

Table 12-24 Estimated Annual Discharge and Recharge Rates

Year	Rainfall (mm)	Effective Porosity=5%			Effective Porosity=2%		
		Discharge (mm)	Recharge (mm)	R-D (mm)	Discharge (mm)	Recharge (mm)	R-D (mm)
1988	177.0	37.3	38.8	1.4	14.9	15.5	0.6
1989	166.0	60.3	47.0	-13.3	24.1	18.8	-5.3
1990	179.4	37.7	31.2	-6.5	15.1	12.5	-2.6
1991	298.0	38.6	34.9	-3.7	15.5	14.0	-1.5
1992	131.0	27.3	24.0	-3.3	10.9	9.6	-1.3
1993	256.5	27.4	25.7	-1.7	11.0	10.3	-0.7
1994	111.1	45.3	49.9	4.6	18.1	20.0	1.8
1995	66.6	48.7	28.2	-20.5	19.5	11.3	-8.2
1996	175.3	43.7	37.5	-6.2	17.5	15.0	-2.5
1997	223.4	75.5	56.0	-19.6	30.2	22.4	-7.8
1998	155.8	36.8	36.9	0.1	14.7	14.8	0.1
1999	166.9	31.2			12.5		
Average	176.4	42.5	37.3	-5.2	17.0	14.9	-2.1

Table 12-25 Fixed Hydraulic Conductivity and Storage Coefficient

No.	Hydraulic Conductivity (m/s)	No.	Specific Storage (1/m)	Effective Porosity (%)
1	1×10^{-5}	1	1×10^{-6}	1
2	1×10^{-5}	2	5×10^{-5}	2
3	1×10^{-6}	3	1×10^{-5}	2
4	1×10^{-6}			
5	1×10^{-10}			
6	1×10^{-6}			
7	5×10^{-14}			
8	1×10^{-7}			
9	2×10^{-6}			
10	1×10^{-4}			
11	1×10^{-5}			
12	1×10^{-14}			
13	5×10^{-7}			
14	4×10^{-6}			
15	1×10^{-11}			
16	1×10^{-9}			
17	5×10^{-6}			
18	4.5×10^{-5}			
19	1×10^{-8}			

Table 12-26 Fixed Recharge Rate

No.	Ordinary Year (mm/yaer)	1/50years Rain (mm/year)
1	0	0
2	0.021	4.2
3	0.104	5.2
4	0.014	2.8
5	0.015	3
6	0.85	4.25
7	0.005	1
8	0.2	18
9	0.056	2.8

Table 12-27 Future Pumping Plans

Case	Pumping Plan	Pumping Rate (million m ³ /year)					Recharge Rate	
		Aquifer	D	S	I (%)	Total (%)	O	1/50
1	Keeping present groundwater use	Kalahari	1.62	4.59	3.55 (100)	9.76 (100)	4.60	-
		Auob	0.56	1.08	3.33 (100)	4.97 (100)		
		Nossob	0.18	0.02	0.01 (100)	0.21 (100)		
		Total	2.36	5.69	6.89 (100)	14.94 (100)		
2	Keeping present groundwater use	Kalahari	1.62	4.59	3.55 (100)	9.76 (100)	4.60	79.86
		Auob	0.56	1.08	3.33 (100)	4.97 (100)		
		Nossob	0.18	0.02	0.01 (100)	0.21 (100)		
		Total	2.36	5.69	6.89 (100)	14.94 (100)		
3	Increasing irrigation use to 120%	Kalahari	1.62	4.59	4.26 (120)	10.47 (107)	4.60	79.86
		Auob	0.56	1.08	4.00 (120)	5.64 (113)		
		Nossob	0.18	0.02	0.01 (120)	0.21 (100)		
		Total	2.36	5.69	8.27 (120)	16.32 (109)		
4	Decreasing irrigation use to 70%	Kalahari	1.62	4.59	2.49 (70)	8.70 (89)	4.60	79.86
		Auob	0.56	1.08	2.33 (70)	3.97 (80)		
		Nossob	0.18	0.02	0.00 (70)	0.20 (95)		
		Total	2.36	5.69	4.82 (70)	12.87 (86)		
5	Decreasing irrigation use to 50%	Kalahari	1.62	4.59	1.78 (50)	7.99 (82)	4.60	79.86
		Auob	0.56	1.08	1.66 (50)	3.30 (66)		
		Nossob	0.18	0.02	0.00 (50)	0.20 (95)		
		Total	2.36	5.69	3.44 (50)	11.49 (77)		
6	Abandoning irrigation use	Kalahari	1.62	4.59	0 (0)	6.21 (64)	4.60	79.86
		Auob	0.56	1.08	0 (0)	1.64 (33)		
		Nossob	0.18	0.02	0 (0)	0.20 (95)		
		Total	2.36	5.69	0 (0)	8.05 (54)		

*) D: Domestic, S: Stock watering, I: Irrigation, O: Ordinary year, 1/50: 1/50 years rain

Permissible Yield	Sustainable Yield Mining Yield
Climate	Humid ←————→ Arid
Circulating Velocity	Rapid ←————→ Slow
Renewability	Renewable ←————→ Non-renewable
Criterion	Water Balance Economic Risk
	←————→ Water Right Groundwater Contamination

Fig. 12-1 Term of Permissible Limit of Groundwater Development and Conservation (modified after Shibasaki, 1972)

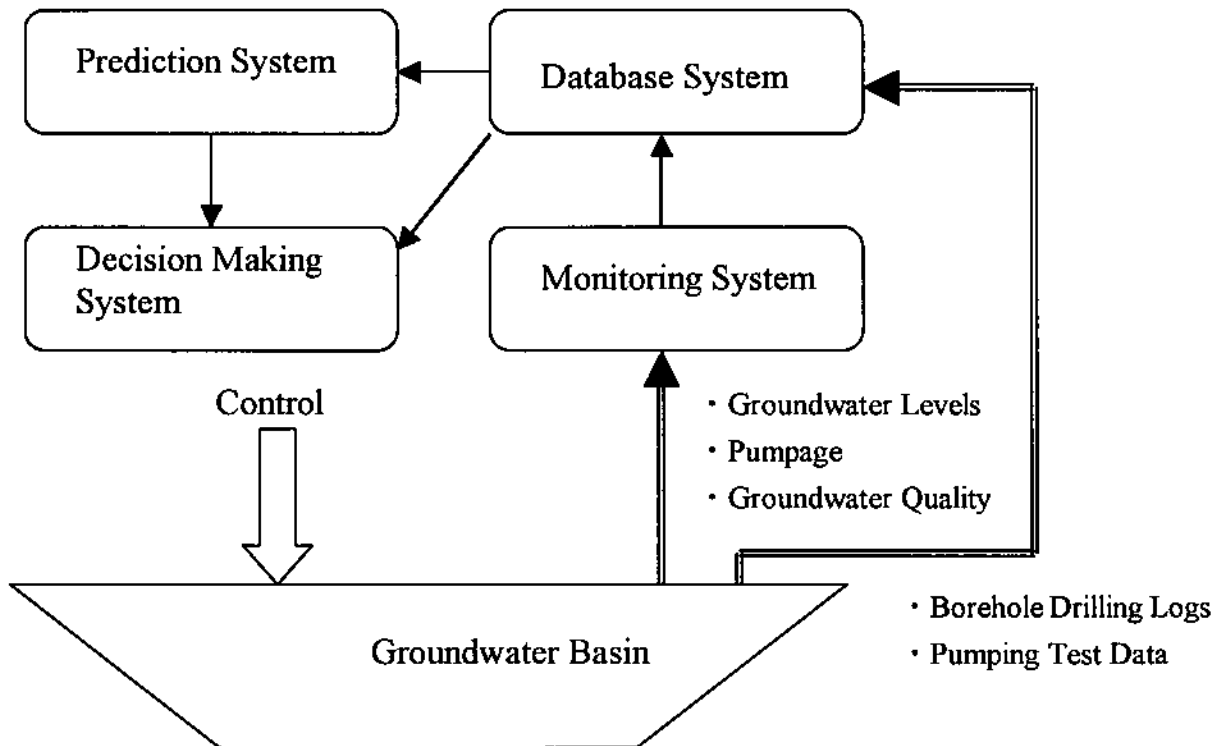


Fig. 12-2 Schematic Diagram of Groundwater Basin Management

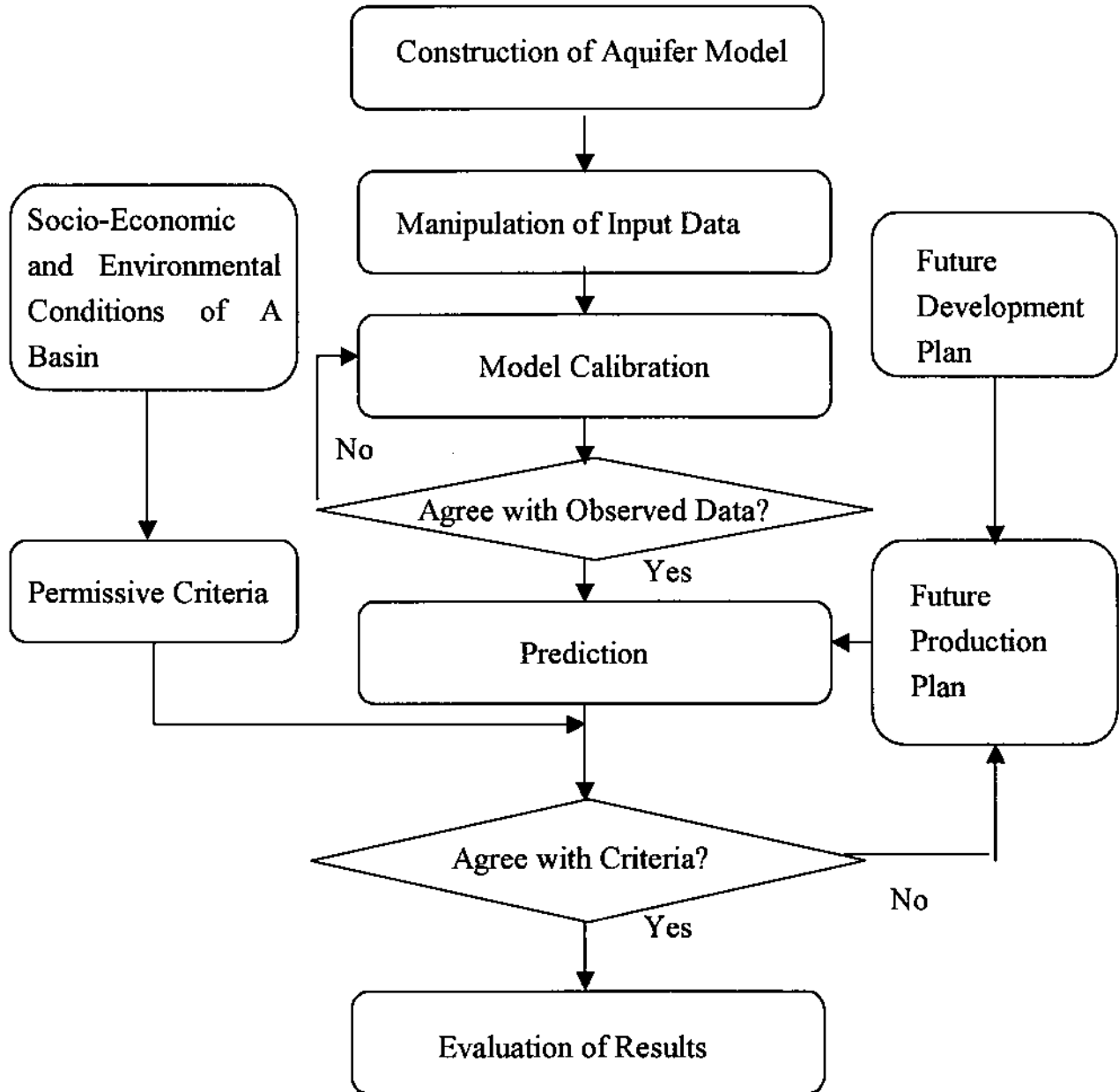
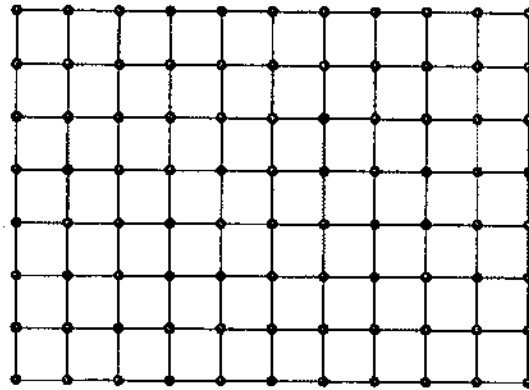
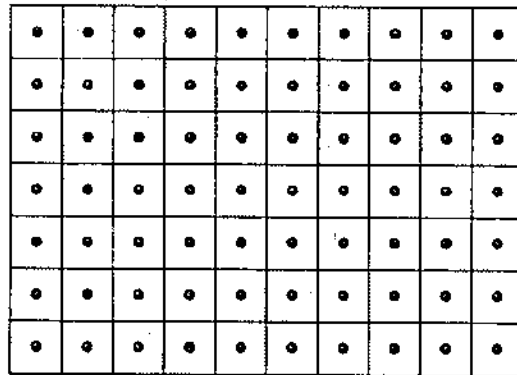


