Chapter 9. Saturated Hydraulic Conductivity

9.1 Saturated Hydraulic Conductivity (Ksat) of Horizon A

Ksat of Horizon A was measured at 336 points across 79 sites. Results are summarised in Table 9.1. It appears that average Ksat decreases from Group 1 to Group 6 excluding Groups 2 and 5. Average Ksat of Group 2 was lower than Group 3 even though Group 2 generally has less clay content than Group 3. On the other hand, Group 5 has higher average Ksat than Groups 2, 4 and 6 even though Group 5 has the highest clay content among all the groups. The higher Ksat of Group 5 could be due to its lower average bulk density. Ksat of Groups 1 and 3 has larger standard deviations compared to other soil groups. Figure 9.1 shows the frequency distribution of Ksat of Horizon A of soils of the SIR. The distribution of Ksat is skewed toward lower values of Ksat.

Table 9.1 Saturated Hydraulic Conductivity of Horizon A

Soil Group	No of Sites	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
			Avg.	Std.	Min.	Max.	Percentile		
							25	50	75
1	11	73	58.6	62.5	10.3	366.9	27.5	39.3	64.2
2	19	112	27.3	18.9	3.9	109.1	14.3	23.3	34.4
3	24	82	44.2	31.3	4.2	143.3	20.8	37.2	60.3
4	11	33	26.1	16.5	5.0	74.8	14.6	23.2	33.1
5	6	14	36.3	20.3	14.4	82.5	23.6	30.3	40.4
6	8	22	21.5	15.5	4.0	55.9	10.8	14.4	30.5

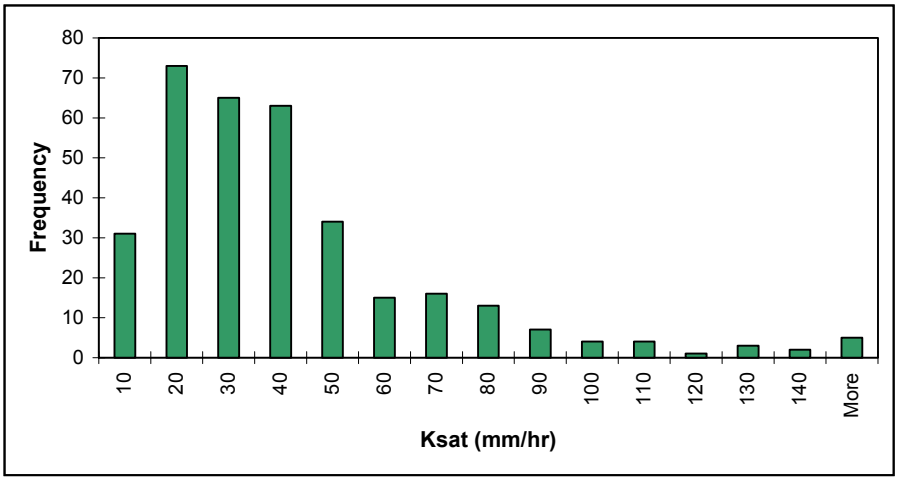

Figure 9.1 Histogram of Saturated Hydraulic Conductivity of Horizon A of Soils of SIR

9.1.1 Ksat of Soil Groups

A box and whisker plot of Ksat data of Horizon A is presented in Figure 9.2 to show the distribution of Ksat data within soil groups. For Groups 2, 4, 5 and 6, the bands between upper and lower quartiles are relatively narrow, suggesting that the average values could be used as indicative values for the respective soils for practical applications. In comparison, Groups 1 and 3 have much larger bands between upper and lower quartiles, and therefore their average values are much less useful for practical applications.

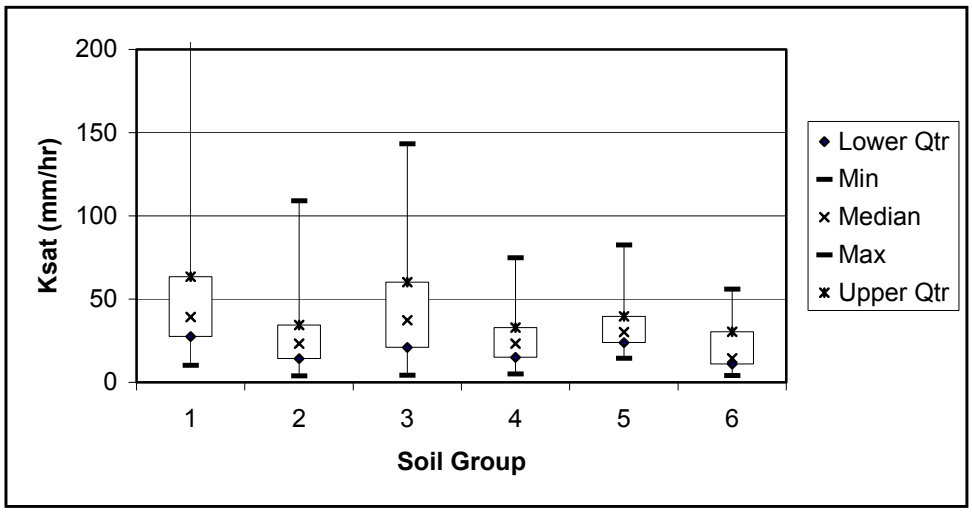

Figure 9.2 Saturated Hydraulic Conductivity of Horizon A

9.1.2 Ksat of Soil Groups of Irrigation Districts

Table 9.2 shows Ksat of Horizon A for the soil groups of three irrigation districts. Average Ksat values of Horizon A for soil groups of three districts are plotted in Figure 9.3. The average Ksat value of Group 1 in the MV District is significantly higher than the values of Group 1 of the other two districts. This is due to large proportion of Sandmount sand soil in Group 1 of the MV District, which contains more than 90% sand. In contrast, Groups 2, 3 and 6 of the MV District have the lowest average Ksat values among three districts.

