / HCO_3	SAR 0.1 - 1.
Hangu valley			
tubewells	< 1.0	Ca / HCO_3	SAR 1.8 - 2.2
shallow w.	0.4 - 1.0(2.0)		
Doaba valley			
tubewells	< 1.0	Ca / HCO_3	SAR 0.1 - 1.1
shallow wells	1.2	Ca-(Na)/ HCO_3	SAR 1.0 - 5.7
Western Karak valley			
Southern side	0.7 - 1.0	mixed / HCO_3	SAR 0.3 - 4.0
Eastern Karak v.	0.7 - 1.0	mixed / HCO_3	
Bannu basin			
Area between the Kashu Algad and Kurram river	0.5 - 1.8	Ca / HCO_3(EC <1.0) Na / Cl (EC >1.0)	SAR 0.6 - 16
Confined aquifer of the Marwat plain	0.9	Na / HCO_3 - SO_4	SAR 4 - 7
Dera Ismail Khan			
Western fans	< 2.0	Ca-Mg / HCO_3	
Northern fans	< 2.0	Na / HCO_3	
Indus floodplains	< 0.3	Ca or Na / HCO_3	
FATA (except Parachinar)	(No data; quality probably good)		
Parachinar	0.4 - 0.5 (1.5)	variable	SAR 0.1 - 2.4

Table 15 (continued)

Moderate quality; EC between 1.0 and 2.0 mS/cm			
Kohat and Karak Districts			
Kohat plain			
shallow wells	0.6 - 1.6 (2.0)		
Lachi plain	0.9 - 1.1 (2.2)	Ca / mixed	
Bannu basin			
Kurram Gambila D.	0.8 - 2.0		SAR 0.1 - 3.1
Lakki plain	0.8 - 2.0		
Marwat plain	0.7 - 2.5	Na-Mg / SO_4-HCO_3	SAR 1.4 - 7.0
Poor quality; EC more than 2.0 mS/cm			
Kohat and Karak Districts			
Teri area	1.0 - 9.0	Na / CL	
Western Karak valley			
Northern side	2.5 - > 5	Na / Cl	SAR 21
Bannu basin			
South of the Kashu Algad			
The area along the Kashu Algad and in a strip up to 10 km wide along the Kurram river below their confluence.	up to 16		SAR up to 40
The area away from the saline strip	0.3 - 2.0	Na / HCO_3	SAR 0.7 - 7.3
Marwat plain, central area			
shallow aquifer	> 2.0	Mg-Na / HCO_3-SO_4	SAR 3 - 5
Dera Ismail Khan			
Central area	2.0 - 20	high sulphate	

groundwater itself or by surface water (e.g. Kashad Algad in Karak and Bannu Districts) that subsequently infiltrates and percolates to the groundwater, may cause high salinity levels in the groundwater. The leaching of soluble matter from weathered rock, but especially of salt that has accumulated as a result of evapotranspiration of irrigation water, is another source of salinity. In the hard rock areas, magmatic emanations may locally cause both a rise in salinity and a change in chemical composition (thermal and mineral springs). Modern developments in agriculture and industry and changing life-styles and consumption patterns of the population carry the risk of widespread groundwater contamination. One of the problems in protecting groundwater against pollution is that the process is treacherously slow and for a long time people remain unaware of the slow poisoning of their precious groundwater resources. The conditions that hide a creeping deterioration of a subsurface water resource also prevent quick remedial action. Reclamation of a polluted aquifer is at least as slow a process as its degradation. Notable pollutants are: fertilizer, nitrate and non-biodegradable pesticides and herbicides from agricultural activities; industrial wastes and the wastes from mining operations; and organic wastes and bacteriological contaminants from domestic activities.

A summary of the chemical quality of the groundwater in NWFP is given in Table 15; for details the reader is referred to Chapters 9 through 15.

3 GROUNDWATER BEHAVIOUR

3.1 THE HYDROLOGICAL CYCLE

Water on earth occurs as vapour, as fluid and as solid matter (ice). Under the influence of solar energy water evaporates - mainly from the seas and oceans - and is transported to the land as vapour and clouds of droplets. It falls on the earth's surface as rain or snow and flows back to the sea. This perpetual circulatory movement is called the hydrological cycle (Figure 14).

In a landlocked area like NWFP we are only interested in the landbased part of the cycle, which is depicted schematically in Figure 15.

Inflow to the hydrological system arrives as precipitation in the form of rainfall or snow, and outflow takes place as runoff and stream flow, as subsurface flow and as evapotranspiration (a combination of evaporation from open water and bare soil and transpiration of water from the soil by plants).

In this book we will concentrate on the subsurface part of the hydrological cycle and will discuss the surface water part only insofar as it has a direct influence on the behaviour of the groundwater. For a full discussion of the hydrological cycle the reader is referred to hydrology handbooks such as the Handbook of Applied Hydrology edited by Ven Te Chow (1964).

Most active fresh water is stored as groundwater and has a long residence time; when it occurs as surface water it is transported rapidly back to the sea (short residence time). Table 16 gives an estimate of the world's water balance.

The water in storage as groundwater is not in "dead storage" because there is a slow, but continuous exchange between the surface water and the groundwater. One could say that each drop of groundwater was once surface water and will become surface water again in the future. A certain amount of the water (rainfall, irrigation, etc.) that reaches the earth evaporates, another part runs off over the surface, entering canals and rivers and the third fraction infiltrates into the soil. Depending on the soil moisture conditions at the time of infiltration, a smaller or larger fraction of the infiltrated water will be retained in the soil as soil moisture. The rest percolates to the water table. Water that percolates downward leaches from the root zone salt that has accumulated as a result of the evapotranspiration of the soil moisture. It is a popular but nevertheless erroneous belief that there is no percolation before the total soil mass has a moisture content corresponding to field capacity. However, most soils are sufficiently inhomogeneous for the infiltrated water to follow preferential paths to circumvent still incompletely wetted portions of the soil. These paths consist of the larger than average pores, cracks, root channels and the burrows of insects and other smaller and larger animals.

If surface water does not infiltrate into the soil or evaporate into the air, it runs off over the land surface and collects in streams and rivers to return eventually to the sea. If the river flows through permeable material it may either lose water by streambed infiltration (in which case it is an influent river) or it may gain water by groundwater drainage or exfiltration (and is called an effluent river) as shown in Figure 16.

A river may be influent along one stretch of its course and effluent along another. A good example is the Kabul river: between Warsak and Peshawar the river is influent, but it becomes effluent near Nowshera near its confluence with the Indus river. When the water table corresponds to the average river level, the river will be influent during the season that the water is high and effluent when it is below the ground-

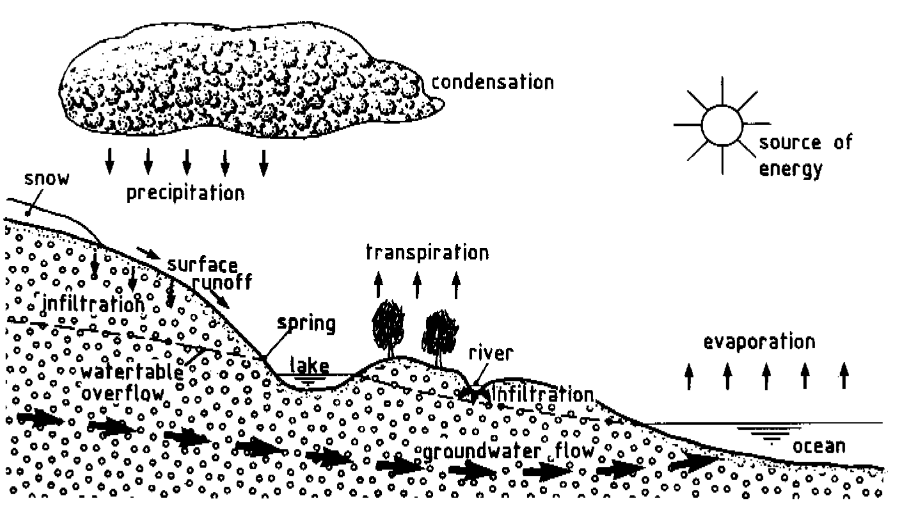


Figure 14: Hydrological cycle (after Todd, 1969)

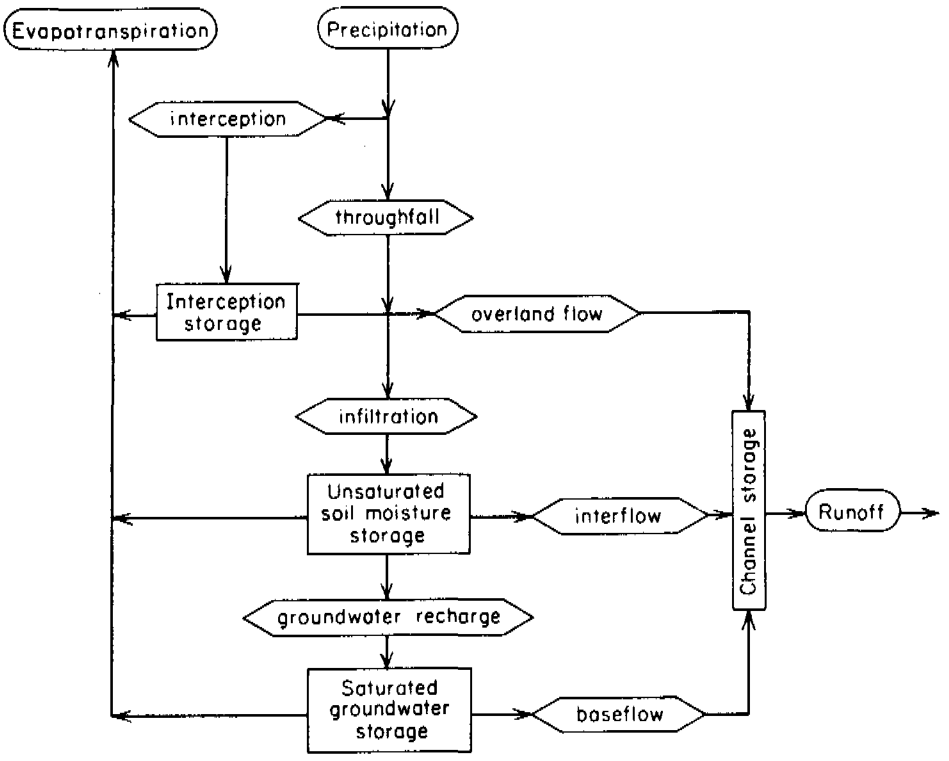


Figure 15: Schematic representation of the landbased part of the hydrological cycle (after Freeze and Cherry, 1979)

Table 16: Estimate of the water balance of the world (Nace, 1971)

Parameter	Surface area $(km^2)x10^6$	Volume $(km^3)x10^6$	Volume (%)	Equivalent depth (m)*	Resident time
Oceans and seas	361	1370	94	2500	~4000 yr
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~ 10 yr
Swamps	<0.1	<0.01	<0.01	0.007	1-10 yr
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	0.01	0.13	2 w-1yr
Groundwater	130	60	4	120	2 w-10,000 yr
Icecaps and glaciers	17.8	30	2	60	10-1000 yr
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric	<0.1	<0.01	<0.01	0.001	~1 week

* Computed as though storage were uniformly distributed over the entire surface of the earth

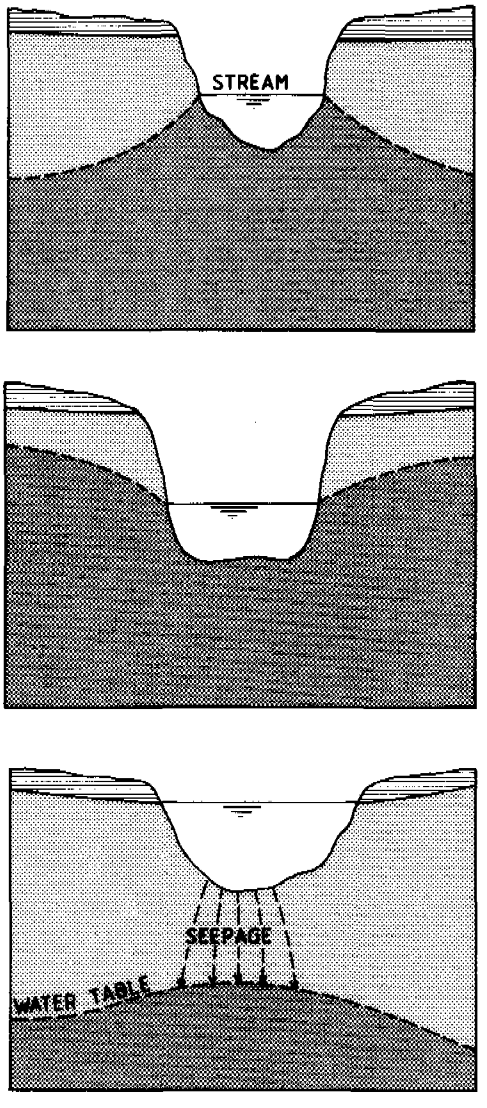


Figure 16: Influent and effluent rivers (after Driscoll, 1986)

water level (Figure 17). The water that infiltrates during the wet season is again drained off during the period with dry weather. This phenomenon is called bank storage. Irrigation canals lose water to the groundwater body in the same way as rivers do.
When a river flows through impervious soil or rock, it will neither lose nor gain water to or from the groundwater (Figure 18).
Lateral subsurface inflow and outflow is the more or less horizontal groundwater flow that crosses the boundaries of a groundwater basin or area under study. The lateral flow sys-

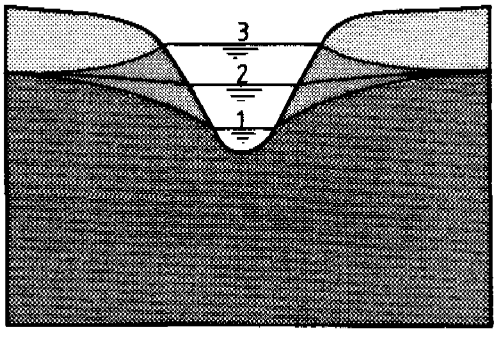


Figure 17: River water level changing with time (after Driscoll, 1986)

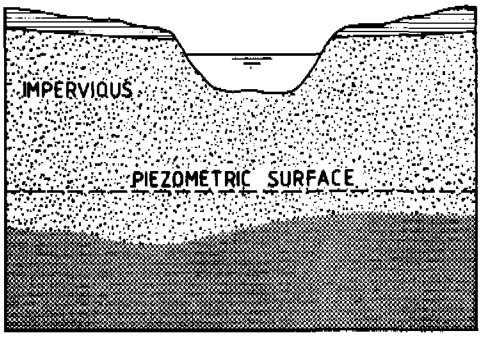


Figure 18: River flowing through impervious material (after Driscoll, 1986).

tems in the NWFP usually satisfy one of the conditions depicted in Figure 19.
Zero-flow boundary: this boundary is an impervious barrier or a streamline i.e. there is no flow across it. All the mountains surrounding the alluvial basins in NWFP - with the exception of the limestones mentioned in the next paragraph - can be considered as impervious and therefore as zero-flow boundaries. A streamline can only be considered an impervious boundary if its position does not change during the considered time period and the prevailing hydrological conditions.
Constant head boundary: An example of a constant head boundary is the sea or a lake or any other "water body" with fluctuations in water level that are negligible compared with the difference in head between the surface water and the groundwater bodies. Examples in NWFP are the Indus and the Kurram rivers. The former is a discharge boundary of the Nizampur area (Section 11.3) and a recharge boundary of the Dera Ismail Khan basin (Chapter 14) and the latter is a discharge boundary of the Parachinar area (Section 15.7). Discharge boundaries drain the groundwater and recharge boundaries lose water to the aquifer.
Constant flux boundary: The groundwater inflow or outflow over the boundary is constant irrespective of changes in the hydraulic head at either side. In NWFP there are constant flux boundaries in the Kohat plain and in the Lachi valley where the mountains consist of karst limestone. They store large quantities of water and the springs that discharge this water have a fairly constant flow, so it may be assumed that the subsurface flow from the limestones into the alluvial deposits is also fairly unchanging.
Variable flux boundary: The flux varies according to a more or less fixed pattern, e.g. influent flow of a seasonally flowing river.
Groundwater loses water by evaporation and transpiration only under the following conditions: (a) the water table is at shallow depth - less than 3 m (10 ft) - and the capillary fringe reaches into the root zone of the vegetation (evapotranspiration) or it evaporates directly by vapour transport through a heated bare soil. Under the climatological conditions of NWFP this may cause serious secondary soil salinization.
(b) the vegetation consist of phreatophytes, i.e. plants, usually trees or shrubs, whose root systems take the water from below the water table. These root systems sometimes penetrate to depths of up to 10 m (30 ft) in search of the water table.

Groundwater can be discharged by artificial means, e.g.:
- pumping from shallow dug wells or tubewells for domestic use and irrigation may be an important factor in the water balance.
- horizontal pipe drain systems to control the water table in areas with a dangerously high water table. Such a system is under construction in the Mardan SCARP.
- man-made galleries (karezes) that intersect with a sloping water table, and divert the water to the exit of the gallery (Chapters 13 and 14).

To understand the groundwater behaviour the recharge and discharge terms of each aquifer have to be quantified. If the recharge exceeds the discharge, the aquifer keeps the difference in storage, i.e. the water table rises, as is seen in many areas that are irrigated with diverted surface water. If the discharge exceeds the recharge, groundwater is taken from storage and the water table declines, as is seen in overpumped aquifers. The relation between recharge, discharge and change in storage is called the water balance or water budget and has the very simple form:

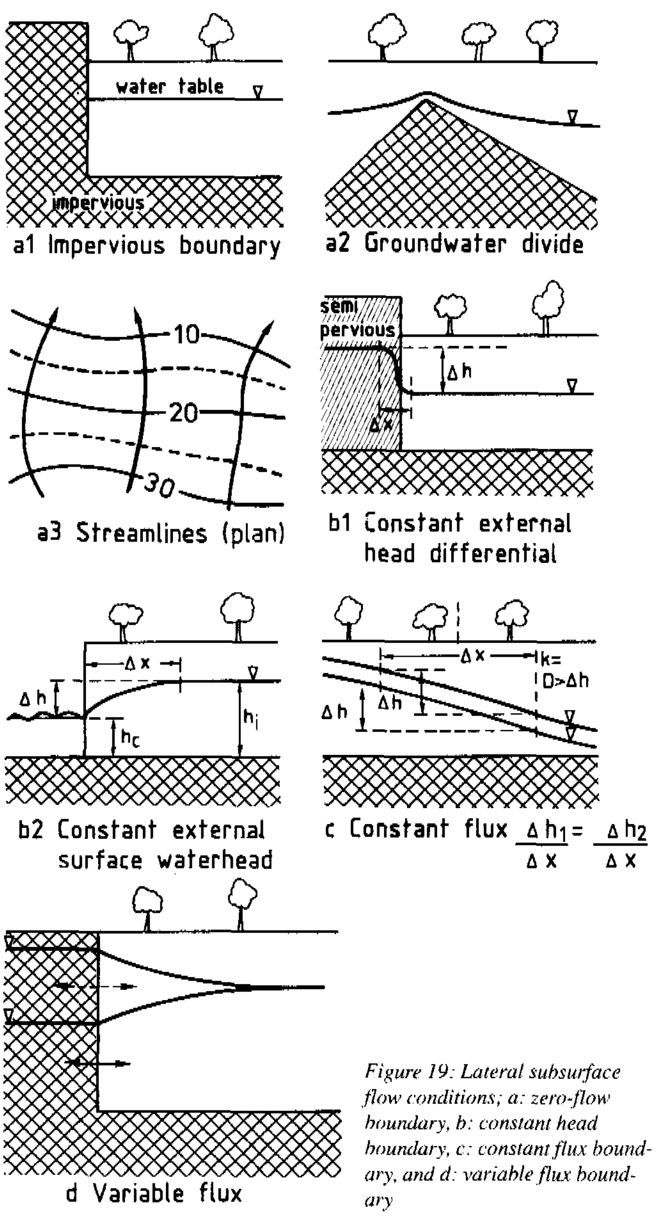


Figure 19: Lateral subsurface flow conditions; a: zero-flow boundary, b: constant head boundary, c: constant flux boundary, and d: variable flux boundary

Recharge - Discharge = Change in Storage

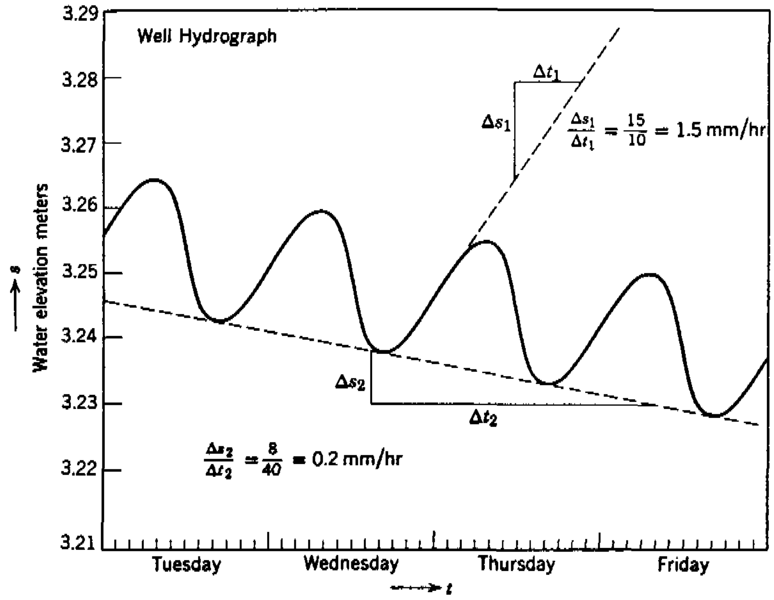
Given sufficient time an equilibrium will develop, i.e. the aquifer reaches a steady state. This does not mean that at any moment the recharge and discharge are in equilibrium; small seasonal fluctuations are normal and variation of the annual average values around the longterm annual mean value are normal too. So it is perhaps better to formulate it in another way and instead of saying that at a certain place "an equilbrium has developed", it is better to say that "there is no systematic disequilibrium", i.e. there is no rising or falling trend in the groundwater levels (Figure 20).
The groundwater budget is usually calculated over a period of 12 months starting at the end of the dry period. At that time the groundwater levels are at their deepest, the irrigation season is over, the crops have been harvested, soil moisture levels are very low and the interannual variations will be negligible.

3.2 GROUNDWATER FLOW

In the previous section it was stated that in every aquifer the groundwater flows from the areas of recharge to the areas of discharge. It goes without saying that the groundwater will meet much resistance from the rock particles when it flows through the maze of pores. To overcome the resistance there has to be a potential difference between the recharge and the discharge areas. At any given place in a homogeneous and isotropic aquifer, the potential or hydraulic head is determined by the groundwater level at that particular place. The groundwater levels are usually measured with respect to ground surface, and after the observation points have been levelled, the elevation of the groundwater level with respect to mean sea level (msl) or groundwater head, h, is calculated. In any basin the groundwater elevation data can be contoured and a groundwater elevation map - a watertable map or a piezometric map - can be constructed. From these maps the direction of the groundwater flow can be deduced because the streamlines are by definition perpendicular to the groundwater-level contours.
The difference in the hydraulic head divided by the distance, l, over which this difference occurs is called the hydraulic gradient, i, or:

$$i = \frac{h_1 - h_2}{l}$$

For a homogeneous aquifer a change in the distance between the groundwater elevation contour lines, which corresponds to a change in the hydraulic gradient, indicates a change in the flow conditions.
Groundwater meets much resistance during its underground flow and consequently the flow is very slow and laminar. The law that governs this laminar flow through a porous medium is called after the French hydraulic engineer Henri Darcy (1803 - 1858). Darcy conducted the experiment shown in Figure 21:



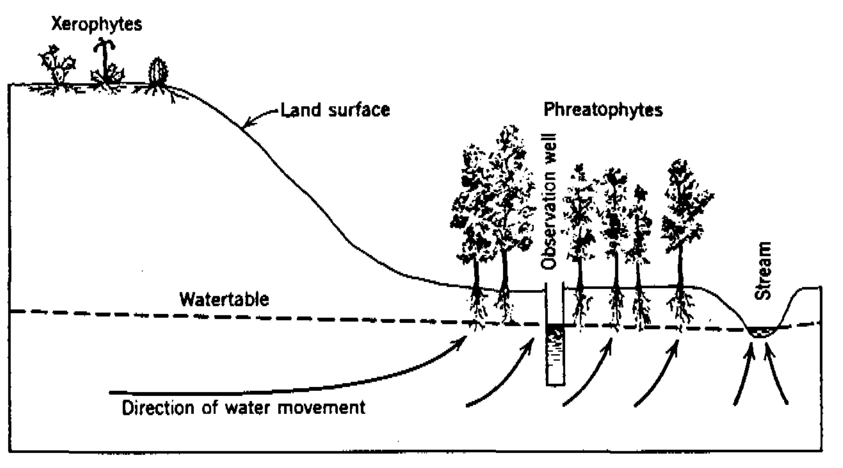


Figure 20: Influence of phreatophytes on the groundwater level; trend and fluctuations; similar patterns are caused by irrigation with groundwater (after Davis and DeWiest, 1966)

and found the empirical relation:

$$Q = K\,i\,A$$

where

Q = flow rate
h = hydraulic head
i = hydraulic gradient as discussed above
A = cross-sectional area
K = proportionality factor (hydraulic conductivity)

The hydraulic conductivity, K, consists of a factor representing the influence of the fluid properties, i.e. the specific weight and the dynamic viscosity, and a geometry factor, representing the influence of the size, sorting, angularity, etc. of the aquifer material. Details on the physical background and mathematical derivation of groundwater-flow equations can be found in handbooks like Freeze and Cherry (1979), Verruijt (1982), etc.

In an aquifer, the cross-sectional area, A, through which the flow takes place equals D x W, the product of the thickness

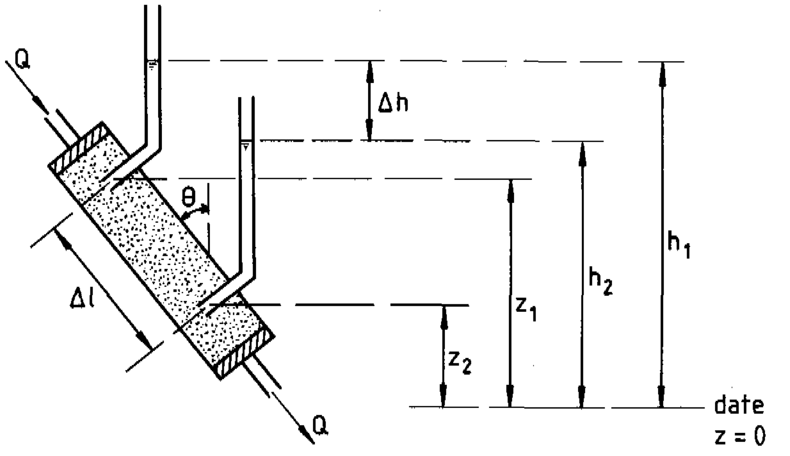


Figure 21: Experimental apparatus for the illustration of Darcy's law (after Todd, 1969)

of the part of the aquifer under consideration, D, and its width, W. So, the law of Darcy can be written as:

$$Q = KD\,i\,W$$

KD is called the transmissivity of the aquifer. It is often denoted by the symbol T and is expressed in m^2/day. An aquifer with a high transmissivity value can sustain a high pumping rate for a small drawdown of the water level in the well. Aquifers with a low transmissivity will only sustain a low pumping rate and the drawdown will be larger.
From Darcy's law it follows that a change in the hydraulic gradient (i) indicates either a change in the amount of water, Q, that is flowing through the aquifer, or a change in the transmissivity, KD (or T).

3.3 GROUNDWATER STORAGE

The specific yield, S or Sy, of an unconfined aquifer is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer and per unit decline in water table (Figure 22). The lowering of the water table by the dewatering of the pores of the upper part of the unconfined aquifer causes a pressure change in the water and in the aquifer. The compaction of the aquifer and the expansion of the water as reaction to the change in pressure contribute slightly to the amount of water released.
A confined aquifer has no water table and therefore the storage coefficient is related to a unit decline of the piezometric level. The storage coefficient, S, is defined as the amount of water a confined aquifer releases from storage per unit surface area of the aquifer per unit decline of the hydraulic head normal to that surface (Figure 22). A confined aquifer remains filled with water even when the piezometric surface declines and therefore the release of water from a confined aquifer is only caused by the compaction of the aquifer and the expansion of the water that is the response to a decline of the hydraulic head.
The specific yield of an unconfined aquifer and the storage

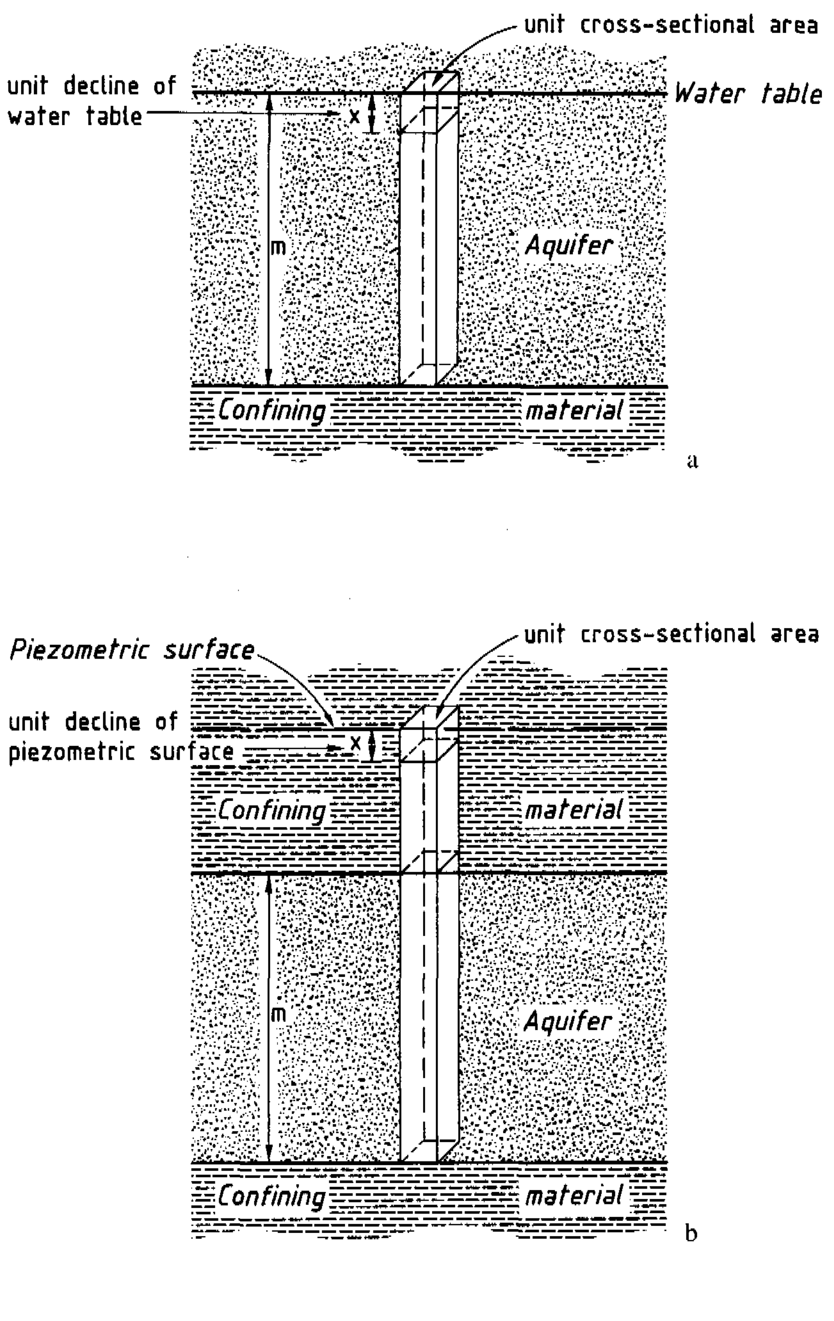


Figure 22: Schematic representation of (a) the specific yield of an unconfined aquifer and (b) the storage coefficient of a confined aquifer (after Ferris et al., 1962))

Table 17: Ranges of hydraulic conductivity and specific yield of various aquifer materials

Material	Hydraulic Conductivity (m/day)	Specific yield (dimension less)
Clay	10^{-5} to 10^{-7}	less than 0.03
Silt	10^{-1}	0.03 - 0.05
Fine sand	10^{-1} to 10	0.05 - 0.10
Coarse sand	10^{0} to 2×10^{2}	0.10 - 0.30
Gravel	10^{0} to 10^{3} or more	0.15 - 0.25

coefficient of a confined aquifer are dimensionless parameters. The specific yield varies from 0.01 in clay to 0.30 in well-rounded and very well-sorted coarse sand. The storage coefficient varies from 0.005 to 0.00005. The higher values of the specific yield reflect the actual dewatering that takes place in an unconfined aquifer and overshadows the effects of water expansion and aquifer compaction. Table 17 gives ranges of values of hydraulic conductivity and specific yield of various aquifer materials.

The amount of water that can be released by an unconfined aquifer equals the aquifer volume times the specific yield; and the amount that can be released by a confined aquifer is the aquifer volume times the storage coefficient. It should be realized that when the piezometric level can be lowered below the top of the aquifer, i.e. below the upper confining layer, the confined aquifer changes into an unconfined one and the specific yield becomes applicable, instead of the storage coefficient. Such a change is seldom witnessed because the groundwater lowering that is required is usually prohibitively expensive.

3.4 FLOW TO WELLS

In Section 3.1 we saw that an imbalance between recharge and discharge causes a rise or fall of the water table. The amount taken in (or released from) storage equals the rise or fall of the water table times the specific yield.

The pumping of an aquifer causes a release of water in the vicinity of the tubewell and consequently a lowering of the water table outside the well. Pumping for some time at a fixed pumping rate, Q, and measuring the changes in the

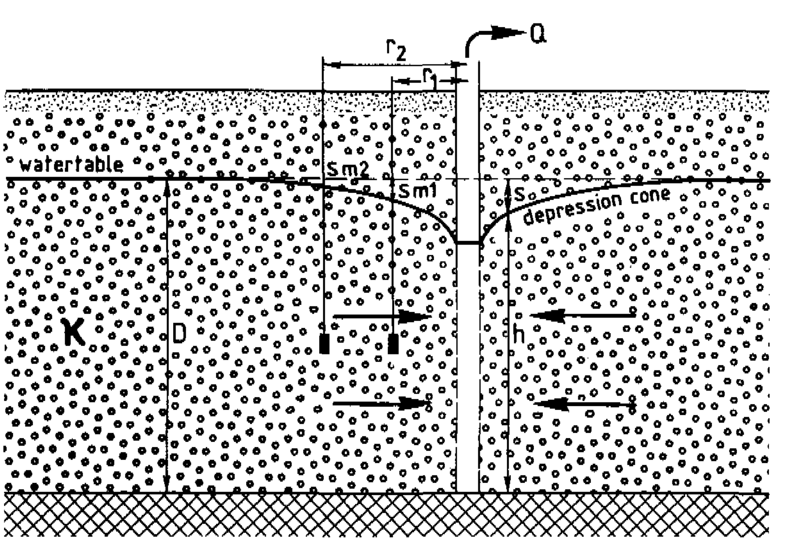


Figure 23: Schematic cross-section of a pumped unconfined aquifer showing principle of the pumping test (after Kruseman and De Ridder, 1970)

water level at various distances from the pumped well, provide the data for calculating the transmissivity of the aquifer, and, if the aquifer is confined, for calculating the storage coefficient too. This method for determining the value of the transmissivity is called a pumping test (Figure 23).

The calculations are based on Darcy's law and the law of continuity, of which the water balance equation is the simplest form. The equations describing the flow to a well are rather complicated as a consequence of the radial flow conditions and different kind of boundary conditions. Methods to analyse pumping tests have been described by Kruseman and De Ridder (1970).

4 GROUNDWATER INVESTIGATIONS

4.1 GROUNDWATER INVESTIGATIONS IN NWFP

The groundwater investigations in NWFP were started in 1960 by WASID as part of a cooperation project with the United States Agency for International Development (USAID). This resulted in a number of published and unpublished reports on the hydrogeology and water resources of the Dera Ismail Khan District, the Doaba and Hangu valleys, and parts of the Peshawar Vale. After WASID was disbanded in 1972 the groundwater studies were continued by what is now WAPDA Hydrogeology Directorate, Peshawar. Since 1978, the groundwater resources in the alluvial areas that are not commanded by surface water irrigation systems have been systematically investigated and assessed. This programme of "Groundwater Investigations in NWFP" was instigated by the Provincial Government and receives financial and technical assistance under the Pakistan-Dutch bilateral cooperation agreement. The technical assistance was provided by TNO Insititute of Applied Geoscience, Delft, The Netherlands. Between 1978 and 1987 the groundwater resources of the following areas were assessed:

Area	District
Adinzai and Talash valleys	Dir
Daggar valley in Buner area	Swat
Maira area in Peshawar Vale	Mardan
Naranji area in Peshawar Vale[1])	Mardan
Warsak uncommanded area in Peshawar Vale[1])	Peshawar
Bazai area in Peshawar Vale	Peshawar
Nizampur area	Peshawar
Kohat plain	Kohat
Doaba and Hangu valleys	Kohat
Lachi plain	Kohat
Teri area	Karak
Karak valley	Karak
Domail plain in Bannu basin	Bannu and Karak
Lakki Marwat area in Bannu basin	Bannu
Kulachi - Tank area	Dera Ismail Khan
Haripur area	Abbottabad
Ghazi area	Abbottabad
Pakhli plain	Mansehra
Parachinar area	Kurram Agency (FATA)

[1]) investigations in progress at time of writing.

As part of the programme for replacing the barani poppy *(Papaver somniferum)* cultivation by irrigated legal crops the following groundwater reconnaissance surveys have been completed or are in progress:
- In 1975-1980 in the Buner area in the Swat District, notably in the Chamla valley, Chingalai basin and Totali area, by the Pakistan Narcotics Control Board (PNCB) and the UN-sponsored Buner Agriculture Project ;
- Since the end of 1986 in a number of small valleys in the Provincially Administered Tribal Areas (PATA), e.g. Jandool valley in Dir and Nikpikhel area in Swat, by WAPDA Hydrogeology Directorate in cooperation with the Project for Groundwater-based Irrigation Development in PATA;
- Since 1985 in the Gadoon plain in Mardan District by FATA-DC in cooperation with WAPDA Hydrogeology Directorate and with assistance from USAID.

The purpose of a reconnaissance survey is the identification of borehole locations for tubewells with a capacity of 100 m^3/h (1 cusec), which is the minimum requirement for government-sponsored groundwaterbased irrigation schemes.
The assessment studies are not restricted to the identification of suitable borehole sites, but include an estimate of the exploitable groundwater resources. Therefore, the aquifer system and the groundwater flow are analysed and the recharge and discharge components are estimated in order to set up a groundwater budget. If sufficient data are available, the assessment study may also include a numerical groundwater-flow simulation model.

4.2 METHODOLOGY

In the assessment studies WAPDA and TNO used a three-step approach:

(1) Survey of available data
(2) Field investigations
(3) Evaluation and Analysis

By the survey of available data is meant the collection and analysis of all relevant data that can be obtained from existing files, reports, libraries, etc., such as:
- topographical maps, aerial photographs and satellite images,
- geographical, demographical and geological data,
- meteorological data such as time series of rainfall, temperature, pan evaporation or anything else that is needed to calculate the evapotranspiration, as well as the coordinates and elevation of the meteorological stations concerned,
- reports of previous studies carried out in the study area that may contain useful information,
- borehole and well data files,

- water quality data,
- data on the present water use and the future water demand for rural and urban domestic supplies, irrigation, and industrial use.

The findings of this survey were used to plan the field investigations in such a way that:

- duplication of earlier investigations is avoided,
- data are collected in the most significant locations,
- the best results are obtained for the least cost.

Details on this part of the survey are presented in Section 4.3.

The following field investigations were usually carried out:

- an inventory of all the wells,
- a geophysical survey, usually an electrical resistivity survey,
- the drilling of test holes and geophysical well-logging,
- the construction of test wells and the execution of pumping tests,
- setting up a groundwater level monitoring network,
- sampling of groundwater and surface water for chemical analysis,
- stream flow gauging.

Details on the field survey methods are given in Section 4.4.
The data obtained by the above-mentioned surveys were used to describe:

- the geometry and hydraulic properties of the aquifer system(s),
- the groundwater conditions,
- the recharge and discharge conditions and the water balance,
- the groundwater development potential.

If possible, a subsurface-flow simulation model was made to simulate the effects of the groundwater development scenarios on the groundwater behaviour and to determine the implications for management of the resource.
Details on the evaluation and analysis phase of the investigation are given in Section 4.5.

4.3 DETAILS ON THE SURVEY OF AVAILABLE DATA

Maps, aerial photographs and satellite images
Topographical maps at the scales 1:250,000 and 1:50,000 are available from the Survey of Pakistan. Aerial photographs can be studied at the office of the Peshawar Branch of the Geological Survey of Pakistan, and Landsat images are available at WAPDA Hydrogeology Directorate.

Geographical, demographical and geological data
These data can be obtained from the appropriate Departments of the Peshawar University, the Bureau of Statistics and various Departments of the Government of the North-West Frontier Province, and from the Geological Survey of Pakistan.

Meteorological data
The meteorological information required in water resources assessment studies is that on rainfall and evapotranspiration. The rainfall data are collected and analysed by the Pakistan Meteorolgical Department (PMD, 1971), which also uses data collected by other institutions, e.g. WAPDA Hydrology Circle, and the Department of Irrigation. At some meteorological stations the evaporation is measured directly by means of a so-called class-A pan (pan evaporation, E_0). The pan evaporation can be converted to potential evapotranspiration, Ep, by applying a conversion factor α. The conversion factor varies between 0.7 and 0.8 with the seasons (ILRI, 1974; Quaglia and Poulisse, 1984). In the WAPDA-TNO studies a value of 0.7 was used throughout.
For the areas where no pan evaporation data are available, Thornthwaite's empirical method (Thornthwaite, 1948), was used to calculate average evapotranspiration values.

Reports on previous studies
During the research for this book it became apparent that many official and unofficial institutions in NWFP lack proper technical documentation and library facilities. As a consequence, a number of previously produced documents have been lost over the years or are very difficult to trace. Often, only incomplete copies lacking the maps and plates were found, locked away in cupboards full of uncatalogued books and reports.
In Chapters 9 through 15 an annotated bibliography of the relevant reports and other documents is given at the end of each area description. A general list of references is placed after Chapter 15.

Data from boreholes and wells, and water quality data
Some of the data collected during the different surveys have been published by the Hydrogeology Directorate in Basic Data Releases. WAPDA's Hydrologic Monitoring Division regularly publishes the results of the performance tests on the tubewells in the SCARPs. Nevertheless, a geohydrological database needs to be set up, so all data from groundwater investigations and from groundwater development and management can be filed systematically.

Data on water use
The available data on groundwater use are discussed in Chapter 5.

4.4 DETAILS ON THE FIELD INVESTIGATION METHODS

General well inventory
The general well inventory includes recording the following for each well: type of well (dug well, tubewell, etc.); its location (coordinates) and elevation above mean sea level (msl); the year of construction and total depth; depth to the water level and electrical conductivity (EC) of the groundwater; pumping means, rate and duration; total annual water withdrawal and its use.

Electrical resistivity survey
During an electrical resistivity survey, vertical electrical soundings are made at selected locations. The soundings enable a specific physical variable of the soil, the electrical resistivity, to be measured, from which a resistivity profile of the soil at the selected location is derived. This enables conclusions to be drawn about the hydrogeological charac-

teristics. The soundings are carried out by means of an arrangement of four electrodes. In the so-called Schlumberger configuration, which was used in the WAPDA-TNO investigations, the electrodes are placed in a straight line, symmetrically from a central point (Fig. 24). Via the outer electrodes A and B an electrical current, I, is passed through the soil. This generates an electrical potential difference, V, between the two inner electrodes M and N. From the values of (V), the current (I), the distance, L, between the outer electrodes A and B, and the distance, a, between the inner electrodes M and N, the apparent resistivity, ρ_a, is calculated. Each sounding consists of a series of resistivity values calculated from the current and potential data measured for increasing values of L while a is kept constant. There are two steps in the interpretation:

The first step is a mathematical operation based on certain assumptions concerning the thickness and specific resistivity. This yields the resistivity profile. Then, geological and hydrogeological characteristics of the geological section are inferred from the resistivity profile. Because the mathematical analyis of the sounding curve does not give a unique solution, the resistivity profile needs to be calibrated with the data collected from nearby boreholes. If necessary, the assumptions that underlie the interpretation are adjusted and subsequent soundings made at a greater distance from the boreholes can be analysed with more confidence. The electrical resitivity method is a quick and relatively cheap way for surveying large tracts of land. If no boreholes are available prior to the resistivity survey, confirmation boreholes should be drilled afterwards, which may lead to reinterpretation of the resistivity survey.

Interpretation is not always easy, because various hydrogeological phenomena may cause the same electrical resistivity in the ground. Examples are:

- a relatively low resistivity, often associated with fine-grained formations with a high clay content and fresh water, may also indicate a coarse formation containing saline water, e.g. in Dera Ismail Khan basin, Domail plain in Bannu basin and Karak valley,
- the correlation between high resistivity values and the presence of coarse, very permeable deposits may be disturbed by the presence of large boulders and cemented gravel beds that increase the resistivity but reduce the permeability, e.g. in the Kohat plain and in the Doaba valley.

Another source of interpretation problems is the presence of non-horizontal layers, e.g. the electrical resitivity survey in the Lachi area was made virtually worthless by the effects of the steeply dipping bedrock.

Test hole drilling and well-logging

The drilling of test holes has the following objectives:

- to establish the lithology of the subsurface layers,
- to identify the water-bearing layers, and

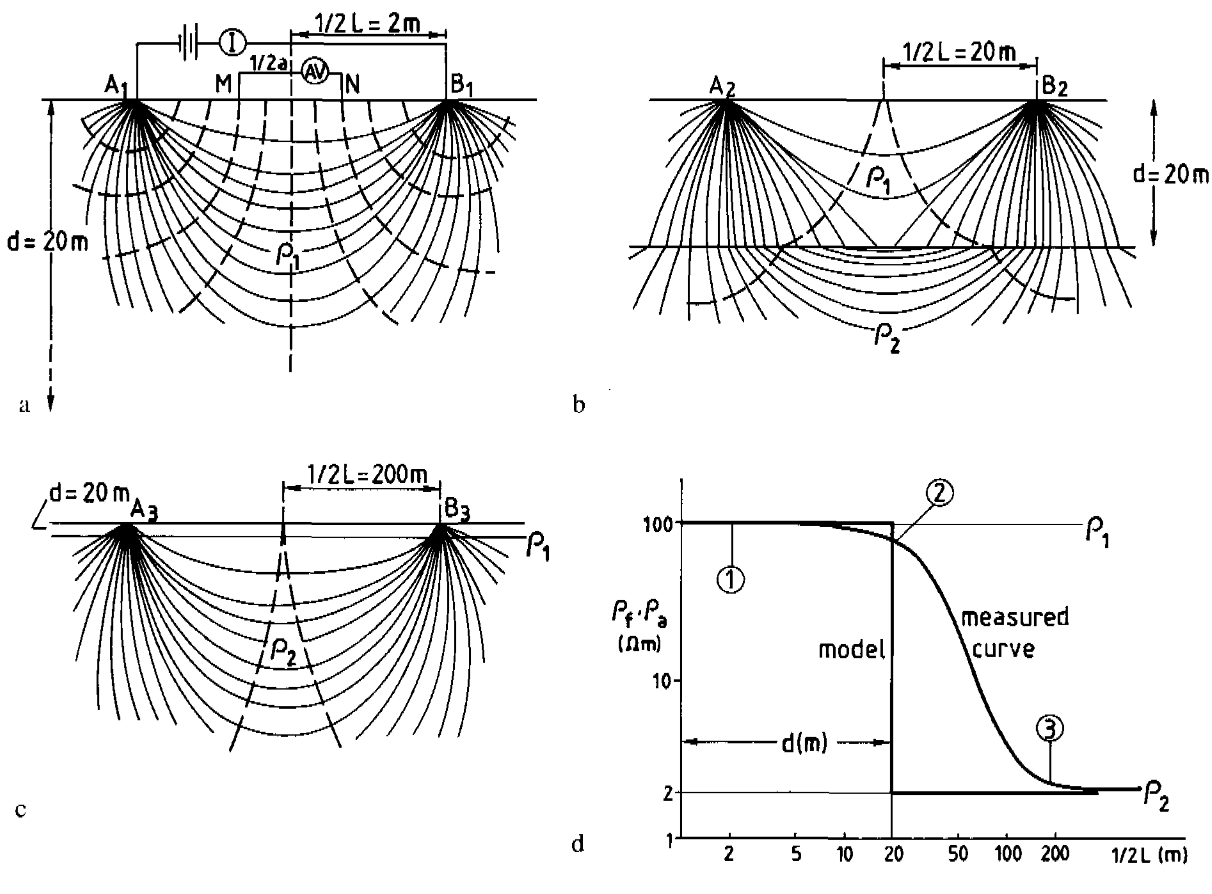


Figure 24: Principle of the vertical electrical sounding. Resistivity sounding in a subsurface section of two layers with resistivities ρ_1 = 100 ohm-m and ρ_2 = 2 ohm-m. The sounding consists of 20 measurements with values of 0.5 L increasing exponentially from 1.5 to 200 m. The configuration of the current (full) and equipotential (dashed) curves are shown for 0.5 L = 2 m (a), 0.5 L = 20 m (b), and 0.5 L = 200 m (c). The resulting sounding graph (measured curve) and the interpretation model are shown in (d)

- to verify the indications about the subsurface conditions given by the electrical resistivity survey (or by any other surface geophysical method).

WAPDA uses two types of drilling rig to drill test holes in the relatively soft alluvial formations:

- the percussion rig, and
- the rotary rig.

The percussion rig uses a big steel chisel on a steel cable, which rythmically strikes the bottom of the hole to break the formation into small pieces. Every 10-15 cm, the loosened material is removed from the borehole with a bailer. In loose unconsolidated formations a chisel may not be required and the "chiselling" is done directly with the bailer. To prevent the borehole from collapsing, a steel casing is lowered close behind the drilling tool. Because of the friction between the casing and the borehole wall, the maximum depth that can be drilled with one casing diameter is 50-70 m. If the drilling is continued beyond this depth a chisel, bailer and casing of a smaller diameter are used.

After every metre drilled a sample is taken from the material brought to the surface, and is placed in a special box. In this way a lithological record of the borehole is built up. The advantages of the percussion drilling method are: the equipment is simple and sturdy; lithological samples can be collected easily; and the position of the water table is established immediately. The disadvantages are that drilling progresses slowly, and that no geophysical well log can be done, due to the casing.

The borehole casing is retrieved when the test hole is abandoned or when the hole is converted into a tubewell.

The rotary rig uses a rotating chisel or drill bit at the end of a hollow drill rod or drill pipe to break up the formation. Flowing fluid, air or foam is used to prevent the borehole from collapsing, to cool the drill bit, and to transport the cuttings to the surface. Of the different rotary drilling methods, only the direct circulation method (Figure 25), which is the only method used in NWFP, will be discussed here.

In the direct circulation or "straight flush" method the transporting medium is usually water, in which bentonite and other additives are mixed to increase the viscosity and/or the density. The fluid is pumped down through the inside of the hollow drill rods or drill pipes. It enters the borehole at the bottom of the drill column through the bit, which it cools and cleans, and rises upwards to the surface through the annulus, i.e. the space between the drill pipe and the borehole wall. The hydrostatic pressure of the fluid in the annular space prevents the borehole from collapsing. The rising fluid carries the cuttings to the surface. At the surface the mud flows from the borehole through a narrow ditch to the settling pits. The coarse cuttings settle in the ditch, from where samples are taken. The ditch has to be cleaned frequently. The fine and very fine cuttings settle in the first pit. In the second pit the fluid is treated before being pumped down the borehole again. To bring the cuttings to the surface the upward velocity of the mud in the borehole must be higher than the slip velocity, i.e. the velocity with which the cuttings slip downward through the fluid under the influence of gravity. When the flow velocity in the annulus is too low, cuttings from dif-

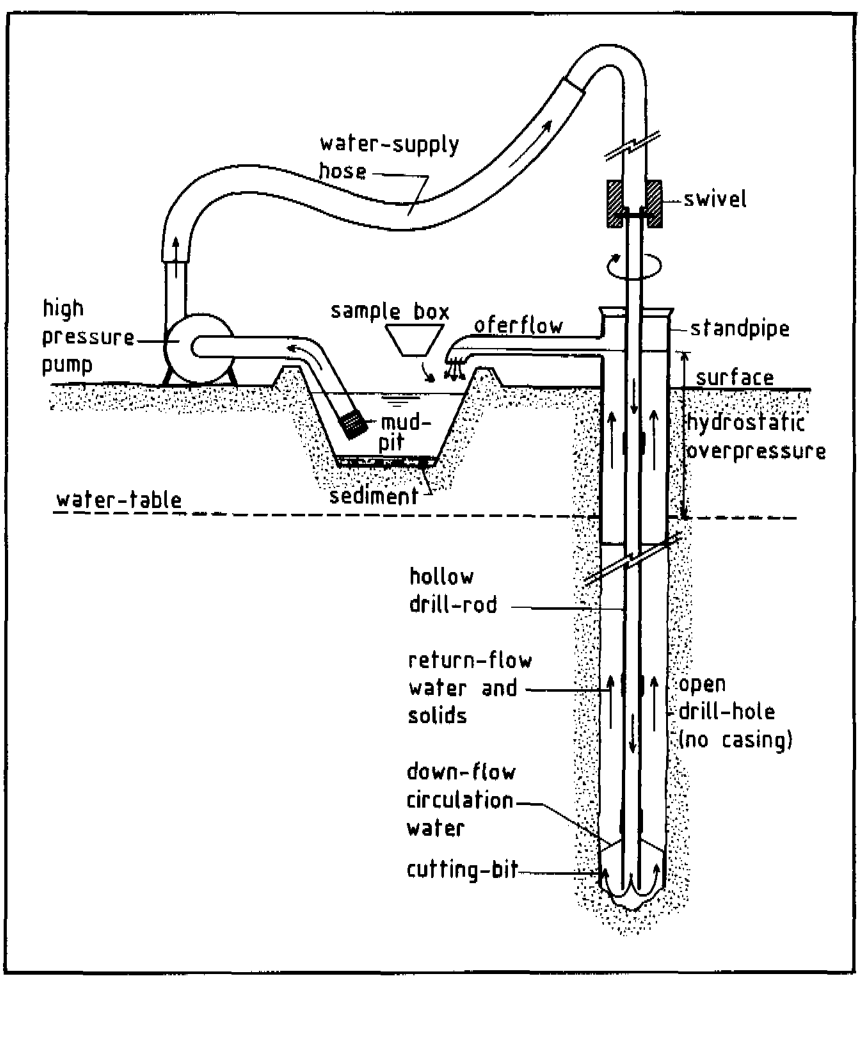


Figure 25: Principle of the direct rotary method

ferent layers become mixed and larger cuttings may not come up at all and may choke the drill bit, which will get stuck. Generally, when water is the transporting medium an annular velocity of 30.5-38.5 m^3/min. must be maintained. The annular velocity is calculated by dividing the volume of the annular space by the output of the mudpump. The deeper the borehole and the larger its diameter, the higher the output of the mudpump must be. The capacity of the standard mudpump sold with a drilling rig is often too small to properly drill a hole with maximum diameter to maximum depth.

By its nature the rotary drilling method does not allow good samples to be taken from the cuttings. It is therefore common practice to build up a picture of the lithological sequence by running a geophysical borehole log or well log in a rotary drilled borehole when its total depth is reached. Geophysical well-logging implies the recording of one or more physical variables to provide information on the lithology, stratigraphy and physico-chemical properties of the liquid filling the pores of the perforated formations. In NWFP a conventional combination of methods is used. It consists of continuously determining the spontaneous potential, the formation resistivity and the natural gamma radiation. All variables are recorded continuously as a function of the depth of the probe, when it is moving upward at a controlled speed between 3 and 15 m/min. It takes about 3-4 h to log a hole 200 m deep. A field interpretation of the recordings in combination with the data on the cuttings is made to establish the lithological sequence. The latter is used to determine the proper depths at which to place piezometer or production screens and to set clay plugs to close off confining clay layers that have been punctured by the borehole (Figure 26). For details on the procedures and the interpretation of borehole-logging the reader is referred to Scott Keys and MacCary (1971) and to Ewalts and Stavenga (1985) or to the forthcoming Unesco - IAH publication in preparation by Repsold, Brummer and Otte.

Test well construction and well-testing

Test holes penetrating coarse-grained deposits of several tens of metres thickness below the water table, may be converted into test wells by lowering a string of casing and screen into the bore hole (Figure 27). The screen is positioned opposite the layers that are expected to be aquiferous, and well-sorted round silicious gravel, the so-called gravel pack or filter pack, is placed between the screen and the borehole wall. The function of the gravel pack is:

- to stabilize the borehole,
- to prevent overlying non-aquiferous material from falling into the annular space and blocking the connection between the aquifer and the well screen, and
- to prevent sand of the aquifer from flowing into the well.

The gravel pack should form a highly pervious medium between the aquifer and the well string if the well is to have the highest possible yield, Q, for the least drawdown, s, i.e. if the well is to have a high specific capacity. Therefore, the size of the slots of the screen and the size of the grains of the gravel pack should be selected as a function of the grainsize distribution of the aquifer material. For details see Driscoll, 1986.

When, irrespective of the composition of the aquifer, "standard" screens are used and wrongly sized or not well-rounded gravel is used, the permeability of the filter will be low. Consequently, the hydraulic head between the aquifer and the inside of the well screen will be unnecessarily high and the specific capacity of the well will be lower than it would have been with a good gravel pack. The well may even fail altogether.

Another cause of premature failure of a tubewell is the installation of a casing and screen string composed of dissimilar materials, such as brass screens in a mild steel casing string. Placed in an electrolytic solution, i.e. groundwater, the iron and brass act as the different poles of a galvanic cell or battery. This will result in electrolytic corrosion of the mild steel. The higher the electric conductivity of the groundwater, the stronger the corrosive action. It is therefore important to use a single metal or an inert material, e.g. PVC in a string of casing and screen pipes.

After installing the casing string and the gravel pack the well must be developed by pumping or air-lifting. The purpose is to remove the drilling mud and the finest fraction of the aquifer material, so the pumped water will be clean and contain no clay or very fine sand. Then the well will be pumped to test its performance and to obtain data from which the hydraulic parameters of the aquifer can be calculated.

The performance of the well is checked with a step-drawdown test, which allows the best production yield to be deduced from the graph of s/Q versus Q. The hydraulic properties of an aquifer, notably the transmissivity value, can be calculated from the constant-rate single-well pumping test and from the so-called recovery test. If the aquifer is confined and nearby wells can be used as observation wells, it is possible to calculate the storage coefficient too. Detailed descriptions of the execution of pumping tests and the interpretation of their results can be found in Kruseman and De Ridder, 1970, and in Kruseman, De Ridder and Verwey, 1988. The latter also contains the methods for executing and analysing well tests.

In unconfined aquifers the specific yield is estimated from the grainsize distribution in the aquifer.

Groundwater level monitoring network

The groundwater level is the reaction of the aquifer system to hydraulic stress (recharge and discharge). As the hydraulic stress changes with time - incidentally, over the seasons, or over a number of years - the groundwater levels change with it. Fluctuations (seasonal) around a more or less constant (annual) average value may be the result, and they may show a trend, e.g. the rising water table in an area irrigated with surface water.

The reaction of the groundwater to a sudden flood may provide insight into the recharge mechanism, both conceptually as well as quantitatively. The reaction to drought periods gives information on the inertia of the aquifer system, its ability to provide water when surface water sources fail and the time that is needed before the aquifer has restored its depleted resource.

It must be remembered that the groundwater level is one of the few hydrogeological parameters that is not measured by indirect means but can be observed directly. Therefore, historical groundwater levels are used as the yardstick to calibrate groundwater flow simulation models.

It is unfortunate that in NWFP groundwater level monitoring

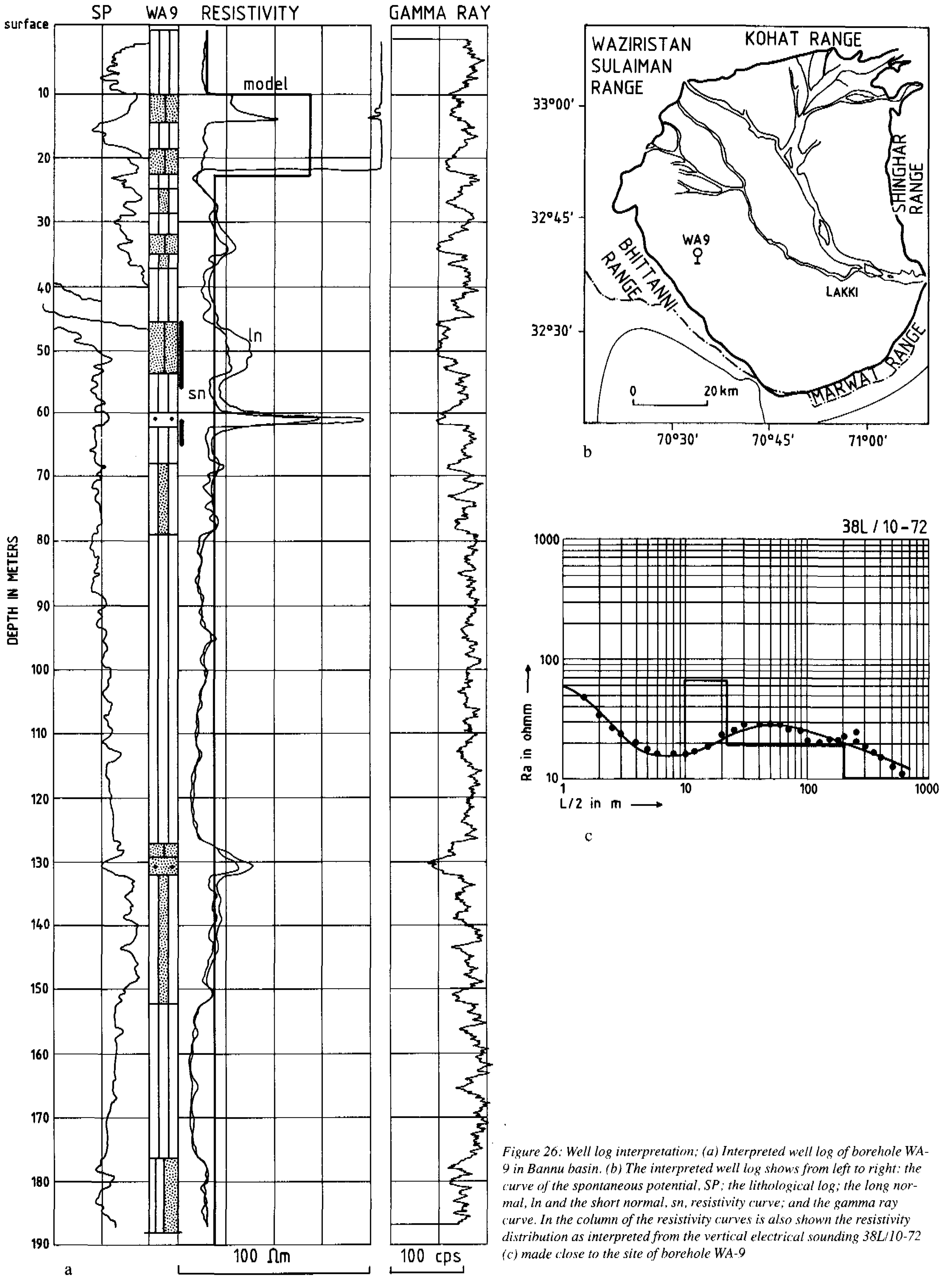


Figure 26: Well log interpretation; (a) Interpreted well log of borehole WA-9 in Bannu basin. (b) The interpreted well log shows from left to right: the curve of the spontaneous potential, SP; the lithological log; the long normal, ln and the short normal, sn, resistivity curve; and the gamma ray curve. In the column of the resistivity curves is also shown the resistivity distribution as interpreted from the vertical electrical sounding 38L/10-72 (c) made close to the site of borehole WA-9

outside the SCARPs has been done haphazardly. Even during the WAPDA/TNO investigations, monitoring networks were seldom observed for more than two years, and those records often show gaps. Recently, the Provincial Government and WAPDA decided to set up a permanent groundwater level monitoring system in the non-SCARP areas; a laudable initiative.

Hydrochemistry
In NWFP, groundwater samples have been analysed mainly to determine suitability for domestic supplies and irrigation. The analysis consisted of determining the main anions Cl^-, HCO_3^-, SO_4^{--}, and NO_3^{--} and the main cations Ca^{++}, Mg^{++} and Na^+ plus K^+, which typify the groundwater, and of determining the electrical conductivity (EC), the pH and the Sodium Absorbtion Rate (SAR) (Section 2.5).
Extensive sampling and detailed analysis may contribute to the understanding of the groundwater recharge and discharge mechanism. However, this approach has not yet been used in NWFP. Another technique, not used in NWFP either, is the analysis of the environmental isotopes: deuterium (H^2), tritium (H^3), O^{16}, O^{18} and C^{14}. With this technique the approximate age of the water and the elevation of the recharge area can be established.

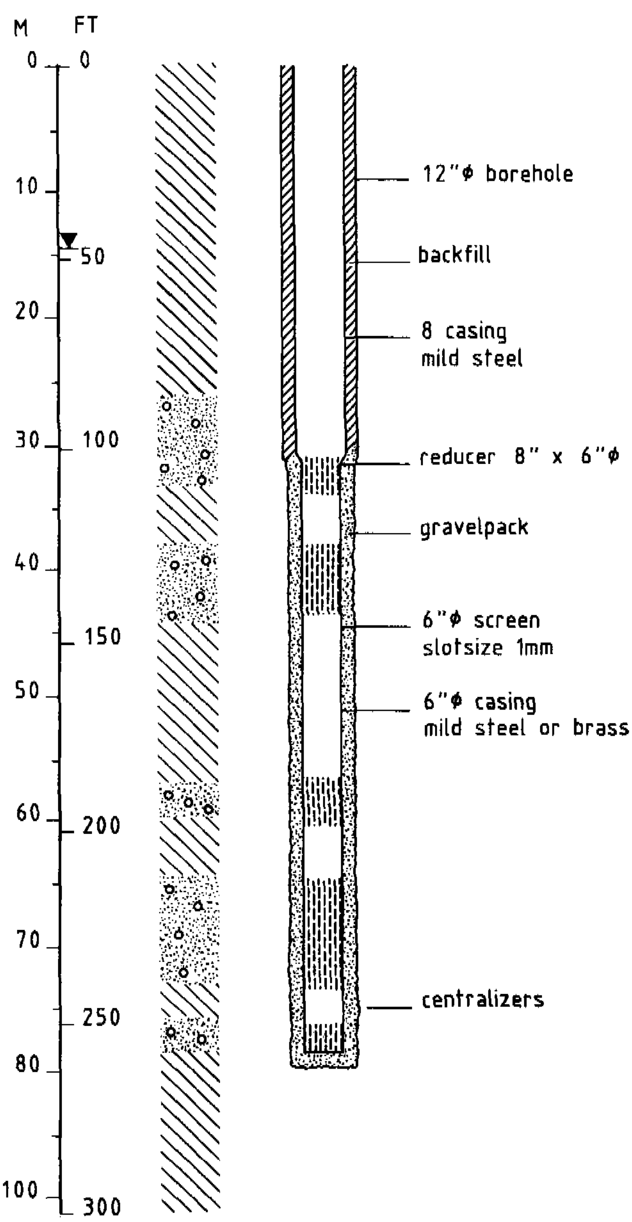


Figure 27: Schematic representation of a well completion

Stream flow gauging
The amount of water a stream carries depends on its supply. The main sources are runoff, snow-melt and groundwater drainage. Given the rainfall pattern of NWFP, the runoff component produces large amounts of stream flow of brief duration. Some of this water infiltrates into the banks of the river during the high stages of the flood (bank storage) and is released soon afterwards. Snow-melt is an important source of the rivers that arise in the high mountains, such as the Indus, Kabul, Swat, Kurram, Tochi and Zhob/Gumal rivers. It produces a sustained supply during the summer months. Groundwater drained by the river is water that has previously accumulated in the aquifer system (Figure 28). The driving force of the groundwater flow to the river is the hydraulic gradient in the aquifer, i.e. the hydraulic head between the outer boundary of the flow system and the river level, divided by the distance between them. Because groundwater level fluctuations are usually small compared with the hydraulic head, the groundwater discharge is fairly constant. Therefore, it is assumed that the river discharge during periods of low flow, i.e. no contribution by runoff or snow-melt, corresponds to the average groundwater supply to the river flow. By averaging the base flow measurements over a number of years one obtains a measure of the average groundwater discharge into the river.

4.5 DETAILS ON EVALUATION AND ANALYSIS METHODS

The geometry and hydraulic properties of the aquifers
The lateral and vertical boundaries of the aquifer(s) are established on the basis of the results of the resistivity survey and the test holes. They are usually presented on maps and cross-sections. A picture of the spatial distribution of the transmissivity and the storage coefficient or specific yield is obtained by combining the results of pumping tests with the geometry of the aquifer and the grainsize and sorting of the pervious material.
The position of the pervious coarse layers with respect to impervious clayey layers and the position of the water table and piezometric level(s) with respect to each other, determine the aquifer type (phreatic, leaky, or confined).

The groundwater conditions
The depth to the water table (or to the piezometric level) measured in levelled wells enables a contour map of the water table (or piezometric level) to be drawn. The groundwater flow direction and the groundwater gradient are then calculated and, in combination with the transmissivity value, the groundwater flow rate will be known. The flow paths indicate the location of the recharge and discharge areas.
The data from the general well survey are used to estimate the annual amount of groundwater withdrawal for domestic water supply and irrigation.

The recharge and discharge conditions

It is assumed that the aquifers are in steady state, i.e. in all the alluvial basins the average annual recharge equals the average annual discharge. Whenever possible the recharge and discharge components are calculated independently, although it is generally easier to quantify the latter than the former.

The following recharge components are commonly encountered in NWFP:

- Infiltration and deep percolation of runoff from the catchment area in the coarse deposits (alluvial fans) at the foot of the mountains along the boundary of the plain.
- Infiltration and deep percolation of stream flow in nalas and rivers.
- Deep percolation of irrigation water is an unavoidable consequence of any irrigation system and occurs in the conveyance system as well as in the irrigated fields. Percolation losses may be as high as 30 per cent of the diverted amount of surface water or 25 per cent of the pump discharge when groundwater is used.
- Lateral subsurface inflow is only of importance if there is an extensive aquifer system in the catchment area. In the Kohat District this phenomenon is observed where water from karst aquifers in the limestome discharges into the alluvial deposits south of Kohat town and in the Lachi valley.
- Infiltration and deep percolation of rainfall over the alluvial plain is usually not very important because the central parts of the alluvial plains are often clayey; so, a low percolation rate. Infiltrated precipitation remains as soil moisture in the upper layers of the soil and is evapotranspired. A soil moisture balance based on daily rainfall data may indicate if there is any percolation. Uil (1983) carried out such an analysis for the Domail plain (Table 31) and showed that the percolation is negligible.

The common discharge components are:

- Exfiltration of groundwater into nalas and rivers; under the present conditions this is the main discharge component in most alluvial plains. It is measured as the increase in the base flow generated in the alluvial plain,
- Evapotranspiration in areas with a shallow water table,
- Withdrawals from open (dug) wells and from tubewells, and discharge by springs. These are measured during the general well inventory.
- Lateral subsurface outflow. This plays a minor role because most basins are hydraulically closed or almost so. It is of some importance on the southern boundary of the D.I. Khan basin (Chapter 14).

The groundwater development potential

The potential of an area for groundwater development by public sector tubewells depends on the quality of the soils, the regional renewable supply, and the hydraulic characteristics of the aquifer.

Soils with a high infiltration rate have excellent recharge rates, but are not suitable for irrigation, because of the high percolation losses and related low efficiency.

The hydraulic characteristics of the aquifer determine if the required pumping rate of at least 100 m^3/h (1 cusec) can be realized without provoking a prohibitive drawdown.

Finally, the average annual recharge is a measure of the maximum permissable withdrawal of groundwater that is allowable without resorting to groundwater mining. In combination with the maximum well yield and the pumping requirements of the irrigated crops the maximum number of groundwater-based irrigation schemes to be installed is calculated.

Numerical groundwater flow simulation models

The purpose of a groundwater flow simulation is:

- to integrate all the available data into a numerical model that faithfully reproduces the historical behaviour of the groundwater,
- to assess the long-term influences of different groundwater development scenarios on the groundwater system and therefore on the water levels in dug wells and on the pumping lifts in the tubewells. In this way the groundwater assessment study becomes an important tool in the development planning process.

A numerical groundwater flow model is a mathematical model of the aquifer system, formulated in partial differential equations. With numerical methods an approximate solution of the partial differential equations can be found. The finite-difference technique or the finite-element method are commonly used for this purpose. In doing so one replaces continuous variables by discrete variables that are defined at grid blocks (or nodes). Thus the continuous differential equation

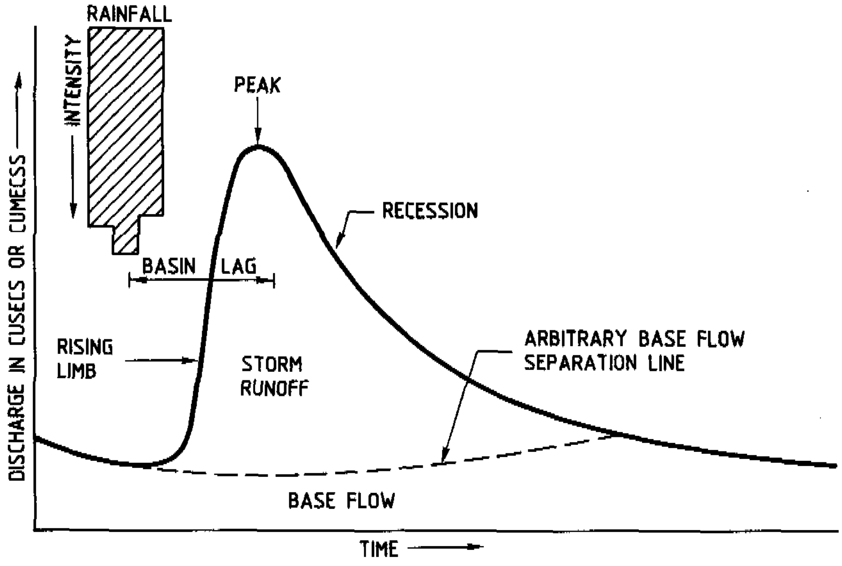


Figure 28: Streamflow components in a hydrograph (after Rodda, 1969)

defining hydraulic head everywhere in an aquifer, is replaced by a finite number of algebraic equations that define hydraulic heads at specific points. This approach constitutes a numerical model and a computer program is used to solve the equations (Mercer and Faust, 1981).

The first step in preparing data for a groundwater model is to determine the boundaries of the region to be modelled. For a regional aquifer system physical boundaries (e.g. impermeable, constant recharge or constant head boundaries) are selected; once they are defined the region is discretized, i.e. subdivided into a grid. The aquifer may have rectangular or irregular, polygonal subdivisions, depending on the numerical procedure used.

Once the grid has been designed, it is necessary to specify for each grid block the aquifer parameters (such as transmissivity and storage coefficient), the hydraulic stress with its variation in time and space and the initial data (such as hydraulic head). The hydraulic stress in a groundwater flow system is defined by the type and extent of recharge areas (irrigated areas, recharge basins, etc), the distribution in time and space of groundwater pumpage, the infiltration and exfiltration of stream flow, and precipitation. The output consists of the hydraulic heads calculated for each of the grid blocks. The computed hydraulic heads are compared with the historical data. This is the first step in a process of history matching or model calibration. The initial estimates of aquifer parameters and of the hydraulic stress components may have to be modified to obtain a satisfactory match between the historical (observed) data and the calculated values. These modifications have to be made with considerable skill because they should always remain within the physical possibilities. A satisfactory match is obtained by trial and error (Boonstra and De Ridder, 1981). The number of "runs" required to produce such a match depends on the objectives of the analysis, the complexity of the flow system and the length of the observed history.

Once completed, the model gives an integrated picture of the interaction of the aquifer characteristics and the hydraulic stress. It can now be used to predict the future behaviour of the aquifer under a variety of pumping schemes (different stress patterns) and so it becomes a powerful tool for groundwater development planning and groundwater management. More specifically, groundwater modelling allows estimates to be made of: (a) recharge (both natural and induced) resulting from leakage from confining beds, (b) the effects of boundaries and boundary conditions, (c) the effects of well locations and spacing, and the effects of various withdrawal (or injection) rates.

5 GROUNDWATER DEVELOPMENT

5.1 GENERAL

Groundwater development is defined as the action that brings the groundwater to the surface to be harnessed for social and economic use or to be removed when it is harmful. Social use is the domestic water supply to a single house, to a village or to a major town. Economic use is groundwater development to provide irrigation water to areas that are not under the effective command of a surface water irrigation system and to supply the industrial establishments of NWFP with a safe supply of high quality water. Removal of harmful groundwater takes place in the SCARPs where drainage systems are installed to control the water table in otherwise waterlogged areas.

Groundwater is usually brought to the surface by tubewells and dug wells equipped with pumps or other lifting devices, e.g. Persian wheels, but it may also flow by gravity, e.g. springs and karezes, and horizontal drainage systems for groundwater removal. No exact figures are available on the annual amount of groundwater withdrawal.

No legal framework exists for the development of the groundwater resources of the NWFP. Anybody is free to dig a well or to drill a borehole on his land to exploit any amount of groundwater. The only controlling factors are the economic and, in the case of public sector tubewells, social considerations, i.e. the investment costs of digging or drilling the well, the purchase of a pump and its energization, and the operational costs, such as energy, and maintenance of the pump versus the income from the agricultural production or the improvement of the primary health situation.

The planning of the groundwater development activities of the public sector is done by the Planning and Development Department of the Provincial Government in close cooperation with the Department of Irrigation and the Public Health Engineering Department (PHED).

Only a small percentage of the exploitable groundwater resources has so far been developed by dug wells, tubewells or otherwise, and there is ample scope for expansion of the groundwater development. This is of special importance because shortage of water for irrigation is a common phenomenon in NWFP, even in the command areas of the surface water irrigation systems. The conjunctive use of surface water and groundwater may be very beneficial, especially during Kharif, when tubewells may provide the required supplemental supply if the surface water system carries insufficient water. Moreover, the pumping of groundwater in areas irrigated with surface water combats waterlogging.