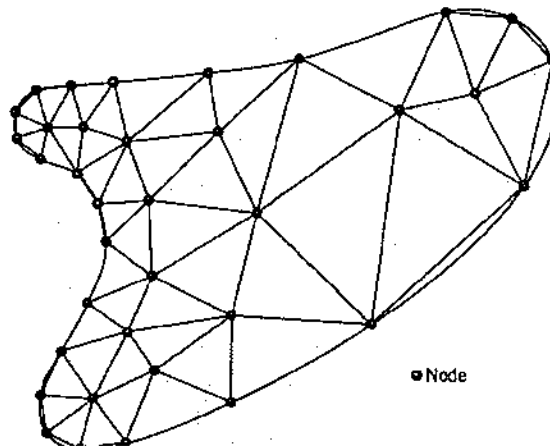
Fig. 12-3 General Procedure of Groundwater Simulation



(a)



(b)



- (a) Mesh-centered finite-difference grids
- (b) Block-centered finite-difference grids
- (c) Triangular finite-element mesh

Fig. 12-4 Finite Difference Grids and Finite Element Mesh (Domenico and Shwarts, 1998)

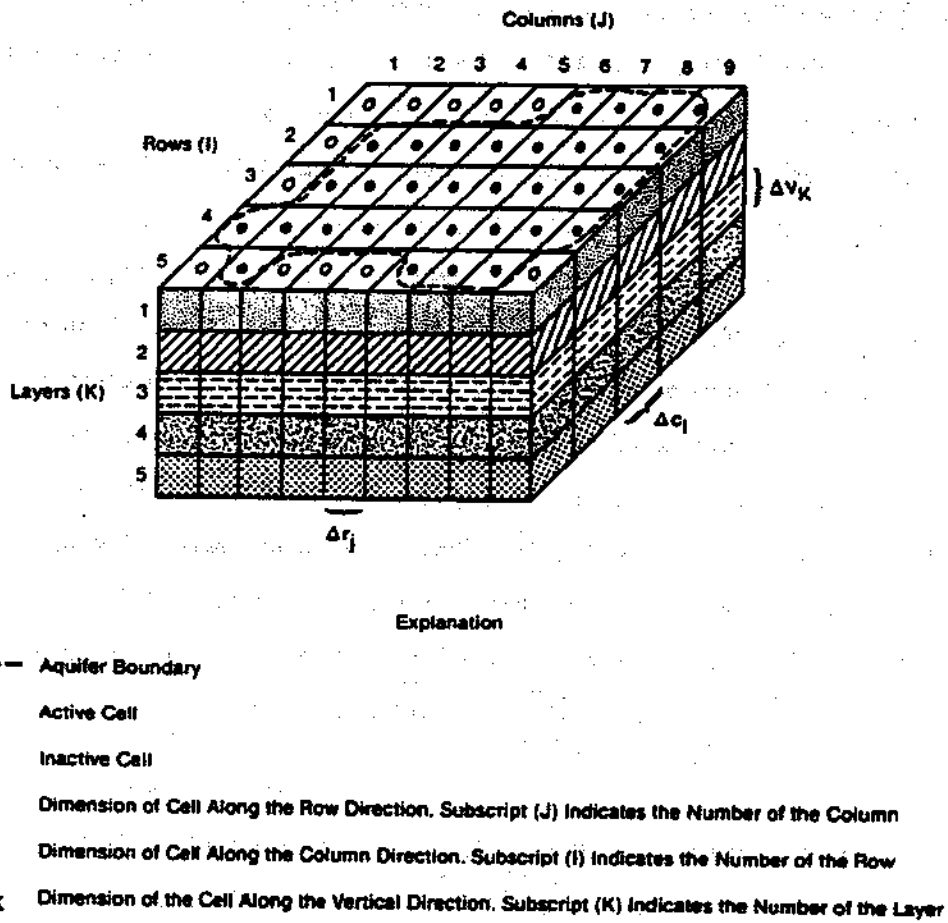


Fig. 12-5 A Discretized Hypothetical Aquifer System (Harbaugh and McDonald, 1996)

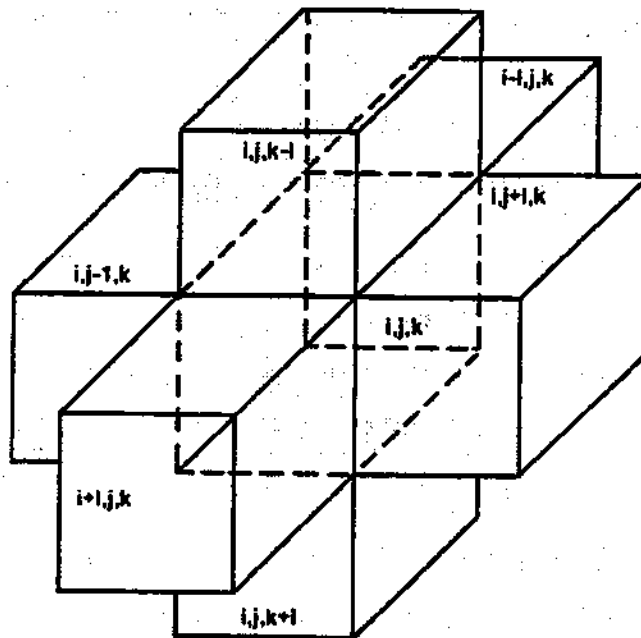


Fig. 12-6 Cell i, j, k and Indices for the Six Adjacent Cells
(Harbaugh and McDonald, 1996)

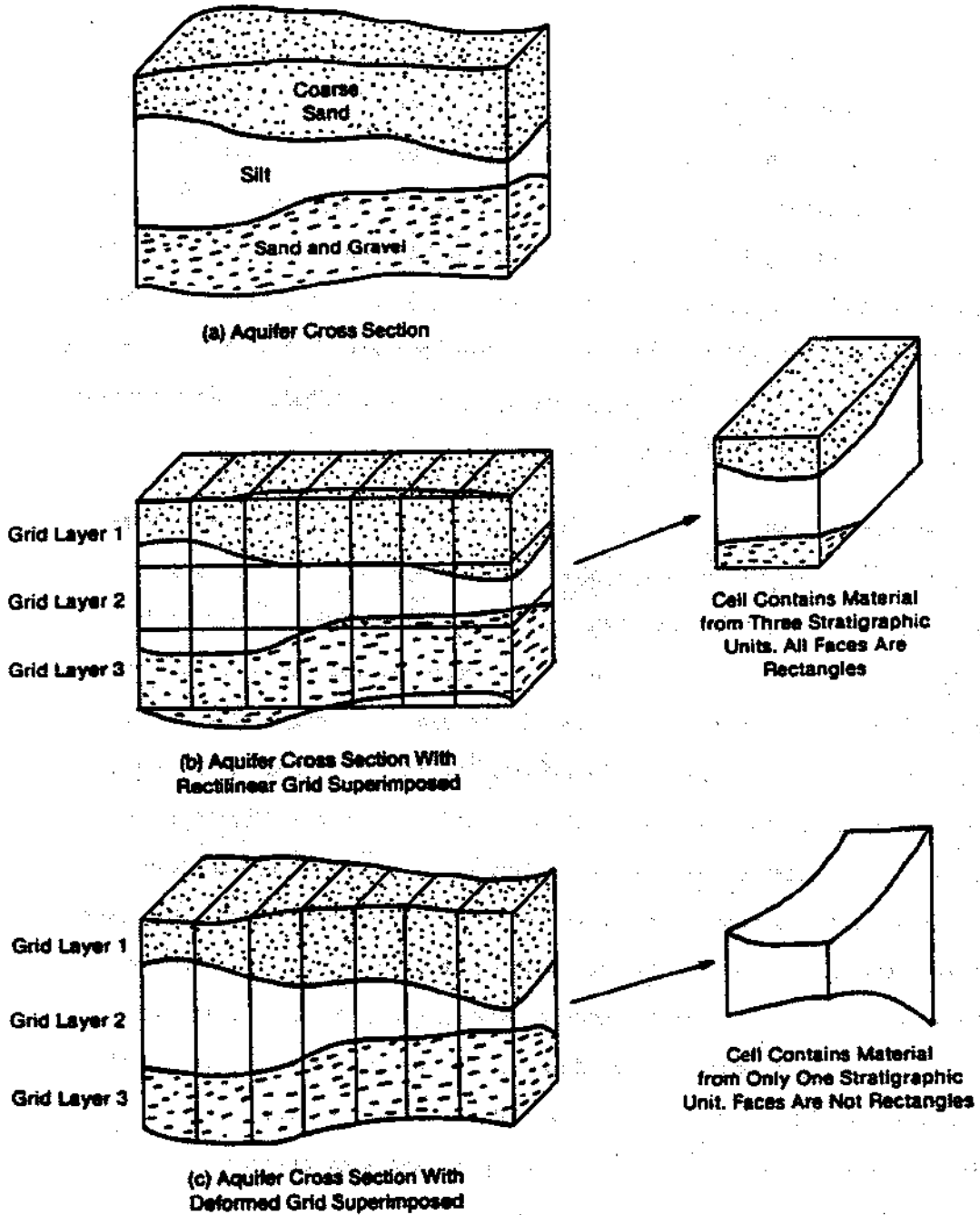


Fig. 12-7 Schemes of Vertical Discretization (Harbaugh and McDonald, 1996)