Table 9.2 Saturated Hydraulic Conductivity of Horizon A of Irrigation Districts

Irrigation District	Soil Group	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
			Avg.	Std.	Min.	Max.	Percentile		
							25	50	75
MV	**1**	10	118.1	142.6	17.8	366.9	24.3	36.4	250.6
	2	36	20.9	12.0	4.4	49.9	11.2	16.6	29.9
	3	10	19.8	11.0	6.6	39.4	12.8	17.3	23.1
	4*	*	*	*	*	*	*	*	*
	5	2	44.8		37.2	52.5			
	6	12	14.2	9.9	4.8	42.7	8.4	11.8	15.5
GV	**1**	14	58.7	38.4	10.3	143.3	27.2	49.0	80.9
	2	58	27.3	15.9	3.9	67.4	14.5	24.5	34.6
	3	54	47.8	32.7	4.3	143.3	26.0	41.5	67.0
	4	24	25.9	15.3	5.0	64.4	14.2	24.5	32.5
	5	5	37.1	20.6	23.6	72.6	24.1	28.0	45.9
	6	4	41.1	11.6	30.5	55.9	31.9	38.9	50.2
RO	**1**	49	46.4	27.5	10.3	130.5	28.1	38.2	61.0
	2	18	40.1	30.3	9.4	109.1	19.2	29.5	45.0
	3	18	46.8	29.1	12.0	120.7	26.3	36.4	72.6
	4	9	26.7	20.4	9.8	74.8	14.7	17.4	35.5
	5	7	33.2	23.6	14.4	82.5	17.4	24.6	38.4
	6	6	23.0	16.5	4.0	49.6	12.8	20.7	30.1

Note: * No soil is defined under Group 4 of MV District in the existing soil maps

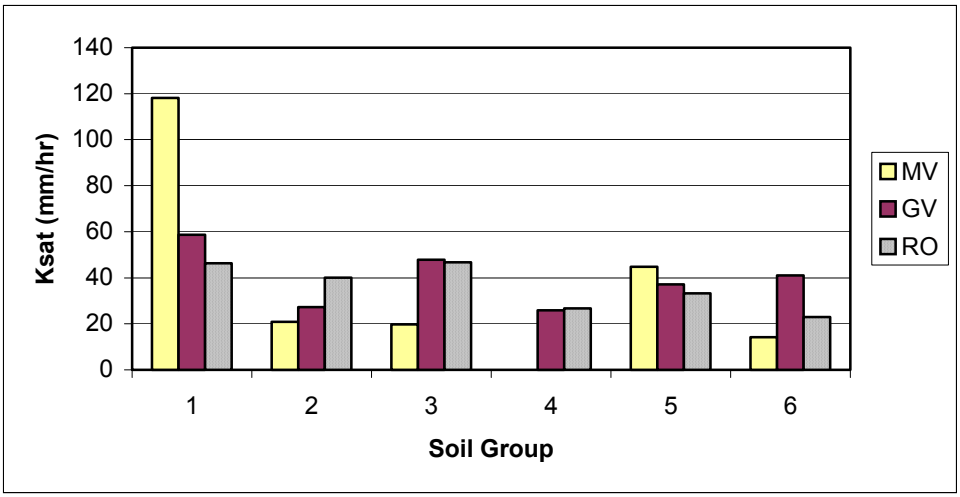

Figure 9.3 Average Saturated Hydraulic Conductivity of Horizon A of Irrigation Districts

9.1.3 Ksat of Soil Types

Table 9.3 shows Ksat of Horizon A for 34 soil types of the MV, GV, and RO Districts. Sandmount sand of Group 1 has the highest and Boosey loam friable phase of Group 6 has the lowest average Ksat among all soil types.

To understand the sources of the within-soil-group variability, Ksat data of Horizon A of a selected number of soil types are presented in Figure 9.4. It shows that for Groups 1 and 3, both between-soil-type variability and within-soil-type variability contributed to the large within-soil-group variability. In Group 1, the non duplex Ss soil type has significantly higher Ksat values than other duplex soil types. Group 1 can be subdivided into Ss soil type and other duplex soil types. Soil types of Group 3 such as Ll cover a very large area. During the 1970s, soil survey was re-conducted in part of the GV District near Kyabram, and the Ll soil type was subdivided into Llfp, Llsfp and Ll soil types. The Llsfp soil type has significantly higher Ksat than Llfp and Ll soil types. However, there was no significant difference observed between the Ksat of Ll and Llfp soil types.