According to the Bureau of Statistics (B.o.S., 1986[a]) 10 per cent of the irrigated land in NWFP is irrigated with groundwater and 80 per cent with canal water (Table 8 in Chapter 1). In most areas the groundwater is developed by means of shallow wells (Table 18).

More than 90 per cent of the wells are privately owned shallow dug wells. Nearly all of them supply water for domestic use and animal watering and an unknown number is also used for small-scale irrigation and garden watering. Less than 10 per cent of the wells are tubewells and only a minority of the tubewells are used to supply irrigation water. This indicates that groundwater development is still mainly restricted to the shallow aquifers.

Both the private sector and the public sector invest in groundwater development. The private sector consists of individual farmers. The shallow (although occasionally more than 50 m (150 ft) deep dug well is their traditional tool of groundwater development. The well inventories that were carried out by WAPDA Hydrogeology Directorate and TNO Institute of Applied Geoscience in many alluvial plains of NWFP indicate that farmers generally invest in a private well only if the water table is less than 20 m deep. The pumps fitted on dug wells often have a yield larger than the inflow into the well. So, the water level in the well drops below the pump intake and the pump has to be stopped until the well has recovered. This limits the daily yield considerably.

The public sector uses tubewells for groundwater-based irrigation schemes (Irrigation Department) and for rural water supply, i.e. for domestic use and animal watering (PHED).

5.2 GROUNDWATER-BASED IRRIGATION DEVELOPMENT

The Department of Irrigation has as norm that an irrigation tubewell has to have a capacity of 100 m^3/h (1 cusec) and has to serve an irrigated area of 40 - 60 ha (100 - 150 acres). It uses this relationship as a guideline for the installation of public sector tubewells.

The construction of private tubewells with a yield of 100 m^3/h is too costly for all but for the richest farmers. Moreover, the owner has to have 40 - 60 ha irrigable land around the tubewell site, and suffi cient sharecroppers to cultivate the irrigated land. So, generally a tubewell can only be exploited by a cooperative of landowners (water users association). The prospects of forming a cooperative may differ from village to village, and even then the chances of an economically sound exploitation of a tubewell are slim.

At the request of individual farmers the Directorate of Agricultural Engineering drills approximately 125 tubewells with a depth of 30 - 50 m (100 - 165 ft) annually. The amount of money available for this purpose each year is limited and it may take years before an application is approved. A common practice is that the farmer digs a well down to the water table and that the Directorate then deepens it by drilling. The costs are paid by the farmer but he can receive a considerable subsidy. Up to Rs 35,000 can be obtained towards the cost of tubewell installation in barani areas and up to Rs 18,000 for tubewells in areas irrigated with surface water. Moreover, the electricity for the irrigation pumps of private farmers is charged by WAPDA's Power Wing at the flat rate of Rs 50/- per hp (of the pump) per month; this rate is independent of the actual consumption. Consequently, diesel oil, which is taxed, is not a competitive alternative as an energy source, even in areas where no electrical grid for groundwater pumps is available.

Table 18: Water wells and their production in selected areas

Area	Water wells	Water Production Mm^3/yr	References
Basins in the Dir and Swat Districts			
Talash valley	137	0.5	Jousma, 1983[a]
Adinzai valley	1119	0.5	Jousma, 1983[a]
Daggar valley (Buner)	1986	3	Bloemendaal, et al. 1985
Other valleys in Buner	??	?	not investigated
Nikpikhel area	660	0.8	Wazir, 1987
Other areas in Dir and Swat Districts	??	?	not investigated
Basins on the left bank of the Indus			
Haripur area	??	13	Sheikh, 1985[a]
Pakhli plain	202	0.5	Sheikh, 1985[b]
Ghazi area	400	10.5	Malik and Riaz, 1987
Peshawar Vale			
Maira area	2333	8.4	Bloemendaal and Sadiq, 1985
Baizai area	1370	7.2	Malik and Riaz, 1987[a]
Other parts of Peshawar Vale	??	?	Not investigated or investigation not yet completed
Other basins in the Mardan and Peshawar Districts			
Gadoon area	??	1.9	Sajjad, 1988
Nizampur area	413	1.5	Sheikh, 1985
Basins in the Kohat and Karak Districts			
Kohat plain	3230	7	Bloemendaal, 1983
Hangu valley	860	1.3	Jousma, 1986
Doaba valley	871	1.25	Jousma, 1986
Lachi plain	319	2.5	Malik, 1983
Teri area	274	0.03	Malik and Riaz, 1986
Karak valley	661	6.2	Malik and Jousma, 1984
Bannu basin			
Lakki Marwat	220	7	Dalfsen, et al., 1986
Domail plain	1571	2.5	Uil, 1983
Kurram-Gambila Doab	??	?	not investigated
Dera Ismail Khan basin	8000	13	Malik, 1985
FATA			
Parachinar area	180	?	Dalfsen, et al., 1986
Other areas in FATA	??	?	not investigated

The Cooperative Societies may subsidize individual farmers to a maximum of Rs. 20,000 for the construction of a well and to Rs 10,000 for the purchase of a pumping set. The amount of money annually available suffices for the construction of 12 wells and the purchase of 128 pumping sets only. The subsidies are given on the recommendation of the District Development Advisory Committees.

Most of the deep, high-yield tubewells for irrigation have been drilled by the Irrigation Department in the non-irrigated (barani) areas, e.g. in the Talash and Adinzai valleys in Dir District, in the Doaba valley in Kohat District, and in the northern Indus river plains of the Dera Ismail Khan basin. As a rule the wells have a depth of 60 - 200 m and a yield of at least 100 m^3/h (1 cusec). The size of the irrigation scheme is at least 40 - 60 ha (100 - 150 acres) and increases when the capacity of the well is larger; 400 m^2 per 1 m^3/h (or 1 acre per 0.01 cusec).

Table 19 gives a review of the public sector tubewells in use or designated to be used for irrigation.

In the Dera Ismail Khan basin the 60- and 30-well schemes were constructed in the 1970s. They are located on the Indus river lowlands (Chapter 14); originally they were outside the irrigated perimeter of the Peharpur canal, but since the completion of the first phase of the Chasma Right Bank Canal (CRBC) the schemes have been under the command of the canal system.

In 1983 and 1985 after WAPDA and TNO had completed the groundwater investigations the Department of Irrigation started groundwater development projects of approximately ten tubewells each in the Talash and Adinzai valleys, and in the Doaba valley. The groundwater activities in Talash and Adinzai valleys are now incorporated in the project for "Groundwater-based irrigation development in PATA" (P&D Dept., 1984), which comprises the design and implementation of 50 schemes for irrigated agriculture. Each scheme is served by a tubewell with a capacity of at least 100 m^3/h (1 cusec).

The "PATA project" has also undertaken the drilling of irrigation tubewells in Daggar valley (Buner area, Swat District). Here it is faced with implementation problems, due to the lack of flat, unobstructed plots of at least 40 ha (100 acres) of good irrigable soils. Replacing some of the planned tubewells by a larger number of dug wells on smaller plots is now contemplated.

The public sector wells are funded by the Department of Irrigation, which pays the investment (Table 20) plus the operation and maintenance costs (Table 21). In return it charges abiana rates (water rights) to the owners and sharecroppers of the irrigated land (Table 22; see page 56). The current abiana rights hardly cover the operation and maintenance costs, let alone the amortization of the investment.

The abiana rates are established by the Secretary of the Irrigation and Public Health Engineering Department on behalf of the Government of NWFP. They vary per crop, per region, and per water source. In a given area, for a specific crop the water rights paid on crops irrigated in lift schemes and in tubewell schemes are double the amount paid on crops irrigated with surface water under gravity flow (Table 23).

Quaglia and Poulisse (1984) calculated that depending on the crop in the Buner area the cost of water per acre is from 3.5 to more than 10 times higher than the abiana rates. The implication is that the public sector tubewells are heavily subsidized, which makes the Provincial Government reluctant to invest in groundwater development for irrigation. Raising the abiana rates is obviously not the solution to this problem, because it would make the farmer's produce too expensive to be competitive on the market. A study of the irrigation water costs in the whole of NWFP may provide the answer to the need for reviewing the current water pricing policy.

During a mission to NWFP in 1984 Mr A. Bosscher from the International Instititute for Aerospace Research and Earth Sciences, The Netherlands collected comparative data on the

Table 19: Public sector tubewells for irrigation outside SCARPs

Area	number	specific capacity m^3/h per m dd.	specific capacity gpm per ft ft dd.
Talash and Adinzai valleys	17	12.8-39.9	(17.1-53.5)
Daggar valley	4	6.0- ?	(8.0- ?)
Jandool	2	unknown	
Haripur area	4	8.6-82.0	(11.5-110)
Ghazi area	6	12.8-759	(17.1-1018)
Maira area (Peshwar Vale)	9	10.1-25.4	(13.6-34.1)
Gadoon area	8		
Nizampur area	6	7.7-26.7	(10.3-35.8)
Kohat plain	5	16.0-77.6	(21.5-104)
Doaba valley	10	13.0-43.4	(17.5-58.2)
Northern Domail area (Bannu)	2	6.7-74.6	(9.0-100)
Lakki Marwat plain (Bannu)	5	unknown	
Dera Ismail Khan basin ("scheme 60" and "scheme 30")	90		

source: Irrigation Department NWFP

investment, operation and maintenance costs of various types of wells in NWFP. These are shown in Table 24.

5.3 DEVELOPMENT OF DOMESTIC WATER SUPPLIES

The growing population and the improvements in the standard of living conditions are leading to a rising demand for better domestic water supply systems in the towns and rural areas. Not only do more people have to be served, but the consumption per capita is increasing too, especially as the number of house connections augments.
Groundwater from shallow wells, springs, infiltration galleries and tubewells and, occasionally surface water, constitutes the supply for the rural population.

Table 20: Construction costs of a tubewell; project estimate

Name of work	:	Public Sector Tubewell
Name of subwork	:	Construction of One no. tubewell
Size of drilling	:	18 inch
Average depth of bore	:	300 feet

1.		Mobilization shifting of drilling rig machine and accessories, etc. to the site & back (L.S.)	RS 11500.=
2.		Operation of drilling machine, drilling of 18 inch dia.bore over 300 ft at Rs 350/ft	Rs 105000.=
			Rs 116500.=
3.		Well construction	
	a.	Mild steel, blank casing 12" I.D., 1/4" thick, 163 ft at Rs 320/ft	Rs 52160.=
	b.	Mild steel, blank casing 10" I.D., 3/16" thick, and 36 ft at Rs 250/ft	Rs 9000.=
	c.	Brass strainer, 10" I.D. 3/16" thick, 100 ft with socket at Rs 410/ft	Rs 41000.=
	d.	Mild steel well cap, 12"/10" diameter. One No. Rs 250/no.	Rs 250.=
	e.	Mild steel reducer 12" x 10" diameter and one ft long One no.	Rs 550.=
	f.	Mild steel bail plug 10" diameter 4 ft long one no.	Rs 1240.=
	g.	Gravelpack material	Rs 9000.=
			Rs 113200.=
3A.		Lowering of location material, including welding studding, packing of shrouding material over 300 ft Rs 35/ft	Rs 10500.=
4.		Development and testing of the bore with compressor	Rs 10000.=
5.		Testing of the bore for its yield and drawdown with D&T unit	Rs 3000.=

6.	Pumping set	
	a. Supply, including transport to site of Deepwell turbine pump of 1 cusec discharge at a head of 150 ft, complete with pump assembly of required hp or Supply of submersible pumping unit KSB/PECO with discharge capacity of 1 cusec water at a head of 150 ft	Rs 75000.=
	b. Supply of control panel with automatic star-delta starter for 40 hp electric motor complete with Amp.meter 0-100 Amp., Voltmeter 0-500 Volt and indication system	Rs 9000.=
		Rs 84000.=
7.	Installation of tubewell	
	a. Lowering and installation of pump and motor (L.S.)	Rs 3000.=
	b. Connection of electric motor to control panel box, grounding of motor and control panel box, and electrification of pump house and operator's quarter (L.S.)	Rs 8500.=
		Rs 11500.=
8.	Extension of electric line, including cost of transformer (L.S.)	Rs 50000.=
9.	Construction of pump house, operator's quarter and stilling basin	Rs 89100.=
10.	Construction of approach road	Rs 2500.=
11.	Land acquisition cost of 1 Kanal of land	Rs 10000.=
12.	Inspection/transportation charges of officer and mechanical crews (L.S.)	Rs 5000.=
		Rs 505300.=

Privately owned water supplies come from open wells equipped with buckets or centrifugal pumps, or from springs, while PHED exploits springs, infiltration galleries, and tubewells to provide water for the larger settlements. According to PHED (1987) 1126 public rural water supply systems were in operation by mid-1986 (Table 19). They catered for the needs of 5.2 million people (Table 25) or 45 per cent of the rural population.

The distribution over the supply sources is: springs 33.5 per cent, galleries 13.8 per cent, tubewells 43.2 per cent, open wells 7.9 per cent and surface water 1.6 per cent. There are 499 tubewell-based rural water-supply systems, many serving their customers through house connections. They provide 2.8 million people with water, i.e. 24 per cent of the rural population or 54 per cent of the people served by one of PHED's rural water supply schemes. A summary of 372 tubewell schemes for which the number of people served is known as well as the construction costs of the systems

Table 21: Operation and maintenance costs of a tubewell

1.	DIRECT CHARGES			
	1.	One No. Operator Rs 625/month and for 12 months	Rs	7500.=
	2.	One No. T/well Chowkidar (Watchman) Rs 375/monts and for 12 months	Rs	4500.=
		Sub total	Rs	12000.=
2.	ELECTRIC CHARGES			
	Size of electric motor is 30 HP. 1 HP is 0.746 kW. 30 HP is 22,38 kW, say 22 kW. Assuming working hours per day is 16 hours. Then working hours in a year after allowing 2 months closure and repair etc. is 305 days, is 305 x 16 is 4,880 hours. Electric consumption is 4,880 hours x 22 kW is 107,360 units.			
	a.	Fixed charges Rs 19 per kW; for 12 months 19x12x22	Rs	5016.=
	b.	Actual consumption charges Rs 0.19/unit (0.19x107,360)	Rs	19714.=
	c.	Fuel charges Rs 0.27/unit (0.27x107,360)	Rs	28687.=
	d.	Excise duty Rs 0.005/unit (0.005x107,360)	Rs	537.=
	e.	Meter rent Rs 4/mtr; for 12 months (12x4)	Rs	48.=
	f.	Service rent Rs 1/month; for 12 months (12x1)	Rs	12.=
		Sub total	Rs	54314.=
3.	MAINTENANCE			
	1.	Civil portion 1.5 on Rs 89100	Rs	1337.=
	2.	P/Machinery, Pump and control pannel box 6% of Rs 84000	Rs	5040.=
	3.	Transformer and power line 4.5% of Rs 58500	Rs	2633.=
		Sub total	Rs	9010.=
	Total maintenance charges for 1 No. tubewell		Rs	75324.=

(PHED, 1987) is given in Table 26.
A tubewell with a production capacity of 25 m^3/h (0.25 cusec) suffices for a village of 500 - 1000 inhabitants. To meet the needs of larger villages and towns, tubewells with a large capacity (up to 100 m^3/h) may be constructed. An analysis of the PHED data shows that the per capita expenditure for the installation of a tubewell-based rural water supply system varies from Rs 43/- in Malakand Agency to Rs 352/- in Karak District.
Most towns are supplied by tubewells that have been constructed at the foot of an elevated tank in the middle of a town quarter, e.g. Peshawar where more than 150 tubewells are scattered over the town. When the exploited aquifer is at a relatively shallow depth, the groundwater is not properly protected against contamination by infiltrating urban waste water. In future it may be good policy to supply the large towns with properly protected wellfields outside the built-up areas, preferably on the upstream side of the regional groundwater flow.

5.4 GROUNDWATER DEVELOPMENT FOR WATER TABLE CONTROL

Artificial drainage of groundwater is needed in waterlogged areas, to stabilize the water table at a depth of at least 3 m below the surface. This is necessary to prevent the capillary fringe from rising into the rootzone of the plants, where it will adversely affect crop yields and cause soil salinization. The groundwater drainage may be effectuated by tubewells (vertical drainage) or by horizontal pipe drain systems.
A comparison of the two systems shows the following:
A vertical drainage system consists of a wellfield that operates independently of the depth of the water table, which it

can keep at any desired level. By lowering the water table prior to the wet season, recharge can be stored without creating waterlogging. The temporarily stored water is used for irrigation during the next dry season. The installation costs per hectare are lower than those of a horizontal system but the operation and maintenance are more expensive. The effectiveness of a vertical drainage system largely depends on the vertical distribution of pervious and less pervious layers in the aquifer. Vertical drainage with reuse of the discharge for irrigation is practised in the Bannu SCARP on the Kurram-Gambila Doab (Chapter 13). The effect of the pumping of the 176 tubewells and 83 dug wells, which were constructed and brought into operation between 1978 and 1982 has not yet been evaluated.

A horizontal drainage system consists of near-horizontal perforated pipes (the laterals) that discharge into collector drains from whence the water is pumped or discharged by gravity into a canal, or river. It is essentially a gravity system, and this makes its operation mainly automatic. The water only has to be pumped out of the sump at the end of the collector system if there is no possibility for gravity discharge. The maximum depth at which such drainage systems can be installed is between 2 and 3.5 m; consequently, they can only be used in severely waterlogged areas. The system cannot store groundwater, so it reacts with instantaneous discharge to any rise of the water table. The installation costs per hectare are higher than those of a vertical system but the operation and maintenance is much cheaper. In the Mardan SCARP in the Peshawar Vale (Section 11.2) a horizontal drainage system is under consideration (Broughton, 1984).

Table 23: Selected abiana rates

Name of crop	Per	23 Major Canal irrigated systems including Lower Swat Canal, Upper Swat Canal, Warsak Gravity Canal, Warsak Left Bank Canal, *Sarai Saleh* Dor river, Non-perennial channel, Pehur Canal Rate per acre Rs.	22 Lift schemes including, Warsak Lift Canal Rate per acre Rs.	Tubewell on the right bank of Kabul River Tubewells on the Left Bank of Kabul River Tubewells in Haripur Tehsil, Ziarat Talash Tubewell Rate per acre Rs.	Minor Canal irrigated system, including Kabul River Canal, Tanda Dam Irrigation Scheme, Paharpur Canal Rate per acre Rs.	Tehkal Lift Irrigation Scheme Rate per acre Rs.	Qasba Begram Tubewell, 10 Nos. T/Wells in Sherkera area, 5 Nos. T/Wells in Jaluzai Mattani Adezi Passani & Bagh Miankhel Tappi T/Wells 7 Nos. T/Wells in Tail area of existing Canals in Bannu 60 T/Wells Scheme in D.I. Khan 30 T/Wells Scheme in D.I. Khan Rate per acre Rs.
Sugar cane	Crop	82.40	164.80	164.80	67.20	134.40	134.40
Garden, Orchard, Vegetable, including Onion and Turnips and Sugarbeet	Garden, Orchard, Sugarbeet per half year the rest per crop	53.60	107.20	107.20	53.60	107.20	107.20
Tobacco	Crop	43.20	86.40	86.40	30.40	60.80	60.80
Rice	Crop	37.60	75.20	75.20	29.60	59.20	59.20
Cotton	Crop	37.60	75.20	75.20	22.40	44.80	44.80
Drugs, Dyes, Spices, Chillies, Melon	Crop	37.60	75.20	75.20	30.40	60.80	60.80
Oil Seeds	Crop	30.40	60.80	60.80	24.00	48.00	48.00
Wheat, Barley and Oats	Crop	24.00	48.00	48.00	22.40	44.80	44.80
Maize	Crop	24.00	48.00	48.00	17.60	35.20	35.20
Un-specified crops	Crop	28.00	56.00	56.00	22.40	44.80	44.80
Jawar, Chana and Grass which has received two or more waterings and all fodder crops	Grass per half year the rest per crop	17.60	35.20	35.20	17.60	35.20	35.20
Bajra, Gram, Masoor and Pulses	Crop	22.40	44.80	44.80	22.40	44.80	44.80

Table 22: Abiana receipt of a groundwater-based irrigation scheme (one well)

	Tubewell (elect.)	Dug-cum-tubewell		Dug well/centr.pump		Dug well/ Persian wheel		Tubewell (diesel)
Well construction	250,000	110,000*	100,000**	10,000*	**	10,000*	**	250,000
Pump & fittings	85,000	5,000	5,000	3,000	3,000	4,000	4,000	200,000
Pump house	15,000	-	-	-	-	-	-	15,000
Investment costs	350,000	115,000	105,000	13,000	3,000	14,000	4,000	465,000
Capacity	$150m^3/h$	$40m^3/h$		$10m^3/h$		$3.6m^3/h$		$100m^3/h$
Yield/day peak season	$3,000m^3$	$720m^3$		$60m^3$		$20m^3$		$2,000m^3$
Yield/season June-Sept.	$300,000m^3$	$72,000m^3$		$6,000m^3$		$2,000m^3$		$200,000m^3$
Annual interest 10% depreciation in 25 years	38,500	12,650	11,550	1,430	330	1,540	440	51,000
Chowkidar and operator	6,000	-	-	-	-	-	-	6,000
Energy Rs $0.1/m^3$	30,000	7,200	7,200	600	600	-	-	132,000
Maintenance 6% pump and fitt.	5,000	300	300	180	180	200	200	12,000
Operation and maintenance	79,500	20,150	19,050	2,210	1,110	1,740	640	201,000
Cost of water per m^3 (Rs)	0.265	0.280	0.265	0.368	0.185	0.870	0.320	1.0
Tomato crop 4000 kg/ha, Rs 4/kg								
Cost of water 12,000 m^3/ha	3,180	3,360	3,180	4,416	2,220	10,440	3,840	12,000
Seed	20	20	20	20	20	20	20	20
Fertilizer	600	600	600	600	600	600	600	600
Recurrents costs	3,800	3,980	3,800	5,040	2,840	11,060	4,460	12,620
Production Value 4000x4=	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Return to labour (Rs/ha)	12,200	12,000	12,200	11,000	13,200	4,900	11,500	3,380

* Well construction against payment
** Well construction through exchange oflabour

Table 24: Comparative costs of various types of wells in NWFP

Crop	percent. under crop	area under crop (acres)	Abiana Rates per acre	Total in Rs
Kharif				
Sugarcane	5	4	Rs 131.2	Rs 524.8
Maize	60	45	Rs 38.4	Rs 1728
Other	35	26	Rs 44.8	Rs 1164.8
Sub Total				Rs 3417.6
Rabbi				
Sugarcane	5	4	Already included in Kharif	
Wheat	65	49	Rs 38.4	Rs 1881.6
Other	30	22	Rs 44.8	Rs 985.6
Sub Total				Rs 2867.2
Total Abiana Receipt/year (3417.6 + 2867.2)				Rs 6284.8

Table 25: Public rural water supply systems

District/ Tehsil	Schemes	Population served (1000)	Expenditure Rs 1000	Exp. per scheme Rs 1000	Exp. per capita
Abbottabad					
Abbottabad	114	384.10	54,565	479	142
Haripur	60	282.94	30,918	515	109
Mansehra					
Mansehra	109	299.43	37,180	341	124
Batagram	42	74.85	4,337	103	58
F.R. Kala Dacca	2	2.46	387	193	157
Kohistan					
Dassu	10	15.14	2,408	241	159
Pattan	29	67.61	3,200	110	47
Swat					
Swat	41	117.36	27,260	665	232
Daggar	25	108.07	14,910	596	138
Alpurai	29	71.22	2,037	70	29
Dir					
Timergara	53	104.36	18,940	357	181
Jandool	6	18.59	2,657	442	143
Wari	7	23.36	2,495	356	107
Dir	15	46.49	7,039	469	151
Malakand	32	147.40	14,010	438	95
Chitral	24	51.56	12,485	520	242
Mardan					
Mardan	38	835.85	34,283	902	41
Swabi	35	575.26	30,376	868	53
Peshawar					
Peshawar	48	266.20	46,897	977	176
Nowshera	54	342.97	37,566	696	110
Charsadda	29	253.80	22,860	788	97
Kohat					
Kohat	36	165.07	27,982	777	169
Hangu	28	138.85	25,144	898	181
Karak					
Karak	48	137.12	48,284	1,006	352
Banda Daud Shah	20	47.74	9,094	455	190
Bannu					
Bannu	42	292.33	42,087	1,002	144
Lakki	60	280.93	53,307	888	190
Dera Ismail Khan					
D.I. Khan	42	243.66	38,621	919	158
Tank	16	86.42	18,447	1,153	213
Kulachi	32	95.28	22,977	718	241

Table 26: Tubewell-based water supply systems in NWFP; 127 tubewell schemes are omitted from this table, because no data are available on the expenditure incurred or on the number of people being served.

District/ Tehsil	Schemes	Population served (1000)	Expenditure Rs 1000	Exp. per scheme Rs 1000	Exp. per capita
Abbottabad					
Abbottabad	8	41.4	9,243	1,155	199
Haripur	27	170.3	18,129	671	106
Mansehra					
Mansehra	3	11.5	1,406	469	122
Batagram	0	-	-	-	-
F.R. Kala Dacca	0	-	-	-	-
Kohistan					
Dassu	0	-	-	-	-
Pattan	0	-	-	-	-
Swat					
Swat	12	74.8	11,863	989	158
Daggar	7	45.5	5,646	807	124
Alpurai	0	-	-	-	-
Dir					
Timergara	10	32.7	4,818	482	147
Jandool	0	-	-	-	-
Wari	0	-	-	-	-
Dir	0	-	-	-	-
Malakand	4	63.2	2,716	679	43
Chitral	0	-	-	-	-
Mardan					
Mardan	28	245.3	27,255	973	111
Swabi	23	288.3	25,250	1,098	88
Peshawar					
Peshawar	42	351.9	42,207	1,005	120
Nowshera	41	303.7	35,063	855	115
Charsadda	21	238.4	18,046	859	76
Kohat					
Kohat	12	79.5	11,420	952	144
Hangu	8	39.4	6,120	765	155
Karak					
Karak	14	51.4	14,243	1,017	277
Banda Daud Shah	0	-	-	-	-
Bannu					
Bannu	38	294.7	40,432	1,064	137
Lakki	29	193.3	29,941	1,032	155
Dera Ismail Khan					
D.I. Khan	28	161.1	35,119	1,254	218
Tank	4	54.0	12,990	3,247	240
Kulachi	13	49.6	9,004	693	181
Total	372	2,790.3	360,914	970	129

6 GROUNDWATER DEVELOPMENT POTENTIAL

6.1 GENERAL

Groundwater may be found in soft rock, that is to say, unconsolidated sediments such as gravel, sand, and clay beds, as well as in hard rock, i.e. consolidated sediments, volcanic, metamorphic and igneous rock. However, hardrock usually has a low permeability and therfore only limited amounts of groundwater are found in hills and mountains, because these consist of hard rock. The aquifers in such terrain with a low primary porosity (Section 2.4) are often related to weathered intrusions of igneous rock, to faulting and jointing in sandstones and quartzites and to dissolution of limestone in karst areas. Extensive aquifers are found only in limestone terrain, so, it will be worthwhile to investigate the limestones of the Kohat mountains in more detail. Groundwater usually discharges from aquifers in hard rock as springs, which as a matter of course are important as a local resource. Spring flow supplies water for domestic use and livestock watering, and for irrigating small gardens. However, the sustained flow is usually too small to be of interest for public sector irrigation schemes. So, in general, the groundwater development potential of the mountains is small to negligible.
The main groundwater reservoirs of NWFP are the alluvial plains and valleys, of which many are intermontane basins of tectonic origin (Section 2.1 and 2.2). The basins are filled with unconsolidated alluvial deposits, the coarse grained layers of which form the aquifers. The yield of wells tapping the aquifers depends on the hydraulic characteristics of the water-bearing layers, i.e. transmissivity, specific yield or storage coefficient (Sections 3.2 and 3.3). The amount of groundwater that can be withdrawn from an aquifer annually without causing overexploitation of the resource, i.e. the number of wells that can be installed, depends on the flow regime and amount of uncommitted recharge. So, the well discharge depends on the hydraulic characteristics of the aquifer and the number of wells that can be exploited depends on the recharge (and discharge) conditions.
Finally, the chemical characteristics of the water determine if it is suitable for domestic, agricultural and industrial use (Section 2.5).
It is recalled from Chapter 5 that public sector groundwater-based irrigation schemes should be served by a well with a capacity of at least 100 m^3/h (1 cusec). Private development, and development of rural water supply schemes by the Public Health Engineering Department (PHED) are not hampered by this criterion. The 100 m^3/h norm means in practice that the exploited aquifer has a transmissivity of at least 500 m^2/d. The annual water production by such a well is not more than one-third of the maximum production capacity, because only in periods of peak demand does the pump work a maximum number of hours a day. In short, for the exploitation of 0.9 Mm^3/yr three tubewells with a capacity of 100 m^3/h (1 cusec) each are needed.
On the groundwater maps of the alluvial plains the groundwater development potential is classified according to transmissivity and depth to the static water level. The classification is as follows:

Class I : Suitable for tubewells with a yield of 100 - 150 m^3/h (1-1.5 cusec); sub-Class I+ indicate yields of more than 150 m^3/h.
Class II: Moderately suitable for tubewell development; yield of the well is 50 - 100 m^3/h (0.5 - 1.0 cusec)
Class III: Unsuitable for tubewell development; yield of the dug well is less than 50 m^3/hour (0.5 cusec)

The suffix "s" is added to the classification number to indicate a current average depth to the water table or to the piezometric level of less than 30 m. The suffix "d" is used to indicate a greater depth and "dd" warns that the depth to water can locally exceed 100 m. The complete legend to the groundwater maps and hydrogeological cross-sections is given in Figure 30 in Chapter 8 and in the fold-out at the back of the book.
In the text of Chapters 9 - 15 additional information is given about drilling depth, specific capacity (the yield of a well in m^3/h per m drawdown (dd.) or in gpm per ft dd.), present and future pumping level, etc. Last but not least, recommendations are made about the maximum exploitation rate.
In those Chapters the expression "first phase development" is often used. It refers to the conviction of WAPDA Hydrogeology Directorate and TNO Institute of Applied Geoscience that the groundwater resources should be developed stepwise, so unforeseen behaviour of the aquifer can be taken into account in the next step. This prevents the loss of investments if the aquifer appears to sustain only a smaller number of wells than originally expected. It is therefore extremely important to monitor carefully the behaviour of the aquifer when increased pumping changes the hydraulic stress pattern. In general, it has been recommended not to develop more than 50 per cent uncommitted recharge at the moment. When this "allocation" is exhausted a conclusion on further development can be reached in the light of the effects that the first phase of development has invoked in the aquifer.
Only the water resources side of the groundwater development has been discussed, but obviously, successful development of the water resources for irrigation does not depend solely on the availability of water, but on other elements as

well, namely:

- the availability of an uninterrupted electricity supply for the pumping equipment,
- the availability of irrigable soils; many areas with a good groundwater development potential are characterized by a high groundwater recharge linked to soils with a high infiltration rate. Such soils are often unsuitable for irrigation, because of the substantial percolation losses and related low irrigation efficiency; examples are the Parachinar area (Section 15.7) and the downstream part of the Adinzai valley.
- the availability of unbroken land of at least 40 - 60 ha. Where the soils are dissected by erosion gullies, or otherwise unbroken pieces of land are less than 40 ha (100 acres) in area, irrigation development will be impossible; this situation occurs in the western part of Daggar valley.
- the availability of farm inputs, e.g. seed, fertilizer, machinery, and not to be forgotten the services to maintain and

Table 27: Groundwater development potential in NWFP

Area	Potential Mm^3/year (and recommended development)	Exploited Mm^3/year	Number and type of wells and capacity in m^3/hour	
Dir and Swat Districts				
Talash valley	10 (4.7)	2.7	6 TW	100
Adinzai valley	22 (11)	6.7	14 TW	100 - 150
Daggar valley	100 (50)	3		
Western part	22 (11)		5 TW	100
Eastern part			DW	50
Chamla valley	??	1.6	6 TW	100
Chingalai basin	negligible		DW	
Totali area				
Eastern sub-basin	low		TW	25
Western sub-basin	low		TW	100
Nikpikhel area	high (10)		TW	20 - 50
Jandool area	probably high			
Indus Left Bank Areas				
Haripur area				
Upstream of Sarai Saleh	(10)	3	TW	250
SE part of plain	(10)			50 - 100
N part of plain, confined	(10)	high pump lifts		100
SW part of plain, confined	(15)	high pump lifts		100 - 250
Pakhli plain	50 (25)			
Central part of the plain			TW	50
Peripheral part of the plain			TW	25
Ghazi area	60 (60)	10	TW	100 - 250
Peshawar and Mardan Districts				
Peshawar Vale	300	???	TW,	75 - 200
Nizampur area				
E. Nizampur area	20	1.1	TW,	50 - 100
W. Nizampur area	3.4	0.4	DW,	20
Gadoon area	24	1.9	9 TW	100
Kohat and Karak Districts				
Kohat plain (NW. + N. Centr.)	50 (25)		TW,	100
(elsewhere)	23		DW	
Hangu valley	12 (3)	1.3	DW,	20
Doaba valley	20	1.8	9 TW,	100
Lachi valley	1.6		DW,	20
Teri valley	negligible			
Karak valley				
W. catchment	11	5	DW,	20
E. catchment	4.4	1.1	DW,	20

repair the well pump, which will enhance the possibility of a qualitatively and quantitatively satisfactory crop to be produced,

- the cropping patterns that generate sufficient income to recover the agricultual input costs and the water charges (abiana). Currently, the latter do not fully cover the ammortization of the investment and the operation and maintenance costs. This means that public sector tubewells are still heavily subsidized by the Irrigation Department, but that may change in future.
- the access to markets to sell the produce at a remunerative price. As a consequence of the relatively large distances to the markets of Peshawar and Islamabad, farmers are forced to grow non-perishable crops e.g. onions, cotton, etc., which may be financially less attractive than vegetables.

These elements are not considered in this book, but have to be given due attention when groundwater development projects are planned.

Table 27: (Continued)

Area	Potential Mm^3/year (and recommended development)	Exploited Mm^3/year	Number and type of wells and capacity in m^3/hour
Bannu basin			
Northern alluvial fans	29.6	1.6	100
Western alluvial fans	35	2.0	100
Northern Kurram-Gambila Doab	??	surplus of surface water	
Southern Kurram Gambila Doab	??	waterlogging,	TW and DW
Lakki plain	11	5.0	TW, 25 - 50
Laki Marwat confined aquifer	??	??	TW, 20
Domail plain (S. of Kashu Algad)	6	0.9	TW, 25 - 50
Dera Ismail Khan basin			
N. Indus river lowlands	large		100 TW, 100 - 200
S. Indus river lowlands	large	saline	
N. boundary area			25
W. alluvial fans			50
Kot Azam area	??		100 - 200
Central plain		saline	
"Corridor" of the central plain		fresh below saline	20
FATA			
Bajaur Agency	8	15	80 TW, 75
Mohmand Agency	6	6.6	30 TW, 110
Khyber Agency	??	no data available	
Orakzai Agency	??	no data available,	
Kurram Agency			
Parachinar area	200	no irrigable soils	
Sateen plain	2	0.8	5 TW, 50 - 100
Chulam Chakmanni plain	??		no data available
Khoidad Khel area	??		unsuccesful test holes
North Waziristan			
Spinwam plain	0.2	overexpl.	7 TW
Shera Tala	1.3	no data	
Muhammad Khel area	1.3	no data	4 TW
Miran Shah area			
(Right Bank)	1.0	1.0(?)	5 TW
(Danday plain)	6.2	??	no data available
Mir Ali plain	2.6	1.2	8 TW, 50 - 100
South Waziristan			
Shaki plain	2.7	0.2	2 TW, 50
Wana plain	10	3.4	17 TW, 50 - 150
Barwand plain	1.1	1.6	11 TW, 50 - ?
Spin plain	0.8	0.6	3 TW, 100 - 150
Zarmelan	5.2	4.5(?)	25(?) TW,

6.2 CLASS I AREAS

The following areas are classified as suitable from a water resources point of view for groundwater development by high-yielding - at least 100 m^3/h (1 cusec) - tubewells. This does not imply that there are no restrictions on the development of irrigated agriculture, e.g. unsuitable soil conditions, no electricity supply, insufficient interest by the farmers, etc.

- The Talash and Adinzai valleys (Dir District)
- The western sub-basin of the Totali area (Swat District)
- The area along the Dor river upstream of Sarai Saleh (Abbottabad District)
- The Ghazi area (Abbottabad District)
- The southern and western part of the Peshawar Vale (Peshawar and Mardan Districts)
- The eastern part of the Nizampur area (Peshawar District)
- The Gadoon plain (Mardan District)
- The valley northwest and the central plain south of Kohat town (Kohat District)
- The Doaba valley (Kohat District)
- The northern and northwestern parts of the Bannu basin (Bannu and Karak Districts)
- The Indus river lowlands of the Dera Ismail Khan basin (D.I. Khan District)

The recommended groundwater extraction is more than 200 Mm^3/yr, which requires the installation of approximately 600 wells. The number of wells that should be installed in each of the above-mentioned valleys varies from only a few in the mini plain of the western sub-basin of Totali to 180 in Ghazi area and in the northern and northwestern parts of the Bannu basin (Table 27 and Figure 29).

It is not certain that the recommended development can be realized in each of the plains. In the northwestern part of the Bannu basin, in the southwestern part of the Peshawar Vale and in the Adinzai valley the soils may be very permeable and consequently, the percolation losses may be unacceptably high. Unacceptable from an economic point of view rather than from a hydraulic one, because the percolation losses from the irrigation return to the aquifer and the resulting net waste will be small.

In the northern part of the Bannu basin, particularly in the Doab where the better soils occur, is a plentiful supply of surface water and the inclination to use expensive groundwater will be small. On the other hand a more extensive use of groundwater may be helpful to control the water table and to combat waterlogging. The same holds true for the Indus river lowlands of the Dera Ismail Khan basin, where the risk of waterlogging is ever present too. Another problem in the Dera Ismail Khan basin is the existence of saline groundwater below the southern part of the river lowlands. In this zone the water is only suitable to irrigate rather salt-tolerant crops; that is why cotton has become so popular.

In the southwestern part of the main plain of Haripur area the aquifer is confined, and the pumping lifts will be high, making the groundwater too expensive.

6.3 CLASS II AREAS

The areas classified as class II have only moderate transmissivities, so the well yields are less than 100 m^3/h:

- The Nikhpikhel area (Swat District)
- The western part of the Daggar valley (Swat District)
- The northern part of the main plain of Haripur (Abbottabad District)
- The southeastern part of the main plain of Haripur (Abbottabad District)
- The central and northern parts of the Peshwar Vale (Mardan and Peshawar Districts)
- The eastern part of the Domail plain (Bannu and Karak Districts)
- The western alluvial fans of the Dera Ismail Khan area

The following comments can be made:

In the western Daggar area tubewells have to be exploited at a rate below the 100 m^3/h norm of class I, because the irrigable soils are so dissected by erosion gullies that single areas of 40 - 60 ha cannot be found.

In the northern part of the main plain of Haripur the aquifer is confined and yields of 100 m^3/h, which are theoretically possible, will result in a large drawdawn and consequently, prohibitive high pumping lift; so, lower yields are recommended.

The eastern part of the Domail plain has meagre fresh water resources, the transmissivity of the aquifer is moderate to low and the available water resources should be reserved for domestic requirements, including livestock watering.

The western alluvial fans of the Dera Ismail Khan basin have steep slopes, shifting torrents and stony soils without any agricultural potential; the development of groundwater other than for domestic use and watering of livestock is not feasible.

In the southeastern part of the main Haripur plain and in the central and northern parts of the Peshawar Vale the transmissivities are below 500 m^2/d and the well yields will be correspondingly low.

6.4 AREAS WITH A LOW GROUNDWATER DEVELOPMENT POTENTIAL

Many of the basins that have to be classified as having a low potential for groundwater development are characterized by a thin or a very clayey alluvial fill. Such areas are:

In the Buner area (Swat District)

- The eastern part of the Daggar valley,
- The Ghamla valley,
- The Chingalai basin, and
- The easter sub-basin of the Totali area,

The following areas in Kohat District:

- The peripheral areas of the Kohat plain
- The Hangu valley,
- The Teri valley, and
- The Lachi valley,

and further:

- The Pakhli plain (Mansehra District),

Other areas classified in this category because of saline groundwater are:

- Most of the western zone of the Karak valley, and
- The central part of the Dera Ismail Khan area,

and finally:

- The Lakki plain in the Bannu basin. It has a low recharge, deep groundwater levels (i.e. high pumping lifts) and poor soil conditions, and

- The western part of the Nizampur area. It has a thin, unconfined, shallow aquifer and a deep confined one. The latter has its ceiling at a depth of 120 - 180 m below the surface and probably a low transmissivity. Consequently, only the shallow aquifer is exploitable for domestic supplies.
- The Lakki Marwat area between Takhti Khel and Khawaja Khel. It has a deep confined aquifer system with its ceiling at a depth of 60-200 m. Although wells drilled in this aquifer are often freeflowing at present, it is expected that development of this aquifer will quickly lead to unacceptable pumping lifts.

6.5 NON-CLASSIFIED AREAS

This category comprises all the zones on which insufficient data are available to enable a reasonable assessment of their groundwater development potential to be made. They are:

- The Jandool area (Swat District)

The scope of the groundwater development depends mainly on the as yet unknown groundwater recharge and discharge regime and, of course on the availability of irrigable soils, which may be the limiting factor (Section 9.5)

- The southern part of the Kurram Gambila Doab (Bannu District)

This part of the Doab has conditions comparable with those of the Lakki plain (Section 6.5), but, as a consequence of the percolation losses of the surface water irrigation system, the water table is at shallow depth, often less than 3 m. Conjunctive use of surface water and groundwater has been initiated in the Bannu SCARP, the effects of which must be assessed before recommendations for further development can be made.

- The Federally Administered Tribal Areas

In FATA no groundwater assessment studies have been carried out, except for the study by WAPDA/TNO in the Parachinar area in Kurram Agency. Therefore only preliminary estimates of the development potential could be made (Chapter 15). Nevertheless, there is reason to expect that the Bajaur Agency, Mahmond Agency, the Sateen plain in Kurram Agency, the Spinwam plain in North Waziristan and the Zarmelan plain in South Waziristan are overexploited.

6.6 CONCLUSIONS

It is concluded that there is ample scope for further groundwater development to introduce irrigation in barani areas and for conjunctive use with surface water to combat waterlogging. In areas where the aquifer conditions are not suitable for high-yielding public sector tubewells, groundwater can still be exploited by PHED for rural water supply systems and by individual farmers for irrigation of private plots and gardens.

Figure 29: Alluvial plains in the North-West Frontier Province

7 GROUNDWATER MANAGEMENT: A LOOK AHEAD

7.1 PURPOSE

The purpose of groundwater management is to ensure the rational use and conservation of the groundwater resources. Unfortunately, it is often neglected until undesired effects take place. Some of the reasons for this are:

- The urge to develop and exploit the groundwater resources comes easily at the local level, and finds expression in a multitude of wells dug by individual farmers to exploit the shallow aquifers, but the initiative to conserve and protect, i.e. to manage the resource, has to be taken at the regional level, e.g. in Pakistan by the Provincial Governments.
- The processes in a groundwater basin are slow ones and groundwater, in contrast to surface water, is "invisible", so that the slow changes escape attention. Consequently, it can take a long time before the effects of overexploitation or of contamination of an aquifer become apparent, giving the false impression that all is well. But when they eventually emerge there is no quick remedy, because the recovery is also a slow process and will take a long time.

There has to be a common awareness among the groundwater users and the government institutions about the importance of proper management of the groundwater resources. This is vital because in many parts of NWFP groundwater is the only source for a safe water supply that will provide water to man and his animals and crops, even in periods of severe drought. On the other hand, measures have to be taken to protect farmland through watertable control from the adverse effects of waterlogging and the resulting soil salinization.

Groundwater management is often portrayed as a separate activity on a par with groundwater investigations and groundwater planning. In fact the investigations and the development should be part of a groundwater management plan. Such a plan should be based on a clear policy and a set of legally prescribed rules that govern the groundwater exploitation.

In the North-West Frontier Province there is no legislation on groundwater management, nor is there a formal groundwater management plan, but many activities that belong in such a plan have already been undertaken on an ad hoc basis. They include: the execution by WAPDA and TNO of a programme of groundwater studies in the non-commanded parts of the alluvial plains, the exploitation of the deep aquifers by the Irrigation Department, the initiative to set up a network for groundwater monitoring in the non-SCARP areas, and the projects to control the water table in the SCARPs. Nevertheless, much remains to be done.

7.2 GROUNDWATER INVESTIGATIONS AND MONITORING

The programme "Groundwater Investigations in NWFP", has assessed the groundwater resources in the non-commanded parts of most of the alluvial plains (Chapter 4). In the alluvial plains in FATA and in some of the smaller valleys of the settled areas of NWFP, such as Gadoon valley in Mardan District and some small valleys in Dir and Swat Districts this still has to be done. These assessment studies can be carried out in the same way as those of WAPDA and TNO (1980 - 1988).

In the areas under the command of the surface water irrigation systems, and of SCARPs the groundwater behaviour also has to be studied, particularly in the Kurram-Gambila Doab in the Bannu basin, in the Paharpur area of the Dera Ismail Khan basin, and in the central part of the Peshawar Vale. Attention should be given to the groundwater behaviour in the plains as a whole and to the possibilities for the conjunctive use of surface water and groundwater. These studies will be more complicated than the investigations in the non-commanded areas, and will require more time-dependent data, e.g. groundwater time series, information on the actual discharge by surface water and subsurface-water drainage systems, and on the water use and the return flow to the groundwater. Eventually, the results of these studies should be used to decide if and how adjustments to the surface water and groundwater development systems should be made.

In areas where the aquifer is underlain by saline groundwater, e.g. Dera Ismail Khan basin, Karak valley, Lachi plain and Bannu basin, groundwater quality monitoring data are needed as well. Groundwater-flow simulation models will be useful to understand the flow system and to study the effects of various development scenarios.

In the SCARPs some monitoring is being done by WAPDA's SCARP Monitoring Division, but no reports could be found indicating that the monitoring data have been analysed and evaluated to check if the implementation of the SCARP brings the predicted results.

Currently, outside the SCARPs, neither the groundwater level, nor the groundwater quality or the water production are being monitored. Consequently, the data required to take sound resource management decisions are lacking and there is a need to set up groundwater monitoring networks on a priority basis. Monitoring should be started in those areas where a sharp increase in the groundwater production, e.g. through the installation of high-yielding tubewells, is expected in the near future. To set up a benchmark of the current situation is of interest not only from a scientific point of view but also for practical purposes, because it can be used to judge claims for damages that are attributed to the drying up of dug wells as a consequence of the installation of tube-wells.

The objectives of the monitoring should be clearly defined before a network is set up in a particular area, and its wells should be selected with these objectives in mind. Sometimes existing wells can be used, but often piezometers, observation wells and sampling wells for the waterlevel and the quality monitoring will have to be drilled at specific locations and screened at specific depths. When more than one aquifer is present, in each one the level and the quality of the water have to be monitored. In such cases special care is necessary to avoid leakage from one aquifer into the other through the borehole.

The frequency of the observations should be at least once a month, and more often during periods in which large fluctuations are expected, e.g. periods of recharge of the aquifer. Proper evaluation of these data requires the availability of information on the precipitation, pumping, river stages, etc.

Groundwater sampling for chemical analysis can be done once a year because changes in groundwater quality usually occur as the result of very slow processes. An obvious exception to this rule is sampling to check on sudden contamination by, say, industrial wastes.

Groundwater production is best monitored by regularly interviewing the users in combination with observation of the energy consumption. From the interviews and a simple bookkeeping by the water users the duration and frequency of the pumping can be ascertained and the pumped volume can be calculated. These figures can be crosschecked by monitoring the energy consumption, provided of course that the pump is an electrical one and that an electricity meter has been installed. The evaluation of the collected data will also require statistics on the extent of the irrigated areas, the crops grown, the number of animals watered and the number of people in the household(s) that use the particular well for their domestic needs.

The areas most in need of a monitoring network are the Peshawar Vale as a whole, the Indus river plains in Dera Ismail Khan, The Bannu basin as a whole, the Talash and Adinzai valleys, the Daggar valley, the Kohat plain, the Doaba valley, the eastern part of the Nizampur area, and the Haripur area, and in FATA the Bajaur plain in Bajaur Agency, the Nawagai plain and the plain between the Laharai and Kharzie Khwars in Mohmand Agency, as well as the Spin and Zarmelan plains in South Waziristan. In the other alluvial plains a general well survey once every five years will be sufficient for the time being.

7.3 GROUNDWATER POLICY FORMULATION

It is recalled that there is no legal framework for the development of the groundwater resources of NWFP, and that currently the only controlling factors are the socio-economic conditions. The Government uses subsidies and charges to influence the water exploitation. In future this may be insufficient and a groundwater law may have to be introduced. It will only be effective if the rules are enforceable.

Groundwater can be developed according to different models:

- In their groundwater investigations (1980-1987) WAPDA and TNO used the safe-yield model to calculate the groundwater potential. It limits the exploitable resource to the avarage annual unused groundwater outflow, i.e. the groundwater recharge minus the already developed resource. This exploitation model uses the annually renewable quantity but leaves the groundwater storage virtually untapped and uses it only as a buffer for dry years.
- The mining model not only includes the annually renewable resource in the groundwater development potential, but also all exploitable groundwater in storage. Ultimately, groundwater development according to the mining model leaves an exhausted aquifer or one with uneconomically deep pumping levels.
- An intermediate development model, the so-called deferred safe-yield model, allows a temporary overexploitation of the aquifer, under the assumption that after some time the water demand will decrease and the annual groundwater extraction will return within the limits of the average annual recharge. However, the assumption of the temporariness of the overexploitation is often wishful thinking, and at a certain moment painful decisions will have to be taken to keep the groundwater exploitation under control.

The safe-yield approach as used by WAPDA has been adopted by the Irrigation Department and may be adopted by FATA-DC as well. This means that appropriate measures will have to be taken in all areas where overpumping will occur in the near future. These include the alluvial areas of the Bajaur Agency, and the Spin and Zarmelan plains in South Waziristan.

7.4 GROUNDWATER DEVELOPMENT AND CONSERVATION PLANNING

The Department of Irrigation has decided to approach the groundwater development for irrigation by drilling high-yield tubewells in the barani areas that have aquifers to sustain the well yield. The planning of the rural water supply systems by the Public Health Engineering Department is, justifiably, based more on local needs than on resource considerations.

For each of the groundwater basins a development plan has to be drawn up:

- In the basins with low resources and shallow water tables, such as the Kohat plain, the Hangu valley, the Teri area, some of the valleys on the northern fringe of the Peshawar Vale and some of the valleys in Dir and Swat Districts, the development plan can be restricted to guidelines for the development of dug wells, and a plan for a general well survey once every five years.
- Groundwater development plans for areas with low resources and deep water levels, e.g. the south and west of the Bannu basin, the northern and western fringes of the Dera Ismail Khan basin, and the Parachinar area call for the installation of tubewells with a relatively low yield (25 - 50 m^3/h or 0.25 - 0.5 cusec) as rural water supply schemes for domestic use and animal watering.
- Plans for the installation of high-yield tubewells can be made in the Talash and Adinzai valleys in Dir District, The Daggar valley in Buner (Swat District), the Gadoon plain (Mardan District), large parts of the Peshawar Vale, the

eastern part of the Nizampur area, the Kohat plain, the Doaba valley, the Indus river lowlands of D.I. Khan basin, etc. Monitoring of water levels and groundwater exploitation will provide the input data for developing groundwater simulation models to test the effects on the groundwater of various development scenarios (Chapter 9 and Jousma, 1983 concerning the model made for the Talash and Adinzai valleys (Dir District), and Section 15.7 and Elderhorst, 1987 for the model of the Parachinar area).

- In areas with limited fresh groundwater resources hydraulically connected with saline water, e.g. the western Karak valley (Section 12.7), the Lachi plain (Section 12.5), the "corridor" and the fringes of the central part of the Dera Ismail Khan basin (Chapter 14), and the Domail plain in Bannu basin (Chapter 13), groundwater development planning is needed to protect the fresh water resource against overpumping and contamination by subsurface inflow of saline groundwater,
- In areas with intensive agriculture one should be aware of the risk of contamination of the aquifer by fertilizers and other chemicals. Protection zones against groundwater pollution should be established around the wellfields that produce the water for the towns.

7.5 COSTS AND BENEFITS

It is expensive to develop groundwater-based irrigation through the exploitation of deep aquifers by high-yielding tubewells. Currently, the Provincial Government pays all the costs of construction, operation and maintenance of most tubewells and in return receives only a fraction of these amounts in the form of abiana rights. Understandably, this makes the Government reluctant to continue the policy of developing groundwater-based irrigation schemes in uncommanded areas.

In principle, the gross production value should be sufficient to cover all the production costs, including water. If one adheres strictly to this policy, farmers who have access to cheap water may have a distinct advantage over farmers with tubewells, who incur high costs to bring water to their lands. For various reasons the Government may decide on another policy, e.g. to equalize the price of water for all farmers, independent of the source, or to use the water charges to stimulate the use of certain water sources, e.g. in waterlogged areas to raise the water charges for surface water to such an extent that it becomes economically attractive to use groundwater instead of surface water for irrigation.

The decisions on the financial policy regarding groundwater management cannot be taken in isolation. Accordingly, the overall socio-economic policies in NWFP and the position of the agricultural sector, in particular the irrigated agriculture, with respect to the other Provinces of Pakistan will have to be considered. This aspect falls outside the scope of this book.

8 THE REGIONAL GROUNDWATER RESOURCES

In Chapters 9 through 15 the regional groundwater resources are described in some detail. All the alluvial plains and valleys are discussed insofar as data are available. Hence, the intermontane basins and valleys that were investigated under the Pak-Dutch programme are described in much more detail than areas for which only reconnaissance reports are available.

The regional descriptions are grouped as shown below. The regions marked "*" were investigated under the PAK-Dutch programme:

The intermontane basins of the Districts of Dir, Swat and Chitral:

* The Talash and Adinzai valleys
  The Buner area (incl. the * Daggar valley, Chamla valley, Chingalai basin, and Totalai area)
  The Nikpikhel area
  The Jandool area

The areas on the left bank of the Indus river:

* The Pakhli plain
* The Haripur area
* The Ghazi area

The intermontane basins of Peshawar and Mardan Districts:

  The Peshawar Vale
* The Nizampur area
  The Gadoon plain

The intermontane basins of Kohat and Karak Districts:

* The Kohat plain
* The Hangu valley
* The Doaba valley
* The Lachi plain
* The Teri area
* The Karak valley

The basins of the Bannu and Dera Ismail Khan Districts:

* The Bannu basin
* The Dera Ismail Khan basin

The intermontane basins of FATA

  The Bajaur Agency
  The Mohmand Agency
  The Khyber Agency
  The Orakzai Agency
  The Kurram Agency (excl. the Parachinar area)
* The Parachinar area (Kurram Agency)
  North Waziristan
  South Waziristan

The descriptions comprise sections on Location, Physiography, Geology, Climate, Population and domestic water supply, Agriculture, Groundwater investigations, Groundwater conditions, Groundwater levels, Groundwater flow, Recharge, Discharge, Groundwater development potential, Groundwater management and an Annotated bibliography.

The reader should realize that the conclusions on the groundwater development potential and the descriptions of the hydrogeological conditions concern groundwater on a regional scale. Areas have been delineated with a high, moderate or low potential for groundwater development with high capacity - at least 100 m^3/h (1 cusec) - tubewells. In these areas detailed investigations will be required when the actual drilling sites have to be selected.

This book does not contain detailed data sheets for the alluvial areas The interested reader will find them in the original research reports that are listed in the "Annotated bibliographies".

All the groundwater maps and hydrogeological cross-sections have a common legend which is presented in Figure 30 which is placed as a fold-out at the back of the book.

9 THE INTERMONTANE BASINS OF DIR, SWAT AND CHITRAL DISTRICTS

9.1 GENERAL

The northern part of the North-West Frontier Province comprises the Chitral, Dir and Swat Districts. The area is bordered in the south by the rim of the Peshawar Vale (Section 11.2) and in the southwest by the Bajaur Agency. In the west and north it has a long border with Afghanistan and in the east it is bordered by Gilgit Agency and the Kohistan and Mansehra Districts.

This vast area is mainly mountainous terrain with limited groundwater resources in fractured zones in the hardrock and in the alluvial fill of relatively small valleys and intermontane depressions. In Chitral District and in the northern parts of the Dir and Swat Districts groundwater cannot be found other than as springs in fractured hardrock and in very small amounts in hillside deposits and stream deposits, just sufficient to supply scattered farms and settlements. The only exception to this rule is the Chitral valley, where Chitral town is supplied from a well in the floodplain of the river. Fortunately, along the major rivers and their main tributaries these areas have considerable surface water resources for domestic use and irrigation. More extensive groundwater resources are present in the southern parts of the Dir and Swat Districts. Figure 31, which is based on Groen (1987) shows the alluvial areas that have, or may have, exploitable groundwater resources. They are all located between latitudes 34°12' and 35°00' N and longitudes 71°37' and 72°40' E. The following alluvial areas shown in Figure 31 will be dis-

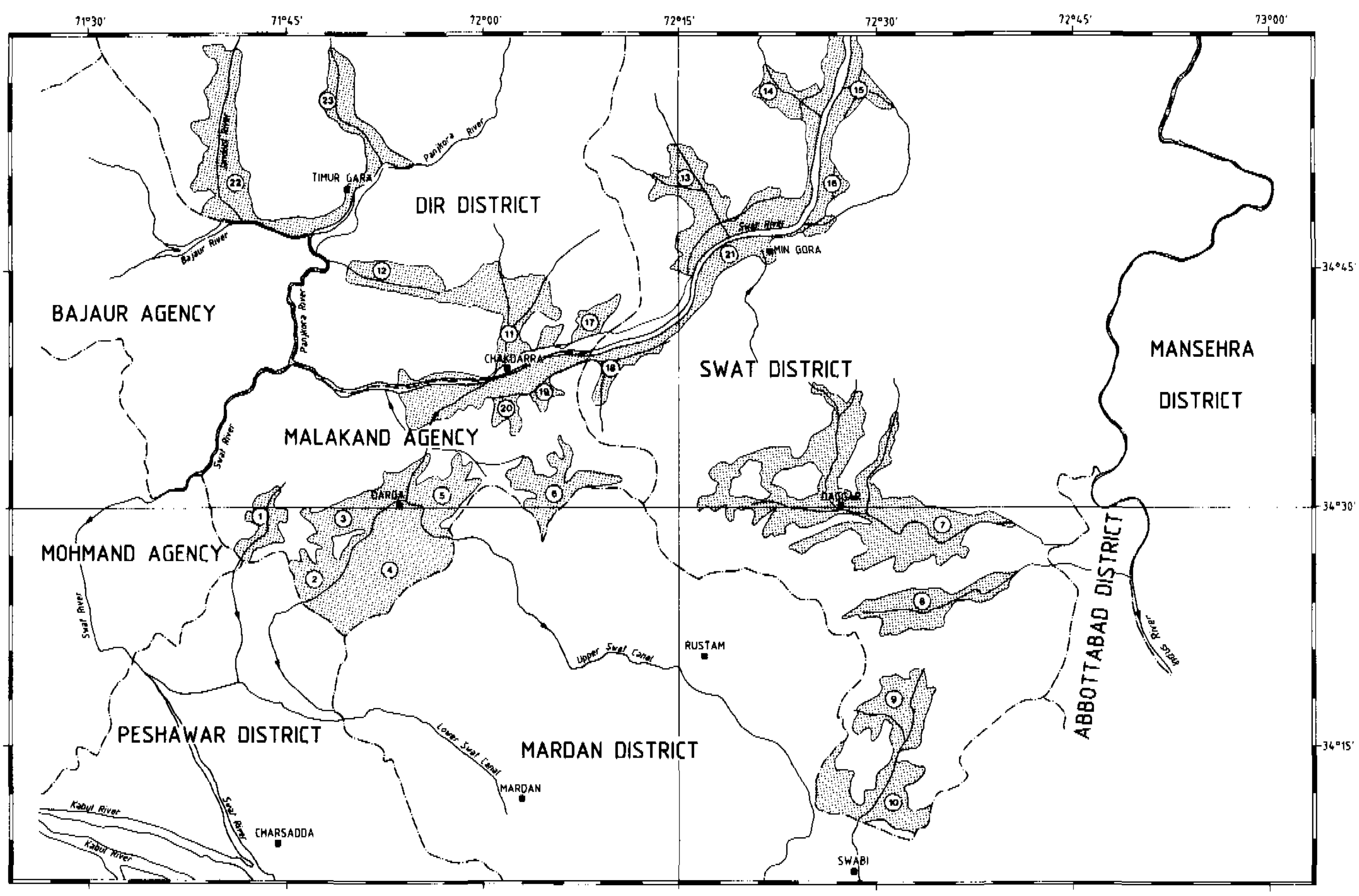


Figure 31: Alluvial areas in Dir District, Swat District and Malakand Agency

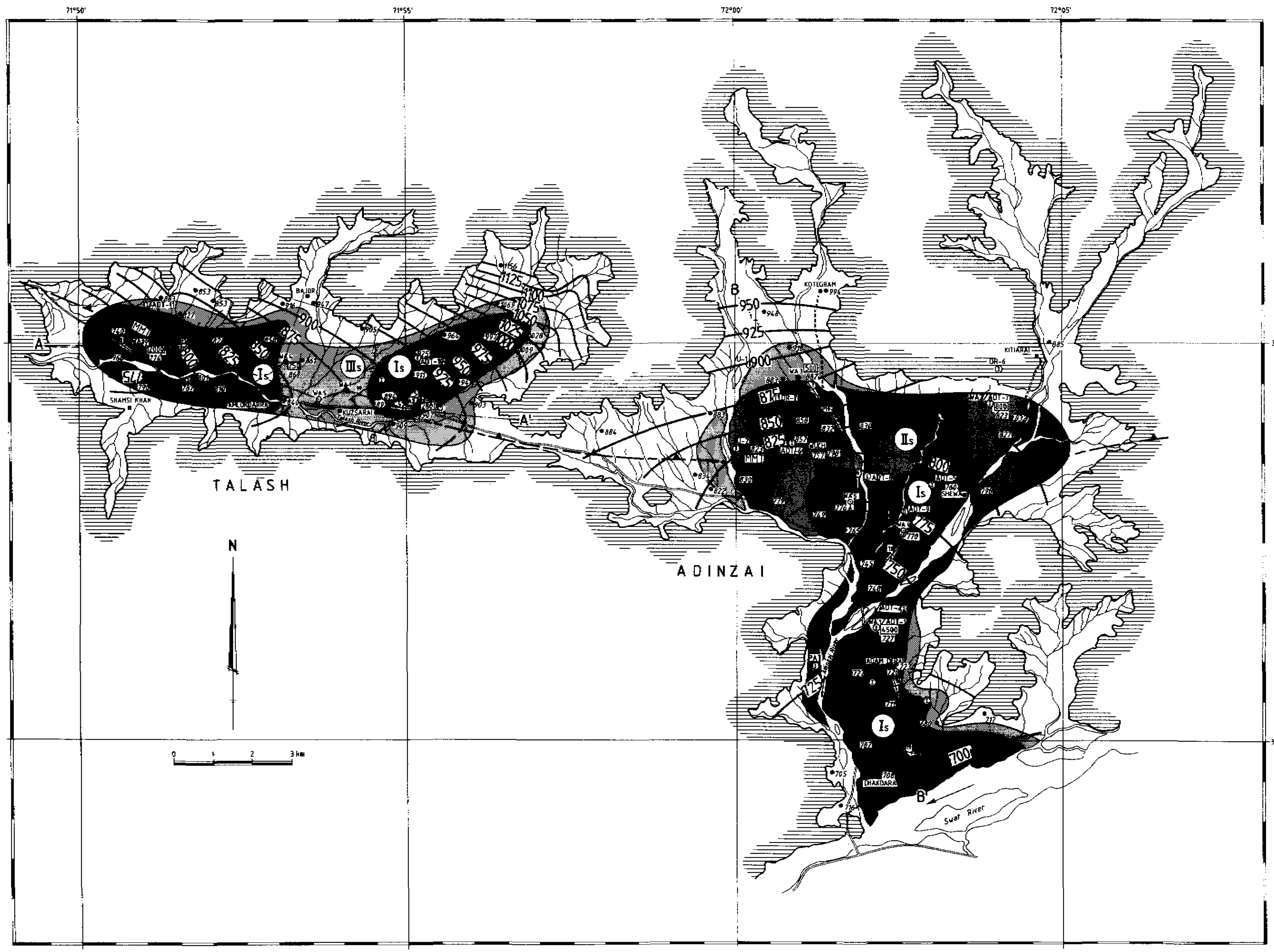


Figure 32: Groundwater map of the Talash and Adinzai valleys (For legend see fold-out at back of book)

cussed in this Chapter:
- the Adinzai valley (11) and the Talash valley (12) in Section 9.2,
- the Daggar valley (7), Chamla valley (8), Chingalai basin (9), and Totalai area (10) in the Buner area that forms the southwestern part of Swat District in Section 9.3,
- Nikpikhel area (13) in Section 9.4,
- Jandool area (22) in Section 9.5,

The remaining areas comprise:
- the areas numbered 14 - 20 that are small tributary valleys of the Swat river. Whether exploitable groundwater resources will be found depends on the size of the catchment areas and on the thickness and composition of the alluvial fill. The water quality is expected to be good. However, these valleys cannot be discussed in any detail because they have never been investigated or explored.
- The Swat valley (21) and the Panjkora valley, upstream of the Jandool river (23), have also never been investigated, because there is an abundance of perennial surface water to irrigate all the available irrigable land. Groundwater of good quality can undoubtedly be found in the stream deposits.
- The Kot (1), Heroshah (2), Harian Kot (3), Sakhd Kot (4), Wartair (5), and Palai (6) areas belong to the northern fringe of the Peshawar Vale and will be discussed in Section 11.2.

9.2 THE TALASH AND ADINZAI VALLEYS

Location

The Talash and Adinzai valleys are located in the southern part of Dir District between latitudes 34°37' and 34°47' N and between longitudes 71°50' and 72°08' E. They are the northernmost alluvial basins of any consequence in NWFP.

Physiography

The valleys consist of small plains (average altitude 840 m or 2755 ft above msl) surrounded by mountains. The Adinzai valley has a drainage basin of 297 km^2 of which 87 km^2 is covered by alluvium that at the southern end of the valley merges into the alluvial fill of the Swat valley. The Adinzai river is an ephemeral tributary of the Swat river.
The Talash valley extends over 125 km^2, of which 47 km^2 is covered by alluvium. The river of the same name drains the valley and is perennial where it leaves the valley and flows through a narrow gorge to the Panjkora river, another tributary of the Swat river. The two valleys are separated from each other by a narrow subsurface ridge of the basement rock (Figure 32).

Geology

The Talash and Adinzai valleys overlie the main mantle thrust fault (Section 2.2). North of the fault the basement consists of black amphibolites and south of it there are schists and calcareous (marble) rocks intruded by white granites. The impervious basement is overlain by alluvial deposits, made up of thick layers of silt and clay with intercalated lenses of sand and gravel, often with numerous boulders.

Climate

The climate of the area is of the sub-humid subtropical continental lowland type (Section 1.3). The mean annual rainfall in Chakdara is 710 mm. March is the month with the highest average (114 mm). The winter precipitation (December - March) with 46 per cent of the annual total is higher than the summer (June - September) rainfall, which is 36 per cent of the annual total. The mean monthly temperature ranges from less than 9°C in January to more than 30°C in June. Thornthwaite's method gives a value of about 1200 mm for the annual potential evapotranspiration.

Population and domestic water supply

The estimates of the population of the valleys are: Talash valley: 40,000 and Adinzai valley: 70,000. Most people live in small villages, of which Chakdara near the bridge over the Swat river is the most important. The domestic water supply is mainly based on groundwater extraction from shallow open wells (137 x 10^3 m^3/yr) and from tubewells drilled by Public Health Engineering Department (PHED) that produce 545 x 10^3 m^3/yr.

Agriculture

Most of the cultivated land is rainfed only. The Rabi crop is the most important and consists mainly of wheat and barley. Maize is grown as a barani Kharif crop. Irrigated crops include fruit trees, horticultural crops and, in summer, maize. Irrigation water is mainly supplied by shallow wells equipped with centrifugal pumps. Near the village of Wuch (Adinzai Valley) the irrigation water comes from springs.
It is estimated that in the Adinzai valley in 1980/1981 250,000 m^3 of irrigation water was produced from shallow wells and an unknown amount from springs; in the Talash valley 16,000 m^3 was obtained from shallow wells plus 63,000 m^3 from tubewells.
After WAPDA and TNO completed the groundwater investigations the Irrigation Department started a number of groundwater development projects. In October 1987 the tubewells for 17 schemes were drilled while two others were being prepared by the Irrigation Department and the Pak-Dutch project "Groundwater-based Irrigation Development Project in the Provincially Administered Tribal Areas", respectively. Their locations are shown on Figure 32. Of the 17 original schemes, five are in the Talash valley and 12 in the Adinzai valley. Each scheme covers an area of 60 - 100 ha (150 - 250 acres) and is or will be irrigated by a well which has a production capacity of 100 - 150 m^3/h (1.0 -1.5 cusec). The installed capacity after completion of all the schemes will be 4.5 Mm^3/yr (or 5 cusec) in the Talash valley and 13.5 Mm^3/yr (or 15 cusec) in the Adinzai valley. The full capacity will only be required during short periods of peak demand and the actual annual groundwater withdrawal will be between one-third and one-half of the full annual capacity, i.e. 1.5 - 2.7 Mm^3/yr (or 1.7 - 3.0 cusec) in the Talash and 4.5 - 6.7 Mm^3/yr (or 5.0 - 7.5 cusec) in the Adinzai valley.
According to Darr and Ahmad (1981), the soils of the Adinzai valley are mostly classified as "land with a high and very high potential under irrigation". Only a small part of the Talash valley has this classification, most of the area is classified as "land mainly with a moderate potential under dry farming".

Groundwater investigations

The first comprehensive study of the groundwater conditions in the Talash and Adinzai valleys was made between 1980 and 1982 under the Pak - Dutch Programme and resulted in a technical report edited by Jousma (1983) and published by WAPDA and TNO. The only data reported prior to 1979 are from the Talash valley, where two wells had been drilled by the Irrigation Department and two by the PHED. The WAPDA/TNO study included the drilling of ten test holes, seven of which (four in the Talash and three in the Adinzai valley) were drilled by percussion rig to a maximum depth of 70 m and three (one in the Talash valley and two in the Adinzai Valley) by straight-rotary method to depths between 118 and 165 m; the seven percussion-drilled test holes were converted into test wells and pump-tested.

Groundwater conditions

Groundwater occurs in exploitable quantities only in the alluvial fill, because the basement consists of impervious rock. This fill is very heterogeneous and consequently the relation between the electrical resistivity values and the hydraulic conductivity is weak. Moderate resistivity values in the range of 70 to 150 ohm-m indicate the areas with the best hydraulic characteristics. High values indicate areas with a low permeability caused by the presence of large boulders in the subsoil or by cementation of the alluvial deposits.
The thickness of the alluvial fill increases towards the centres of the valleys where it reaches approximately 100 m. The maximum saturated thickness of the fill is about 75 m (Figures 33 and 34).
The transmissivity values calculated from pumping tests vary from 150 to 4500 m^2/d. Notwithstanding local high values, the mean value in the Talash valley and in the northern part of the Adinzai valley is in the order of 600 m^2/d. In the narrow passage where the southern part of the Adinzai Valley enters the Swat Valley it is much higher, i.e. 4500 m^2/d.
The average specific yield of the coarse material is estimated as 0.15.
The volume of water stored in the coarse alluvial material is calculated as 210 Mm^3 for the Talash valley and 320 Mm^3 for the Adinzai valley.
The groundwater in both valleys occurs mainly under phreatic conditions at depths of more than 20 m below the land surface. The area in the immediate vicinity of the Talash river and the downstream part of the Adinzai valley close to the Swat river show the water table at less than 10 m depth. Near the village of Wuch the transmissivity of the aquifer declines, probably rather abruptly. This causes confined conditions that result in a large amount of spring flow.
The chemical quality of the groundwater is good. The EC value in the groundwater samples from shallow dug wells varies from 0.270 to 0.550 mS/cm and in those from tubewells from 0.310 to 0.400 mS/cm. SAR values are below 1.0 indicating that the water is suitable for irrigation and drinking water supply. The water has not been bacteriologically analysed.

Water level fluctuations

The relatively few data available do not show a long-term trend in groundwater level variation; so it may be assumed that the aquifer is in steady state.

Groundwater flow

The watertable contour lines are shown on Figure 32. For the

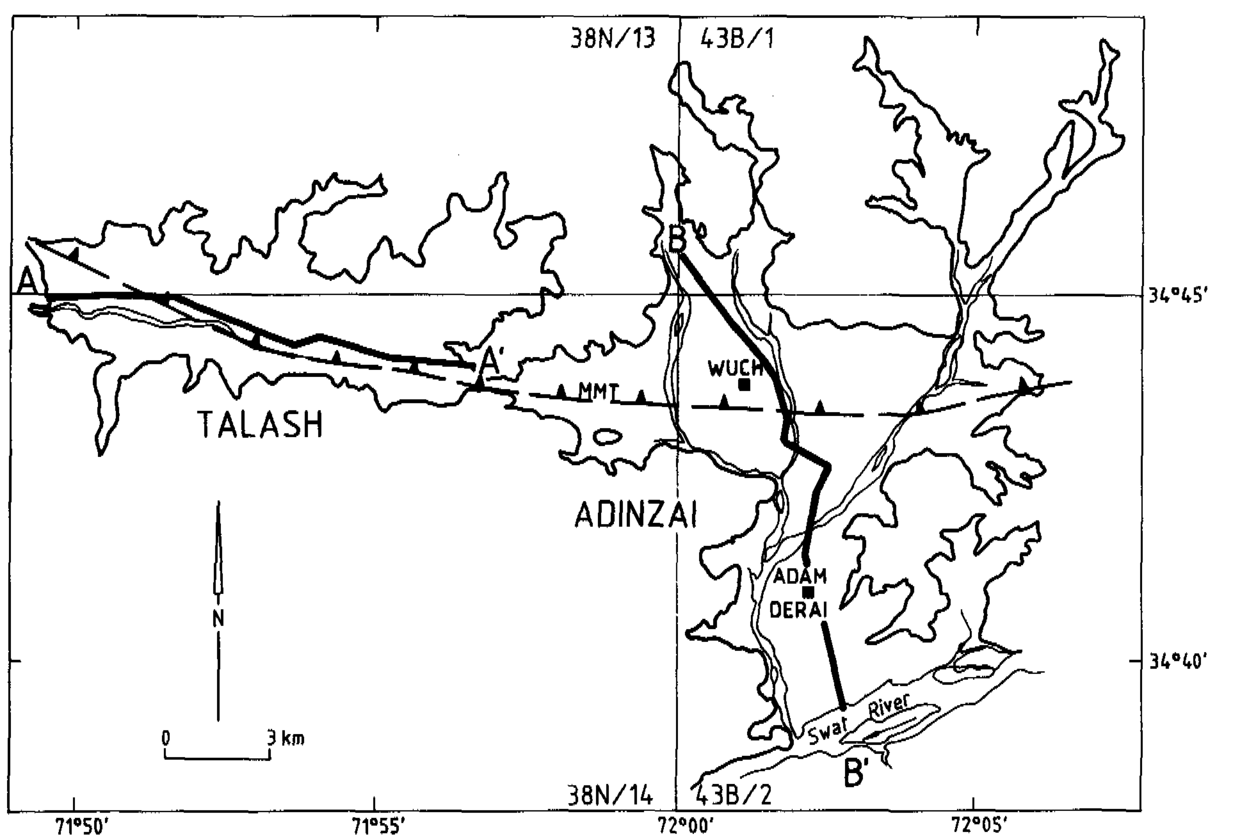


Figure 33: Location map of the cross-sections of Figure 34

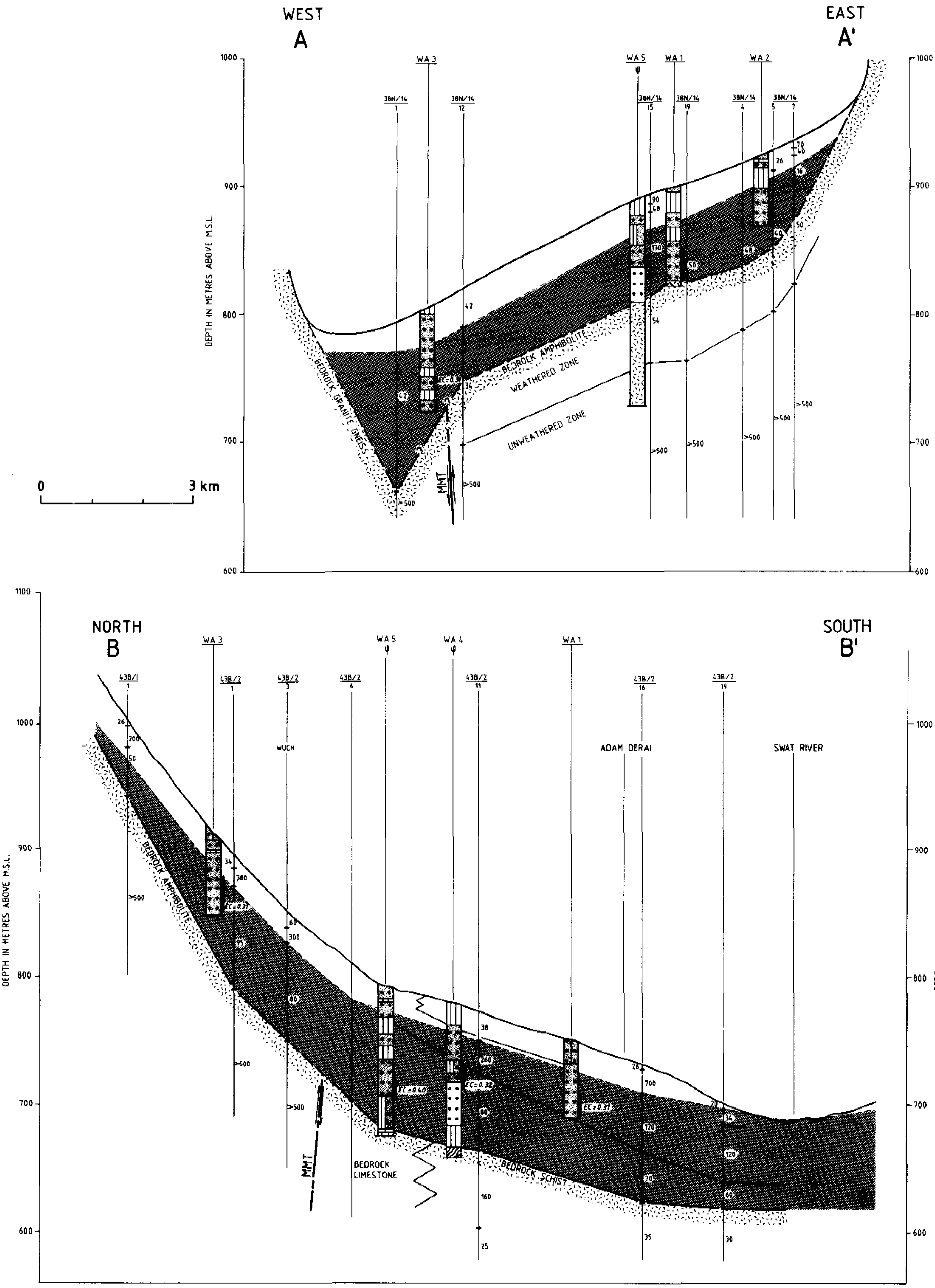


Figure 34: Hydrogeological cross-sections over the Talash and Adinzai valleys (For legend see fold-out at back of book)

Talash valley they indicate flow southwestwards from the mountains to the river, with the gradient decreasing from 0.060 near the mountains to 0.020 close to the river. The groundwater flow in the Adinzai valley is directed from north to south, that is from the mountains to the Swat river valley. The gradients that are between 0.050 and 0.075 in the north decrease to 0.008 in the direction of the Swat river, as a consequence of the increase of the transmissivity values.