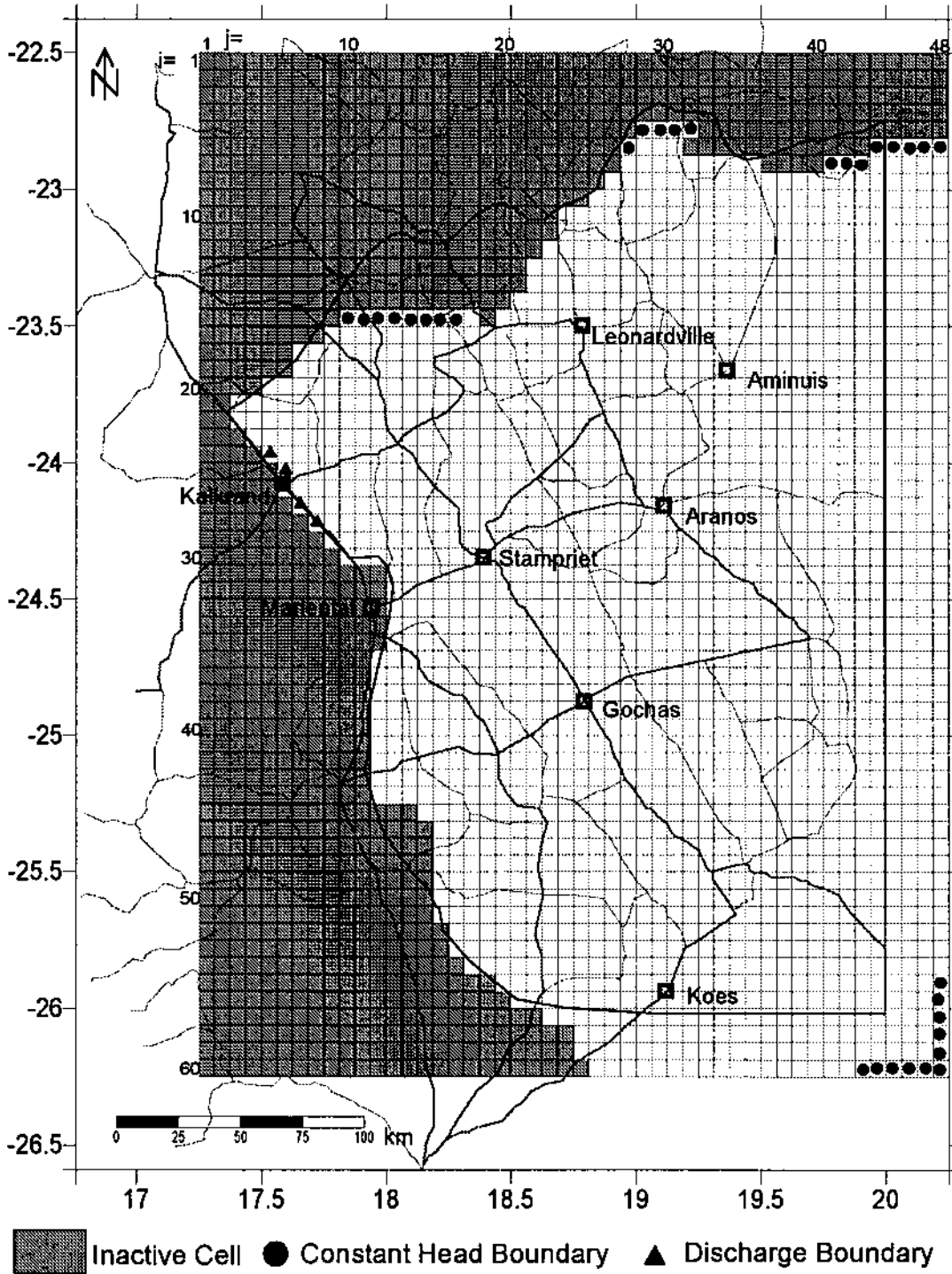


Fig. 12-8 Study Area and Finite Difference Grids

Present Grid System in Namibia

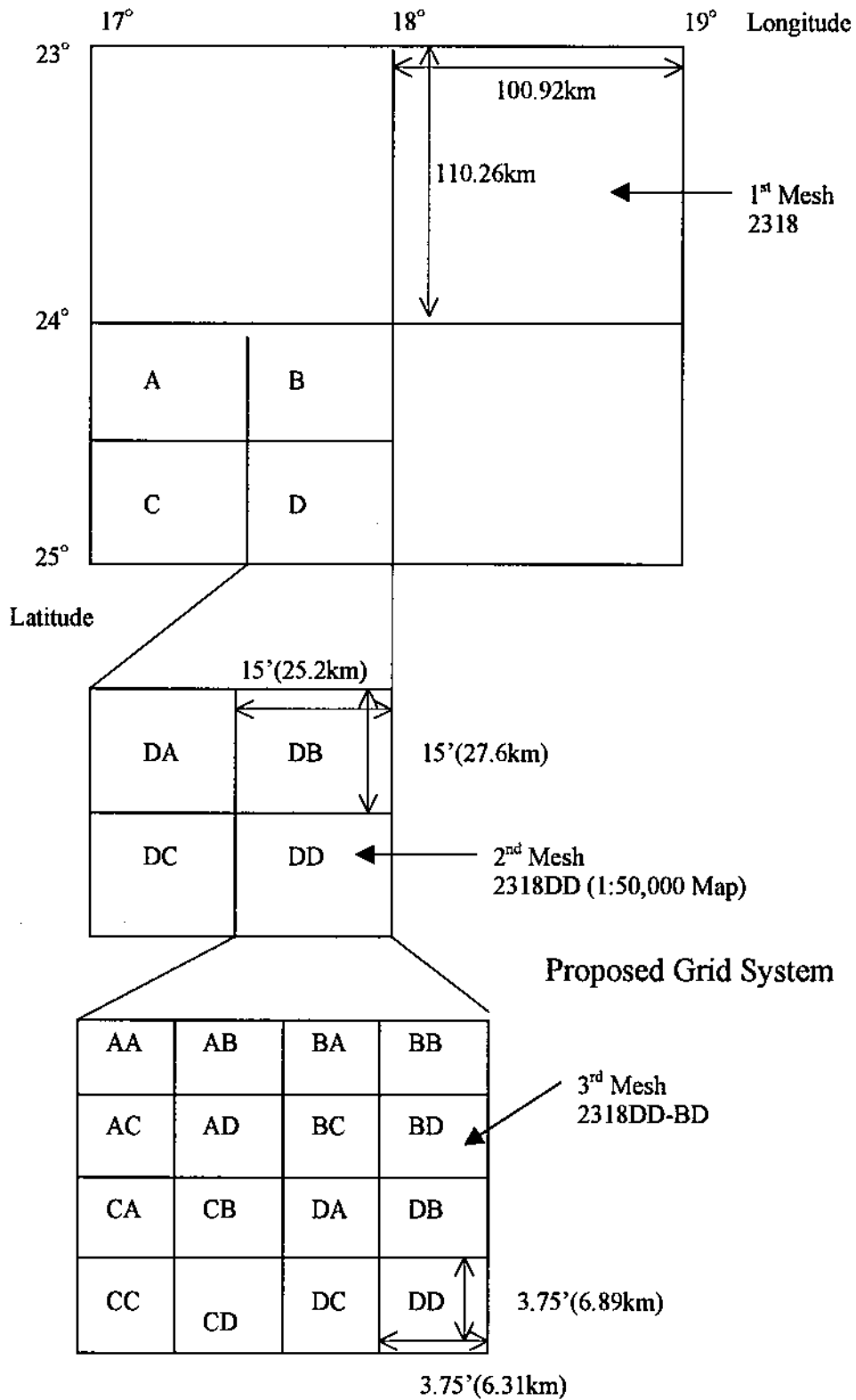
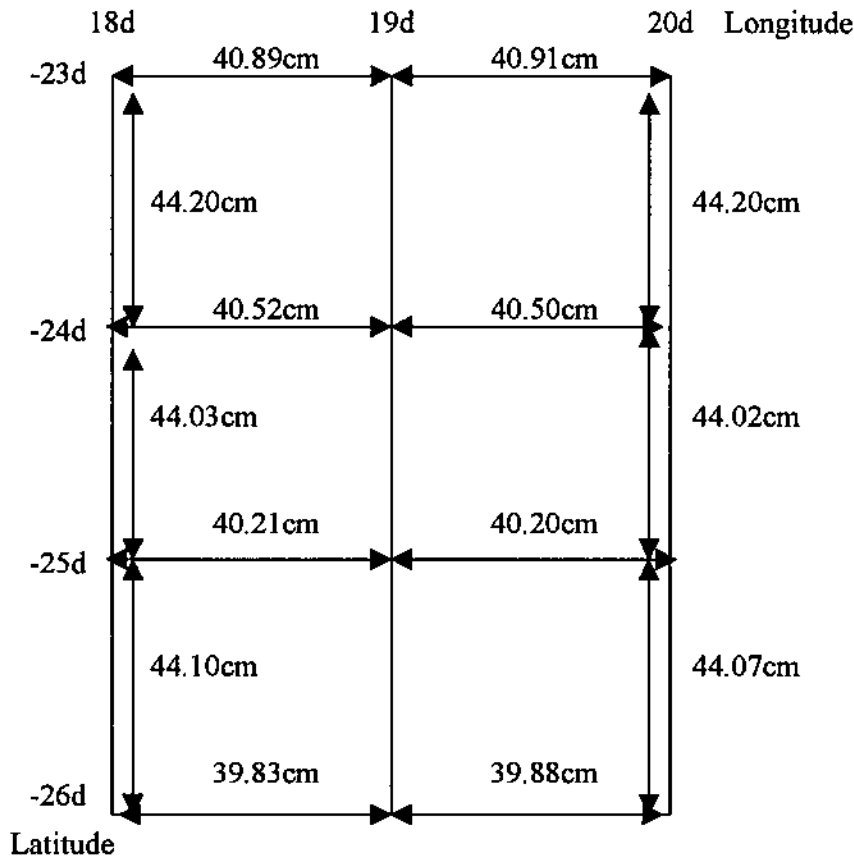


Fig. 12-9 Grid System

Size of 1:250,000 Maps



Length of 1 degree in longitude

Latitude (degrees)	Longitude 1 degree= (km)	Ratio of Length to Average (%)	Ratio of Squared Length to Average (%)
-23	102.25	101.32	102.65
-24	101.28	100.36	100.71
-25	100.51	99.59	99.19
-26	99.64	98.73	97.48
average	100.92	100.00	100.00

Length of 1 degree in Latitude

Latitude (degrees)	Latitude 1 degree=(km)	Ratio of Length to Average (%)	Ratio of Squared Length to Average (%)
-23 to -24	110.50	100.22	100.44
-24 to -25	110.06	99.82	98.64
-25 to -26	110.21	99.95	99.91
average	110.26	100.00	100.00