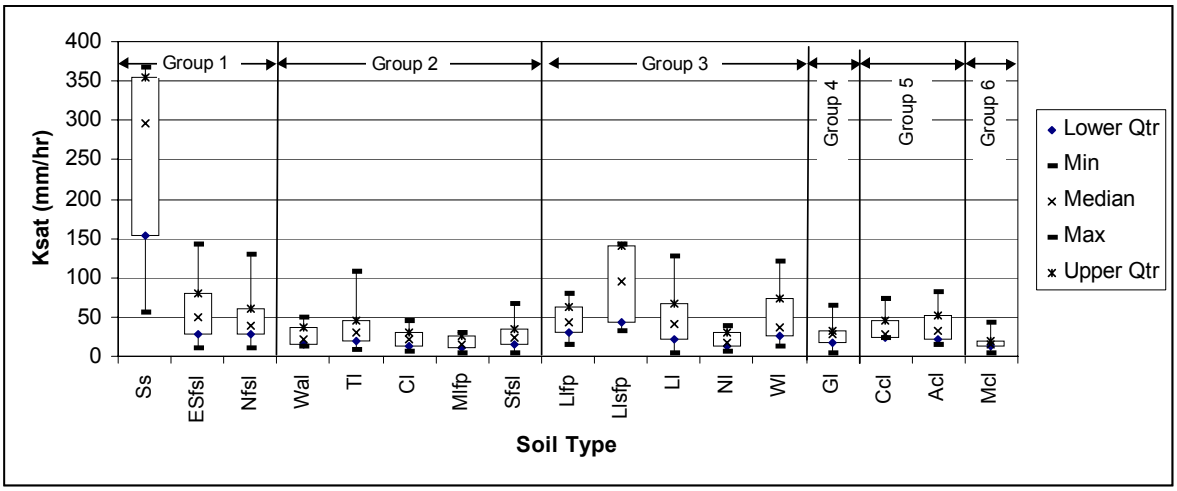

Figure 9.4 Saturated Hydraulic Conductivity of Horizon A of Selected Soil Types

Table 9.3 Saturated Hydraulic Conductivity of Horizon A of Soil Types

Irrigation District	Soil Group	Soil Type	Abbre.	No. of Points	Saturated Hydraulic Conductivity (mm/hr)						
					Avg.	Std.	Min.	Max.	Percentile		
									25	50	75
MV	1	Sandmount sand	Ss	4	254.2	140.6	57.2	366.9	153.9	296.4	354.6
	1	Sandmount sand phase	Ssp	4	26.7	10.3	17.8	39.4	18.3	24.8	35.1
	1	Cobram sandy loam & Ss	Csl	2	28.8		24.3	33.4			
	2	Waaia loam	Wal	10	25.3	12.6	13.6	49.9	15.0	20.9	35.7
	2	Waaia loam phase	Wlp	4	16.0	14.9	6.8	38.2	7.7	9.4	24.2
	2	Cobram loam	Cl	12	22.5	12.6	6.5	44.9	12.5	20.6	29.4
	2	Moira loam friable phase	Mlfp	10	16.5	9.0	4.4	30.3	10.5	14.4	25.3
	3	Moira loam	Ml	2	16.1		12.8	19.4			
	3	Naring loam	Nl	8	20.7	12.1	6.6	39.4	12.1	17.7	30.2
	5	Ulupna clay	Uc	2	44.8		37.2	52.5			
	6	Muckatah clay loam	Mcl	6	18.1	13.0	4.8	42.7	12.6	14.4	20.0
	6	Boosey loam friable phase	Blfp	4	9.7	1.5	8.3	11.0	8.4	9.7	10.9
	6	Boosey loam	Bl	2	11.6		7.1	16.2			
GV	1	East Shepparton fine sandy loam	ESfsl	14	58.7	38.4	10.3	143.3	27.2	49.0	80.9
	2	Katamatite loam	Kl	4	26.6	16.0	9.5	46.1	14.1	25.4	39.1
	2	Shepparton fine sandy loam	Sfsl	54	27.4	16.1	3.9	67.4	14.5	24.5	34.6
	3	Lemnos loam friable phase	Llfp	8	46.1	21.9	16.0	80.9	29.8	42.4	63.7
	3	Lemnos loam semi friable phase	Llsfp	4	91.4	56.9	31.8	143.3	42.8	95.2	140.0
	3	Lemnos loam	Ll	38	45.2	30.6	4.2	127.5	21.0	41.8	67.0
	3	Goulburn loam friable phase	Glfp	4	33.0	8.6	20.8	40.6	27.2	35.3	38.9
	4	Goulburn loam	Gl	20	28.7	15.2	5.0	64.4	17.1	27.1	33.3
	4	Goulburn clay loam	Gcl	4	11.6	3.2	8.0	14.9	9.0	11.7	14.2
	5	Congupna clay loam	Ccl	5	37.1	20.6	23.6	72.6	24.1	28.0	45.9
	6	Congupna clay	Cc	4	41.0	11.6	30.5	55.9	31.9	38.9	50.2
RO	1	Nanneella fine sandy loam	Nfsl	49	46.4	27.5	10.3	130.5	28.1	38.2	60.9
	2	Timmering loam	Tl	18	40.1	30.3	9.4	109.1	19.2	29.5	45.0
	3	Wanalta loam	Wl	18	46.8	29.1	12.0	120.7	26.3	36.4	72.6
	4	Wana loam	Wnl	2	49.0		23.2	74.8			
	4	Koyuga clay loam	Kycl	3	23.4		15.8	37.0			
	4	Koga clay loam	Kocl	4	18.1	11.6	9.8	35.0	10.6	13.8	25.6
	5	Rochester clay	Rc	2	19.5		14.4	24.6			
	5	Alta clay loam	Acl	5	38.7	26.2	15.8	82.5	20.7	32.6	50.9
	6	Wallenjoe clay	Wc	2	26.8		4.0	49.6			
	6	Carag clay	Crc	4	21.0	9.6	12.8	30.1	12.8	20.7	29.3

9.1.4 Paddock Scale Variability of Ksat

Figure 9.5 shows within-paddock-variability of Ksat in 5 paddocks mapped with a single soil type and one paddock having 4 soil types. The Mixed soil paddock had Csl, Mlfp, Wal and Nl soil types. Comparison of Figure 9.5 with Figure 9.4 shows that a single paddock of uniformly mapped soil type covers a large part of variability of Ksat within soil type. Within-paddock-variability of the Mixed soil paddock is relatively less.

