On-line Appendix: Statistical Analysis

Data in Table 1 came from two sources: Toby Pike (SEKID: water use data, area of land permitted for irrigation, and policy history on metering, education and charges) and Denise Neilsen (AAFC Kelowna: moisture deficit index calculated from Kelowna data using a modified Penman-Monteith approach, strongly correlated with Penman-Monteith results).

The analysis proceeded in four stages:

1) Removal of trend caused by increasing area licensed for irrigation through time by dividing water used by area licensed, to produce an estimate of water used per unit area of land licensed (Table 1, Figure 1).

2) Calibration analysis by simple regression of the 1977-1993 water used per unit area licensed against the estimated moisture deficit (Tables 1, 2, Figure 2).

    - Three years in which the moisture deficit was more than one standard deviation below the mean for the period (i.e. unusually wet years) were removed from the calibration analysis as they were clear outliers in the relationship between weather and water use (i.e. water use did not decline as significantly in these years as the weather alone would predict, presumably because irrigators were in the habit of a base level of irrigation even in wet times).

    - The resulting regression had a degrees of freedom adjusted $r^2 = 0.67$, indicating that 67% of the variation in water use during the calibration period can be accounted for by weather alone.

    - The residuals of this simple regression showed a clear trend towards decreasing water use over time during the calibration period of 1977-1993 (Figure 3).

    - This could be due to a number of factors, such as the increased land base not being for some reason as water-demanding as the previously licensed land base, the increasing urbanization of the area resulting in decreased actual irrigation per unit land area, the adoption of more efficient technologies, the adoption of less water-demanding crops, other unknown factors, or a combination of two or more of the above.

3) Multiple regression using the calibration time period 1977-1993, regressing water used per unit land area against estimated moisture deficit and year (input as years after 1976) (Tables 1, 3, Figure 2).

- This produced a high correlation coefficient (degrees of freedom adjusted $r^2 = 0.75$, indicating that 75% of the variation in the water used per land area over this period of time is accounted for by these two factors alone).

- The residuals of this multiple regression showed a clear trend towards decreasing water use over time during the calibration period of 1977-1993 (Figure 3).

4) Using the resulting regression function to predict water use per unit land area for the period 1994-2004, based solely on the pattern established prior to metering in 1994 (Table 1, Figure 4).

   - This resulted in a predicted use curve that matches closely with the actual use curve, except for the years after 2000 when the pricing program was introduced.

   - There is no clear change in the pattern of the residuals at the time of introduction of metering in 1994, but there is a clear decline at the time of introduction of pricing for exceeding allocation, in 2001 (Figure 5).

This leads to the conclusion that the metering and education programs have had no significant effect beyond business-as-usual, while pricing has had a significant impact. However, metering and education may have had an impact on the success of the pricing program. The progressive phases, which allowed the metering program to be introduced first with a promise of no price increase in the following five years, and the education has helped irrigators to accept and prepare for the pricing program. Moreover, the punitive increasing block rate volumetric charge for excess users introduced in 2001 depends on metering.

The number of users exceeding their allotment decreased substantially in 2004 (Figure 6). However, this was also a relatively ‘wet’ year compared to the other three years for which this data is available.