Fig. 12-10 Estimation of Cell Size Error

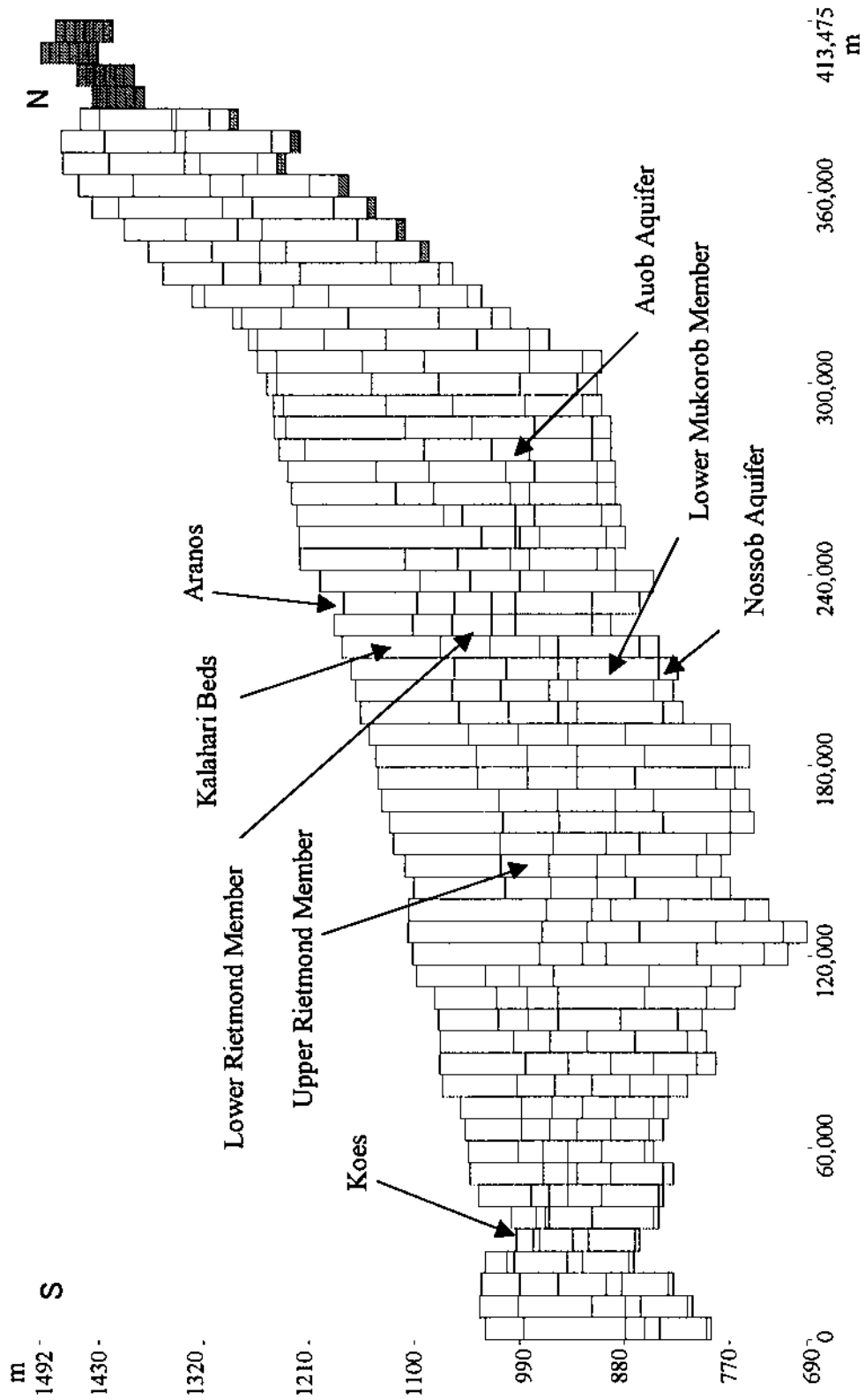


Fig. 12-11 N-S Cross Section at Column 30

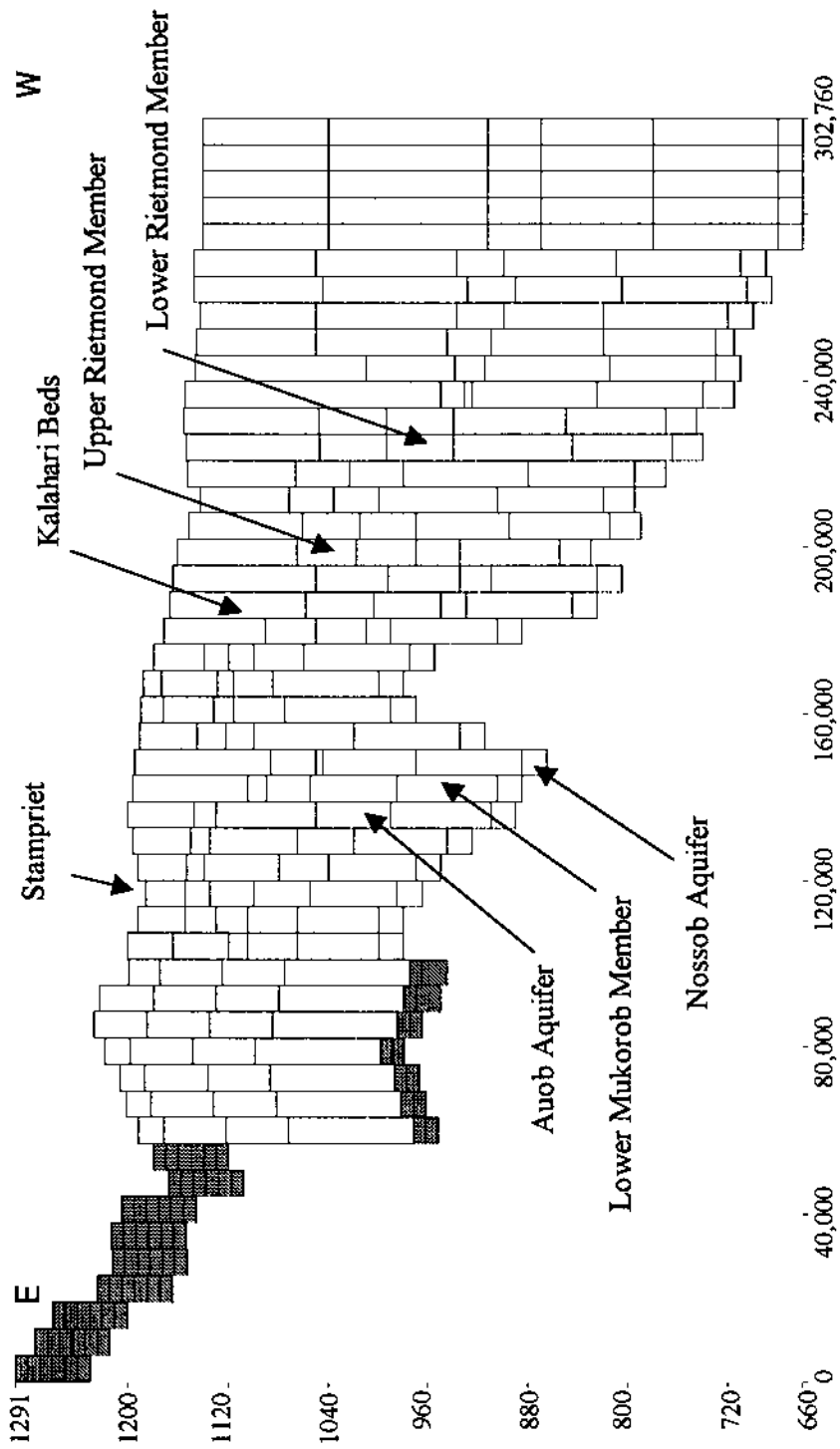


Fig. 12-12 E-W Cross Section at Row 30

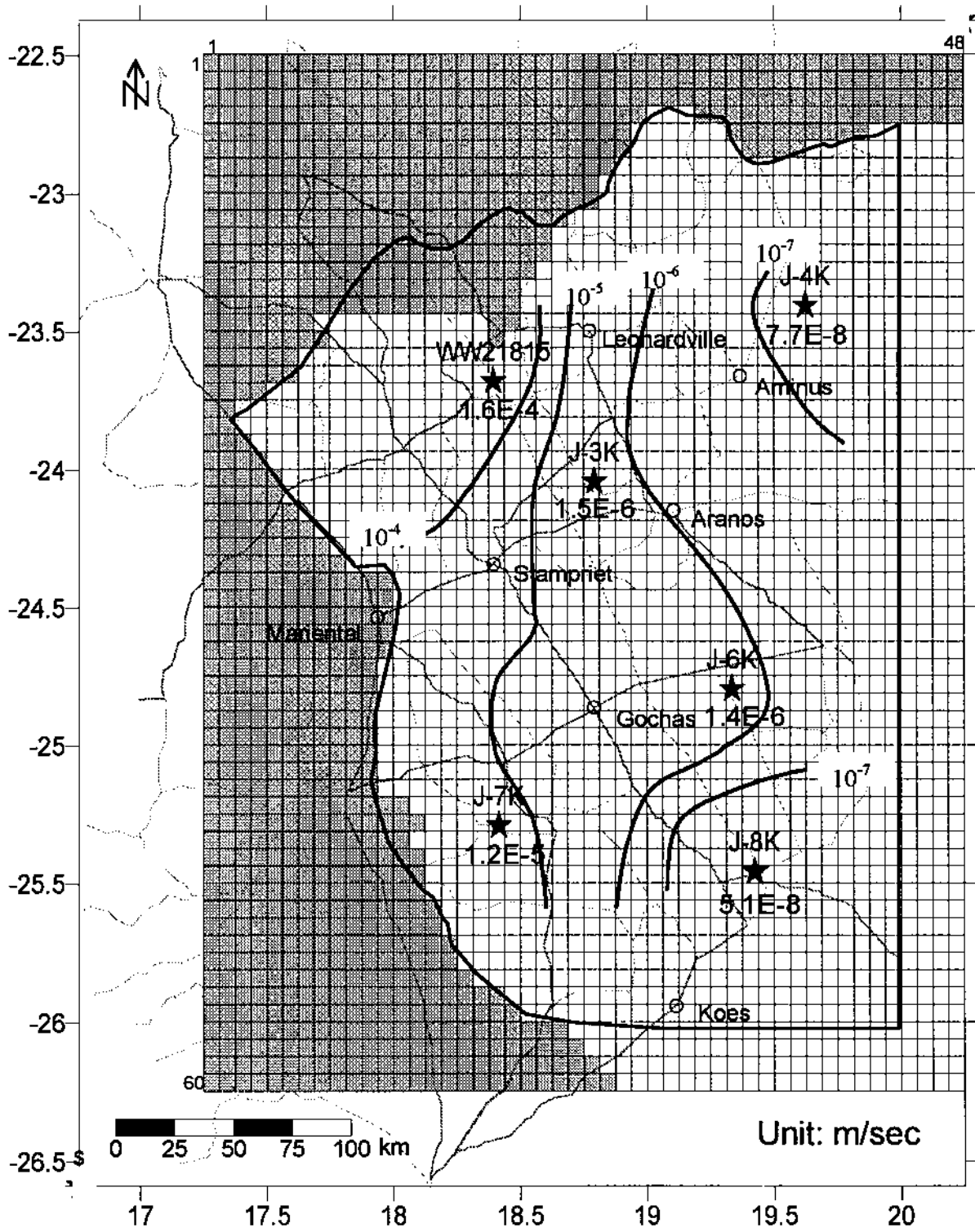


Fig. 12-13 Distribution of Permeability of the Kalahari Aquifer