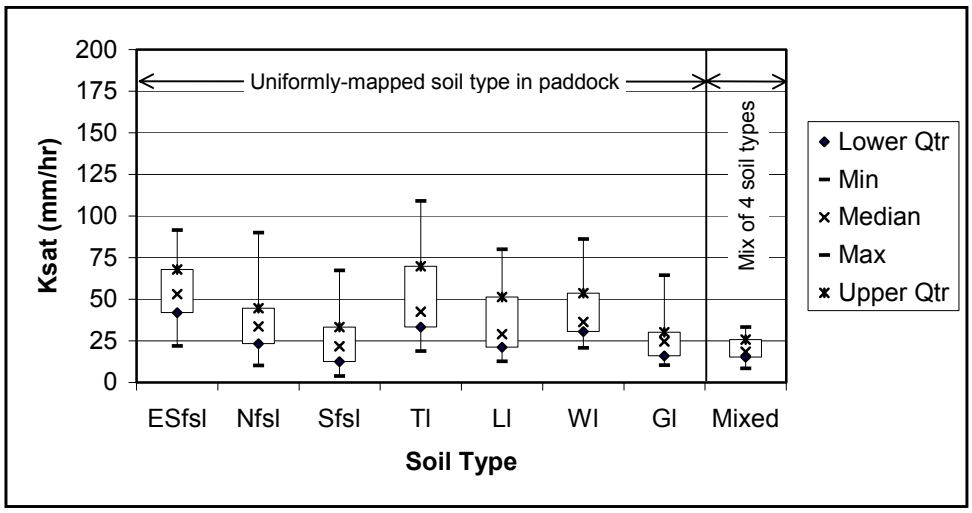

Figure 9.5 Paddock Scale Variability of Ksat of Horizon A

Figure 9.6 shows within-paddock-variability of Ksat of a Nfsl soil type observed on a 10 m x 20 m grid in a 70 m x 80 m paddock. It shows that Ksat varies greatly within the paddock. The paddock has a few pockets of high Ksat values. No particular spatial pattern can be observed in Ksat data.

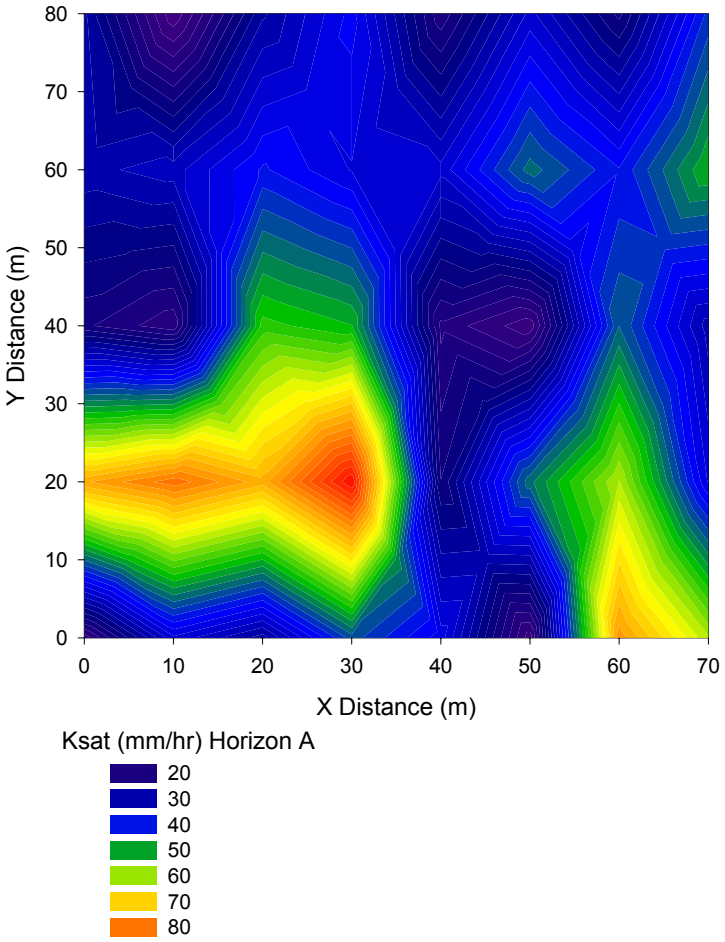

Figure 9.6 Variability of Ksat of Horizon A within a Paddock of Nfsl Soil Type

9.2 Saturated Hydraulic Conductivity of Horizon B1

Ksat of Horizon B1 was measured at 237 points across 79 sites. Results are summarised in Table 9.4. Average Ksat of Horizon B1 decreases from Group 1 to Group 6 except for Group 2, which has a lower Ksat value than Group 3. The average and standard deviation of Ksat of Horizon B1 is much greater for Group 1 than for other soil groups. Figure 9.7 shows the frequency distribution of Ksat of Horizon B1. The distribution of Ksat data is skewed and the Kolmogorov-Smirnov test showed Ksat data are lognormally distributed.