Recharge and discharge

The Talash river leaves its valley over a sill of basement rock and there is thus no subsurface groundwater outflow. The main groundwater discharge component corresponds to the average annual base flow of the Talash river; it amounts to approximately 9.0 Mm^3. To this amount should be added 0.5 Mm^3 direct evapotranspiration and 0.5 Mm^3 groundwater withdrawal by dug and drilled wells, not counting the wells drilled since 1983. This adds up to a total groundwater discharge of 10 Mm^3/yr (or 11.2 cusec).

In contrast, the groundwater body of the Adinzai valley discharges mainly by subsurface flow into the groundwater body of the alluvial deposits of the Swat valley. The discharged amount, calculated with Darcy's law using the hydraulic gradient and the transmissivity value, comes to 21.7 Mm^3/yr. Spring flow and groundwater extraction from wells amount to 1.8 and 0.5 Mm^3/yr, respectively; making a total of 24.0 Mm^3/yr (or 26.9 cusec).

As the aquifers are apparently in steady state, the average annual recharge in each of the valleys equals the average annual discharge. The recharge occurs mainly as infiltration at the foot of the mountains, where the surficial deposits are coarse. In the central parts of the valleys the upper layers are much richer in clay and therefore the groundwater recharge conditions are less favourable.

Groundwater development potential

Over large parts of the valleys the aquifer characteristics are favourable for the installation of high-yielding tubewells. The distribution of the groundwater development potential is shown on Figure 32.

Jousma (1983) equates the groundwater development potential to the undeveloped part of the annual discharge, which is 9.5 Mm^3 in the Talash valley and 22.0 Mm^3 in the Adinzai valley. It is recommended to restrict the first phase of the groundwater development to 50 per cent of these volumes, that is 4.7 Mm^3/yr (5.3 cusec) in Talash valley and 11.0 Mm^3/yr (12.3 cusec) in Adinzai valley. These quantities are sufficient to irrigate gross areas of approximately 900 and 2000 ha (2250 and 5000 acres), respectively. The groundwater development projects implemented and planned in the period 1983/1987 (see paragraph Agriculture) will probably realize 2 Mm^3/yr and 5.5 Mm^3/yr (or 2.2 and 6.1 cusec) of the above-mentioned potential in the Talash valley and the Adinzai valley, respectively.

Numerical groundwater flow simulation predicts that if 4.7 Mm^3 is pumped in the Talash valley the result will be a regional drawdown of 5 m. In the Adinzai valley, pumping 11 Mm^3/yr will result in a permanent regional drawdown of 9 to 14 m. The maximum stable drawdown will be reached ten years after the pumping regime is established.

The ultimate drawdown will depend on the tubewell pattern and the pumping schedule. If, for example, the well field is constructed in the lower part of the Adinzai valley where the best aquifer characteristics are found, the maximum regional drawdown will be 9 m only. But a well field in that part of the area has the disadvantage that the groundwater resource is developed in an area with soils unsuitable for irrigation. Consequently, the water will have to be pumped up to the higher areas to where good soils occur.

Groundwater management

It is of great importance that the development of the groundwater resources goes hand in hand with further collection and evaluation of data. The regional development of the drawdown as a result of the actual groundwater extraction and groundwater recharge can then be compared with the predicted development. It is therefore essential to monitor the groundwater levels, and to collect groundwater discharge data, such as pumping and stream flow, as well as data on groundwater quality. After five years all the data should be evaluated and the water balance be recalculated.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Darr, M.A. and M. Ahmad, 1981. Reconnassance soil survey Swat catchment 1976. Soil Survey of Pakistan, Lahore; 205 pp., 5 app., 12 tbls, 4 figs and 3 pl. *Annotation.* Description of the soils and their genesis, present use and capability.

Jousma, G. 1982. A note on groundwater availability in Adinzai and Talash Valleys, Dir District, NWFP. WAPDA Hydrogeology Directorate Peshawar and TNO Institute of Applied Geoscience, Delft, The Netherlands; 5 pp., 1 tbl, 2 figs. *Annotation.* Preliminary results of the study fully reported by Jousma (1983).

Jousma, G. 1983. Groundwater resources in Talash and Adinzai Valleys, Dir District, NWFP, Technical Report No II-2. WAPDA Hydrogeology Directorate Peshawar and TNO Institute of Applied Geoscience, Delft, The Netherlands; 45 pp., 6 app., 15 tbls, 7 figs and 8 pl. *Annotation.* The report contains the results of studies carried out by WAPDA-HDP and TNO during the period 1980/1982. The fieldwork included an inventory of 1256 open wells (mainly located in the villages) and of some tubewells and springs; a resistivity survey of 23 vertical electrical soundings in the Talash valley and 25 soundings in the Adinzai valley; the drilling of 10 testholes (five in the Talash valley and five in the Adinzai valley), three of which were geophysically logged; the conversion of seven test holes (four in the Talash valley and three in the Adinzai valley) into test wells on which pumping tests were done; water sampling for chemical analysis, stream flow gauging, and the moni toring of groundwater levels in 20 wells during 18 months. The report contains a groundwater budget analysis and an estimate of the groundwater development potential.

Groen, J., 1987. An inventory of waterresources for irrigation schemes in the Malakand Division. Unpublished research report of project "Groundwater-based Irrigation Development in PATA"; 13 pp. *Annotation.* Brief review of the areas in PATA with a groundwater piotential and a plan of operations for hydrogeological investigations and drilling.

9.3 THE BUNER AREA

Location

The Buner area of some 1760 km^2 forms the southeastern part of Swat District. It is a mountainous area, located between latitudes 34°08' and 34°41' N and longitudes 72°14' and 72°40' E. It is drained by three perennial rivers: the eastward flowing Barandu and Chamla rivers and the southward flowing Badri Khwar. The river valleys comprise intermontane depressions that are partly filled with alluvial deposits (Figure 35).

From north to south the depressions are:

- The Barandu river valley upstream of Budal, which is known as the Daggar valley. The valley floor covers an area of 234 km^2 and the catchment covers 846 km^2;
- The Chamla river valley upstream of Malasar, which has a catchment area of 275 km^2 and an alluvial valley floor of 52 km^2.
- The nearly closed Chingalai basin in the upper part of the catchment of the Badri Khwar. It does not contain any groundwater resources worth mentioning because its alluvial cover is only a few metres thick.
- The lower part of the valley of the Badri Khwar that is known as the Totali valley. The valley floor covers an area of 78 km^2 and the catchment has an area of 220 km^2.

Physiography

The catchment areas consist of deeply dissected mountain terrain that is the northeastern end of the ridges along the northern boundary of the Peshawar Vale. The elevation ranges from more than 2800 m (nearly 10,000 ft) to 365 m (1200 ft) above msl; the highest point is the Ilam mountain, which reaches an altitude of 2810 m (9217 ft).

The eastward flowing Barandu and Chamla rivers are formed by headward erosion from the Indus valley along the main tectonic structures. The Chamla river flows into the Barandu

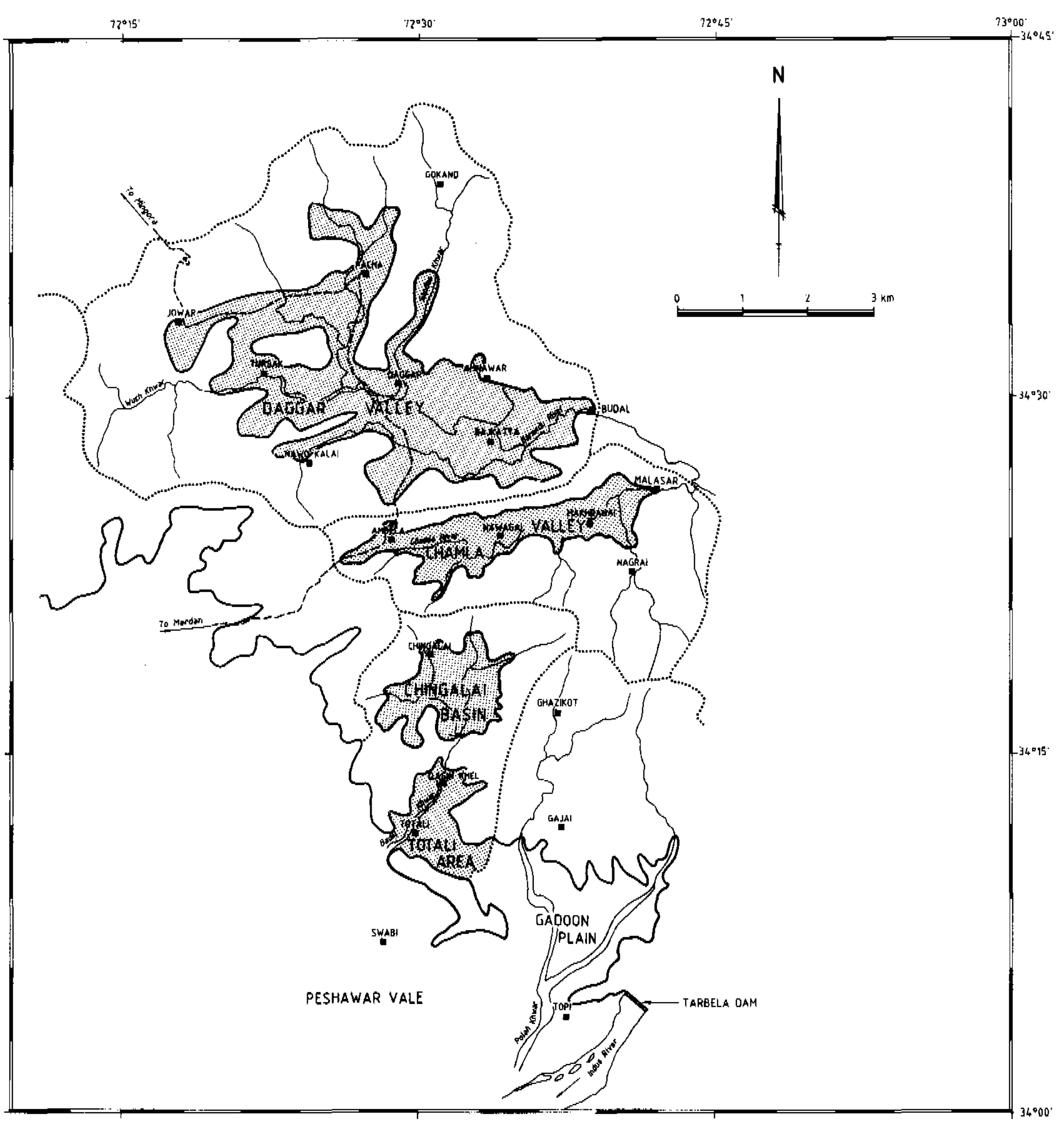


Figure 35: Location map of the Buner and Gadoon Amazai areas

river before it discharges into the Indus upstream of the Tarbela Dam. The Badri Khwar flows to the south and after leaving the mountains just downstream of the Totali Valley it crosses the northeastern corner of the Peshawar Vale to discharge into the Indus river.

Geology
The Buner area lies just south of the Main Mantle Thrust, one of the major fault zones related to the uplift of the Himalayas. Martin et al. (1962) gave a general description of the geology of the area (see also Rafiq et al., 1984). They distinguish the following units:
- the lower Swat-Buner Schistose Group,
- the Swat granitic gneisses,
- the Swabi-Chamla Sedimentary Group,
- the Ambela granite.

The lower Swat-Buner Schistose Group occupies most of lower Swat, Buner and the northeastern part of Mardan District. It consists of formations that give rise to marked variations in topography, with high steep hills in which fold structures are clearly evident. Generally, the rocks are weathered quartz-muscovite schists, often rich in garnet and tourmaline. They are associated with marbles and quartz biotite schists. The Swat granitic gneisses occur in the top of the siliceous schists.
The Swabi-Chamla Sedimentary Group is made up of quartzites overlying shales and frequently forming the tops of scarp faces and dip slopes. They occur in the Totali area.
The Ambela granite covers a large part of central Buner and is composed of massive porphyritic granite with pegmatites, which contain large zircon crystals. The granites are intrusive between the Schistose Group and the Sedimentary Group and they outcrop in rounded weathered boulder forms throughout the southern and western parts of the Chamla catchment area.
The valleys formed in these formations are filled with recent valley fill that consists of:
- loam soils derived from loess
- piedmont soils of colluvial origin
- riverine alluvium

Climate
Despite its mountainous character the Buner area is considered to belong to the region with a climate of the sub-humid subtropical continental lowland type (Section 1.3). The average annual rainfall ranges from 908 mm in Daggar at an altitude of 720 m (2360 ft) to about 825 mm in Totali at an altitude of 396 m (1299 ft). Totali does not have a meteorological station, but it is assumed that it receives the same amount of rainfall as at the station of Hamza Kot that lies at the same elevation but 30 km to the west. The annual precipitation in the upper parts of the catchment (rain in summer and snow in winter) may exceed 1200 mm. In contrast to the Swat valley (Chakdarra station) the summer rains in Buner are more plentiful than those of the winter and spring.
Temperatures in Daggar are moderately high in summer (average daily maximum: 37.1 °C) and cold (average daily minimum: 0.5 °C) in winter.
The potential evaporation in Daggar is 885.6 mm, and is calculated by applying a pan coefficient of 0.7 to the average annual pan evaporation of 1265 mm.

Groundwater investigations
Groundwater investigations in Buner area were instigated in 1975 by the Pakistan Narcotics Control Board (PNCB) as part of its project to promote new agricultural practices to replace poppy cultivation; a project carried out in cooperation with the United Nations Fund for Drug Abuse Control (UNFDAC) and the Food and Agriculture Organization of the United Nations (FAO). As part of a groundwater investigations programme instigated by Astier (1975), Abdul Wahab Nagi (Nagi, 1975) prepared a hydrogeological reconnaissance report of the whole Buner area, while the Compagnie Général de Géophysique (CGG, 1977) did electrical resistivity and seismic surveys in the Chamla and Chingalai valleys, and in the Totali area. In 1979 PNCB drilled one tubewell in the Daggar valley, five in the Chamla valley and one in Totali. In 1980 Pike summarized the results of the work done so far and estimated the irrigation water potential. In the following years more boreholes were drilled by PHED and by the Buner Agricultural Development Project, which is the second phase of the PNCB project. In 1984/1985 a comprehensive groundwater study of the Daggar valley was made by WAPDA as part of the Pak-Dutch programme (Bloemendaal et al., 1985).

9.3.1 The Daggar Valley

Population and domestic water supply
An estimated 100,000 people live in the Daggar valley; most of them in small villages such as Pir Baba, Jowar, Tursak, Daggar, etc. Village water supply is mainly based on shallow (less than 20 m deep) open wells. Springs found along the mountains near the villages of Anghapur, Pir Abai, Thakhta Banda and Diwana Baba provide water for domestic use and for irrigation. The villages of Daggar and Gatkala receive spring water through a pipeline constructed by the PHED, which also drilled five tubewells. One well is located near Daggar, the others are in the western part of the valley (west of the line Gatkala - Tursak) where the water table is more than 25 m deep and drinking water is scarce.

Agriculture
The relatively abundant rainfall allows double cropping, even on unirrigated (barani) land. The major crops are wheat, barley and maize. Poppy cultivation was abolished in 1984 and has been replaced by irrigated crops like tobacco, vegetables, fruit trees and, to a lesser extent, sugar cane. Groundwater is used for irrigation in areas where the water table is shallow and dug wells with an electric centrifugal pump or with a Persian wheel can be constructed, or where abundant spring water is available. In the area southeast of Daggar, water from the Barandu river is pumped up to higher ground for irrigation (uplift schemes).
Based on the results of the WAPDA/TNO investigations (Bloemendaal et al. 1985) groundwater-based irrigation development has started as part of the "PATA project". At least five tubewell schemes are planned or under construction in the western part of the valley and a number of dug well schemes are planned in areas not suitable for tubewell development.
According to Khan and Ali (1975) soil development poten-

Figure 36: Hydrogeological cross-sections over the Daggar valley (For legend see fold-out at back of book)

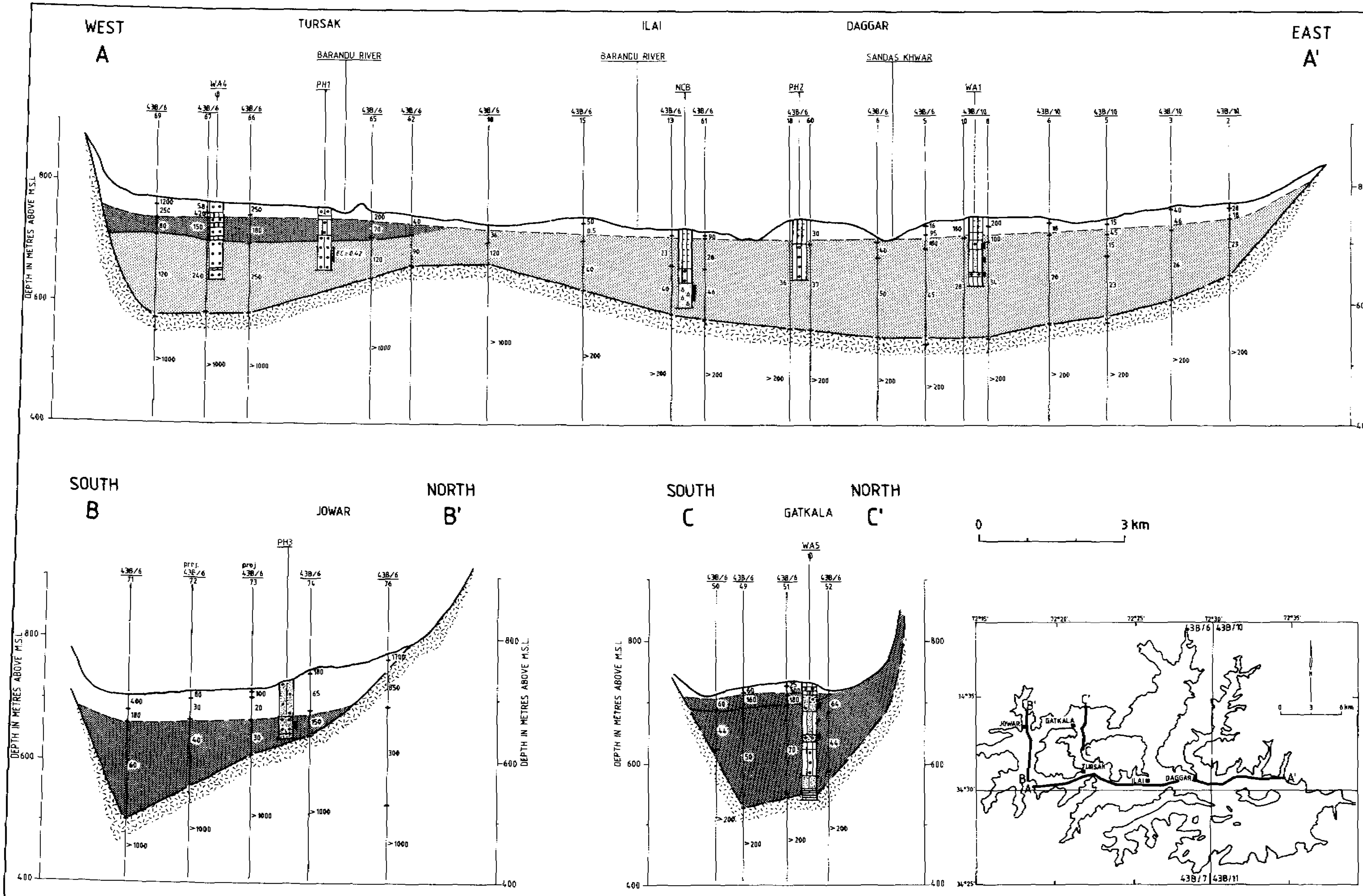


Figure 37: Groundwater map of the Daggar valley

tial is moderate; most soils on the alluvial deposits are characterized as: "land with a moderate economic potential under dry farming". In any case, the soils in the eastern part are are less dissected and therefore more suitable for irrigation development than the soils in the western part.

Groundwater conditions

The Daggar valley is actually a collection of small valleys eroded by the Barandu river and its tributaries in an intermontane depression upstream of Budal. The small valleys are separated from each other by outcrops of the bedrock and filled with alluvial deposits. The bedrock consists of Swat granitic gneisses in the northern catchment area, rocks, mainly limestone (marble) of the Lower Swat-Buner Schistose Group in the central and southwestern part, and Ambela granite in the southern catchment.

In the area between Pir Abai and Anghapur springs occur that are possibly related to fractured zones in the limestone. According to Bloemendaal et al., (1985) they have a total yield of 8.5 Mm^3/yr (9.5 cusec).

The alluvial fill consists of layers of silt and clay with intercalated layers of sand and gravel, often with a considerable clay content. Boulders are found among the coarse material as well as in the clay layers. Several erosion cycles have caused the dissection of the alluvial deposits and the formation of terraces at different levels along the valleys.

The thickness of the alluvial deposits along the axes of the valleys is about 150 - 200 m in the western part and about 100 m in the eastern sector (Figure 36).

Transmissivity data obtained from pumping tests range from 15 to 450 m^2/d. From the spacing of the groundwater level elevation contours (Figure 37) it can be deduced that the transmissivity in the western part is much higher than in the eastern part.

The groundwater occurs mainly under phreatic conditions, but locally confined conditions have been encountered and free-flowing boreholes have been drilled. The estimated specific yield of the saturated coarse deposits is 10 per cent. Bloemendaal et al. (1985) estimated that the coarse deposits make up 59 per cent of the total saturated volume and they calculated the volume of groundwater stored in the coarse deposits of the Daggar valley as 948 Mm^3.

The depth to the water table varies over short distances, as a result of the irregular land surface. Near the perennial rivers the water table is seldom deeper than 10 m below the surface. On the terraces it may be 10 - 25 m deep. In the area south of Jowar and west of Tursak the gullies are dry and the water table is more than 25 m below the surface. The seasonal fluctuations in the areas with a shallow water table are generally less than 2 m, but where the groundwater level is deep the watertable fluctuations are considerable and values as high as 17 m were recorded between January and June 1984. The pattern of the fluctuations is the same as that of the base flow of the Barandu river.

The groundwater is of the calcium magnesium bicarbonate type and the quality is good; EC values range mainly from 0.3 to 0.5 mS/cm with SAR values less than 2. This water is suitable for domestic supply and irrigation. Groundwater samples with an EC value of 0.6 mS/cm or more have a relatively high content of potassium and of sulphate or chloride, which may indicate influence of the metamorphic bedrock. The highest salinity level (EC : 4.6 mS/cm) was found near the village of Lar Maira.

Groundwater flow

Figure 37 shows the groundwater level elevation contours, from which the groundwater flow can be deduced. The general groundwater flow is along the axis of the valleys. In the southwestern part the groundwater levels are deep below the river beds and the contours have wide curves. In the areas where the rivers drain the groundwater, the contours are strongly curved and the flow is towards the river. The Daggar valley ends in a narrow gorge through the impervious bedrock, so the base flow at the exit of the valley, which is approximately 95 Mm^3/yr (or 106 cusec), corresponds to the natural groundwater outflow of the valley.

Discharge and recharge

Bloemendaal et al. (1985) calculated the groundwater discharge as 103 Mm^3/yr (115 cusec); 3 Mm^3/yr as extraction by wells and 100 Mm^3/yr as exfiltration of which 5 Mm^3/yr evaporates and 95 Mm^3/yr disappears as river base flow. The base flow that originates in the west of the valley where conditions are suitable for drilling high-yielding tubewells, is 22 Mm^3/yr (24.6 cusec).

The recharge cannot be established independently but as the aquifer system may be considered to be in steady state, the recharge can be equated to the discharge i.e. 103 Mm^3/yr. This amount corresponds to 6 per cent of the annual precipitation over the catchment and the valley. The rest evapotranspires or disappears as runoff.

Groundwater development potential

From the point of view of the transmissivity of the aquifer the western part of the Daggar valley has the best conditions for groundwater deve lopment. However, the situation is not ideal, because the water table is relatively deep (more than 25 m) and the specific capacity will be less than 18 m^3/h per metre drawdown (24 gpm per ft dd.). Moreover, not all the soils in this area are suitable for irrigation.

In 1986 the project "Groundwater-based Irrigation Development in the Provincial Administered Tribal Areas" (PATA project) instigated groundwater development activities by drilling a tubewell in Gatkala to provide water for a 40 ha (100 acres) irrigation scheme, and by encouraging cooperative dug well schemes in the areas where the conditions are not suitable for tubewell drilling because of a low transmissivity.

Groundwater management

Given the adverse conditions for large-scale groundwater development it is unlikely that the groundwater resources will be overexploited in the near future. Nevertheless, the development should be monitored by making an inventory of the groundwater production and its effect on the groundwater regime at regular time intervals, say every five years.

Annotated bibliography

At end of Section 9.3.4

9.3.2 The Chamla valley

Population and domestic water supply
Population figures are not available for the Chamla valley. Water supply is mainly from shallow wells and springs. The PHED has constructed tubewells in Koga and Nawagai with a production of 220,000 m^3/yr.

Agriculture
The agricultural pattern is the same as in the Daggar valley. In addition to a few surface water schemes the Buner Agricultural Development Project has constructed six tubewells for irrigation, serving a total command area of 325 ha (805 acres) and designed to produce 1.58 Mm^3 water per year.

Groundwater conditions
The western part of the Chamla valley is surrounded and underlain by the Ambela granite and granitic gneiss, whereas phyllitic shales outcrop at the eastern end of the valley. Silt and clay cover the entire area, giving rise to badland topography.
In the catchment area groundwater only occurs in fractured zones, which may produce small springs.
The CGG survey showed a V-shaped bedrock topography filled with silt and clay with a maximum thickness of 90 m. The original silt and clay deposits were subsequently subjected to periods of erosion alternating with periods of sedimentation. The younger sediments comprise coarse material that is presently found as a lens of 12 x 1 km and 10 - 20 m thick below a clayey top layer. The 1000 ohm-m^2 contour of the transverse resistance map (CGG, 1977) delimits the horizontal extent of the coarse deposits (Figures 38 and 39) that form the aquifer.
Recent hydrogeological inventory data are not available; the following description is therefore based on the reports by Nagi (1975) and Pike (1980).
In 1975, the depth to the water table was measured in 11 open wells, and ranged from 3 to 22 m.
Pike used Logan's method (Logan, 1964) to estimate transmissivity values from the well test data on five tubewells drilled in 1979; these values range from 700 to 1530 m^2/d with an average of 1200 m^2/d. He found the aquifer thickness varying from 10 to 27 m with an average of 17 m. Specific yield was not determined but may be estimated as 10 per cent and in that case the stored groundwater volume will be 20 Mm^3.
The groundwater quality is good; EC values range from 0.2 to 0.7 mS/cm. The water is of the calcium magnesium bicarbonate type.

Groundwater flow
From the watertable contour map (Figure 38) based on Nagi's data it follows that the groundwater flow is directed towards and along the axis of the valley. The subsurface flow rate can be estimated by substituting the following parameter values in Darcy's law: transmissivity: 1200 m^2/d, hydraulic gradient 6/1000, width of the section through which parallel flow takes place: 1000 m. The resulting flow rate is 7000 m^3/d or 2.6 Mm^3/yr.

Discharge and recharge
The aquifer is recharged in the upstream part. In the downstream sector the transmissivity decreases and the bedrock nearly closes the basin, causing the groundwater to exfiltrate into the river and to leave the basin as a base flow of 290 m^3/h. No hydrological data are available to verify this calculation. Nor are data available on the present amount of groundwater withdrawal by pumps and Persian wheels for irrigation, cattle watering and domestic use.

Groundwater development potential
The groundwater development potential is low. The estimated annual flow rate will be sufficient to provide irrigation water for 520 ha (1300 acres). This amount can be developed by the existing tubewell capacity.

Groundwater management
Given the limited groundwater resources it is important to monitor the groundwater production and its effect on the groundwater levels and the surface water flow. Subsequently, a groundwater flow simulation model should be made, to predict the further effects on the groundwater regime and to test the effects of changes in the groundwater exploitation.

Annotated bibliography
At the end of Section 9.3.4 (ex-21.5).

9.3.3 The Chingalai Basin

Population and domestic water supply
Population data are not available. Water supply is based on shallow dug wells.

Agriculture
CGG (1975) reports that most cultivated land is in the southern part of the basin where the alluvial deposits are more or less continuous. In the north of the area, cultivation is restricted to small terraces among hundreds of outcrops of the basement.
Khan and Ali (1975) characterize the development potential of the soils as: "land with a low economic potential under dry farming".

Groundwater conditions
The survey by CGG (1977) showed that the alluvial deposits are nowhere more than 10 m thick, and that they consist of clay and silt underlain by a sandy layer. They cover weathered granite of varying thickness, which forms the main water-bearing layer. The transmissivity values are expected to be low and the continuity of the weathered granite is probably poor. The water table is at shallow depth.
The water quality is good, as in the Chamla valley.

Groundwater flow
Groundwater may be expected to flow from north to south, towards the outflow of the Badri Khwar. Infiltration takes place along the mountain front. The groundwater is drained by the river close to the narrow outlet of the basin.

Discharge and recharge
No data are available for a quantitative estimate of the groundwater recharge and discharge.

Groundwater development potential
The groundwater development potential is very poor. Prolonged periods of drought may cause depletion of the very thin aquifer.

Annotated bibliography
At end of Section 9.3.4 (ex-21.5).

9.3.4 The Totali Area

Physiography
After leaving the Chingalai basin the Badri Khwar flows southward through a narrow valley. Beyond Iahandirgarra the valley opens up and widens toward the Peshawar Vale. The area downstream of Ghurghusto is called the Totali valley. A southwest-northeast ridge of outcrops divides this area into two sub-basins. The western one, the Totali valley, is elongated along the Badri Khwar itself, whereas the eastern one is round and related to a tributary of the Badri Khwar; the sub-basins communicate through a narrow passage located east of Totali village (Figure 40).
The bedrock consists of metamorphic rocks, mainly quartzites, with a V-shaped subsurface topography along the Badri Khwar and a bowl-shaped topography in the eastern sub-basin. It is covered by clayey deposits of lacustrine or allu-

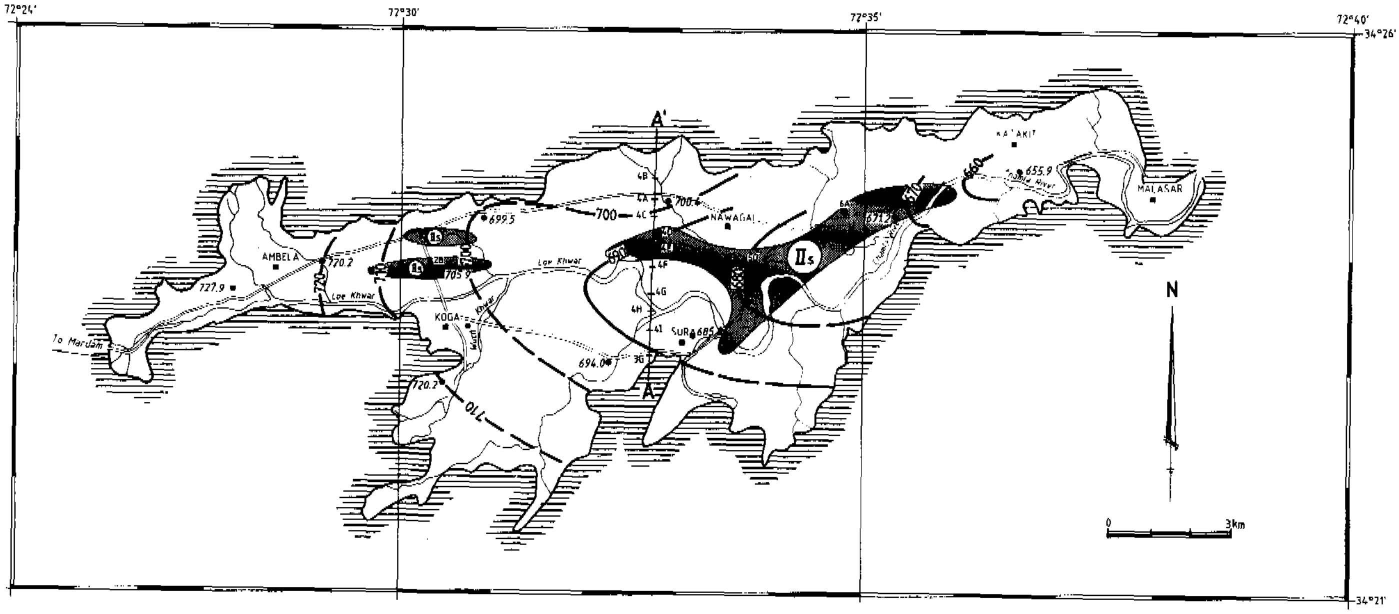


Figure 38: Groundwater map of the Chamla valley (For legend see fold-out at back of book)

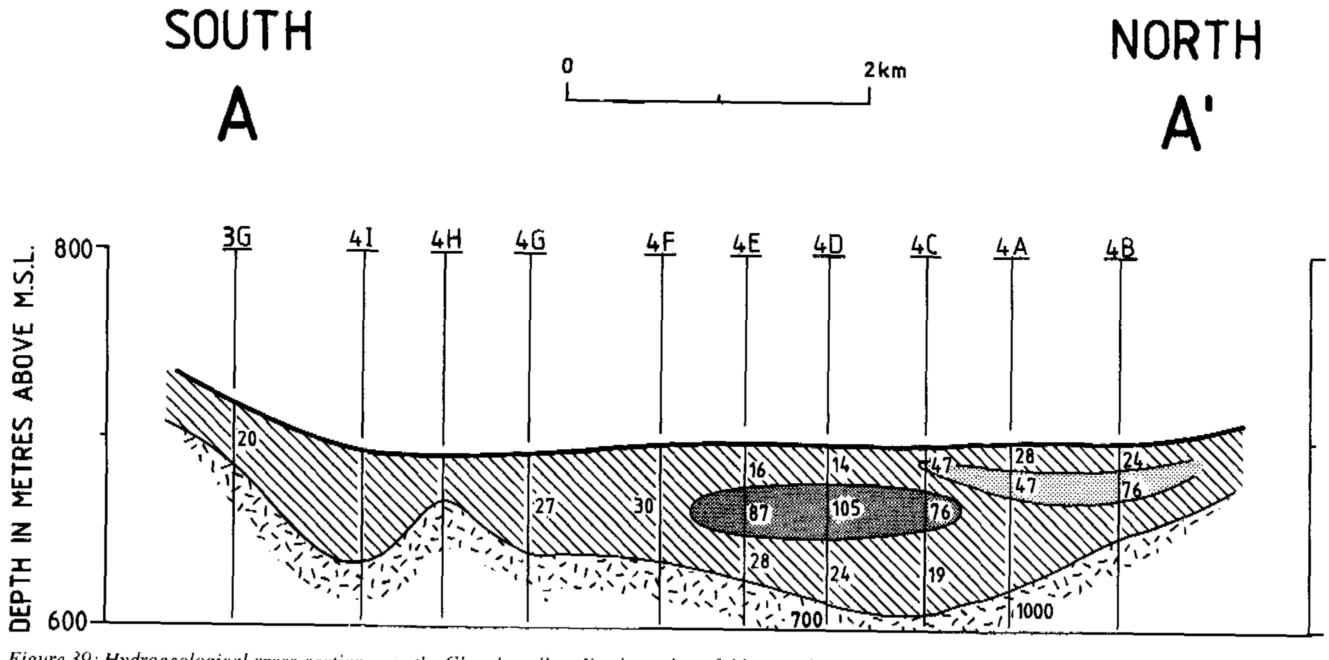


Figure 39: Hydrogeological cross-section over the Chamla valley (For legend see fold-out at back of book)

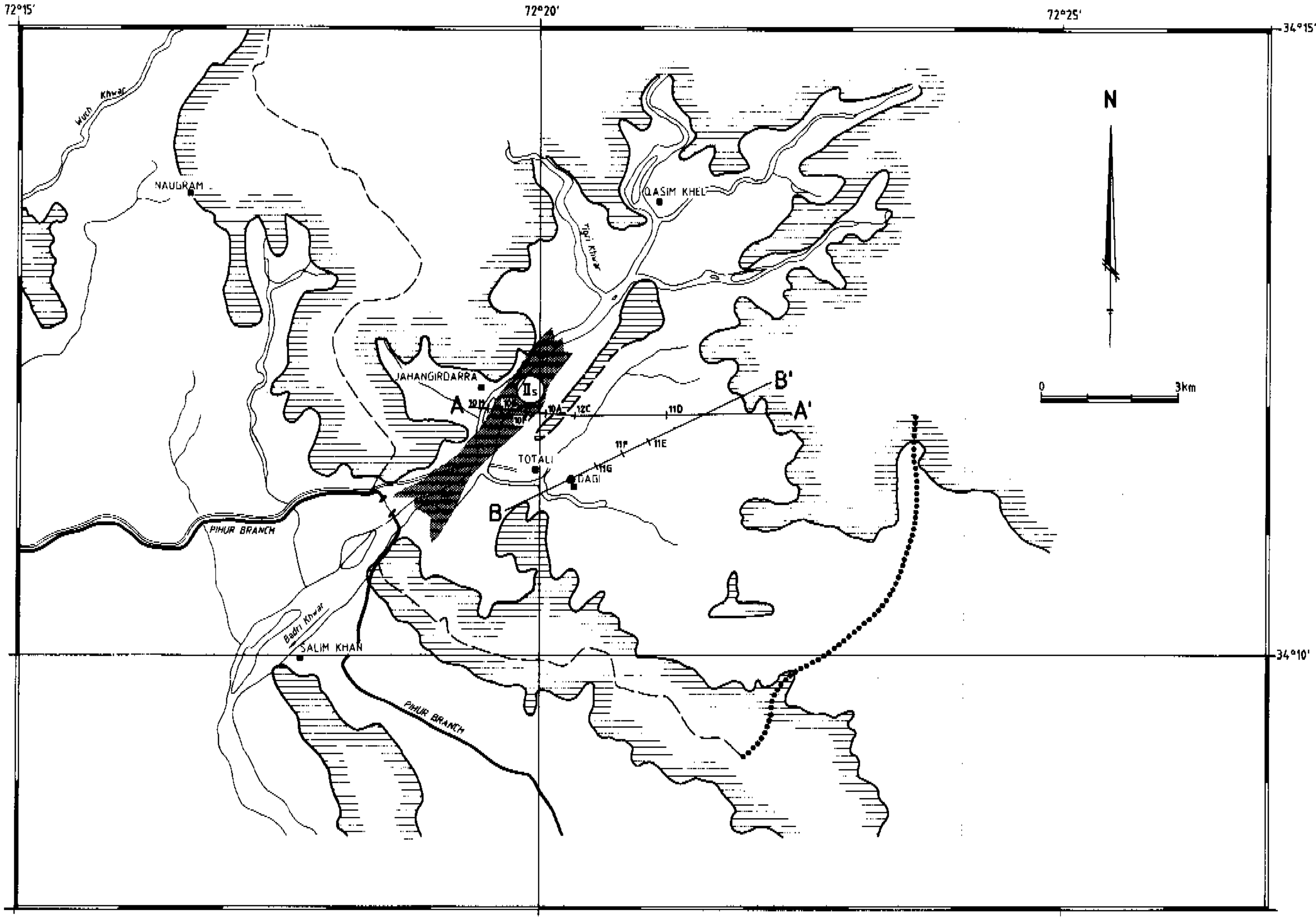


Figure 40: Hydrogeological map of the Totali area (For legend see fold-out at back of book)

vial origin with thin intercalations of sandy material. In the western sub-basin a layer of coarse material developed during a later episode. This layer is absent or very thin in the eastern basin.

Population and domestic water supply

No data are available on the number of people and on their water supply. Shallow wells are probably the most common source of domestic water. The PHED has drilled a few tubewells, e.g. in Dagi in the eastern sub-basin.

Agriculture

Khan and Ali (1975) indicate that the land along the Badri Khwar in the vicinity of Totali has "a high economic potential under irrigation". The land is irrigated by many shallow wells and by two tubewells drilled by the PNCB and the BADP.

Groundwater conditions in the eastern sub-basin

In the eastern sub-basin the alluvial cover is approximately 75 m thick (Figure 41). Depth to the water table is 13 m. Water-bearing layers are present below 30 m depth and extend to the bedrock. They consist of thin layers of gravel and sand, mixed and intercalated with clay (Qureshi and Nadeem-ul-Haq, 1985). The transmissivity is probably low; 80 m^2/d in a well drilled in January 1985 by WAPDA on behalf of the PHED in the village of Dagi. After seven hours pumping at a rate of 48 m^3/h the drawdown in the pumped well was 12.75 m and still increasing at a rate of 9 cm per half-hour. The quality of the water is good.

The groundwater flow in the eastern sub-basin converges towards the narrow connection with the western sub-basin. No data are available to allow estimates of the groundwater recharge and discharge. Given the clayey nature of the top layers, the volumes are expected to be very low.

Groundwater conditions in the western sub-basin

In the Totali valley the alluvial cover has a maximum thickness of 80 m. At a depth of 10 to 20 m CGG (1975) discovered a layer with an electrical resistivity of 200 ohm-m and a thickness of 5 - 20 m, indicating good aquifer characteristics (Figure 41). The estimated transmissivity may be as high as 5000 m^2/d (Pike, 1980). The aquifer starts approximately 1 km north of Totali and has a width of only 500 m, but it widens towards the Peshawar Vale (Chapter 11). The groundwater flows from north to south, parallel to the valley axis. The water quality is good.

Pike (1980) assumed that the aquifer is recharged by infiltration of water from the Badri Khwar and discharged by subsurface outflow towards the Peshawar Vale as well as by groundwater withdrawal from many shallow dug wells and from a few tubewells. No data are available to make an estimate of the recharge and discharge volumes.

Groundwater development potential

The groundwater development potential in the eastern sub-basin is very low. Only wells for public water supply with a yield of 25 m^3/h can be sustained.

The possibilities for groundwater development in the western sub-basin seem much better. The aquifer characteristics allow the installation of high-yielding (100 m^3/h or more) tubewells; however, the restricted dimensions of the aquifer will limit the sustained yield.

Groundwater management

Given the risk of overpumping the aquifer of the Totali valley, which may result in the depletion of the aquifer during a sequence of dry years, the groundwater resources must be managed carefully according to a water resources development plan. This requires a quantitative study of the recharge and discharge components of the aquifer. The effect of pumping and of the variations in the flow of the Badri Khwar on the groundwater levels should be studied.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Astier, J.L., 1975. Groundwater Investigation Programme with particular emphasis on the geophysical survey, Buner area. PNCB and FAO. *Annotation.* This report, quoted by Nagi (1975) and Pike (1980) could not be traced.

Khan, S.H. and Anwar Ali, 1975. Reconnaissance soil survey of the Buner valley. *Soil Survey of Pakistan, Lahore*; 165 pp., 11 tbls, 16 figs, app. *Annotation.* Description of

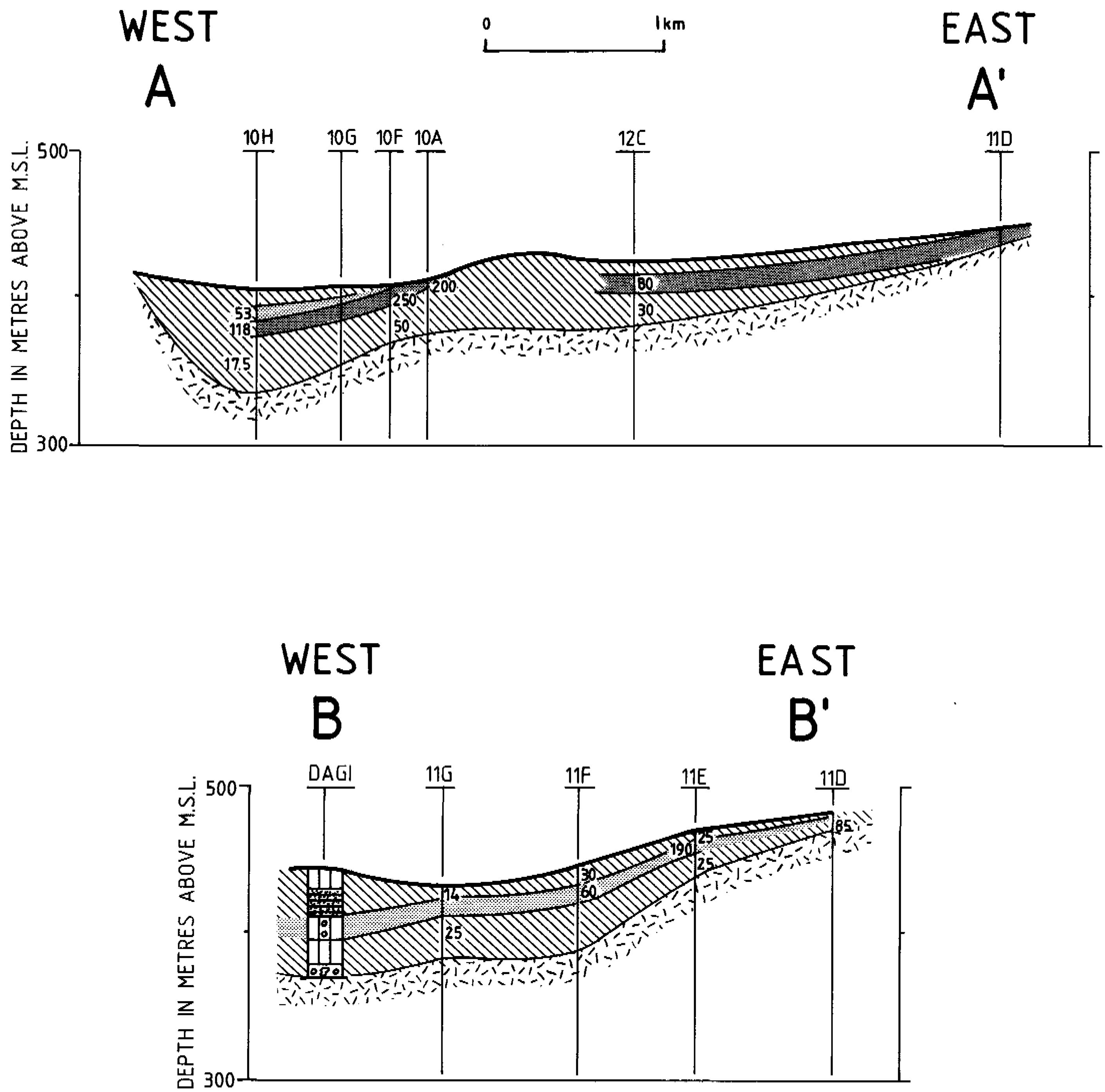


Figure 41: Hydrogeological cross-sections over the Totali valley (For legend see fold-out at back of book)

the soils and their genesis, present use and capability.

Nagi, Abdul Wahib, 1975. Hydrogeologic reconnaissance of Buner area, Swat District, NWFP. Reconnaissance series report no. 4, Hydrogeol. Sect. Ground Water Directorate WAPDA, Peshawar; 51 pp., 9 tbls, 5 figs. *Annotation.* Description of available data, notably the log of one of the two old boreholes in the Buner area; details including water quality analysis, data of 47 open wells that were selected from a total of 400 wells, water quality data of some springs and nalas, streamflow data of the three major rivers measured in April 1975.

CGG (Compagnie Général de Géophysique), 1977. Geophysical investigations in Buner area. UNFDAC and FAO; 20 pp., 3 app., 8 figs. *Annotation.* The report contains the results of a survey in the Totali valley, the Chingalai basin and the Chamla valley consisting of 122 vertical electric soundings with an AB line of 1000 m and of 24 seismic spreads with a length of 460 m, a spacing of 20 m between the geophones and seven shot-points.

Pike, J.G., 1980. The water resources and irrigation potential of the Buner area, Swat District, NWFP. UNFDAC and FAO; 35 pp., 4 app., 10 tbls, 5 figs. *Annotation.* Contains an analysis of the earlier mentioned reports, an analysis of rainfall data from Daggar station, runoff data of the Barandu and Badri rivers, analysis of data obtained from six boreholes in the Chamla valley as well as an approximate general water balance. The conclusion is that the surface and groundwater resources are sufficient to match the irrigable soil potential.

Quaglia, G. and J.Poulisse, 1984. Irrigation development in Buner. Buner Agricultural Development Project. PNCB and UNOPE; 84 pp., 4 app., 36 tbls, 2 figs. *Annotation.* This publication is a guide to the planning of irrigation schemes. The following is discussed: (a) A method of calculating crop water requirements and net irrigation water applications in order to maximize the rate of return under optimum water conditions; (b) an economic analysis of the various types of schemes; (c) the design criteria that influence the planning of irrigation schemes; (d) a comparison between the real cost of water and the abiana rate (water rate) charged by the Irrigation Department; (e) the effect of the warabandi system on the optimization; (f) comparison of the net production values derived from irrigated agriculture compared with poppy cultivation.

Qureshi,I.H. and Nadeem-ul-Haq, 1985. Electric resistivity survey in Totali area. WAPDA Hydrogeology Directorate Peshawar; 10 pp., 3 figs. *Annotation.* Report on 27 vertical electrical soundings in the eastern part of the Totali valley.

Bloemendaal, S., Zaibiullah Khattak and Abdullah Mir Khan, 1985. Groundwater resources in Daggar Valley (Buner area), Swat District, N.W.F.P., Technical report No. X-1. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 37 pp., 5 app., 10 tbls, 7 figs, 4 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO-DGV during 1984/1985. The fieldwork entailed an inventory of 1979 open wells, six tubewells from the PHED, one tubewell from the PNCB and some springs; a resistivity survey of 186 vertical electrical soundings; the drilling of six test holes, three of which were geophysically logged while four were converted into test wells; water sampling for chemical analysis, watertable monitoring and streamflow gauging. A groundwater balance of the area is included.

9.4 THE NIKPIKHEL AREA

Location

The Nikpikhel area is located in Upper Swat, about three kilometres northwest of Mingora on the right bank of the Swat river, between lattitudes 34°45' and 34°54' N and longitudes 72°12' and 72°25' E. The Nikpikhel catchment is 207 km^2 in area, of which 107 km^2 is covered by alluvial fill. The area corresponds more or less with the Kalibat Tehsil of Swat District and on the west it borders Dir District.

Physiography

The area has a triangular shape and consists of three coalesced triangular valleys bounded by the Swat river in the southeast and by mountains on the other sides. The relief of the valley is moderate to steep, varying from 1.6 to 4.0 per cent. The valley floor rises from an altitude of 887 m (2909 ft) above msl at Kabbal close to the banks of the Swat river to 1134 m (3720 ft) at Tutan Banda. The high peaks of the watershed reach altitudes of 2360 and 2744 m (7741 and 9000 ft). The Deolai Khwar and the Qualagai Khwar which originate in the mountains to the northwest are the only perennial streams, carrying snow-melt and spring water. The other nalas are ephemeral.

Geology

The Nikpikhel area lies just on the northwest side of the Main Mantle Thrust, which here follows the Swat river (Kazmi et al., 1984). The catchment area consists mainly of amphibolites of the Upper Swat Hornblendic Group. Before the closure of the Tethys they were part of the Kohistan island arc (Section 2.2). Associated with the amphibolites are dioritic rocks, peridotites, and quartz-diorites. Outcrops of metamorphic rocks of the Lower Swat-Buner Schistose Group are found in the southwestern part of the area (Jalil-ur-Rehman and Zeb, 1970). These mainly impervious formations are overlain by flood deposits consisting of gravel, sand and clay along the Swat river and of piedmont deposits composed of boulders and gravel with clay in the tributary valleys.

Climate

The climate is of the sub-humid subtropical continental lowland type (Section 1.3), with July and August the wettest two months. The mean annual precipitation at Saidu Sharif, on the other side of the Swat river, is 810 mm, of which 42 per cent falls in the summer (June - September) and 35 per cent in the winter (December - March). The summers are mild with an average temperature of 28°C and a mean daily maximum temperature in June of 36°C, but winters are cold with an average temperature of 8.5°C and a mean daily minimum temperature in January of 2°C.

Population and domestic water supply

The population of Kalibat Tehsil numbers approximately 147,000. The people live in scattered villages, strung out along the electricity lines that follow the main roads. Groundwater drawn from shallow wells is the main source for domestic water supply. In some villages near the mountains, in particular around Tutan Banda, spring water is used for drinking as well as for irrigation. The PHED has installed two tubewells in Kabbal and one in Derai to serve these towns.

Agriculture

Agriculture is the main source of income. The main crops are wheat, maize and barley, to which are added in the irrigated areas: oilseeds, vegetables, rice, and shaftal (a fodder crop). Most of the upper part of the valley is barani land with poor yields. Where irrigation can be practised, as in the Tutan Banda area, the yields are much higher. On the lower slopes dug wells provide irrigation water and in a strip along the Swat river an irrigation canal of about 14.5 km length diverts water from the river at Ningulai to command an area of 1120 ha (2769 acres).

According to Darr and Ahmad (1981) the soils in the central part of the valleys and along the Swat river are suitable for irrigation.

Groundwater investigations

In 1986/1987 WAPDA Hydrogeology Directorate made a hydrogeological reconnaissance and an electrical resistivity survey in the area, as part of the PATA groundwater irrigation project, (Wazir, 1987 and Qureshi et al., 1987).

Groundwater conditions

The mountains that surround the valley and form the bedrock of the alluvial fill consist mainly of amphibolites and to a lesser extent of dioritic rocks and of quartzites and schists of the Lower Swat-Buner Schistose Group. Near Tutan Banda there are many springs that apparently arise in the hardrock of the mountains. They have not been inventoried, nor has their mode of occurence and their origin been investigated. Although they are of considerable local significance, they are considered to be of less importance as a groundwater resource than the alluvial fill that contains the main aquifer of the area. The bedrock topography below the alluvial fill is irregular, because V- and U-shaped valleys in the bedrock extend to more than 250 m below the present land surface (Figure 42).

The alluvial fill consists of piedmont deposits in the form of alluvial fans that are dissected by hill torrents, and of recent floodplain deposits along the bank of the Swat river.

According to Qureshi et al. (1987) the thickness of the alluvium varies from 30 to 250 m but this still has to be confirmed by test drilling. The greatest thickness is expected in the central part of the main valley and along the Swat river. The alluvial deposits consist of layers of sand and gravel, either clean or mixed with boulders, clay or both, that alternate with clay layers. In the central parts of the valleys at a depth below 120 - 200 m, cemented boulder beds or weathered bedrock with low permeability may be present. So, the saturated thickness of the aquifer will not exceed 200 m in the central part of the Deolai Khwar valley and be less everywhere else, particularly in the upstream part of the valleys where it will not exceed 25 m. Assuming that the coarse layers make up 40 per cent of the saturated part of the alluvial fill that has an average thickness of 100 m and a specific yield of 0.15 and covers over half the total area of the plain, i.e. 53 km^2, it follows that the stored groundwater volume is circa 300 Mm^3. This estimate may be considered conservative.

The aquifer is mainly unconfined and depth to the water table ranges from 10 m in the central part of the valley of the Deolai Khwar and along the Swat river, to more than 50 m near the foot of the mountains.

Locally, confined conditions occur, as shown by one of the boreholes in Kabbal that has a free flow of 51 m^3/h (0.5 cusec). The unconfined tubewell in Kabbal and the tubewell in Derai have yields of 12 and 20 m^3/h, respectively and specific capacities of 15.4 m^3/h per m dd. (4.69 gpm/ ft dd.) and 18 m^3/h per m dd. (5.4 gpm/ ft dd.). Based on Logan's assumptions (Logan, 1964; also Kruseman and De Ridder, 1970) transmissivity values of 150 - 500 m^2/d may be expected.

The groundwater quality is good. The water is of the calcium magnesium bicarbonate type with EC values that are less than 0.6 mS/cm and a SAR of 0.1-0.2.

Water level fluctuations

No data are available on the fluctuations of the water table.

Groundwater flow

The groundwater elevation contours are shown on Figure 43. They indicate flow parallel to the valley axis and towards the Swat river.

The variation in the spacing of the contour lines correlates with the results of the resistivity survey. Wide spacings correspond with thick sequences of coarse material, i.e. with relatively large transmissivity values.

Discharge and recharge

Wazir (1987) reports that present groundwater abstraction amounts to 0.81 Mm^3/yr (or 0.9 cusec). This volume comprises:

- the apparently unused discharge of the artesian well in Kabbal, 0.46 Mm^3/yr, which disappears as surface flow,
- irrigation use, which accounts for 0.19 Mm^3/yr,
- domestic supplies that amount to 0.16 Mm^3/yr. This figure implies that with a per capita consumption of 25 l/d only 10 per cent of the population, say 15,000 persons, are supplied with groundwater.

The groundwater outflow was estimated by subdividing the outflow front into more or less homogeneous segments. Transmissivity values between 150 and 500 m^2/d were attributed to each segment, and the length of each segment and the hydraulic gradient over the segment were determined. Darcy's law was applied to each segment to calculate its outflow, and after summation the total subsurface outflow was found to be 39 Mm^3/yr (or 44 cusec). Under steady state flow conditions the recharge must have a similar value. The recharge would then correspond to approximately 20 per cent of the average total rainfall over the catchment. This seems high, but may be correct if the soils over most of the plain are sandy and gravelly with a high infiltration rate.

Groundwater development potential

The groundwater development potential appears to be good. Although the many assumptions have to be verified by ad-

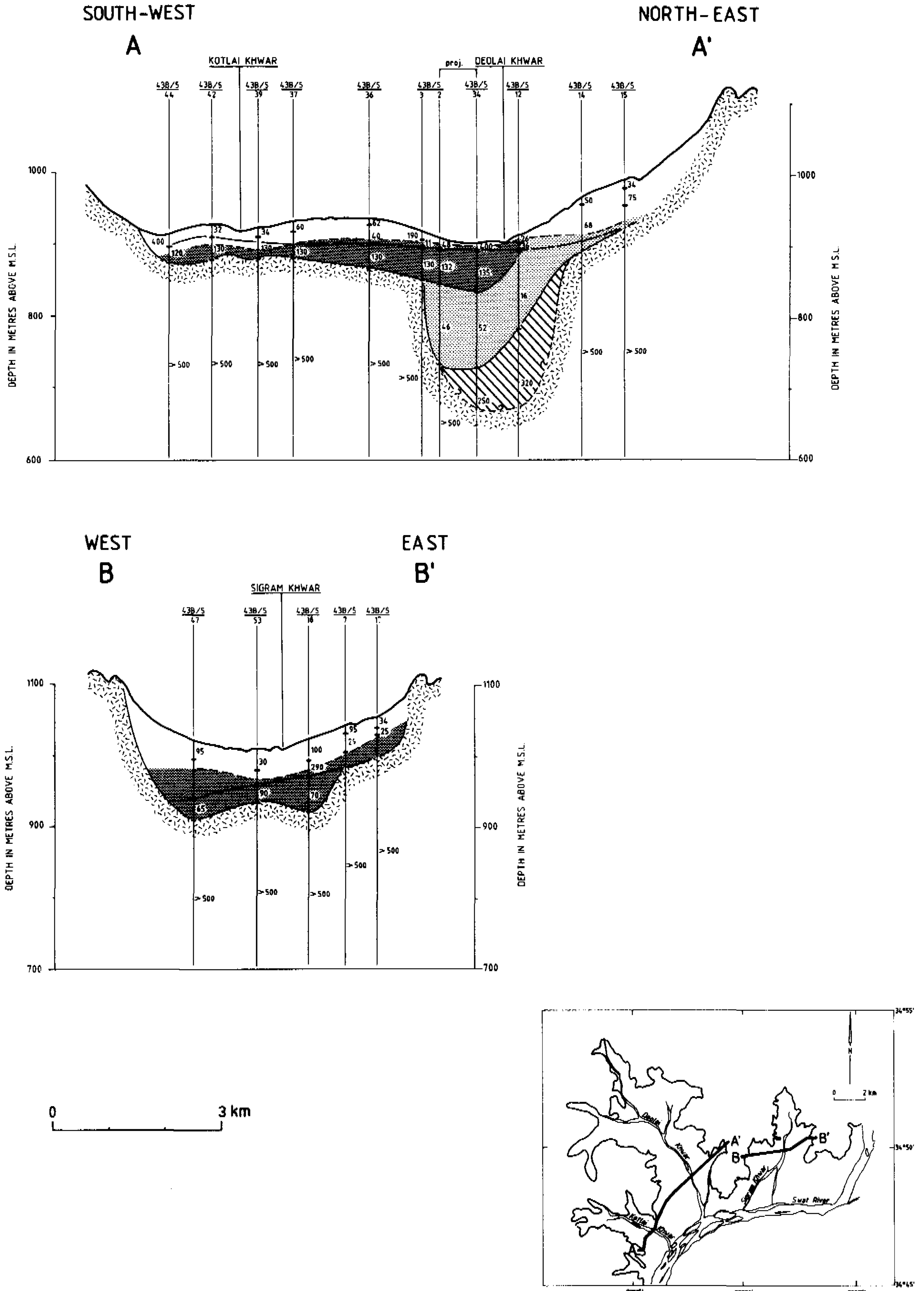


Figure 42: Cross-sections over the Nikpikhel area, based on resistivity soundings (For legend see fold-out at back of book)

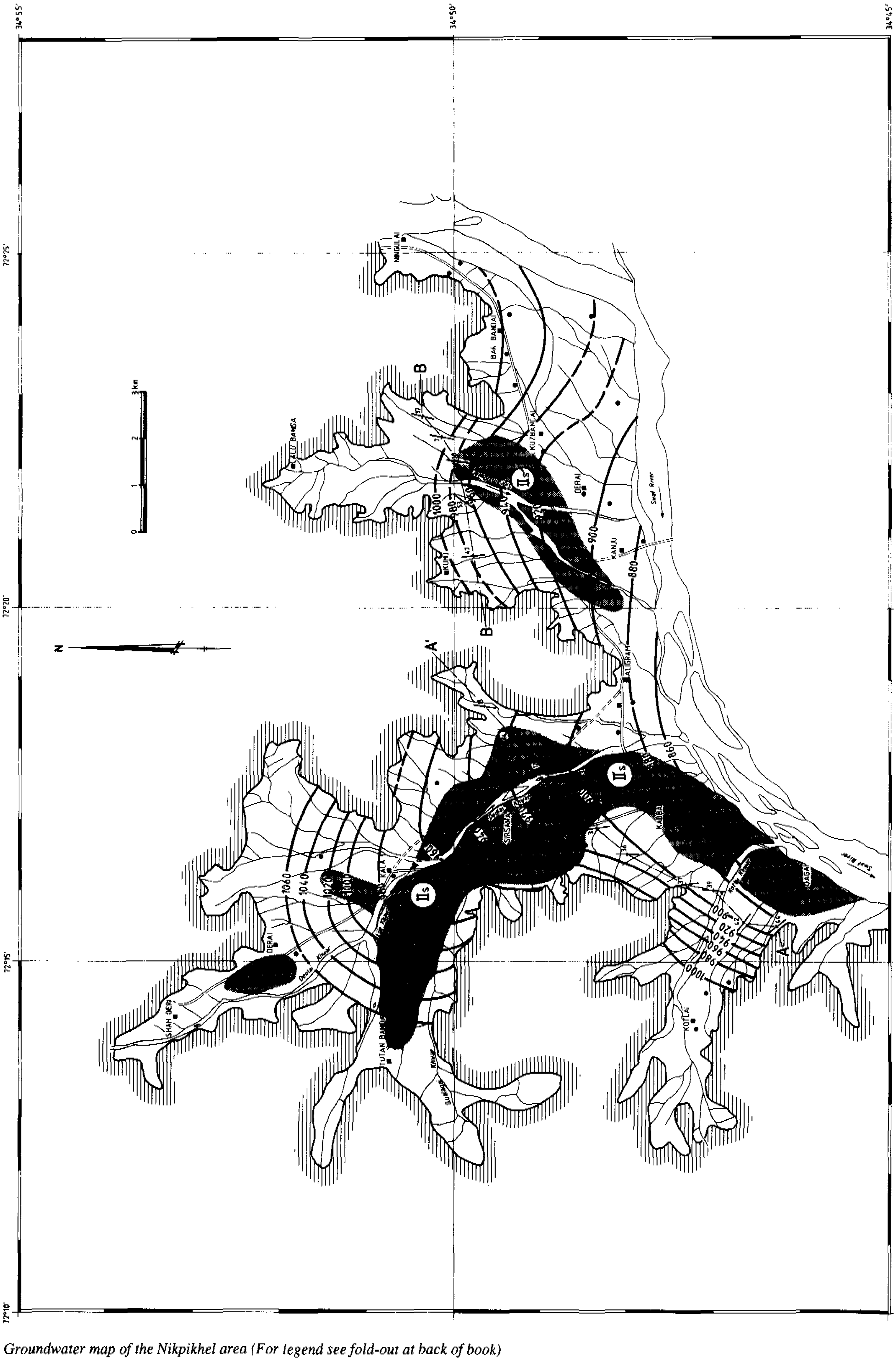


Figure 43: Groundwater map of the Nikpikhel area (For legend see fold-out at back of book)

ditional investigations, it is justifiable to allow the development of an additional 10 Mm^3/yr (11 cusec) as a first step.

Groundwater management
The development of the groundwater potential should go hand in hand with groundwater investigations, in order to obtain a proper insight into the groundwater regime and its recharge and discharge characteristics. So, more detailed groundwater development can be planned.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Darr, M.A. and M. Ahmad, 1981. Reconnaissance soil survey Swat catchment 1976. Soil Survey of Pakistan, Lahore; 205 pp., 5 app., 12 tbls, 4 figs and 3 pl.
Annotation. Description of the soils and their genesis, present use and capability.

Wazir, Taj Khan, 1987. Report on a reconnaissance survey in Nikpikhel area (Swat). PATA irrigation project in NWFP Technical Report No.3; 15 pp., 6 tbls, 4 figs and 4 pl.
Annotation. It is the first hydrogeological report on the area. It contains, in addition to general information on the area, the results of the chemical analysis of 14 groundwater samples, a description of the boreholes and tubewells drilled and constructed by the PHED, an estimate of the present groundwater withdrawal (in our opinion probably too low) based on an inventory of 660 open wells, and recommendations for drilling test holes and determining the hydraulic characteristics of the aquifer. This report is best studied in conjunction with Qureshi et al., 1987.

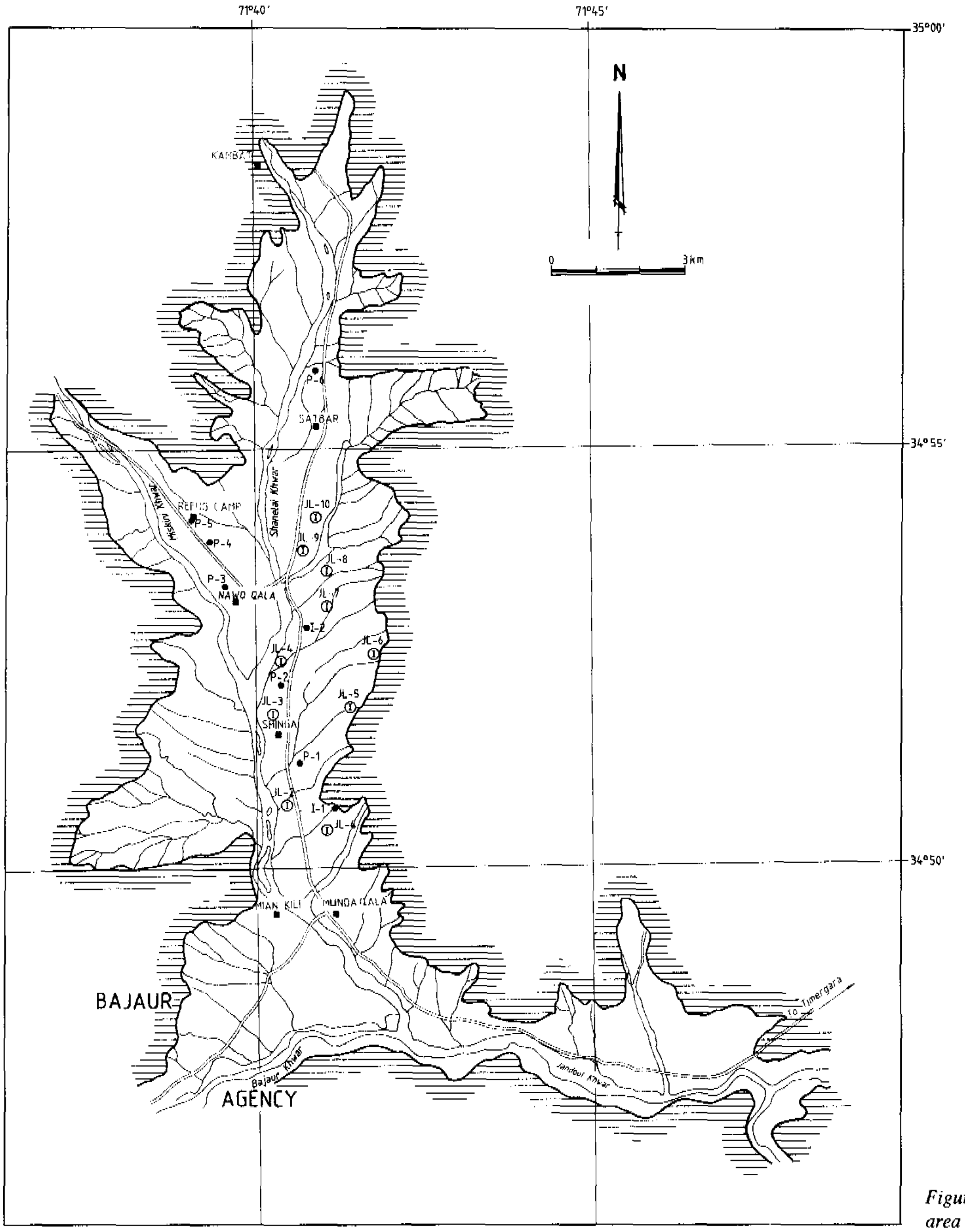


Figure 44: Location map of the Jandool area

Qureshi, I.H., Abdullah Mir Khan and Nadeem-ul-Haq, 1987. Electrical resistivity survey in Nikpikhel area (Swat). WAPDA Hydrogeology Directorate and PATA groundwater irrigation project; 8 pp., 1 app., and 3 pl. *Annotation.* Report on the interpretation of 68 vertical electrical soundings in Schlumberger configuration. Interpreted curves are appended and plates show resistivity cross-sections and promising zones for groundwater exploitation. This report is best studied in conjunction with Wazir, 1987.

9.5 THE JANDOOL AREA

Location

The Jandool river is a tributary of the Panjkora river in the southwestern part of Dir District. The area under discussion is located between latitudes 34°47' and 35°00' N and 71°32' and 71°45' E. It comprises a catchment area of 382 km^2, of which 80 km^2 are underlain by alluvial sediments.

Physiography

The Jandool alluvial area comprises the valleys of the Shandai Khwar and the Miskini Khwar that converge south of Nawa Qala to form the valley of the Jandool Rud. South of Munda Qala this valley is joined by the Bajaur Khwar and its north-south course changes to west-east (Figure 44). The Jandool Rud and its main tributaries are perennial rivers, because much of the annual precipitation falls as snow, which is slowly released. Moreover, considerable amounts of groundwater may exfiltrate in the alluvial area. The elevation of the alluvial plain decreases from 1200 m (3940 ft) in the north to 750 m (2460 ft) above msl in the south.

Geology

Kakar et al. (1971) distinguish four major stratigraphic units that make up the catchment and the bedrock for the alluvial fill of the valley:
- the Palaeozoic, probably Siluro-Devonian, amphibolites of the southern and central parts,
- the Jurassic-Cretaceous dioritic and granitic rocks in the east, west and northeastern parts of the valley; in intensely sheared zones they are associated with small intrusions of basic and ultrabasic rocks,
- the Tertiary volcanic and porphyry dykes occur in the north and northwestern parts. They consist of a very thick series of andesite and dacite tuffs interbedded with fossiliferous metasedimentary rocks,
- the Late Tertiary porphyry dykes that cut through the older rocks.

All these units have been folded and faulted at least once. In the valley they are covered by Quaternary alluvial deposits.

Climate

Meteorological data are not available, but from the agricultural practices it can be surmised that the southern part of the Jandool valley belongs to the region with a semi-arid subtropical continental highland climate with rainfall around 450 mm and that the northen part belongs to the region with a sub-humid subtropical continental highland climate with precipitation between 500 and 1250 mm per year. Summers are pleasantly warm, but winters are quite cold with mean daily minimum temperature below freezing point. Snowfall in the catchment area ensures perennial flow in the rivers.

Population and domestic water supply

No population data are available. Dug wells and surface water are probably the main sources for domestic water supply. The PHED has drilled six tubewells to supply major villages and Afghan refugee camps.

Agriculture

Darr and Akhtar (1979) characterized the soils in the Jandool area as "land with a high to very high potential under irrigation" and as "land with a moderate potential under dry farming". Because of the perennial stream flow, large areas bordering the Jandool river and its tributaries are irrigated with surface water. In the non-irrigated areas barani agriculture is practised. The higher rainfall in the northern part of the plain means that Kharif crops can be grown in the area north of the line Nawa Qala - Satbar.

Tubewell-based irrigation is not yet practised, because the electrification of two tubewells drilled by the Irrigation Department has not yet been realized. Sufficient irrigable land is available to increase the groundwater-based irrigation. At the request of the Irrigation Department, the PATA project will drill ten boreholes, which will be converted into tubewells for irrigation schemes by the UN-sponsored Dir Development Project.

Groundwater investigations

The groundwater resources of the area have not yet been studied. The only data come from drilling reports. (J. Groen, Pata project, and Moh. Riaz, WAPDA Hydrogeology Directorate Peshawar, oral communication). An investigation of the area is planned for 1988 by the PATA project.

Groundwater conditions

The alluvial fill of the valleys consist from top to bottom of a clayey layer underlain by a badly sorted mixture of sand gravel and clay, followed by clean gravels and boulders that make up the aquifer. The bedrock is situated at a depth of 55 to more than 75 m below the surface. In most boreholes the top of the aquifer was reached at a depth of 43 m. Pumping test results from four tubewells drilled by PHED indicate transmissivity values ranging from 70 - 1800 m^2/d and specific capacity values ranging from 3.6 - 33.6 m^3/h per metre drawdown (4.9 - 45.1 gpm/ft dd.). No hydrochemical data are available, but the groundwater quality is expected to be good.

Groundwater flow

The groundwater flows from the mountains towards the valley axis, where it is likely to exfiltrate into the rivers.

Discharge and recharge

As yet there are no data for a quantitative assessment of the groundwater recharge and discharge conditions. However, based on the estimated precipitation over the catchment area these are likely to be considerable.

Groundwater development potential

The scope of the groundwater development depends mainly on the groundwater recharge and discharge regime, as well as on the availability of irrigable soils. The latter may be the limiting factor.

Groundwater management

A quantitative assessment of the groundwater regime is a prerequisite to proper groundwater use planning and should be undertaken.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Darr M.A. and N.A. Akhtar, 1979. Reconnaissance soil survey Dir. Soil Survey of Pakistan, Lahore; 210 pp., 5 app., 11 tbls, 3 figs and 3 pl. *Annotation.* Description of the soils and their genesis, present use and capability.

10 THE LEFT BANK AREAS

10.1 GENERAL

The part of the North-West Frontier Province that is located on the left bank of the Indus river comprises from north to south the Kohistan, Mansehra and Abbottabad Districts. The area is bordered in the west by the Indus river, in the north by the Gilgit Agency, in the east by Jammu and Kashmir and in the south by the Punjab. The main tributaries of the Indus that rise in this area are the Siran river and the Haro river. Kohistan District is an area of high mountains belonging to the Himalaya chain, and it lacks extensive groundwater resources. Alluvial deposits with exploitable groundwater resources are found in the Pakhli plain in Mansehra District, in the Haripur area in Abbottabad District and in the Ghazi area (Abbottabad District), which is mainly a part of the Indus valley floodplain.

10.2 THE PAKHLI PLAIN

Location
The Pakhli plain forms the major part of Mansehra Tehsil in Mansehra District. It lies between latitudes 34°20' and 34°31' N and between longitudes 73°05' and 73°20' E. The valley extends over an area of 250 km^2 and the catchment covers an area of 153 km^2.

Physiography
The Pakhli plain is drained by the Siran river, which enters the plain in its northeastern corner, and by the Ichhar Nala. Both streams are perennial. The Ichhar Nala, which arises on the southeastern mountain slopes, joins the Siran river in the southwest close to the point where the Siran river leaves the plain. The mountains north of the plain rise to a height of 4500 m (13,000 ft) and more, those to the south are much lower, about 2000 m (6600 ft) above msl. The plain slopes along its east-west axis from 1080 m in the east to 860 m in the west; a gradient of 0.011.