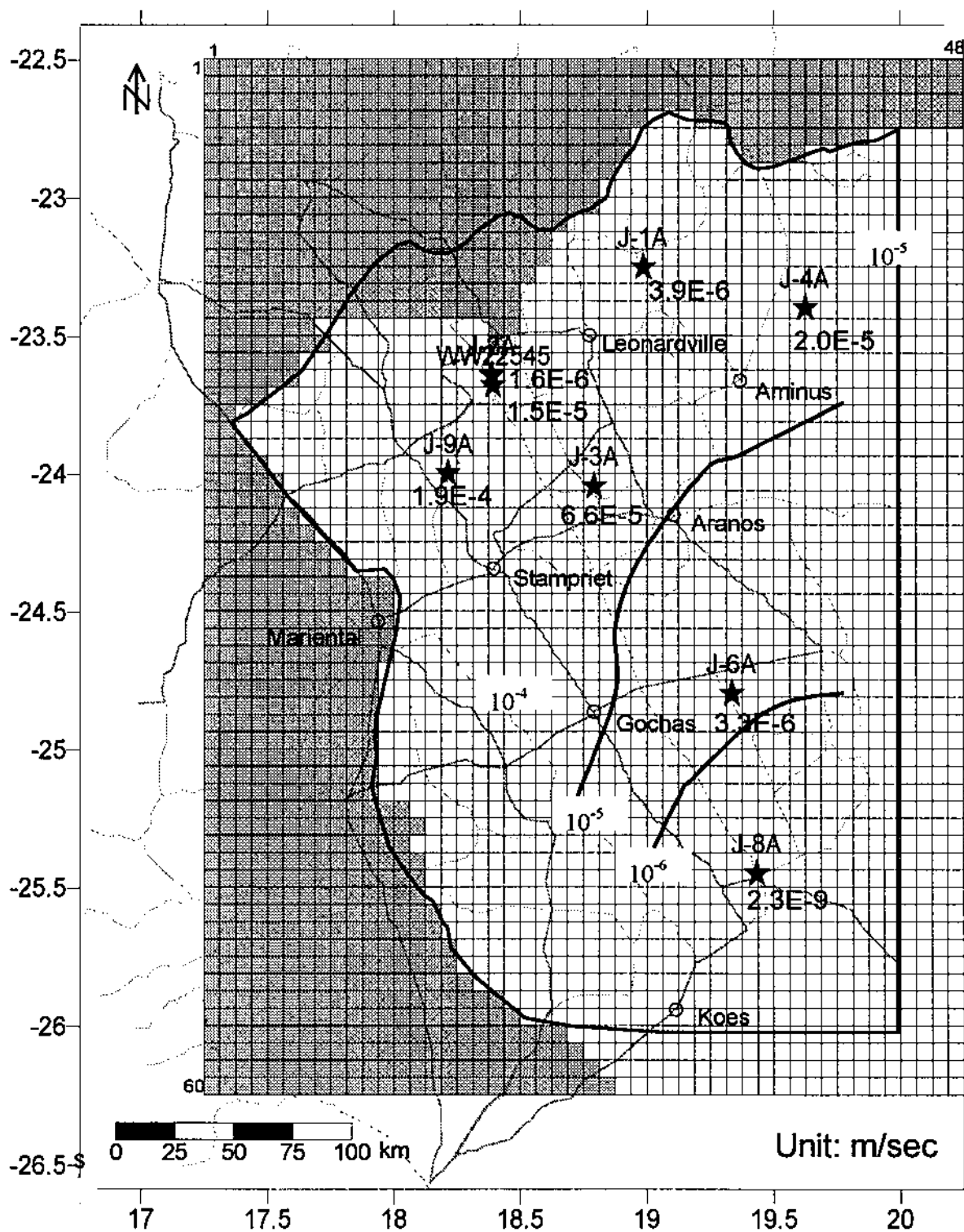


Fig. 12-14 Distribution of Permeability of the Auob Aquifer

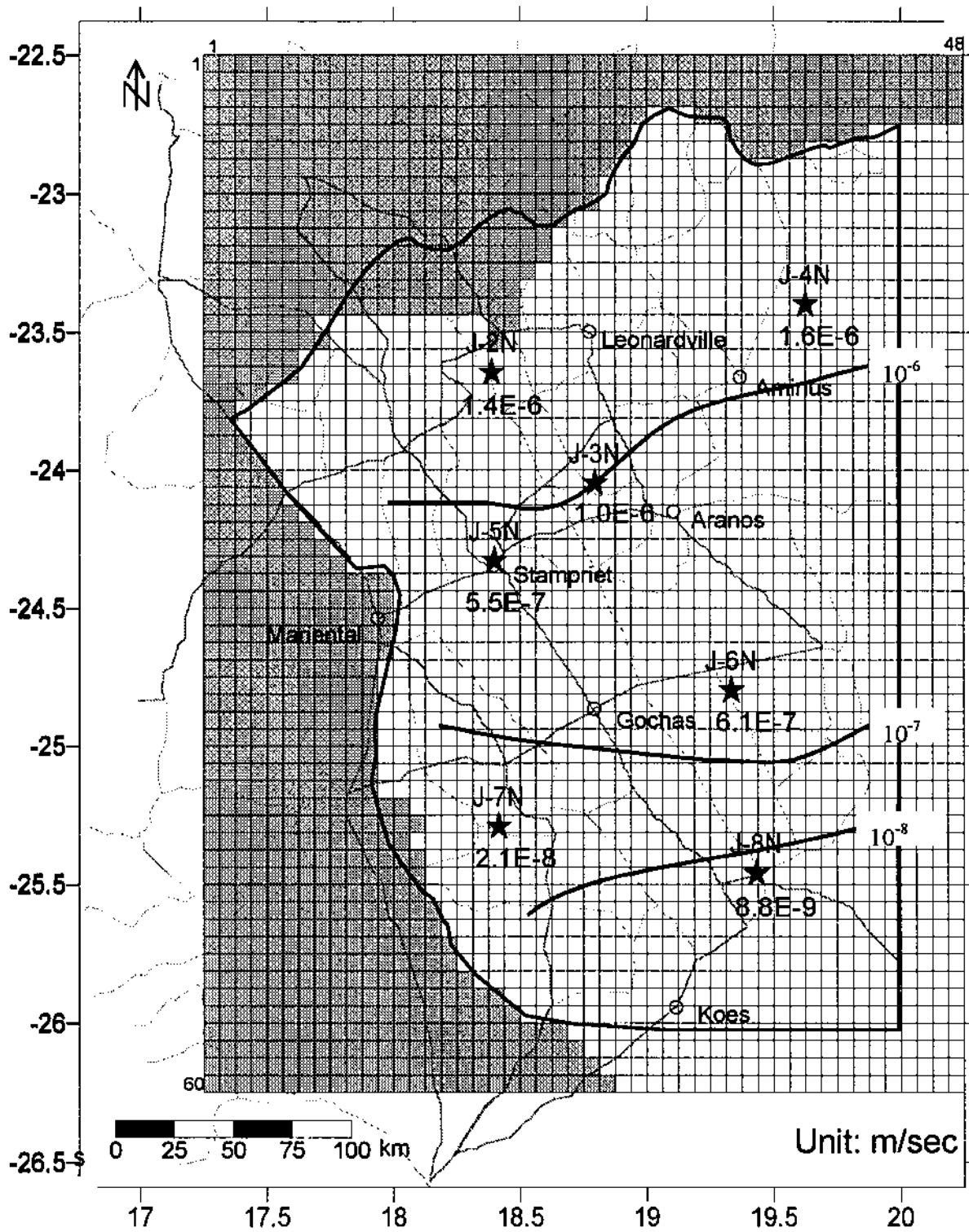


Fig. 12-15 Distribution of Permeability of the Nossob Aquifer

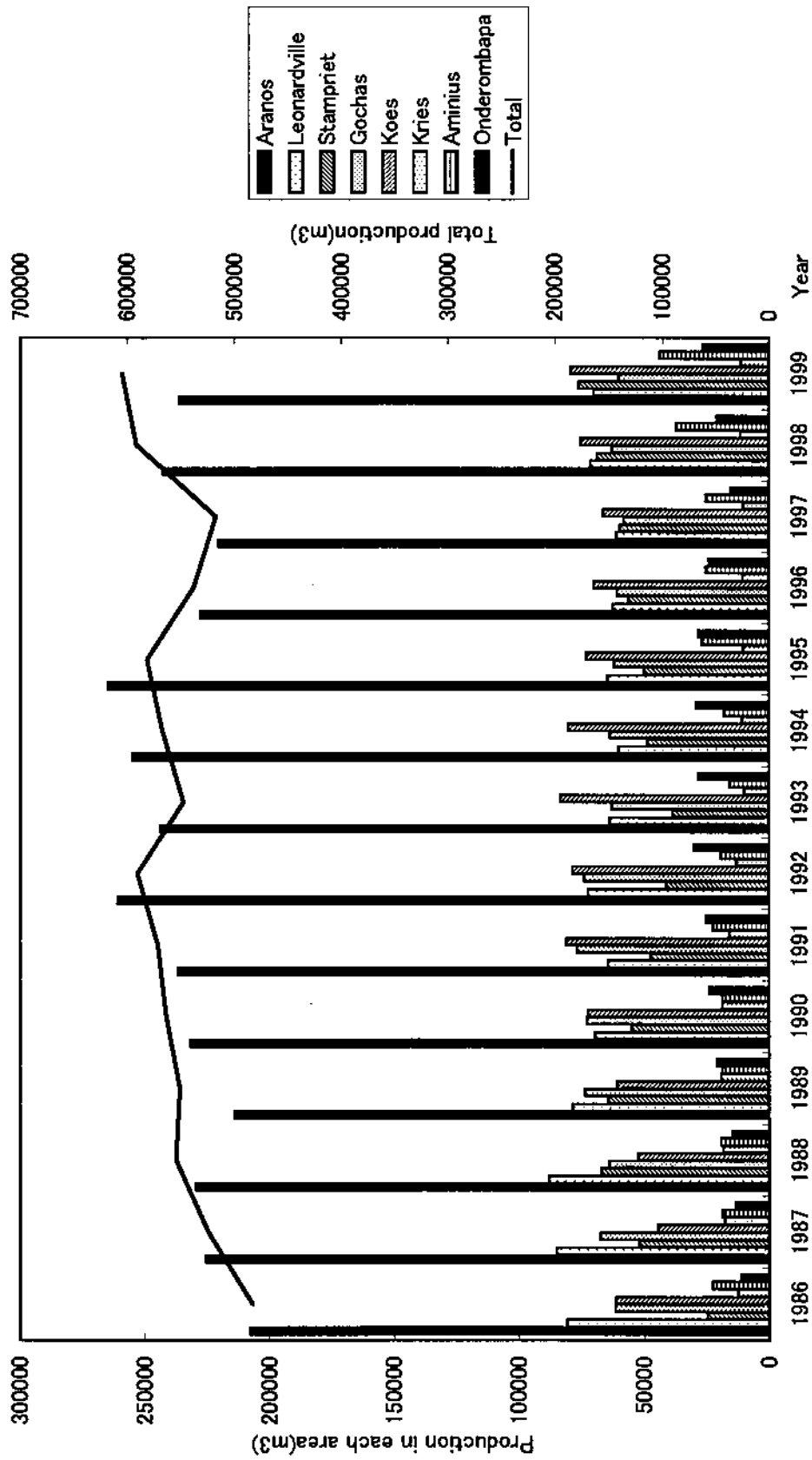


Fig. 12-16 NamWater Scheme Productions

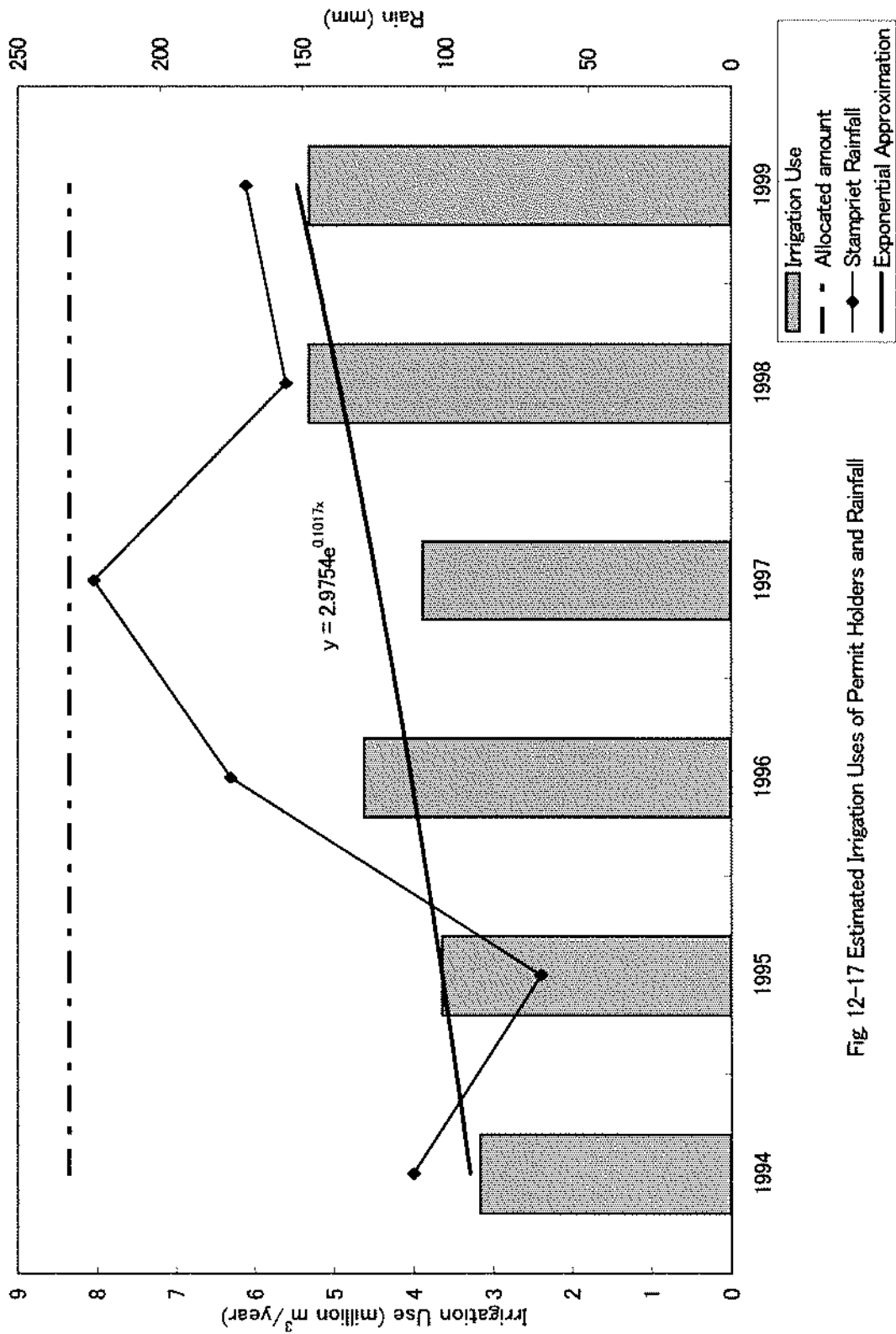


