Modelling spatial variability using soil profiles in the Riverland of South Australia

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Abstract The soils of the Riverland vary significantly throughout the region. Soils from a vineyard near Loxton, whilst having only half the topsoil depth of two near Waikerie, are comparable in water holding capacity because the soils are less sandy. Topographic difference can cause an additional variation between areas in the same neighbourhood. Highland soils typically develop a dune swale topography which gives rise to anisotropic semivariograms. First slope soils on the other hand give isotropic semivariograms. Semivariograms for topsoil depth and readily available water for the three vineyards are used in the calculation of the efficiency of the sampling grids employed to gain an understanding of the soils. Kriging variance values have been calculated for 1, 2, 3 and 4 hectare square irrigation valve areas using the industry standard grid 75m x 75m as well as grids 50m x 50m and 100m x 100m. Choice of the appropriate sampling grid to achieve a specified accuracy can thus be made.

1. INTRODUCTION

Irrigation in the Riverland of South Australia allows for an horticultural industry in what would otherwise be an arid region. Citrus, wine and vegetable production contribute significantly to the wealth of the region. Fundamental to the design of the irrigation systems and their scheduling is an in depth understanding of the variability of soil characteristics. Before the development of a property it has been prudent practice to undertake a soil survey to provide this understanding. Such sensible practice is now regulated by some state water authorities before the granting of an irrigation licence. Although the Riverland has been producing for decades, the size of the sample grid used by farmers had until recent years been more a matter of rule of thumb than one established by scientific modelling. To address this question in a rigorous fashion a series of geostatistical studies began in 1993. Brooker et al [1995] looked at an irrigated vineyard near Waikerie and analysed the spatial variability of two variables; topsoil depth, important in ensuring that sustainable agriculture is possible, and readily available water (RAW), a measure of the water reservoir available to plants between irrigations. That analysis is extended in this paper to two other vineyards in the Riverland.

Geostatistical analysis allows calculation of the efficiency of estimators used to calculate the average values of the variables for irrigation valve areas. These areas are those that are watered upon opening the irrigation valves and the irrigation manager will adjust the water supplied to a section of the property on the basis of the water holding capacity of the irrigation valve area. Kriging is the estimation technique chosen as amongst linear estimators it provides the most accurate estimates. It requires knowledge of the spatial variability of the data and uses the semivariogram; the function measuring correlation between pairs of data as a function of the distance between the pairs. The accuracy of the estimates is determined in the kriging process and depends on the size of the area to be estimated, the size of the sample grid used and its geometrical setting relative to the estimated area and the spatial variabilty of the variable as reflected in the semivariogram. Calculations can be made for sample grids in place on a property or for suggested alternatives. In this paper the accuracy associated with grids 50m x 50m, 75m x 75m and 100m x 100m are presented for irrigation valve areas which are square and of 1, 2, 3 and 4 hectares. The spatial variability models are those of vineyards at Sunlands near Waikerie, downstream at nearby Markaranka Flat on the other side of the River Murray and about one hundred kilometres upstream at Loxton.

2. SOIL SURVEY

Soil variables recorded in the typical soil survey include the depth and texture of each soil layer as assessed by hand texturing (McDonald, [1990]). From these the water holding capacity of the soil between irrigations may be calculated. Specifically, the parameter readily available water is used to measure the water holding capacity. For the Riverland, this is defined as the reservoir of soil water (in mm) which can be stored between -8 kilopascals (full point) and -60 kilopascals (refill point). These suction pressures correspond to a soil water depletion range which maintains maximum crop production for a broad range of horticultural crops in the Riverland. Each soil texture encountered in the profile has a readily available water coefficient (mm/cm of soil) determined from a soil moisture retention curve which is experimentally calculated from cores using a range of suction pressures (Loveday [1974]). The readily available water value for the whole profile is obtained by summing the values within each soil layer. Readily available water is always calculated for the full topsoil depth. Developed properties can also have the root zone readily available water calculated as this reflects the actual depth to which the roots of established plants are able to absorb water. The carbonate classes which underlie the topsoil (Wetherby and Oades [1975]), the depth and extent of root zone activity in developed properties, and soil salinity and pH are also measured in the soil survey but are not discussed here.