Table 9.4 Saturated Hydraulic Conductivity of Horizon B1

Soil Group	Mean Depth to Horizon B1 (mm)	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
			Avg.	Std.	Min.	Max.	Percentile		
							25	50	75
1	196	36	17.2	23.1	0.6	91.2	3.5	9.5	19.0
2	185	63	3.6	3.9	0.1	18.3	0.8	2.1	5.3
3	170	80	5.7	6.5	0.1	43.3	2.0	3.7	7.4
4	186	29	3.2	5.0	0.4	27.4	1.1	1.4	3.0
5	176	12	2.0	1.5	0.4	5.7	0.8	1.7	2.5
6	190	17	1.3	1.1	0.0	3.8	0.4	1.1	2.4

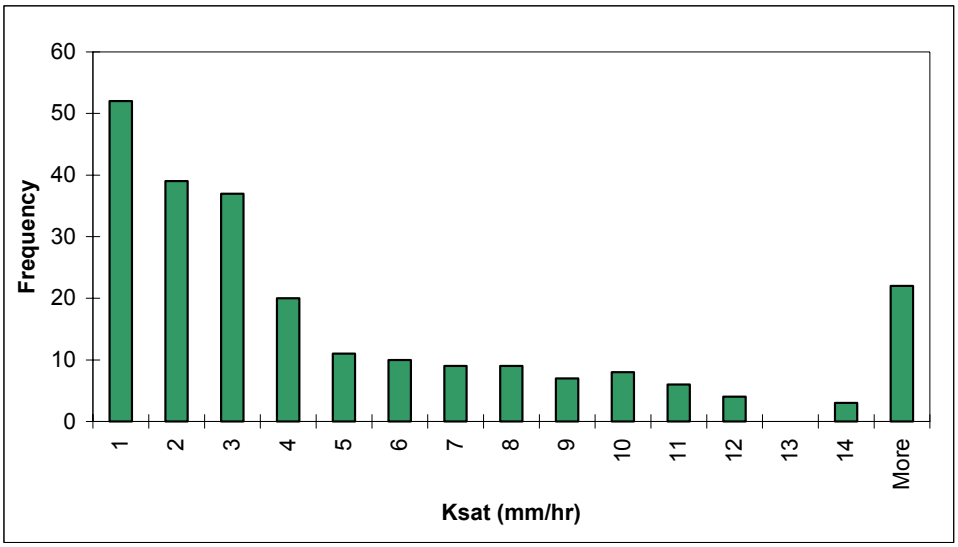

Figure 9.7 Histogram of Saturated Hydraulic Conductivity of Horizon B1

9.2.1 Ksat of Soil Groups

A box and whisker plot of Ksat data of Horizon B1 is presented in Figure 9.8 to show the distribution of Ksat data within soil groups. The distribution of Ksat data of soil groups is skewed due to a few very large values of Ksat. For Groups 2, 4, 5 and 6, the bands between upper and lower quartiles are relatively narrow to suggest that the average values could be used as indicative values for the respective soils for practical applications. In comparison, Groups 1 and 3 have larger bands between upper and lower quartiles, and therefore their average values are much less useful for practical applications. Ksat of Groups 5 and 6 was not found significantly different when their means were compared in a t-test.

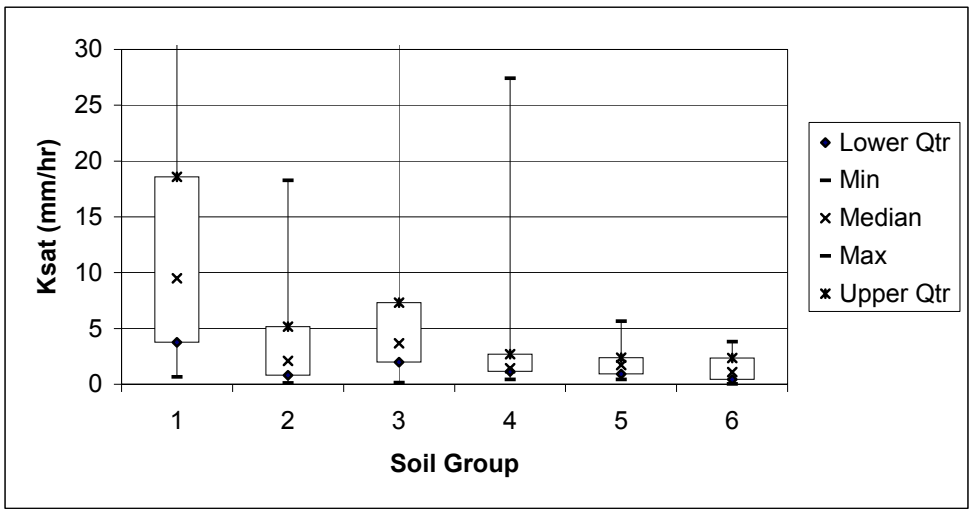

Figure 9.8 Saturated Hydraulic Conductivity of Horizon B1 of Soil Groups

9.2.2 Ksat of Soil Groups of Irrigation Districts

Table 9.5 shows Ksat of Horizon B1 for soil groups of three irrigation districts. Average Ksat values of Horizon B1 of soil groups of three districts are plotted in Figure 9.9. Similar to Horizon A, the average Ksat value of Group 1 of MV District is significantly higher than the values of Group 1 of the other two districts. This is due to a large percentage area of Sandmount sand soil in Group 1 of MV District, which contains more than 90% sand. However, Groups 3, 5 and 6 of MV District have the lowest average Ksat value among three districts. Except for Group 1, the soil types of the GV District generally have higher Ksat than soils of the RO and MV Districts.