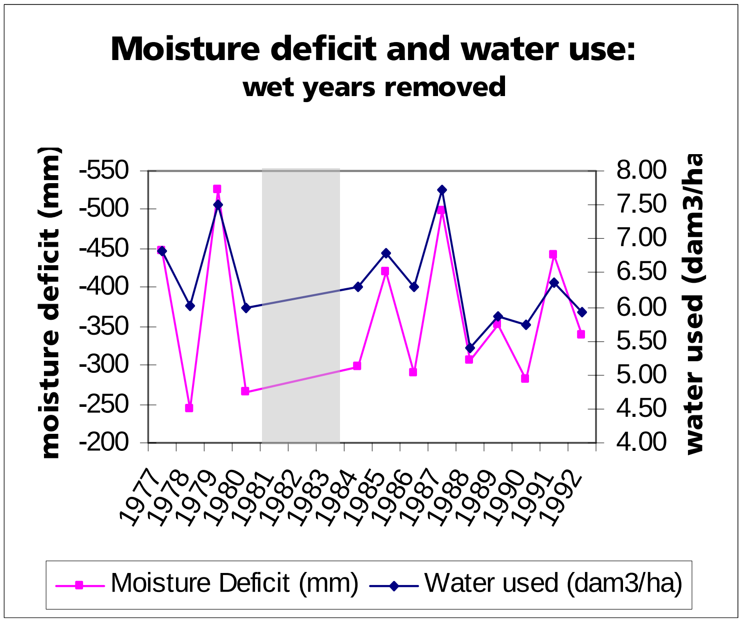

Figure 1. Moisture deficit and water use. The calibration period for the regression analysis ran from 1977 to 1993, with wet years (1981, 1982, 1983, 1993) removed. They clearly move in parallel, although there is a long-term increase in moisture deficit while there is a long-term decline in water use.

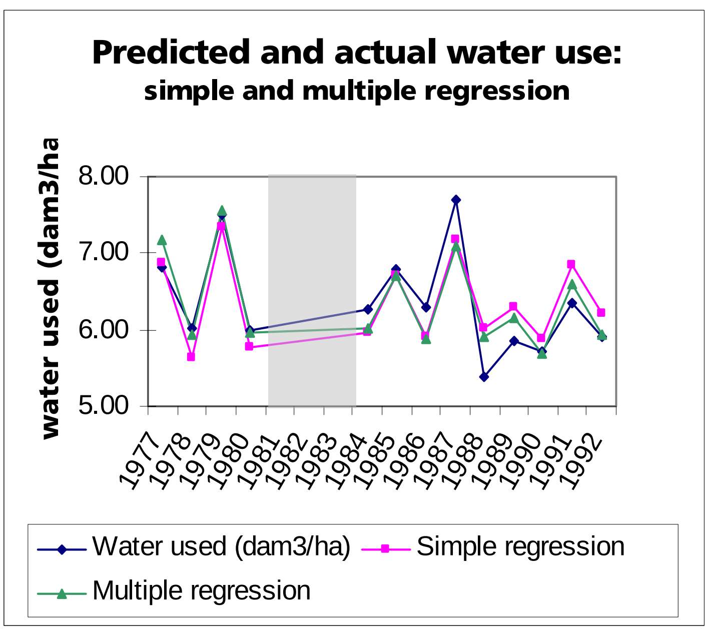

Figure 2. Predicted and actual water use during the calibration period. The multiple regression tracks actual water use more closely.