3. SITES AND SUMMARY STATISTICS

The first vineyard is at Sunlands, about 15 kilometres downstream from Waikerie. It is a few hundred metres from the river and elevations throughout the property range from 30 to 40 metres above the river level. Sampling was carried out at 928 sites on a square grid, 75m x 75m. The second is at Markaranka Flat and a rectangular grid, 75m x 50m, was used in sampling 310 sites. The third vineyard, about one hundred kilometres upstream near Loxton, was sampled at 334 sites and once again the industry standard square grid, 75m x 75m, was used. In general, the sites were excavated with a back hoe to a maximum depth of 1.8m, unless a layer of sheet calcrete was encountered earlier.

The level of variation of topsoil depth is similar in both vineyards near Waikerie. Average depth is 90 cm and 87 cm respectively, whilst standard deviations are 63 cm and 55 cm. In contrast the vineyard at Loxton is on much shallower soil, an average of 39 cm. Not surprisingly the standard deviation is less than the other two and registers 23 cm. However, it is interesting to note that the relative standard deviation; the standard deviation divided by the mean, is similar in all cases. The soil types at Loxton are higher in water holding capacity than those near Waikerie and so despite the more shallow depths on average, the statistics for readily available water are similar in all three vineyards. Table 1 lists the summary statistics.

Parameter	Statistic	Sunlands	Markaranka	Loxton
Topsoil depth	mean	90.5 cm	87.4 cm	38.8 cm
	variance	3995 cm^2	3026 cm^2	508 cm^2
	standard deviation	63.2 cm	55.0 cm	22.5 cm
	relative standard deviation	0.70	0.63	0.58
	number of samples	928	310	334
Rootzone RAW	mean	39.9 mm	46.6 mm	42.6 mm
	variance	254 mm^2	451 mm^2	430 mm^2
	standard deviation	15.9 mm	21.2 mm	20.7 mm
	relative standard deviation	0.40	0.46	0.49
	number of samples	764	161	334

Table 1 Summary statistics for topsoil depth and readily available water for the three vineyards

4. SEMIVARIOGRAMS

Soil characteristics may vary considerably over small distances. A geostatistical treatment quantifies this variation in the semivariogram, a function which measures the spatial correlation between data pairs as a function of the displacement between the pairs. The semivariogram, $\gamma(\mathbf{h})$, is half the average squared difference between pairs of data $Y(\mathbf{x})$ and $Y(\mathbf{x}+\mathbf{h})$ separated by displacement $\mathbf{h}$. It is estimated using the standard estimator below, with $N(\mathbf{h})$ being the number of pairs of data separated by displacement $\mathbf{h}$ over which the summation is performed.

$$\gamma^*(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} \{Y(\mathbf{x}+\mathbf{h}) - Y(\mathbf{x})\}^2$$

The function should be evaluated in several directions to identify any anisotropic variation which might be present. Only semivariograms of topsoil depth are shown below; however readily available water semivariograms display very similar characteristics.

Experimental semivariograms must be modelled for subsequent calculations and a frequently used model is the spherical. Its form, for isotropic variation, is given below. The parameters to be specified are the range, a, over which correlation occurs; the nugget effect, Co, representing the very short range variability which is undetectable with the finite size sampling grid, and which may also reflect any errors of measurement; and the sill, $Co + C$, the maximum value of the function.

$$\gamma(h) = \begin{cases} 0 & h = 0 \\ Co + C[1.5(h/a) - 0.5(h/a)^3] & h < a \\ Co + C & h \geq a \end{cases}$$

The variography associated with the vineyard at Sunlands has been discussed at length in Brooker et al [1995]. Figure 1 shows the experimental semivariograms for this vineyard. It can be seen that in all directions the tendency is for the value of the semivariogram to increase with distance until the function reaches a plateau level of around 3500 cm^2. Semivariogram values for greater distance fluctuate about this so-called sill. The increasing function simply reflects the expected behaviour that neighbouring pairs of samples should, on average, be closer in value compared to more distant pairs. The distance at which the sill value is reached is the range. Pairs at a separation of less than the range are correlated whilst those separated by distances greater than the range are independent. From the figure it is immediately apparent that variation in the N-S direction is much more rapid than in the E-W direction; the range N-S is around 220 metres compared to around 1000 metres in the E-W direction. This anisotropy is a fundamental feature of the variability of this data set and reflects the typical dune swale system which has developed on the highland soils (Herriot and Johnston [1941]).