Table 9.5 Saturated Hydraulic Conductivity of Horizon B1 of Irrigation Districts

Irrigation District	Soil Group	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
			Avg.	Std.	Min.	Max.	Percentile		
							25	50	75
MV	**1**	10	33.2	29.0	6.1	83.2	11.4	21.6	52.4
	2	29	3.2	3.2	0.1	11.0	0.9	2.2	3.7
	3	10	1.7	1.3	0.2	4.5	0.8	1.3	2.4
	4*	*	*	*	*	*	*	*	*
	5	2	1.7		1.0	2.3			
	6	8	0.5	0.3	0.0	1.2	0.4	0.5	0.7
GV	**1**	14	12.3	23.3	1.8	91.2	2.4	4.7	8.0
	2	16	5.2	5.1	0.1	18.3	0.6	4.5	8.2
	3	53	6.2	7.4	0.1	43.3	2.3	3.7	8.2
	4	22	3.3	5.7	0.4	27.4	1.1	1.3	2.7
	5	4	2.4	2.4	0.4	5.7	0.5	1.7	4.2
	6	4	2.9	0.7	2.4	3.8	2.4	2.7	3.3
RO	**1**	12	9.6	6.6	0.6	20.4	3.5	10.1	13.9
	2	18	3.0	3.5	0.2	13.8	0.8	1.3	4.1
	3	17	6.3	4.4	0.2	14.9	2.9	6.0	9.6
	4	7	2.8	1.6	0.8	4.8	1.3	2.6	4.3
	5	6	1.8	1.0	0.5	3.7	1.4	1.7	1.9
	6	5	1.4	1.0	0.4	3.1	0.9	1.1	1.6

Note: * No soil is defined under Group 4 of MV District in the existing soil maps

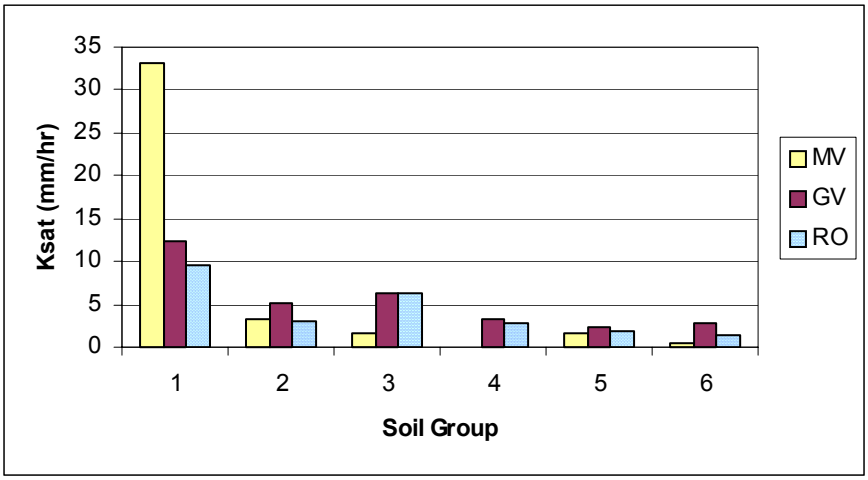

Figure 9.9 Saturated Hydraulic Conductivity of Horizon B1 of Irrigation Districts

9.2.3 Ksat of Soil Types

Table 9.6 shows Ksat of Horizon B1 of 32 soil types of MV, GV, and RO Districts. Sandmount sand of Group 1 has the highest and Boosey loam of Group 6 has the lowest average Ksat among all soil types. Soil types of Groups 3, 5, 6 of MV District appear to have lower Ksat than the soils of GV and RO Districts.

To understand the sources of the within-soil-group variability of Ksat in Horizon B1, data for a selected number of soil types are presented in Figure 9.10. Similar to Horizon A, the large within-soil-group variability of Ksat of Horizon B1 for Groups 1 and 3 is due to both between-soil-type variability and within-soil-type variability. In Group 1, non duplex soil types such as Ss and Ssp have significantly higher Ksat values than duplex soil types. Group 1 can be subdivided into non duplex soil types such as the Ss soil type and duplex soil types.

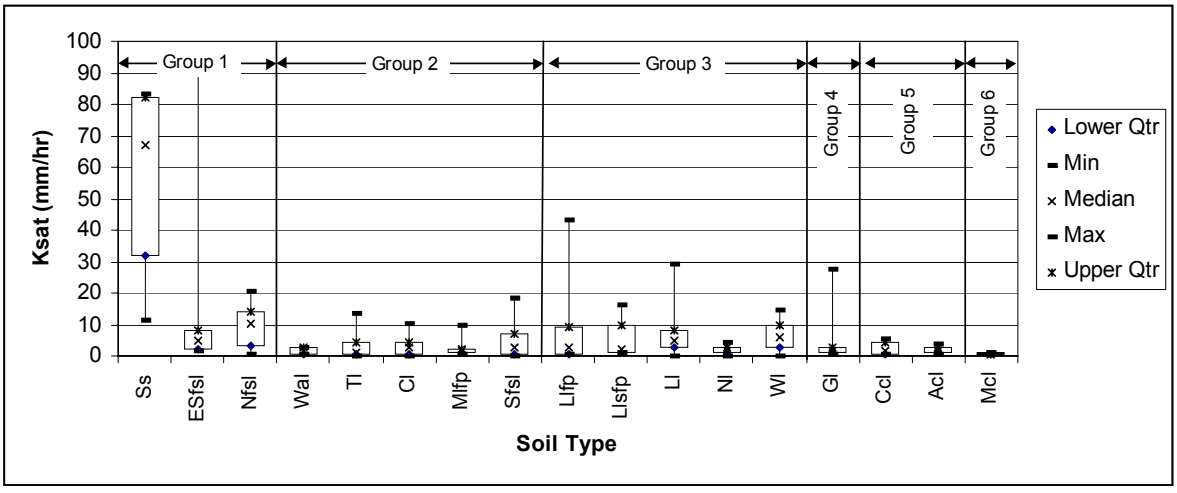

Figure 9.10 Saturated Hydraulic Conductivity of Horizon B1 of Selected Soil Types