Fig 12-17 Estimated Irrigation Uses of Permit Holders and Rainfall

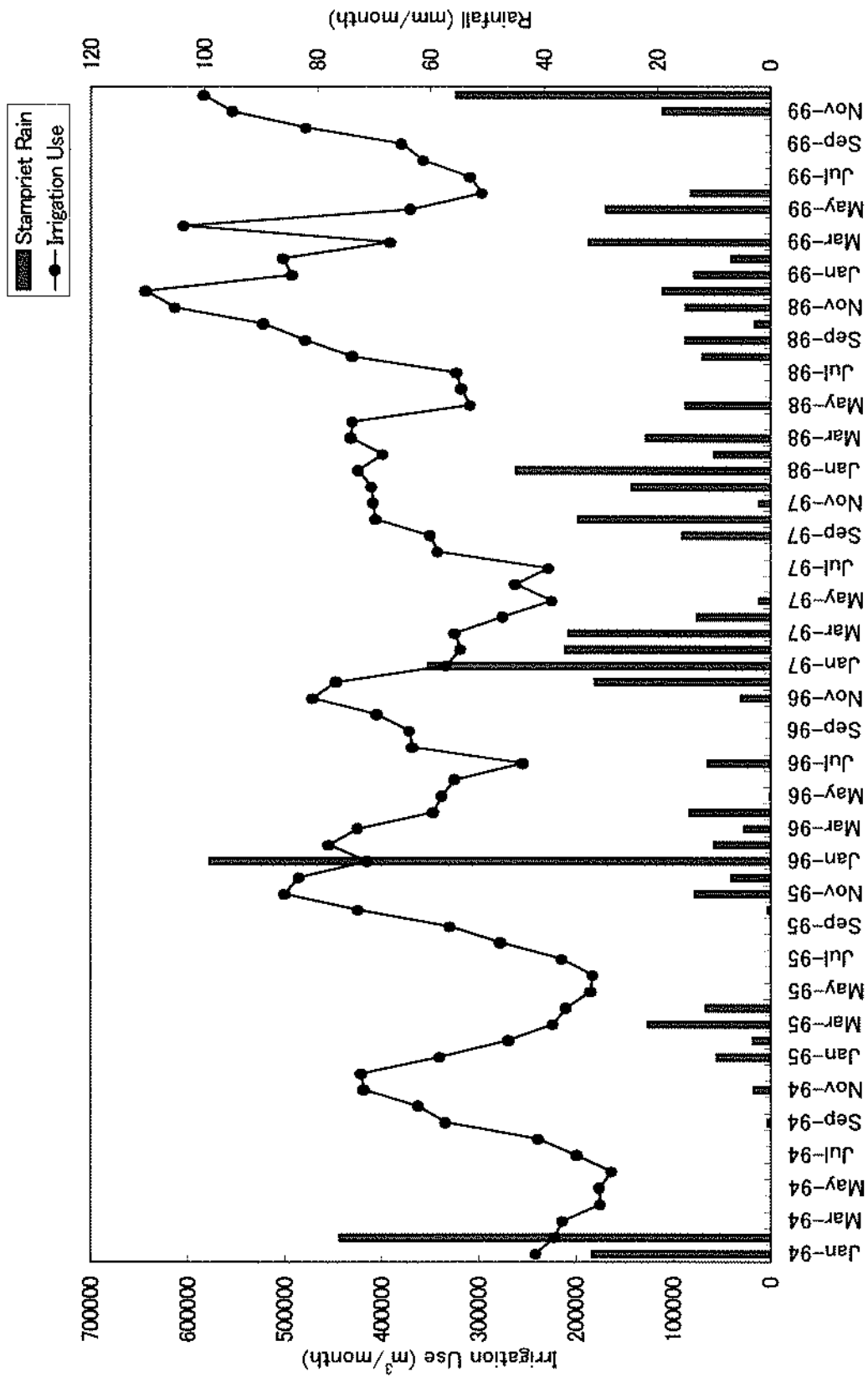


Fig. 12-18 Monthly Estimated Irrigation Uses of Permit Holders and Rainfall

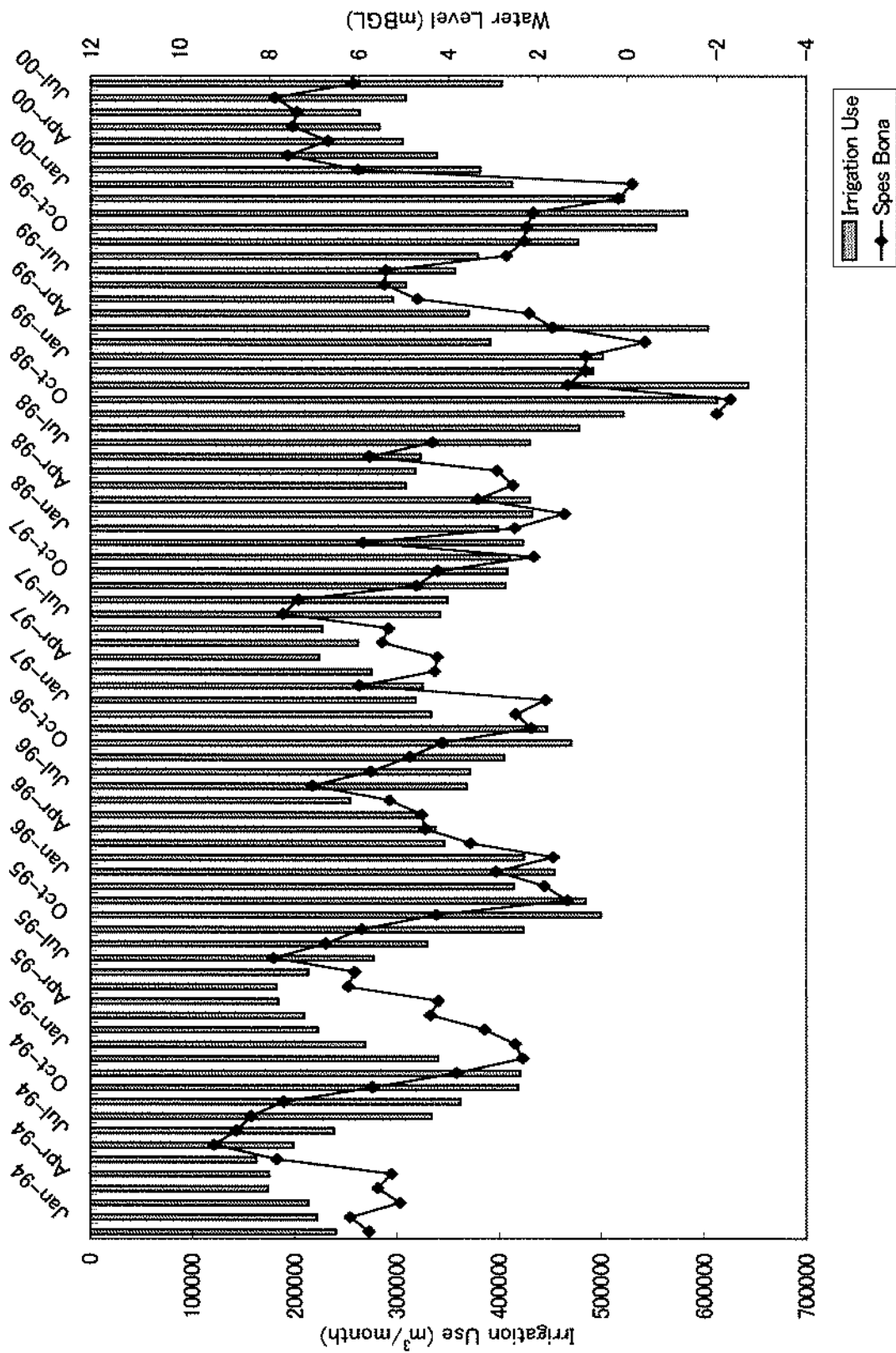


Fig. 12-19 Estimated Irrigation Uses of Permit Holders and Water Level of Spes Bona