Geology
The Pakhli plain is located on the south flank of the northern Hazara highlands that are the western extension of the Himalayan chain. The area consists mainly of metamorphic slates of the Tanawal Formation and of the igneous Mansehra Granite. Subordinate amounts of the metamorphic Hazara Formation and of limestones of Triassic to Eocene age are found in the southwestern part of the catchment area.
The Mansehra Granite forms the bedrock of the alluvial fill of the southeastern part of the plain; the remaining area is underlain by metamorphic rocks. The alluvial fill is of Quaternary age and consists of the erosion products of the surrounding hills. The lower portion is made up of boulders and gravels mixed with silt and clay. It is overlain by thick layers of silt and clay with intercalations of sand, gravel and boulders. The fine material may be loess or reworked loess deposits.
Recent floodplain deposits extend in a narrow belt along the Siran river. They consist mainly of sand, silt and clay with thin bands of gravel. The thickness of the floodplain deposits has not been established, but is presumably slight; the maximum width, 4 km, is found near Malak Pur.

Climate
The Pakhli plain is on the fringe of the region with a climate of the humid subtropical continental highland type. Mean annual precipitation is around 1250 mm in the plain (Shinkiari) and more than 1400 mm in the northern mountains (Bala Kot), where most of the winter precipitation falls as snow. The mean monthly temperature is about 28°C in June and July and is 7°C in January. This means that the summers are pleasantly warm, but the winters are cold with temperatures frequently below 0°C.
The potential evapotranspiration is approximately 1150 mm per year and this makes it the only alluvial plain in NWFP where the mean annual rainfall exceeds the mean annual evapotranspiration.

Population and domestic water supply
The population of Mansehra District is estimated as 1.5 million, but data for the Pakhli plain alone are not available. The domestic water supplies are mainly obtained from shallow dug wells and from streams and springs. The PHED has added to the water supply by drilling four tubewells.

Agriculture
Agriculture is the principal occupation. Animal husbandry is predominant in the mountains. Over most of the plain agriculture is of the barani type. Irrigation is practised along the Siran river and the Ichhar Nala, from which water is diverted. According to Sheikh (1985) the design capacity of the diversion structures is 8.8 Mm^3/yr or 30 cusec. This will correspond to a command area of 1800 ha (4500 acres). The main barani crops are wheat and maize, and the main irrigated crops are wheat, maize, rice and tobacco; less common are vegetables and fruits.
According to Nizami (1978) the central part of the plain is "land with a high potential under irrigation"; the peripheral part of the plain is classified as "land with a high potential

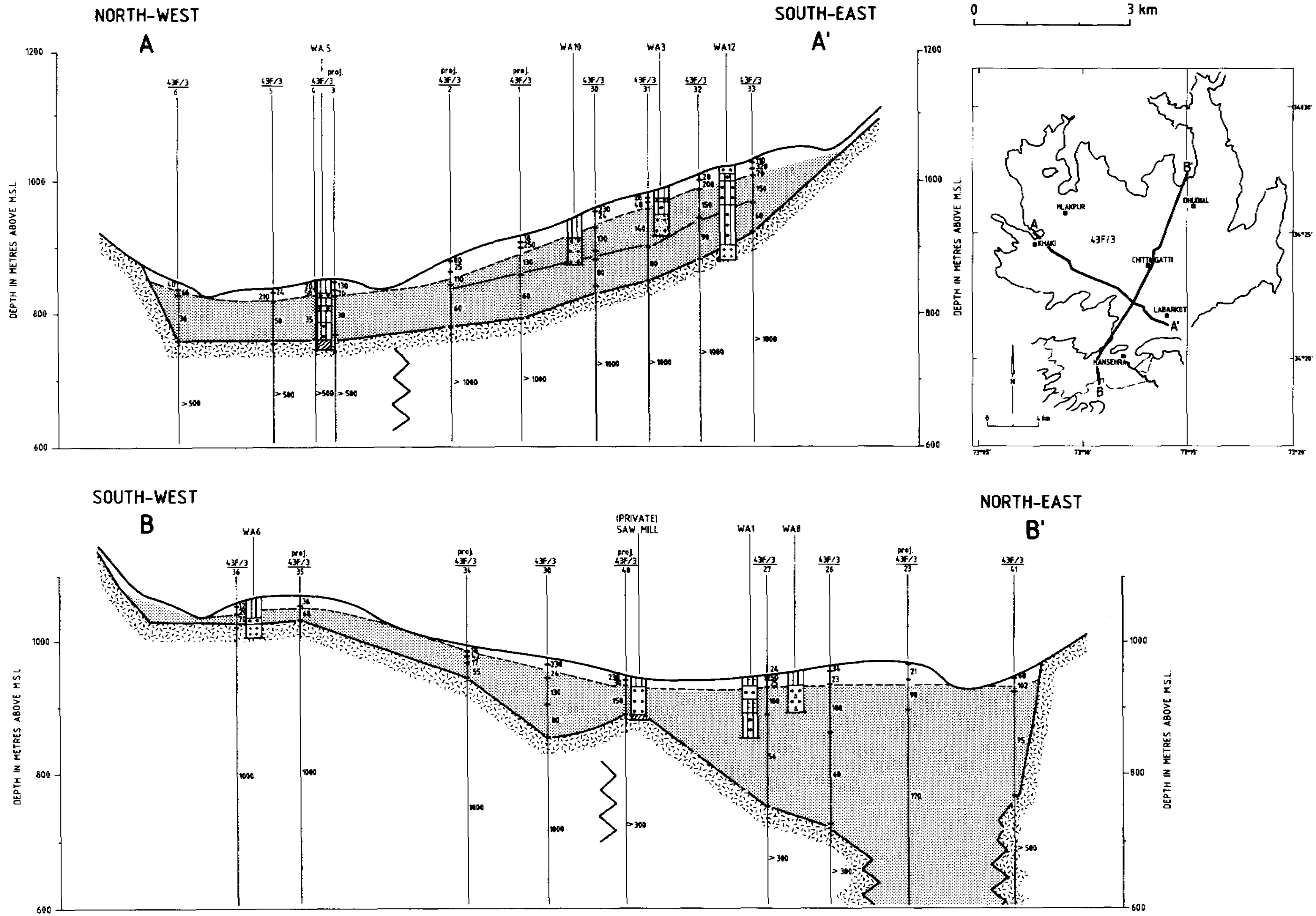


Figure 45: Hydrogeological cross-sections over the Pakhli plain (For legend see fold-out at end of book)

under dry farming" but it has a much higher potential when irrigation water is provided.

Groundwater investigations
Groundwater investigations were started by WASID, which drilled two test holes in 1966. WAPDA drilled four additional ones in 1975. A comprehensive groundwater survey was carried out from 1981-1985 by WAPDA Hydrogeology Directorate Peshawar in cooperation with TNO Institute of Applied Geoscience under the Pak-Dutch programme of Groundwater investigations in NWFP. The study included the drilling of another six test holes. Five of them were converted into test wells on which pumping tests were carried out.

Groundwater conditions
The thickness of the alluvial deposits varies because of the irregular bedrock topography below the fill. In the central part of the plain it is more than 100 m thick and in the centre of this area it even exceeds 200 m. As already mentioned under "geology", the alluvial fill is very heterogeneous. Coarse material, such as boulders and gravel, fine material, such as sand, silt and clay, occur as ill-sorted mixtures and as well-defined layers (Figure 45). Well sorted coarse layers are relatively rare and consequently the transmissivity of the fill is not very high, approximately 200 m^2/d, with the exception of the transmissivity of 2400 m^2/d found in well P-1 drilled by the Forest Department. Although semi-confined conditions may occur locally, it is assumed that the aquifer system as a whole reacts as an unconfined aquifer. The specific yield of the relatively coarse layers is around 0.10, but in the layers with a high silt and clay content it is probably about 0.07. With few exceptions the depth to the water table varies between 10 and 35 m.
The chemical quality of the water samples from open wells is generally good: the groundwater is of the calcium bicarbonate type, the EC value is less than 0.7 mS/cm, and the SAR is less than 2 and mostly less than 1. So, the water is suitable for domestic use and irrigation. The few wells that show higher EC values (up to 1.8 mS/cm) probably suffer from local contamination.

Water level fluctuations
From late 1974 until 1982 groundwater levels were monitored in open wells. Until 1979 the observations were made monthly, thereafter quarterly. Seasonal fluctuations are generally in the order of 2 to 3 m, but in recharge zones fluctuations of 6 m were observed.

Groundwater flow
The watertable elevation contours are shown in Figure 46. They indicate that in the southern part of the plain the groundwater flows towards the Ichhar Nala and in the northern part it flows towards the Siran river. A water divide can be drawn to separate the two flow systems. Note that changes in the flow pattern, e.g. caused by groundwater development, will cause a shift in the position of the water divide.

Discharge and recharge
The southern part of the plain and its catchment that drain to the Ichhar Nala upstream of its confluence with the Siran river, covers 217 km^2. Most of the groundwater recharge occurs by percolation of runoff in the zone directly adjacent to the mountains and by percolation of rainfall over the plain. According to Sheikh, the total recharge is 27 Mm^3/yr, which corresponds to 10.5 per cent of the rainfall over this sub-basin.
The northern part of the plain and its catchment are 186 km^2 and are drained by the Siran river. According to Sheikh (1985) the groundwater body in this area is recharged with 23 Mm^3 annually; this corresponds to 9 per cent of the rainfall over the catchment area.

Groundwater development potential
Because of the low transmissivity of the alluvial fill it is not possible to install tubewells with a yield of at least 100 m^3/h (1 cusec). An area has been defined in the central part of the plain (Figure 46) where tubewells with a yield of 50 m^3/h (0.5 cusec) can be installed. The drilling depth of such wells should be 120 m, unless a good aquifer is encountered at a lesser depth. The water table in the well will be at a depth of 10 - 30 m and the drawdown caused by the pumping will be 8 - 20 m.
In the peripheral zone, where the transmissivity is still smaller than in the central part, only wells with a yield of 25 m^3/h (0.25 cusec) can be installed. During a first phase of development the total groundwater extraction should not exceed 25 Mm^3/yr. Depth to water table and drawdown will be approximately the same as in the central zone.

Groundwater management
Large-scale groundwater development is not expected; therefore, it will be sufficient to monitor the groundwater development by making a well inventory once every five years and evaluating the changes since the previous surveys.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

ACE (Associated Consulting Engineers Ltd.), undated, Siran Basin reconnaissance report, Technical report, circa 100 pp. and 5 app. *Annotation.* This report contains a good general description of the Siran basin to which the Pakhli plain belongs, but it lacks a description of the groundwater conditions.

Nizami, M.M.I.,1978. Reconnaissance soil survey of Tarbela Watershed. Soil survey of Pakistan; 374 pp., 6 app., 17 tbls, 4 figs, 4 pl. *Annotation.* Description of the soils, their genesis, present use and capability.

WAPDA Hydrogeology Directorate, 1985. Electrical resistivity survey in Hari-Maira village, Mansehra District. WAPDA Hydrogeology Directorate Peshawar; 2 pp., 6 figs. *Annotation.* The report contains the data and interpretation of five vertical electrical soundings.

Sheikh, A.G., 1985. Groundwater resources in Pakhli plain, Mansehra District, N.W.F.P., Technical Report No. VII-1.

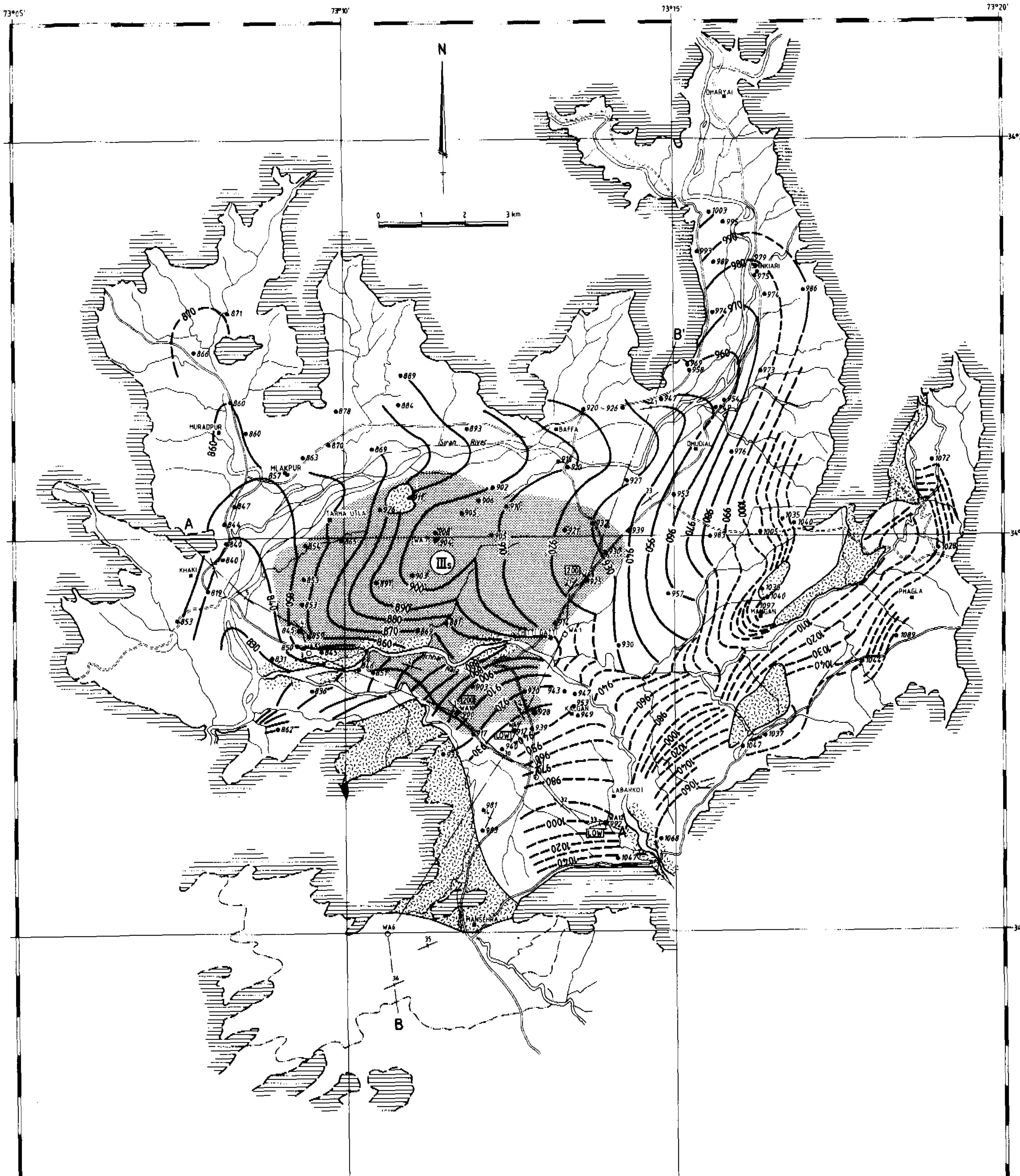


Figure 46: Groundwater map of the Pakhli plain (For legend see fold-out at end of book)

WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 37 pp., 5 app., 7 tbls, 13 figs and 5 pl.
Annotation. The report comprises the results of the investigations carried out by WAPDA-HDP and TNO-DGV during 1981/1984. It is based on fieldwork that included an inventory of 202 open wells, a resistivity survey of 54 vertical electrical soundings, the data from 6 test holes drilled by WAPDA during 1974/1975 and from 6 test holes drilled by WAPDA in the period 1981/1983, chemical analysis of groundwater samples, watertable monitoring and streamflow measurements. The author presents a water budget and makes a recommendation for additional groundwater development.

10.3 THE HARIPUR AREA

Location

The Haripur area is located in the northwestern corner of the Potwar Plateau, between latitudes 33°50' and 34°10' N and longitudes 72°45' and 73°15' E. It covers an area of 644 km^2 of which 272 km^2 is mountainous catchment area and 372 km^2 is alluvial plain. Administratively it belongs to the Abbottabad District.

Physiography

The Haripur area can be subdivided into: (1) the Dor river valley and (2) the main plain south of Haripur town, which occupies the western and southwestern parts of the area and is chiefly drained by the Jabbi Kas. The watershed between the Dor river and the Jabbi Kas, which is located in the north of the main plain, is hardly noticeable in the field.

The Dor is a perennial river that drains the northern and northeastern parts of the area, including most of the mountainous catchment. This river was formerly a tributary of the Siran, which was itself a tributary of the Indus. After the completion of the Tarbela reservoir the lower reaches of the valleys of the Siran and Dor rivers and the northwestern point of the Haripur plain were inundated. The Dor now flows directly into the Tarbela reservoir. The Jabbi Kas, which drains most of the main plain, is a tributary of the Haro, another tributary of the Indus. The Haro is a perennial river on which a dam has been constructed in Khanpur. The water from the Khanpur reservoir is used to supply Islamabad and Rawalpindi and to irrigate the southern part of the main Haripur plain.

The main plain is covered by dissected loess deposits that have a badland topography and are separated from the mountains by dissected alluvial fan and piedmont deposits. The slope of the plain is 0.020 toward the southwest, but near the mountains it is steeper. The Dor river valley is covered by young floodplain deposits that merge imperceptibly into alluvial fans towards the foot of the mountains. The altitude of the alluvial area varies from 435 to 900 m (1430 to 3000 ft) above msl; the mountains reach up to 3000 m (9800 ft) above msl.

Geology

The mountains surrounding the alluvial plain belong to the southwestern extension of the Himalayas. They consist of rocks ranging in age from Precambrian to Eocene. From north to south the following formations which are separated from each other by fault zones, can be distinguished:

- The Cambrian Tanawal Formation, which consists mainly of quartzite and quartzose schists.
- The Hazara Formation also of Cambrian age, consisting of slate, phyllites, and metamorphosed shales with limestone and graphitic intercalations.
- The Triassic to Eocene sedimentary rocks; they comprise grey, thickly bedded, poorly fossiliferous, Triassic limestone; massive limestone overlain by black shale of Jurassic age; and dark grey, very hard, massive and compact limestone occasionally alternating with calcareous shales that are of Palaeocene/Eocene age.

The Precambrian Salkhala Formation consists of schists and laminated limestone and it outcrops in the western part of the Haripur area.

Climate

The climate is of the sub-humid subtropical continental lowland type (Section 1.3). Based on the data of the meteorological stations at Tarbela and Haripur it is assumed that the average annual rainfall in the plain is approximately 950 mm. In the mountains the rainfall may be 20 per cent higher, i.e. 1140 mm. August is the wettest month and 58 per cent of the annual precipitation falls in the period June - September. The winter rainfall is concentrated in February and March. The average annual potential evapotranspiration is 1000 mm. The mean monthly temperature in Haripur is highest in June, 32.7 °C, and lowest in January, 10.1 °C.

Population and domestic water supply

The population of the Haripur Tehsil is approximately 501,000. Most people live scattered over the plain in small villages, of which Haripur, Havelian and Najibullah are the largest. The District headquarters, Abbottabad town, is located in the northwestern catchment area.

Nearly all the domestic and industrial water requirements are met from groundwater. At least 11 tubewells are in use by different industrial establishments in Haripur and Havelian. More than 20 tubewells have been constructed for the water supply of the towns and large villages, 13 of which were drilled by PHED. In the small villages the public water supply is from open wells.

Agriculture

Barani agriculture is the main economic activity. Irrigated agriculture is restricted to a small area near Haripur that uses water diverted from the Dor river, and to the area between Darwesh and Panian where small schemes use groundwater from springs and wells. The Department of Irrigation has drilled 15 tubewells for this purpose, while three private tubewells are also believed to be used for irrigation. The main crops of the area are wheat, maize, barley, oilseeds, and vegetables, as well as fruits such as guavas, apricots, pears and oranges.

Groundwater investigations

Groundwater investigations in the Haripur area were started in 1975 by WAPDA Hydrogeology Directorate Peshawar and subsequently continued in cooperation with TNO-DGV

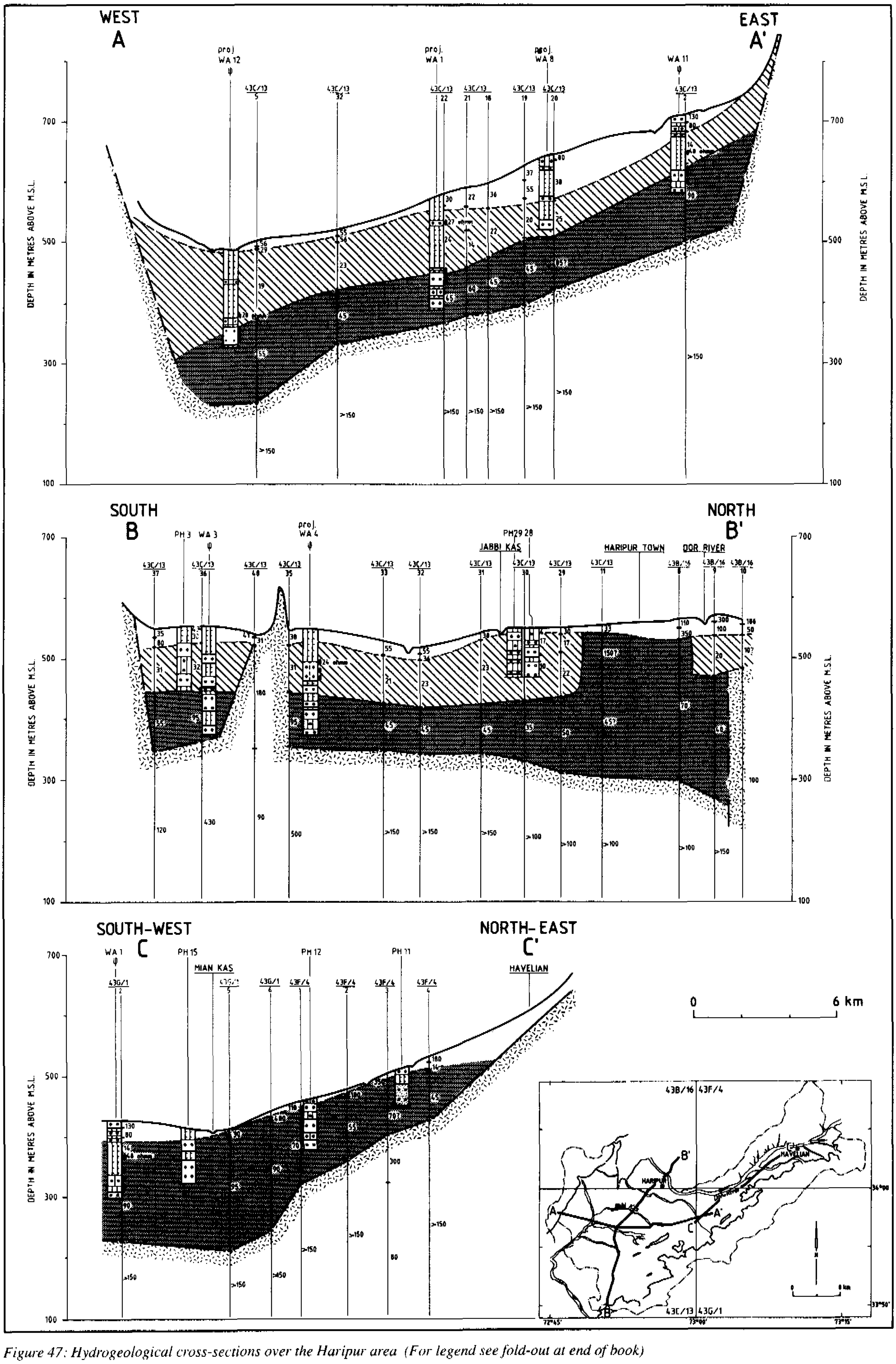


Figure 47: Hydrogeological cross-sections over the Haripur area (For legend see fold-out at end of book)

under the bilateral Pak-Dutch programme. In 1982 Sheikh and Yasin published the first results, followed in 1985 by a comprehensive technical report (Sheikh, 1985). Twelve test holes were drilled by WAPDA between 1978 and 1981. On six of them well tests and step tests were carried out. The area on the right bank of the Dor river between Rajola and Sarai Saleh was not investigated.

Groundwater conditions

The groundwater conditions of the bedrock areas were not investigated. As the bedrock consists mainly of metamorphic rocks, it may be assumed that groundwater will only occur in small amounts in fractured zones and possibly in solution channels in limestone formations.

The alluvial fill is the main water-bearing formation. Over most of the plain it is 200 - 300 m thick. The thickness is less towards the mountains, and in the Dor valley it decreases upstream to less than 100 m near Chamba. The aquifer is formed by the lower part of the alluvial fill, which consists of sand, gravel and boulder deposits intercalated with clay lay-

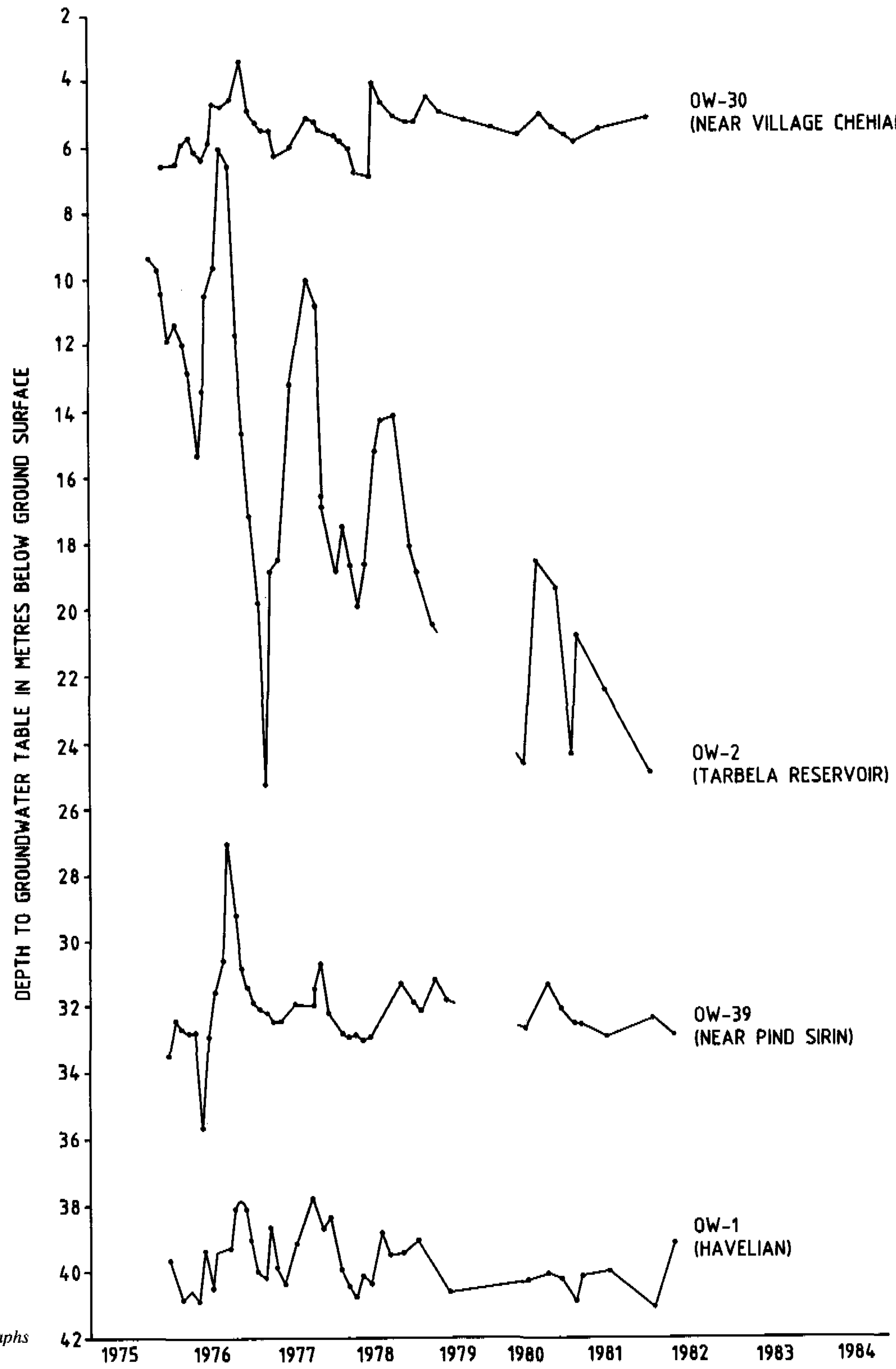


Figure 48: Groundwater hydrographs of the Haripur area

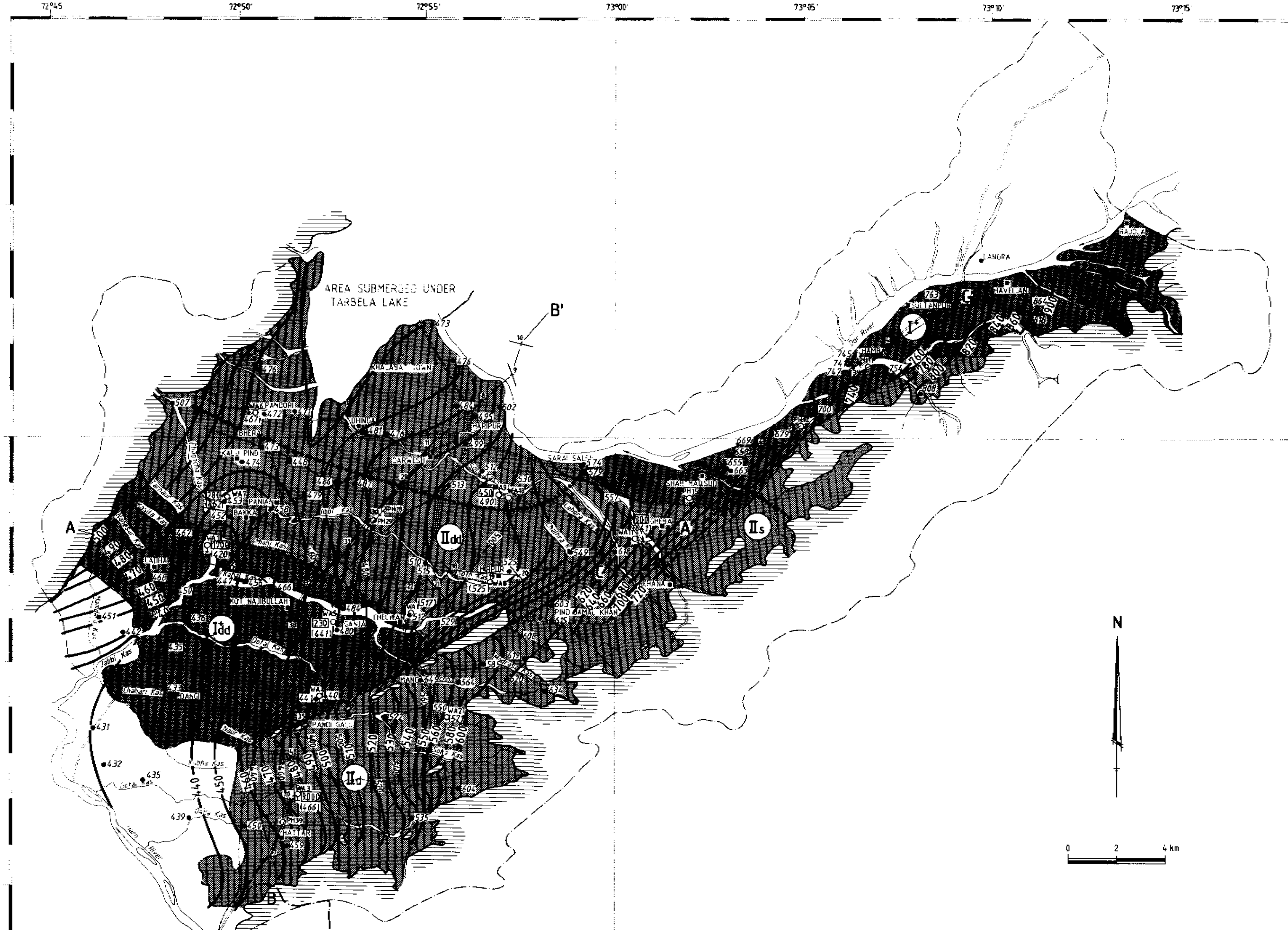


Figure 49: Groundwater map of the Haripur area (For legend see fold-out at end of book)

ers. It is 80 - 200 m thick. In the whole central part of the plain south and southwest of Haripur the aquifer is overlain by a clay layer 20 - 100 m thick with intercalations of sand and gravel beds. The composition of the unsaturated top layer varies from clay to boulders (Figure 47).

In the Dor valley the clayey upper part of the saturated zone is missing and the aquifer is unconfined. The transmissivity values must be quite high because most tubewells drilled in the valley have yields of 100 - 150 m^3/h (1.0-1.5 cusec). No transmissivity data are available from well tests. The average specific yield is expected to be about 0.10. In most of the valley the water table is at a depth of less than 30 m below land surface. According to Sheikh (1985), the river is influent upstream of Sultanpur and downstream of Sarai Saleh, i.e. it is losing water to the aquifer. In the area between Sultanpur and Sarai Saleh the river drains the aquifer, i.e. it is effluent.

In the main plain south of Haripur the deep aquifer is confined or semi-confined (leaky). Near the surface, shallow perched aquifers have been formed in gravel lenses intercalated in the unsaturated clay cover. The deep aquifer has its top at a depth between 55 and 120 m and the depth to the piezometric level varies from about 20 to nearly 80 m. The transmissivity values of this aquifer show a large variation, from less than 400 m^2/d to 9000 m^2/d. There are no data on the storage coefficient.

Little is known of the hydraulic characteristics of the shallow unconfined perched aquifers. No data are available on their transmissivity, nor on their specific yield. The depth to the water table is generally less than 30 m, except in the area north of the Kahal Kas and east of the road from Haripur to Taxila where the water table is at a depth of 30 - 60. The water table is generally at a much higher elevation than the piezometric surface of the deep, confined aquifer; locally the difference is as much as 50 m.

In the area adjacent to the mountains the alluvial fill is much thinner than in the central part of the plain; for example, in test hole WA-2 bedrock (shale) was reached at a depth of 97 m. In this part the deep confined aquifer is absent and groundwater occurs only in unconfined or leaky aquifers formed by the gravel intercalations in the thick clay series.

All the groundwater has a good chemical quality. The EC value is, with a few exceptions, less than 0.650 mS/cm. The water is of the calcium bicarbonate type and its SAR value is around 1.0, which makes it suitable for domestic use and irrigation.

Water level fluctuations

From late 1975 until 1982 WAPDA regularly measured the water levels in open wells. Until 1978 the measurements were taken monthly; thereafter quarterly. The seasonal fluctuations are sometimes more than 10 m, for example in the recharge areas close to the mountains and near Tarbela lake (see hydrographs OW-39 and OW-2 on Figure 48). Elsewhere the seasonal fluctuations are less, usually in the range of 1.5 - 2.5 m.

Groundwater flow

The watertable elevation contours are shown on Figure 49. They indicate three groundwater sub-basins:

- The Dor valley upstream of Shah Maqsud, which is drained by the Dor river,
- The Dor valley downstream of Sarai Saleh, which is drained by the Tarbela lake,
- The central plain including the Dor valley between Shah Maqsud and Sarai Saleh, drained by the Jabbi Kas and the Haro river.

The confined aquifer apparently drains towards the southwest. The flow pattern indicates that the main recharge takes place along the southeastern boundary and perhaps in the Tarbela lake area too.

Discharge and recharge

In his report Sheikh (1985) presents a quantitative assessment of the aquifer system of the Haripur area. However, he assumes that there is a single aquifer, while in reality there are two, one confined and the other unconfined.

The base flow of the Dor river measured at Rajola at the upstream end of the alluvial plain is approximately 45 Mm^3/yr. This corresponds to 13.3 per cent of the average annual rainfall over the catchment upstream of the gauging station.

The base flow measured at Sarai Saleh is approximately 66 Mm^3/yr, so the increment is 21 Mm^3/yr (23.5 cusec). This is a conservative value of the groundwater discharge, because it neglects the net amount of base flow diverted for irrigation, as well as the groundwater discharge by pumping. The areas contributing to the baseflow increment are the right bank area between Rajola and the bedrock outcrops at Sarai Saleh, and the left bank area upstream of Shah Maqsud. This area of 264 km^2 receives 285 Mm^3 rainfall annually. Consequently, the baseflow increment is equal to 7.4 per cent of the rainfall that the area receives.

The subsurface outflow of the confined aquifer in the southeastern part of the plain (i.e. the valley behind the hills along the line through Pandi Galu and Mang) is 23.4 Mm^3/yr if a transmissivity of 1500 m^2/d is allowed for. The discharge corresponds to 17 per cent of the rainfall in this valley and in the adjoining catchment.

The outflow from the confined aquifer of the northern and western parts of the main plain corresponds to the outflow over the piezometric contour line of 440 m above msl. It is 54.8 Mm^3/yr if a transmissivity of 1000 m^2/d is assumed.

The discharge by tubewells and open wells is estimated at 10 Mm^3/yr. Assuming that the recharge is the same as the discharge, it follows that the combined recharge from percolating rainfall and runoff water, and from percolation of water from the Dor river and the Tarbela reservoir, is approximately 65 Mm^3/yr (72.8 cusec).

The perched shallow aquifer is recharged by infiltrating rainfall and runoff. Its discharge components are: horizontal subsurface flow, vertical percolation into the confined aquifer and groundwater withdrawal through shallow wells.

Groundwater development potential

The Haripur area can be subdivided into areas with specific groundwater development charcteristics (Figure 49).

Area along the Dor river upstream of Sarai Saleh

The aquifer is unconfined, transmissivity is circa 800 m^2/d (Sheikh, 1985), depth to water ranges from 5 to 45 m, present groundwater extraction: 3 Mm^3/yr (3.4 cusec). Lowering the water table by pumping will induce recharge from the Dor river. Tubewells with a total depth not exceeding 100 m and a yield up to 250 m^3/h (2.5 cusec) can be installed. The recommended limit for a first-phase annual groundwater development is 10 Mm^3/yr (11.2 cusec).

Southeastern part of the main plain
The aquifer is unconfined in the upstream part of this sub-area, where the drilling depth is less than 100 m, the depth to water is less than 30 m and yields between 50 and 100 m^3/h (0.5 and 1.0 cusec) may be obtained. In the downstream part where the aquifer is confined, it is found below 85 m depth, transmissivity is high, the depth to water is more than 40 m, and tubewells with a yield of 50 - 100 m^3/h can be drilled. The recommended limit for the annual extraction during the first groundwater development phase in this sub-area is 10 Mm^3/yr (11.2 cusec).

The northern part of the main plain
In the northern part of the main plain the aquifer is confined and its top is at a depth of 75 - 120 m, the piezometric level is often at a depth of more than 60 m and the transmissivity is around 300 m^2/d. Yields of 100 m^3/h (1 cusec) can be obtained, but the pumping lift may be prohibitive. The recommended limit for additional groundwater extraction is 10 Mm^3/yr (11.2 cusec) at the start of further groundwater development.

The southwestern part of the main plain
The aquifer is confined and its top is at a depth of approximately 100 m. The depth to the piezometric level varies from 30 to 70 m. The transmissivities are high, more than 1000 m^2/d, and pumping rates can be 100 to 250 m^3/h but the pumping lifts may be very high. The recommended limit for additional groundwater extraction is 15 Mm^3/yr (16.8 cusec).

Groundwater management
The confined character of the aquifer and its deep piezometric level should be taken into account when further groundwater development is planned. Because of the complicated recharge and discharge conditions this area requires careful monitoring and additional investigation, including a study of the effects of the development of the shallow aquifer on the recharge of the confined aquifer. The groundwater conditions of the right bank of the Dor river also need to be looked into.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

ACE (Associated Consulting Engineers Ltd., undated, Siran Basin reconnaissance report, Technical report, circa 100 pp. and 5 app. *Annotation.* The central and north-eastern part of the Haripur area, which is drained by the Dor river, formed the southernmost part of the Siran river catchment before the construction of the Tarbela Dam. The Dor river now discharges directly in the Tarbela reservoir. This report contains a good general description but does not record the groundwater conditions.

Sheikh, A.G. and Mohd. Yasin, 1982. A note on ground water availability in Haripur plain, Abbottabad District, N.W.F.P. WAPDA Hydrogeology Directorate Peshawar; 14 pp., 3 tbls, 4 figs. *Annotation.* This note briefly describes the groundwater conditions. It is based on a well inventory and on the data from the drilling of eight test holes, their conversion into test wells and their testing, some unspecified geophysical work and stream discharge measurements; it also contains a list of 45 tubewells operating in the area and an estimate of their annual discharge. The conclusion is a recommendation for the development of 17.2 Mm^3 groundwater per year.

Qureshi, I.H. 1983a. Electrical resistivity survey in Khanpur (Dam) area. WAPDA Hydrogeology Directorate Peshawar; 2 pp., 5 figs. *Annotation.* A report with data on eight vertical electrical soundings and their interpretation.

Qureshi, I.H. 1983b. A note on electrical resistivity survey in Suraj Gali Area (Khanpur Dam). WAPDA Hydrogeology Directorate Peshawar; 2 pp., 3 figs. *Annotation.* Data and interpretation of five vertical electrical soundings.

Faiz, M. Akram, 1984. Electrical resistivity survey in Pind Jamal Khan (Haripur area). WAPDA Hydrogeology Directorate Peshawar; 2 pp., 2 figs. *Annotation.* The report contains the data and interpretation of four vertical electrical soundings.

Sheikh, A.G., 1985. Groundwater resources in Haripur area, Abbottabad District, N.W.F.P., Technical Report No. VI-1. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 45 pp., 5 app., 10 tbls, 9 figs and 6 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO-DGV during 1980/1982. It is based on fieldwork that included an inventory of an unspecified number of open wells and 49 tubewells, a resistivity survey of 79 vertical electrical soundings, the data from the test holes mentioned by Sheikh and Yasin (1982), chemical analysis of groundwater samples, watertable monitoring and streamflow measurements. A water budget and a recommendation for additional groundwater development are included.

Qureshi, I.H., Abdullah Mir Khan and Musharraf Jan, 1986. Electrical resistivity survey in Siri Kot Area. WAPDA Hydrogeology Directorate Peshawar; 2 pp., 3 figs. *Annotation.* Short report with the data and interpretation of 12 vertical electrical soundings.

10.4 THE GHAZI AREA

Location
The left bank floodplain of the Indus between the Tarbela dam and the Attock range is crossed by the provincial boundary that separates the North-West Frontier Province from the Punjab Province. The Ghazi area occupies the triangular-shaped portion of the floodplain and the adjacent catchment on the NWFP-side of this boundary; the part of the floodplain that lies in the Punjab is called the Hazro area (Attock District).
The Ghazi area lies in the southwestern corner of Abbottabad

District, between latitudes 33°56' and 34°04' N and longitudes 72°32' and 72°42' E. It is bordered in the west by the Indus river, in the east by the Gunger mountains and in the south by the Provincial boundary. The plain has an area of 72 km^2 and the adjacent catchment covers 186 km^2.

Physiography
The plain, which is fairly flat, is almost entirely covered by flood deposits, except near the mountains, where they are overlain by piedmont deposits. Away from the Indus river it rises at an average gradient of 0.001; the gradient is almost zero close to the river and becomes steeper in the piedmont area. The elevation of the plain varies from 315 m (1030 ft) above msl in the southwest to 380 m (1250 ft) above msl at the foot of the mountains. The highest point in the catchment area is 1000 m (3300 ft) above msl. Numerous gullies and ephemeral streams, locally called Darra, originate in the Gunger mountains and flow across the Ghazi plain to discharge into the Indus. In the southeastern part of the plain they deeply incise the piedmont deposits, causing badland topography, but they fan out when they reach the plain and percolate through the streambed.

Geology
The catchment area consists mainly of phyllites and slates with shale and limestone of the Precambrian Hazara Formation. In the north, near Tarbela, are outcrops of quartzite with graphitic layers of the Cambrian Tanawal Formation.
The valley of the Indus river of which the Ghazi plain is a part, is filled with more than 160 m Pleistocene and Holocene unconsolidated deposits that can be divided into river deposits and piedmont deposits. The river deposits, notably those of the palaeo-Indus, consist of layers of boulders, gravel and well-rounded coarse sand that were built up by ever changing braided river channels. They show perfect cut-and-fill structure in the outcrops of the deeply incised nalas. In the southwestern corner of the area, so-called overbank deposits of sand mixed with clay and silt are present.
The piedmont deposits are the erosion products of the adjacent highlands that form ill-sorted breccias composed of angular to subangular gravel mixed with sand or sand and clay. They merge into alluvial fans along the eastern hills and overlie the older flood deposits.

Climate
The Ghazi area has a climate of the sub-humid subtropical continental lowland type (Section 1.3). The average annual rainfall in the plain is approximately the same as the rainfall in nearby Tarbela (868 mm); the adjacent mountainous areas receives 20 per cent more. The mean monthly June temperature is 34.8°C and the January temperature is 12.3°C. The mean daily maximum temperature in June is close to 40 °C and in winter freezing has been observed. The potential evapotranspiration, calculated by the Thornthwaite method, is 1304 mm; calculated as 70 per cent of the class-A pan evaporation, it is 1686 mm.

Population and domestic water supply
The population lives mainly in the low area close to the river bank and probably exceeds 70,000. Domestic water and also some water for irrigation comes from open wells and, near the mountains, from springs.

Agriculture
The agricultural crops of the area are: wheat, maize, barley, oilseeds, tobacco, and vegetables. There are a few orchards where guava, apricot, pear and orange trees grow.
No soil survey data could be traced.

Groundwater investigations
The only groundwater investigations done in this area are those by WAPDA and TNO (Malik and Riaz, 1987). They included the drilling of nine test holes, six of which were converted into test wells.

Groundwater conditions
The bedrock consists mainly of impervious phyllites and slates. Groundwater may occur in small amounts in fractured zones in the quartzites of the Tanawal Formation and in fractured zones and solution channels in the limestones of the Hazara Formation.
The saturated part of the alluvial fill consists mainly of gravels and boulders intermixed with medium to coarse sand; in the southwestern corner the proportion of fine material is high. Clayey deposits constitute the dry top part. The depth to bedrock varies from a few metres near the mountains to more than 160 m near the Indus (Figure 50).
The aquifer is unconfined. Transmissivity values vary from 60 to 25,000 m^2/d. The exceptionally high values of more than 10,000 m^2/d are found where the alluvial deposits are well sorted, and free of either very coarse or very fine material. Low transmissivity values are caused by an abundance of large boulders or by an abundance of fine material, or by cementation of the deposit.
The specific capacity of the test wells varies from 1.6 to 1135 m^3/h per metre drawdown (2.18 - 1521 gpm/ft dd.).
In the well-sorted coarse parts of the aquifer the specific yield may be as high as 0.25, but in areas with a large amount of fine material it is expected to be less than 0.07.
According to Malik and Riaz (1987) the total groundwater storage in the area is 862 Mm^3.
The depth to the water table ranges from less than 5 m close to the Indus river to more than 30 m near the mountains. The quality of the water is good; it is of the calcium bicarbonate type and the EC value is not more than 0.850 mS/cm.

Water level fluctuations
Groundwater level data are too few to allow definite conclusions to be drawn on the cause of the fluctuations in groundwater level, but it is expected that they are related to infiltration of rainfall and runoff as well as to the level of the Indus.

Groundwater flow
Figure 51 shows the groundwater level elevation contours, from which it may be concluded that between Ghazi and Qazipur the groundwater flows from north to south. South of Qazipur the southward flow is met by a northward flow that comes from the Punjab, and both turn west and discharge into the Indus.

Recharge and discharge
The calculation of the recharge components of the aquifer

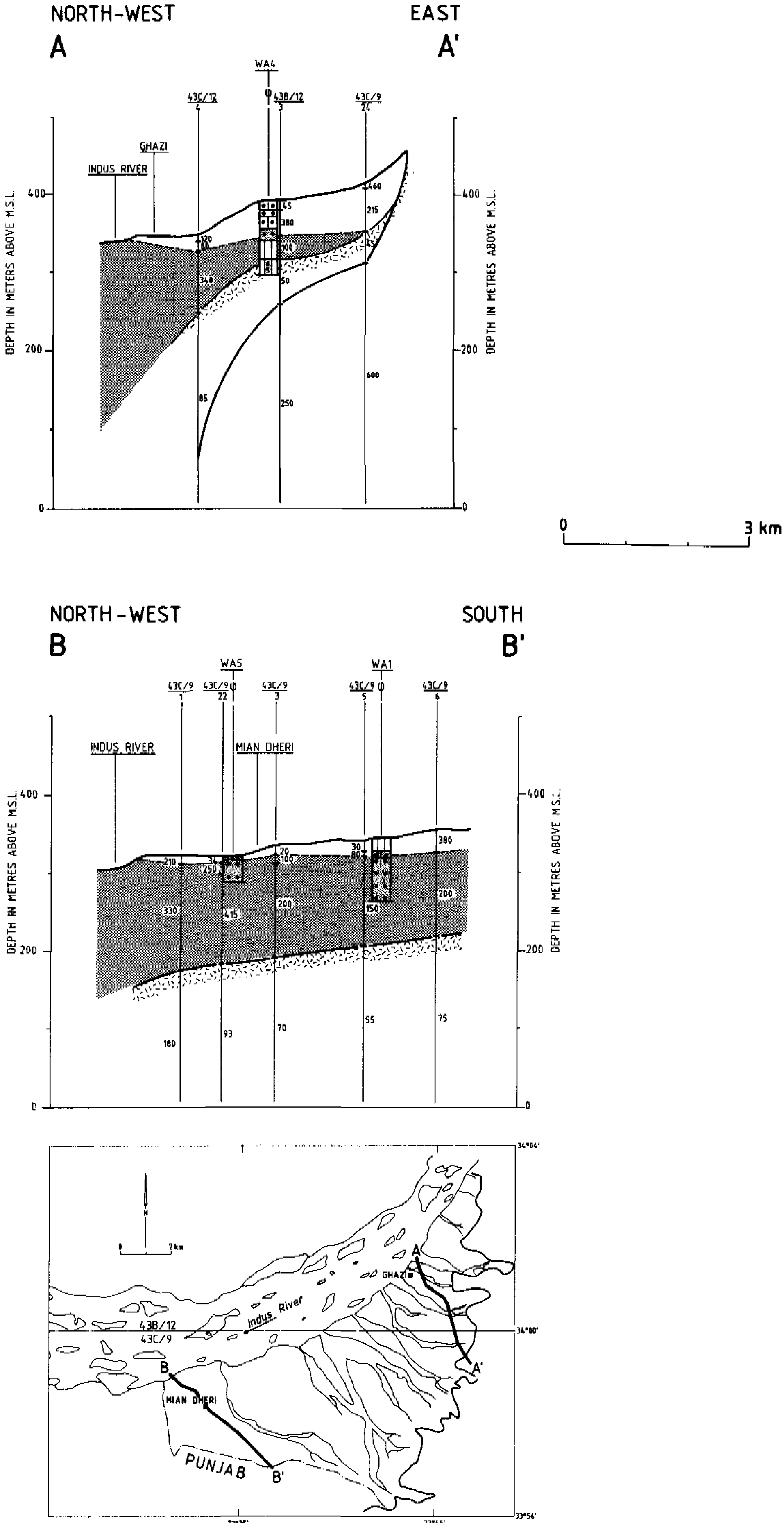


Figure 50: Hydrogeological cross-sections over the Ghazi area (For legend see fold-out at end of book)

system by Malik and Riaz (1987) shows the following:

Subsurface inflow from the deposits below the present streambed	35 Mm³/yr
Subsurface inflow from the south	18
Return flow of groundwater used for irrigation	1
Water recharging the aquifer by percolation in the piedmont area	4
Total	58 Mm³/yr

The recharge by percolation of rainfall and runoff in the piedmont area corresponds to only 2 per cent of the rainfall over the catchment; this seems low.

The discharge components are difficult to estimate, because the available data are insufficient to calculate the subsurface outflow toward the Indus. There are also insufficient data to calculate the evapotranspiration in the waterlogged areas.

The following estimates were made by Malik and Riaz (1987):

Subsurface outflow to the deposits below the present streambed of the Indus downstream of Qazipur	38 Mm³/yr
Groundwater withdrawal by pumping	10.5
Groundwater evapotranspiration in the waterlogged areas	6.5
Total	55 Mm³/yr

Groundwater development potential

Over most of the Ghazi area tubewells that may often yield as much as technically possible, may be constructed. Also, the amount of groundwater extracted annually can be at least as high as the present annual recharge, say 60 Mm³/yr (67 cusec). Any lowering of the water table will induce an in-

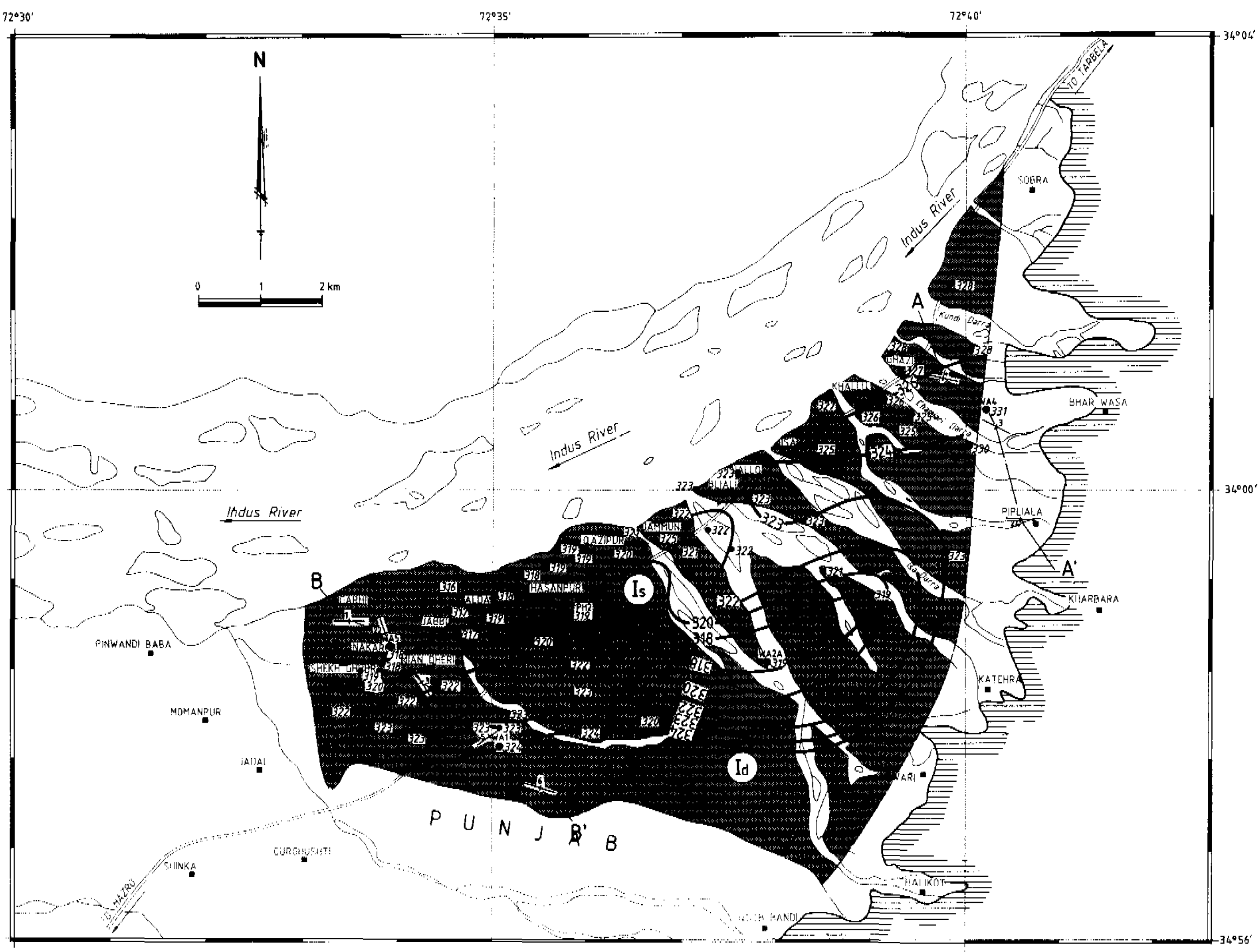


Figure 51: Groundwater map of the Ghazi area (For legend see fold-out at end of book)

creased replenishment by subsurface inflow from the Indus river through the highly transmissive aquifer.

Groundwater management
No special management practices are required, but an inventory of the water production and of the watertable data, say every five years, is recommended.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Malik, Moh. Y and Moh. Riaz, 1987. Groundwater Resources in Ghazi area, Abbottabad District, NWFP, Technical Report no. VI-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 32 pp., 5 app., 8 tbls, 10 figs and 4 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO-DGV during 1985/1987. The fieldwork included an inventory of 400 open wells; a resistivity survey of 28 vertical electrical soundings; drilling of nine test holes of which the only rotary drilled hole was geophysically logged but the log was lost, six holes were converted into test wells in which pumping tests were carried out; water sampling for chemical analysis and watertable monitoring. A tentative groundwater balance of the area is included.

11 THE INTERMONTANE BASINS OF PESHAWAR AND MARDAN DISTRICTS

11.1 GENERAL

The Peshawar and Mardan Districts lie astride the Great Trunk Road, which crosses northern Pakistan from the Indian border, through Lahore and Rawalpindi to the bridge over the Indus river at Attock and onwards by way of Nowshera (Mardan District) and Peshawar to the Khyber pass and to the frontier with Afghanistan at Tokam. Together the two Districts cover 7138 km^2, 9.6 per cent of the total area of NWFP, and they have an estimated population of 5.0 million, circa 35 per cent of the total population of NWFP.
The Peshawar and Mardan Districts comprise three intermontane basins: the Peshawar Vale, the Nizampur area, and the Gadoon plain. The Peshawar Vale, which covers 85 per cent of the two Districts is economically by far the most important region of the North-West Frontier Province. Its hydrogeology and groundwater resources are described in Section 11.2. The hydrogeology and groundwater resources of the Nizampur area, which is located in the southeastern part of Peshawar District and of the Gadoon plain in the northeastern part of Mardan District are presented in the Sections 11.3 and 11.4, respectively.

11.2 THE PESHAWAR VALE

Location
Peshawar Vale is located between latitudes 33°40' and 34°35' N and longitudes 71°15' and 72°45' E. It is 6270 km^2 in area. Administratively the Vale includes most of the Peshawar and Mardan Districts. The Vale comprises the Charsadda, the Nowshera and the Peshawar Tehsils in Peshawar District, and the Mardan and the Swabi Tehsils in Mardan District. Peshawar Town, the Administrative Headquarters of the North-West Frontier Province is located in the southwestern part of the Vale.

Physiography
The Peshawar Vale is surrounded by hills on all sides, except in the southeast where it is bounded by the Indus river.
Most of the Vale is fairly flat with gentle slopes; the average elevation is 300 m (1000 ft) above msl. Near to the mountains the land is more undulating and here the elevation rises to 500 or 700 m (1600 or 2300 ft) above msl. Some slopes are very steep and most are bare and sometimes severely eroded.

The following physiographical units are distinguished:

Piedmont plain
Piedmont deposits are exposed in the southwestern part of the Vale. Near the boundaries of the plain they consist of coalesced alluvial fans, which are often deeply dissected by hill torrents.

Floodplain
Floodplain deposits are predominant on the Daudzai Doab between the Kabul and Swat rivers, along certain stretches of the Kabul river, and along the Indus river.

Loess plain
Loess deposits cover the piedmont deposits in the central part of the plain west of Charsadda and north of the Kabul river.
There are four important rivers in the Vale. The main one is the Kabul river that drains almost the whole Vale. It enters the plain near Warsak in the west and discharges into the Indus, 4 km downstream of Jehangira. It divides the Vale into a northern and southern part. The Swat river enters the plain in the northwest near the village of Munda Qila and discharges into the Kabul river, near the village of Charsadda. The Bara river flows from the south and near Jhansi Post it enters the Vale, whose southwestern part it drains. The flow of the Bara river is diverted by private canals and is used as drinking and irrigation water. Any excess water discharges near Charsadda into the Kabul river. In winter it carries little water. Kalpani Nala arises in the Vale itself, and drains a large area in the north of the Vale; finally it discharges into the Kabul river 5 km downstream of Nowshera.
Besides these four rivers there are several perennial and non-perennial nalas that contribute to the drainage of the Vale. Most discharge into the Kabul river. In the east some nalas drain directly into the Indus.

Geology
The area now covered by the Peshawar Vale was originally part of the Indogangetic foredeep. Some 2.3 million years ago it became an intermontane basin, when the uplift of the Attock ridge cut off the northwestern corner of the Indogangetic plain (Burbank and Tahirkheli, 1985).
The Vale is surrounded by ridges of rocks ranging in age from Precambrian to Tertiary. (Rafiq et al., 1983). Igneous rocks like granites and seyenites and metamorphic rocks like gneiss and schists are common along the northern and northeastern boundary (Kempe and Jan, 1979). In the south and

west the rocks are consolidated sediments, such as sandstones, shales and limestones formed during the Mesozoic and Lower Tertiary. The consolidated basement rock of the Vale itself consists of Tertiary molasse deposits (Section 2.2). According to Nizami (1973), the Peshawar area was transformed into a lake several times during the Middle Pleistocene, when the outflow of the Indus river was blocked. The lake deposits show alternating sandy and silty layers. At some places loess is intercalated between different lacustrine strata, indicating a dry period between two lake periods. The lake must have been quite extensive, since its deposits are even encountered near Matanni, high up the southern piedmont. When the area was properly drained, sandy to silty alluvial deposits were formed by the shifting rivers and by the sheet wash that brought the runoff to the rivers. Several erosion cycles since the Middle Pleistocene have been recognized. During that time much of the loess cover was removed.

Climate

The climate ranges from the semi-arid subtropical continental lowland type in the western part to the sub-humid subtropical continental lowland type in the eastern part of the Vale (Section 1.3). The meteorological station of Peshawar, with 340 mm rainfall, is typical of the first type and that of Mardan, with 630 mm, is typical of the second type. In Peshawar the hottest months are June and July, with an average daily maximum temperature of 40°C; the coldest month is January when the average daily minimum temperature is about 0°C. The mean annual potential evaporation is approximately 1200 mm in Mardan and 1500 mm in Peshawar.

Population and domestic water supply

Peshawar Vale has a total population of 4.6 million people (1987 estimate; excluding Afghan refugees) and it includes the two largest towns of NWFP: Peshawar Town with approximately 1.5 million and Mardam town with nearly 0.3 million inhabitants. It is the most urbanized part of the Province, with nearly 50 per cent of the working population employed in the non-agricultural sector.

The domestic water supply in the Vale is largely served by groundwater. In the rural areas open wells are mainly used to satisfy domestic needs. To supply the major towns and villages the Public Health Engineering Department (PHED) had, up to 1986, drilled 209 wells and brought them into production. The town of Peshawar has approximately 150 tubewells. The exact locations of the water supply tubewells have not been inventoried, neither are data available on the total amount of water that is pumped for domestic use. Assuming that the per capita use of the urban population is 50 l/d and that of the rural population is 25 l/d, the estimated total groundwater withdrawal for domestic use reaches 24 Mm^3/yr for the urban areas and 37 Mm^3/yr for the rural areas.

Industrial Water Supply

With 156 registered industries Peshawar Vale is the most industrialized area of NWFP. These industries need water for washing and cooling, and not for industrial processes. Hence, some of the water returns to the aquifer. No exact figures are available on the groundwater use by industry, but it may be assumed that the water consumption by this sector is negligible, compared with domestic and agricultural use.

Agriculture

In Peshawar Vale only 53 per cent of the working population from the age of ten and onwards (i.e. 610,000) is employed in agriculture. The cultivated area is approximately 400,000 ha (1 million acres), of which 65 per cent or 260,000 ha (650,000 acres) is irrigated. Table 28 shows the areas irrigated by different sources of water. They can be divided into two types: surface-water irrigated and groundwater irrigated areas. They are discussed below:

Irrigation with surface water

Surface water irrigation depends on rivers. It began centuries ago when farmers started to dig small canals, locally known as Kathas, close to the rivers. The Jue Seikh canal, constructed in the 17th century by the Moghul Emperors, was the first large canal in the Vale. In that period several more were constructed, tapping the Kabul, Swat and Bara rivers. All these canals only carried water during periods of high river discharges in summer.

In the 19th century the construction of perennial canals was started. Headworks were built in the river to control the water level.

The Lower Swat Canal (1885) takes off from the left bank of Swat river at Munda Qila headworks in the northwest of the Vale. Its commanded area (CCA) lies between Charsadda and Mardan town and is 54,200 ha (135,500 acres).

The Upper Swat Canal (1914) takes off from the left bank of Swat river at Amandara Canal headworks in the Swat Valley. It enters the Vale through a 3400 m long tunnel near Dargai. There it bifurcates into the Abazai branch, which commands 28,000 ha (70,000 acres) in the northwest of the Vale and the Machai branch, which commands 84,000 ha (210,000 acres) in the north and east.

Table 28: Area irrigated by different sources in Peshawar Vale, for 1983-1985 (10^3 ha)

District	Total area	Barani	Irri-gated	Canals govt.	Canals priv.	Tube wells	Other wells	Other source
Peshawar	195.4	52.7	143.8	87.5	46.6	3.0	3.2	3.5
Mardan	203.1	86.9	117.3	98.4	-	0.4	14.6	3.9
Total	398.5	139.6	259.1	185.9	46.6	3.4	17.8	5.4

The Kabul River Canal (1895) takes off from the right bank of the Kabul river near Warsak. It feeds the Jue Seikh Canal, and together they have 31,200 ha (78,000 acres) under command between Peshawar and the Kabul river.
The Warsak High Level Left Bank Canal (1968) takes off from the left bank of Kabul river just upstream of the Warsak Dam. It enters the Vale through a 600 m long tunnel and its command area lies in the Doaba between the Kabul and Swat rivers.
The Warsak High Level Right Bank Canal (1969) takes off from the right bank of the Kabul river opposite the Left Bank Canal and flows through a 5700 m long tunnel to the Vale. At the end of the tunnel part of the water is lifted 48 m to feed the Lift Canal while the rest flows through the Gravity Canal. The CCA of 108,300 ha (271,000 acres) lies between the Lift Canal and the Kabul River Canal.
The Pehur Main Canal (1956) takes off from the right bank of the Indus river 8 km downstream of Tarbela Dam. It has a CCA of 17,870 ha (45,700 acres), lying on both sides of the canal.
The private canals and Kathas are situated in the south and west of the Vale. They irrigate the area between the Kabul and Swat rivers, certain areas on the right bank of the Kabul river, and a command area of 46,000 ha (115,000 acres) astride the Bara. No figures are available on the discharge of these canals.

Groundwater-based irrigation
Since time immemorial wells have been dug, and later drilled, at places in the Vale with a shallow water table. In dug wells the water is raised by Persian weels or centrifugal pumps and in tubewells by turbine pumps or underwater pumps for small-scale irrigation. The use of groundwater for irrigation is still largely privately controlled and restricted to locations where the water table is at a shallow depth.
Most of the innumerable open wells used for irrigation are found in Mardan District. Their exact number is unknown, because no recent inventory of the dug wells in the Peshawar Vale is available.
The first tubewells were drilled in 1960. It is not known how many private tubewells are used for irrigation. The Irrigation Department operates 190 tubewells, including those of the Peshawar and Mardan SCARPs. The latter are needed to alleviate the waterlogging and salinity by vertical drainage. The performance of these wells is tested every year by the Tubewell Monitoring Division of WAPDA. The quality of the pumped water is good, so the water can be used for irrigation.

In the absence of observations on the groundwater withdrawal for irrigation, Robberts (1988) made an estimate of the total groundwater withdrawal (Table 29) under the following assumptions:
- the total area irrigated by groundwater is 21,200 ha (53,000 acres);
- half of the total area is cropped during Rabi and half during Kharif;
- the efficiency of the water use is 75% during Rabi and 90% during Kharif. The irrigation demand for these efficiencies is calculated in Table 29.

The water lost due to inefficient use percolates back to the groundwater. This means that the net groundwater withdrawal equals the total water demand and is 101 x 10^6 m^3/yr.

Groundwater investigations
Figure 52 shows the areas that have been investigated since 1960, some of them more than once. Only the most recent investigation is shown.
Groundwater research started in the early 1960s in the Mardan area, mainly because of the waterlogging problems there. Siddiqi (1972) reported on the studies carried out up to 1970 and Sajjad (1983a) added the results from the 1970s. The area between Charsadda and Mardan Town is being investigated under Mardan Scarp project by WAPDA in cooperation with a Canadian drainage team (Broughton, 1984).
From 1963 to 1974 several reports were written about the right bank of the Kabul river. The area north of Peshawar was investigated because of waterlogging problems, while the area south of this town was studied in relation to the construction of the Warsak Right Bank Canals. Basic Data Release no. 11 (Sajjad, 1983b) contains a compilation of the results of these studies.
Since 1980, some groundwater research in the Peshawar Vale has been carried out by WAPDA and TNO under the Pak-Dutch cooperation programme. The investigations in Maira area (Bloemendaal, 1985) and in Bazai area (Yousuf, 1987) are already finished, while at the time of writing those in the Warsak uncommanded area are still in progress. The Heroshah area is being investigated as part of the Pak-Dutch project Groundwaterbased Irrigation Development in Provincially Administered Tribal Areas (PATA Project).

Groundwater conditions
With the exception of a few isolated outcrops, the bedrock of Peshawar Vale lies too deep to play a special role in the groundwater behaviour. Along the edges of the plain minor

Table 29: Calculation of annual groundwater withdrawal for irrigation

No.	Description	unit	Rabi	Kharif
1.	Water demand	m	0.160	0.786
2.	Water demand	m^3/ha	1.6 x 10^3	7.86 x 10^3
3.	Cropped area	ha	10.7 x 10^3	10.7 x 10^3
4.	Total water demand (2x3)	m^3	17 x 10^6	84 x 10^6
5.	Efficiency	-	0.75	0.90
6.	Pumped volume (4:5)	m^3	23 x 10^6	93 x 10^6
7.	Percolation losses (6-4)	m^3	6 x 10^6	9 x 10^6

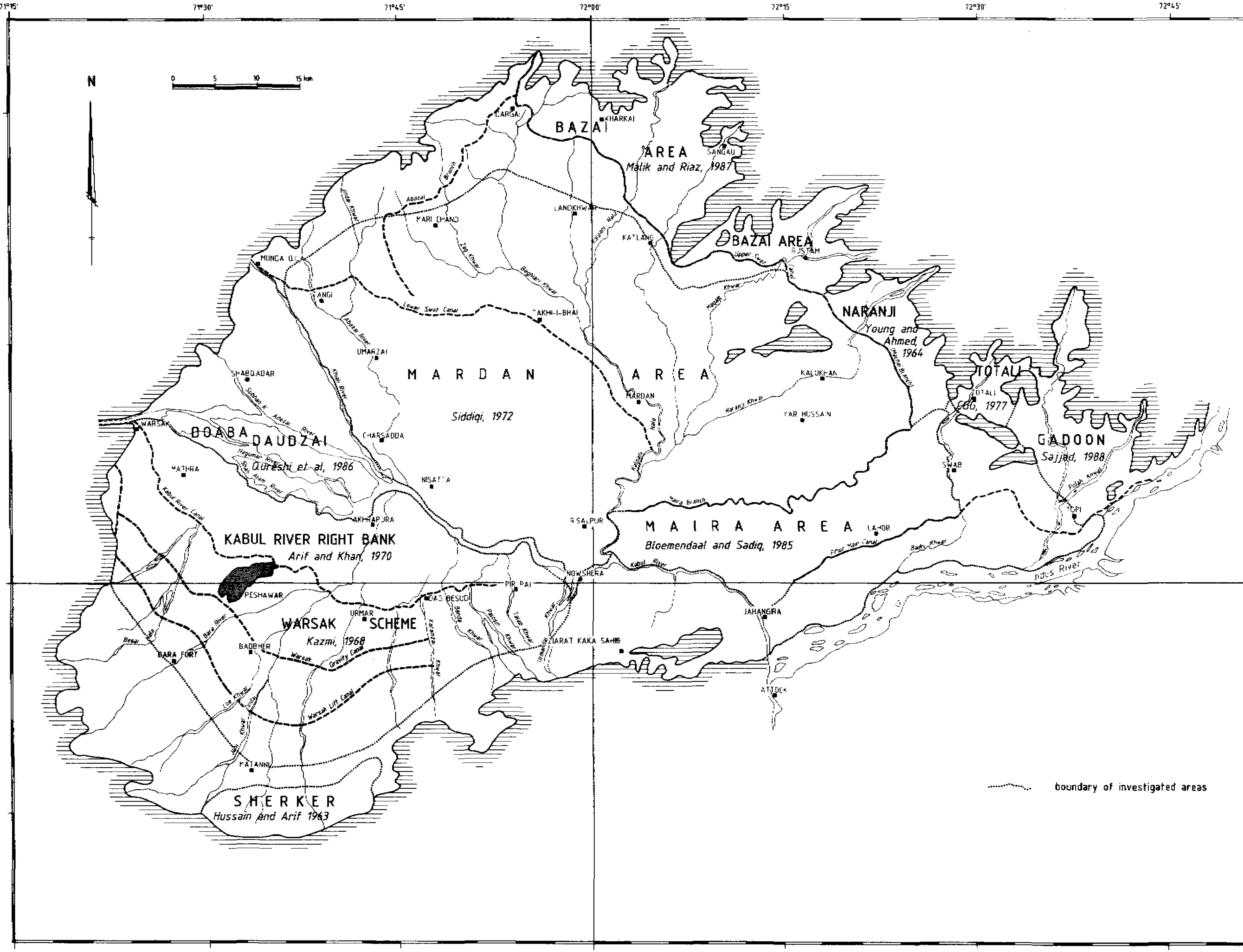


Figure 52: Groundwater investigations in the Peshawar Vale

springs arise from the bedrock. It may be safely assumed that there is no significant subsurface outflow from the surrounding mountains into the alluvial fill.

The alluvial fill of the central part of the plain contains a relatively large proportion of fine material such as sandy silt and fine sand. Coarse deposits of sand and gravel are generally found near the mountains in the western part of the Vale and along the rivers. They form the main aquifer. Comparison of the aquifer thickness and the transmissivity values indicate that there is a fair correspondence between the thickness of the coarse layers in the first 125 m below the surface, and the transmissivity and specific capacity.

The cross-sections (Figures 53 and 54) show the distribution of the coarse layers. The stratification differs from borehole to borehole and at first it seems that coarse layers occur only as lenses and that they are not interconnected. However, the absence of significant changes in the groundwater level over short distances is an indication of hydraulic continuity between the gravel layers and consequently it may be assumed that the gravel and sand layers are hydraulically interconnected and form a large regional aquifer.

Semi-confined aquifer conditions prevail over most of the plain and in the areas where the topographic gradient is steep and the transmissivity of the deep aquifers rapidly decreases as the result of a diminishing average grain size, the piezometric level rises above the land surface. As a consequence, many boreholes are free flowing or "artesian".

In a large number of boreholes water samples for chemical analysis have been taken at different times and at different depths. The results of the analyses can be found in: Basic Data Releases nos. 11 and 14 (Sajjad, 1983[a] and [b]). The EC of the water from the tubewells is generally below 1.0 mS/cm. The water in the southwest of the Vale is of the calcium and magnesium bicarbonate type. North of the Kabul river the main cation is sodium and the main anions are bicarbonate and chloride. Samples taken in 266 shallow open wells on the right bank of the Kabul river give an average EC value of 1.35 mS/cm. In Mardan District hydrochemical data on 22 shallow open wells show an average EC value of 1.30 mS/cm. Generally, the dominant cations are calcium and sodium; bicarbonate is the predominant anion.

Local pollution of the wells and an increase in the groundwater salinity caused by direct groundwater evaporation in the waterlogged areas may cause the EC values of individual groundwater samples to greatly exceed the average value.

Groundwater levels

The depth to the water table decreases from 30 or 40 m near the mountains to less than 0.5 m along the Kabul river where waterlogged conditions prevail.

In 1967 Malik published a report about the water table in the Peshawar Vale. He used data collected since 1920 in 88 wells, which had been measured once or twice a year, and data from 107 wells located throughout the Vale, which had been observed monthly from May 1963 until July 1966. The long-term series showed that the water table had risen since the start of the observations. It also indicated that groundwater levels react to losses from the irrigation canals and to the different stages of the rivers. Rainfall does not have much influence on the groundwater levels. In waterlogged areas the influence of evapotranspiration on the water table could be recognized.

No network for groundwater level monitoring is at present operational.

Groundwater flow

Figure 55 shows the position of the watertable contours indicating the elevation of the water table in metres above sea level. The map is based on data from different reports prepared at different times and is therefore imprecise. Nevertheless, the general shape of the contours is believed to be correct. The groundwater flow, which is by definition perpendicular to the contours, is towards the Kabul river. This river drains the groundwater body when the streambed level is below the groundwater level, as is the case downstream of the confluence with the Swat river. Upstream of the confluence it is likely that the Swat and Kabul rivers are influent, i.e. they are losing water to the groundwater body by infiltration. In the eastern part of the Vale the groundwater flows away from the slight rise on which the Maira branch of the upper Swat canal is constructed. Although percolation losses from this irrigation canal may have influenced the groundwater level configuration, it is believed that there is a subsurface ridge of impervious material that deflects the water from the north towards the southwest, towards Mardan town. The groundwater that occurs south of the Maira branch flows southwards to the Indus or more or less parallel to this river towards its confluence with the Kabul river.