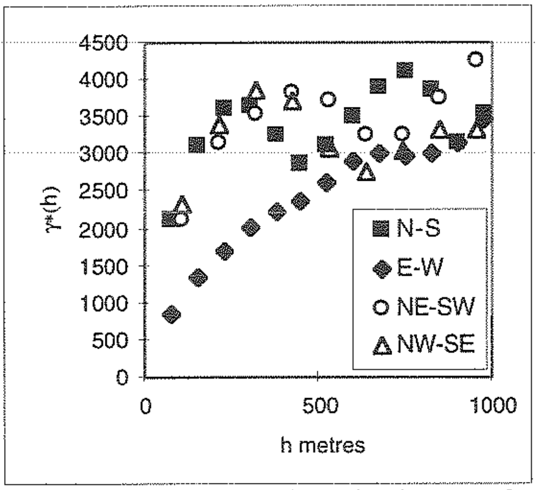

Figure 1 Experimental semivariograms for topsoil depth for the vineyard at Sunlands

Modelling the experimental semivariograms must be carried out separately for each direction in anisotropic situations and Table 2 shows the parameters of the spherical models for maximum (E-W) and minimum (N-S) ranges.

In the case of the second vineyard near Waikerie there is a significant difference: experimental semivariograms show isotropic variation. The difference in semivariograms can be understood in terms of the topography of the region. At Markaranka the vineyard is on first slope soils (Herriot and Johnston [1941]) and there is no dune swale system. When modelling the semivariogram in isotropic situations, semivariogram values for a particular distance may be determined without regard for direction. Thus, the combined diagonals plot as one point in Figure 2 and the two principal directions are combined at multiples of 150m. Parameters of the fitted spherical models are given in Table 2.

	Topsoil Depth		
Parameter	Sunlands	Markaranka	Loxton
Co	600 cm^2	500 cm^2	40 cm^2
C	2950 cm^2	2300 cm^2	460 cm^2
Sill	3550 cm^2	2800 cm^2	500 cm^2
a(N-S)	220 m	340 m	225 m
a(E-W)	995 m	340 m	225 m

Table 2 Spherical semivariogram model parameters for topsoil depth

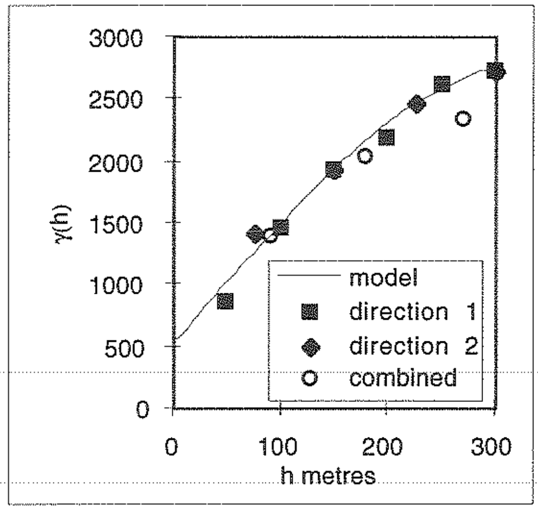

Figure 2 Experimental and model semivariograms for topsoil depth for the vineyard at Markaranka

For the third vineyard at Loxton there is isotropy once again and the combined semivariogram and model are shown in Figure 3. Table 2 lists the fitted spherical semivariogram parameters.