Table 9.6 Saturated Hydraulic Conductivity of Horizon B1 of Irrigation Districts

Irrigation District	Soil Group	Soil Type	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
				Avg.	Std.	Min.	Max.	Percentile		
								25	50	75
MV	1	Sand mount sand	4	57.1	33.5	11.4	83.2	31.9	66.8	82.2
	1	Sand mount sand phase	4	15.9	7.5	6.1	23.2	10.2	17.2	21.6
	1	Cobram sandy loam & Ss	2	19.9		9.8	29.9			
	2	Waaia loam	8	1.6	1.0	0.4	2.9	0.6	1.5	2.6
	2	Waaia loam phase	4	7.5	3.6	2.5	11.0	5.2	8.3	9.9
	2	Cobram loam	11	2.9	3.0	0.1	10.4	0.7	2.7	4.2
	2	Moira loam friable phase	6	2.8	3.5	0.8	9.9	1.2	1.5	2.2
	3	Moira loam	2	0.9		0.8	1.1			
	3	Naring loam	8	1.9	1.4	0.2	4.5	1.0	1.7	2.6
	5	Ulupna clay	2	1.7		1.0	1.3			
	6	Mucktah clay loam	6	0.6	0.3	0.4	1.2	0.4	0.6	0.8
	6	Boosey loam	2	0.2		0.0	0.5			
GV	1	East Shepparton fine sandy loam	14	12.3	23.3	1.8	91.2	2.4	4.7	8.0
	2	Katamatite loam	2	7.6		5.5	9.6			
	2	Shepparton fine sandy loam	14	4.8	5.3	0.1	18.3	0.5	2.8	7.2
	3	Lemnos loam friable phase	8	8.5	14.8	0.3	43.3	0.4	2.7	9.2
	3	Lemnos loam semi friable phase	4	5.4	7.1	1.2	16.0	1.2	2.2	9.5
	3	Lemnos loam	37	6.0	5.4	0.1	29.4	2.8	5.1	8.2
	3	Goulburn loam friable phase	4	4.2	2.8	2.2	8.4	2.5	3.2	6.0
	4	Goulburn loam	18	3.8	6.3	0.4	27.4	0.9	1.9	2.7
	4	Goulburn clay loam	4	1.2	0.0	1.1	1.2	1.2	1.2	1.2
	5	Congunpa clay loam	4	2.4	2.4	0.4	5.7	0.5	1.7	4.2
	6	Congupna clay	4	2.9	0.7	2.4	3.8	2.4	2.7	3.3
RO	1	Nanneella fine sandy loam	12	9.6	6.6	0.6	20.4	3.5	10.1	13.9
	2	Timmering loam	18	3.0	3.5	0.2	13.8	0.8	1.3	4.1
	3	Wanalta loam	17	6.3	4.4	0.2	14.9	2.9	6.0	9.6
	4	Koyuga clay loam	3	3.6		2.6	4.5			
	4	Koga clay loam	4	2.1	1.8	0.8	4.8	1.0	1.5	3.3
	5	Rochester clay	2	1.7		1.6	1.8			
	5	Alta clay loam	4	1.9	1.3	0.5	3.7	0.9	1.6	2.8
	6	Wallenjoe clay	1	3.1						
	6	Carag clay	4	1.0	0.3	0.4	1.1	0.8	1.1	1.1

9.2.4 Paddock Scale Variability of Ksat

Figure 9.11 shows within-paddock-variability of Ksat of Horizon B1 in 5 paddocks mapped with a single soil type and one paddock mapped with 4 soil types. The Mixed soil paddock has Csl, Mlfp, Wal and Nl soil types in a single paddock. It appears that paddock scale variability of some soil types largely covers the within soil type variability of Ksat between upper and lower quartiles. The maximum Ksat of the Mixed paddock is associated with a soil type from Group 1. Except for the ESfsl soil type, the bands between upper and lower quartiles are relatively narrow to suggest that the average values could be used as indicative values for the respective soils for practical applications.