Recharge

The recharge of the groundwater body occurs mainly at the edges of the plain where, along the mountain ridges, the alluvial fill consists of coarse material with high infiltration and percolation rates. In the central part of the plain, notably in the area between Mardan and the Kabul river, irrigation water losses undoubtedly contribute to the groundwater recharge. Robberts (1988) has made the following tentative estimate of the recharge:

Direct percolation of rainfall 4% of 600 mm over 6270 km^2	=	151 Mm^3/yr
Percolation losses from irrigation with surface water 60% of total losses (40%) of total diversion (3 060 Mm^3/yr)	=	734 Mm^3/yr
Percolation losses from groundwater-based irrigation according to Table 29, item 7	=	15 Mm^3/yr
Percolation of runoff water 20% of 60 mm over the piedmont area of 2630 km^2	=	23 Mm^3/yr
Subsurface inflow	=	nil
Total		923 Mm^3/yr

Discharge

The discharge of the groundwater takes place mainly as surface water flow after exfiltration in and along the downstream part of the Kabul river and its tributaries. Additional amounts are discharged by subsurface outflow into the Indus valley, by pumping for irrigation, drainage, domestic use and industrial purposes and by direct evaporation from the

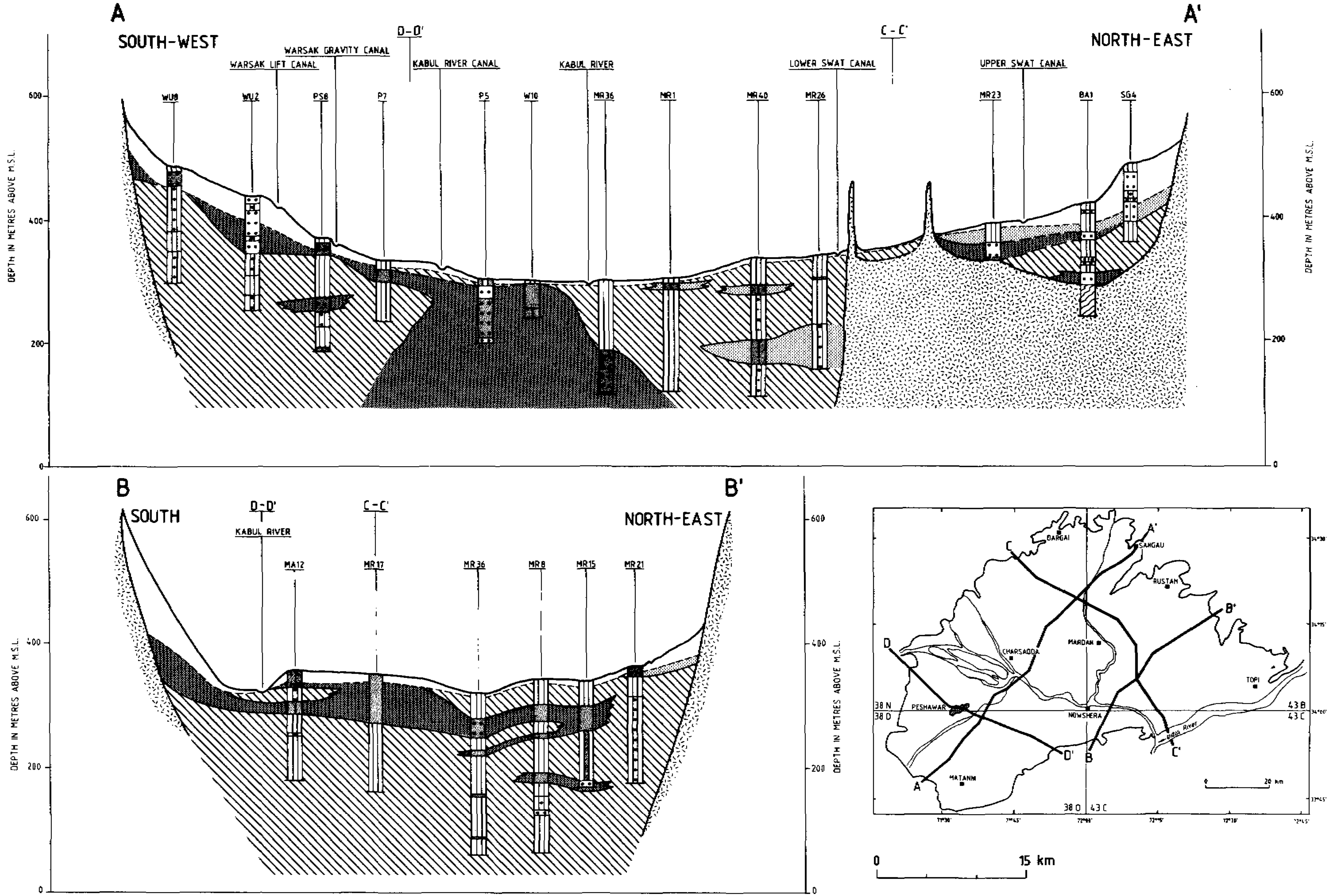


Figure 53: Hydrogeological cross-sections A - A' and B - B' over the Peshawar Vale (For legend see fold-out at back of book)

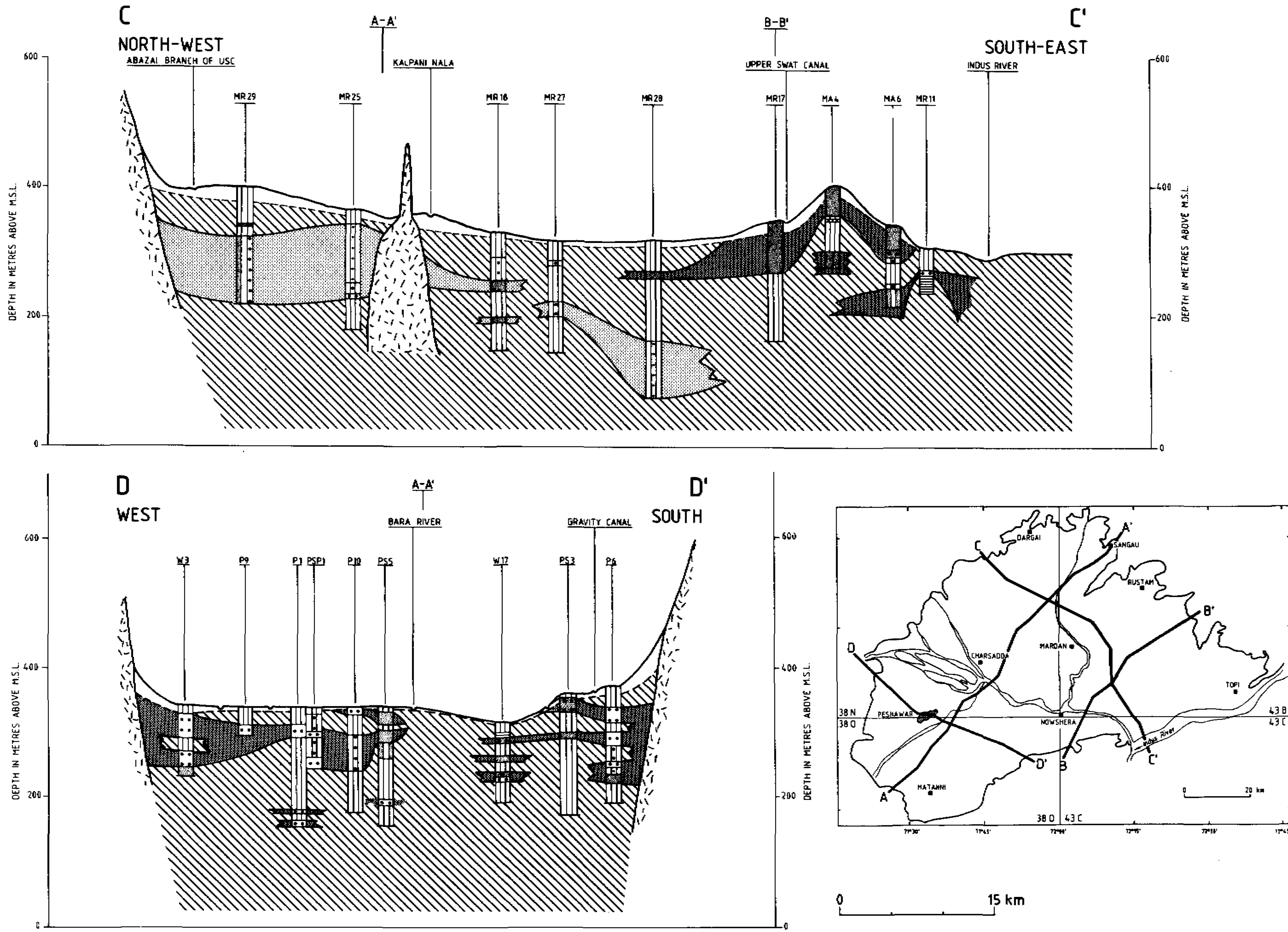


Figure 54: Hydrogeological cross-sections C - C' and D - D' over the Peshawar Vale (For legend see fold-out at back of book)

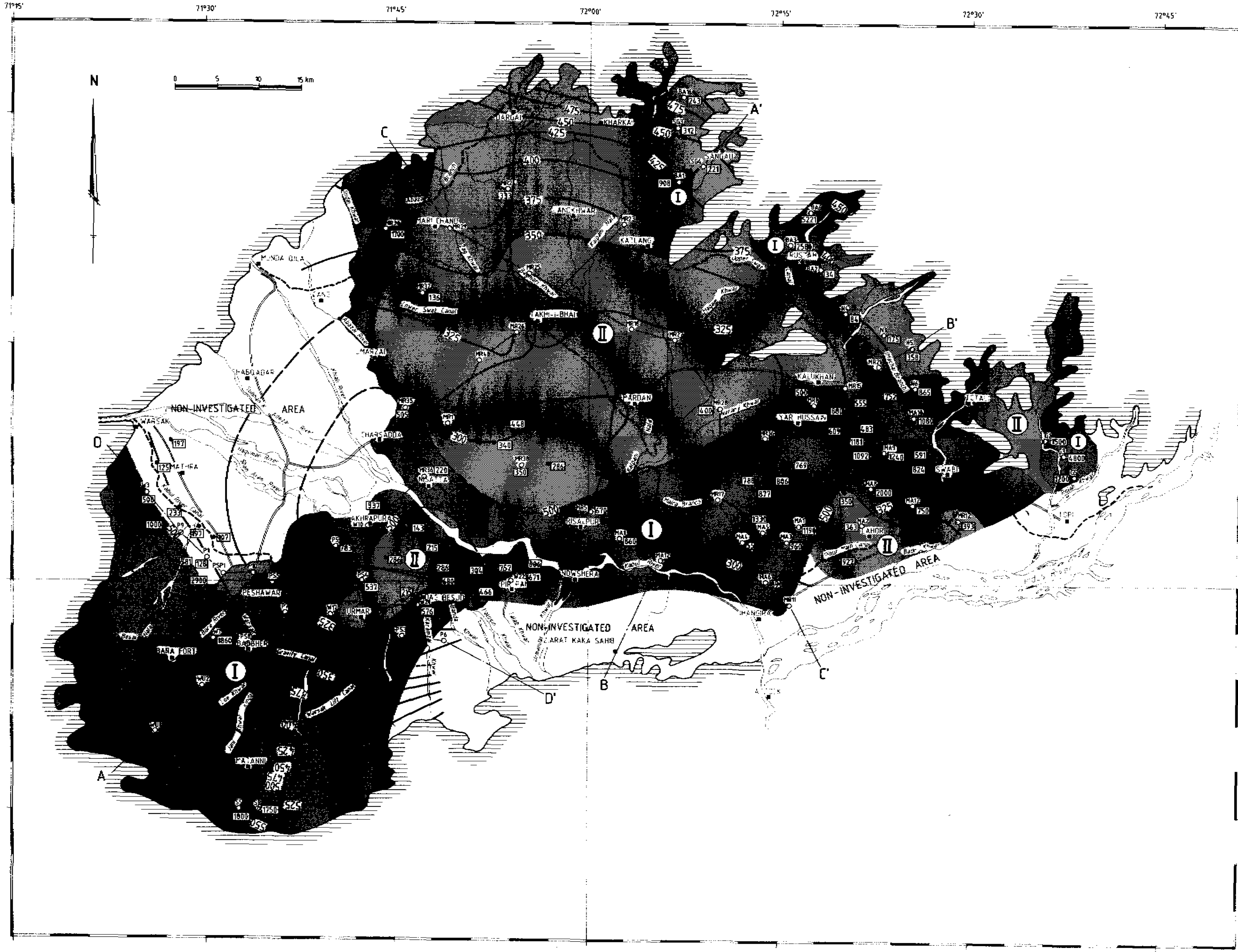


Figure 55: Groundwater map of the Peshawar Vale (For legend see fold-out at back of book)

SCARP areas. Robberts (1988) has made the following tentative estimate of the groundwater discharge:

Discharge as surface water (base flow)	=	701 Mm^3/yr
Subsurface outflow into the alluvium of the Indus river	=	12 Mm^3/yr
Groundwater withdrawal for irrigation	=	116 Mm^3/yr
Groundwater withdrawal for domestic and industrial purposes	=	61 Mm^3/yr
Groundwater pumped for drainage purposes and discharged in the surface waters	=	unknown
Groundwater evaporation in the SCARP areas	=	1 Mm^3/yr
Total		891 Mm^3/yr

Groundwater development potential
In Peshawar Vale enough water is available to allow the installation of more tubewells. Figure 55 shows the areas with a high transmissivity that probably have a good potential for groundwater development by tubewells to continue. The groundwater discharge by wells is small compared with the total discharge. Further groundwater development will cause local decline of the water table or the piezometric level and subsequently a decrease of the discharge to the rivers. However, for a proper evaluation of the groundwater development potential a groundwater assessment study must be made of the entire Peshawar Vale.
Recent investigations indicate a development potential of at least 33 Mm^3/yr (37 cusec) for the Maira area (Bloemendaal and Sadiq, 1985). This is 50 per cent of the recharge. The development potential of the Baizai area is much smaller. Only the Rustam and Sangau valleys have substantial aquifer systems and they receive recharges in the order of 17 and 21 Mm^3/yr (19 and 23.5 cusec), respectively. Malik and Riaz (1987) recommend that groundwater development should not exceed this amount.

Conjunctive use of surface water and groundwater
Shortage of water for irrigation is a common phenomenon in the Vale especially during Kharif, even in the command areas of the surface water irrigation system. A detailed survey of the actual water distribution is needed to identify the locations that suffer most. Groundwater may provide supplemental irrigation water.
On the other hand, in many places the water table is rising as a result of the irrigation with canal water; this will result in waterlogging, a decrease in crop yield and, eventually, in soil salinization. In such areas water table control is required. As there is no risk of upconing of deep saline groundwater this may be realized by vertical drainage, i.e. drainage by wells. The pumped water can be discharged in the canal system to augment its supply or it may be used to irrigate soils uncommanded by the canal irrigation system. Technical and economic feasibility studies are required to indicate whether horizontal or vertical land drainage systems are best.

Development of domestic water supplies
The demand for domestic water supply systems is likely to grow because of the multiplying population and the rising levels of prosperity. This not only means that more people have to be served, but also that the per capita consumption will increase, especially in the towns, where the number of house connections will augment.
In rural areas, open wells with handpumps or centrifugal pumps can serve the demand for water where the water table is not too deep and where a scattered population makes a tubewell economically unattractive.
Tubewells exploit the deep groundwater, which is of good quality and more suitable for domestic use than the water in open wells, which is sometimes contaminated. For village water supply systems a tubewell with a production capacity of 25 m^3/h (0.25 cusec) is sufficient for the needs of 500 - 1000 inhabitants.
Large wellfields with high capacity tubewells that are protected against groundwater contamination are most suitable to supply the towns.

Groundwater management
Peshawar Vale is the area in NWFP with the highest economic development, increasingly efficient agriculture, and rapid urbanization, all leading to a growing demand for safe water supply systems. Fortunately, Peshawar Vale has ample surface water and groundwater resources, which, when properly managed, can meet future demands.
The quantitative aspects of the groundwater flow in Peshawar Vale as a whole must be assessed, to provide a scientific basis for groundwater development planning in such a way that the people will benefit most. The assessment study should include a detailed evaluation of the recharge and discharge conditions, and of the interaction between surface water and groundwater. The first step in such a study is setting up and properly maintaining a groundwater level monitoring network.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Cobb, E.H., 1931. North-West Frontier Province Gazetteer, Peshawar district, vol. A.
Hussain, A. and A.H. Arif, 1963. Geohydrology of the Sherkera area, West Pakistan, WASID/WAPDA; 28 pp., 8 tbls, 10 figs. *Annotation.* The results of a groundwater investigation carried out by WASID from 1960 to 1962. Five test holes were drilled and pumping tests were carried out in two of them.
WAPDA, Directorate of planning and investigation, 1963. Sherkera tubewell irrigation project, P&I publ. no. 27, Lahore; 18 pp., 7 tbls, 4 pl. *Annotation.* Project planning report that contains a summary of groundwater investigations. Five test holes were drilled, two of which were converted into tubewells for test pumping. The results of the pumping tests are included, as well as some information on

groundwater levels, an estimate of the stored volume of water and annual recharge, and a table of chemical analysis results. Details were presented in a WASID report which could not be traced.

Young, H.L. and E. Ahmed, 1964. Geohydrology of the Naranji area, NWFP, (not published), WAPDA/WASID preliminary report no. 3; 48 pp., 5 tbls, 13 figs. *Annotation.* This report gives the results of a groundwater investigation programme carried out by WASID from 1962 to 1963. The investigation consisted of a field survey, the drilling of six test holes, the installation of five test wells, water quality measurements; an estimate of the development potential was made.

Khan, M.A., 1965. Groundwater investigations in Sangau area, West Pakistan, WAPDA/ WASID; 30 pp., 3 tbls, 9 figs. *Annotation.* This report gives the results of a groundwater investigation programme carried out by WASID from 1963 to 1964. It consisted of a field survey, the drilling of seven test holes, the installation of two testwells, groundwater level measurements and water quality analysis.

WAPDA, 1965.Reconnaissance report Kabul-Swat-Chitral basin, Appendix "A": Hydrology, P&I publ. no. 37, Lahore; 15 pp., 77 tbls. *Annotation.* This publication contains the precipitation and river disch arge data for the Kabul, Swat and Chitral basins. The meteorological and gauging stations are described.

Dichter, D., 1967. The North West Frontier Province of Pakistan, a study in regional geography, Clarendon press, Oxford; 211 pp., 21 figs. *Annotation.* This book gives a good description of the geography of NWFP. One chapter is devoted to the Peshawar Vale.

Malik, M.S., 1967. Records of groundwater levels of Peshawar Vale, West Pakistan, WASID/WAPDA, Basic Data Release no. 12, Lahore; 18 pp., 8 tbls, 19 figs. *Annotation.* This report presents the results of a watertable investigation in the canal commanded areas of the Peshawar Vale carried out by WASID from 1963 to 1966. The irrigation development is described. The report also contains the water level data from 88 wells measured once or twice a year from 1920 to 1963. The report is a good database of the groundwater levels in the Vale. It was published in a very limited number and the illustrations are not available.

WAPDA, Directorate of planning and investigation, 1967. A brief discussion of Warsak High Level Canals, P&I publ. no. 25, Lahore; 33 pp., 9 tbls, 5 figs. *Annotation.* This publication gives information about the water supply and water demands of the command area of the Warsak high level canals. The lack of water to supply the canals was already recognized at this stage (before the opening of the canals). A calculation of irrigation requirements and losses is included.

Kazmi, S.A.T., 1968. Groundwater investigation in Warsak reregulating reservoir scheme area, WASID bull. no. 16, Lahore; 61 pp., 6 tbls, 24 figs., 4 app. *Annotation.* A description of the results of a groundwater investigation carried out by WASID from 1963 to 1968. The investigation consisted of a field survey, the drilling of 15 test holes, and five aquifer tests. The appendices give basic data on groundwater levels, all known borehole logs and chemical analysis in the project area.

Arif, A.H. and M.A. Khan, 1970. Groundwater investigations on the right bank of the Kabul river, Peshawar Valley, with emphasis on waterlogging problems. WASID publ. no. 84, WAPDA/WASID bull. no. 17, Lahore; 58 pp., 8 tbls, 21 figs, 4 app. *Annotation.* This report gives the results of a groundwater investigation carried out by WASID. The report is based on Kazmi, 1968. Some additional studies focusing on the waterlogging problems were carried out.

Siddiqi, M.R., 1972. Groundwater hydrology of Mardan area. Reclamation division, WAPDA, Lahore; 72 pp., 13 tbls, 16 figs. *Annotation.* This is a presentation of the results of groundwater investigations carried out by WAPDA from 1968 to 1970. The investigations consisted of a field survey, the drilling of 38 test holes, and 12 aquifer tests. Much useful information is contained in this report which was never officially published. Only a few photocopies of the text remain. The original illustrations could not be traced but the reports by Naqavi, 1970 and Sajjad, 1983 have reproductions of them.

Nizami, M.M.I., 1973. Reconnaissance soil survey of Peshawar Vale (revised), Soil Survey of Pakistan, Lahore, Pakistan; 165 pp., 6 figs. *Annotation.* This report gives a good overall picture of the soils of the Vale and their potential for agricultural development. The geological history of the Vale is described.

WAPDA, Project planning organization (N.Z.), 1973. Project report Peshawar SCARP, P&I publ. no. 12, Lahore; 97 pp., 57 tbls, 30 app. *Annotation.* This report gives the programme of the Peshawar SCARP. Part of the project was the installation of tubewells for vertical drainage. The report is the complete description of the development scheme, from problem analysis to economic feasibility study. A groundwater balance and a groundwater development survey are included.

Naqavi, S.A.H., 1974, Ground water investigations in NWFP. Ground Water Department WAPDA Peshawar; 13 pp. *Annotation.* A brief account of groundwater investigations carried out by West Pakistan WAPDA in NWFP during 1960/1974.

Naqavi, S.A.H. and L. Hamadan, 1978. Planning report of Mardan SCARP, app. C: Groundwater resources, WAPDA, Planning Directorate, Peshawar; 37 pp., 1 tbl., 12 figs. *Annotation.* Description of groundwater resources in Mardan SCARP areas, based on Siddiqi, 1972. No new investigations were carried out. The illustrations are useful.

Faiz, M.A., 1983. A note on electrical resistivity survey conducted in Mardan township area, Hydrogeology Directorate, WAPDA, Peshawar; 2 pp., 2 figs. *Annotation.* Report on 27 soundings.

Sajjad, A.M., 1983a. Hydrogeological data of Mardan area, vol. 1, Basic Data Release no. 14, WAPDA Directorate-general of Hydrogeology, Lahore; 27 pp., 6 tbls, 5 figs. *Annotation.* Hydrogeological data of Mardan area, vol. 1. This report is a compilation of several reports concerning the hydrogeology of the Mardan area. The information is mainly taken from Siddiqi, 1972 and Malik, 1967. No new fieldwork was carried out.

Sajjad, A.M., 1983b. Hydrogeological data of Peshawar Valley, vol. 1, Basic Data Release no. 11, WAPDA Directorate-general of Hydrogeology, Lahore; 132 pp., 3 tbls, 7 figs, 14 app. *Annotation.* Hydrogeological data of Peshawar Vale, vol. 1. This report is a compilation of the data from the following reports dealing with the right bank of the Kabul river: WAPDA, 1963, Sherkera tubewell irrigation project, Malik, 1967, Kazmi, 1968, and some previously unpublished data. Much useful information is included, such as: borehole logs, pumping test results, and water quality measurements.

Ullah Khan, H., 1983. Evaluation report of Peshawar SCARP. WAPDA, Monitoring and Evaluation publ. no. 9, Lahore; 163 pp., 65 tbls, 10 figs. *Annotation.* Evaluation of Peshawar SCARP from Pre-project until 1979-1980. Discusses hydrology, tubewell performance, water quality, soils, agriculture and agricultural economics. Describes the different characteristics of a waterlogged area and the effects of vertical drainage. No borehole logs or other hydrogeological data are presented. A new evaluation report is in preparation (oral communication).

Faiz, M.A., 1984. Electrical resistivity survey in Cherat cement factory. Hydrogeology Directorate, WAPDA, Peshawar; 2 pp., 12 figs. *Annotation.* Report on 10 soundings.

Ullah, H.G.M., 1984. Tubewell performance report on pilot project scheme Yar Hussain Sharif area Mardan, for the year 1982-1983, Hydrologic Monitoring Division, WAPDA, Peshawar, Monitoring and Evaluation Publ. no. 43; 12 pp., 4 tbls, 1 fig.

Bloemendaal, S. and M. Sadiq, 1985. Groundwater resources in Maira area, Mardan and Peshawar districts NWFP, Technical Report IX-1, Hydrogeology Directorate WAPDA, Peshawar, Pakistan and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 36 pp., 11 tbls, 9 figs, 5 pl., 5 app. *Annotation.* Technical report on groundwater resources in Maira area. The results of a WAPDA/TNO-DGV groundwater investigation carried out in 1983/1985. The investigation consisted of a well inventory, electrical resistivity survey (51 soundings), the drilling of 13 boreholes, geophysical well-logging, 12 aquifer tests, and a groundwater budget calculation.

Faiz M.A., 1985. Electrical resistivity survey in Risalpur locomotive factory area. Hydrogeology Directorate, WAPDA, Peshawar; 5 pp., 2 figs. *Annotation.* Report on 23 soundings.

Qureshi, I.H., 1985. Electrical resistivity survey in Kharkai village, Mardan. Hydrogeology Directorate, WAPDA, Peshawar; 2 pp., 10 figs. *Annotation.* Report on 8 soundings.

Qureshi, I.H., 1985. Electrical resistivity survey in Warsak dam power house colony. Hydrogeology Directorate, WAPDA, Peshawar; 2 pp., 5 figs. *Annotation.* Report on 6 soundings.

Qureshi, I.H., 1986. Electrical resistivity survey in Doaba Daudzai area. Hydrogeology Directorate, WAPDA, Peshawar; 8 pp., 1 tbl., 5 figs. *Annotation.* Report on 114 soundings.

Qureshi, I.H., 1986. Electrical resistivity survey in Tappa Mohmand and Khalik area, Hydrogeology Directorate, WAPDA, Peshawar; 8 pp., 1 tbl., 10 figs. *Annotation.* Report on 37 soundings.

Malik, Y.M. and Moh. Riaz, 1987. Groundwater resources in Baizai area, Mardan District and Malakand Agency, NWFP, Technical Report IX-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 38 pp., 5 app., 10 tbls, 5 figs and 6 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO-DGV during 1985/1987. It is based on fieldwork that included an inventory of 1370 open wells; a resistivity survey of 135 vertical soundings; the drilling of 16 test holes, ranging in depth from 50 to 200 m, 12 of which were geophysically logged (SN and LN resistivity, SP, and gamma) and 9 of which were converted into test wells used for pumping tests; water sampling for chemical analysis, groundwater level monitoring and stream gauging. The evaluation includes water balances of each of the valleys. A recommendation about the groundwater development has been added.

Khan, R.A., 1987. Draft reports tubewell performance 1985-1986 in Pabbi unit I and II, Warsak gravity canal unit, Jue Seikh unit, Kafur Dehri unit, SCARPS monitoring. Tubewell and Groundwater Monitoring Division, WAPDA, Peshawar; 64 pp., 16 tbls, 8 figs.

Robberts, J.H., 1988. Groundwater in the Peshawar Vale, Peshawar District, Mardan District and Malakand Agency, NWFP, Technical Report V-2. WAPDA Hydrogeology Directorate Peshawar and TNO Institute of Applied Geoscience, Delft, The Netherlands; (in print). *Annotation.* The report is the result of a desk study of the available reports dealing with groundwater investigations and groundwater development in Peshawar Vale.

11.3 THE NIZAMPUR AREA

Location

Nizampur area in the southeastern corner of Tehsil Nowshera, Peshawar District, is located between latitudes 33°45' and 33°52' N and longitudes 71°54' and 72°15' E.

Physiography

The Nizampur area consists of an alluvial plain with its long axis running east-west, bordered on the northern and western sides by mountain ranges. The plain is undulating and is dissected by a denditric network of gullies that discharge into the Indus, which forms the southern and eastern boundaries. The catchment of the plain is 420 km^2 including 200 km^2 occupied by the plain itself. The plain slopes from north to south with an average gradient of nearly 2 per cent. Outcrops of bedrock form part of the southern boundary, and west of Kahi village they divide the plain into two parts, each with its own groundwater system.

Geology

The catchment area covers parts of two mountain ranges:
(1) The Cherat range in the north, which separates the Nizampur area from the Peshawar Vale; it consists of low grade metamorphic rocks of Palaeozoic origin such as phyllite, slate, quartzite and limestone (Hussain, 1977).
(2) The Kala Chitta range in the south consists mainly of Tertiary rocks, such as limestones and shales of Palaeocene and Eocene age and alternating beds of red and purple clay and sandstone of the Miocene. The whole area is intensely folded and faulted. Thrust faulting and strike slip faulting are common. The latter may have caused the formation of the intermontane depression of Nizampur between the two

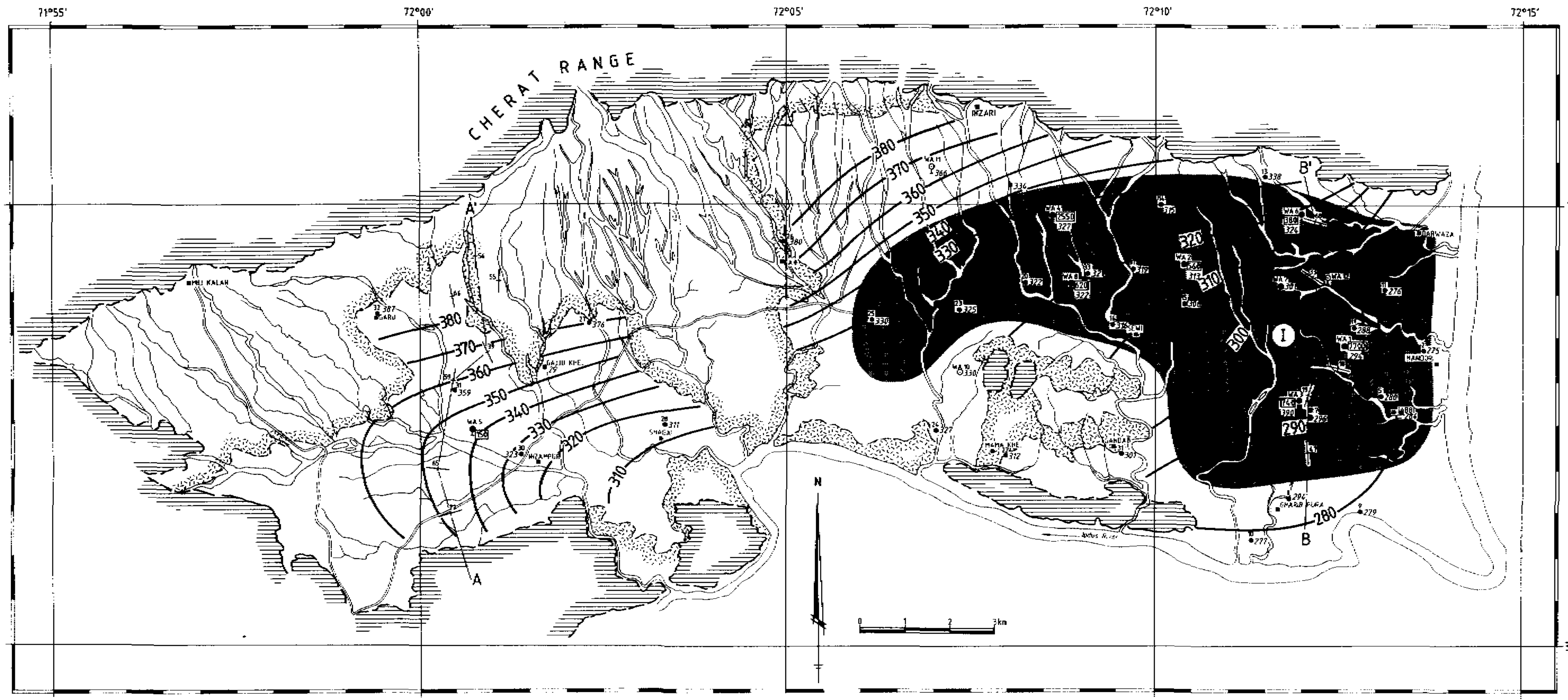


Figure 56: Groundwater map of the Nizampur area (For legend see fold-out at back of book)

mountain ranges. The depression is filled with alluvium, which can be classified as piedmont and floodplain deposits. The former are derived from the eroded material from the adjacent mountains, which has been transported to the depression by stream floods and sheet wash during or shortly after rainstorms. They are a mixture of boulders, gravel, sand of varying sizes, silt and clay. The floodplain sediments are finer-grained. They consist of sand, gravel, silt and clay deposited by overbank flooding of the Indus river. Although they are relatively young, the river has already incised them and the present stream bed is several metres below the (abandoned) floodplain.

Climate
The climate is of the sub-humid subtropical continental lowland type (Section 1.3). The annual rainfall is approximately 600 mm and is concentrated in two wet seasons: one with a peak in March, and the other with a peak in July/August. The annual potential evaporation is approximately 1300 mm.

Population and domestic water supply
The population is approximately 40,000. The people obtain their domestic water supply mainly from open wells; 31,000 m^3/yr in the eastern part and 11,000 m^3/yr in the western part. In the latter some of the wells are fitted with centrifugal pumps that provide not only domestic water but irrigation water as well. Along the mountains a few springs of low discharge supply the local drinking water and also water for smallscale irrigation. In the eastern part of the area near Inzari and Kahi the Public Health Engineering Department (PHED) has installed tubewells that yield 0.15 Mm^3/yr.

Agriculture
Agriculture is the main economic activity. Groundwater-based irrigation has developed locally, but most farmers depend on the scanty rainfall for a Rabi crop of wheat and barley. Some irrigation water is available locally from tubewells installed by the Irrigation Department and from open wells. In the eastern part tubewells supply 0.49 Mm^3/yr and dug wells contribute 0.41 Mm^3/yr, but the western part of the area has dug wells only, with a total annual yield of 0.40 Mm^3.

Groundwater investigations
The only hydrogeological study of the area has been done by WAPDA under the Pak-Dutch project for Groundwater Investigations in NWFP. The study started in 1980 and resulted in a preliminary note by Ghulam Akbar (1982) and a Technical Report based on a draft by Abdul Ghafar Sheik (1985). The fieldwork encompassed an inventory of 407 open wells and 6 tubewells, and an electrical resistivity survey of 86 vertical soundings with an electrode distance of 600 - 1000 m. Twelve test holes were drilled: in three of them a geophysical well-log was made and all test holes were sampled for lithological and water quality analysis. Eight test holes were converted into test wells and seven of them were actually test pumped to determine the hydraulic characteristics of the aquifer.

Groundwater conditions
The aquifers of the eastern and western parts of the area are described separately because the impervious hillocks west of the village of Kahi form an effective subsurface watershed (Figure 56).
In the eastern part of the Nizampur area the intermontane depression is filled with heterogeneous alluvial deposits with relatively few clay layers (Figure 57). The deepest layers often show very high resistivity values (110 -160 ohm-m): this may indicate the presence of large boulders or of cemented gravel, both of which have a low permeability. Excluding this layer the saturated thickness of the aquifer is at least 150 m. The groundwater occurs mainly under unconfined conditions at depths ranging from 5 m below the surface near the Indus river to 60 m near the mountains. The transmissivity values range from 380 - 7700 m^2/d; they have been calculated from pumping test data. Based on the lithological data the specific yield is estimated as 0.08 - 0.18.
In the western part of the Nizampur area, a layer of about 18 m sand and gravel overlies a 60 - 160 m thick layer of sandy clay with gravel and boulders. This sequence forms the roof of a deep aquifer that has its top at a depth of 120-180 m below the surface and has a saturated thickness of approximately 100 m.
This aquifer is under semiconfined (or leaky) conditions and therefore its storage coefficient will be in the order of 10^{-3} to 10^{-4}; the only pumping test indicates a transmissivity of 143 m^2/d.
An unconfined aquifer is found in the pervious near-surface layers. Its water table is generally between 3 and 10 m below the surface. The average saturated thickness is only 10 m and the transmissivity must be relatively low. The estimated specific yield of the upper aquifer is 0.15.
The groundwater is of good quality and it is of the calcium bicarbonate type. Its EC value ranges from less than 0.5 to 1.1 mS/cm. Groundwater from the bedrock may show higher EC values because of a high sodium chloride and sulphate content.

Water level fluctuations
Groundwater levels were monitored in 32 open wells for 18 months. The water levels were highest in March because of the combination of recharge and non-withdrawal of irrigation water, and lowest in June and July. The greatest fluctuations, up to 6 m, were recorded close to the mountains, indicating large-scale percolation along the foothills.

Groundwater flow
The watertable contours on the groundwater map (Figure 56) show that the groundwater flows from the mountains towards the Indus. The amount of groundwater flow can be calculated with Darcy's law, when the groundwater gradient and the transmissivity values are known. The flow rates through the alluvial fill in the eastern part along the mountain ranges and along the Indus were calculated. They were 8.1 Mm^3/yr and 19.0 Mm^3/yr, respectively. This indicates a considerable recharge over the whole area, not only near the mountains.
In the western part, the groundwater outflow was calculated as 3.0 Mm^3/yr.

Discharge and recharge
In the eastern part of the area the groundwater discharge consists of:

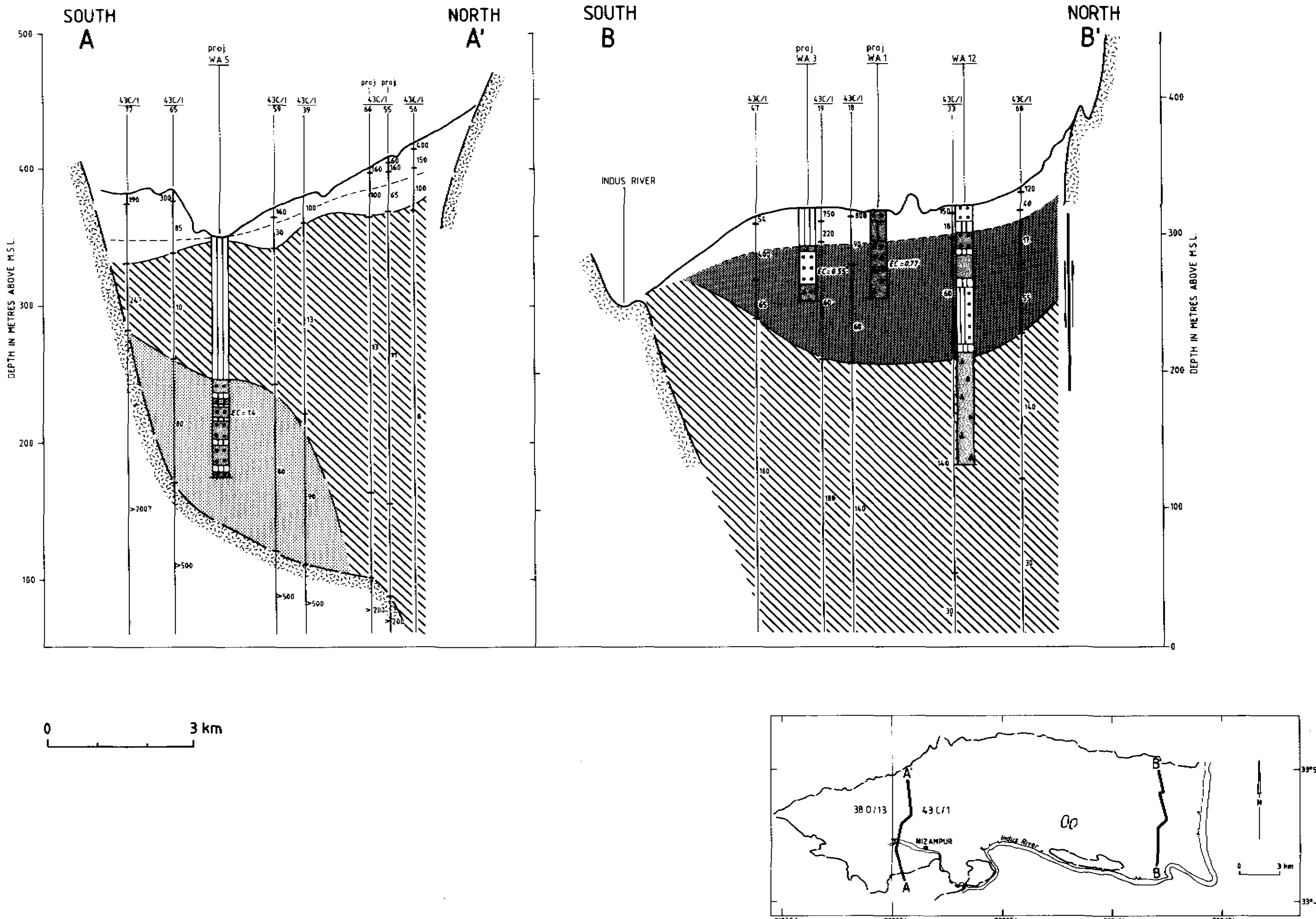


Figure 57: Hydrogeological cross-section over the Nizampur area (For legend see fold-out at back of book)

- Subsurface drainage (This includes both the subsurface outflow and the exfiltration into the lowermost parts of the nalas and in the riverine zone of the Indus)	19	Mm^3/yr
- Estimated groundwater withdrawal by pumping	1.1	
- Evaporation of groundwater at very shallow depth	0.1	
Total	20.2	Mm^3/yr

and the recharge consists of:

- Percolation along the mountain front (calculated with Darcy's law)	8.1	Mm^3/yr
- Percolation over the lower part of the plain (calculated as the difference between total outflow and the recharge along the mountains)	12.1	
Total	20.2	Mm^3/yr

The calculated recharge over the eastern part of the plain would correspond to a percolation of approximately 120 mm rainfall or 20 per cent of the annual total. This seems quite high.
In the western part of the area the groundwater discharge consists of:

- Subsurface drainage	3.0	Mm^3/yr
- Estimated groundwater withdrawal by pumping	0.4	
Total	3.4	Mm^3/yr

There are insufficient data to enable the groundwater recharge to be estimated independently. If it is assumed that the average annual recharge equals the average annual discharge of 3.4 Mm^3/yr (3.8 cusec), this would correspond to a percolation of 110 mm rainfall or 18 per cent of the annual total; this seems quite high too.

Groundwater development potential
The eastern part of the Nizampur area has good prospects for groundwater exploitation in an area of approximately 70 km^2 (Figure 56) where the water table is at a depth between 20 and 50 m and the transmissivity varies from 7700 - 380 m^2/d. The annual recharge of 20 Mm^3/yr (22.4 cusec) will satisfy the irrigation requirements of an area of 6000 ha (15,000 acres). Considering that the soil and slope conditions make large tracts of land unsuitable for irrigation it is obvious that the irrigation requirements of the good soils in the centre of the eastern part of the Nizampur area can easily be met.
In the western part the transmissivity of the deep confined aquifer is rather low and the top of the aquifer is at a depth of 120 - 180 m below the surface. Consequently, the exploitation of the deep aquifer will be expensive and therefore the prospects for development of the groundwater resource are not very good. The water supply requirements in this area should be met by pumping from shallow wells that are dug into the shallow unconfined aquifer that overlies the thick clay series.

Groundwater management
Prior to large-scale drilling of new boreholes a groundwater flow model should be made, to assist planning. The new well sites should be selected in such a way that the best yields can be obtained for the lowest increase in pumping lift, i.e. with the lowest permanent drawdown. A groundwater level observation network will be required to monitor the influence of the pumping on the groundwater regime.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Akbar, Ghulam. (1982). A note on the groundwater availability in Nizampur area, Peshawar District, N.W.F.P. WAPDA Hydrogeology Directorate Peshawar; 9 pp., 1 tbl. and 5 figs. *Annotation:* The report briefly presents the results of the first investigation period 1980/1981.

Sheikh, Abdul Ghaffar. (1985). Groundwater Resources in Nizampur area, Peshawar District, N.W.F.P. Technical Report No. V-1. WAPDA Hydrogeology Directorate Peshawar and TNO Institute of Applied Geoscience, Delft, The Netherlands; 30 pp., 5 app., 11 tbls, 2 figs, 5 pl. *Annotation.* Report on the results of the investigations carried out by WAPDA and TNO during the period 1980/1981 and in 1984. The report comprises a groundwater budget based on extensive fieldwork that included a general well survey of 407 open wells and 6 tubewells, drilling of twelve test holes of which eight were converted test wells and seven of them were actually testpumped. Furthermore, a electrical resistivity survey of 86 vertical soundings, and the chemical analysis of groundwater samples are described. The report of Abdul Ghafar Sheikh contains a soil moisture balance based on monthly average rainfall figures. This is now considered an unrealistic approach and is therefore not followed in this book.

11.4 THE GADOON PLAIN

Location
The Gadoon Amazai area comprises a mountainous area in the north and an alluvium filled plain, the Gadoon plain, in the south. It lies between latitudes 34°05' and 34°20' N and longitudes 72°32' and 72°45' E. The plain, which covers an area of 48 km^2, is part of the Tehsil Swabi of Mardan District. The catchment covers 155 km^2. The Gadoon plain is bordered in the south by the Peshawar Vale (Section 11.2), in the west by the Totali area (Section 9.3.4); in the north its catchment stretches all the way to the catchment of the Chamla river (Section 9.3.2), and in the east a mountain

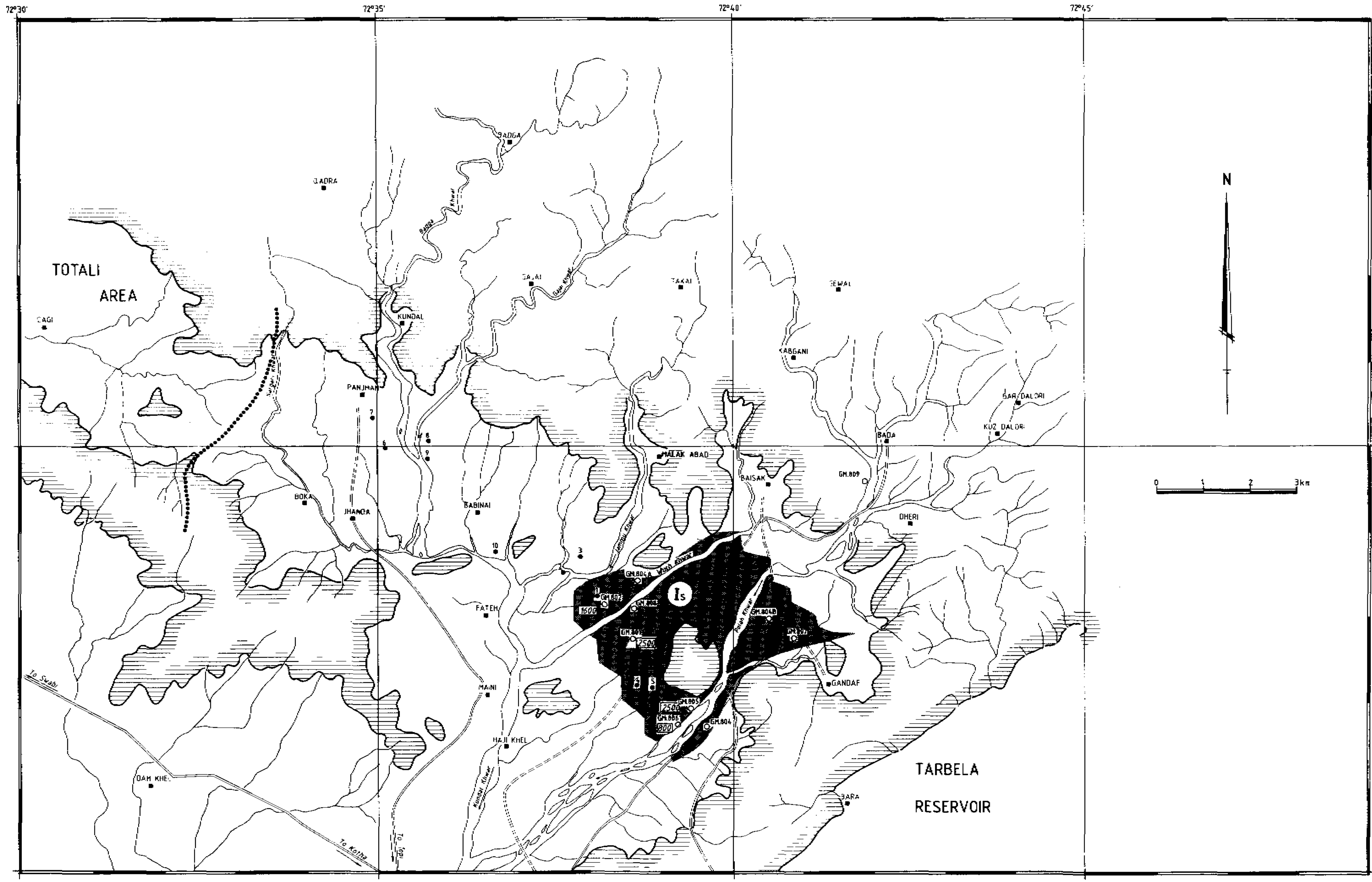


Figure 58: Location map of the Gadoon plain

range separates it from the Tarbela reservoir (Figure 35).

Physiography

The Gadoon plain is covered by alluvium consisting of flood deposits over most of the plain and with alluvial fans at the foot of the mountains. The relief is moderate to steep. The plain rises from 364 m (1193 ft) above msl near Topi to 463 m (1519 ft) at Baisak village. The surrounding mountains rise to 2066 m (6776 ft) at the northern boundary of the catchment.

The main nalas rise in the northern catchment area, and are, from west to east: Sargari Khwar, Badgai Khwar, Gajai Khwar, Jammu Khwar, Wuch Khwar and Polah Khwar (Figure 58). They coalesce and leave the area as one river, the Kundal Khwar, which eventually discharges into the Indus. The Kundal Khwar is ephemeral in its upper reaches but becomes perennial near Babinai village because of groundwater exfiltration.

Badland erosion is prominent east of the Badgai Khwar.

Geology

The catchment area consists mainly of schists and quartzites. According to Sajjad (1988), the quartzites, quartzitic schists, marbles and graphitic schists of the Precambrian Salkhala Formation cover 80 per cent of the catchment area. The Early Palaeozoic to Precambrian Hazara Formation comprises brown, black and green slates and phyllites and is found near Topi. The Devonian - Silurian Tanawal Formation occurs as small outcrops at many locations in the catchment area; it consists mainly of bedded, coarse- and medium-grained quartzite with intercallations of green phyllite. Intrusions of dolerite dykes, sills and plugs of the Tertiary have been found along fault zones.

The Gadoon plain is underlain by Quaternary alluvial deposits of clay, silt, gravel and boulders; near the foot of the mountains the deposits are fan-shaped and consist of angular to subangular coarse material intermixed with clay.

Climate

The climate is of the sub-humid subtropical continental lowland type (Section 1.3). The average annual rainfall in Tarbela, which is the nearest meteorological station, is 868 mm; more than half of it falls in the summer period. It is assumed that the rainfall in the catchment area is 20 per cent higher, i.e. 1040 mm. The mean monthly temperature varies from 12.2°C in January to 34.8°C in June. The average daily maximum temperature in June is more than 40°C and the average daily minimum will be close to freezing point, because freezing spells are common.

Population and domestic water supply

No population data are available. The domestic water supply is secured through shallow tubewells and through tubewells drilled by PHED.

Agriculture

Barani agriculture is the most important economic activity. Locally water from shallow wells is used to irrigate orchards. Poppy has been an important crop, but in cooperation with USAID the Government is strongly stimulating the cultivation of irrigated substitute crops. At the request of the Gadoon Amazai Development Project WAPDA Hydrogeology Directorate drilled 13 boreholes between September 1985 and June 1987 in the eastern part of the Gadoon plain, nine of which have been converted into production wells.

Nizami (1975) characterized the soils of the Gadoon plain as "land with a moderate economic potential under dry farming".

Groundwater investigations

Prior to 1985, the data from two PHED boreholes constituted the total hydrogeological knowledge of the area. Since then the above-mentioned drilling programme combined with a hydrogeological reconnaissance survey (Sajjad, 1988) has shed more light on the groundwater conditions.

Groundwater conditions

The alluvial fill is 40 - 60 m thick near the mountains, but it may be as much as 100 - 150 m in the centre of the plain. The borehole data show the following lithological sequence:

- a dry top layer, composed of clay and silty clay in the upper part and of silt and sand intermixed with boulders and gravel beds in its lower part.
- the upper part of the saturated zone, which in some areas may consist of silt and sand and in others of gravel and boulders.
- the lower part of the saturated zone, which consists of sand, gravel, cobbles and boulders, with few intercalations of clay. It probably forms an extended unconfined aquifer of variable thickness.

Transmissivity values obtained through pumping tests range from 800 - 1800 m^2/d, and the specific capacity of the wells ranges from 37 - 320 m^3/h per metre drawdown (50 - 430 gpm/ft dd.). The depth to the water table ranges from 5 m near the Kundal Khwar to 26 m in the alluvial fans. The estimated specific yield varies from 0.08 in badly sorted coarse deposits to 0.20 in well sorted coarse sand and fine gravel beds. The groundwater quality is good; EC values range from 0.45 - 0.75 mS/cm.

Groundwater flow

It may be assumed that the groundwater flows from the recharge areas along the northern and eastern sides of the plain towards the Kundal Khwar, where it exfiltrates. A relatively small amount of groundwater will leave the area as subsurface flow in the alluvial fill of the Kundal Khwar.

Discharge and recharge

The groundwater extraction by wells and tubewells is estimated by Sajjad (1988) as 1.9 Mm^3/yr. The surface water flow of the Kundal Khwar was measured in June 1987 after a six-week drought period following a spring with above-normal rainfall in March and April. The increase of the discharge of the Kundai Khwar between Babinai and Topi was 1700 m^3/h (17 cusec). It is therefore assumed that the order of magnitude of the annual groundwater exfiltration is 15 Mm^3/yr as surface flow and that 7 Mm^3/yr is discharged as subsurface flow. Equating discharge to recharge implies that the recharge is approximately 24 Mm^3/yr (25 cusec), which corresponds with 15 per cent of the rainfall over the catchment.

Groundwater development potential

A tentative conclusion is that the groundwater development potential is good, but a proper evaluation requires a comprehensive survey over the whole plain.

Groundwater management

When a comprehensive assessment of the groundwater resources has been made, the results should be translated into a groundwater development plan for the whole plain.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Nizami, M.M.I., 1975. Reconnaissance soil survey of the Peshawar Vale (Revised). Soil Survey of Pakistan, Lahore; 274 pp., 5 app. 14 tbls, 3 figs, 3 pl. (Restricted).
Annotation. Description of the soils and their genesis, present use and capability.

Sajjad, M.A., 1988. Hydrogeological reconnaissance survey in Gadoon area. WAPDA Hydrogeology Directorate Peshawar (in preparation).

12 THE INTERMONTANE BASINS OF KOHAT AND KARAK DISTRICTS

12.1 GENERAL

Location

The intermontane basins of the Kohat and Karak Districts (Figure 59) are situated in the Kohat mountains in the central part of the North-West Frontier Province, between latitudes 33°04' and 33°45' N and longitudes 70°35' and 71°45' E. From north to south they are:

- the Kohat plain between latitudes 33°20' and 33°47' N and longitudes 71°10' and 71°45' E; it covers 522 km^2 and is part of a subcatchment of 2,000 km^2 of the Kohat Toi,
- the interconnected Doaba and Hangu valleys that have alluviumcovered areas of 106 and 95 km^2 surrounded by catchment areas of 450 and 390 km^2, respectively. The former, between latitudes 33°23' and 33°30' N and longitudes 70°36' and 70°50' E, belongs to the catchment of the Kurram river, while the latter, between latitudes 33°24' and 33°34' N and longitudes 70°50' and 71°07' E, is part of the catchment of the Kohat Toi upstream of the Kohat plain.
- the Lachi valley between latitudes 33°19' and 33°27' N and longitudes 71°15' and 71°40' E, belongs to the catchment of the Kohat Toi downstream of the Kohat plain; it covers a total area of 560 km^2 of which 290 km^2 form the alluvial plain,
- the Teri area, between latitudes 33°10' and 33°22' N and longitudes 70°50' and 71°17' E, an alluvial plain of 210 km^2 in a catchment area of 615 km^2, belongs to the catchment of the Teri Toi.
- the Karak valley, between latitudes 33°03' and 33°12' N and longitudes 71°00' and 71°22' E, of which the small eastern part drains to the Teri Toi and the western area to the Kurram river. The drainage basin of the valley is 275 km^2 of which 150 km^2 are covered by alluvial deposits.

Physiography

The basins are surrounded by mountain ridges that have a general west east trend. Most rivers also flow eastwards following antecedent patterns that they maintained when the mountain ridges emerged. They have cut narrow gorges through which they enter and leave the intermontane basins.

Geology

The area lies between the Peshawar Vale in the north and the Trans Indus Salt range in the south. It is underlain by tightly folded and faulted sedimentary rocks which, according to Meissner et al. (1974) vary in age from Jurassic to Pliocene. The Cherat range forms the boundary with the Peshawar Vale. Here again are tightly folded and faulted Palaeocene, Cretaceous and Jurassic limestone, sandstone and shale. South of the Cherat range is a broad belt underlain by rocks of Eocene and Miocene age. The Eocene sequence consists of limestone, clay, salt and gypsum, and the Miocene sequence of sandstone, siltstone, shale, and clay. These tightly folded rocks form narrow ridges, 1000-1500 m (3300-5000 ft) in height separating broad, flat valleys. Recumbent folds and overthrusts are common along the southern flanks of the anticlines. With the exception of the Karak valley, all the groundwater basins in the Kohat mountains are located in this belt. The Karak valley lies in the belt of Pliocene strata immediately south of the Eocene - Miocene belt. The Pliocene is composed of sandstone, siltstone and clay containing conglomerate lenses. They form a rugged mountain terrain that has about the same elevation as the previous belt. Table 30 shows a simplified stratigrapic column with emphasis on the hydrogeological properties of the lithological units.

Climate

The climate is of the sub-humid (in the north) and sub-arid (in the south) subtropical continental highland type (Section 1.3). The average annual rainfall decreases from north to south, but increases with altitude, which makes comparison more difficult. The average annual precipitation in the northern part of the area is 546 mm in Kohat (alt. 466 m or 1528 ft), 624 mm in Hangu (alt. 815 m or 2673 ft) and 826 mm in Fort Lockhart up in the mountains (alt. 1905 m or 6428 ft). The annual average of 331 mm of the meteorological station of Bannu town (alt. 381 m; Chapter 13) is used as reference for the southern part of the area. In summer the daily maximum temperature may rise to over 40°C and in winter the daily minimum may be below freezing point. The average annual evapotranspiration increases from 1374 mm in Kohat to 1542 mm in Bannu.

Soils

According to Ansari and Darr (1974) most of the soils in the Kohat plain, in the Hangu and Doaba valleys and in the northeastern part of Lachi valley are classified as "land with a high to very high potential under irrigated agriculture". The southwestern "arm" of the Kohat plain and the northwestern part of the Lachi valley are described as "land with a moderate economic potential under dry farming and irrigation". The rest of the Lachi valley, the Teri area and the Karak valley are classified as "lands with a poor economic potential under dry farming".

Population

Kohat and Karak Districts are estimated to have 586,000 and

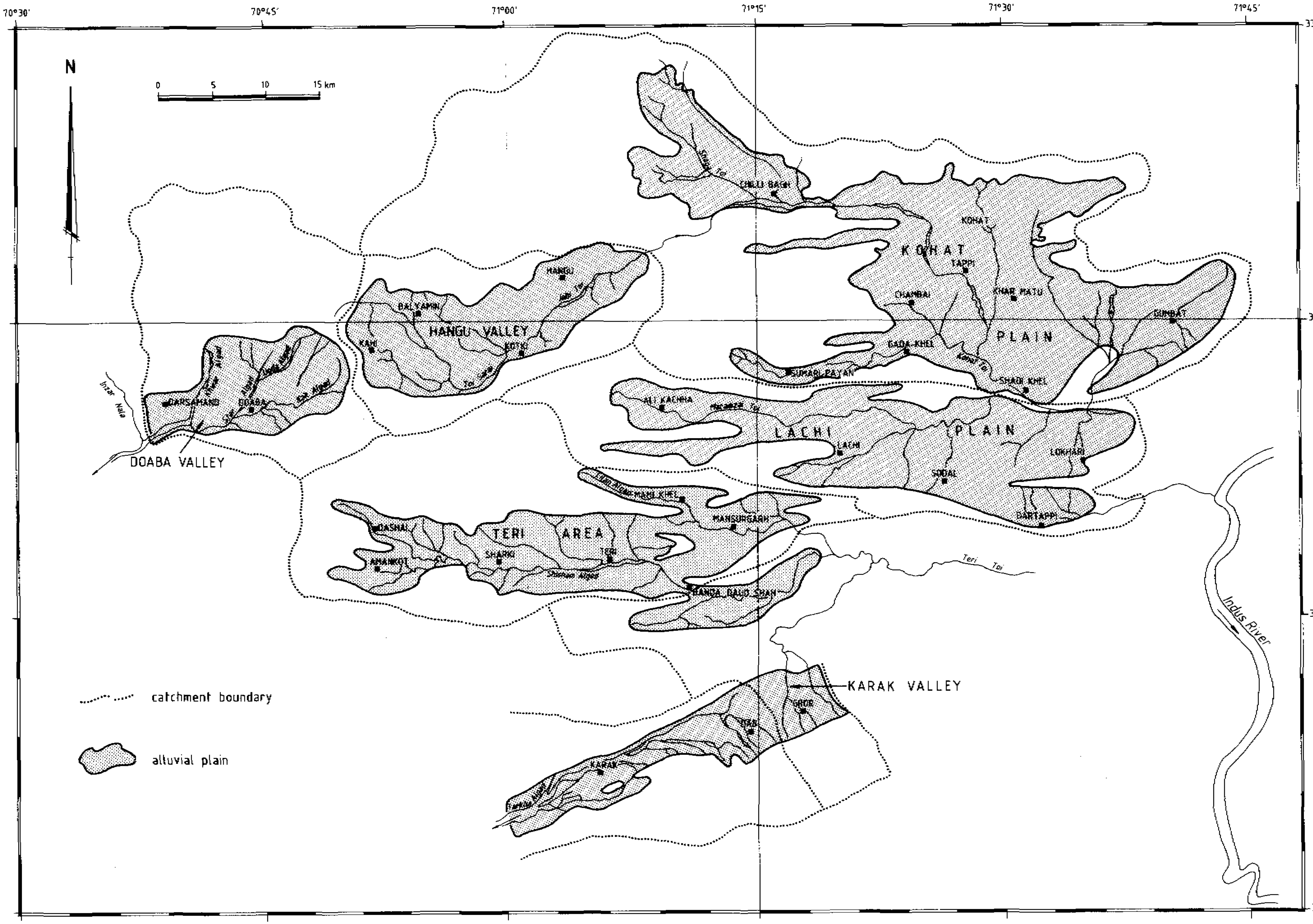


Figure 59: Location map of the intermontane basins of the Kohat and Karak Districts

287,000 inhabitants, respectively. Kohat town has approximately 80,000 inhabitants. No details are available about the population of each of the alluvial plains.

12.2 THE KOHAT PLAIN

Domestic water supply
In the rural areas domestic water is mainly provided by dug wells. Kohat town is supplied by a piped distribution system fed by tubewells drilled by PHED. Other villages supplied by PHED tubewells are Sher Kot, Ustarzai Bala, Payan, Muhammad Zai, Togh, Billitang, Tappi and Gumbat.

Agriculture
A considerable part of the Kohat plain is irrigated with water from the Tanda reservoir. During floods excess water from the Kohat Toi is diverted through a tunnel near Nusrat Khel to the Tanda Lake, from whence an average amount of 102 Mm^3/yr is distributed. The commanded area is 13,200 ha (43,300 acres), but in 1982 only 5000 ha (12,500 acres) were actually irrigated (Bloemendaal, 1983). The depth of the applied irrigation water is 2100 mm per year, which is much more than the actual requirements and leads to a rising water table. In areas without surface water irrigation, water from dug wells is used for small-scale irrigation.

Groundwater investigations
WASID started hydrogeological investigations in the Kohat plain in August 1965. They were later continued by the Hydrogeological Section of the Groundwater Directorate, WAPDA, Peshawar. During the period 1965 to 1978 23 test holes ranging in depth from 43 to 147 m were drilled, four of which were converted into test wells. The drilling results alone were insufficient to estimate the groundwater potential, therefore detailed investigations were made in the period 1980-1982 under the Pak-Dutch programme. This included the drilling and geophysical logging of another ten boreholes and the conversion of six test holes into test wells for executing pumping tests.
In 1982 WAPDA published a first note on the groundwater availability (Malik and Bloemendaal, 1982) followed in 1983 by a Technical Report (Bloemendaal, 1983).
Local electrical resistivity surveys were carried out by WAPDA Hydrogeology Directorate for the National Bank of Pakistan (NBP) in Kohat.

Groundwater conditions
The bedrock in the western part of the Kohat plain consists of Tertiary shale. In the central part are outcrops of Kohat limestone and in the eastern part the Kamlial sandstone and shale are present at shallow depths. The bedrock is overlain by clay and gravel, either alternating or mixed. Clay and clay/gravel mixtures have a very low permeability and are

Table 30: Geological formations exposed in the catchment areas of the intermontane basins in Kohat and Karak Districts

Epoch	Lithostratigraphy Unit	Formation	Type of Rock	Hydrogeological Properties
Holocene and Pleistocene			Alluvial deposits consisting of clay, sand, gravel and boulder beds	Aquifers, except for clay beds or clayey deposits
Miocene	Rawalpindi Group	Kamlial	Sandstone with conglomerate lenses and silty clay beds	Some secondary permeability may exist
		Murree	Sandstone with conglomerate lenses and purple to reddish-brown shale beds	Some secondary permeability may exist
Eocene	Cherat Group	Kohat	Limestone interbedded with greenish-grey shales	Secondary permeability
		Mami Khel	Clay, brownish-red with sandstone and conglomerate beds	Impervious
		Sheikhan and Jatta	Limestone, gypsiferous with shale beds	Secondary permeability, water quality poor
		Panoba	Shales, greyish-green	Impervious
Palaeocene		Patala	Shales	Impervious
		Lockhart	Limestone, massive, with sandstone and shale beds	Secondary permeability
		Hangu	Sandstone	Secondary permeability
Cretaceous		Darsamand and Lumshiwal	Limestone	Secondary permeability
		Chichali	Sandstone	Secondary permeability
Jurassic		Datta	Limestone	Secondary permeability

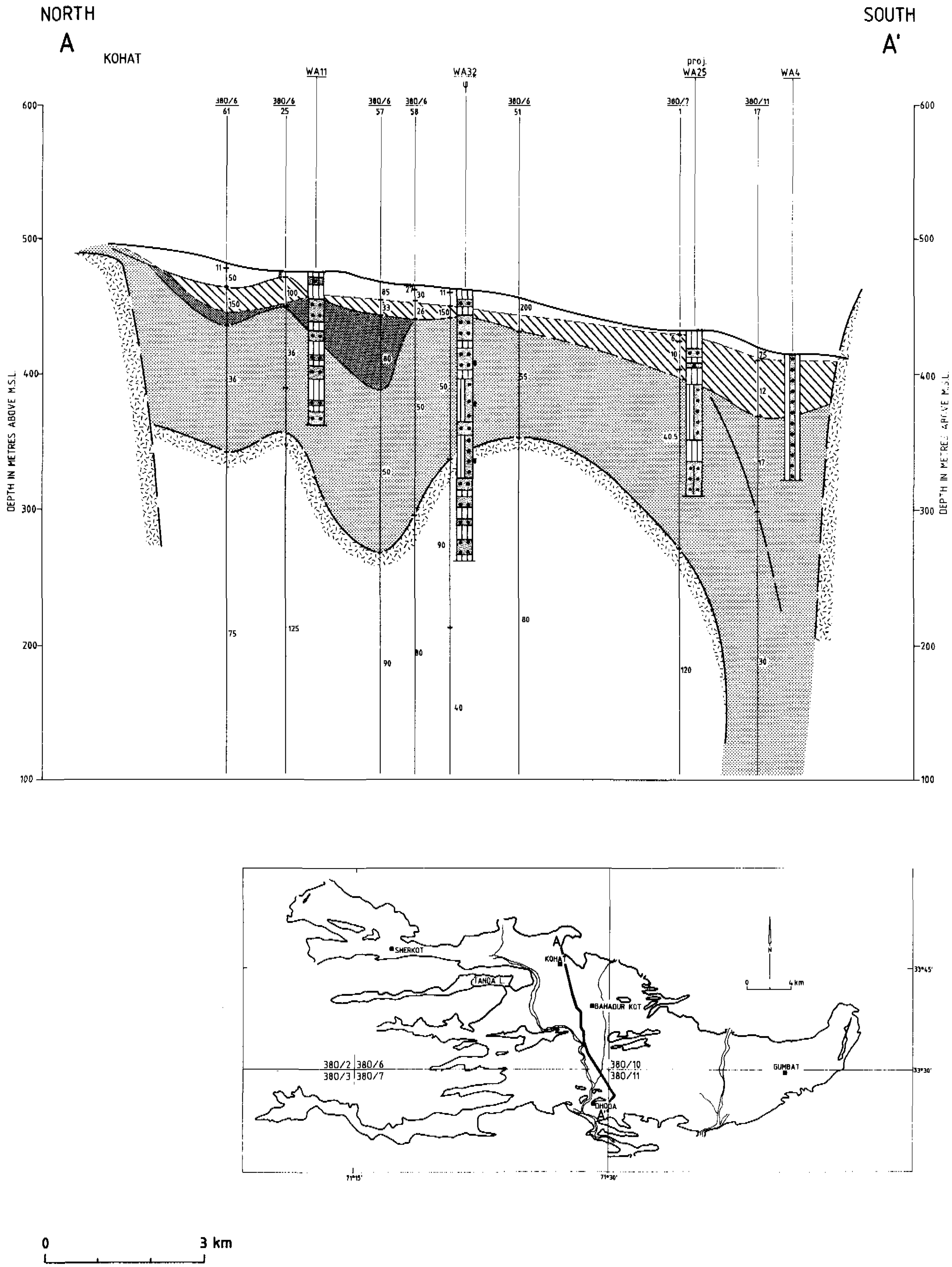


Figure 60: Hydrogeological cross-section over the Kohat plain (For legend see fold-out at back of book)

considered aquitards. Sand and gravel layers, even when alternating with clay, are aquifers. (Figure 60).

With the help of the electrical resistivity soundings it is often possible to determine the extent of the aquifers. Unfortunately, in the Kohat plain the correlation between high resistivity values and very permeable coarse deposits is disturbed by the presence of large boulders and by cementation of the gravel beds; these increase the resistivity but reduce the permeability. The thickness of the saturated alluvial fill ranges from several hundred metres in the central part to a negligible amount in the valleys along the western boundary and in the eastern and southeastern zones.

The alluvial fill of the central part of the plain is the main groundwater reservoir. About 40 per cent consists of thick, well-sorted gravel layers with a specific yield of 0.1 - 0.3. This gravel also has the best transmissivity, ranging from 500 to more than 6000 m^2/d (Figure 61). The top layers are often clayey and may cause confined aquifer conditions. Near Kohat town the aquifer peters out against the Kohat limestone, which results in large springs with a total yield of more than 400 m^3/h (4 cusec).

The chemical quality of the groundwater is generally good. Water from tubewells is of the calcium bicarbonate type, EC values hardly exceed 1.0 mS/cm and SAR values are between 0.1 and 1.6. The water from shallow open wells has a somewhat higher salinity, resulting in EC values between 0.6 and 1.6 mS/cm. Near the southern mountains that contain rock salt the EC values may rise to 2.0 mS/cm.

Groundwater levels

The results of the general well inventory were used to compile a map of groundwater elevation contours (Figure 61). The wide spacing of the contour lines in the central part of the plain indicates a gentle groundwater gradient, which agrees with the high transmissivity values.

The depth to the water table varies from less than 5 m to 30 m. In the area south of Kohat town, between that city and Jarma, the water table is rising because of percolation losses in the areas irrigated with surface water from the Tanda reservoir. In Billitang this causes waterlogging. At the same time, increased groundwater exploitation has lowered the water table (30 m below surface) near Bahadur and prevented waterlogging.

The total amount of groundwater stored in the coarse alluvial deposits within the first 200 m below the surface is estimated as 1,590 Mm^3, of which about 1,100 Mm^3 occurs in the central area south of Kohat town.

Groundwater flow

In the western valleys the groundwater flows eastwards towards the central part of the plain, where the direction changes towards the south, more or less parallel to the Kohat Toi. The latter drains the groundwater before it leaves the plain. The groundwater from the eastern part also flows to the south and is drained by the Gandial Algad.

Recharge and discharge

The discharge has several components that can be measured:

- Withdrawal of groundwater from open wells and tubewells and outflow from springs,
- Exfiltration of groundwater into nalas and rivers,
- Evapotranspiration of very shallow groundwater.

The amount of groundwater withdrawn from wells and tubewells is 7 Mm^3/yr (7.8 cusec) of which 4 Mm^3/yr (4.5 cusec) are produced in the central area. The spring flow amounts to 8 Mm^3/yr (9 cusec), half of which is discharged by the springs in Kohat town and the other half by springs in the area northwest of Kohat.

The discharge of the rivers and nalas consists of a rather stable groundwater drainage component, the baseflow, and the surface runoff after precipitation that causes brief flash floods. The base flow has been measured at suitable sites in the river system: it amounts to 73 Mm^3/yr (81.7 cusec).

Evapotranspiration from the saturated groundwater zone can only take place in the small areas north of Kohat, south of the Tanda Dam and near Billitang where the water table is at less than 2 m below the surface. However, the areas are so small that the discharge by direct evaporation from the saturated groundwater zone can be neglected.

Total discharge is 88 Mm^3/yr (98.5 cusec).

Recharge of the groundwater basin is derived from percolation of precipitation and runoff water and from percolation losses of surface water irrigation systems such as the Tanda reservoir. The recharge from precipitation and irrigation cannot be directly measured or calculated; however, under the assumed steady state conditions the recharge can be equated to the discharge.

The analysis of the rainfall/baseflow relations in subcatchments of the Kohat Toi has shown that the groundwater recharge from rainfall and runoff corresponds to 3-9 per cent of the total rainfall over the catchment: 67.5 Mm^3/yr. Assuming 7 per cent for the central area of the Kohat plain, Bloemendaal (1983) determined that in this part of the plain the recharge by percolation of irrigation water amounts to 20.5 Mm^3/yr, which corresponds to nearly 24 per cent of the design value of the irrigation application.

Groundwater development potential

The gross groundwater development potential corresponds to the baseflow of the river system, insofar as this water is not committed to downstream users. The baseflow generated in the Kohat plain amounts to 73 Mm^3/yr (81.7 cusec). The areas with hydraulic properties that allow groundwater development by tubewells are the valley northwest of Kohat town and the central area south of it as indicated on Figure 61. The baseflow generated in these areas is estimated as 68 per cent of the total baseflow, or 50 Mm^3/yr (56 cusec). Therefore, it is recommended to restrict further groundwater development to 25 Mm^3/yr (28 cusec) in the first instance and to monitor the influence on the groundwater regime. In the areas not suitable for tubewell schemes, groundwater development by private farmers using open wells or low-capacity tubewells can be allowed. The effects on the groundwater regime must be monitored.

Groundwater management

The groundwater development by the government and by the private sector should be monitored by regularly assessing the groundwater production and the effects of pumping on the levels and quality of the groundwater. The data obtained by the monitoring will be an important element in the decision-making process about further groundwater development.

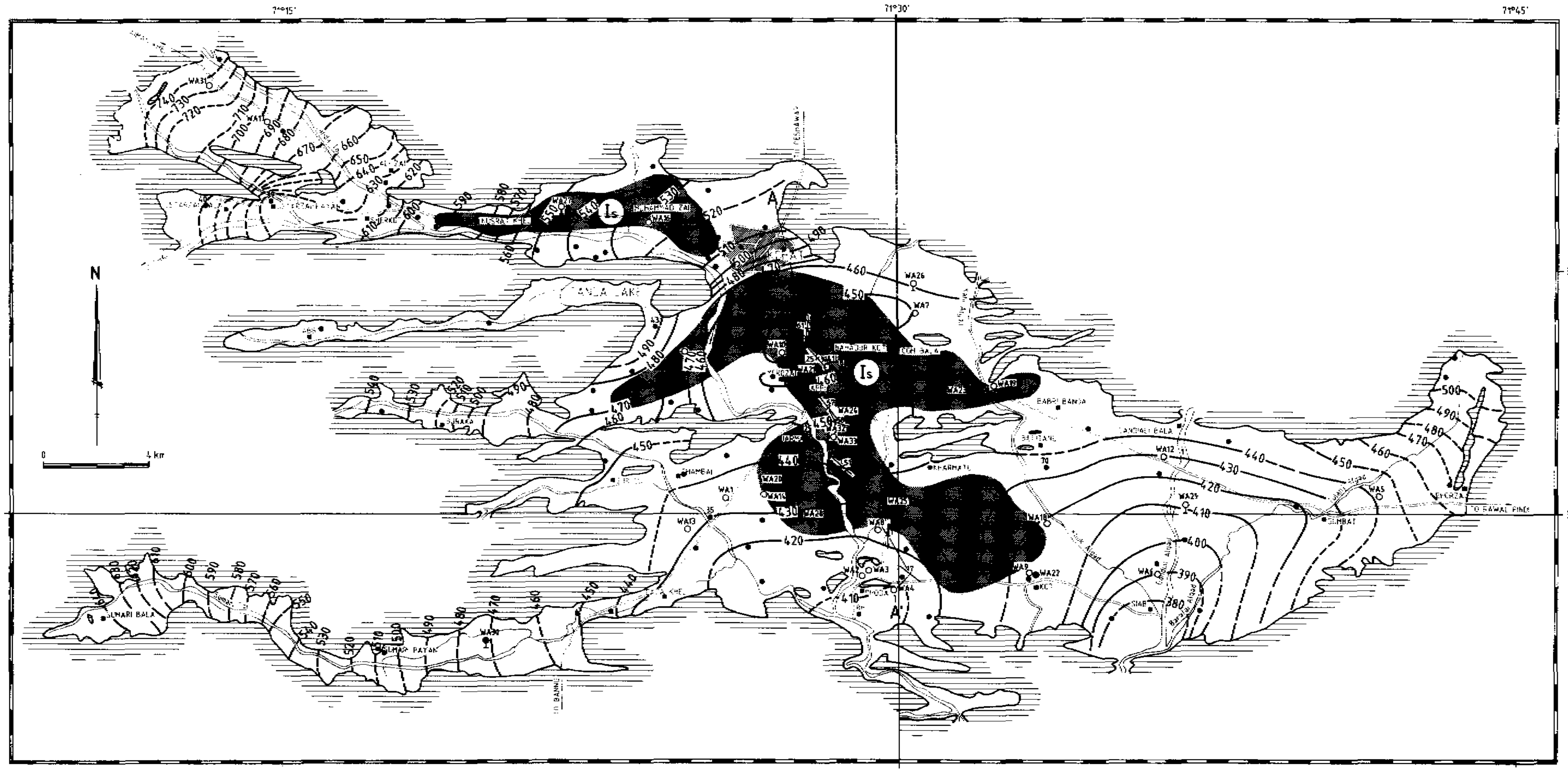


Figure 61: Groundwater map of the Kohat plain (For legend see fold-out at back of book)

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Ansari, A.H. and M.A. Darr, 1974. Reconnaissance soil survey Kohat area; 193 pp., 5 app., 16 tbls, 4 figs, 3 pl. *Annotation.* Description of the soils, their genesis, present use and capability.

Malik, M.Y. and S. Bloemendaal, 1982. A note on the groundwater availability in Kohat Plain, Kohat District, NWFP. WAPDA Hydrogeology Directorate Peshawar and TNO Groundwater Survey, Delft, The Netherlands; 17 pp., 2 tbls, 4 pl. *Annotation.* This note was used to present the preliminary results of the investigations carried out in the Kohat plain. It has been superseded by Bloemendaal's 1983 report.