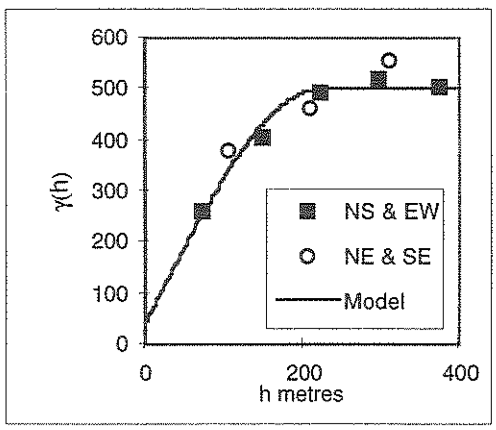

Figure 3 Experimental and model semivariograms for topsoil depth for the vineyard at Loxton

As mentioned previously, semivariograms for readily available water are similar to those for topsoil depth. The parameters of the spherical models are given in Table 3.

	Root Zone RAW		
Parameter	Sunlands	Markaranka	Loxton
Co	100 mm^2	120 mm^2	90 mm^2
C	130 mm^2	335 mm^2	350 mm^2
Sill	230 mm^2	455 mm^2	430 mm^2
a(N-S)	200 m	345 m	337.5 m
a(E-W)	650 m	345 m	337.5 m

Table 3 Spherical semivariogram model parameters for readily available water

5. ACCURACY OF ESTIMATES

The values of the variables of interest for irrigation valve areas may be computed by forming a weighted average of sample values in the vicinity of the valve areas.

$$Y^*_{IVA} = \sum_i \lambda_i Y(x_i)$$

Geostatistics allows the optimal weights to be assigned so that an estimate will, on average, be non-biased and as close as possible to the true, unknown value. The process is known as kriging (Brooker, [1991]) and a measure reflecting the accuracy of the estimate is calculated. This is the kriging variance; the variance of the error between the estimate and the true value. As mentioned in the introduction, the kriging variance is a function of the geometry of both the sample grid and the area to be estimated, and also the semivariogram, the function reflecting sample variability. In tables 4-6 kriging variances have been calculated for the three vineyards for sample grids 50m x 50m, 75m x 75m and 100m x 100m and for irrigation valve areas which are square and of 1, 2, 3 and 4 hectares. The kriging variance may, under assumption of a specified error distribution, be converted to a confidence interval for the estimate. For a normal distribution of errors the 95% confidence interval is the estimate ± 1.96 times the kriging standard deviation. As an example, for a typical readily available water estimate of 46.6 mm at Markaranka, the 95% confidence interval for the estimation of a 2 hectare irrigation valve area using a 100m x 100m grid is (35.1 mm, 58.1 mm). This interval is reduced in size by a factor of just over half if the grid is 50m x 50m. Of course the improvement in accuracy comes at a cost: four times as many samples need to be taken.

Standardising the numbers in Tables 4-6 to the scale of the variables by dividing through by the mean, gives the relative standard deviation of the error. Tables 7-9 report these values. A visual picture, useful in comparison, is presented in Figures 4 and 5 for 1 ha and 3 ha irrigation valve areas for readily available water. Figures 6 and 7 show similar results for topsoil depth. The change in confidence intervals for the estimates as the grid size is changed is the ratio of the ordinates of the figures.

	Topsoil depth				Readily available water			
IVA Sample grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	94.39	56.61	46.19	38.10	9.60	6.51	5.19	4.29
75m x 75m	176.23	131.98	94.94	75.66	16.73	12.63	9.85	8.18
100m x 100m	237.45	214.64	184.62	151.77	22.99	19.22	16.24	13.70

Table 4 Kriging variance associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Sunlands

	Topsoil depth				Readily available water			
IVA Sample Grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	87.67	52.26	38.70	30.44	17.19	10.81	8.11	6.45
75m x 75m	166.00	113.62	82.88	66.04	30.98	21.88	16.55	13.47
100m x 100m	235 .49	186.35	150.06	122.22	43.65	34.64	28.28	23.47

Table 5 Kriging variance associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Markaranka

	Topsoil depth				Readily available water			
IVA Sample Grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	9.27	5.19	3.83	2.98	14.79	8.97	6.66	5.26
75m x 75m	18.96	12.59	8.75	6.75	27.57	19.05	14.06	11.28
100m x 100m	26.88	21.32	16.87	13.39	39.09	30.93	25.00	20.47