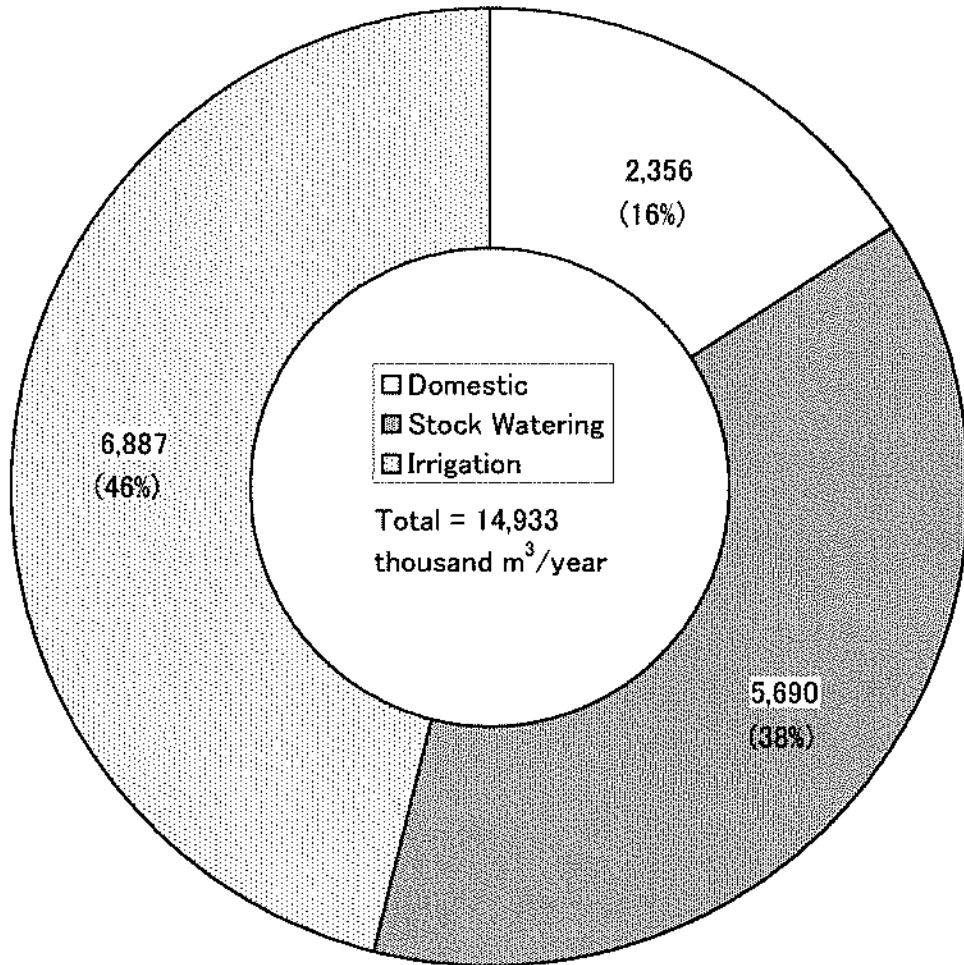


Fig. 12-20 Present Groundwater Use in the Study Area

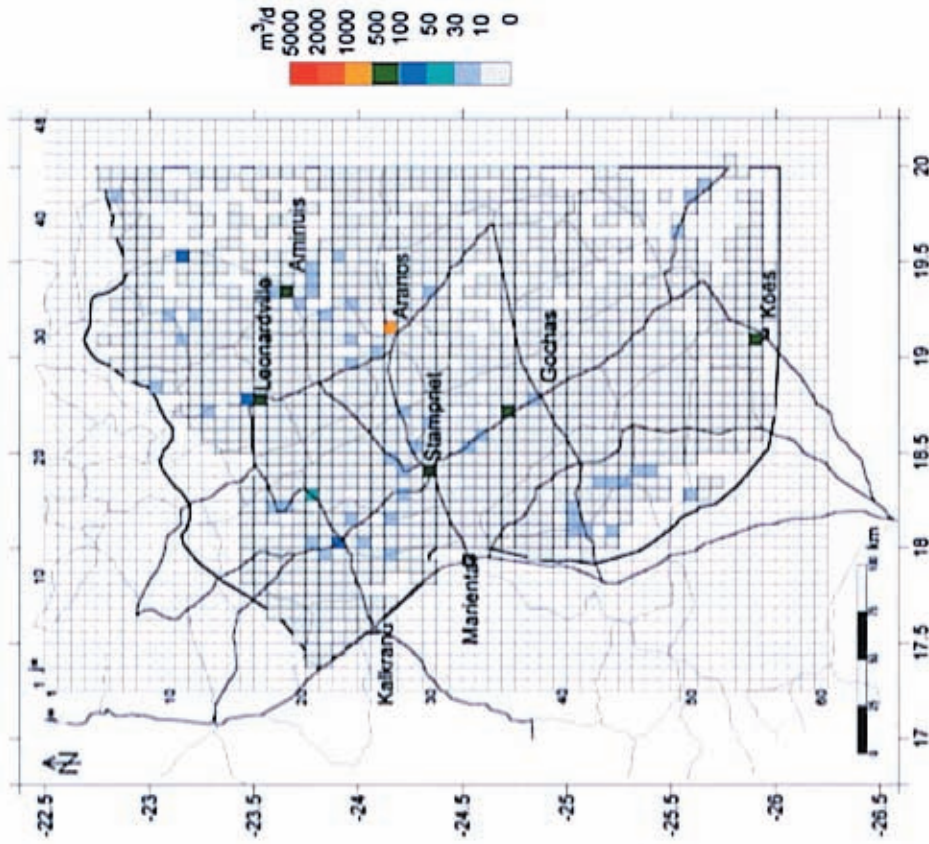


Fig. 12-22 Distribution of Domestic Use in 1999

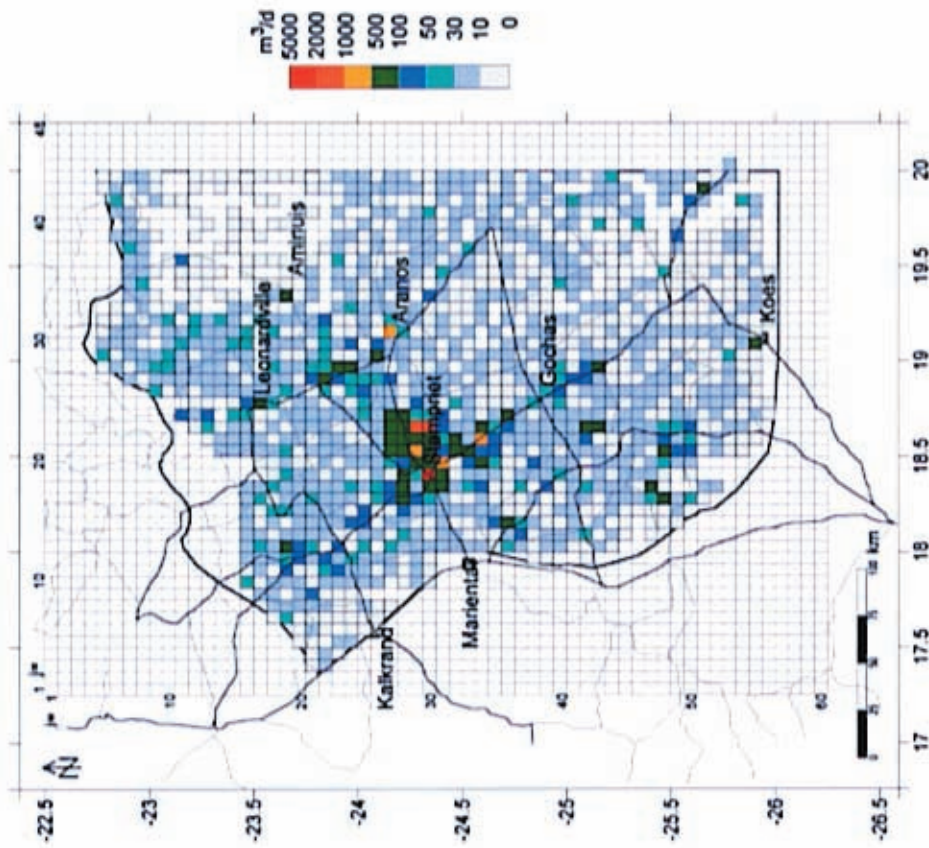


Fig. 12-21 Distribution of Groundwater Use in 1999

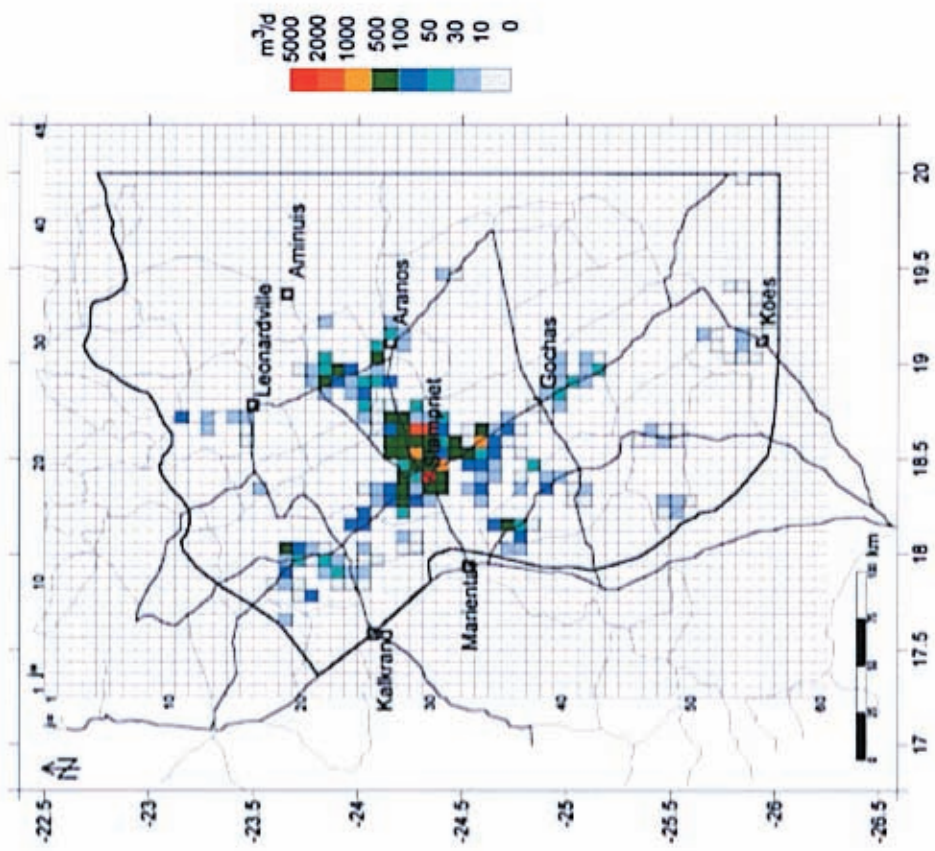


Fig. 12-23 Distribution of Stock Watering Use in 1999

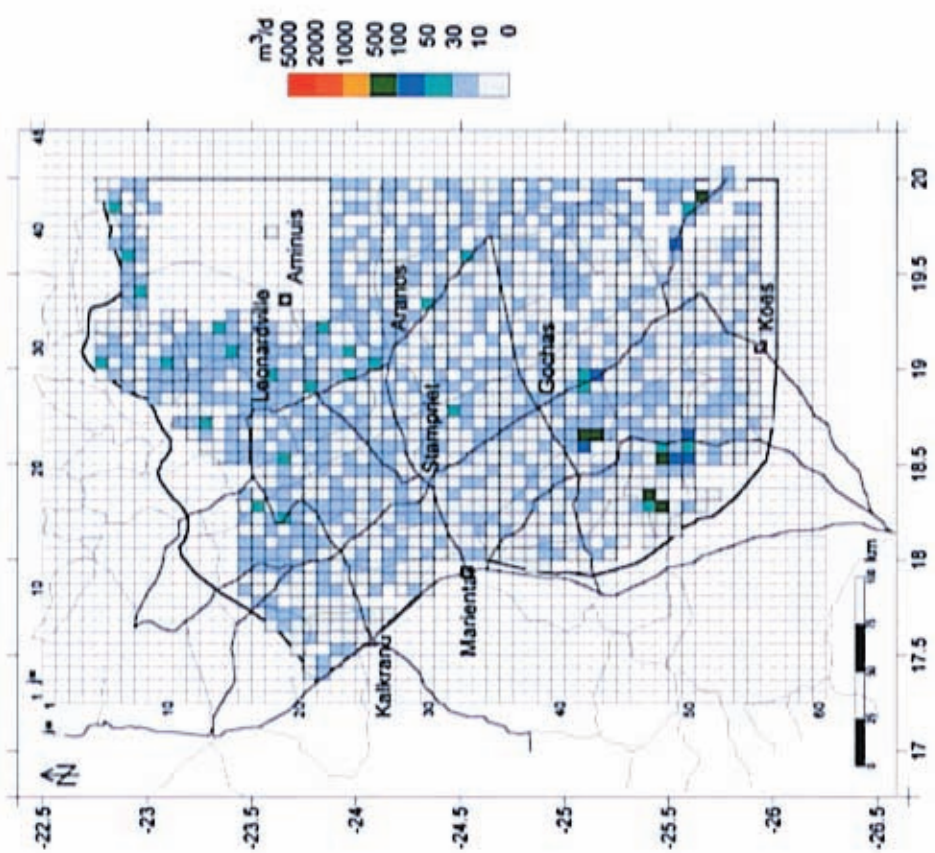


Fig. 12-24 Distribution of Irrigation Use in 1999

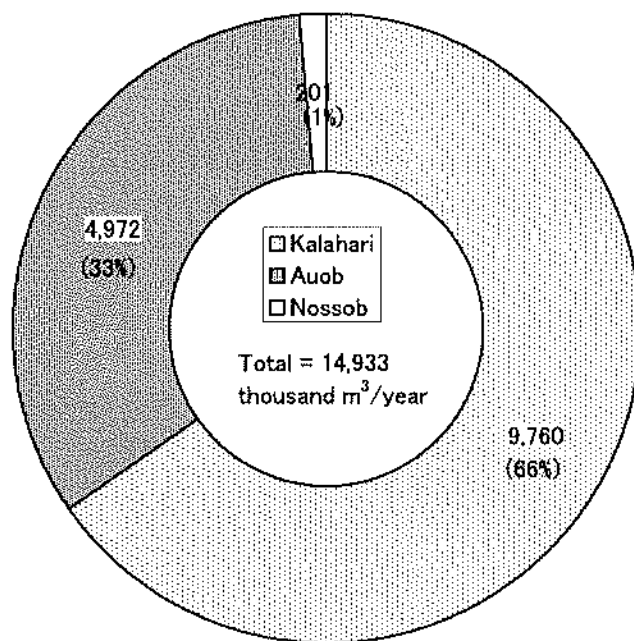


Fig. 12-25 Present Groundwater Use by Aquifer