Bloemendaal, S., 1983. Technical Report on Groundwater Resources in Kohat Plain, Kohat District, NWFP. Report No. III-1. WAPDA Hydrogeology Directorate Peshawar and Groundwater Survey TNO, Delft, The Netherlands; 37 pp., 5 app. 8 tbls, 4 figs, 5 pl. *Annotation.* This is the first and only full report on the groundwater resources of the Kohat plain and the result of the investigations carried out by WAPDA Hydrogeological Directorate Peshawar and TNO Institute of Applied Geoscience, Delft, The Netherlands during 1979 and 1982. It is based on extensive field work that comprises an inventory of 3,230 open wells, the drilling of 14 test holes in addition to the 19 test holes drilled previously by WASID and WAPDA, the conversion of ten boreholes into test wells of which eight were successfully test pumped, the geophysical well logging of five test holes, a resistivity survey of 175 vertical electrical soundings, chemical analysis of water samples from 28 open wells, 16 tubewells and some surface water sources and monitoring of groundwater level fluctuations in 75 wells since 1976.

WAPDA, 1985. Electrical Resistivity Survey in NBP, Kohat Building. WAPDA Hydrogeology Directorate Peshawar; 3 pp. *Annotation.* Report on two soundings.

12.3 THE HANGU VALLEY

Domestic water supply
Domestic water comes from open wells and springs. The most important springs arise from the limestones along the northern side of the valley.

Agriculture
Large areas are used for barani agriculture, with wheat, barley and maize as the main crops. On the lower parts of the plains and in the surroundings of Hangu town irrigation is practised to grow sugar cane and, to a lesser extent, potatoes and horticultural crops. Near Hangu the water from the Hangu spring, 14 Mm^3/yr, is used for irrigation. According to Jousma (1986), the efficiency of the system is 50 per cent.

Groundwater investigations
Hydrogeological data in this area were first collected when a borehole was drilled along the Hangu - Thal road in 1970/1971. They were used by Ahmad (1973) in a preliminary hydrogeological report that covered the Doaba-Hangu area. This report could not be traced. The systematic study of the valley was undertaken under the Pak-Dutch programme in the period 1980/1982 (Jousma, 1986). The fieldwork carried out during that time included the drilling and geophysical logging of two test holes, one of which was converted into a test well to carry out a pumping test.

Groundwater conditions
The Hangu valley covers the eastern part of the Doaba-Hangu basin. The mountains on its northern flank consist largely of fractured limestones which appear to be very permeable and give rise to important springs such as the spring near Hangu town with a yield of 450 l/s or 14 Mm^3/yr. The southern flank is formed by the rather impermeable Panoba shales that also underlie most of the alluvial fill.
The alluvial deposits consist of clay alternating with gravelly sand layers. The major part of the valley has only a thin cover of alluvial sediments but there are two sub-basins with thicker accumulations, up to 30 and 70 m, respectively. One is a small sub-basin south of Hangu and the other is a larger one located between Kahi and Togh, along the Jabi Toi in the southwestern part of the valley (Figure 62).
In the Kahi - Togh sub-basin the formation resistivity is about 30 ohm-m, which indicates alternating sand and clay layers and a transmissivity of only 250 m^2/d (Figure 63). In the small sub-basin south of Hangu the aquifer consists of a 15 m thick gravel layer that is overlain by a 15 m thick clay layer and underlain by the basement shales. The formation resistivity is 100 ohm-m and the corresponding transmissivity is a moderate 500 m^2/d. The specific yield of the sand layers is probably not more than 0.15.
The depth to groundwater in the relatively thin alluvial cover of the Hangu valley is less than 10 m except in some patches of higher ground where a maximum depth of 17 m has been observed.
The volume of water stored in the Kahi-Togh sub-basin is calculated as 66 Mm^3 and as 37.5 Mm^3 in the sub-basin south of Hangu.
The chemical quality of the water is good. The water from the tubewells is of the calcium bicarbonate type with an EC value that is less than 1.0 mS/cm and a SAR value of about 2. No reliable full chemical analysis is available. The EC values of the water from open wells varies from less than 0.4 to more than 2.0 mS/cm. The vast majority of the samples show values of less than 1.0 mS/cm. The spring water near Hangu town is approximately 0.7 mS/cm.

Groundwater flow
Figure 62 shows the water table elevation contour lines. The groundwater flows more or less parallel to the rivers, which tend to be effluent, i.e. the rivers are drainage channels for the groundwater flow. In the western part of the valley the flow is from northwest to southeast towards the Jabi Toi and in the eastern part of the valley from the southwest to the northeast. The water table gradient varies from 0.020 in the higher parts to 0.010 near the Jabi Toi.

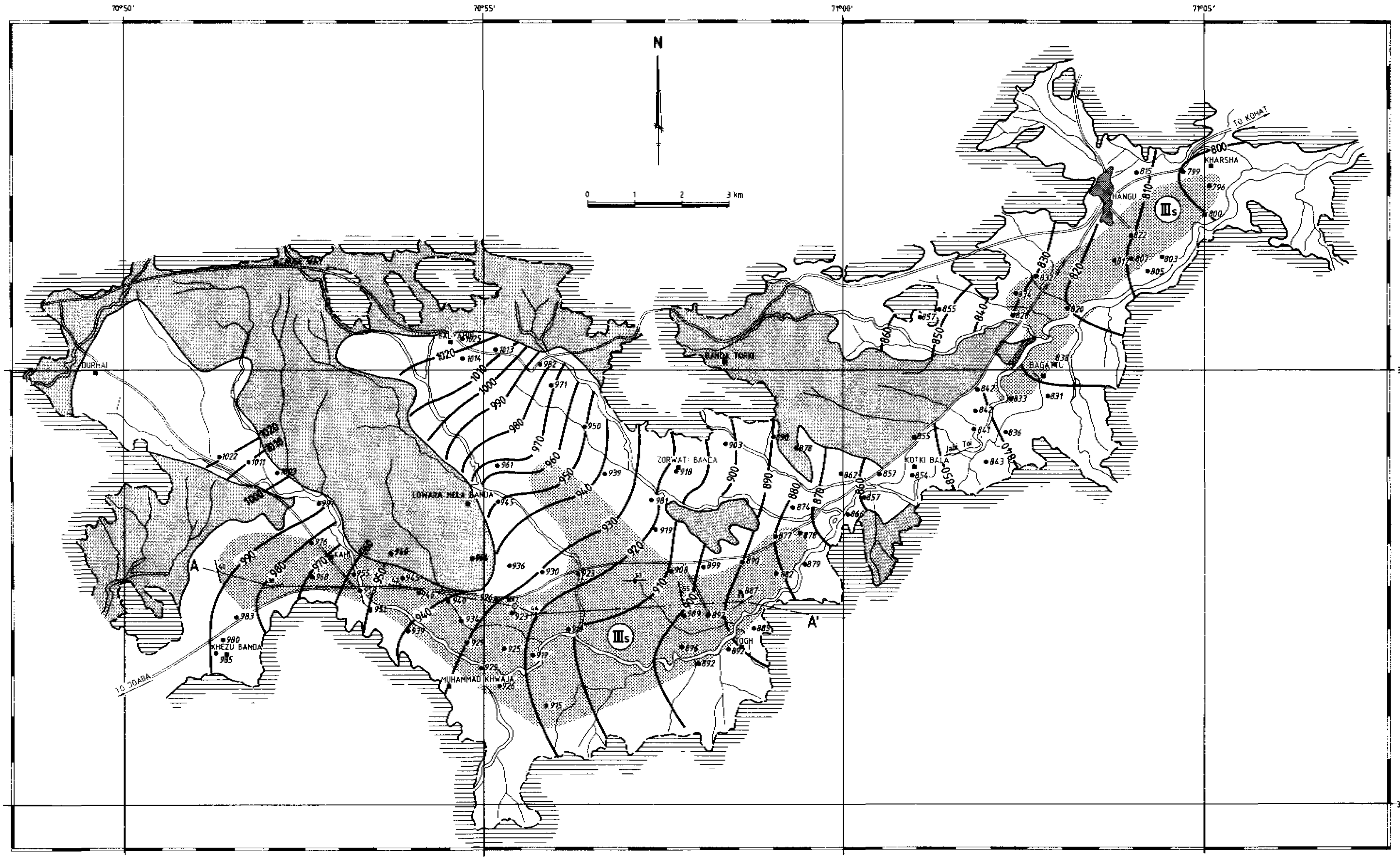


Figure 62: Groundwater map of the Hangu valley (For legend see fold-out at back of book)

Discharge and recharge

Groundwater drainage by the Jabi Toi is the main discharge component of the Hangu valley and amounts to 17.9 Mm^3/yr (20 cusec). It comprises 6.4 Mm^3/yr (7.2 cusec), which originates in the Kahi-Togh sub-basin, 4.4 Mm^3/yr (4.9 cusec), which comes from the Hangu sub-basin, and half the flow from the Hangu spring, i.e. 7.1 Mm^3/yr (8 cusec). The calculated total base flow of the Jabi Toi is 17.9 Mm^3/yr (28 cusec), which compares well with the baseflow measurements in the river: 20.2 Mm^3/yr (22.6 cusec). The other half of the flow of the Hangu spring, 7.1 Mm^3/yr, is evapotranspired by irrigated crops. Finally, small quantities are discharged by wells (1.3 Mm^3/yr) and by direct evapotranspiration (not estimated) in areas with very high groundwater levels. Consequently, the total groundwater discharge is 26.3 Mm^3/yr (29.5 cusec). This corresponds to approximately 10 per cent of the annual rainfall over the catchment area.

The recharge of the alluvial fill by subsurface inflow from the pervious limestone in the north, by deep percolation of surface runoff, especially along the northern mountain front, and by percolation of rainfall and irrigation water cannot be calculated directly. However, under steady state conditions the average annual recharge equals the average annual discharge.

Groundwater development potential

The potential for groundwater exploitation is low. The only scope for installing open wells or low-yield (about 20 m^3/h or 0.2 cusec) tubewells is in the Kahi-Togh sub-basin and in the sub-basin south of Hangu. The total withdrawal during an initial development phase should not exceed 3 Mm^3/yr (3.4 cusec). The expected annual production per well is about 30,000 m^3; so, approximately 100 wells can be installed.

Groundwater management

Inventories of groundwater production and groundwater levels should be made every five to ten years to monitor the effects of pumping on the groundwater regime and to help plan any further development.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Ahmad, S. Ilyas., 1973. Hydrogeological reconnaissance survey of the Doaba-Hangu area. WAPDA unpublished report. *Annotation.* In 1987 this report could not be traced.

Ansari, A.H. and M.A. Darr, 1974. Reconnaissance soil survey Kohat area; 193 pp., 5 app., 16 tbls, 4 figs, 3 pl. *Annotation.* Description of the soils, their genesis, present use and capability.

Akbar, Ghulam, 1978. Ground water conditions in Doaba area, Kohat District, NWFP. Preliminary Report No.1. Hydrogeol. Div., Planning Directorate, Ground Water Projects, WAPDA, Peshawar; 31 pp., 6 tbls and 4 figs. *Annotation.* The oldest available groundwater study of the area. The description of the borehole HU-1 in this document corresponds to Hangu-WA-1 in Jousma (1986).

Jousma, G., 1986. Groundwater Resources in Doaba and Hangu Valleys, Kohat District, NWFP. Report No.III-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 42 pp., 8 app., 15 tbls, 6 figs, and 11 pl. (4 pl. con-

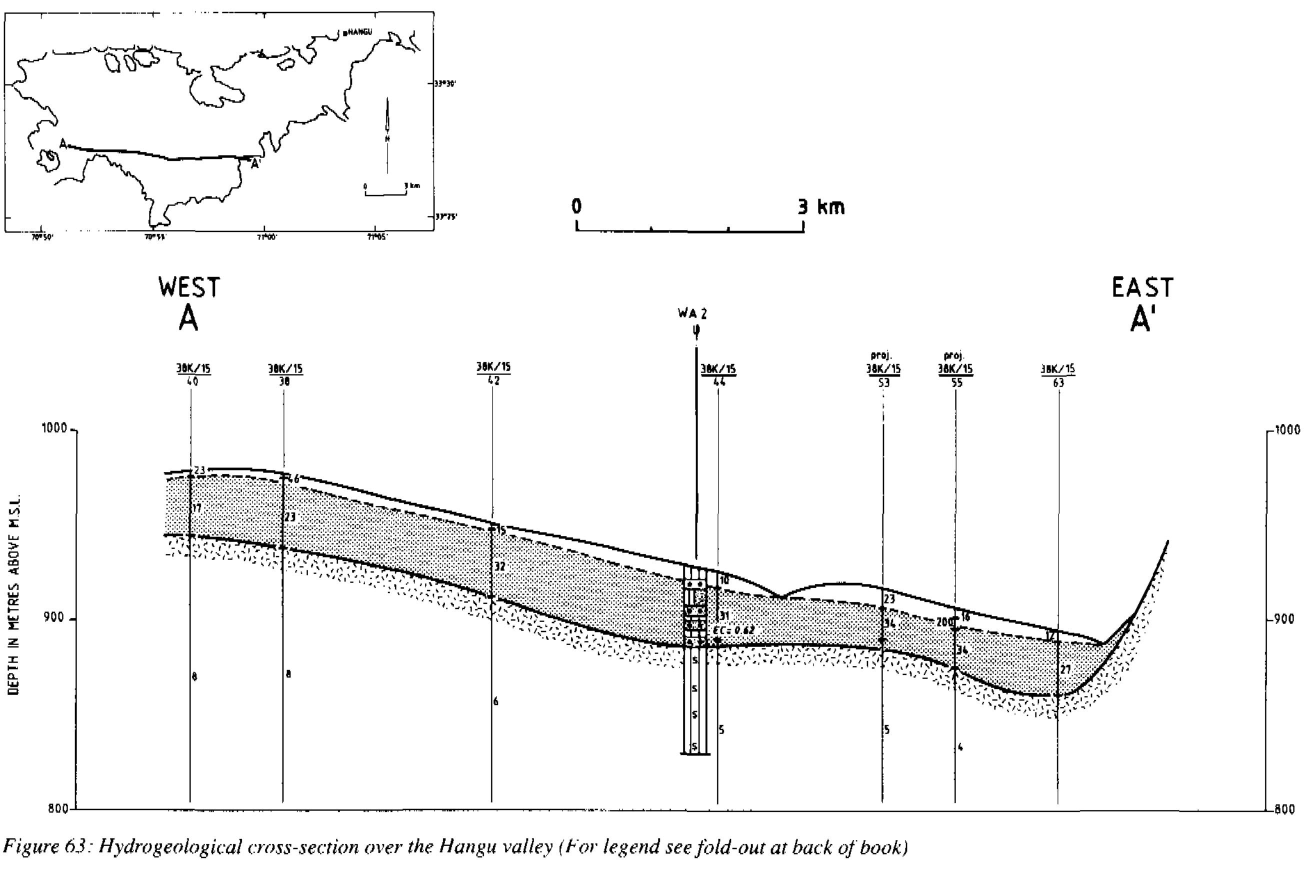


Figure 63: Hydrogeological cross-section over the Hangu valley (For legend see fold-out at back of book)

cern Hangu area). *Annotation.* Report on the whole Doaba - Hangu basin. It comprises the results of the investigations carried out by WAPDA Hydrogeology Directorate and TNO during the period 1980/1982 in which the previous studies are incorporated. The fieldwork included a general well inventory of 1731 open wells (860 in Hangu valley) and some natural springs, a resistivity survey of 123 vertical electrical soundings (41 in Hangu valley), drilling of six test wells (two in Hangu valley) of which four (one in Hangu valley) were converted into test wells to carry out pumping tests; and chemical analysis of water samples of 16 open wells and tubewells. For both the Doaba valley and the Hangu valley a water balance was calculated and the groundwater development potential discussed.

12.4 THE DOABA VALLEY

Domestic water supply
Domestic water supply comes mainly from dug wells and springs.

Agriculture
Most of the agricultural activities consist of the cultivation of barani crops, such as wheat, barley and maize. Irrigation is practised in the lower parts of the valley with water from dug wells and along the northern boundary where springs discharge groundwater from the limestones. Important springs are found near Darsamand, Torawari and Nariab.
Based on the conclusions of the WAPDA/TNO investigations, the Irrigation Department formulated a groundwater development project for which nine tubewells were drilled in 1983/1985 (Figure 64).

Groundwater investigations
Previous groundwater investigations date back to 1973 when a reconnaissance survey was carried out by WAPDA. At that time there were only two test holes in the area; one was drilled by WAPDA and the other by the Irrigation Department. A preliminary report was prepared by S. Ilyas Ahmad (1973). Subsequent investigations in the period 1973/1977 included the drilling of four test holes (Tahirkhelli, 1975), and resulted in a proposal for 14 investigation-cum-development wells (Ghulam Akbar, 1978), which was not implemented. The groundwater investigations under the Pak-Dutch programme carried out in the period 1980/1982, included the drilling and geophysical logging of four test holes, three of which were converted into test wells and pump-tested.

Groundwater conditions
The Doaba valley covers the western part of the Doaba-Hangu basin. The mountains on its northern flank consist largely of fractured limestones which appear to be very permeable. The southern flank is formed by the rather impermeable Panoba shales with locally some sandstone and limestone intercalations.
The alluvial fill is mainly underlain by the impervious Panoba shales and consists of sand and gravel beds alternating with clay layers. The thickness increases from north to south and from east to west. It reaches a maximum of about 250 m in the area between the Star Algad and the Khwar Algad. In the lower part of the fill the clays predominate, but in the upper part the sand and gravel layers are more abundant. The specific yield of the sand and gravel layers is 0.15 - 0.20, provided that they are not cemented. Vertical electrical soundings in the upper part show electrical resistivity in the range of 70 - 250 ohm-m. Resistivity values between 70 and 170 ohm-m indicate a good permeability, but higher values, i.e. above 170 ohm-m, are an indication that the coarse material is cemented, which results in a very low transmissivity (Figure 65). The average transmissivity of the upper sand and gravel layers is around 2000 m^2/d, but in the more clayey zone below it is not more than 500 m^2/d.
In the downstream parts of the Star Algad and along the Kak Algad thick clay layers are present at shallow depth. They range in thickness from 30 - 50 m and confine the aquifers at greater depth. Consequently, the piezometric level of the deeper aquifers rises to 6 m above the land surface in the lowest-lying areas. This results in free-flowing wells in a zone that probably has a width of 1 - 2 km on both sides of the Star Algad.
The depth to the water table measured in open wells increases from less than 10 m near the mountains to more than 30 m in the central areas between the Algads. Records from 1974 indicate that the seasonal water table fluctuations were less than 2 m. More recent data on water level fluctuation are not available.
The volume of water stored in the aquifer system is calculated by multiplying the saturated volume of the alluvial fill by the percentage of the contributing aquifers and the specific yield; it amounts to 700 Mm^3. The chemical quality of the water is good. The EC value of the water from the tubewells is generally less than 1.0 mS/cm and the SAR values vary between 0.1 and 1.1. The water is of the calcium carbonate type and is extremely low in sodium. It seems that the deeper aquifers are fed by subsurface water from the limestone area along the northern boundary of the Doaba valley. The water from the shallow open wells is of the bicarbonate type without a dominant cation. It has a somewhat higher salinity (EC value approximately 1.2 mS/cm) and a significantly higher sodium content. The SAR value varies from 1.5 to 5.7.

Groundwater flow
The watertable elevation contour lines are shown on Figure 64. The groundwater flow is perpendicular to the contour lines and gradually changes from north - south (more or less parallel to the Khwar and Star Algads) to more or less east - west (parallel to the Kak and Shkalai Algads). The water table gradient varies from 0.04 near the mountains around Torowarai Village to 0.004 near the Kak Algad. Jousma (1986) calculated that the groundwater flow across the 880 m contour line is equal to 30 Mm^3/yr (33.5 cusec).

Recharge and discharge
Most of the recharge enters the alluvial fill as subsurface inflow from the pervious limestone mountains in the north. Additional amounts come from deep percolation of surface runoff, especially along the northern mountain front, and as percolation of rainfall. As most of the recharge originates along the northern boundary we can assume that the total tallies with the groundwater flow that passes the 880 m watertable contour line, i.e. an amount of 30 Mm^3/yr. This corre-

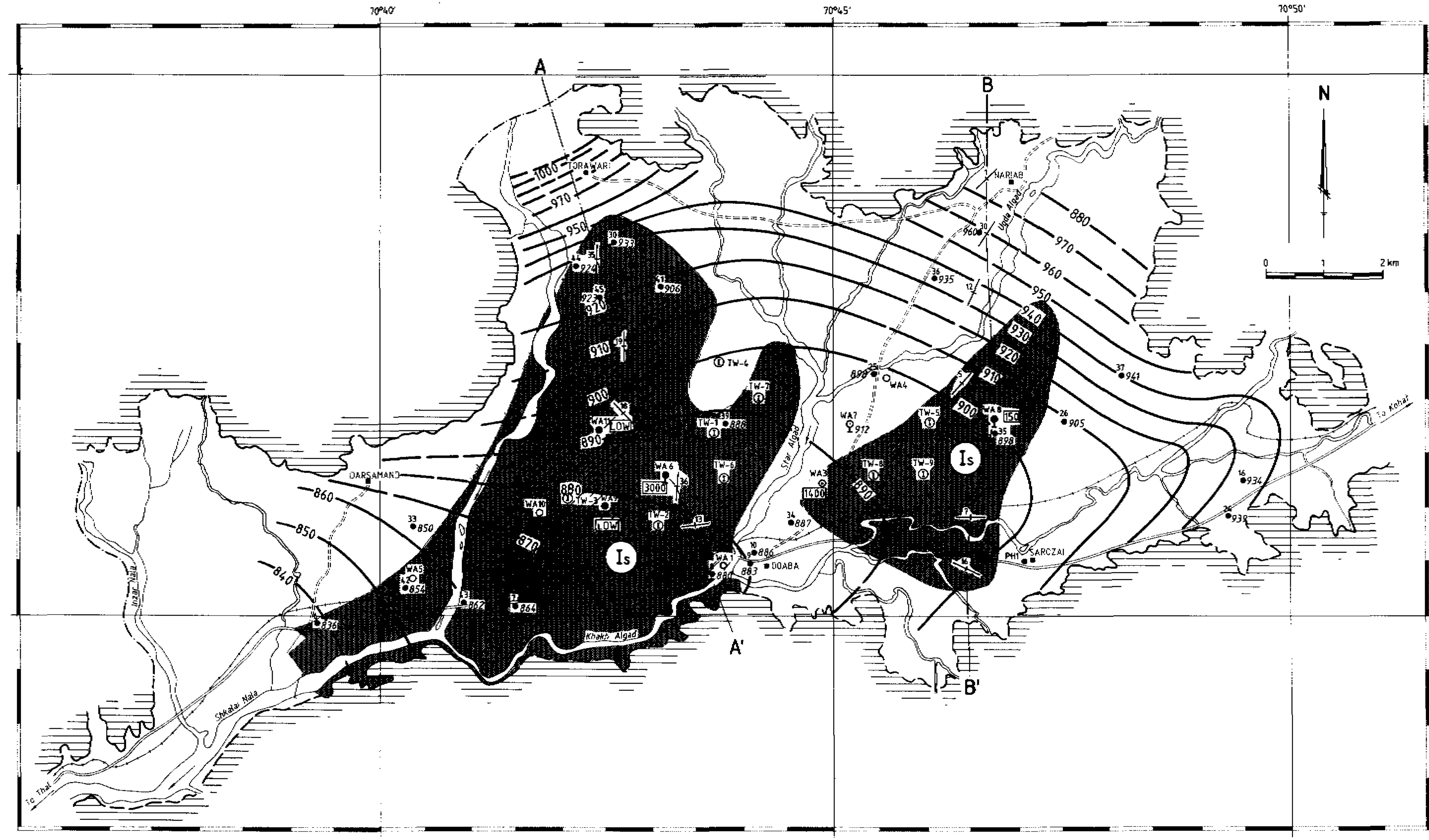
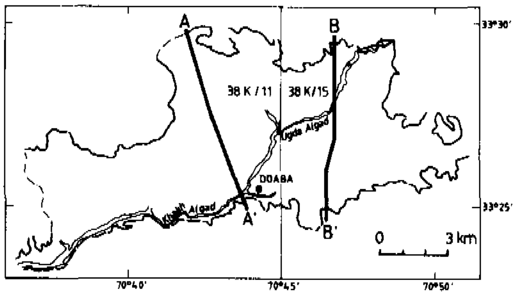


Figure 64: Groundwater map of the Doaba valley (For legend see fold-out at back of book)



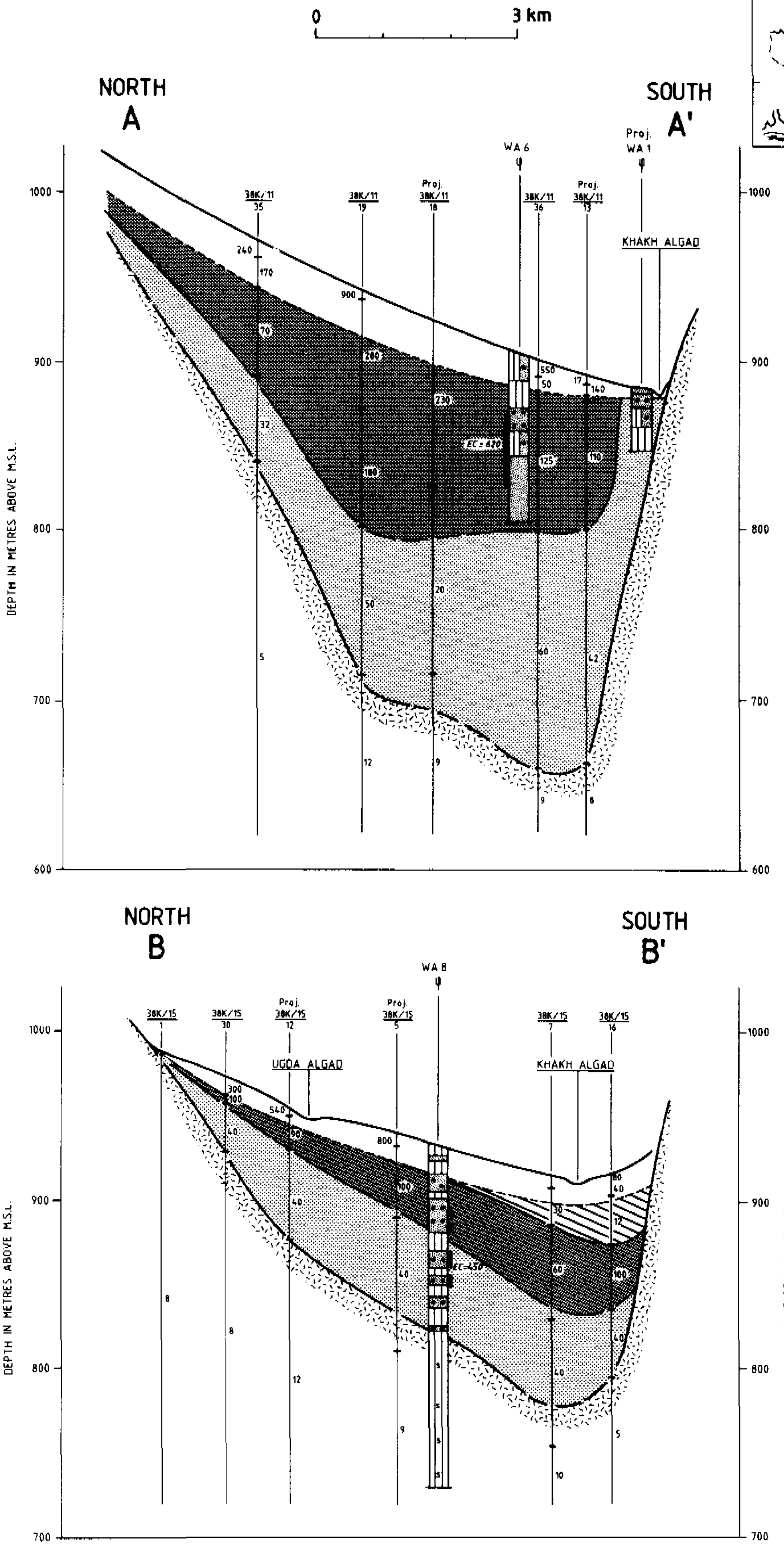


Figure 65: Hydrogeological cross-sections over the Doaba valley (For legend see fold-out at back of book)

sponds to approximately 10 per cent of an average annual rainfall of 624 mm (Hangu meteorological station) over the northern catchment area.

The discharge components are: (1) the amount of groundwater drained by the Algads, which is measured as the base flow of the Shkalai Algad at the outlet of the valley or 28 Mm^3/yr (31.4 cusec), (2) the subsurface outflow through the alluvial fill at the same location or 1 Mm^3/yr (1.1 cusec), (3) the total groundwater withdrawal by wells, which according to the well inventory of 1982, amounts to 1.25 Mm^3/yr. The water lost by direct evapotranspiration can be ignored, because nearly everywhere the water table is so deep that the capillary fringe is below the rootzone of the plants. Hence the total discharge is 30.25 Mm^3/yr (33.8 cusec) which corresponds extreemly well with the calculated throughflow in the upstream part of the valley.

Groundwater development potential

The gross groundwater development potential equals the base flow of the Shkalai Nala (30 Mm^3/yr or 33.5 cusec) insofar as this water is not committed to downstream use. In the areas where the coarse upper part of the alluvial fill is well developed and not cemented, tubewells with a yield of 100 m^3/h (1 cusec) can be installed (Figure 64). The drilling depth will be less than 150 m and the depth to the water level approximately 10-35 m. To avoid drilling in cemented gravel beds (electrical resistivity more than 170 ohm-m), electrical soundings must be made at each proposed drilling site.

The base flow generated in these areas is estimated as 68 per cent of the total base flow or 20 Mm^3/yr (22.4 cusec). Jousma (1983) recommends initially restricting further groundwater development to this amount. Since this recommendation was put forward, the Irrigation Department has constructed nine tubewells, each with a capacity of 100 m^3/h. The expected annual water production by these tubewells is 1.8 Mm^3 (2 cusec) or 9 per cent of the base flow.

In the areas not suitable for tubewell schemes, the use of open wells or low capacity tubewells by private farmers can be allowed. The effects on the groundwater regime must be monitored.

Groundwater management

The groundwater development by the government and the private sector should be monitored by regular inventories of the groundwater production and of the effects of pumping on the groundwater levels and groundwater quality. The data obtained by this monitoring should be an important element in the decision-making process about further groundwater development.

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Tahirkhelli, A.R., 1975. Preliminary Hydrogeologic report on Doaba area (Distt. Kohat), preliminary reprt no.2, WAPDA Grw. Direct. Peshwar, unpublished report. *Annotation.* This unpublished report comprises inventory data of 23 open wells (some of which have been deepened by a driven pipe), the description of five test holes, including those published by Ahmad (1973), and chemical data on 12 groundwater samples.

Akbar, Ghulam, 1978. Ground water conditions in Doaba area, Kohat District, NWFP. Preliminary Report No.1. Hydrogeol. Div., Planning Directorate, Ground Water Projects, WAPDA, Peshawar; 31 pp., 6 tbls and 4 figs. *Annotation.* The oldest available groundwater study of the area. The descriptions of the boreholes HU-2, HU-DB-3, HU-DB-4 and HU-DB-5 in Ghulam Akbar (1978) correspond to Doaba-WA-1, Doaba-WA-3, Doaba-WA-4 and Doaba-WA-5 in Jousma (1986).

Jousma, G., 1986. Groundwater Resources in Doaba and Hangu Valleys, Kohat District, NWFP. Report No.III-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 42 pp., 8 app., 15 tbls, 6 figs, and 11 pl. (4 pl. concern Hangu area). *Annotation.* Report on the whole Doaba - Hangu basin. It describes the results of the investigations carried out by WAPDA Hydrogeology Directorate and TNO during the period 1980/1982 in which the previous studies are incorporated. The fieldwork included a general well inventory of 1731 open wells (871 in Doaba valley) and some natural springs, a resistivity survey of 123 vertical electrical soundings (82 in Doaba valley); the drilling of six test wells (four in Doaba valley) four of which (three in Doaba valley) were converted into test wells to carry out pumping tests; chemical analysis of water samples of 16 open wells and tubewells. For both the Doaba valley and the Hangu valley a water balance was calculated and the groundwater development potential discussed.

12.5 THE LACHI PLAIN

Population and domestic water supply

The population is estimated to exceed 80,000, living in small villages scattered over the area. The largest villages are situated in those parts of the valley where water is easily available for domestic use and irrigation. The water supply comes mainly from open wells. In the west and southeast of the plain some springs are found and on this side of the Lachi plain the number of wells equipped with small centrifugal pumps is rapidly increasing.

Agriculture

The main crops are wheat, barley and maize and, to a lesser extent, potatoes and horticultural crops. Cash crops such as tobacco and sugar cane are only cultivated in irrigated areas, such as those on either side of the Kohat - Bannu road north of Lachi town, where irrigation water is pumped from dug wells.

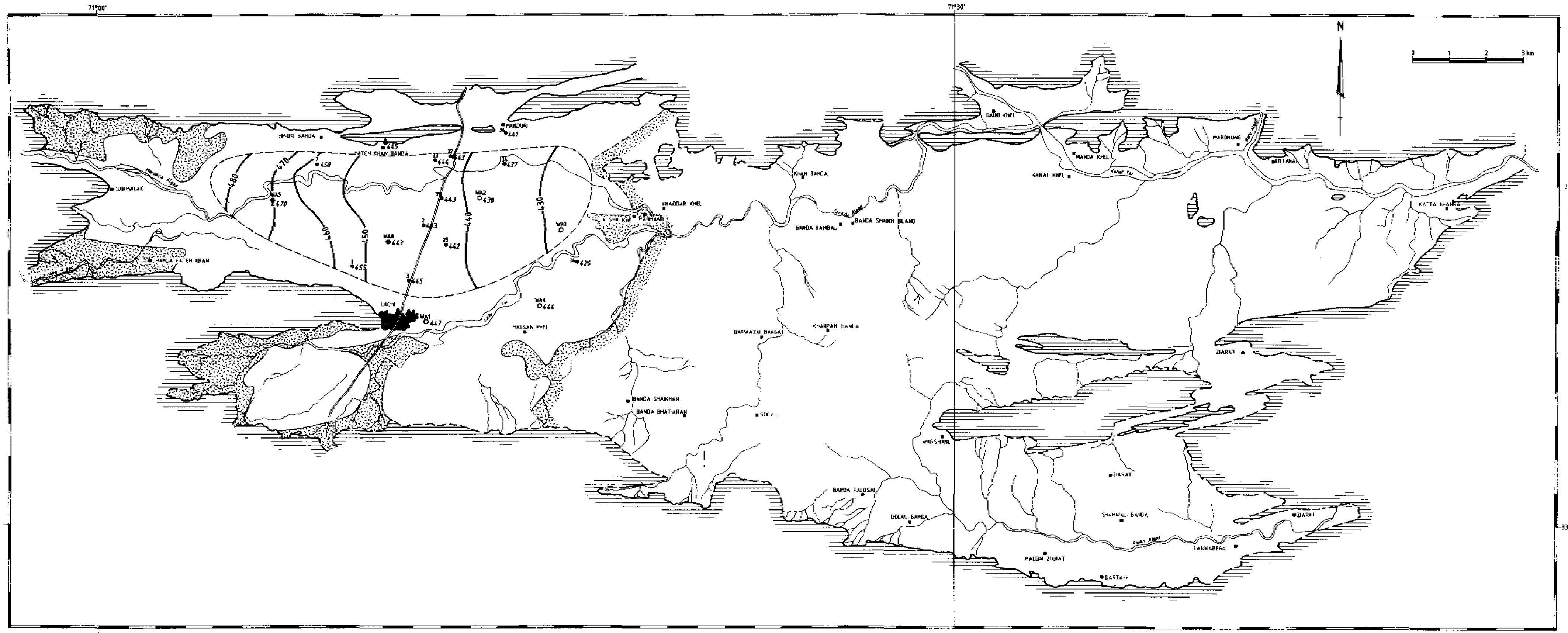


Figure 66: Groundwater map of the Lachi valley (For legend see fold-out at back of book)

Groundwater investigations
The hydrogeological investigations were started by WASID in 1971. Between 1971 and 1978 they drilled four boreholes ranging in depth from 28.7 to 103.6 m. Under the Pak-Dutch programme the studies were continued and included the drilling of four additional test holes. Two test holes were converted into test wells and were pump tested. A report (Malik, 1983) containing the findings was published in 1983.

Groundwater conditions
The mountains surrounding the Lachi valley consist of limestone, sandstone, siltstone and shales. According to the resistivity survey results the basement of the alluvial deposits is mainly composed of steeply dipping impervious shale and siltstone. The occurrence of groundwater in the bedrock has not been systematically studied. However, the presence of groundwater in the limestones is proven by the existence of natural springs. Measurements of the resistivity are hampered by the steeply dipping bedrock. Therefore this survey technique is not suitable for the Lachi plain.
The cover of unconsolidated material is very thin over most of the valley, and often the saturated layer is not more than a few metres thick. Only in an area of 29 km^2 north of Lachi town does the thickness of the alluvial cover increase to a maximum of 70 m, which is sufficient to contain an aquifer. The aquifer consists of sand, gravel, and boulders covered by a clay layer approximately 9 m thick.
The groundwater occurs under phreatic conditions and the estimated specific yield is 0.15. The depth to water measured in this area is everywhere less than 20 m and the seasonal fluctuations are less than 2 m. The amount of water stored in the sand and gravel layers is 83 Mm^3. Pumping tests have been carried out in two wells with a saturated aquifer thickness of 30 and 12 m, respectively. The specific capacity values are 61 and 2.7 m^3/h per metre drawdown and the calculated transmissivity values are 1800 and 130 m^2/d, respectively.
The groundwater quality is passable. The EC value of most samples both from open wells and from tubewells is between 0.9 and 1.1 mS/cm, but in a few open wells higher values, up to 2.2 mS/cm, have been found. Calcium is the predominant cation, except in the samples with a high EC value, where sodium becomes predominant. The ratio between the main anions is variable.

Groundwater flow
The groundwater map of the Lachi plain shows the water-table elevation contours in the area north of Lachi town (Figure 66). They indicate a groundwater flow from west to east more or less parallel to the Maramzai Algad. The groundwater gradient is approximately 0.006. The groundwater flow through the cross-section of the alluvial fill between Lachi and Fateh Khan Banda was calculated for steady state conditions with Darcy's Law. It amounts to 4.4 Mm^3/yr (4.9 cusec).

Discharge and recharge
Downstream of the junction with the Maramzai Algad the alluvial deposits wedge out against the bedrock and the subsurface outflow becomes negligible. So, the base flow of the Lachi Toi at this site corresponds to the natural drainage of the aquifer. The annual baseflow volume was calculated as 3.2 Mm^3 (3.6 cusec).
The well inventory indicated the presence of 319 open wells and no tubewells. Forty per cent of the wells are fitted with a centrifugal pump and nearly 30 per cent with a Persian wheel. The remainder are operated manually. The annual groundwater withdrawal in the area north of Lachi town is 0.070 Mm^3 for domestic use and 2.4 Mm^3 for irrigation. Evapotranspiration and subsurface outflow to adjacent areas are negligible discharge elements. So, the total discharge amounts to 5.6 Mm^3/yr (6.3 cusec).
It is probable that the main recharge components are the infiltration through gully bottoms and the subsurface inflow from bedrock with secondary porosity. No data are available to calculate the recharge directly. However, it may be assumed that, on average, discharge equals recharge. When the total discharge is compared with the rainfall (500 mm) over the catchment (270 km^2), it follows that 4.5 per cent of the precipitation recharges the aquifer.

Groundwater development potential
The area of the alluvial basin north of Lachi town is small and it has only restricted recharge possibilities. It is therefore recommended to limit the additional groundwater development to 50 per cent of the base flow at the outlet of the valley, that is 1.6 Mm^3/yr (1.8 cusec). To prevent large fluctuations in the groundwater level it is suggested to install either open wells or low-yield (20 m^3/h or 0.2 cusec) tubewells with an annual production not exceeding 30,000 m^3/yr.

Groundwater management
The fragile aquifer system has to be managed carefully, because local overpumping may cause large seasonal fluctuations that may leave many dug wells dry in the irrigation season. Therefore, high-yielding tubewells should not be permitted and a groundwater level monitoring programme should be set up. It can be restricted to observations four times a year in a maximum of ten wells.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Malik, Moh. Yousuf, 1983. Groundwater resources in Lachi Valley, Kohat District, NWFP. Report No.III-3. WAPDA Hydrogeology Directorate Peshawar and Groundwater Survey TNO, Delft, The Netherlands; 37 pp., 5 app., 8 tbls, 4 figs and 5 pl. *Annotation.* Comprises the results of the investigations carried out by WAPDA Hydrogeology Directorate and TNO Institute of Applied Geoscience (ex-Groundwater Survey TNO) during the period 1980/1982. The fieldwork included a general well inventory of 319 open wells, a resistivity survey of 93 vertical electrical soundings, the drilling of four test holes in addition to the four test holes drilled previously by WASID, the conversion of two test holes into test wells and their pump-testing, groundwater sampling for chemical analysis and

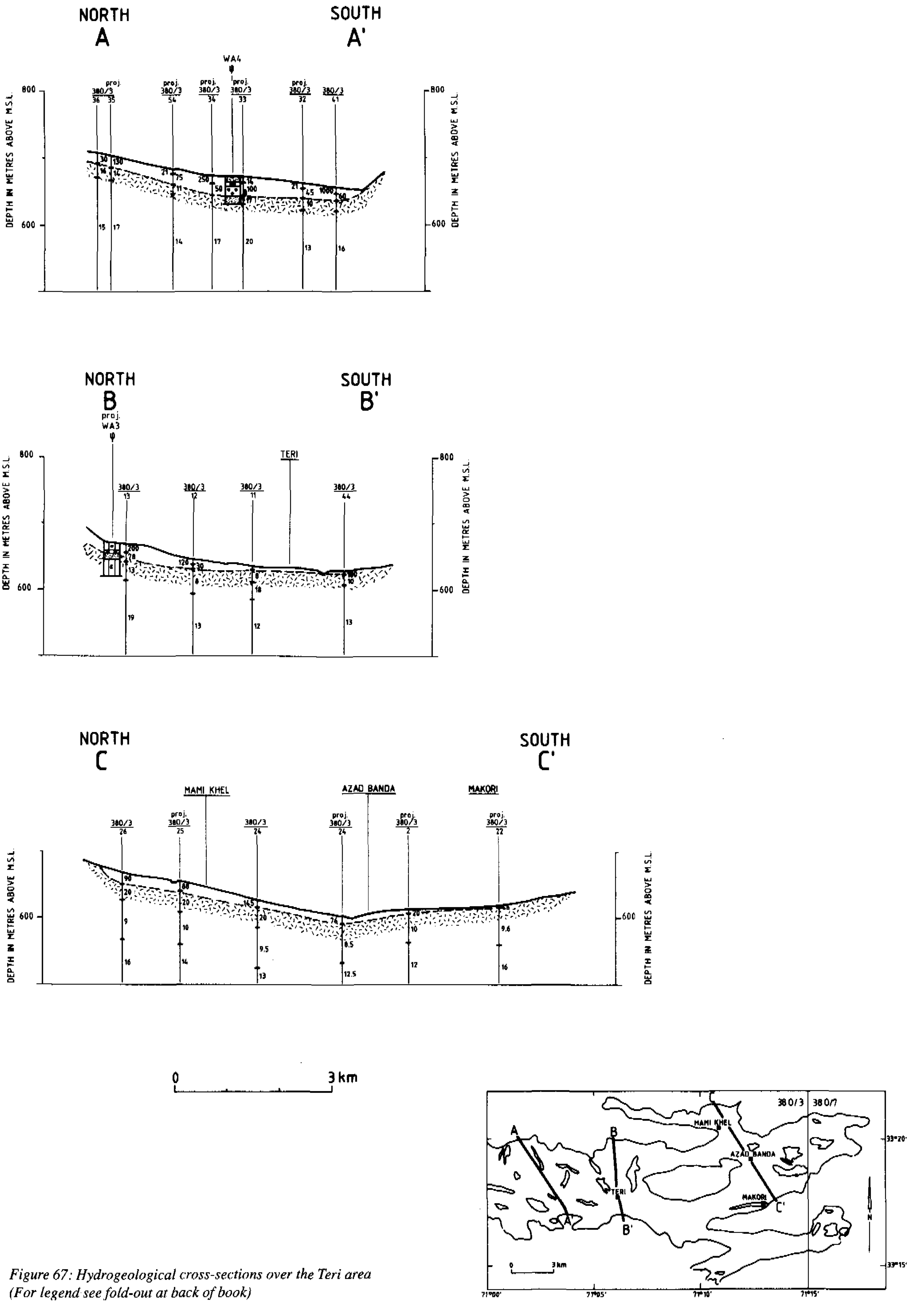


Figure 67: Hydrogeological cross-sections over the Teri area
(For legend see fold-out at back of book)

the gauging of stream flow. A water balance is presented for the area north of Lachi town.

12.6 THE TERI AREA

Domestic water supply
Locally, dug wells provide domestic water. Where the alluvium is too thin to yield sufficient water, PHED has developed spring water resources.

Agriculture
Most land is used for barani cultivation. Locally, the Irrigation Department has constructed stream diversions for irrigation.

Groundwater investigations
The first systematic investigation of the area was made in 1985 by WAPDA Hydrogeology Directorate Peshawar in cooperation with TNO-DGV Institute of Applied Geoscience, The Netherlands under the Pak-Dutch programme (Malik and Riaz, 1986). It resulted in the drilling of five test holes varying in depth from 23 to 60 m, one of which was converted into a test well in which a pumping test was carried out.

Groundwater conditions
Groundwater occurs both in the bedrock that outcrops all over the area and in the alluvial deposits. In the bedrock the groundwater is mainly found in fractured zones from which it is discharged by springs. However, the total amount of water involved is small. The alluvial deposits are very thin, and consist mainly of silt and clay (Figure 67). Only in test well WA-4 (Figure 68) was a gravel lens encountered. Here, the alluvium attains a thickness of 30 m, 14 m of which are saturated. A well test indicated a transmissivity of 1870 m^2/d. This is the only instance of reasonable hydraulic conditions being found. The depth to water is generally less than 10 m. The groundwater is of the sodium chloride type, often with high levels of sulphate. The quality is poor; the EC values vary from 1.0 - 9.0 mS/cm as a consequence of the presence of evaporite layers (rock salt and gypsum) in the bedrock.

Discharge and recharge
The discharge through open wells is calculated as 0.035 Mm^3/yr.
The deeply incised streams drain the groundwater: 1.5 Mm^3/yr is drained by the Shishan Algad - Teri Toi and 1.2 Mm^3/yr by the Lilan Algad. The combined baseflow of 2.7 Mm^3/yr is partly water from the alluvial fill and water from the bedrock aquifers.
The average annual recharge of the alluvial aquifer is probably equal to the average annual discharge and will be in the order of 2.7 Mm^3/yr (3.0 cusec). It will come from percolation in the upper reaches of the nalas, from percolation of precipitation over the valley, and from subsurface inflow from the pervious zones in the bedrock.

Groundwater development potential
Considering the generally thin veneer of alluvial deposits, the mainly impervious bedrock and the poor groundwater quality, it is concluded that the groundwater development potential is low. Only in the area around test well WA-4 is there some scope for groundwater development with low-yielding wells (0.20 m^3/h).

Groundwater management
There is no need for groundwater management in this area, provided the population is properly informed about the limited possibilities for groundwater development. Occasional groundwater level surveys (say, every five to ten years) are recommended.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Malik, Moh. Yousuf and Moh. Riaz, 1986. Groundwater resources in Teri area, Karak District, NWFP. Report No.IV-4. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 17 pp., 5 app., 5 tbls, 4 figs, 5 pl. *Annotation.* This is the only report on the groundwater conditions in Teri area. It is the result of the investigations carried out in 1985 by WAPDA Hydrogeology Directorate in cooperation with TNO-DGV under the Pak-Dutch programme. The conclusions are based on the following field investigations: an inventory of 254 wells, 74 vertical electrical soundings, and the drilling of five test holes that were all geophysically logged. One test hole was converted into a test well in which a pumping test was carried out. Groundwater level observations, chemical analysis of groundwater samples, and stream gauging were also part of the investigation.

12.7 THE KARAK VALLEY

Population and domestic water supply
An estimated 60,000-70,000 people live in the Karak valley. Most inhabit scattered villages, of which Karak village is the largest. The water supply of the people inhabiting the narrow western part of the valley is based on open wells, installed in the fresh water zone. If the water is used for irrigation, the wells are equipped with centrifugal pumps or with Persian wheels. In the southeastern zone where the water table is relatively deep, villages like Talab Khel, Mangar Khel and Badin Khel are connected to a pipeline system that collects water from nalas breaking through the southern mountain ridge. The water supply of Karak village, Dam Kili (Sabir Abad) and Kimanai is assured by tubewells drilled by PHED. In the mountains small springs provide for the domestic water needs.

Agriculture
Agriculture is the main economic activity. Most farmers depend entirely on the winter rains for their main (Rabi) crop of wheat and barley.

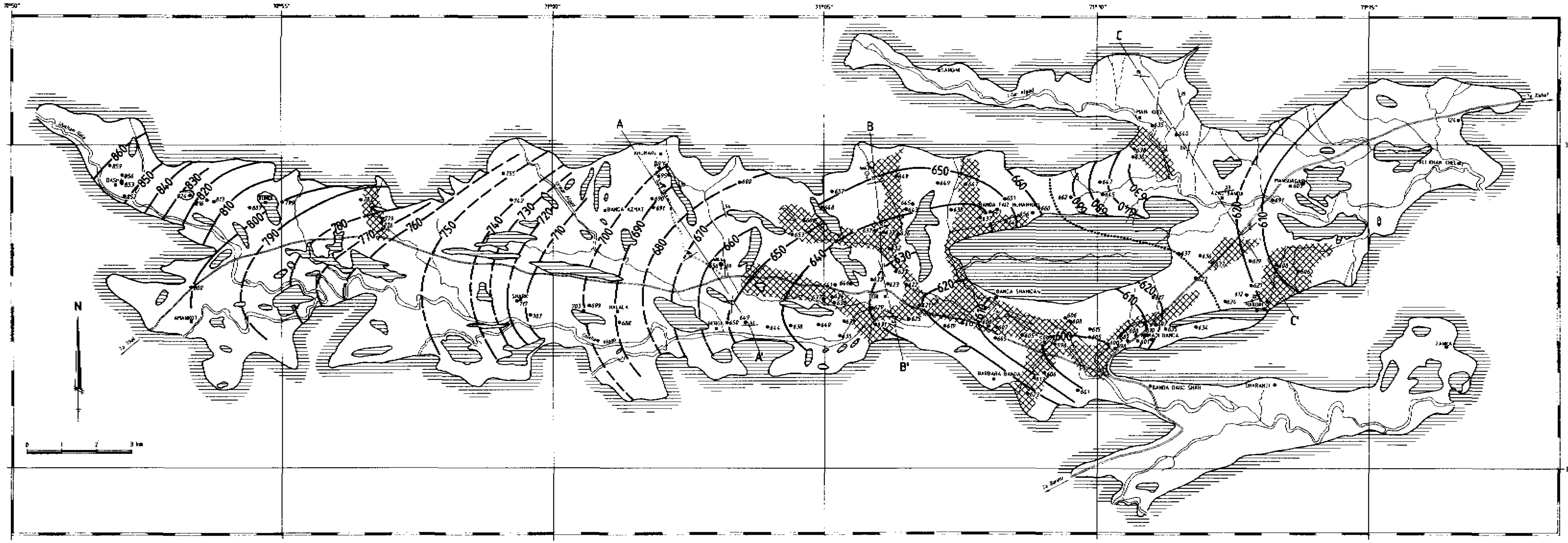


Figure 68: Groundwater map of the Teri area (For legend see fold-out at back of book)

More than 90 per cent of the inventoried open wells are equipped with a centrifugal pump or with a Persian wheel to irrigate some horticultural crops.

Groundwater investigations

In the period 1973/1974 WAPDA drilled two test holes in the Karak valley; subsequently PHED drilled a number of tubewells. The lithological logs of two PHED wells are included in the report by Malik and Jousma (1984). This report contains the results of the groundwater investigations undertaken by WAPDA Hydrogeology Directorate Peshawar and TNO in the framework of the Pak-Dutch Programme. The investigation included the drilling of three additional test holes that were all converted into test wells and on which pumping tests were carried out.

Groundwater conditions

The drainage basin of the Karak valley measures 274 km^2, of which 150 km^2 is covered by alluvial deposits.

The mountains bordering the northern side of the valley consist mainly of limestone interbedded with gypsum and underlain by shale and clay. The southern part consists of sandstones, conglomerates, and shales.

The valley is an east-west elongated alluvial plain, which opens to the west where it is connected to the Domail plain of the Bannu basin.

The alluvial fill of the valley is very heterogeneous and contains much silt and clay. Locally, sand and gravel beds have been encountered in the boreholes (Figures 69 and 70).

The vertical electrical soundings of the resistivity survey were difficult to analyse because in some parts of the aquifer the high salinity of the groundwater blurred the differences in resistivity between the aquifer material and the bedrock shales. In other parts of the valley the gravels and boulders of the fill showed hardly any resistivity contrast with the underlying conglomerates of the bedrock. The estimate of the thickness of the saturated part of the fill had to be based on the few borehole data. It is expected to be not more than 30 m, of which only part consists of coarse material with an average specific yield of 0.10.

The two pumping tests, one near Karak in WA-3 and the other in WA-5 near Talab Khel, gave transmissivity values of 280 and 90 m^2/d, respectively. The specific capacity values of the same tests are 4.8 and 0.8 m^3/h per metre drawdown (or 6.52 and 1.06 gpm/ft dd.)

A drainage divide separates the relatively large western catchment of the Tarkha Algad from the much smaller eastern ones of the Zebi Algad, Damo Algad and a number of smaller streams. The Tarkha Algad flows southwest towards the Kurram River and the surface water of the eastern catchment is carried northwards towards the Teri Toi (Figure 71).

The groundwater quality in the northern part of the western catchment is very poor. This is caused by the presence of rock salt in the northern mountains, which is dissolved by runoff water and contaminates the groundwater by deep percolation. The groundwater south of the Tarkha Algad is fresh. The fresh water/salt water interface winds through the middle of the valley. The pumping in the freshwater area combined with the difference in density between salt and fresh water results in a slow displacement of the fresh water by the saline water. In the eastern catchment the groundwater is mainly fresh. Relatively high EC values (1.0 mS/cm) have been found near the northern mountains only. They are probably caused by evapotranspiration directly from shallow groundwater.

Groundwater flow

The groundwater elevation contours shown on the groundwater map (Figure 71) indicate a vague groundwater divide that corresponds with the surface water divide. The groundwater of the eastern part of the valley flows north and discharges into the streams that become perennial where they enter the mountains and where the aquifer ends. The groundwater flow in the western part is southwestward, parallel to the Tarkha Algad.

Discharge and recharge

Western catchment

The Tarkha Algad receives water in the central part of the valley east of Karak, part of which it loses again in its lower reaches. The base flow of the Tarkha Algad as measured at the outlet of the valley is less than 100 m^3/h or less than 0.85 Mm^3/yr. The water is highly saline, exceeding 10 mS/cm in dry periods.

The groundwater withdrawal from open wells and some tubewells in the western catchment has been estimated as 5.1 Mm^3/yr (5.7 cusec), and takes place in the southern part, where the groundwater is fresh.

Eastern catchment

The most important streams draining the eastern catchment toward the north are the Zebi and the Damo Algads. They are ephemeral over most of their length, but become perennial in the gorges where they leave the plain and where the alluvium virtually ends. Base flow measured in January 1984 at the outlets amounted to 150 and 50 m^3/h (or 1.3 and 0.44 Mm^3/yr) for the Zebi and Damo Algads, respectively.

The estimate of the groundwater withdrawal from open wells and certain tubewells is based on the well inventory and amounts to 1.1 Mm^3/yr.

Along the northern boundary the water table is shallow and direct evapotranspiration may be considerable. Malik and Jousma estimate these losses from the saturated groundwater as 2 Mm^3/yr.

The recharge components could not be calculated individually, but for the eastern catchment the subsurface through-flow was calculated using Darcy's law (Malik and Jousma, 1986). This calculation indicates a subsurface flow of 12,000 m^3/d or 4.4 Mm^3/yr.

Groundwater development potential

Western catchment

The alluvial fill along the southern mountain that contains the fresh groundwater body, is heterogeneous and thin. Its thickness will not exceed 40 m, and as the depth to the water table is 5-15 m, the saturated thickness will be 30 m or less. The undeveloped outflow is only 6 Mm^3/yr (6.7 cusec), a major part of which is saline water. Increasing the withdrawal of fresh groundwater may result in a further incursion of the saline groundwater into the fresh water zone. The area west of Karak is particularly sensitive. East of Karak, where the hydraulic head of the fresh groundwater is considerably

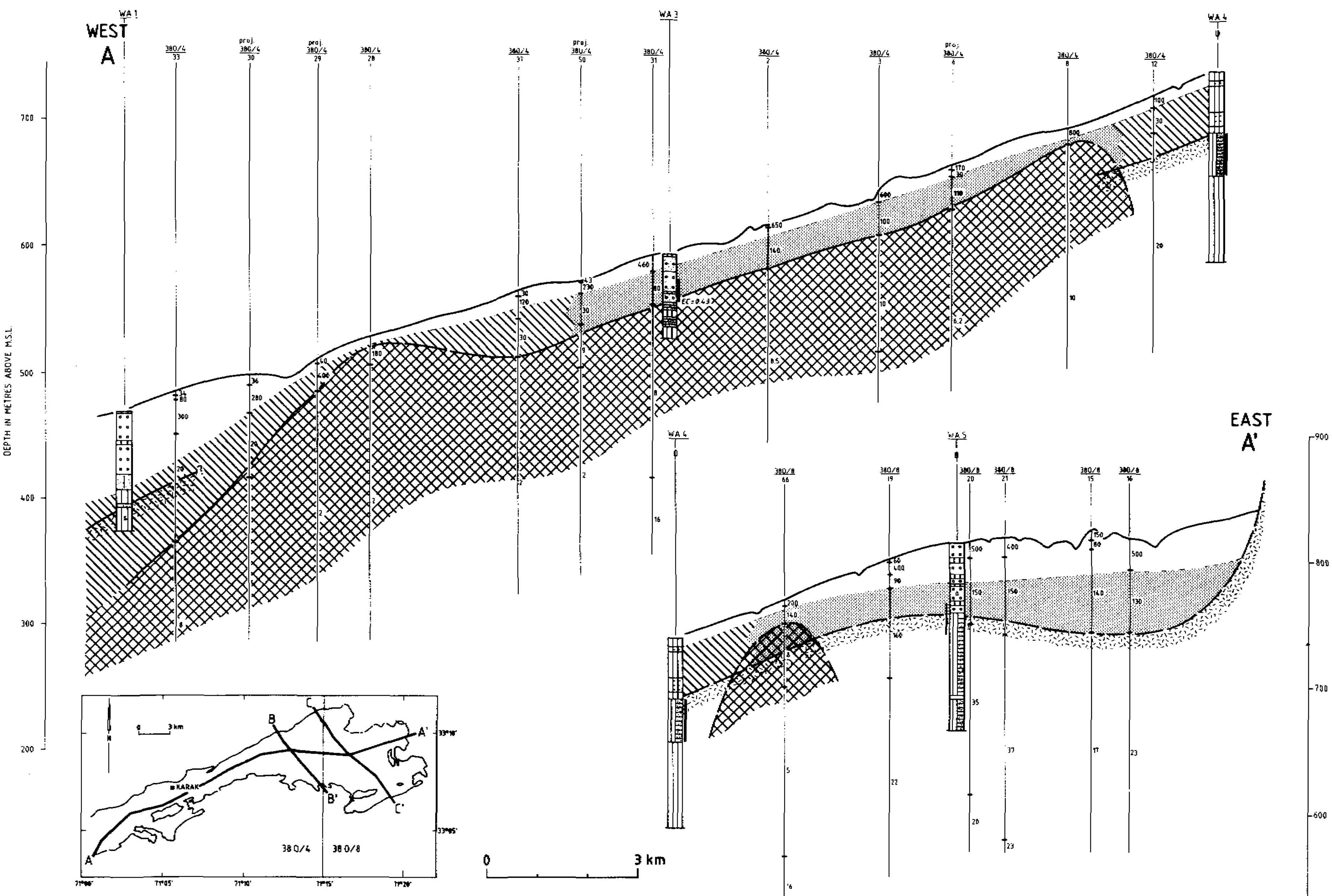


Figure 69: Hydrogeological cross-section A - A' over the Karak valley (For legend see fold-out at back of book)

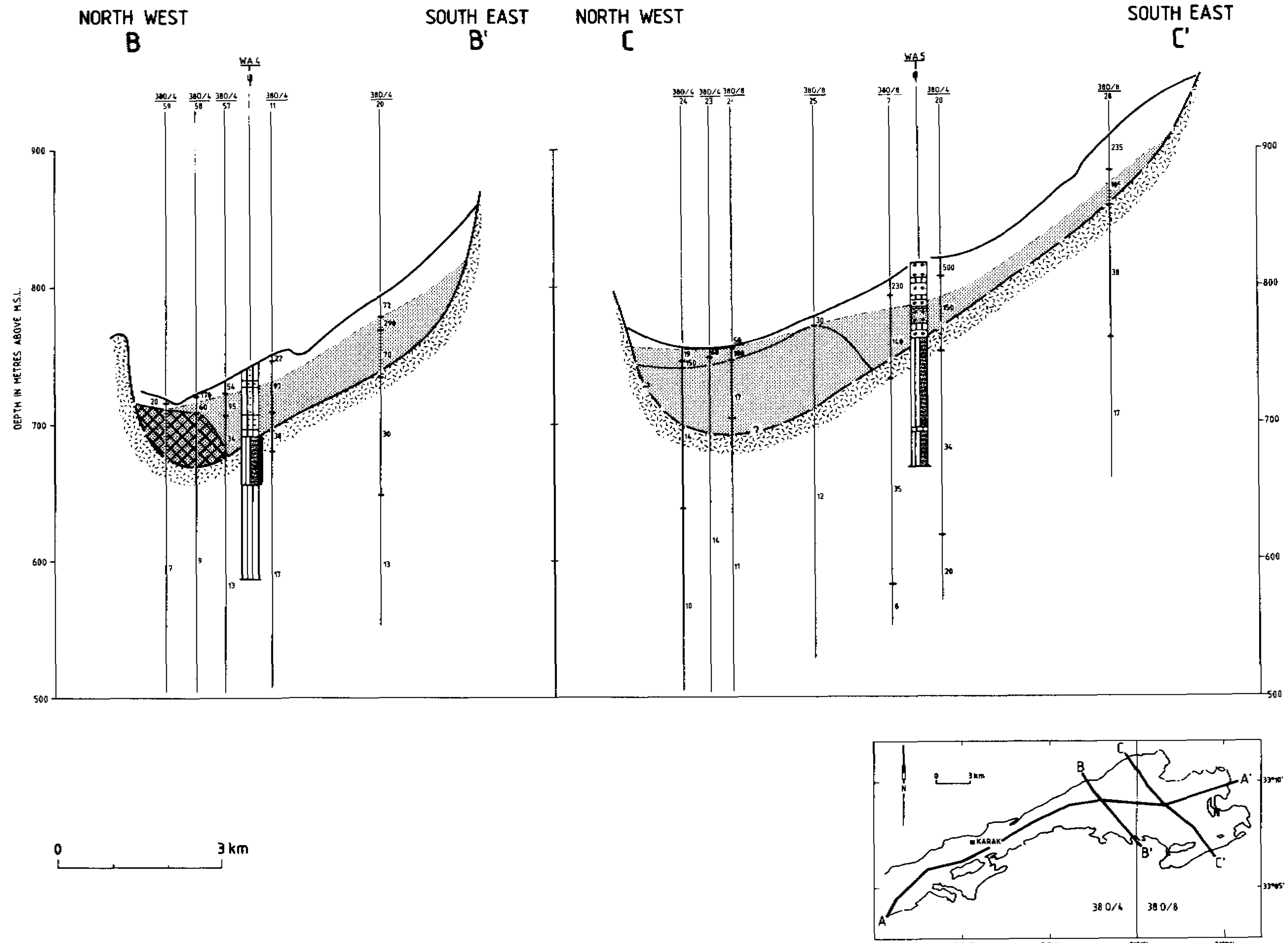


Figure 70: Hydrogeological cross-sections B - B' and C - C' over the Karak valley (For legend see fold-out at back of book)

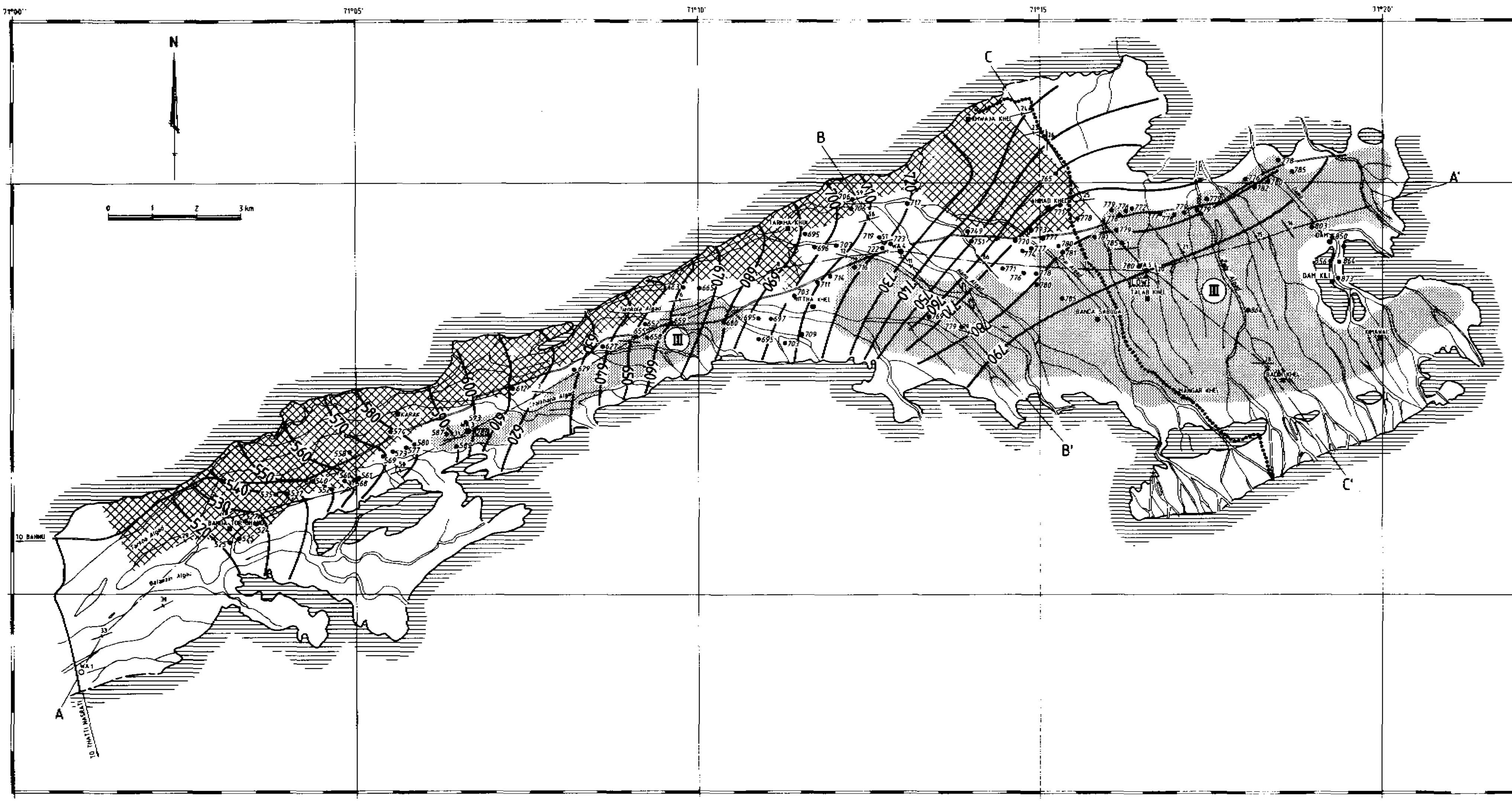


Figure 71: Groundwater map of the Karak valley (For legend see fold-out at back of book)

higher than that of the saline water, the risks are less. Any groundwater development should avoid the creation of deep drawdown cones and therefore use low-capacity pumps.

Eastern catchment
In this part of the Karak valley the groundwater development potential is only 3.3 Mm^3/yr (3.7 cusec). In the north the water table is very shallow but towards the south the depth increases to 30 m or more.
The transmissivity values are very low, which precludes the use of high-capacity pumps.

Groundwater management
The western catchment is vulnerable to further incursion of the saline water interface. An annual survey of water levels and EC values is recommended. Once every five years a survey of the groundwater withdrawals should be made.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Malik, Moh. Yousuf and G. Jousma, 1984. Groundwater resources in Karak Valley. Technical Report No.IV-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 31 pp., 5 app., 7 tbls, 3 figs, 5 pl. *Annotation.* The only report on the groundwater conditions in the Karak valley. It is based on the investigations carried out by WAPDA and TNO in the period 1981/1983. The fieldwork included a general well inventory of 661 open wells, a few tubewells and some natural springs, the drilling of three additional test wells that were geophysically logged and in which pumping tests were carried out; a resistivity survey of 78 vertical electrical soundings, chemical analysis of water samples from open wells and tubewells; the monitoring of groundwater level fluctuations; and stream flow measurements.

13 THE BANNU BASIN

Location

The Bannu basin is located on the right bank of the Indus river, from which it is separated by the very young Marwat and Shinghar ranges. It corresponds approximately to the District of which Bannu town is the administrative centre. The extreme northern part of the basin belongs to Karak District. The basin is bordered on the west by the North Waziristan Agency, on the south by Dera Ismail Khan District, and on the east by the Isa Khel area, the plain between the Shinghar range and the Indus river that is part of the Mianwali District of Punjab Province. The bowl-shaped Bannu basin covers an area of 10,030 km^2, including the alluvial plain that measures 4200 km^2 and is located between latitudes 32°21' and 33°07' N and longitudes 70°20' and 71°10' E (Figure 72).

Physiography

The Bannu basin is surrounded by mountains: the Sulaiman range in the northwest, the Kohat mountains in the north, the Shinghar range in the west, the Marwat range in the southeast and the Bhittanni range in the southwest. The highest points in these mountains are 1943 m (6373 ft) above msl near Mad Amir Kili in the Bhittannis and 1376 m (4513 ft) above msl at Sheikh Budin in the Marwat range. The elevation of the plain decreases from 600 m (1968 ft) along the Sulaiman range to 225 m (738 ft) at Darra Tang.

The Kurram river is the main stream of the Bannu basin; it is a perennial river that rises on the snow fields of the Safed Koh range in Afghanistan. It enters Pakistan in the Parachinar area (Section 15.7) and following a southeasterly course it enters the Bannu plain northwest of Bannu town, which it passes on the north side. Thirty kilometres downstream it receives the saline water from the Kashu Algad (or Karak Toi; Section 12.7). The salinity of the Kashu Algad is caused by outcrops of rock salt in the Kohat mountains. The Loughar Algad supplies the Kashu Algad with fresh water within the Bannu basin.

The Baran Algad rises in the Sulaiman range and enters the plain 6 km south of the Kurram river. It flows more or less parallel to the Kurram river and 30 km downstream it discharges into the Tochi river, which originates in the mountains along the Pakistan-Afghanistan border. Below the confluence the river is called Gambila river. Further south three perennial rivers join the Gambila; they are the Zendi, Chhal/Nugram and Chunai Nalas, of which the Chhal Nala is by far the largest. They all become perennial by exfiltrating groundwater. Near the eastern edge of the plain the Baran/Gambila discharges into the Kurram river, which at Darra Tang flows towards the Indus by way of a rather wide gorge that cuts through the Shinghar range at its junction with the Marwat mountains.

Apart from the above-mentioned perennial streams, numerous ephemeral nalas enter the basin from all sides; they only flow briefly after rainstorms over their catchment areas.

The rivers divide the Bannu basin into three units. From northeast to southwest these are:

- the Domail plain
- the Kurram-Gambila Doab
- the Lakki and Marwat plains

The Domail plain covers an area of 1476 km^2 north and east of the Kurram river. It has a catchment area of 1204 km^2 in the Kohat mountains and the Shinghar range. In its northeastern part the Kashu Algad and a number of its tributaries enter the basin.

The Kurram-Gambila Doab is the land enclosed by the Kurram and Baran/Gambila rivers. It covers 621 km^2 and is intensively cultivated. Its surface slopes from the Baran/Gambila towards the Kurram river. In the downslope area artificial surfacewater drains have been installed.

Southwest and south of the Baran/Gambila river lies the Lakki-Marwat area, which measures 2104 km^2. It has a catchment of 1440 km^2 in the Sulaiman, Bhittanni and Marwat ranges.

Based on the detailed work of Fraser (1958) the following broad physiographic units are recognized in the Bannu basin (Figure 72).

- A piedmont area, subdivided into the alluvial fans and the piedmont plain, which is found in the northern part of the Lakki-Marwat area, (Marwat plain),
- The Kurram river plain which encompasses the Kurram-Gambila Doab,
- A rolling sand plain that covers the southern part of the Lakki-Marwat area (the Lakki plain) and the Domail plain.

The 380 km^2 of boulder-strewn alluvial fans at the base of the Sulaiman and Bhittanni ranges, have a gradient that is as much as 0.009. Towards the centre of the basin the gradient decreases to 0.002. Consequently, the deposits become finer and gradually the alluvial fans merge with the piedmont plain that extends towards the Gambila river. The nalas have locally dissected the sand and silt deposits into badland topography. Erosion is a serious problem, particularly along the Chhal Nala and the Gambila river, where drainage is deeply entrenched into an intricate pattern of interconnected gullies.

The Kurram river plain is composed of an abandoned floodplain, a basin plain and a narrow strip of active floodplain. The abandoned floodplain is 170 km^2 in size and is situated in the northern and northeastern parts of the Doab and in an area of 40 km^2 at the confluence of the Gambila and Kurram rivers north of Lakki. It is a broad level surface marked by a few meander scars and abandoned channels of low relief that lies about 12 m above the streambeds of the Kurram and Gambila rivers. The basin plain of 325 km^2 comprises most of the central and southern parts of the Doab. It is a surface of low relief traversed by a few abandoned channels and probably underlain by river-borne sediments and mountain outwash. The active floodplain is a narrow strip of land of about 11 km^2 along the Kurram river east of Tortalla village. The rolling sand plain occupies the 510 km^2 of the Lakki plain, south of the Gambila river and nearly the whole Domail plain (1436 km^2), east of the Kurram river. The surface is an undulating plain of windblown sand which forms a thick cover over sandy piedmont deposits that originated in the Marwat and Shinghar ranges. The plain is traversed by nalas from the Marwat, Shinghar and Kohat ranges.

Geology

The north-south oriented (Waziristan) Sulaiman range consists of Cretaceous and Jurassic sedimentary formations with local bodies of Late Cretaceous and Early Tertiary intrusive rocks. The east-west oriented Kohat mountains are composed of rocks that were densely folded and faulted in Early and Middle Tertiary time. During the Late Tertiary and Early Quaternary the Bhittanni, Marwat and Shinghar ranges emerged and these young and not very high (usually less than 1200 m or 3940 ft above msl), narrow ridges cut off the northwestern tip of the Indogangetic foreland (Section 2.2). This left the Bannu basin behind a closed ring of mountains. The molasse deposits of the Indogangetic foredeep became the bedrock of the young alluvial and lacustrine deposits that slowly filled the basin. For a long time, until the Darra Tang gorge had formed, water that entered the basin either as rainfall or runoff could not escape, except by evaporation.

Climate

The Bannu basin has a semi-arid subtropical continental lowland type climate (Section 1.3). The average annual rainfall

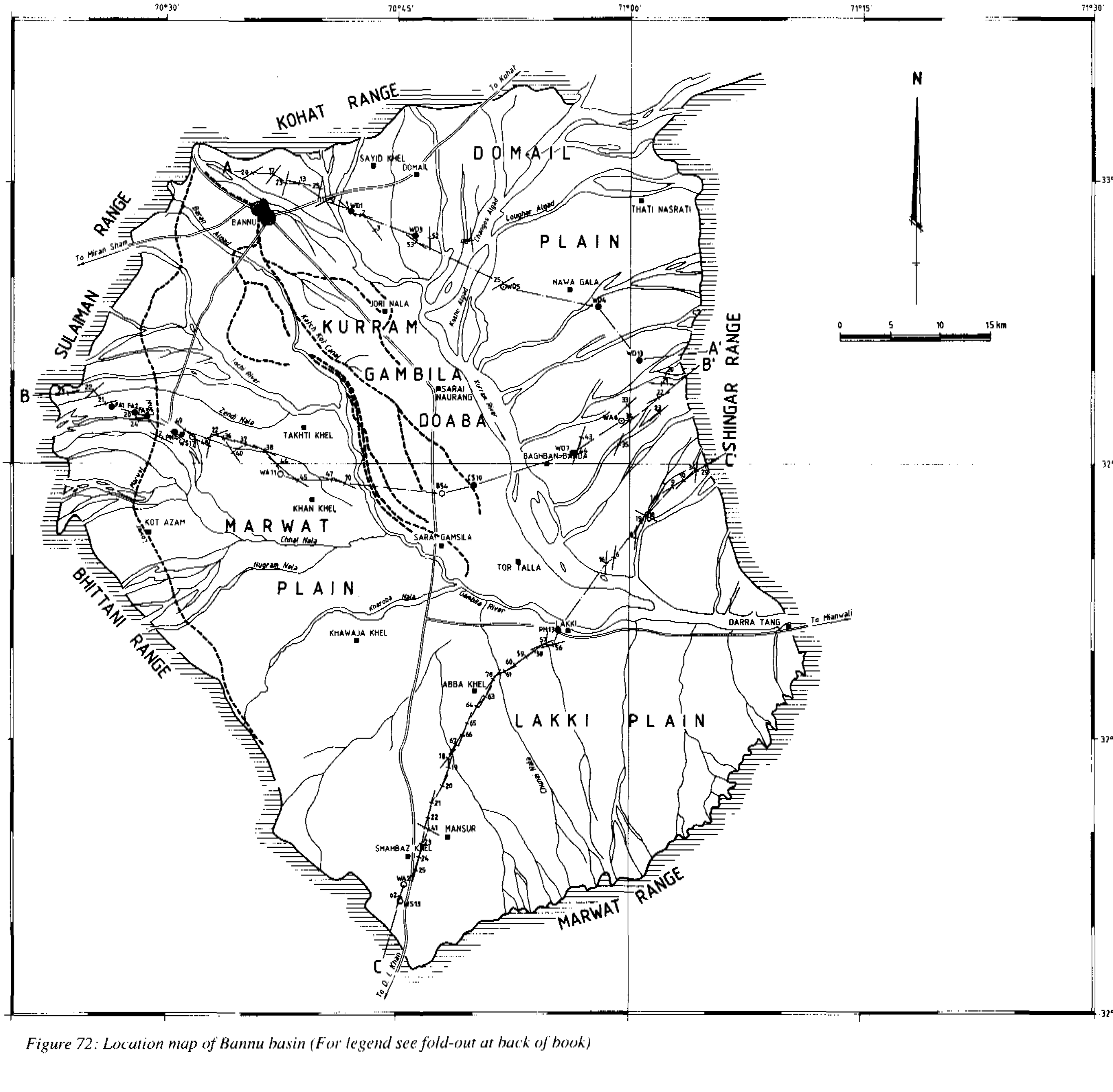


Figure 72: Location map of Bannu basin (For legend see fold-out at back of book)

at the meteorological stations of Bannu, Sarai Naurang and Lakki is 331, 295 and 258 mm, respectively. Summer rains (June through September) amount to 47 per cent and winter rains (December through March) to 30 per cent of the annual total. Average annual potential evapotranspiration is 1550 mm. The mean monthly temperature at Bannu town in June, the hottest month, is nearly 34 °C and in January, the coolest, it is 11.8 °C.