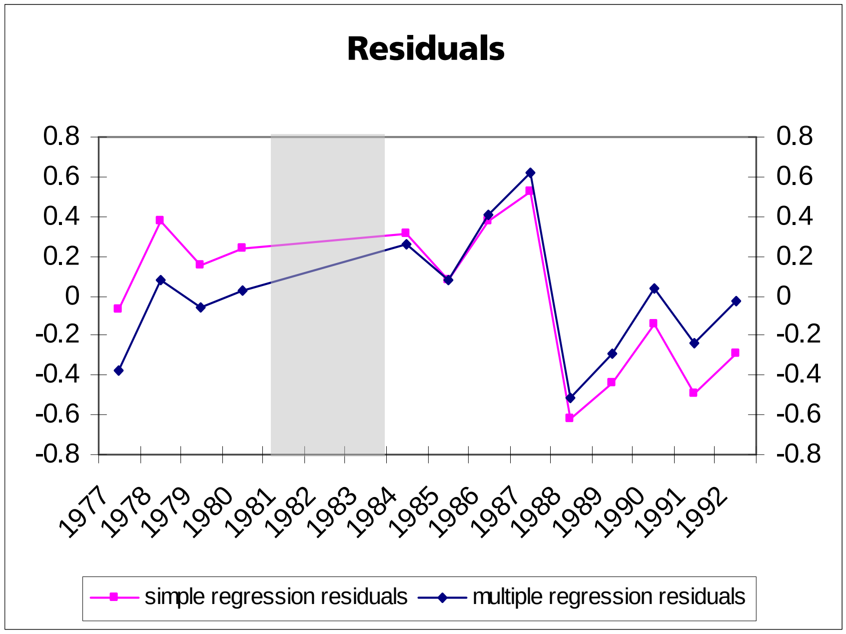

Figure 3. The residuals from the two regressions. The multiple regression residuals are smaller than the simple regression residuals. The temporal trend in both regression residuals is clear.

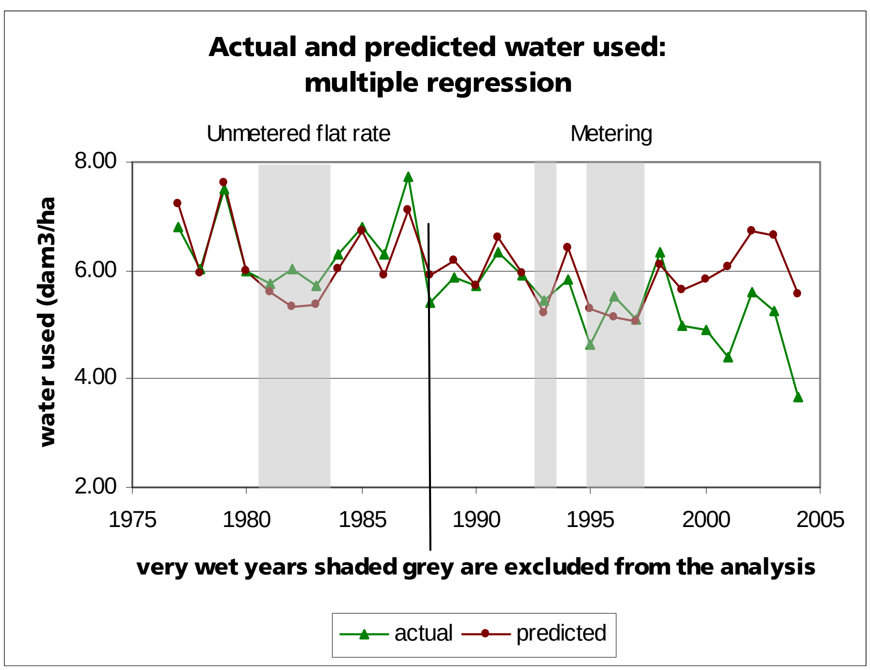

Figure 4. The multiple regression provides a function which can be used to project water use into the metering and pricing period, based solely on trends and relationships established during the calibration period. The regression is a strong predictor of water use until the introduction of pricing.