Table 6 Kriging variance associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Loxton

	Topsoil depth				Readily available water			
IVA Sample grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	10.74	8.31	7.51	6.82	7.77	6.39	5.71	5.19
75m x 75m	14.69	12.69	10.77	9.61	10.25	8.91	7.87	7.17
100m x 100m	17.03	16.19	15.01	13.61	12.02	10.99	10.10	9.28

Table 7 Relative standard deviation (%) associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Sunlands

	Topsoil depth				Readily available water			
IVA Sample grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	10.71	8.27	7.12	6.31	8.90	7.06	6.11	5.45
75m x 75m	14.74	12.20	10.42	9.30	11.94	10.04	8.73	7.88
100m x 100m	17.56	15.62	14.02	12.65	14.18	12.63	11.41	10.40

Table 8 Relative standard deviation (%) associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Markaranka

	Topsoil depth				Readily available water			
IVA Sample grid	1 ha	2 ha	3 ha	4 ha	1 ha	2 ha	3 ha	4 ha
50m x 50m	7.85	5.87	5.04	4.45	9.03	7.03	6.06	5.38
75m x 75m	11.22	9.14	7.62	6.70	12.33	10.25	8.80	7.88
100m x 100m	13.36	11.90	10.59	9.43	14.68	13.06	11.74	10.62

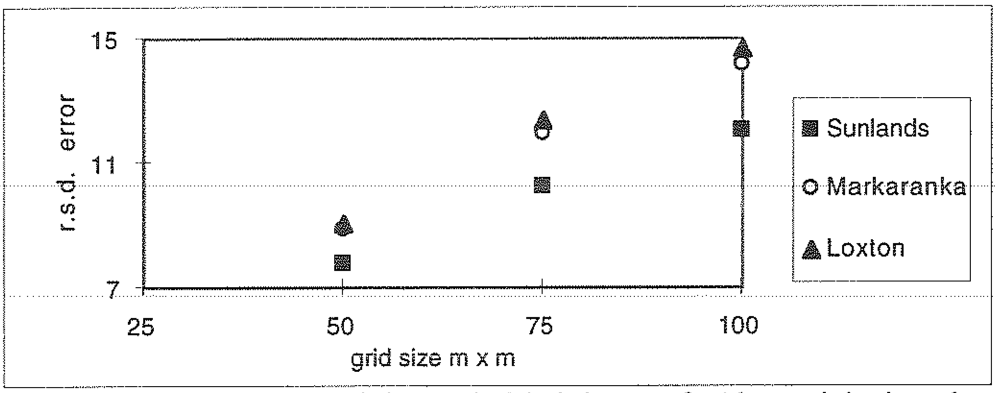

Figure 4 Readily available water relative standard deviation error for 1 hectare irrigation valve area

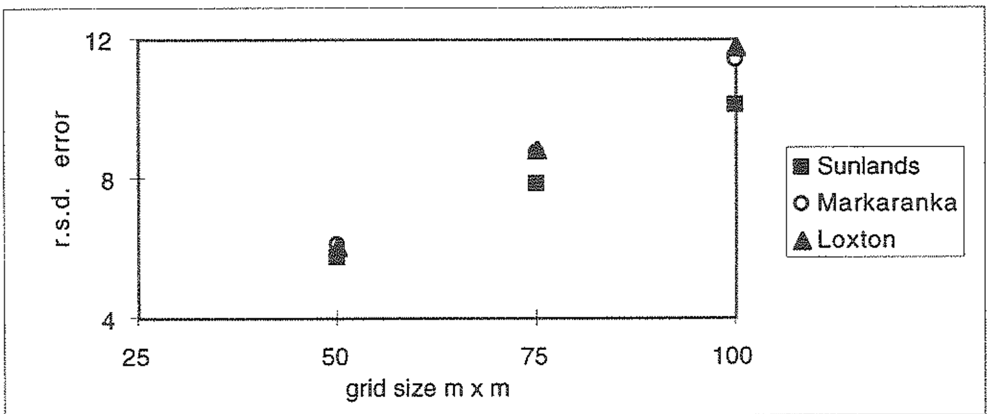

Figure 5 Readily available water relative standard deviation error for 3 hectare irrigation valve area.