Population and domestic water supply

The number of people living in the District is approximately 830,000 persons, 800,000 of whom live in the Bannu plain. Nine per cent inhabit Bannu town, the only urban centre; the others dwell in the rural areas. The Kurram-Gambila Doab accommodates more than 50 per cent of the District's population and has the highest density.

In the area east of the Kashu Algad and Kurram river, i.e. in the northern part of the Domail plain, the Kurram-Gambila Doab and the Lakki-Marwat area, open wells are the common source of domestic water. The very thinly populated area south of the Kashu Algad has few private dug wells or tubewells. The PHED supplies this area with water from galleries ("karezes") in the Loughar valley and from tubewells in the vicinity of the villages. Bannu town and the larger villages, especially in the areas with a deep water table, receive their water from 131 tubewells operated by PHED.

Agriculture

Ahmad et al. (1974) classified the Kurram-Gambila Doab and a large part of the piedmont plain with a total area of nearly 120,000 ha (300,000 acres), as "land with a high to very high economic potential under irrigation". The rolling sands of the Lakki and the Domail plains have a poor economic potential under dry farming, but where the soil is loamy it will make very good irrigable land if irrigation water could be provided.

According to Ullah Khan and Ullah Khan (1986), the cultivable area in the Bannu basin amounts to 101,640 ha (254,109 acres) of which 82,240 ha (205,600 acres) is cropped. In 1983/1984 the irrigated area was 78,770 ha (194,560 acres). The upper part of the Kurram-Gambilla Doab has the oldest and most developed canal system (Section 1.4). The irrigated holdings are usually less than 0.8 ha (2 acres) and are intensively cultivated. The main crops are sugar cane, wheat, maize and vegetables; turmeric and bananas are found around Bannu town. Crops of secondary importance are rice, cotton, oilseeds (mustard), and dates (palm groves).

On the left bank of the Kurram river 10,500 ha (26,000 acres) are commanded by the Left Bank Canal. The Marwat or Right Bank Canal was constructed to irrigate 68,240 ha (169,235 acres) on the Marwat plain, but the water supply is meagre, irregular and uncertain, resulting in a low irrigation intensity. Near Thati Nasrati where the Loughar Algad enters the Domail plain and on the triangle between Kashu Algad and Kurram river, respectively 0.94 Mm^3 and 0.32 Mm^3 of groundwater are developed annually for irrigation by means of open wells.

In 1986, after the completion of WAPDA and TNO's groundwater investigations in the Lakki Marwat area, four test wells were handed over to the Irrigation Department to be used as the nucleus for groundwater-based irrigation schemes.

The Bannu SCARP plan (WAPDA, 1977) deals with a large part of the Kurram-Gambila Doab. Its objective is to lower the water table in waterlogged areas, to reclaim salinized soils, and to bring additional land under irrigation by installing 176 tubewells, 83 dug wells and to improve the surface water drainge system. In 1982 the 176 tubewells were commissioned and when they were tested in 1985 158 of them were still operational with a total capacity of 15,164 m^3/h or an average capacity of 96 m^3/h (0.96 cusec) per well.

Groundwater investigations

The first groundwater studies were started in 1963 by WAPDA-WASID and resulted in the mainly qualitative report by Lutfe Ali Khan (Khan, 1968). In 1977 WAPDA Project Planning Directorate (Water), Peshawar Region, prepared a project planning report for the Bannu SCARP (WAPDA, 1977). It describes in detail the water and soil conditions of the Kurram-Gambila Doab and the means to combat waterlogging and soil salinization, as well as the way to increase the number of irrigated farms through groundwater development. In 1981 WAPDA, in co-operation with TNO-DGV started a programme of groundwater investigations in the Domail plain (Uil, 1983) followed in 1983 by a similar study of the Lakki-Marwat area (Dalfsen, et al., 1986). In 1985 WAPDA's Tubewell and Groundwater Monitoring Division tested the 176 Bannu SCARP tubewells (WAPDA, 1985).

Groundwater conditions

The consolidated sediments of the catchment have not been investigated systematically. The Jurassic, Cretaceous and the Early and Middle Tertiary rocks are, with the possible exception of their limestones, unlikely to yield large amounts of groundwater. Dalfsen et al. (1986) suggest that the Plio-Pleistocene sandstone formations of the Bhittanni, Marwat and Shinghar ranges, which have a low degree of diagenesis and underlie the alluvial deposits, may not be impervious but part of the groundwater flow system.

The principal aquifers in the alluvial fill are hydraulically interconnected and form a single groundwater flow system. Nevertheless the groundwater conditions differ from place to place because of differences in the nature of the alluvial deposits. Therefore the following units are distinguished:

- the Marwat plain, between the Sulaiman and Bhittanni ran ges and the Baran and Gambila rivers,
- the Lakki plain in front of the Marwat range and south of the Gambila river,
- the Kurram-Gambila Doab.
- The northern part of the Domail plain, i.e. the triangular area between the Kashu Algad and the Kurram river, and
- The eastern part of the Domail plain, i.e. the area south of the Kashu Algad on the left bank of the Kurram river.

The Marwat plain

Close to the mountains the Marwat plain consists of ill-sorted mixtures of boulders, gravel, sand, silt and clay that form the apex of the alluvial fans. The principal aquifer is unconfined and is characterized by a low transmissivity and a 50 - 160 m deep water table. Locally, perched aquifers occur above the water table of the principal aquifer. Such a thin perched water-bearing layer is present in the alluvial fan of

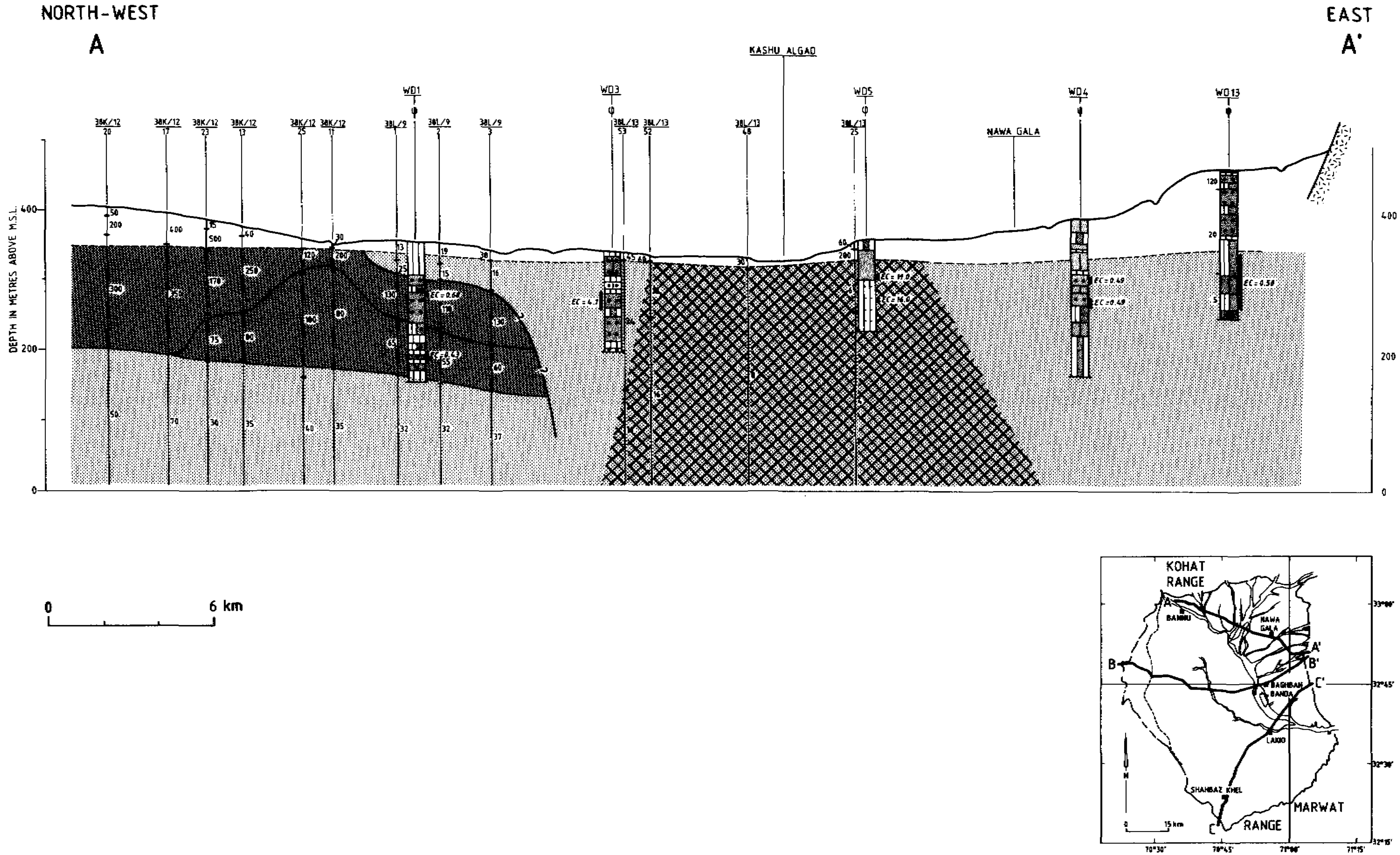


Figure 73: Hydrogeological cross-section A - A' over the Bannu basin (For legend see fold-out at back of book)

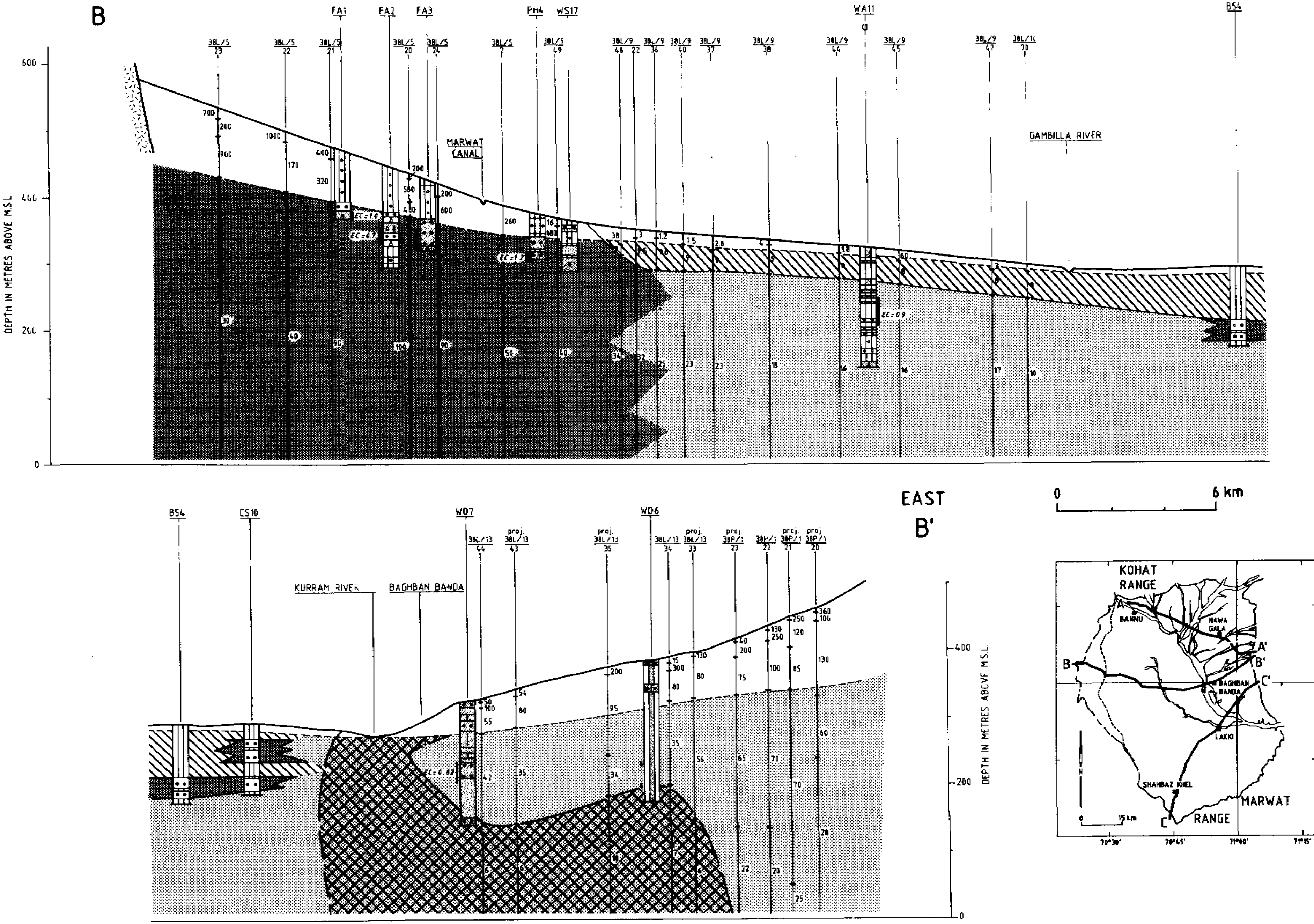


Figure 74: Hydrogeological cross-section B - B' over the Bannu basin (For legend see fold-out at back of book)

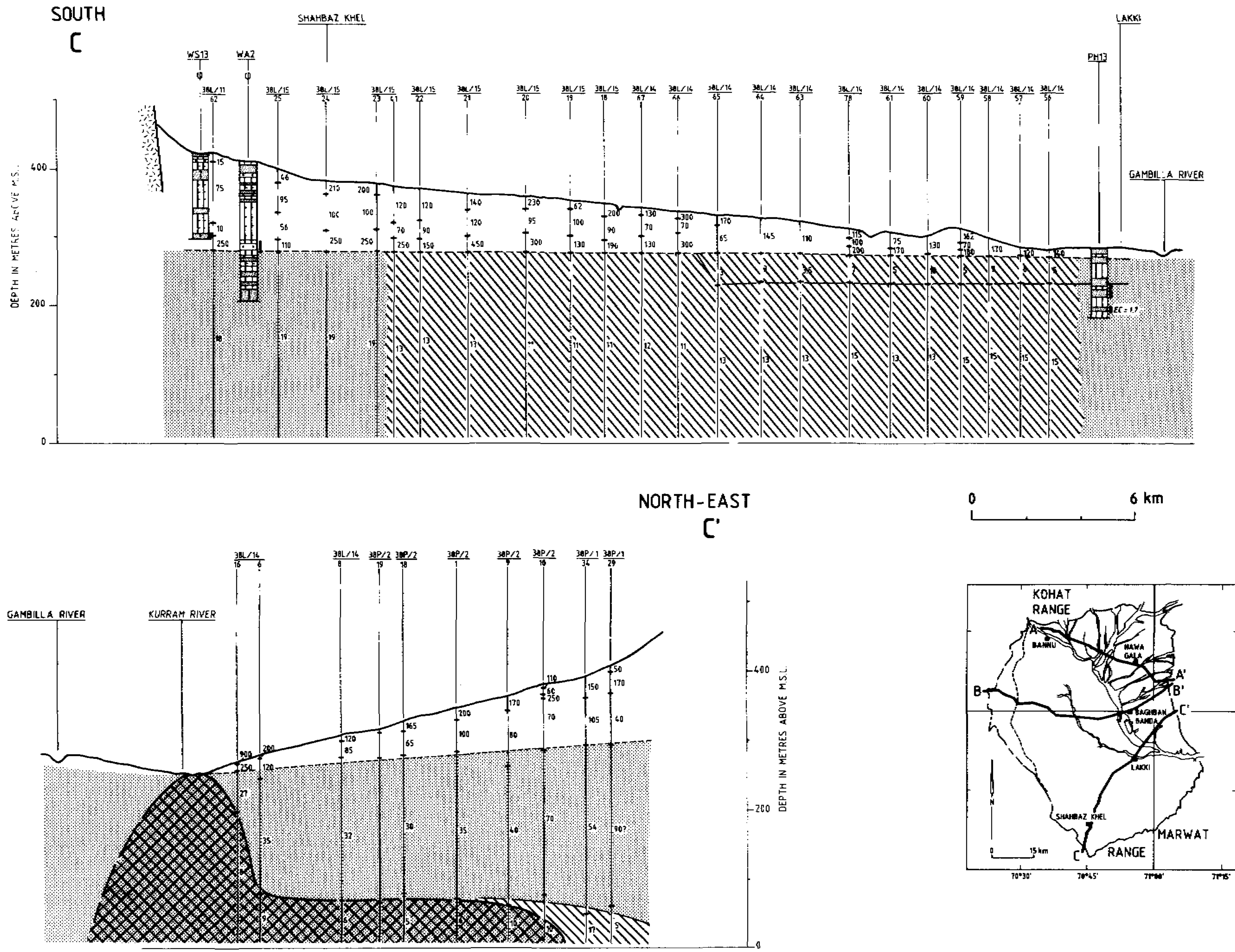


Figure 75: Hydrogeological cross-section C -C' over the Bannu basin (For legend see fold-out at back of book)

the Nugram Nala. Its water table is at a depth of 20 m below land surface and its base is at a depth of 20 - 30 m. According to Riaz (oral communication) the perched water exfiltrates in the Nugram Nala at a rate of 500 m^3/h (5 cusec). In the downstream portion of the fans the boulders disappear from the formation and the deposits are better sorted, resulting in a belt where the principal aquifer has a transmissivity of 600 - 1000 m^2/d (Figures 73, 74 and 75) and tubewells have a specific capacity from 7 to more than 40 m^3/h per metre drawdown (9.4 - 53.6 gpm per ft dd.). The water occurs under unconfined conditions and the water table is at a depth of 20 - 40 m. The specific yield is probably 0.10 - 0.15. The groundwater from this zone has EC values ranging largely from 0.7 to 2.5 mS/cm and SAR values from 1.4 to 7.0; sodium and, to a lesser degree, magnesium are the dominant cations and sulphate and bicarbonate the dominant anions. This zone extends along the Marwat canal from Bannu to approximately Kot Azam (Figure 76).

Beyond the toe of the fans the sandy deposits grade into fine-grained silty and clayey sediments that may have accumulated in a flood basin, or possibly, in a lake. Sand layers become fewer and in the area between Khawaja Khel and Takhti Khel they are only encountered buried under a 60 m thick clay layer. The water in the deep sand layers is confined and wells drilled in them are free-flowing in the Khan Khel - Takhti Khel area and near Khawaja Khel. The transmissivity of the deep aquifer is less than 100 m^2/d and the storage coefficient is 0.0005, the groundwater is of the sodium bicarbonate or sodium sulphate type with an EC value of 0.9 mS/cm and SAR values that range from 4 to 7. In the upper section of the thick clay cover some sandy layers may be present that sometimes contain a shallow unconfined aquifer. Generally, its water has EC values exceeding 2.0 mS/cm and SAR values between 3 and 5; magnesium and sodium are the main cations and bicarbonate and sulphate the main anions. This aquifer has not been tested as its thinness and its water quality make it unsuitable for large-scale exploitation.

The Lakki plain

The aquifer of the Lakki plain is unconfined; it occurs in a thick series of fine sand intercalated with clayey beds. Dalfsen et al. (1986) point out that the friable sandstone below the alluvial fill may belong to it. Nevertheless, the transmissivity is rather low, between 100 and 300 m^2/d, as a result of the fine-grained nature of the sands. Over most of the plain the water table is at a depth of more than 20 m below the surface, but perched aquifers of limited extent and with a shallow water-table occur locally. The water quality of the principal aquifer is from good to usable, with EC values between 0.8 and 1.8 mS/cm. The groundwater elevation contours between boreholes WS-15 and WS-19 (i.e. between Mansor and Abba Khel) (Figure 76) indicate a jump in the water table elevation, as witnessed by the sudden change in the direction of the contour lines. This may be related to a fault structure (Khan, 1968).

The Kurram-Gambila Doab

Interconnected waterbearing sand layers with intercalations of silty clay and clay make up the Kurram-Gambila Doab. In the north the sand is coarser and mixed with gravel, and the layers of sand are thicker than in the central sector of the Doab. Transmissivity values vary from 800 to 4000 m^2/d, and the specific yield may be 15 per cent. The depth to the water table ranges from 60 m close to the mountains to less than 5 m towards the centre of the Doab. The water quality at some depth is good to usable, with EC values between 0.8 and 2.0 mS/cm and SAR values ranging from 0.1 - 3.1. Groundwater close to the surface may show higher salinity levels as a result of the influence of evapotranspiration on waterlogged areas, and also higher SAR values.

In the central and southeastern sectors of the Doab the sand layers are thinner and finer grained. Clay becomes more preponderant, which results in confined conditions. In the bend of the Gambila river the confined aquifer of the Marwat plain with its free-flowing wells, seems to extend to a narrow zone on the Doab. Towards the axis of the Doab and towards the east the sand layers increase in number and thickness and the hydraulic characteristics become similar to those of the Lakki plain. The chemical composition of the water is also similar to that of the Lakki plain aquifer but the depth to the water table is less, only 3 - 15 m below the surface.

The northern part of the Domail plain

The area between the Kashu Algad and the Kurram river has an unconfined aquifer in a series of 200 m gravel and coarse sand. The electrical resistivity survey indicated fine-grained, probably clayey deposits below 200 m depth, but no drilling was done to verify this. The transmissivity values in this area vary from 500 to 5000 m^2/d. North of Bannu and around Sayid Khel the sediments may be partly cemented and, consequently, the transmissivity values may be lower. Specific capacity values range from 7.5 - 75 m^3/h per metre drawdown (10 - 100 gpm/ ft dd.). The specific yield is probably between 0.10 and 0.15. The water levels vary from 5 m below surface close to the rivers to 50 m below surface at the top of the fans. The EC values in open wells and tubewells range from 0.5 to 1.8 mS/cm and the SAR values from 0.6 to 16.1. The water with EC levels below 1.0 is of the calcium bicarbonate type and the water with higher salinity levels is of the sodium chloride type. The high salinity levels may be caused by infiltrating saline surface water (Kashu Algad).

The eastern part of the Domail plain

The area south of the Kashu Algad consists mainly of silty and clayey deposits with intercalations of fine to medium sand. The transmissivity values vary from less than 100 to 400 m^2/d and in one location a transmissivity of 1000 m^2/d was calculated. Specific capacity values are in the order of 1 to 10 m^3/h per metre drawdown (2 to 12 gpm/ ft dd.). The specific yield of the sand layers is probably between 0.05 and 0.10. The depth to water is less than 5 m near the Kurram river and more than 120 m at the top of the alluvial fans along the eastern mountains. Uil (1983) discovered an abrupt change in the depth to groundwater in the transition zone between the Domail plain and the upstream valleys of the Loughar Algad and the Tarkha Algad (Karak valley). In the valleys where the thickness of the alluvium is less than 100 m, the depth to the groundwater is less than 10 m, but where they join the plain the thickness of the alluvium increases to more than 300 m and the transmissivity will be much larger as well. Consequently, the depth to the water table suddenly drops to more than 80 m.

The groundwater is saline along the Kashu Algad and in a

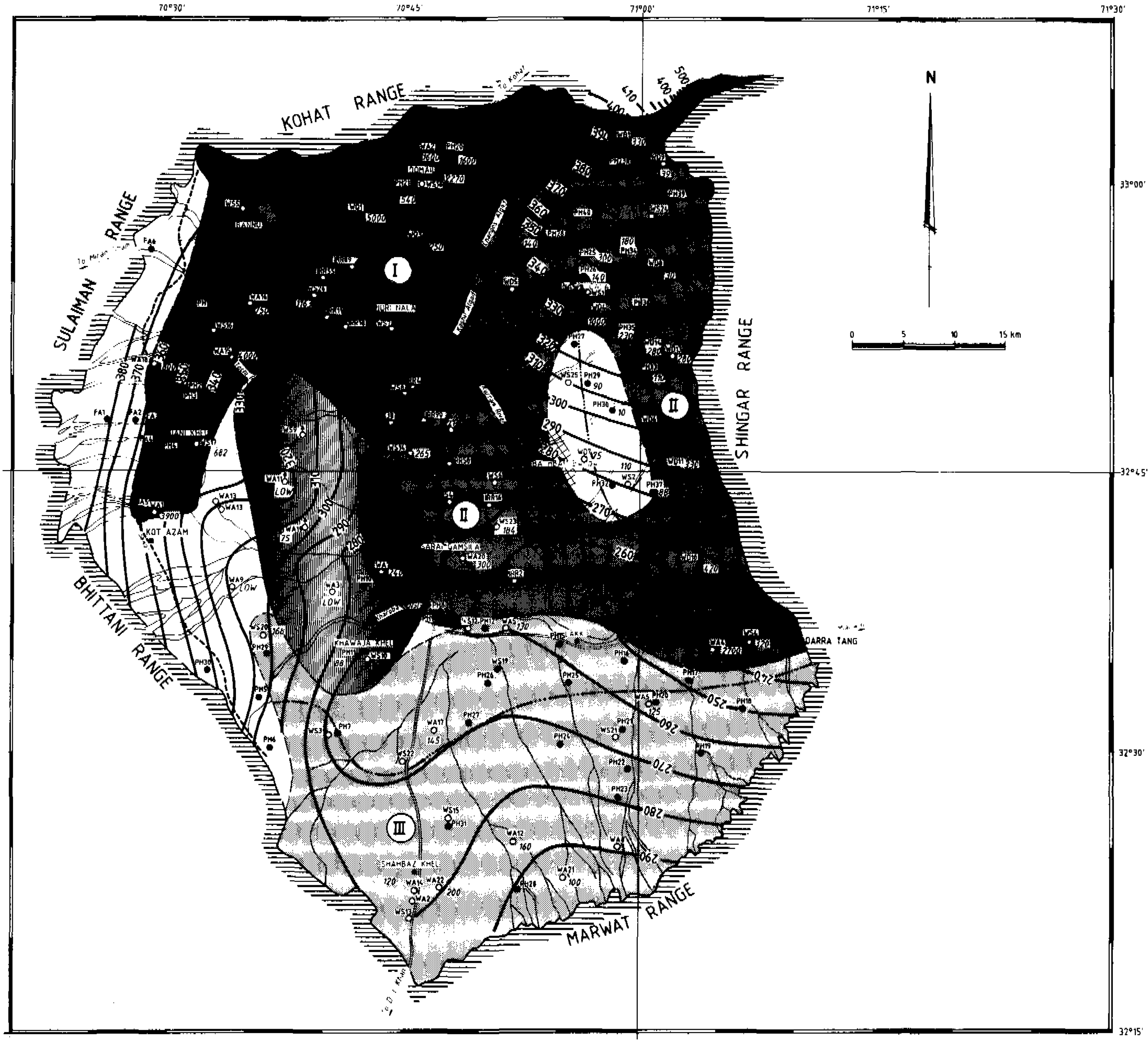


Figure 76: Groundwater map of the Bannu basin (For legend see fold-out at back of book)

strip up to 10 km wide along the Kurram river below their confluence. The EC values may be as high as 16 mS/cm and SAR values are also very high, up to 40. Away from the saline strip the water is usually of the sodium bicarbonate type, the EC values are between 0.3 and 2.0 mS/cm and SAR values are between 0.7 and 7.3 (an exceptional value of 12.8 has been found). Uil (1983) reports very high nitrate levels, up to 7 meq/l, in water samples from the tubewells drilled by WAPDA/TNO.

Water level fluctuations

The seasonal fluctuations in the groundwater levels vary from 0.2 to 5 m. According to Uil (1983) the high values are probably influenced by pumping. In the irrigated areas, notably the Kurram-Gambila Doab, water tables are rising under the influence of deep percolation of irrigation water and leakage from the distribution network. When the water table is within a depth of 2-3 m below surface, fluctuations occur under influence of the evapotranspiration.

Groundwater flow

The watertable contours of the Bannu basin are shown on Figure 76. This map is based on groundwater level data that were collected in different years and seasons. Nevertheless, it is believed to give a representative picture because the departure from the "true" values is in general negligible on a regional scale. Only on the Kurram-Gambila Doab are the groundwater levels likely to be lower than shown on the

Table 31: Soil moisture balance of the Domail plain

Month	Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Feb. 1982	Ep							2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2				44
	P																		17	5							1						23
	R																		0	0							0						0
	I																		15	0							0						15
	SM																		15	18	16	14	12	10	8	6	5	3	1				1*
	Ea																		2	2	2	2	2	2	2	2	2	2	2				22
March 1982	Ep	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	93
	P	8			11	7	1		4	18	3						2				7	5		4	6		1		2				79
	R	0			0	0	0		0	0	0						0				0	0		0	0		0		0				0
	I	5			8	4			1	15							0				4	2		1	3		0		0				43
	SM	6	3	0	8	12	10	7	8	23	23	20	17	14	11	8	7	4	1	0	4	6	3	4	7	4	2	0	0	0	0	0	0*
	Ea	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	2	2	0	0	0	80
April 1982	Ep	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4		120
	P						1																1		2	8					6		18
	R																						0		0	0					0		0
	I																									4					2		6
	SM																									4	0				2		2*
	Ea						1																1		2	4	4				4		16
May 1982	Ep	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	217
	P	2										4			8									1							1		16
	R											0			0									0							0		0
	I											0			1									0							0		1
	SM											0			1									0							0		0*
	Ea	4										4			7									1							1		18
June 1982	Ep	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8		240
	P															6	9	7	14		1								1				38
	R															0	0	0	0		0								0				0
	I																1	0	6		0								0				7
	SM																1	0	6	0	0								0				0*
	Ea															6	8	8	8	6	1								1				38
July 1982	Ep	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	248
	P	3	7		1								10										54										75
	R	0	0		0								0										16										16
	I	0	0		0								2										30										32
	SM	0	0		0								2		0								30	22	14	6	0						0*
	Ea	3	7		1								8		2								8	8	8	8	6						59
August 1982	Ep	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6										132
	P								4				2			15					19												40
	R								0				0			0					2												2
	I								0				0			9					11												20
	SM								0				0			9	3	0			11	5	0										0*
	Ea								4				2			6	6	3			6	6	5										38

Ep = Potential evapotranspiration (average values).
P = Precipitation.
R = Run-off.
I = Infiltration (maximum 15 mm/hour).
SM = Soil Moisture (* = situation by the end of the month).
Ea = Actual evapotranspiration.

map, because of the installation of 176 tubewells in the Bannu SCARP.

The flow is perpendicular to the contours, indicating a groundwater movement that starts on the alluvial fans and converges to the rivers and especially to the exit of the Kurram river at Darra Tang. The only subsurface outflow from the basin is through the alluvial fill of the Kurram river at Darra Tang. The amount is small however; Darcy's law gives a rate of 882 m^3/d or 0.3 Mm^3/yr when the following estimated aquifer parameters are used: width of the section: 500 m, hydraulic gradient: 10/8500 and transmissivity: 1500 m^2/d.

Discharge and recharge

The main groundwater recharge component is infiltration of runoff in the alluvial fans at the foot of the mountains. The runoff volume, and consequently the groundwater recharge is related to the rainfall depth over the catchment area. The amount of recharge over the fans cannot be measured directly but can be calculated from the subsurface flow rate at their foot. Another important component is the deep percolation of irrigation water losses by the conveyance system and as a result of over-irrigation in the field. A third recharge component is infiltration through the streambeds of the Kurram and Gambila rivers in the first 15 km of their flow through the plain, when the river bed is still above the water table.

Uil (1983) made a soil moisture balance based on daily precipitation data, which showed that the percolation of rainwater that has fallen directly on the Domail plain is negligible (Table 31).

The principal groundwater discharge component is exfiltration of the groundwater in the Kurram and Gambila rivers and in the lower reaches of the nalas that so become perennial; it is measured as their base flow. Another one is the pumping from open wells and tubewells for domestic use and irrigation. Minor components are direct evaporation in waterlogged areas and the subsurface outflow at Derra Tang. The recharge and discharge rates of the area on the right bank of the Baran-Gambila river, i.e. Lakki and Marwat plains, are based on the figures presented by Dalfsen et al. (1986).

The recharge components are:

- Percolation of runoff equal to 7 % of the rainfall (397 mm) over the catchment area (1440 km^2) southwest of the Tochi river	40	Mm^3/yr
- Percolation of 5 % of the rainfall over the sandy Lakki plain	2	
Percolation losses from the Marwat canal irrigation scheme contributing to subsurface flow	unknown	
- Percolation losses from the Marwat canal irrigation scheme contributing to increase in groundwater storage (rise of the water table)	unknown	
Total	42	Mm^3/yr

The discharge components are:

- Exfiltration through Chhal Nala	15	Mm^3/yr
- Exfiltration through other nalas from Baran river to Kharoba Nala and directly into Tochi/Gambila river	16	
- Exfiltration from the Lakki plain	4	
- Groundwater extraction on the Marwat plain	2	
- Groundwater extraction on the Lakki plain	1	
- Freeflow losses and evapotranspiration from areas with shallow water table	2	
Total	40	Mm^3/yr

The recharge and discharge volumes of the Domail plain are based on the figures presented by Uil (1983).

The recharge components are:

- Groundwater infiltration calculated as subsurface flow at the foot of the northern alluvial fans	30	Mm^3/yr
- Groundwater inflow in the saline area along he Kashu Algad	4	
- Groundwater infiltration calculated as subsurface flow at the foot of the Shinghar range	6	
- Groundwater infiltration from rainfall over the sandy part of the area south of the Kashu Algad	unknown	
Total	40	Mm^3/yr

If it is assumed that the average annual rainfall over the catchment area is 397 mm, which is 20 per cent higher than in Bannu, it follows that the groundwater recharge over the Domail plain corresponds to 8.3 per cent of the annual rainfall over the 1204 km^2 of the catchment area.

The discharge components are:

- Calculated groundwater exfiltration in the Kurram river from the Kashu Algad - Kurram river triangle	26	Mm^3/yr
- Ditto of the saline groundwater area along the Kashu Algad	4	
- Ditto of the area south of the saline groundwater belt along the Kashu Algad	9	
- Groundwater extraction from wells in the Kashu Algad - Kurram river triangle	2	
- Ditto in the area south of the Kashu Algad	1	
- Evapotranspiration in shallow groundwater areas close to the river	unknown	
Total	42	Mm^3/yr

Kurram-Gambila Doab

The principal source of recharge water is the irrigation supply. Data from the period 1958/1974 show an average daily discharge of 412 cusec at the head of the Katchkot canal, which corresponds to an annual supply of 361 Mm^3/yr. No data are available on the water delivered by the Baran Lohra system. A considerable amount of the diverted river water will evapotranspire, but another part will be returned through the surface drains to the river, or it will percolate to the water table and either return by subsurface flow and exfiltration to the river or it will contribute to the rise of the groundwater level.

Data for a quantitative groundwater evaluation are lacking, but the following estimate can be made:

The total outflow from the basin equals the surface water discharge of the Kurram river at the outlet of the basin at Darra Tang, which, according to Khan (1968), is 160 Mm^3/yr (179 cusec), because the subsurface outflow is probably not more than 0.3 Mm^3/yr and thus negligible. The discharge is composed as follows:

- Exfiltration of Kurram river water that has infiltrated in the upstream part of the plain where the river is influent	negligible	
- Exfiltration from the Lakki and Marwat plains	35	Mm^3/yr
- Exfiltration from the Domail plain	39	,,
- Exfiltration from the Kurram-Gambila Doab	86	,,

The contribution of the Kurram-Gambila Doab, 86 Mm^3/yr (96.3 cusec), is determined by subtracting the other components from the total. It corresponds to approximately 24 per cent of the discharge at the head of the Katchkot canal. This is a likely figure.

Groundwater development potential
The best areas for groundwater development are the northern and northwestern alluvial fans, from Kot Azam in the west to the Kashu Algad in the northeast, and the northern part of the Kurram-Gambila Doab. The aquifer in this area not only has a high transmissivity, 500 - 5000 m^2/d, but also receives the most recharge. The groundwater is mainly unconfined and the depth to the water table is generally less than 20 m. The outer boundary of the high potential development zone, (Figure 76), follows the 50 m depth-to-watertable contour. The annual recharge amounts to 29.6 Mm^3 (33.2 cusec) in the northern, and 35 Mm^3 (39 cusec) in the western fans, 1.6 and 2.0 Mm^3 of which, respectively, are already developed by open wells and tubewells. In the western alluvial fans the water is often brackish with EC values exceeding 2.0 mS/cm. SAR values are between 0.6 and 16.1, but in the northern fans the groundwater is classified as usable to good with EC values ranging from 0.5 to 1.8 mS/cm, occasionally with higher values. Along the Kashu Algad the groundwater is very saline and not suitable for drinking water or irrigation (see Figure 76).
In both series of alluvial fans large amounts of irrigation water can be developed if the water resources can be matched with the irrigable soils. The groundwater conditions are suitable for the construction of tubewells with a drilling depth of less than 100 m and a capacity of at least 100 m^3/h (1 cusec). To be on the safe side, the total installed tubewell capacity in the first phase of a groundwater development programme should not exceed the amount of uncommitted recharge: 28 Mm^3/yr (31.4 cusec) in the northern fans and 32 Mm^3/yr (35.8 cusec) in the western fans. In this way the actual water production rate will not exceed half the recharge rate.
In its groundwater conditions the northern part of the Kurram-Gambila Doab resembles the northern fans, but there is little need for groundwater development because of the abundantly available surface water resources of the Katchkot canal system. Over-irrigation has resulted in high water tables, and pumping may be required for watertable management. (WAPDA, 1977).
The part of the Domail plain located south of the Kashu Algad has restricted possibilities for groundwater development. The transmissivity values vary from less than 100 to 400 m^2/d and the recharge is only 6 Mm^3/yr (6.7 cusec), of which 0.9 Mm^3/yr is already developed, largely for the supply of domestic water. A strip of land up to 10 km wide on the left bank of the Kashu Algad and Kurram river is underlain by saline water and is unsuitable for groundwater recovery. The eastern limit of the saline zone coincides more or less with the 50 m depth-to-watertable contour, so in the freshwater zone the depth to water is more than 50 m. The conditions in this area are unfavourable for large-scale groundwater development. The available fresh groundwater resources should be reserved for domestic use and livestock watering. The water quality in the fresh water zone is good to usable, with EC values between 0.3 and 1.2. Uil (1983) reports high nitrate values, but they are not corroborated by the analyses of Lutfe Ali Khan (Khan, 1968). Tubewell capacities should be restricted to 50 m^3/h (0.5 cusec) in the areas where the transmissivity is more then 100 m^2/d and to 25 m^3/h (0.25 cusec) where it is less. Drilling depth will be from 150 to 200 m.
The Lakki plain is also characterized by a low recharge, 2 Mm^3/yr (2.2 cusec) of which 1 Mm^3/yr (1.1 cusec) is already developed, mainly as drinking water. It also has low transmissivity values, between 100 and 300 m^2/d. The water quality is generally good. EC values range from 0.8 to 1.8, but higher values are found locally. The depth to the water table in the south is more than 50 m, but it decreases towards the north until it is less than 10 m near the Kurram river.
The available groundwater resources can be developed for domestic supplies by tubewells with a low yield, 25 - 50 m^3/h (0.25 - 0.50 cusec) or for irrigation by private tubewells or dug wells. Drilling depth will range from 100 to 200 m.
The southern part of the Kurram-Gambila Doab has conditions comparable with those of the Lakki plain, with the exception that the water table of the Doab is at a shallow depth, often less than 3 m, as a consequence of the percolation losses of the surface water irrigation system. Conjunctive use of surface water and groundwater has been initiated in the Bannu SCARP. An evaluation of the effects is required before recommendations for further development can be made.
In the Lakki Marwat area between Takhti Khel and Khawaja Khel lies an area with low transmissivity values, less than 100 m^2/d, related to a deep (60 - 200 m) aquifer system consisting of thin sandy layers. The aquifer is confined and wells drilled in it are often free-flowing. The quality of the water is good, the EC varies between 0.8 and 1.0 mS/cm and SAR values range from 4 to 7. It is expected that development of the confined aquifer system will quickly lead to unacceptable pumping lifts.

Groundwater management
A study should be made of the quantitative aspects of the groundwater regime of the Bannu plain as a whole, with special emphasis on the groundwater hydrology and the water balance of the Kurram-Gambila Doab and the other irrigated areas. Subsequently, a groundwater flow model should be made to prepare a management plan for the conjunctive use of surface water and groundwater. A basin-wide groundwater level and quality monitoring system is required to collect data for the calibration of the models.

Annotated bibliography
The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Khan, Lutfe Ali, 1968. Report on geohydrological investigations in Bannu Basin, W. Pakistan. WAPDA-WASID, Lahore; 120 pp. of which 57 pp. text, 10 tbls, 20 figs of which 7 h.t. *Annotation.* The study was carried out as part of the comprehensive programme of groundwater investigations on the right bank of the Indus. The reconnaissance of the Bannu basin started in 1963 and fieldwork was completed in 1966. The report is a qualitative description of the groundwater conditions of the Bannu basin based on data concerning the drilling and geophysical logging (spontaneous potential and single-point resistivity) of 33 test holes, ranging in depth from 11 to 336 m, 9 of which were converted into test wells in which pumping tests were done; the water level observations, often at different depths, in the test holes; the inventory of 266 shallow dug wells, tubewells and springs that are mainly used for public water supply; the chemical analysis of 206 water samples from the test wells and from shallow wells; and river discharge measurements. The report contains a section on "Aquifer characteristics of alluvium" by A.H. Arif.

Ahmad, Mushtaq, Aurangzeb Khan, M.A. Darr, A.Q. Khan and N.A. Akhtar, 1974. Reconnaissance soil survey in Bannu Basin. Soil Survey of Pakistan; 177 pp., 4 app. 17 tbls, 3 figs and 3 pl. *Annotation.* Description of the soils and their genesis, present use and capability.

Qureshi, M.I. and Abdul Jaleel Abrar, 1982. Hydrogeological Data of Bannu Basin, vol 1; Basic Data Release no. 8. WAPDA Hydrogeology Directorate General, Lahore; 89 pp., 3 app., 3 tbls, 13 figs. *Annotation.* Contains the basic data from Khan et al. (1968) plus a summary of the introduction, physiography, geology and water quality chapters of that report.

Uil, H., 1983. Groundwater resources in Domail plain, Bannu and Karak Districts, N.W.F.P., Technical Report No. IX-1. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 51 pp., 6 app., 13 tbls, 7 figs, and 6 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO during 1981/1983. It is based on fieldwork that included an inventory of 1571 open wells, a resistivity survey of 251 vertical soundings, the drilling of 14 test holes, ranging in depth from 130 to 230 m, 13 of which were geophysically logged (SN and LN resistivity, SP, and gamma) and 12 were converted into test wells; the sampling of water for chemical analysis and the monitoring of groundwater levels. The evaluation includes a groundwater balance of the area.

WAPDA,1985. Tubewell performance in Bannu SCARP for the year 1984/1985. SCARP's Tubewell and Groundwater Monitoring Division, Peshawar. 20 pp., 4 tbls, 4 figs. *Annotation.* Report on the performance of 158 operational tubewells, out of the 176 that were installed. Short specific capacity tests were carried out and the results are compared with the designed specific capacity and with the specific capacity at the time of acceptance of the well.

Dalfsen, W. van, Muhammad Riaz and Nadeem-ul-Haq, 1986. Groundwater resources in Lakki-Marwat area, Bannu District, N.W.F.P., Technical Report No. IV-3. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 30 pp., 5 app., 7 tbls, 6 figs, and 5 pl. *Annotation.* The report comprises the results of the investigations carried out by WAPDA-HDP and TNO during 1983/1985. It is based on fieldwork that included an inventory of 183 open wells, 31 PHED tubewells and 6 FATA-DC tubewells; a resistivity survey of 382 vertical soundings; the drilling of 22 test holes, ranging in depth from 67 to 230 m, which were all geophysically logged (SN and LN resistivity, SP, and gamma) and three of which were converted into test wells on which pumping tests were done; the sampling of water for chemical analysis, groundwater level monitoring and stream gauging. The evaluation includes a groundwater balance of the area but does not give any quantitative recommendations about the groundwater development.

14 THE DERA ISMAIL KHAN BASIN

Location
The Dera Ismail Khan (D.I. Khan) District is situated in the southern-most region of NWFP between latitudes 31°15' and 32°30' N and longitudes 70°00' and 71°00' E. It is subdivided into the Tehsils of D.I. Khan, Tank and Kulachi. D.I. Khan town is the District Headquarters.
An alluvial plain of 7000 km^2 belongs to the District and its catchment extends into the Sulaiman, Bhittanni, Marwat and Khisor mountain ranges. The eastern boundary is the Indus river, and in the south the plain continues into the Dera Ghazi Khan District of the Punjab.

Physiography
In the eastern part of the basin the Indus shaped the river lowlands, as a result of which abandoned and active floodplains emerged. The transi tion between the two is rather abrupt. Near the northern and southern boundaries of the plain recent dune areas occur (Figure 77).
The centre and the west of the basin is a piedmont plain with its associated string of alluvial fans along the mountains. It has been formed by the so-called "western tributaries" of the Indus. Most of the western tributaries originate either in the Shirani hills or on the piedmont plain itself. They have small to very small catchment areas and carry water only intermittently in response to local rainstorms. The Tank Zam and the Khora river have their origins deep in the Sulaiman range, and the headwaters of the Gumal river are found far away in Afghanistan and Baluchistan. These three rivers have perennial flow and are the source of irrigation water for land on the upper slopes of the plain. The flow rate of the tributaries varies widely: during the low stage it is commonly less than 100 l/s, but snow-melt or thunderstorms rapidly increase it to peaks of tens or even hundreds of cubic metres per second (thousands of cusecs), which can cause extensive damage to diversion channels, fields, roads and houses.
The nalas deeply incise the flat piedmont plain and the stream channels are still developing actively. Those that have their beginnings on the plain itself have a dendritic pattern, which indicates that the infiltration rate is low. The flow of most nalas disappears by spreading, evaporation and infiltration when the stream channels reach the undissected, sandier river lowlands.

Geology
The mountains bordering the alluvial plain are mostly late Tertiary rocks of the Siwalik Group. Consolidated or semiconsolidated sandstone with thick clay or shale beds predominate. Hood et al. (1970) assumed that these rocks extend as basement rock at relatively shallow depth below the alluvial fill. In fact, the basement of the piedmont deposits is formed by the hard clay layer that is encountered at the bottom of some of the test holes drilled in the plain. This layer, found at a depth of more than 200 m below the surface, may well belong to the Plio-Pleistocene molasse deposits of the Indogangetic foredeep and not to the older Siwalik Group.
During the upper Pleistocene and Holocene the basin has filled up with silty clay, sand and gravel which occur either as: (a) piedmont deposits in the west and the centre of the basin, or as (b) floodplain deposits of the Indus river that are found in the east. They interfinger in a transition zone.
Close to the mountains the piedmont deposits consist of gravel and boulders with intercalations of clay that form alluvial fans. With increasing distance from the mountains the grain size decreases rapidly, and stratified, silty clay becomes the predominant material in the central plain. Layers of fine to medium textured sand are sometimes intercalated.
The floodplain deposits cover an area of 1200 km^2 of the Indus river lowlands and consist of sand with only a little intercalated clay. The sequence is generally 250 - 350 m thick, but in the WASID test hole D.I.K. T/H-14 near D.I. Khan town its thickness exceeds 426 m. The sands resemble the Punjab-type sands found beneath the Thal Doab on the left bank of the Indus (Greenman, et al., 1967).

Climate
The climate is of the semi-arid subtropical continental lowland type (Section 1.3). The average annual precipitation ranges from 290 mm in the hills in the north to not more than 200 mm in Ramak in the south. The annual potential evapotranspiration is approximately 2200 mm.

Population and domestic water supply
In 1987 the total population was estimated to be 778,000, of whom 635,000 were living in the rural areas. These people obtain their domestic water from dug (open) wells and shallow drilled wells equipped with handpumps, ponds that store runoff, the Indus river, and irrigation ditches or perennial streams. The Public Health Engineering Department (PHED) has drilled tubewells for the supply of the major towns and larger villages.

Agriculture
Agriculture is the main economic activity and the main user of groundwater. According to the available statistical data (B.o.S., 1986a and c; Ullah Khan and Ullah Khan, 1986), 300,600 ha (743,000 acres) are cultivated, of which the cropped part covers 233,900 ha (578,100 acres). Some 128,800 ha (316,200 acres) are rainfed (or barani) land and

Figure 77: Physiographical map of the Dera Ismail Khan basin (after Hood et. al., 1970)

105,100 ha (259,600 acres) are irrigated. Of the irrigated area 41,180 ha (101 780 acres) in the Indus river plain receive their water supply from the government-operated Paharpur canal, and 36,170 ha (89,400 acres) in the upper piedmont plain are irrigated by private canals that divert water from the western tributaries. According to the same statistics, an area of 26,960 ha (66,600 acres) is irrigated with tubewell water in schemes like the Khanwand tubewell irrigation project and the tubewell schemes implemented in the river lowlands, and 160 ha (395 acres) are irrigated with water from open wells.

The Khanwand project is located near Kot Azam where the Gumal river leaves the western mountains. Of the nine tubewells, eight were commissioned in 1973/1975 as a first stage of the development of a culturable area of 12,300 ha (30,400 acres). In 1982/1983 five wells were still operating and in 1987 only a single one was left.

The river lowland schemes, also known as scheme 30 and scheme 60, were installed in 1964/1965 by the Irrigation Department of NWFP in the area north of D.I. Khan town. Ninety tubewells were drilled with a capacity of 300 m^3/h (3 cusec) each, to irrigate a total area of 21,500 ha (53,000 acres); that is 240 ha per tubewell. According to the Chashma Right Bank Irrigation Feasibility Report (WAPDA, 1970), 32 wells were out of order in 1970: 16 because of technical defects and the other 16 because of high salinity of the pumped water. The actual utilization was only 25 per cent of the installed capacity because of frequent breakdowns. These statistics are the most up-to-date at the time of writing.

An unknown number of farmers have drilled private wells. Data from 1976 relating to 22 wells in the Paharpur area indicate that the total depth of these wells does not exceed 40 m. Table 32 indicates the major crops grown in D.I. Khan.

Groundwater investigations

In D.I. Khan District the first comprehensive groundwater investigations were carried out by WASID during 1961/1964. The results were published by Hood et al. (1970). In 1970 WAPDA published "Groundwater appraisal of Tank-Paniala" (Naqavi et al., 1970) and during 1974/1976 it returned to do additional research in the Paharpur canal command (Naqavi, 1977). The latest study of the D.I. Khan basin, excluding the Paharpur command, took place in the period 1982/1985 and was undertaken by the Pak-Dutch project "Groundwater investigations in NWFP" (Malik, 1985 and Faiz et al., 1985).

Groundwater conditions

There has been no systematic exploration for groundwater in the hills surrounding the D.I. Khan basin. It is likely, though, that some groundwater does occur, because springs have been reported. The fractured and semiconsolidated sandstones and limestone promise to have the best permeability and may transmit water by subsurface flow from the hills into the alluvial fill of the basin. In Loehack on the Khora river in the Sulaiman range west of Daraban (outside the map), FATA-DC recently drilled three test wells in a sedimentary series consisting of limestone, marls, shales and some conglomerates. Groundwater was encountered but the yield was low (about 10 m^3/h).

North of Paniala, karezes, i.e. galleries to obtain drinking water, have been dug in the semiconsolidated Tertiary sandstones of the Marwat range.

The groundwater reservoir of the D.I. Khan basin can be divided into three hydrogeologial zones (Figure 78):

(a) the gravel and boulders of the alluvial fan deposits,

(b) the silty clay series of the piedmont plain in the central part of the basin, and

(c) the Punjab-type sand deposits of the active and abandoned flood-plains along the Indus.

The alluvial fan deposits are a recharge zone along the western boundary. The zone is a few kilometres wide and 200 m thick. The pervious material, mainly gravels, occupies 25 per cent of the sequence up to 150 m below the surface. The transmissivity varies from 100 to 1000 m^2/d; it is higher in the south than in the north. The specific yield of the gravels is around 0.20 and that of the intercalated clay is 0.05. The groundwater occurs mainly under phreatic conditions and the water table is at a depth of 5 - 30 m. Where the gravels start interfingering with the silty clay of the central area the deeper groundwater may be confined. The water is fresh, i.e. the EC is less than 2.0 mS/cm. Along the western mountains it is a calcium magnesium bicarbonate type water in which in

Table 32: Major crops grown in Dera Ismail Khan area

KHARIF CROPS						
Irrigated	Rice	Vegetables	Sugar cane	Fodder	Cotton	Maize
% of area	28.2	19.5	13.3	9.6	8.9	8.6
Rainfed	Jowar	Bajra	Guara			
% of area	64.5	27.9	5.9			
RABI CROPS						
Irrigated	Wheat	Fodder	Gram			
% of area	76.3	9.8	8.7			
Rainfed	Wheat	Gram	R and M*			
% of area	45.5	40.6	10.3			

*Rape and mustard seed

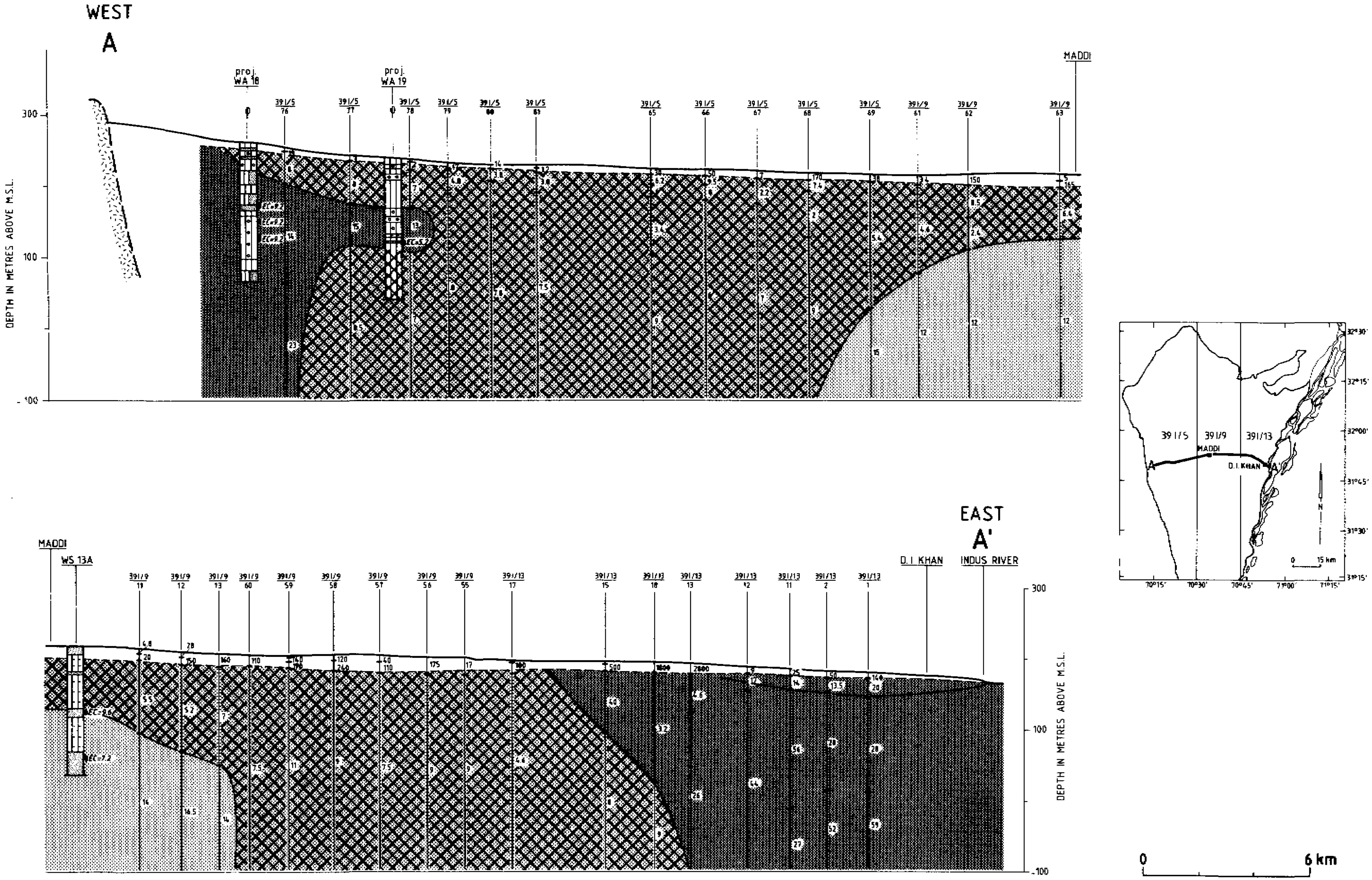


Figure 78: Hydrogeological cross-section over the D.I. Khan basin (For legend see fold-out at back of book)

some cases magnesium is a dominant constituent. Along the northern boundary the water is usually of the sodium bicarbonate type.

The alluvial fans along the Bhittanni range in the north of the basin have groundwater levels at a depth of 40 - 100 m. The transmissivity is low, less than 200 m^2/d and the EC is moderately high, less than 2 mS/cm. Towards the southeast the groundwater salinity increases as this zone merges with the piedmont plain.

The piedmont plain deposits in the central part of the basin consist largely of silty clay with thin intercalations of more pervious material: in the west gravel, and in the east medium sand. The amount of this coarse material in the upper 150 m is less than 25 per cent, and in a number of boreholes it is even nil. It is a water-transmitting area with negligible recharge and very small discharge from wells and tubewells. Water flows through the thin pervious beds and occurs under confined conditions, resulting in free-flowing wells in the Tank-Paniala area. The transmissivity of the piedmont plain deposits varies from 60 to 200 m^2/d, the piezometric level is at a depth of 5 - 30 m below the surface, the water is of the sulphate type and the salinity level is high; EC values vary from 2 to 20 mS/cm.

The so-called "corridor", between the Kiriani Nala and the Luni (Gumal) river, crosses the piedmont plain in a northeast-southwest direction and is characterized by a larger amount, between 25 and 50 per cent, of pervious material. Semi-confined conditions prevail. Transmissivity in the "corridor" may be somewhat higher than in the surrounding clayey deposits. The groundwater has EC values below 2.0 mS/cm and a sufficiently low sulphate content for the water to be classified as usable. However, this fresh groundwater is generally to be found below a layer of saline water.

Towards the east, clayey piedmont deposits and beds of medium sand of the Punjab-type interfinger and form a transition to the Indus river lowland deposits. The amount of pervious material in the upper 150 m is approximately 50 per cent and the transmissivity values range from 200 to 1000 m^2/d. Water in shallow sand layers may be under phreatic conditions but the groundwater at greater depth is confined. North of D.I. Khan town the water quality improves as a consequence of fresh groundwater flow parallel to the Indus.

Farther east the pervious Punjab-type sands completely replace the clayey piedmont deposits. Pervious material occupies from 50 to more than 90 per cent of the upper 150 m. The transmissivity is high: 1000 to 4000 m^2/d is a minimum value and the specific yield of the wellsorted sand is probably between 0.15 and 0.20. The area north of D.I. Khan town receives recharge by seepage from the Paharpur canal and by horizontal subsurface inflow from the canal-commanded area and the Indus. Consequently, the groundwater is very fresh: EC less than 0.25 mS/cm. Near the river it is mainly a calcium bicarbonate type water, but it changes to a sodium type as it moves through the aquifers. The depth to the water table is less than 5 m near the Indus and in the waterlogged irrigated areas but increases to 10 or 20 m in the transition zone with the piedmont deposits. The maps of the groundwater level contours from Hood et al. (1970) and Malik (1985) indicate also inflow from the Indus in the area south of D.I. Khan.

Water level fluctuations

Hood et al. (1970) report that groundwater levels in the Indus river lowlands fluctuate in response to the flood in the Indus river, infiltration from precipitation and runoff, discharge by evapotranspiration and withdrawal from wells. These levels range from 0.3 m to 1.8 m. In the upland areas, similar fluctuations as a result of seasonal variation in rainfall and runoff have been reported both from shallow wells and from wells tapping the deep confined and semi-confined aquifers. In the central area, where the permeable layers are thin and the groundwater bodies are deep, the changes in water level are very small.

Groundwater flow

Figure 79 presents the contours of the water table of the phreatic aquifer and of the piezometric level of the deep water-bearing layers which form a single groundwater system. The flowlines, which are perpendicular to the water level contours indicate groundwater flow from the mountains towards the Indus river lowlands. Along the river the contours enclose a trough-like area, from Saggu in the north to Ramak in the south, to which the flowlines converge. This trough is especially prominent in the area between Paroa and Ramak and indicates an area with groundwater inflow both from the mountains and from the Indus, but without apparent outflow. Greenman et al., (1967) describe the occurence of similar trough-like configurations along the main tributaries on the left bank of the Indus.

Recharge and discharge

The watertable elevation contours show that recharge occurs along the mountains in the west and north and along the Indus in the east. Along the mountains it is a combination of lateral subsurface inflow from the neighbouring hills, of streamflood infiltration in the nala and river beds, and of deep percolation of rainfall and runoff in the alluvial fans. Along the Indus the recharge is caused by percolation losses of the Paharpur canal-irrigation system and by subsurface inflow from the Indus.

It is impossible to evaluate any of the recharge terms individually, but the total can be calculated by applying Darcy's law (Section 3.2) to the subsurface flow across the transition zone between the alluvial fan deposits and the clayey piedmont deposits along the western and northern sides of the basin and, on the eastern side, to the groundwater flow across the Paharpur canal and the bank of the Indus river (Figure 80). The calculated total inflow amounts to 34.5, 0.5 and 24.0 Mm^3/yr (38.6, 0.6 and 26.9 cusec) from the western, northern and eastern sides, respectively. These amounts are minimum values because:

(a) it has been assumed that there is no direct recharge of rainfall over the central piedmont plain, and
(b) the recharge from streams and direct rainfall over the river lowlands has been ignored.

The total amount of 59.0 Mm^3/yr (66.1 cusec) is considerably less than the amounts calculated by Hood et al. (1970): 148 Mm^3 and by Malik (1985): 110 Mm^3. This is mainly because the present writer believes that the transmissivity values in the central part of the area are much lower than admitted by those authors.

The discharge mechanism poses a riddle. Apparently the

Figure 79: Groundwater map of Dera Ismail Khan area

groundwater moves to the trough along the Indus river, but it is unclear what happens afterwards. A small amount of about 4 Mm^3 flows out to the south, and about 13 Mm^3 (Malik, 1985) is discharged by pumping from more than 100 tubewells and 8000 dug wells. The rest, about 42 Mm^3, must disappear in a vertical direction, either by evapotranspiration or by down ward flow.

An argument against the evapotranspiration hypothesis is that the water table is relatively deep (5 to 20 m below the surface) and, therefore, direct evaporation or transpiration by plants with shallow root systems is impossible. On the other hand, the area north of Ramak sustains a dense cover of 2 to 3 m high bush, presumably comprising phreatophytic plants. The vegetation covers an area of at least 400 km^2 (Malik, oral communication) and 42 Mm^3 water corresponds to only 6 per cent of the potential evapotranspiration of an area of that size.

The second hypothesis assumes the presence of a very deep-seated aquifer system with a hydraulic head appreciably lower than the head in the floodplain aquifer. There is, however, no evidence to sustain this hypothesis.

Additional research is required to find a solution to this problem.

Groundwater development potential

The first conclusion concerning the groundwater potential of D.I. Khan is that most of the central area can be excluded because of the poor quality of its groundwater. The remaining area can be divided into five zones:

(a) the northern Indus river lowlands between Chashma and D.I. Khan town,
(b) the partially saline southern Indus river lowlands between D.I. Khan town and the Punjab border near Ramak,
(c) the area along the northern border between Mullazai and Paniala,
(d) the alluvial fan area along the western mountains, and
(e) the corridor between the Kirriani Nala and the Luni (Gumal) river that crosses the central piedmont plain.

Indus river lowlands

The northern as well as the southern Indus river lowlands lie entirely within the command area of the Chashma Right Bank Canal (CRBC) which is presently under construction. The CRBC commands the whole freshwater zone of the Indus river lowlands and it may seem superfluous to contemplate groundwater management at the same time. This, however, is not true. Even if the canals are properly lined, a substantial amount of percolation losses from unlined distributaries, minors, field courses and from the field application and to some extent also from the lined canals, will recharge the aquifer. As a consequence, the groundwater level will rise and waterlogging with subsequent soil salinization will occur. A judiciously planned groundwater development scheme may prevent this process, or at least slow it down. Moreover, the groundwater can be used to irrigate pockets that are unirrigable because of their elevation and it can supply additional water to satisfy the water demand during periods of low canal water supply.

The northern part of the lowlands offers the best opportunities for the conjunctive use of surface water and groundwater, because it is underlain by groundwater with EC values that are generally below 2.0 mS/cm. Tubewells in this area could produce 100 to 300 m^3/h (1 to 3 cusec). Pumping level may be less than 50 m and total depth of the well can be less than 150 m. A tubewell with a capacity of 100 m^3/h may irrigate 21 ha in Kharif plus 45 ha in Rabi when sown with the traditional irrigated crops. It will then effectively remove a quantity of water corresponding to the overall percolation losses of 45 ha canal-irrigated land with an overall irrigation efficiency of 60 per cent. Therefore the ratio of canal-irrigated and tubewell-irrigated land could be 1:1. In this manner the risk of waterlogging can be averted.

The introduction of conjunctive use of groundwater and surface water in the lowlands south of D.I.Khan town is more complicated, because the groundwater is saline over a large part of this area, with EC values between 4 and 16 mS/cm. Groundwater pumping is required to keep the rising saline groundwater out of the root zone of the irrigated land. Depending on the salinity levels, this water may be reused in alternation with canal water irrigation to grow salt-tolerant crops, or it may have to be discharged into a surface drainage system.

Drilling and pumping conditions are as in the northern lowlands, but more clay layers can be expected.

Northern boundary area

The northern boundary area between Mullazai and Paniala is unsuitable for groundwater-based irrigation development. The water levels are relatively deep, from 40 to 100 m, the soils are classified as poor and unsuitable for irrigation, and the expected tubewell yield is less than 25 m^3/h (0.25 cusec). Groundwater may be developed for domestic purposes and livestock watering. The water has an EC value less than 2 mS/cm, but towards the southeast this zone merges with the central saline groundwater area.

Western alluvial fans

In the alluvial fan area along the western mountains the soils are stony with steep slopes and shifting torrents and without any potential for agriculture (Ali et al., 1969). Where better classified soils are found, the groundwater is saline. In the freshwater zone, water levels are less than 25 m deep, except south of Chaudhwan where they drop to more than 30 m. In the northern part, specific capacity values are low, less than 10 m^3/h per m drawdown (13 gpm/ ft dd.), and yields will be about 50 m^3/h (0.5 cusec). EC values will range between 1.2 and 2.0 mS/cm, but higher values indicating saline water may occur locally. Groundwater development for domestic supplies and livestock watering is possible.

In the area of Kot Azam, good soils and high tubewell yields, 100 to 200 m^3/h (1 to 2 cusec), are found. In this area a groundwater-based tubewell scheme, the Khanwand scheme has been in operation (see this chapter's section on Agriculture). The scheme could be rehabilitated and additional tubewells could be drilled after studying the recharge-discharge relationships and making a water balance.

Central plain

The central part of the D.I. Khan plain is largely underlain by brackish to very saline groundwater, which cannot be used for irrigation on the clayey soils or for domestic consumption.

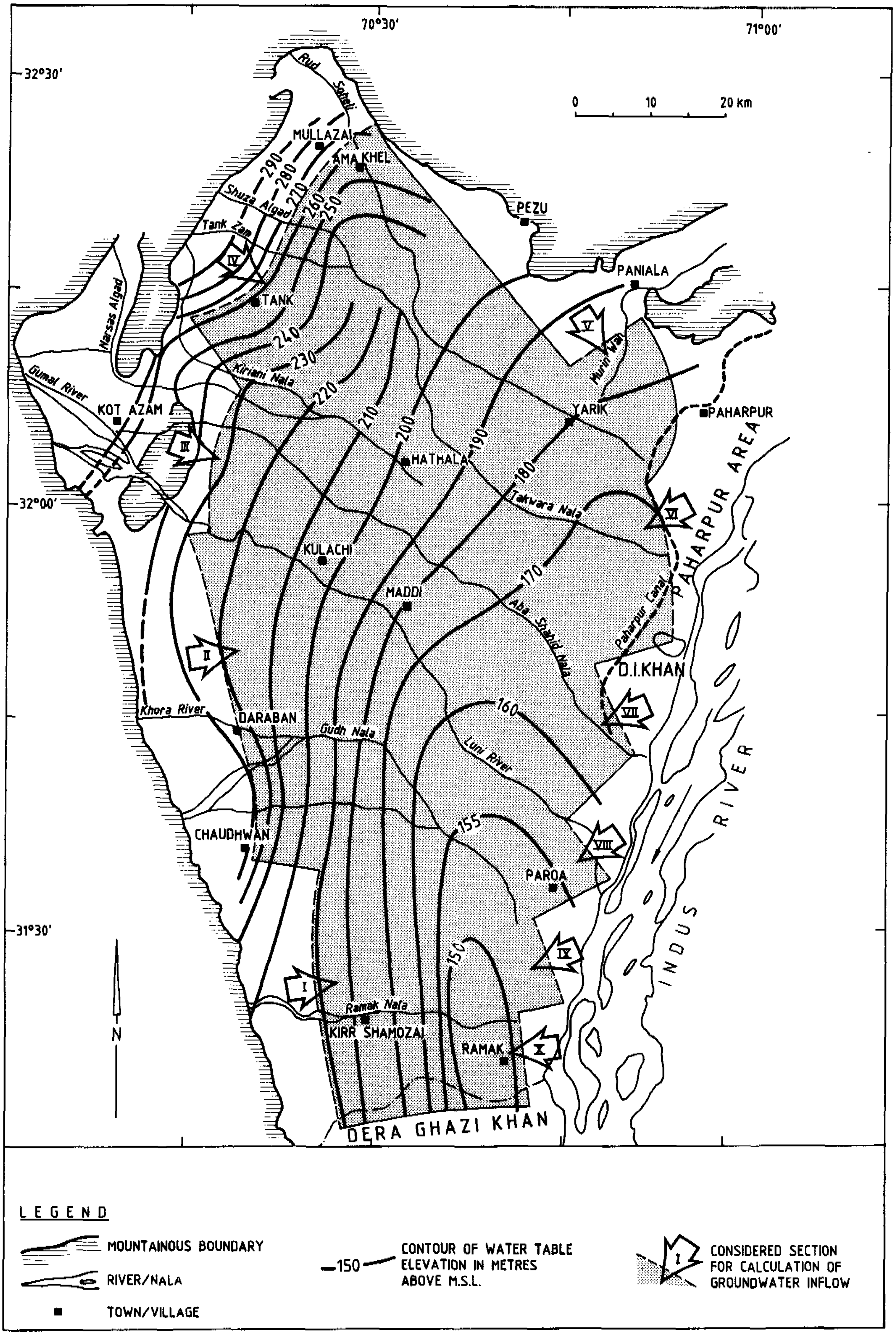


Figure 80: Groundwater recharge areas of the Dera Ismail Khan basin

The "corridor" has the best prospects for groundwater development. It is an area with a flat surface intersected by nalas and river channels. A large part of it is irrigated by surface water diverted from the hill torrents and the perennial Luni (Gumal) river. This area has slightly better prospects for groundwater development than the belt of alluvial fans. The water table is less than 25 m below the surface and near Rori it is even less than 5 m deep. The shallow water up to a depth of 50 m is saline. Below this depth the water gradually becomes fresh. Exploitable freshwater layers may be encountered between 100 and 200 m below land surface. Yields should be kept low, less than 20 m^3/h to prevent large head differences between the shallow saline water and the fresh water below. Large head differences induce vertical flow, which may result in the wells being contaminated with saline water. Consequently, groundwater development in this area should be restricted to wells for domestic use and livestock watering.

Groundwater management

The presence of large amounts of saline groundwater asks for a careful management of the groundwater development and a precise monitoring of changes in the chemical composition of the groundwater. As the risk of contamination of the aquifer with saline water is closely related to the distribution of the hydraulic gradients, it is imperative to monitor the groundwater levels in the Indus river lowlands. A network of deep and shallow piezometers to monitor the groundwater level fluctuations and to sample the groundwater from deep and shallow wells, and to monitor the quality changes, is already overdue and should be set up as soon as possible.

A feasibility study should be made to assess the technical and economic effects of the conjunctive use of groundwater and surface water for irrigation of the Indus river lowlands. This study should include the collection of data on recharge and discharge and the simulation by mathematical modelling of the effects of the CRBC scheme on the groundwater levels and on the groundwater quality. This will produce predictions about when and where waterlogging (and secondary salinization) will occur under different surface water and groundwater irrigation systems.

In the Khanwand tubewell irrigation scheme a network for groundwater level monitoring and for regular groundwater quality control should be installed.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

Hood, J.W., Lutfe Ali Khan and Khalid Jawaid, 1964. Preliminary report on groundwater in the Dera Ismail Khan District, West Pakistan WAPDA/WASID, Preliminary Report No. 4; 27 pp., 1 app., 10 tbls, 16 figs. *Annotation.* Preliminary report on studies carried out by WASID in 1961/1964. Final results were published by the same authors in 1970 (see below).

Ali, M.A., M. Farooq, Q. Ali, M. Afzal, and C.M. Higgings, 1969. Reconnaissance Soil Survey of Dera Ismail Khan. Directorate of Soil Survey, West Pakistan; 185 pp., 1 app., 14 tbls, 4 figs, 5 pl. (9 sheets). *Annotation.* Description of the soils and their genesis, present use and capability.

Hood, J.W., Lutfe Ali Khan, and Khalid Jawaid, 1970. Water resources and related geology of Dera Ismail Khan District. U.S. Geol. Survey W.S. Paper 1608-K; 69 pp., 10 tbls, 16 figs, 6 pl. *Annotation.* The first, and still the best, comprehensive report on the hydrogeology and groundwater resources of D.I. Khan District. Based on studies carried out in 1961/1964 (see also Hood et al., 1964) by WASID. Thirty-eight test holes were drilled, ranging in depth from 30 to 457 m. Ten test holes were converted into test wells and pumptested to determine transmissivity and specific capacity. In most of the test holes observation pipes were installed in the shallowest water-sampling zone and in one or more of the deeper zones. Water level observations were made in 47 wells, first biweekly and later monthly. Eighteen of these wells were in the vicinity of the Paharpur canal, and had already been observed since 1939 by the Irrigation Branch, PWD. Chemical data were obtained from samples collected in 128 wells; the results of the analyses of 22 of these are reported.

WAPDA, 1970. Feasibility report Chashma Right Bank Irrigation Project (gravity system). P&I Publication No. 86, WAPDA, Lahore. *Annotation.* Comprises data on the performance of 90 tubewells drilled by the Irrigation Department.

Naqavi, S.A.H., Khurshid Akhtar Khan and Abdul Wahab Nagi, 1974. Groundwater appraisal of Tank-Paniala area. WAPDA: Groundwater Directorate; 24 pp., 1 app., 5 tbls, 7 figs. *Annotation.* The study was carried out in 1972/1973. Five test holes were drilled, of which two were converted into test wells, and a resistivity survey was carried out near Tank (no details given). The conclusion that wells with a capacity of 100 m^3/h (1 cusec) can be constructed in the area seems not to be justified (low specific capacities). Groundwater quality mainly good. The report draws heavily on Hood, et al., 1970.

Naqavi, S.A.H., 1977. Groundwater conditions in Paharpur area, Dera Ismail Khan District, NWFP. Hydrogeology Directorate, Groundwater Projects, Peshawar; 46 pp., 11 figs. *Annotation.* Report on investigations carried out in 1974/1976 including drilling of 5 tubewells, pumping test on 2 test wells, water sampling in 18 wells, monthly water level measurements (Dec. 1975 - June 1976) in 19 newly installed piezometers and 18 open wells. Topographical survey for construction of watertable contour map. Description of the hydrogeology and groundwater conditions, including recharge and discharge conditions; recommendation to drill 30 tubewells of 3 cusec capacity each in the abandoned floodplain north of D.I. Khan town.