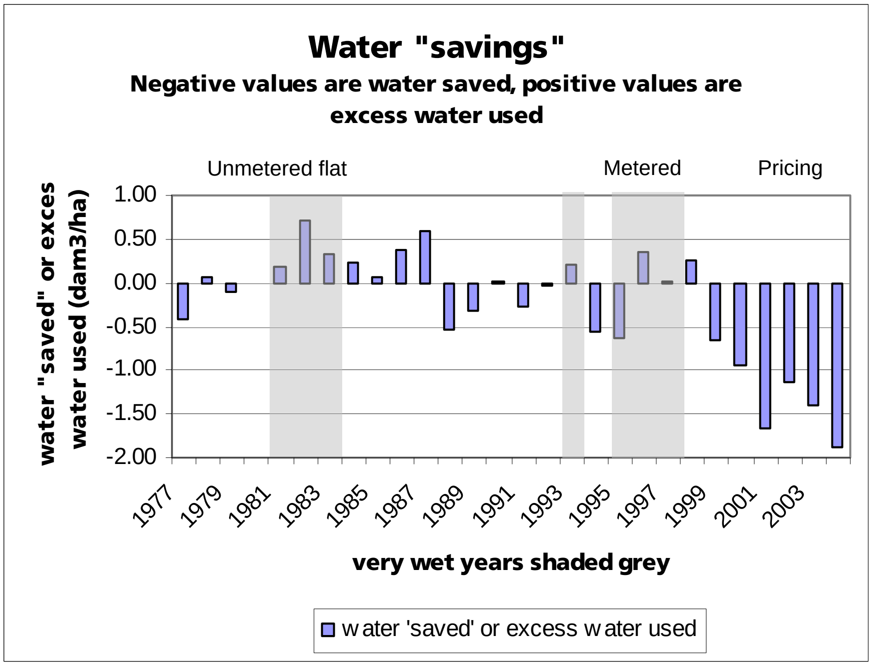

Figure 5. The residuals from the multiple regression projected through the period of metering and pricing again show no real change in the relationship between water use and weather after the introduction of metering but show a strong impact of pricing.

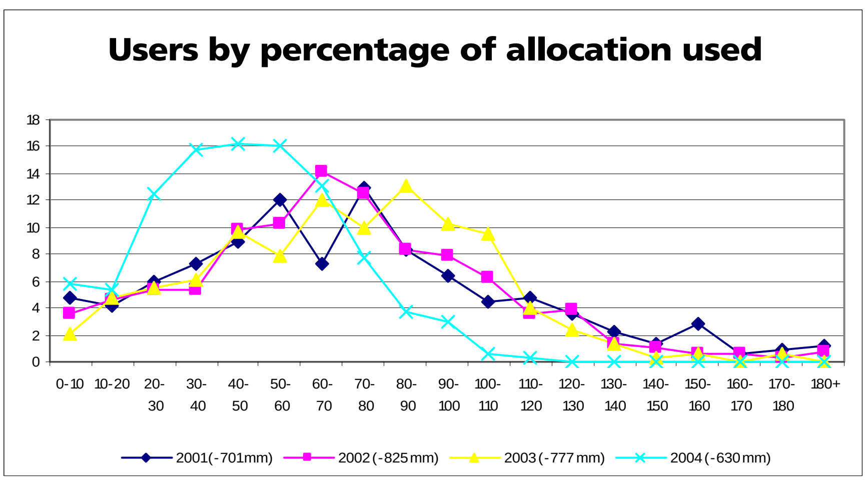

Figure 6. The percentage of users exceeding their allotments declined in 2004. This was the wettest of the four years for which these data are available.

SEKID drought and water use							
year	Kelowna moisture deficit (mm)	SEKID area of water rights (ha)	SEKID water used (dam³/ha)	pred. use (simple regression; dam³/ha)	residuals	pred. use (multiple regression; dam³/ha)	residuals
1977	-447.6	1793	6.81	6.88	-0.07	7.22	-0.41
1978	-244.3	1827	6.02	5.64	0.38	5.96	0.06
1979	-524.6	1828	7.50	7.35	0.15	7.60	-0.10
1980	-264.2	1832	6.00	5.76	0.24	6.00	0.00
1981	-202.0	1880	5.77	5.38	0.39	5.58	0.19
1982	-166.6	1884	6.04	5.17	0.88	5.33	0.71
1983	-179.8	1892	5.71	5.25	0.46	5.37	0.34
1984	-298.7	1904	6.28	5.97	0.31	6.04	0.24
1985	-419.0	1923	6.78	6.71	0.08	6.72	0.06
1986	-289.3	1941	6.29	5.91	0.38	5.91	0.38
1987	-498.4	1961	7.71	7.19	0.52	7.12	0.59
1988	-305.1	1971	5.39	6.01	-0.62	5.92	-0.53
1989	-352.9	1973	5.86	6.30	-0.44	6.17	-0.31
1990	-282.2	2012	5.72	5.87	-0.15	5.70	0.02
1991	-441.8	2054	6.35	6.84	-0.49	6.62	-0.27
1992	-337.9	2077	5.92	6.21	-0.30	5.96	-0.04
1993	-221.4	2091	5.44	5.50	-0.06	5.22	0.22
1994	-424.6	2154	5.84	6.74	-0.90	6.40	-0.56
1995	-246.8	2156	4.65	5.66	-1.01	5.29	-0.64
1996	-230.1	2155	5.51	5.55	-0.04	5.15	0.36
1997	-224.4	2153	5.08	5.52	-0.44	5.08	0.01
1998	-399.9	2240	6.35	6.59	-0.24	6.09	0.26
1999	-328.7	2240	4.98	6.16	-1.18	5.62	-0.65
2000	-371.5	2269	4.89	6.42	-1.53	5.84	-0.95
2001	-416.1	2274	4.41	6.69	-2.28	6.07	-1.66
2002	-532.9	2276	5.60	7.40	-1.80	6.73	-1.13
2003	-527.2	2278	5.26	7.37	-2.11	6.65	-1.39
2004	-349.0	2282	3.67	6.28	-2.61	5.54	-1.87