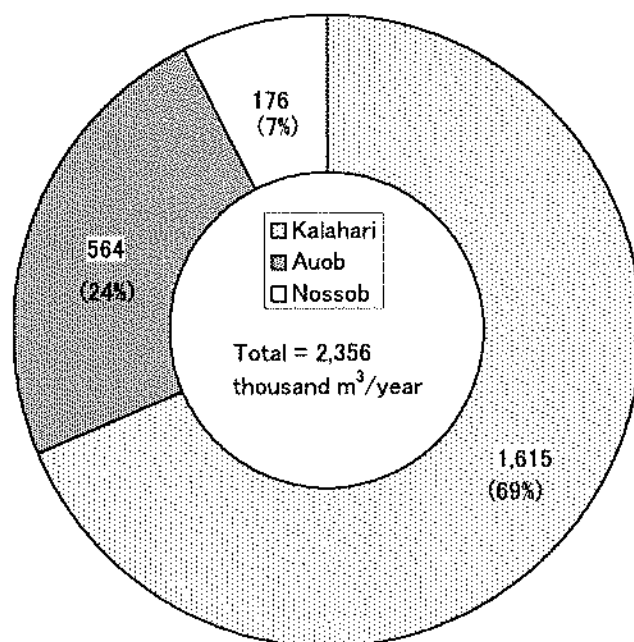


Fig. 12-26 Domestic Use by Aquifer in 1999

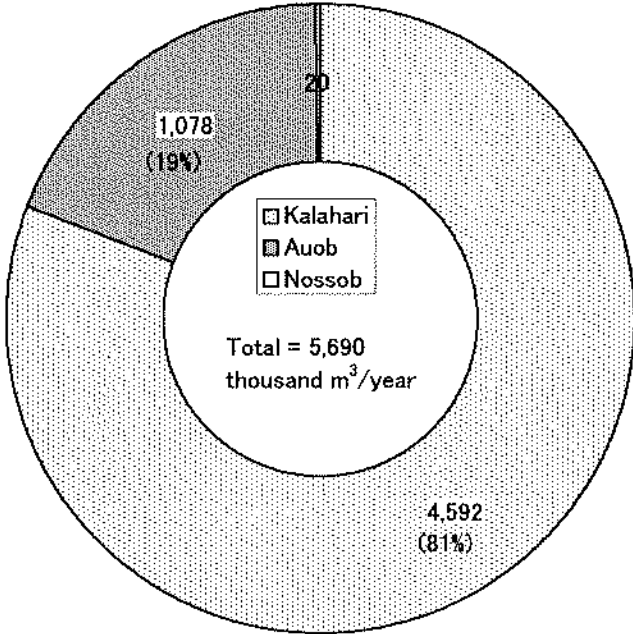


Fig. 12-27 Stock Watering Use by Aquifer in 1999

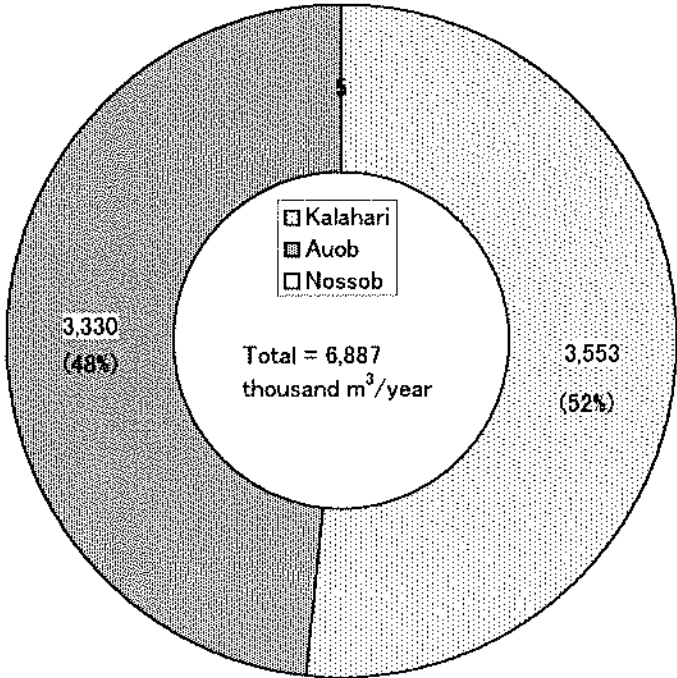


Fig. 12-28 Irrigation Use by Aquifer in 1999

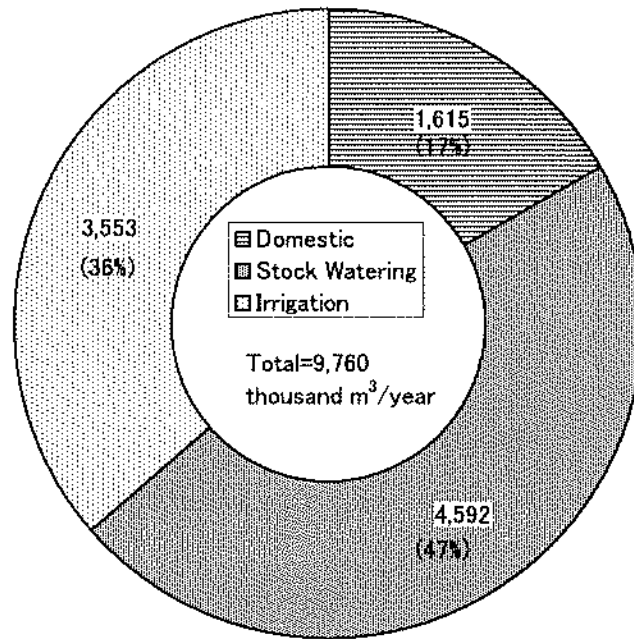


Fig. 12-29 Groundwater Use in Kalahari Aquifer in 1999

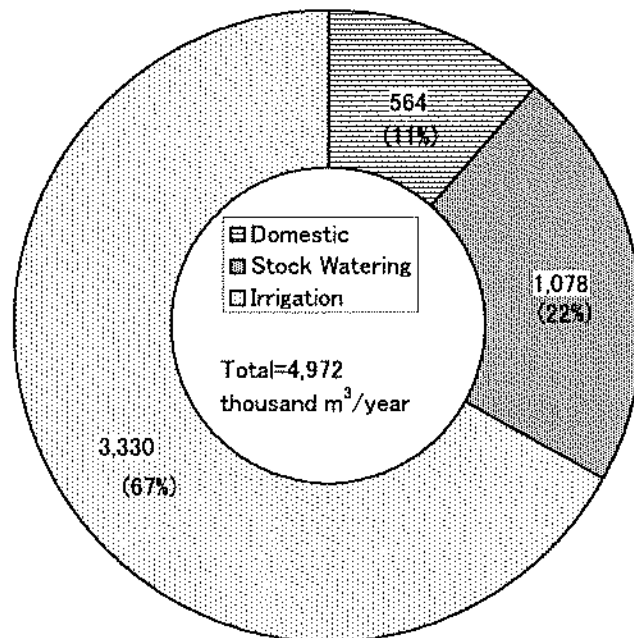


Fig. 12-30 Groundwater Use in Auob Aquifer in 1999

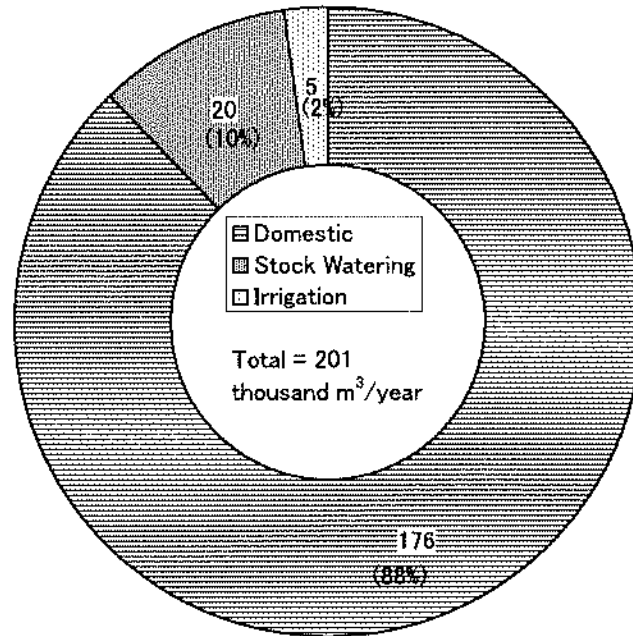


Fig. 12-31 Groundwater Use in Nossob Aquifer in 1999