WAPDA Hydrogeology Directorate, 1981. Basic Data Release: Hydrogeological data of Dera Ismail Khan District; Volume I: Hydrogeologic investigations 1962/1979. Directorate General of Hydrogeology Publication No. 3, WAPDA, Lahore; 110 pp., 6 figs. *Annotation.* Report on the data collected by WASID and Hydrogeology Directorate Peshawar in the period 1962/1974. The document contains the borehole data of 38 WASID test holes (repeat-

ing the same data for 10 holes converted into tubewells), 2 test holes drilled by WASID near Tank, 11 test holes/tubewells drilled in Khanwand by Irrigation Department, 5 test holes drilled by WAPDA in Paharpur area, 3 tubewells drilled near Gomal Zam, 3 test holes drilled by WAPDA near Paniala, 6 test holes drilled in Rodikhel, 1 tubewell drilled in Rori, 9 tubewells drilled by PHED in different localities. It contains chemical analysis data of 165 samples from WASID test holes and of 191 samples taken by WASID from shallow wells, 7 from Paharpur, 10 from Gomal Zam, 9 from Paniala, 7 from Rodikhel and 8 from PHED tubewells. It also contains sieve analysis data from 13 WASID test holes, from 6 Khanwand tubewells, from 4 test holes in Paharpur, from 2 tubewells in Gomal Zam and from 1 test hole in Paniala.
This document and Malik (1985) cover more or less the same ground, but the same test hole/tubewell has a different number. The numbers correspond as follows:

Basic Data Release	Malik (1985)
WASID DIK T/H 1-28	WS 1-28
WASID DIK T/W - 1 = DIK T/H - 5	WS - 5
WASID DIK T/W - 2 = DIK T/H - 9	WS - 9
WASID DIK T/W - 3 = DIK T/H - 1	WS - 1
WASID DIK T/W - 4 = DIK T/H - 10	WS - 10
WASID DIK T/W - 5 = DIK T/H - 14	WS - 14
WASID DIK T/W - 7 = DIK T/H - 22A	WS - 22A
WASID DIK T/W - 8 = DIK T/H - 6	WS - 6
PHED Marah Village	PH - 8
Kirri Shamozai	PH - 7
Ramak Village	PH - 5
Jhok Rind	PH - 8
Jhok Mohana	PH - 9 (?)
Potak	PH - 10
Kot Taga	PH - 11
Kot Lahi	PH - 14
Kot Fateh Ali	PH - 6 (?)
Tank Sp. T/W - 1	SP TW - 1
Tank T/H - 2	SP TW - 2
See also Naqavi et al., 1974	SP TW - 3

WAPDA Hydrol. Monit. Div., Peshawar, 1984. Khanwand tubewell irrigation project; tubewell performance report 1982-1983. *Annotation.* Tubewell performance in 1982/1983 as compared with acceptance tests during 1973/1974. Of the original nine wells, only eight were commissioned; one was later abandoned and two were temporarily out of order. The actual capacity of the well field is only 57% of design capacity. In three wells the operational discharge is somewhat lower than during the acceptance test and in two wells it is somewhat higher.

Faiz, M. Akram, Nadeem-ul-Haq and Abdur Rehman, 1985. Electrical Resistivity Survey in Kulachi-Tank, Dera Ismail Khan District, NWFP. Report No. VIII-2. WAPDA Hydrogeol. Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 16 pp., 3 app., 2 tbls, 8 figs, 4 pl. *Annotation.* The area studied comprises the whole D.I. Khan basin except the Paharpur command area. In all, 574 electrical resistivity soundings were made, mostly along 23 cross-sections. Geophysical well logs were recorded at 21 boreholes. Data from boreholes previously drilled by WASID were also used in the interpretation. This report complements the report by Malik (1985).

Malik, M. Yousuf, 1985. Technical report on Groundwater resources in Kulachi-Tank, Dera Ismail Khan District, NWFP. Report No. VIII-1. WAPDA Hydrogeol. Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 57 pp., 4 app. 13 tbls, 11 figs and 7 pl. *Annotation.* Report on groundwater investigations carried out by WAPDA Hydrogeology Directorate Peshawar and TNO during 1982/1985. The area investigated covers the whole D.I. Khan plain, excluding the Paharpur area. It comprises an inventory of 8000 wells and tubewells, an electrical resistivity survey of 574 soundings (Faiz et al., 1985), the drilling of 39 test holes and geophysical logging of 21 holes that were drilled by straight rotary method, the conversion of 9 test holes into test wells for pump testing, groundwater level monitoring in 77 wells and test holes for 6 months only, etc. Previously drilled wells are mentioned but different identification numbers are used in this report. In the annotation of Basic Data Release, 1981, the corresponding borehole numbers are listed.

15 GROUNDWATER IN THE FEDERALLY ADMINISTERED TRIBAL AREAS

15.1 GENERAL

Location and government
The Federally Administered Tribal Areas (FATA) cover the mountainous area along the boundary with Afghanistan, approximately between latitudes 31°05' and 34°56' N and longitudes 69°15' and 71°52' E. FATA is ruled according to tribal custom by the tribesmen that live there.
FATA is subdivided into seven Agencies (Figure 81), which are, from north to south:

Bajaur	Agency
Mohmand	,,
Khyber	,,
Orakzai	,,
Kurram	,,
North Waziristan	,,
South Waziristan	,,

The FATA Development Corporation (FATA-DC) is responsible for the implementation of infrastructural works, including the drilling of tubewells for domestic water supply and irrigation.

Physiography
The area is hilly to mountainous and often severely denuded because of erosion as a consequence of deforestation and overgrazing. The highest mountain range in FATA is the Safed Koh, with its loftiest peak of 4755 m (15,596 ft) above msl, on the Afghan border west of Parachinar (Kurram Agency). Most streams are ephemeral. Only the rivers that rise in the snow-clad high mountains are perennial; they include the Kurram and Kabul rivers and the latter's tributaries the Swat river and the Bara river.

Climate
Long meteorological records are only available from Landi Kotal in Khyber Agency and from Parachinar in Kurram Agency (Section 1.3).
The climate in the Bajaur, Mohmand and Khyber Agencies is of the semiarid subtropical continental highland type. The mean annual rainfall is approximately 450 mm, of which 200 mm falls in March and April. The average daily maximum of the hottest month is 36°C and the average daily minimum of the coldest is -0.5°C.
The climate of the Orakzai and Kurram Agencies is of the sub-humid, subtropical continental highland type. The mean annual rainfall is between 500 and 800 mm and more falls in March and April than in July. The mean daily maximum of the hottest month is about 32°C and the mean daily minimum is about -1°C.
The climate in the North Waziristan and South Waziristan Agencies is again of the semi-arid subtropical continental highland type. The mean annual rainfall is about 300 mm/yr but decreases southwards. Most rain falls during the winter and spring. The mean maximum temperature of the hottest month is about 40°C and the mean minimum of the coldest month is around freezing point.

Population and domestic water supply
The estimated number of inhabitants of FATA is 2.6 million. They live in scattered villages. Water supply comes from open wells and springs and at some places from tubewells drilled by FATA-DC.

Agriculture
Barani-type agriculture is the main activity. When surface water is available irrigation schemes have been developed by diverting the river water. Locally, tubewells owned by FATA-DC provide water for irrigation free of charge.

Groundwater investigations
With the exception of the Parachinar area (Kurram Agency), no systematic survey of the groundwater resources of FATA has yet been undertaken. This does not mean that no valuable data have been collected during the last decade: the groundwater development section of FATA-DC, in cooperation with USAID, has gathered data on many boreholes and on the chemical composition of groundwater samples.

Groundwater conditions
What is known about the groundwater conditions and the groundwater development will be discussed per Agency in Sections 15.2 - 15.9.

Discharge and recharge
The lack of a comprehensive study of the groundwater conditions makes it impossible to quantify the recharge and discharge of the aquifers. As a first approximation it can be assumed that recharge is, like elsewhere in NWFP, mainly the result of percolation of runoff along the mountain fronts, and to a minor degree the result of on-the-spot percolation of the rainfall on the alluvial plains. It has been found that in NWFP the recharge over an alluvial plain is never less than 5 per cent of the rainfall volume over the immediate catchment of the plain. This "rule" makes it possible to estimate the minimum recharge of the various alluvial plains in FATA. Subsequently, in each case the uncommitted groundwater resource, i.e. the uncommited average annual groundwater recharge, can be estimated by subtracting the amount of groundwater used annually, from the recharge.

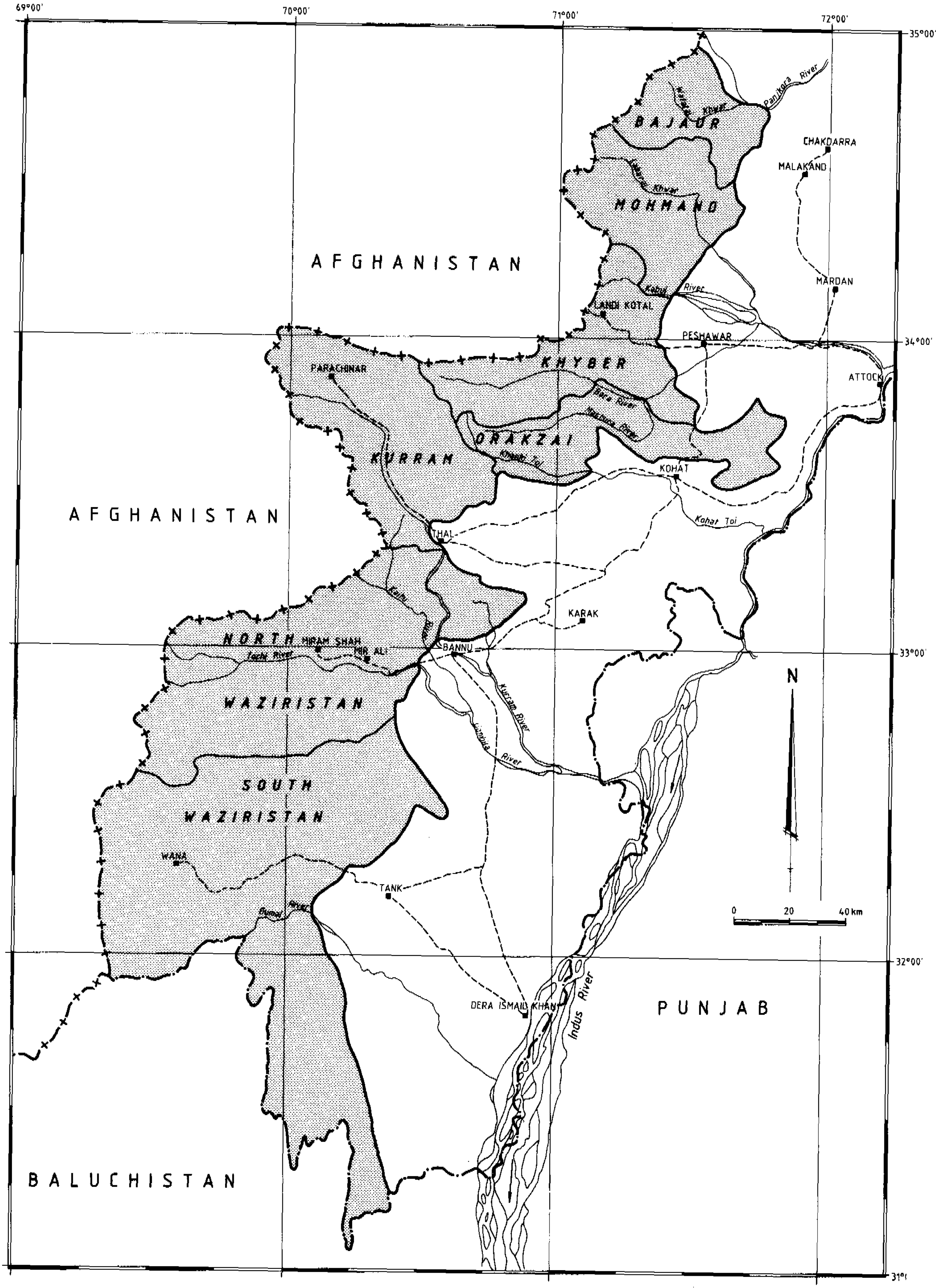


Figure 81: Location map of FATA

Groundwater development potential
In the absence of sufficient data to establish the groundwater recharge and discharge patterns, the goals for the short-term groundwater development should be modest. They should not aim for a groundwater development that exceeds 50 per cent of the currently uncommitted part of the annual recharge, estimated in the way outlined in the previous paragraph.

Groundwater management
As a first step toward groundwater development planning and groundwater management, assessment studies should be carried out in FATA.
This is especially urgent, because ambitious groundwater development plans that assume a far larger potential of the actually available resources than is to be expected have been prepared.

15.2 THE BAJAUR AGENCY

Location
Bajaur covers an area of 1290 km^2 and is the most northern Agency of FATA. It lies between latitudes 34°30' and 34°59' N and longitudes 71°14' and 71°48' E. It is drained by the Natalai Khwar and its tributaries. The Natalai Khwar is a source river of the Jandool river, which in its turn is a tributary of the Panjkora river (Figure 82).

Geology
Bajaur Agency consists mainly of igneous rocks, e.g. granodiorite and diorite; in the south schists and other metamorphic rocks of the amphibolite facies may be present (Ahmad and Khan, 1980). Alluvial deposits of Quarternary age are found in the major valleys.

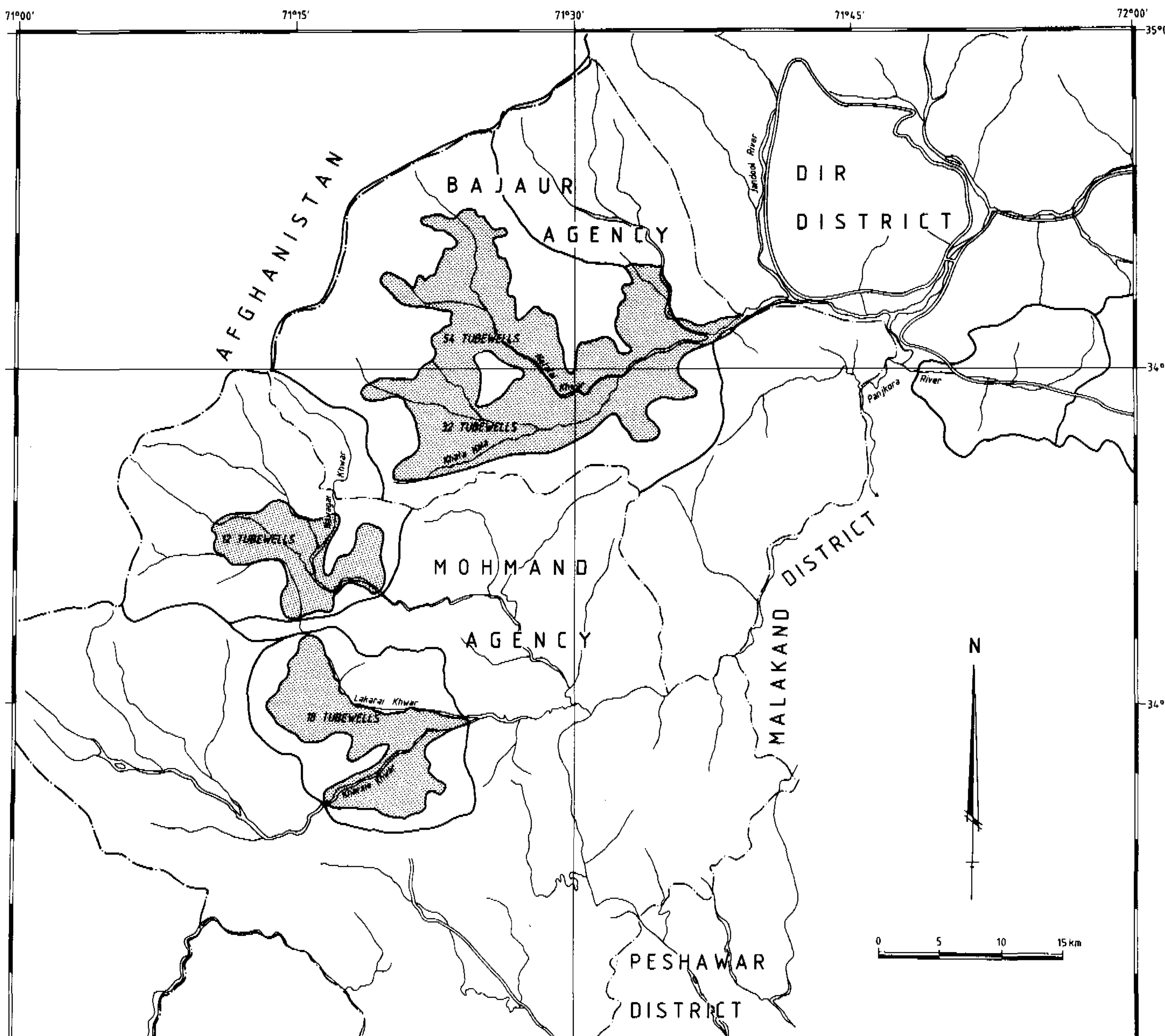


Figure 82: Location map of the alluvial plains in the Bajaur and Mohmand Agencies

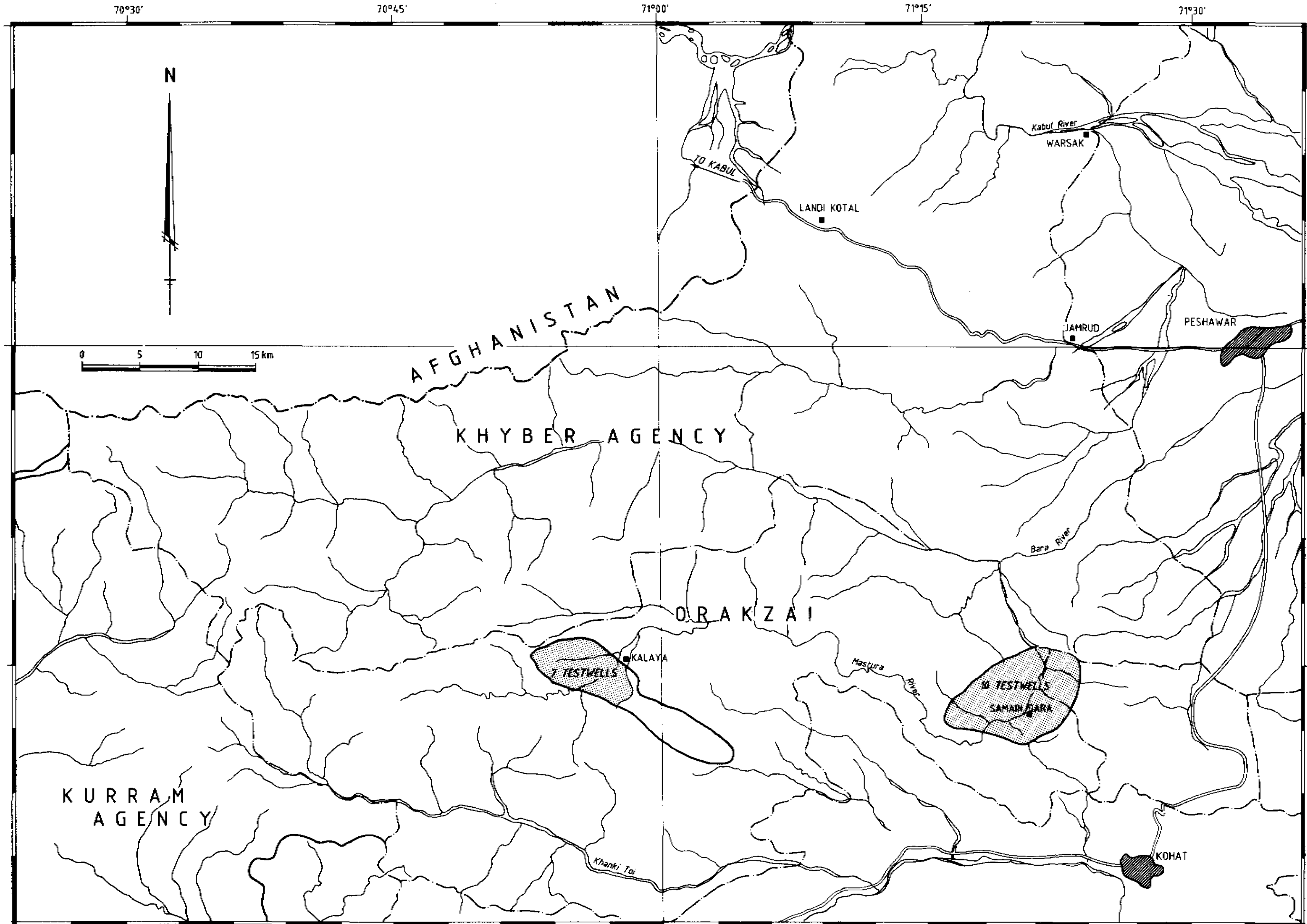


Figure 83: Location map of the alluvial plains in the Khyber and Orakzai Agencies

Groundwater conditions

According to FATA-DC (oral communication) 110 tubewells have been drilled in the Bajaur Agency, mostly in the alluvium-filled valleys of the Khata Nala and the Watalai Khwar. More than 90 per cent were drilled to a depth of between 85 and 125 m. Bedrock (slate) was encountered in only two boreholes. The lithological sequence is usually a clayey top layer, underlain by gravel and sand and a clayey bottom layer. The water level in the wells is usually found at a depth between 27 and 37 m. There is little difference between the water-struck and the waterrest levels, so it is assumed that the groundwater occurs under unconfined (water table) conditions. The tested yield is known from 108 wells. In 11 wells (10 %) the yield is less than 40 m^3/h, in 60 wells it is between 40 and 80 m^3/h, in 37 wells it is more than 80 m^3/h, and in 5 wells it exceeds 120 m^3/h. The specific capacity in the wells with a yield of more than 80 m^3/h varies from 3.2 to 31 m^3/h per m dd. (4.3 - 40.8 gpm/ft dd.) with 65 per cent in the category between 6.3 and 14.6 m^3/h per m dd. (8.4 -19.5 gpm/ft dd.). Using Logan's formula (Logan, 1964) to estimate the average transmissivity results in a value of 300 m^2/d.
The chemical quality of the groundwater is good.
No data are available on the groundwater flow and the water level fluctuations.

Present groundwater use

According to FATA-DC (oral communication) in Bajaur 4800 ha (12,000 acres) are irrigated by tubewells. The irrigated crops are wheat, and mustard in Rabi, and maize, alfalfa and some vegetables in Kharif. Only 10 - 15 tubewells are used solely for domestic water supply.
The annual water production of the average tubewell is 2000 hours at a rate of 75 m^3/h or 150,000 m^3. If 80 wells are in full production the annual water production will be 15 Mm^3 (16.8 cusec).

Groundwater development potential

The catchment of the alluvial plain covers an area of 371 km^2 and receives 450 mm rainfall or a total annual amount of 167 Mm^3. Assuming a groundwater recharge equal to 5 per cent of the annual rainfall over the catchment, the groundwater recharge amounts to 8 Mm^3/yr. Assuming that the present developed resource equals 15 Mm^3, it follows that the aquifer may already be overexploited. No further groundwater development should be undertaken without first carrying out a groundwater resources assessment study, including a quantification of the recharge and discharge of the aquifer.

Annotated bibliography

No reports on the groundwater conditions in Bajaur Agency have been published.

15.3 THE MOHMAND AGENCY

Location

The Mohmand Agency (Figure 82), between latitudes 34°08'and 34°21' N and longitudes 70°58' and 71°42' E, extends over an area of 2,297 km^2. It is drained by tributaries of the Kabul and Swat rivers.

Geology

According to Aslam et al. (1981), the Mohmand Agency consists largely of schists and phyllites with interbedded metamorphosed limestones, tentatively dated as Silurian - Devonian. The schists are interspersed by Late Cretaceous to Early Tertiary ultrabasic intrusions. Unconsolidated alluvial deposits are found as valley fill and in terraces.

Groundwater conditions

According to FATA-DC, 30 tubewells have been drilled in Mohmand Agency; 12 in the Nawagai plain, which stretches out over an area of 74 km^2, and 18 in the plain (98 km^2) between the Lakarai Khwar and the Kharzie Khwar. Most were drilled to a depth of 140 - 160 m. The lithological logs show clay alternating with gravel mixed with variable amounts of sand, pebbles and boulders. Generally, in the lower part of the drilled sections there are more gravel layers than in the upper part. Bedrock schists were only encountered in boreholes drilled in places where the alluvial fill is thin.
The groundwater level is usually found at a depth of 50 - 80 m below the surface. Many wells have a yield of more than 100 m^3/h (1 cusec). The quality of the water is good.
No further details were available.

Present groundwater use

No data are available on the present groundwater use; however, if the 30 tubewells are in full production the amount of groundwater pumped annually will be 30 times 2000 hours times 110 m^3/h, or 6.6 Mm^3 (7.4 cusec).

Groundwater development potential

The estimated average annual precipitation is 400 mm. The catchment area of the Nawagai plain is 288 km^2 and will receive 115 Mm^3 rainfall per year, 5 per cent of which, or 6 Mm^3 (6.7 cusec), is assumed to recharge the aquifer.
The catchment of the plain between the Lakarai and Kharzie Khwars is only 127 km^2. The recharge of the plain is estimated as 2.5 Mm^3/yr (2.8 cusec). Given the estimated groundwater withdrawal, there is little scope for further groundwater development before the assumptions are verified by an assessment study.

Annotated bibliography

No reports on the groundwater conditions in Mohmand Agency have been published.

15.4 THE KHYBER AGENCY

Location

The Khyber Agency covers an area of 2,566 km^2 between latitudes 34°45' and 34°20' N and longitudes 70°26' and 71°32' E. It is drained by the Kabul river in the north and its tributary the Bara river in the south (Figure 83).

Geology

In the eastern part of the Khyber Agency are extensive outcrops of the massive grey limestone with sand and clay beds that make up the Carboniferous Khyber Formation and of the slate, phyllites and schists with minor limestone and quartzite beds of the Ordovician-Silurian Landi Kotal Formation.

Near Warsak on the boundary with the Peshawar Vale is a granite intrusion (Shah et al. 1980). In the western part Jurassic limestone has been found (Meissner at al. 1975).

Groundwater conditions
The Khyber Agency is mountainous without any well developed alluvial plain. According to the available information, approximately 20 test- and tubewells have been drilled in different valleys. FATA-DC made lithological data available on two boreholes in the Jamrud - Landi Kotal area. They indicate an ill-sorted mixture of clay and gravels, probably with low transmissivity values. The depth to water level is quite large (more than 30 m). If these boreholes are representative of the whole area, then the groundwater development potential will be low.

Present groundwater use
No data available.

Groundwater development potential
The estimated average annual precipitation is 440 mm, but the absence of irrigable plains, the low transmissivity values and the deep groundwater levels give the area a very low groundwater development potential.

Annotated bibliography
No reports on the groundwater conditions in Khyber Agency have been published.

15.5 THE ORAKZAI AGENCY

Location
Orakzai Agency, between latitudes 33°33' and 33°54' N and longitudes 70°32' and 71°25'E and with an area of 1538 km^2 is drained by the Mastura river, which is a tributary of the Bara river (Section 15.4), and by the Khanki Toi, which is a source river of the Kohat Toi (Chapter 12). An area near Samain Darrai and one near Kalaya form a plain situated on both sides of the Mastura river, mostly between latitudes 33°42' and 33°48' N and longitudes 70°55' and 71°05' E (Figure 83).

Geology
The mountains consist of undifferentiated mainly grey to dark grey, thin to thick bedded oolitic Jurassic limestones, which are interbedded with dark green sandstone and shale. Subordinate undifferentiated Cretaceous rocks are represented by argillaceous limestone and sandstones. In the eastern part of the Agency dark grey shale and limestone, and white sandstone of the Palaeocene have been found (Meissner et al., 1974 and 1975).

Groundwater conditions
An unpublished sketch map of FATA-DC shows the location of seven boreholes drilled southwest and south of Kalaya and ten boreholes near Samain Darrai in the east of the Agency. NESPAK (1983) gives the lithological sketches of ten test wells and tubewells drilled in the Orakzai Agency. Six of them probably belong to the above-mentioned boreholes southwest of Kalaya, and four to tubewells near Samain Darrai. Locally the aquifers are confined; two tubewells are free-flowing and in two of the test wells the water level is only a few metres below the surface. The water level in the other wells was found at depths between 13 and 64 m. Nine of the ten wells have been pumped. The yield varied from 50 to 100 m^3/h (0.5 - 1.0 cusec). The specific capacity values indicate transmissivity in the order of 250 - 550 m^2/d.
The groundwater quality is probably good. No data are available on water level fluctuations and groundwater flow.

Present groundwater use
No data available.

Groundwater development potential
According to NESPAK, (1983) the average annual precipitation is 630 mm.
No data are available on the size of the irrigable plains and their catchments; therefore, no estimates on the groundwater development potential can be made.
NESPAK (1983) proposed to install 30 tubewells in the Mastura valley, each with a capacity of 81 m^3/h, to irrigate 911 ha (2990 acres) with a water requirement of 1160 mm per year. A total pumping time of more than 4350 h/yr, or 12 h/d would be needed. Given the uneven water demand of the crops during the growing season, the actual operation time of an irrigation tubewell is only 2000 h/yr, so only 410 ha (1345 acres) can be irrigated with the proposed wells, provided that the groundwater development potential is at least 5 Mm^3/yr (5.6 cusec).

Annotated bibliography
At the end of Section 15.9

15.6 THE KURRAM AGENCY (EXCL. THE PARACHINAR AREA)

Location
The Kurram agency covers an area of 3380 km^2 and extends on both sides of the Kurram river from the Afghan border near Kharlachi to Thal, i.e. between latitudes 33°21' and 34°04' N and 69°52' and 70°45' E. Small alluvial plains are found along the Kurram river. The most important is the Parachinar area on the Afghan border. The others are the Sateen plain near Sadda (halfway between Parachinar and Thal), an alluvial plain 10 km south of Sadda on the right bank of the Kurram river near Chulam Chakmanni and the ill-defined Khoidad Khel area northwest of Thal (Figure 84).

Geology
The Kurram Agency's mountains are overthrust Jurassic and Cretaceous rocks (Meissner et al., 1975). The Cretaceous rocks are developed in the so-called western facies represented by the Kurram Formation, which comprises variegated red-brown and green shale, light grey, in places mottled, very thin bedded to platy limestone and brown or grey conglomeratic sandstone. They occur on the right bank of the Kurram river. On the left bank grey to dark grey, thin to thick bedded oolitic Jurassic limestones are found. They are interbedded with dark green sandstone and shale. Subordinate Cretaceous rocks are represented by undifferentiated sandstones of the Lumshiwal Sandstone and Chichali Formations; they are

dark green to dark grey and glauconitic, but some are white and quartzose. North and northeast of Parachinar is a narrow ridge of quartzite that forms the border with Afghanistan.

Groundwater conditions

Parachinar area

The groundwater conditions of the Parachinar area were studied in detail by WAPDA and TNO-DGV and are discussed in Section 15.7.

Sateen plain

The Sateen plain covers 30 km^2 and has a catchment of 47 km^2. It is located between latitudes 33°35'and 33°40' N and longitudes 70°20'and 70°25' E. According to FATA-DC (oral communication) eight test holes were drilled in this area, five of which were converted into test wells. They were tested and gave yields between 50 and 100 m^3/h (0.5 - 1 cusec). The water is said to be of good quality. No other data are available.

Chulam Chakmanni plain

It is unknown if any boreholes have been drilled in this area.

Khoidad Khel area

Here FATA-DC drilled three test holes. They were not promising and therefore they were not converted into test wells.

Groundwater development potential

According to NESPAK (1983), the average annual precipitation is 810 mm.

Consequently, the Sateen plain will receive an estimated recharge of 2 Mm^3/yr (2.2 cusec). As the five test wells will each produce about 150,000 m^3/yr, or a total of 750,000 m^3/yr, further groundwater development should be

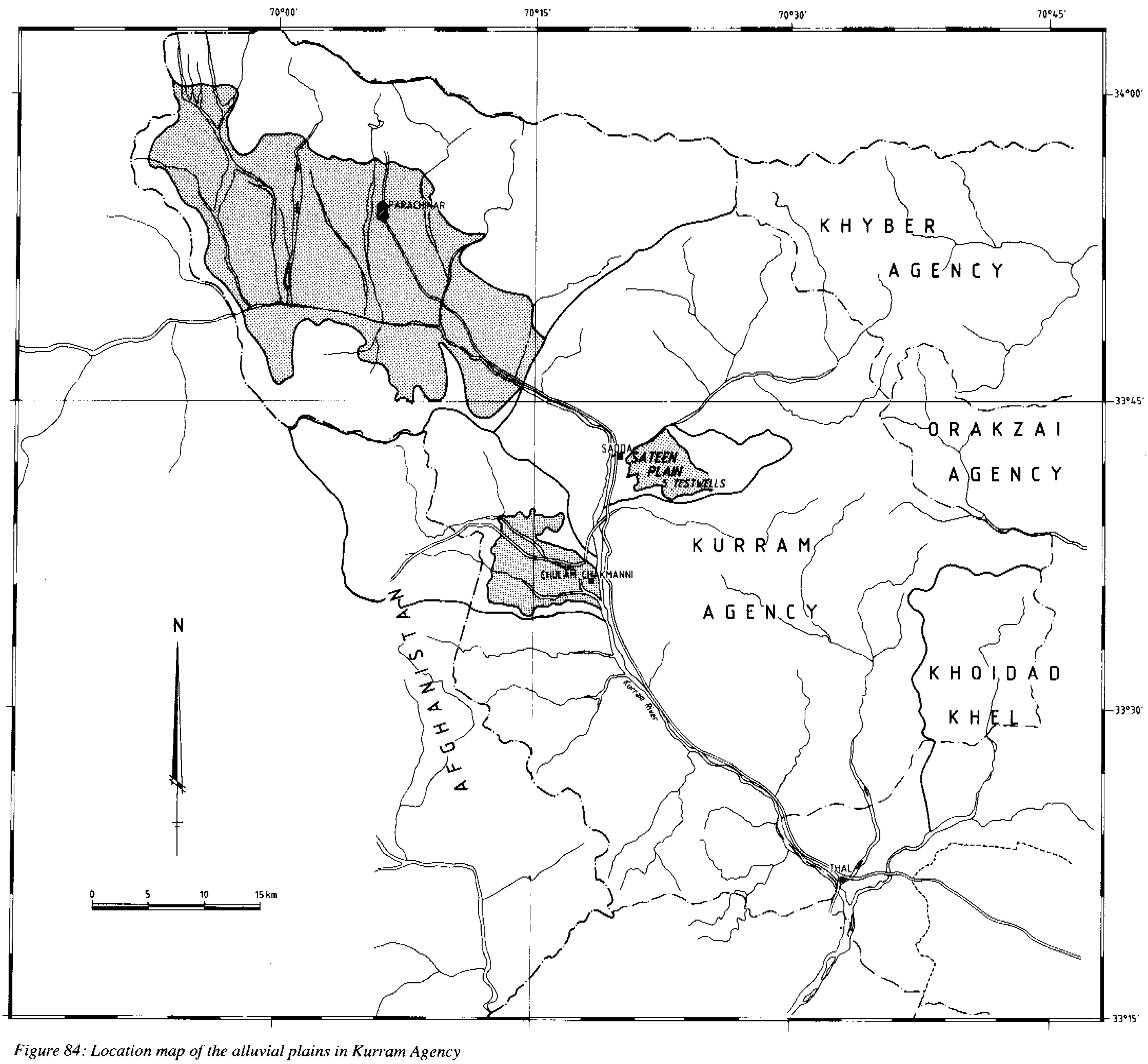


Figure 84: Location map of the alluvial plains in Kurram Agency

halted as long as no assessment study is available.
No estimates can be given on the development potential of the Chulam Chakmanni plain and of the Khoidad Khel area.

Annotated bibliography
At the end of Section 15.9.

15.7 THE PARACHINAR AREA (KURRAM AGENCY)

Location
The Parachinar area encompasses the sloping plains on both sides of the Kurram river between Kharlachi near the Afghan border in the west and Tapakki on the Parachinar - Sadda road in the east. It is located between latitudes 33°45' and 34°00' N and longitudes 69°52' and 70°17' E. Administratively the area belongs to Kurram Agency of FATA.

Physiography
The major part of the area consists of an alluvial plain that slopes from the Safed Koh and Marmora Ghar ranges in the north to the Kurram river in the south. A minor part stretches along the right bank of the Kurram river and is bordered in the south by the Khwaja Kurram Ghar. The total area of the alluvial plain is 430 km^2 and that covered by the catchment area is 930 km^2. The major plain, on the Kurram left bank, has an elevation of 1280 m (4200 ft) above msl near the river and of 2000 m (6560 ft) above msl at the foot of the Safed Koh range. The highest peak in the catchment is the Sikharam Sarin in the Safed Koh range, which is 4755 m (15,600 ft) above msl at Sikharam Sar. In the southern catchment the mountains rise to 2536 m (8320 ft) above msl. The slope of the plain is 0.06 at the foot of the Safed Koh range and 0.03 near the Kurram river.
The Kurram river, the only perennial stream in the area, arises in Afghanistan and enters the Parachinar area near Kharlachi and at the eastern boundary of this area is joined by the Kirman Toi, which drains a relatively large part of the northeast of the catchment area. Other streams coming from the Safed Koh range are, from west to east, the Peiwar Toi, the Shalozan Tangal, Malana Tangal and Zeran Tangal.

Geology
The Parachinar area is an intermontane depression at the western end of the Indo-Pakistani plate, where it collided with the Afghan continental block. As a result of the collision a belt of north-south trending Jurassic and Cretaceous marine shelf deposits, mainly limestones, was uplifted. The east-west trending Safed Koh also comprises Jurassic and Cretaceous limestones, but its crest is formed by Cretaceous quartzites. On the western tip of the crest are mafic igneous rocks in the form of basalt sills (Meissner et al., 1975).
The erosion products of the Safed Koh range and to a minor degree from the Marmora Ghar range and the Khwaja Kurram range have been deposited in the depression. They form coalesced alluvial fans sloping towards the Kurram river. The thickness of this fill varies from 65 m near the entrance of the Kurram river into the plain to more than 243 m north of Parachinar.

Climate
The climate is of the sub-humid subtropical continental highland type (Section 1.3). The average annual rainfall at the meteorological station at Parachinar is 860 mm (Rudloff, 1981). In the mountainous catchment areas the rainfall may be 1000 mm. The rainfall in March and April exceeds the rainfall in July and August (Rudloff, 1981). Summers are cool and winters are cold, with daily average temperatures around 25°C in June and July, and 4°C in January. The estimated potential evapotranspiration is 1200 mm/yr.

Population and domestic water supply
No data were available on the population of the Parachinar area. In 1986, out of 17 tubewells drilled in the area only the one on the premises of the hospital in Parachinar town and the one near the village of Lalmai Kili were operational. Where the water table is at shallow depth open wells provide the water for domestic use and livestock watering.

Agriculture
Where irrigation water is available the agricultural production is high. Such areas are found along the Kurram river and the Kirman Toi and also along the upper reaches of the other major streams. Irrigation water is available through springs, groundwater exfiltration and the diversion of stream water. The Kharif crop is rice, maize and pulses, and the Rabi crop consists of wheat, barley and clover. Fruit growing, especially apples and peaches, is another form of irrigated agriculture.
The non-irrigated areas are nearly all uncultivated, not only because of lack of water, but also because the soil is infertile.

Groundwater investigations
According to Naqavi (1974), sometime between 1960 and 1974 Rashid Ali of WASID made a reconnaissance survey of the Parachinar area; unfortunately his report could not be traced. In 1984 and 1985 WAPDA and TNO-DGV assessed the groundwater of the Parachinar area in the framework of the Pak-Dutch project "Groundwater investigations in North-West Frontier Province" (Dalfsen et al., 1986). Four test holes were drilled, one of which was converted into a test well on which a pumping test was carried out. In 1987, the conclusions of this study were corroborated by the results of a groundwater flow simulation study by Elderhorst (1987) based on the use of a numerical model of the finite difference type.

Groundwater conditions
There is a single unconfined aquifer located in the coarse deposits that underlie the alluvial plain (Figure 85).
The depth to the water table is more than 150 m near the foot of the Safed Koh and gradually decreases to zero in the strip where the groundwater exfiltrates between the Kurram river and the main road parallel to the river. The transmissivities inferred from the well tests vary from 300 to 6700 m^2/d. The areas of relatively low transmissivity - less than 1000 m^2/d - are located south of Lalmai Kili and north of Malli Kili.
From the lithological composition of the aquifer it may be assumed that the specific yield is between 0.10 and 0.15.
Specific capacity values varied from 7.5 to 27.8 m^3/h per m dd. (10.1 - 37.3 gpm/ft dd.). The chemical analysis of

groundwater samples shows that the EC value is generally between 0.40 and 0.45 mS/cm; only in well WA-17 is the EC value relatively high: nearly 1.50 mS/cm. The SAR value varies from 0.1 to 2.4. The ionic composition is variable: in three out of five samples magnesium is the dominant cation, in one of the other samples it is sodium and the last sample has no dominant cation. Sulphate is the dominant anion in one sample, in three of the other samples it is bicarbonate and in the remaining sample there is none.

Groundwater flow

The groundwater level elevation contours (Figure 86) indicate a subsurface flow from the recharge areas at the foot of the mountains to the exfiltration areas along the Kurram river and Kirman Toi.

Discharge and recharge

Based on baseflow measurements in the Kurram river, Dalfsen et al. (1986) calculated the groundwater exfiltration at 260 Mm^3/yr (291 cusec). Comparing this with the rainfall over the catchment and the alluvial plain, it is clear that the groundwater recharge corresponds to 20 per cent of the total annual rainfall.

Groundwater development potential

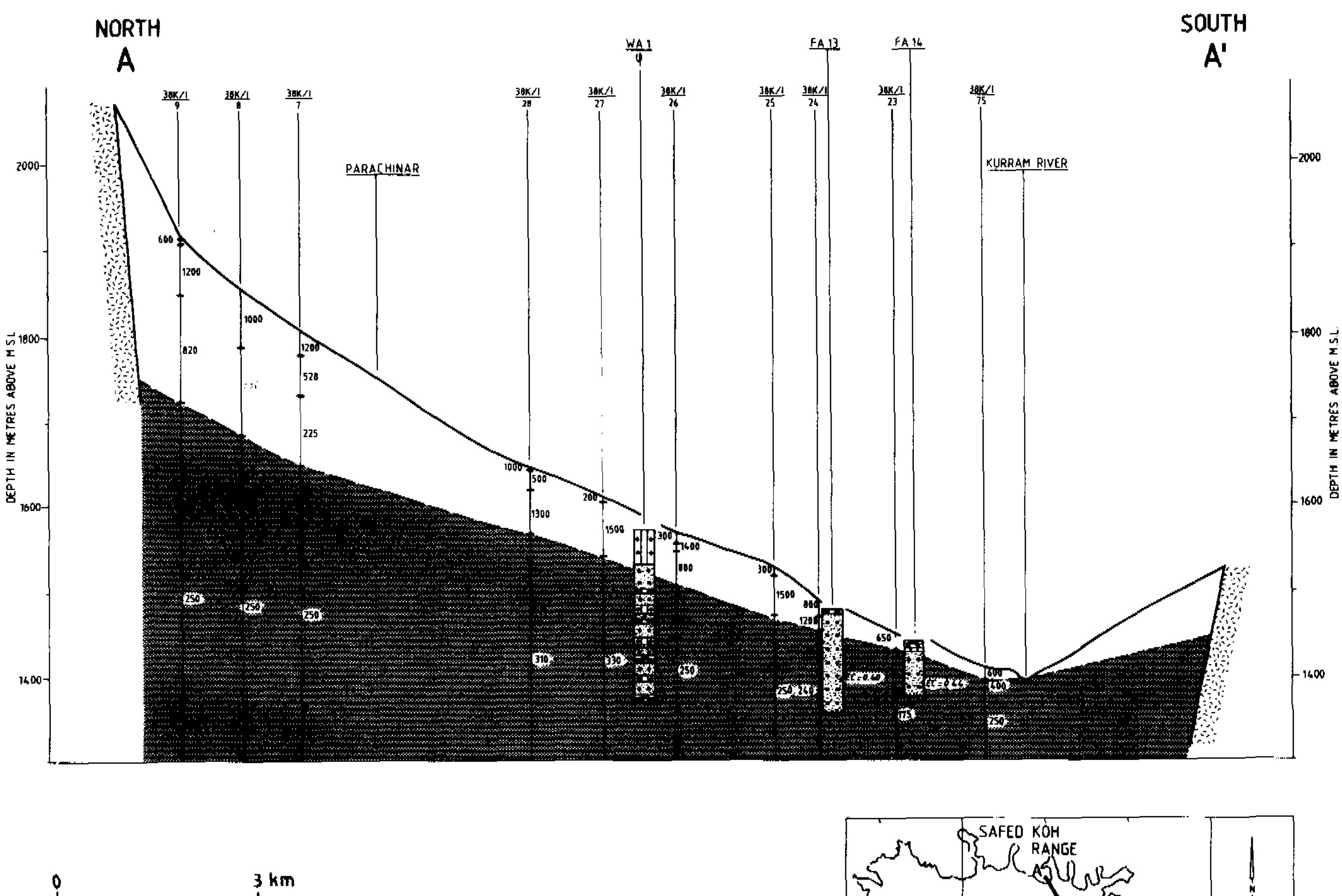
Although plenty of groundwater is available for development, there is a lack of irrigation development opportunities in the area where the water table is shallow enough to make groundwater development profitable. Most of the irrigable soils are located near the streams and rivers, where ample surface water resources satisfy the irrigation requirements. It will be noted that large-scale groundwater development will lead to a reduction of the exfiltration and therefore of the surface water resource in the irrigated area along the Kurram river.

Groundwater management

As it is unlikely that there will be a large increase of groundwater development, as yet there is no need for a groundwater management plan.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.



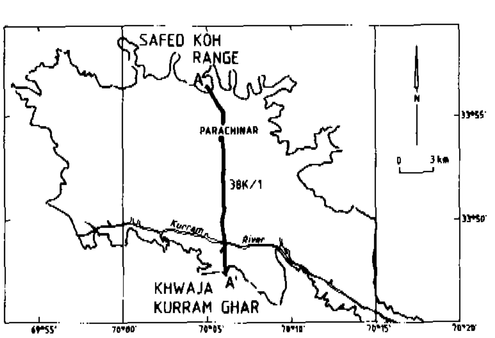


Figure 85: Hydrogeological cross-section over the Parachinar area (For legend see fold-out at back of book)

Figure 86: Groundwater map of the Parachinar area

Ali, Rashid, undated. A short note on the geohydrologic reconnaissance survey of the Parachinar area; unpublished WASID (?) survey report. *Annotation.* This report mentioned by Naqavi (1974) in a review of groundwater investigations in NWFP between 1960 and 1974, could not be traced in 1986.

Dalfsen, W. van, Taj Khan Wazir and Musharraf Jan, 1986. Groundwater resources in Parachinar Area, Kurram Agency, NWFP. Technical Report No. XI-1. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, The Netherlands; 15 pp., 5 app., 5 tbls, 3 figs and 5 pl. *Annotation.* This paper reports the results of the investigations carried out by WAPDA-HDP and TNO during 1984/1985. It is based on fieldwork that included a well inventory of 162 open wells, 1 tubewell drilled by PHED and 18 tubewells drilled by FATA-DC; a resistivity survey of 109 vertical soundings, drilling of four test holes ranging in depth from 130 to 200 m, geophysical well-logging of the test holes and of the PHED borehole, pumping tests in one converted test hole and in five FATA-DC tubewells; water sampling for chemical analysis and streamflow measurements.

Elderhorst, W.I.M., 1987. The use of a groundwater flow model in the Parachinar plain, Kurram Agency, NWFP, Technical Report No XI-2. WAPDA Hydrogeology Directorate Peshawar and TNO-DGV Institute of Applied Geoscience, Delft, The Netherlands; 22 pp., 10 app., 11 figs, and 1 pl. *Annotation.* The report describes the calibration of the Prickett and Lonnquist Aquifer Simulation Model (PLASM3D) and its use to calculate expected drawdown as applied to the aquifer of the Parachinar plain. This work was a case study in a training course in groundwater modelling for WAPDA staff. Therefore the report not only gives the results of the model study, but also details about each step taken during the groundwater flow simulations. A number of exercises for use in training are attached.

15.8 NORTH WAZIRISTAN

Location

A vast area of 4707 km^2 is called North Waziristan and is drained by the Tochi and the Kaitu rivers, both tributaries of the Kurram river. The alluvial plains of North Waziristan that may have interesting groundwater resources are shown on Figure 87. They are:

	latitudes(N)	longitudes (E)
Spinwam plain	33°10'-33°13'	70°21'-70°23'
Shera Tala	33°00'-33°10'	70°20'-70°25'
Muhammad Khel area	32°52'-32°57'	69°49'-69°58'
Miran Shah area (incl. Danday plain)	32°55'-33°10'	70°00'-70°09'
Mir Ali plain	32°52'-33°09'	70°08'-70°20'

Geology

The geology of the northwestern part of North Waziristan is described by Meissner et al. (1975). A thrust fault along the line Thal - Mir Ali separates Cretaceous rocks in western facies (Section 15.6) in the west from the Tertiary formations as described in Section 12.1. South of Mir Ali, the thrust fault separates the Cretaceous rocks of North Waziristan from the Tertiary rocks along the western border of the Dera Ismail Khan basin (Chapter 14).

Groundwater conditions

Spinwam plain.

The Spinwam plain is a small area of 14 km^2 including the catchment. In spring 1987 a programme of drilling seven test holes was in progress. Most test holes gave promising results.

Shera Tala

In Shera Tala, an area of 83 km^2 south of Spinwam, five test holes were drilled, but they were not converted into test wells.

Muhammad Khel area

In this area of 42 km^2 on the Tochi river FATA-DC successfully drilled and constructed four tubewells.

Miran Shah area

In an area of 15 km^2 south of Miran Shah on the bank of the Tochi river FATA-DC drilled six test holes, five of which were successfully converted into tubewells and connected to the electricity grid.

In the Danday plain (72 km^2), north of Miran Shah, two tubewells are in operation. In spring 1987 the drilling of 13 test holes was in progress. The number of wells previously drilled could not be ascertained.

The lithological information is meagre. Two unpublished borehole sketches were made available by FATA-DC (personal communication) and five borehole sketches were published by NESPAK (1983). They indicate an 80 - 90 metre thick layer of gravel, boulders and sand, with a small amount of clay underlain by fine to medium sand or clay; the depth to water level is between 38 and 56 m.

Mir Ali area

The alluvial terrain around Mir Ali covers 138 km^2. In the Palasin plain northwest of Mir Ali FATA-DC drilled 11 boreholes. Eight were converted into tubewells and were energized.

Present groundwater use

No data are available on the present use of groundwater.

Groundwater development potential

Unless otherwise mentioned, it is assumed that the recharge of the aquifer in each plain is 5 per cent of the total rainfall volume over its catchment, which is calculated by using the average annual rainfall figure of 325 mm reported by NESPAK (1983).

Spinwam plain

The catchment area of the Spinwam plain is not much larger than the plain (14 km^2). The recharge will be only 230,000 m^3/yr (0.26 cusec) and two tubewells are overexploiting the aquifer unless the decline of the water table as a consequence of the pumping is inducing the ground water percolation from the Kaitu river to increase.

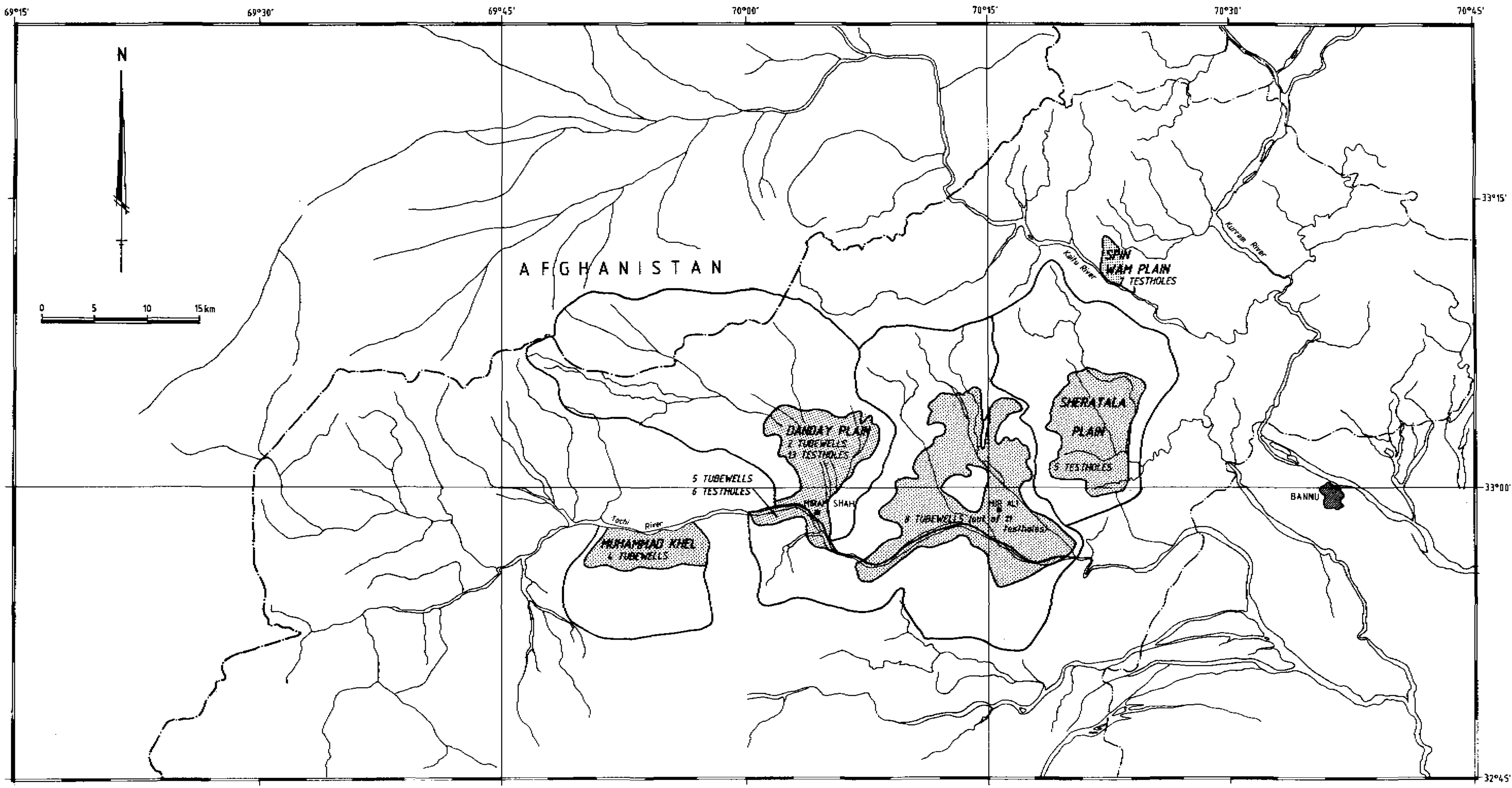


Figure 87: Location map of the alluvial plains in North Waziristan

Shera Tala
The catchment and plain of Shera Tala cover 83 km^2. The estimated recharge is 1.3 Mm^3/yr sufficient to sustain the production of ten tubewells for irrigation with a pumping capacity of 75 m^3/h.

Muhammad Khel area
The estimated recharge here is also 1.3 Mm^3/yr (1.5 cusec). This implies that there may be scope to construct six tubewells in addition to the four already drilled.

Miran Shah area
The area south of Miran Shah on the right bank of the Tochi river has a catchment of 60 km^2 and is recharged by nearly 1 Mm^3/yr (1.1 cusec). The groundwater production of the five tubewells that have been constructed is of the same magnitude. The Danday plain with a catchment of 385 km^2 receives an estimated recharge of 6.2 Mm^3/yr (6.9 cusec). NESPAK (1983) proposed to install 60 tubewells in the Danday plain, each with a capacity of 81 m^3/h, to irrigate 2,732 ha (26,775 acres) with a water use of 1160 mm per year. This would require a total pumping time of more than 6520 h/yr, or 18 h/d. Given the uneven water demand of the crops over the growing season and other operational constraints, the actual operation time of an irrigation tubewell is only 2000 h/yr, so only 910 ha (2250 acres) can be irrigated with the proposed wells, provided that the groundwater development potential is at least 10 Mm^3/yr (11.2 cusec). This is 50 per cent more than the annual recharge of the aquifer estimated above.

Mir Ali plain
The catchment of the Mir Ali plain is 161 km^2, and the estimated recharge is 2.6 Mm^3/yr (2.9 cusec). The eight tubewells constructed by FATA-DC have an annual production of 1.2 Mm^3 (1.3 cusec), which leaves room for another nine tubewells.

Groundwater management
Given the low rainfall, it is essential that assessment studies are done to verify the assumptions in the above calculations, to improve the recharge estimates, and to provide a solid basis for the groundwater development and groundwater management of the Agency.

Annotated bibliography
At the end of Section 15.9

15.9 SOUTH WAZIRISTAN

Location
South Waziristan covers an area of 6620 km^2. It is drained by the Gumal river (known as Zhob river in Baluchistan where it has its origin) and by the Shahur/Tank Zam river. The alluvial plains (Figure 88) that may have interesting groundwater resources are:

	latitudes (N)	longitudes (E)
Shaki plain	32°25'-32°31'	69°36'-69°43'
Wana plain	32°11'-32°23'	69°22'-69°39'
Barwand plain	32°11'-32°21'	69°46'-69°54'
Spin plain	32°05'-32°12'	69°37'-69°46'
Zarmelan	31°55'-32°20'	69°16'-69°38'

Geology
The intermontane basins and major valleys of South Waziristan are filled with Quaternary alluvial deposits, mostly originating from the Cretaceous shales with interbedded limestone formations.

Groundwater conditions
Shaki plain
There are two successful tubewells, each with a yield of 50 m^3/h (0.5 cusec).
The lithology consists of sand and gravel with many clay lenses.

Wana plain
The steep topographical gradient results in a large variation in the depth to the water table, i.e. 15 m in the south and 100 m in the upstream north. Several drilling campaigns have been carried out:
- In the period 1979/1982 seven test wells were drilled. For the test well at Wacha Pana NESPAK (1983) gives a yield of 50 m^3/h (0.5 cusec) and an estimated transmissivity of 310 m^2/d. For one of the two testwells near Shin Warsak NESPAK reports a yield of 150 m^3/h (1.5 cusec) and an estimated transmissivity of 900 m^2/d.
- In 1981/1982 four more wells were drilled, but only two were successful.
- In 1982 four additional wells were drilled near Shin Warsak. They produced about 60 m^3/h with a drawdown between 5 and 25 m, indicating a transmissivity in the order of 300 m^2/d.
- In 1983/1984 a new drilling campaign of ten test wells was started, this time in combination with a resistivity survey. The results of the investigations were not available at the time of writing.

The available lithological information is restricted to two unpublished borehole sketches from FATA-DC, probably from the southern part of the plain, and three borehole sketches presented by NESPAK (1983). They indicate that to a depth of about 60 m there is a layer of ill-sorted coarse material with subordinate amounts of clay, which overlies clay with gravel intercalations of various thickness.

Barwand plain
In 1979/1980 the first borehole was drilled close to Barwand. Since then, 11 wells have been added, all of which have been successful. Five new wells are planned in the northeastern part of the Barwand plain. According to FATA-DC the alluvial deposits are coarse. Drilling depth is approximately 60 m and the water table is at a depth of between 15 and 30 m.

Spin plain
In 1979 three successful tubewells were drilled. Two near Spin had a yield of 100 m^3/h (1 cusec) each and a specific capacity that indicates a transmissivity between 600 and 1500 m^2/d. The well near Sherkani had a yield of 150 m^3/h and a specific capacity indicating a transmissivity of 1500 m^2/d (NESPAK, 1983). A borehole sketch published by NESPAK (1983) shows gravel in a matrix of clayey sand to a depth of 75 m, and sandy clay and clay between 75 and 120 m. The water table is at a depth of 10 m.

Zarmelan plain
In 1987 a programme to drill 25 test wells in this area will be completed. The drilling depth is about 150 m, and the water table is at a depth of approximately 75 m.

Groundwater development potential
Unless otherwise mentioned, it is assumed that the recharge of the aquifer in each plain is 5 per cent of the total rainfall volume over its catchment, which is calculated by using the average annual rainfall figure of 325 mm reported by NESPAK (1983).

Shaki plain
The catchment is 179 km^2 and the recharge of the plain is estimated as 2.7 Mm^3/yr (3.0 cusec). The annual groundwater withdrawal by the two existing tubewells is estimated at 0.2 Mm^3/yr.

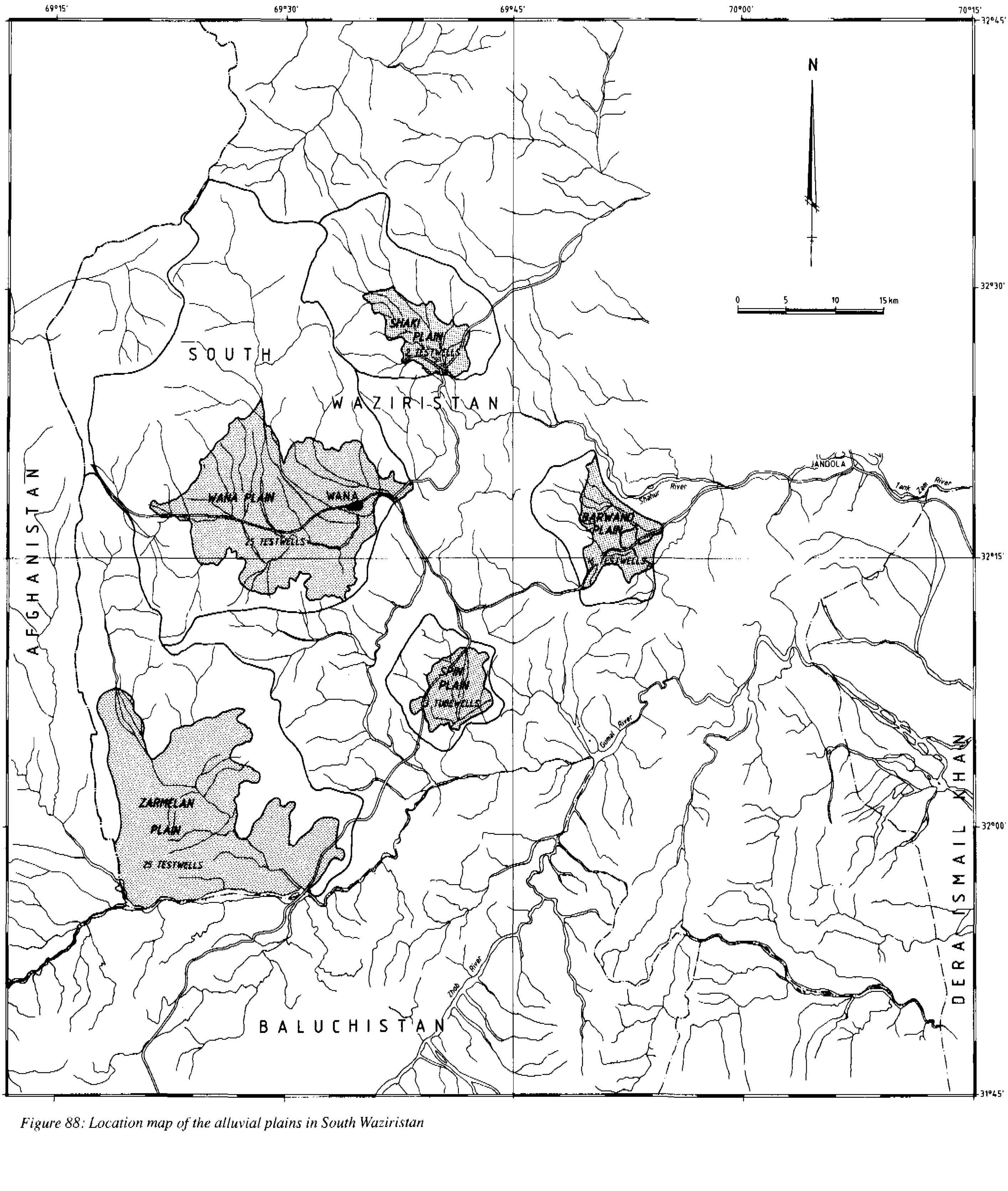


Figure 88: Location map of the alluvial plains in South Waziristan

Wana plain

The catchment area measures 634 km^2 and the recharge is estimated as 10 Mm^3/yr (11.2 cusec), 3.4 Mm^3/yr (3.8 cusec) can already be produced by the 17 tubewells, drilled so far by FATA-DC. NESPAK (1983) proposed to install 60 tubewells, each with a capacity of 81 m^3/h, to irrigate 2,732 ha (6830 acres) with a water requirement of 1160 mm per year. This means a total pumping time of more than 6520 h/yr, or 18 h/d. Given the uneven water demand of the crops over the growing season and other operational constraints, the actual operation time of an irrigation tubewell is only 2000 h/yr. According to the present author, only 910 ha (2275 acres) can be irrigated with the proposed wells, provided that the groundwater development potential is at least 10 Mm^3/yr (11.2 cusec). This is 30 per cent more than the annual recharge of the aquifer estimated above, if the already installed wells are taken into account too.

Barwand plain

The catchment of the Barwand plain is 72 km^2. It provides recharge to the aquifer with an estimated amount of 1.1 Mm^3/yr (1.2 cusec). According to FATA-DC 11 successful wells were drilled, which will produce at least 1.6 Mm^3/yr (1.8 cusec). If the five additional boreholes presently under consideration are also successful, the annual production may rise to 2.4 - 3.2 Mm^3 (2.7 - 3.6 cusec), which is nearly double the estimated annual recharge.

Spin plain

The Spin plain has a catchment of 56 km^2 and receives an estimated recharge of 0.8 Mm^3/yr (0.9 cusec). When the three tubewells drilled so far are fully operational they will produce 0.6 Mm^3/yr (0.7 cusec) or 75 per cent of this recharge.

NESPAK (1983) proposed to install 50 tubewells, each with a capacity of 81 m^3/h, to irrigate 2,428 ha (6000 acres) with a water requirement of 1160 mm per year. A total pumping time of 6960 h/yr, or 19 h/d would be needed. Given the uneven water demand of the crops over the growing season and other operational constraints, the actual operation time of an irrigation tubewell is only 2000 h/yr, so only 700 ha (1730 acres) can be irrigated with the proposed wells, provided that the groundwater development potential is at least 8 Mm^3/yr (9 cusec). This is 10 times more than the annual recharge of the aquifer estimated above. Consequently, the proposal by NESPAK is unrealistic.

Zarmelan plain

The Zarmelan plain has a catchment of 346 km^2 and it receives an estimated annual recharge of 5.2 Mm^3 (5.8 cusec). If the 25 test wells are successful, they will annually produce a total volume of 3.8 - 5.0 Mm^3 which means that the aquifer will be fully exploited.

Groundwater management

Given the low rainfall, it is essential that assessment studies are started to verify the assumptions in the above calculations, to improve the recharge estimates, and to provide a solid basis for the groundwater development and groundwater management of the Agency.

Annotated bibliography

The bibliography contains all known reports with specific information related to the groundwater resources and groundwater development of the area. They are listed chronologically. The references of a general nature are not mentioned in the bibliography, but can be found in the References at the end of this book.

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Annotation. This report contains a summary of the knowledge available in 1983 about the groundwater resources in Orakzai Agency (O-A), North Waziristan (N-W), South Waziristan(S-W) and Frontier Region Bannu. It gives 23 test well and tubewell sketches; test data on 10 tubewells in O-A, on 11 test wells and tubewells in Wana plain (S-W), on 3 tubewells in Spin plain (S-W), on 7 tubewells in the Danday plain (N-W), and on 4 tubewells in Jani Khel, F.R. Bannu. The proposals in this report seem to be unrealistic.

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GLOSSARY

In addition to technical terms both the text and the illustrations contain words, names and concepts that are derived from the languages of the North-West Frontier Province as well as from Urdu. These are also explained below.

Abiana rights: Water charges due by the farmer to the Provincial Government as payment for water received from canals or public tubewell systems. The charges are levied according to kind of crop and area cultivated.

Administrative units: Pakistan is divided into administrative units; in descending order of size they are: Province, Division, District, Tehsil.

Algad: River, stream.

Aquiclude: A deposit or mass of low porosity, which absorbs water slowly, but does not transmit it, e.g. a thick dense clay.

Aquifer: A water-bearing stratum; pervious formation or layer holding water and permitting its movement.

Aquifer, confined: Water-bearing layers confined along top and bottom by aquicludes.

Aquifer, leaky: See AQUIFER, SEMI-CONFINED.

Aquifer, semi-confined: If one of the beds above or below a confined aquifer is an aquitard, this aquifer is called semi-confined or leaky.

Aquifer, unconfined: The upper boundary of the aquifer is a free water table and hence in direct vertical contact with the atmosphere.

Aquitard: Less permeable stratum, but permeable enough to transmit water in quantities that are significant when viewed over large areas and long periods.

Artesian aquifer: A confined aquifer, which (under prevailing conditions) has a piezometric level that lies above land surface.

Artesian flow: Free flow, flow from a well without pumping.

Artesian well: Ambiguous term referring to a free-flowing well.

Bajra: Millet.

Barani: Dryland farming, entirely dependent on rainfall for the maturing of the crops.

Base flow: The flow rate of a river when it receives water from groundwater drainage only.

Cementation: Precipitates of calcite or silicate fill the pores of the sediment, resulting in a reduction of the hydraulic conductivity.

Colluvial deposits: Rock waste consisting for a considerable part of fine-grained weathering products, accumulated by soil creep, mud flows, rain wash, etc. at the base of a slope.

Compaction: The porosity decreases through the weight of the overburden. Confined aquifers whose piezometric level has been substantially lowered are susceptible to this process.

Confined aquifer: See AQUIFER, CONFINED.

Conglomerate: An indurated sediment largely consisting of rounded rock fragments larger than 2 mm, and normally having a matrix of sand.

Cropped area: Net sown area plus area sown more than once a year.

Cultivated area: Net sown area plus current fallow area.

Culturable area: Cultivated area plus culturable waste.

Culturable waste: Uncultivated area that is fit for cultivation but has not been cropped during the current year or the year before.

Current fallow area: Area not sown during the current year, but sown in the previous year.

Darcy's law: Named after the French hydraulic engineer H. Darcy, who concluded from experiments that the flow rate of water through sands is proportional to loss of energy, inversely proportional to the length of the flow path and proportional to a coefficient depending on the nature of the sand.

Darra: Stream.

Dera: A place; the place of.

Diagenesis: All mechanical, chemical, mineralogical and biogenic processes and changes in a sediment and its interstitial water after its deposition, e.g. compaction, cementation, pressure solution, recrystallization and replacement, at temperatures below those leading to metamorphosis (generally not exeeding 300°C).

Depth to water table contour lines: See WATER TABLE CONTOUR LINES, DEPTH TO.

District: An administrative unit.

Division: An administrative unit including several Districts.

Doab: Land between two rivers; interfluve.

Drawdown: The amount by which the hydraulic head is lowered as a result of pumping.

Dug well: A well put down by manual labour.

Effluent river: A river with its streambed in pervious material at a level below the regional water table. It gains water by exfiltration of groundwater.

Electrical conductivity (EC): The capability of water to conduct an electric current. It is expressed as the conductance of a cubic centimetre of water at a temperature of 25°C. The EC of groundwater is usually quite low, so the unit commonly used is the milliSiemens per centimetre (mS/cm).

Electrical resistivity soundings: A geophysical prospecting method in which direct measurements are made of the ratio of voltage to current when a current is forced to flow through the ground to be tested. The conducting property of a rock depends on its water content and its salinity. If these values are high, then its conductivity is also high and its electrical resistivity is low.

Ephemeral river: A river with its channel positioned above the water table; its water is derived from precipitation, so it carries water only during or briefly after rainstorms.

Evapotranspiration: The withdrawal of water from the soil by evaporation and transpiration of plants.

Fan, alluvial: An extensive deposit of coarse detrital material with, in general, a low outward slope.

Fault: Fracture surface along which appreciable displacement has taken place.

Fold: Bend or flexure produced in rocks.

Foredeep: A marginal depression in front of an emerging mountain range, which fills up with molasse sediments, i.e. the coarse erosion products from the rising mountain chain (Indogangetic plain).

Gram: Chick pea.

Groundwater balance: An estimate of the quantities of water added to the groundwater reservoir in a given area during a given period, balanced against estimates of quantities withdrawn or lost from that reservoir during that period, together with an estimate of the change in storage.

Groundwater elevation contours: Lines on a map connecting all points of the water table or the piezometric surface that are at the same vertical distance relative to a datum plane (commonly mean sea level, msl).

Groundwater increment: Groundwater recharge or recharge of aquifer.

Hydraulic conductivity: Or hydraulic permeability; in groundwater flow calculations this is measured as the volume of fluid passing through unit cross-section in unit time under the action of unit pressure gradient. It is a function of viscosity, of the degree of saturation and of the medium.

Hydraulic gradient: The difference in hydraulic head between two points on a flow line divided by the distance between the points. It is expressed in metres per kilometre.

Hydraulic head: The level to which groundwater rises in a well or piezometer.

Iduration: The process by which sediments are hardened by heating, compression and cementation.

Influent river: A river with its streambed in pervious material above the regional water table. It loses water by infiltration.

Isohypse: See GROUNDWATER ELEVATION CONTOURS.

Jowar: Sorghum.

Katha canal: Private irrigation canal in Peshawar Vale.

Kareze: An infiltration gallery made by digging a series of vertical shafts and connecting them with a tunnel that intersects the water table and thus drains part of the groundwater and conveys it by gravity to the surface downslope on alluvial fans and similar sloping areas.

Kas: Stream.

Katha: Small canal dug by manual labour. For centuries a method to divert water in Pakistan.

Kharif: Summer growing season, from April - October.

Khwar: Stream, river.

Koh: Mountain.

Kot: A walled or fortified village.

Leaky aquifer: See AQUIFER, LEAKY.

Main water table: See WATER TABLE, MAIN.

Monsoon: Rainbearing winds of the summer months. In NWFP from the middle of July - middle of September.

Nala: Intermittent stream.

Net potential evapotranspiration: See POTENTIAL EVAPOTRANSPIRATION.

Net sown area: Area sown at least once during the current year.

Nullah: stream.

Open well: A dug well.

Pan evaporation: Evaporation from a Class-A evaporation pan (according to WMO standards).

Percolation: Movement of water through the soil.

Perched water table: The upper limit or surface of a small body of water above the main water table. The water is retained in its elevated position by an impervious stratum and may form a limited source of water supply.

Perennial river: A river that flows continuously throughout the year.

Persian well: Dug well, pumped by animal power. An endless line of clay pots or cans firmly secured to a rope cable is driven by wooden gears which are turned by bullocks, a donkey or a camel.

Phreatic water: Groundwater in an unconfined aquifer.

Piedmont plain: The gentle slopes that extend from the surrounding mountains and hills to the level of the flat plain.

Piezometric or potentiometric surface: The water level in a well that taps a particular confined or a semi-confined aquifer, only. The water level in the well will be above the top of the aquifer.

Porosity, primary: The percentage ratio of volume of voids to the total volume of a rock or soil sample.

Porosity, secondary: The voids that originate as a result of post-depositional or post-crystallization processes such as faulting, fracturing and dissolving.

Potential evapotranspiration: The maximum withdrawal of water through evaporation and transpiration from a flat surface with a short grass cover when soil moisture is not a limiting factor.

Potentiometric surface: See PIEZOMETRIC SURFACE.

Pumping test: A test made with a pump in a well to determine its wateryielding capacity. Quantities and water levels are recorded during the test period. The test pumping-rate is usually greater than that at which water will be required and covers a periodsufficiently long to indicate whether the yield can be maintained.

Primary porosity: see POROSITY, PRIMARY.

Rabi: Winter growing season that includes the period from the middle of October to the middle of March.

Rud: Small river.

Runoff: The part of the precipitation that flows into natural or artificial channels.

Saturated soil: A condition when all the interstices of a soil are filled with water.

Shaftal: Fodder.

Secondary porosity: See POROSITY, SECONDARY.

Semi-confined aquifer: See AQUIFER, SEMI-CONFINED.

Shirani: Tribal unit of the Pathans.
Sodium Adsorption Ratio (SAR): If calcium and magnesium ions on clays and colloids of the soil are replaced by sodium, soil permeability decreases and the soil hardens.
Specific electrical conductance: See ELECTRIC CONDUCTIVITY.
Specific yield: Effective porosity. The ratio of the volume of water a saturated rock (or soil after having been saturated) will yield by gravity drainage to the gross volume of rock or soil.
Static water level: See WATER LEVEL, STATIC.
Storage capacity: Quantity of water that at a certain moment can be stored above the saturated zone, expressed in mm water column.
Storage coefficient: Storativity; the volume of water that an aquifer releases from or takes into storage per unit surface area and per unit change of head.
Stream gauging: Measuring the area of cross-section in a stream channel and the velocity of water flow to determine discharge; usually taken over a period to determine the trend or changing amounts of discharge.
Surface runoff: The water flowing over the surface of the earth that finds its way into rivers and channels by means of small depressions and rivulets.
Suture: Important fault in an orogenic belt, often assumed to mark the boundary between two former plates in a collision zone.
Tehsil: Administrative unit.
Tethys: Former ocean between the Eurasian and Gondwana tectonic plates.
Till: Non-stratified glacial deposit.
Toi: River or stream.
Total dissolved solids: TDS in water is expressed in mg/l or in parts per million (ppm). Fresh water has a specific gravity close to 1, hence, here ppm and mg/l are nearly equivalent.
Transmissivity: Product of permeability or hydraulic conductivity and thickness of the reservoir rock.
Tubewell: A well constructed in a borehole.
Unconfined aquifer: See AQUIFER, UNCONFINED.
Unsaturated zone: The soil above the water table and the capillary fringe, whose pores are only partially filled with water. The fluid pressure is less than atmospheric. Flow in this zone is predominantly vertical.
Viscosity: The resistance of water to flow is called its viscosity; its value varies with temperature and pressure.
Warabandi: Supply-controlled irrigation water distribution system, in which the farmer receives a fixed amount of water according to a fixed roster. The system was introduced by the British in the Punjab in the 19th century.
Water level, static: Regional groundwater level not disturbed by pumping, or other temporary influences.
Water-struck level: In an unconfined aquifer it coincides with the water table; in a confined aquifer it coincides with the top of the aquifer which is lower, sometimes by hundreds of metres, than the piezometric level.
Water table: The surface of a zone of saturation, or other body of unconfined groundwater. It follows in a flatter form the profile of the land surface; it is nearer the surface in valleys and deeper along hills and elevated ground. The water table will fluctuate as a result of natural or artificial causes.
Watertable contour lines: See GROUNDWATER ELEVATION CONTOURS.
Watertable contour lines, Depth to: Lines on a map connecting all points at the same depth below the land surface on a water table.
Watertable gradient: The slope or inclination of the water table, from the horizontal plane, at a given place and in a specific direction; may be obtained from the watertable contour plan.
Water table isohypse: A line on a map connecting all points of the water table that are the same vertical distance relative to a datum level.
Watertable level: The level at which the water table is encountered in boreholes, wells, valleys and deep excavations.
Waterlogged: Saturated with water. The condition may be the result of seepage, over-irrigation or springs.
Water table, main: The surface or water table of the zone of saturation; not applicable to perched water tables.
Well log: A recording in a borehole of one or more physical variables, which provide information regarding the lithology, stratigraphy, and physico-chemical properties of the formations perforated and of the liquid filling the pores. The commonly recorded variables are: spontaneous potential, long and short normal resistivity, natural gamma radiation and diameter of the borehole (caliper log).
Zamandari: Private irrigation canal in Bannu basin.
Zone of saturation: The mass of water-bearing ground below the main water table.