Table 1. Data table with regression model results and residuals. Years in grey are exceptionally wet and were not included in the analysis.

SIMPLE REGRESSION SUMMARY OUTPUT
Formula: Water use (dam^3/ha) = 4.15 dam^3/ha - 0.0061 ($mm*dam^3/ha$)*moisture deficit (mm)

Regression Statistics	
Multiple R	0.84
R Square	0.70
Adjusted R Square	0.67
Standard Error	0.39
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.8877	3.8877	25.5540	0.0004
Residual	11	1.6735	0.15214		
Total	12	5.56119			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.15232	0.4490	9.24720	1.6×10^{-6}	3.16	5.1406335
X Variable 1	-0.0061	0.0012	-5.0551	0.0004	-0.0087	-0.00343598

RESIDUAL OUTPUT

Year	*Predicted Water Use*	*Residuals*	*Standard Residuals*
1977	6.88	-0.07	-0.19
1978	5.64	0.38	1.01
1979	7.34	0.16	0.42
1980	5.76	0.24	0.64
1984	5.97	0.31	0.83
1985	6.70	0.08	0.21
1986	5.91	0.38	1.01
1987	7.19	0.52	1.40
1988	6.01	-0.62	-1.66
1989	6.30	-0.44	-1.18
1990	5.87	-0.15	-0.39
1991	6.84	-0.49	-1.31
1992	6.21	-0.29	-0.79

Table 2. Summary output for the simple regression analysis.

MULTIPLE REGRESSION SUMMARY OUTPUT
Formula: water use (dam^3/ha) = 4.57 - 0.04(yrs*dam^3/ha)*year(yrs) - 0.006(mm*dam^3/ha)*moisture deficit(mm)

Regression Statistics	
Multiple R	0.89
R Square	0.79
Adjusted R Square	0.75
Standard Error	0.34
Observations	13

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.3823	2.1912	18.5868	0.0004
Residual	10	1.1789	0.1179		
Total	12	5.5612			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.5649	0.4436	10.2900	12×10^{-6}	3.58	5.5534
X Variable 1	-0.0397	0.0194	-2.0483	0.0677	-0.083	0.0035
X Variable 2	-0.0059	0.0011	-5.5945	0.0002	-0.0083	-0.0036

RESIDUAL OUTPUT

Year	*Predicted Water Use*	*Residuals*	*Standard Residuals*
1977	7.18	-0.38	-1.21
1978	5.94	0.08	0.25
1979	7.56	-0.06	-0.19
1980	5.98	0.02	0.07
1984	6.02	0.26	0.82
1985	6.70	0.08	0.27
1986	5.89	0.40	1.29
1987	7.09	0.62	1.98
1988	5.90	-0.51	-1.63
1989	6.15	-0.29	-0.92
1990	5.69	0.04	0.12
1991	6.59	-0.24	-0.77
1992	5.94	-0.02	-0.07

Table 3. Summary output for multiple regression analysis.