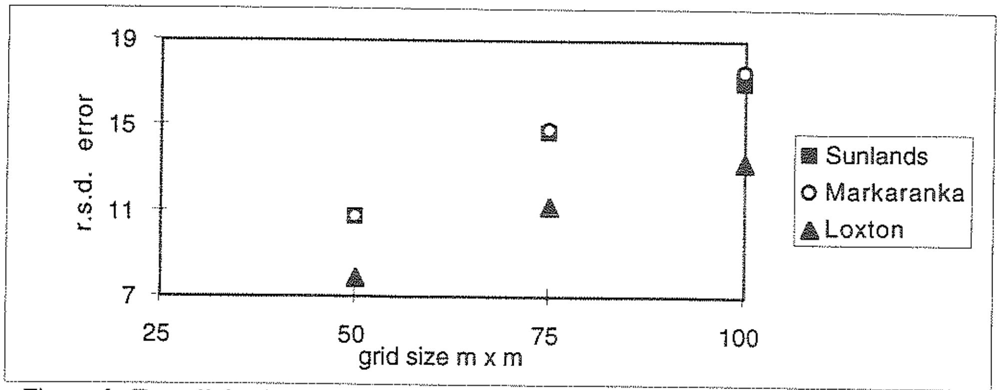

Figure 6 Topsoil depth relative standard deviation error for 1 hectare irrigation valve area

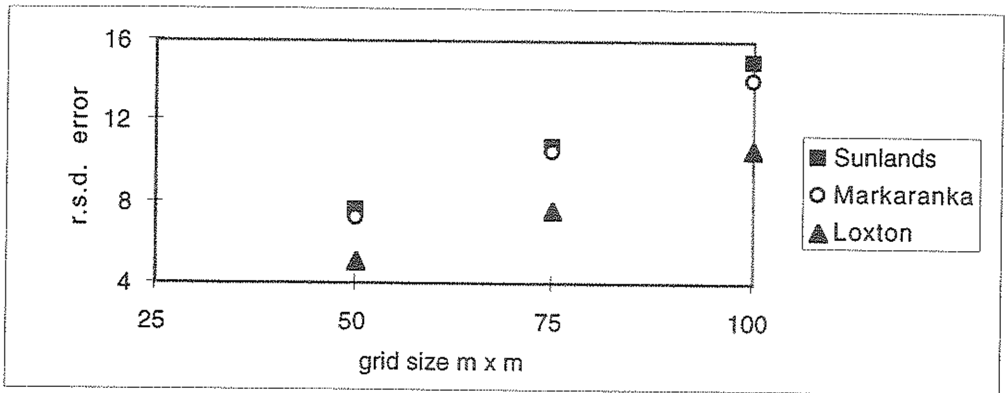

Figure 7 Topsoil depth relative standard deviation error for 3 hectare irrigation valve area

Table 9 Relative standard deviation (%) associated with the estimation of irrigation valve areas by various sample grids for the vineyard at Loxton

6. CONCLUSION

The soils of the Riverland vary significantly throughout the region. Soils near Loxton, whilst having only half the topsoil depth of those near Waikerie are comparable in water holding capacity because the soils are less sandy. There is an additional variation between areas in the same neighbourhood depending on topography. Highland soils typically develop a dune swale topography which gives rise to anisotropic semivariograms. First slope soils on the other hand give isotropic semivariograms.

The efficiency of the sampling grid in assessing the value for the irrigation valve area is measured in the geostatistical procedure of kriging. Kriging variance values have been calculated for irrigation valve areas 1, 2, 3 and 4 hectares using the industry standard grid 75m x 75m as well as grids 50m x 50m and 100m x 100m.

Because water is such a valuable commodity, the water authority should specify the accuracy required for the estimation of readily available water for irrigation valve areas of the size on a property. Then the results of a study such as this will dictate the size of the sample grid required to achieve this accuracy.

7. REFERENCES

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