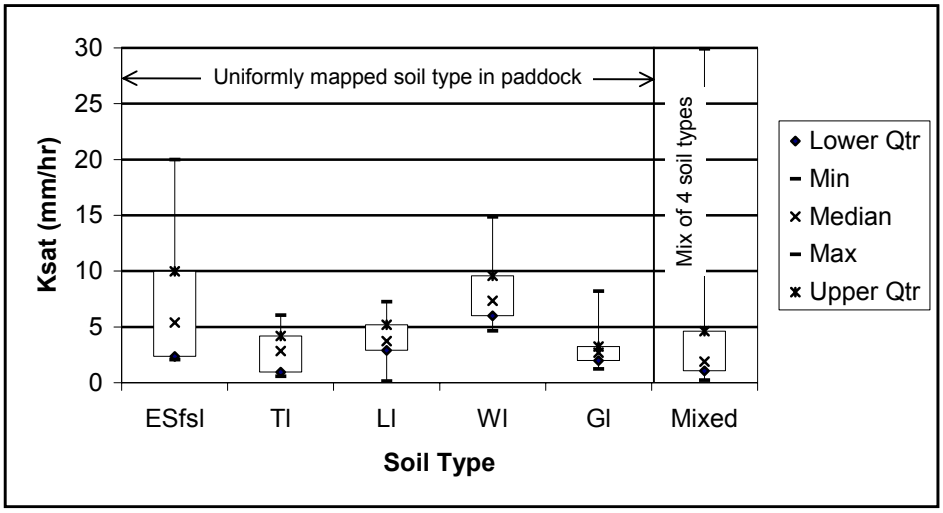

Figure 9.11 Paddock Scale Variability of Ksat of Horizon B1

9.3 Saturated Hydraulic Conductivity of Horizon B2

Ksat of Horizon B2 was measured at 129 points across 49 sites. Results are summarised in Table 9.7. Similar to Horizon B1, the average Ksat of Horizon B2 decreases from Group 1 to Group 6 except for Group 2, which has a lower Ksat value than Group 3. The standard deviation of Ksat of Horizon B2 is greater for Groups 1, 2 and 3 than other soil groups. For Groups 2 and 3, Horizon B2 has higher average Ksat than Horizon B1. However, there is little difference in Ksat between the two horizons for Groups 4, 5 and 6.

Table 9.7 Saturated Hydraulic Conductivity of Horizon B2

Soil Group	Mean Depth to Horizon B2	No of Points	Saturated Hydraulic Conductivity (mm/hr)						
			Avg.	Std.	Min.	Max.	Percentile		
							25	50	75
1	373	20	12.9	11.2	0.7	48.6	5.1	11.8	16.2
2	373	40	5.7	5.8	0.0	24.7	1.9	3.4	6.8
3	319	38	6.5	5.0	0.3	18.1	2.0	5.5	10.2
4	341	16	2.8	3.0	0.0	12.5	1.3	1.7	4.1
5	329	5	1.9	1.8	0.2	4.7	0.6	0.9	3.2
6	398	10	1.1	0.9	0.0	2.4	0.6	1.0	2.0

A box and whisker plot of Ksat of Horizon B2 is presented in Figure 9.12 to show the distribution of Ksat data within a soil group. The distribution of Ksat within soil groups is skewed due to a few very large values of Ksat. For Groups 2, 4, 5 and 6, the bands between upper and lower quartiles are relatively narrow to suggest that the average values could be used as indicative values for the respective soils for practical applications. In comparison, Groups 1 and 3 have larger bands between upper and lower quartiles. Ksat of Groups 2 and 3 is not found significantly different when their means are compared with t-test. The same is found for Groups 5 and 6.

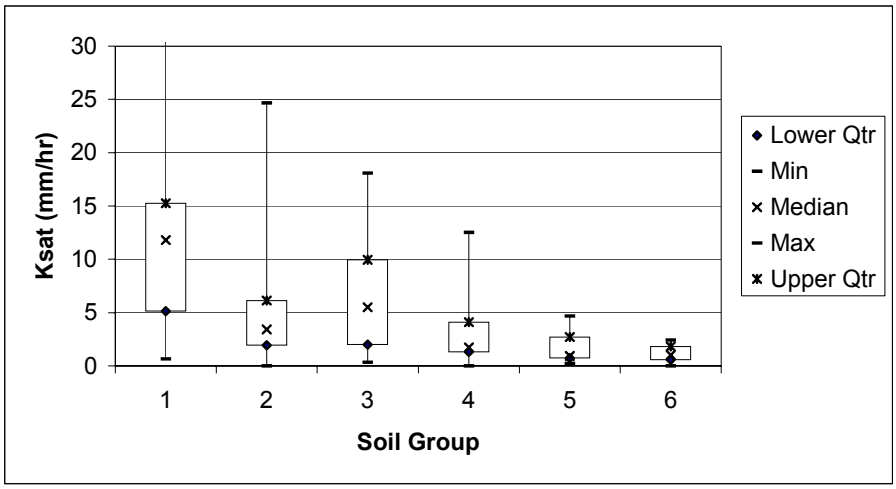

Figure 9.12 Saturated Hydraulic Conductivity of Horizon B2

9.4 Conclusions

Saturated hydraulic conductivity of 34 soil types was measured at Horizons A, B1 and B2 across 79 sites in SIR.

The saturated hydraulic conductivity of Horizons A, B1 and B2 is reasonably well defined between upper and lower quartiles for Groups 2, 4, 5 and 6, and it is recommended that the average values of these groups could be used as indicative values for practical applications. For Groups 1 and 3, however, saturated hydraulic conductivity is quite variable, due to both between-soil-type variability and within-soil-type variability. It is suggested that the soil types of Groups 1 and 3 should be considered individually.

It is noted that even at a paddock scale, variability can be quite high, and in some cases a paddock can cover much of the within-soil-type variability.

Some trends of soil hydraulic properties across the soil groups have been found. Saturated hydraulic conductivity of all soil horizons decreases from Group 1 to Group 6 except for Groups 2 and 5. In terms of saturated hydraulic conductivity of Horizons B1 and B2, Groups 4 and 5, and Groups 5 and 6 were not found significantly different when their means were compared in t-tests.

The saturated hydraulic conductivity of Horizon A was generally one order of magnitude or more larger than that of Horizons B1 and B2. The saturated hydraulic conductivity of Horizons B1 and B2 was similar in each soil group. However, the saturated hydraulic conductivity of Horizon B1 tends to be slightly lower than that of Horizon B2 for Groups 2 and 3.

Some spatial trends of saturated hydraulic conductivity across irrigation districts have been found. Group 1 of MV District has the highest saturated hydraulic conductivity of Horizons A and B1 among all irrigation districts. Groups 3, 5 and 6 of MV District have the lowest saturated hydraulic conductivity of Horizons B1 among all irrigation districts. Soil types of Groups 2, 3, 4, 5 and 6 of GV District generally have higher saturated hydraulic conductivity than soils of other irrigation districts.