

# Household Water Conservation: Who Do You Talk To?

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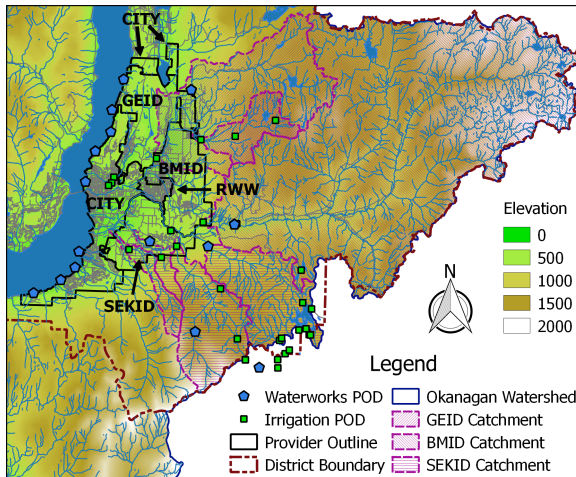
# Location

- Kelowna, British Columbia, Canada
  - Semi-arid: ~320mm annual precipitation.
  - Rapid population growth: 9.3% growth, 2006 to 2011.
    - 107,280 →117,310.
  - Vulnerable to climate change.

# Water Providers

- Five water providers.
  - Volumetric pricing, two.
    - Groundwater or lake source, little shortage risk.
    - Marginal costs include pumping costs.
  - Flat fee, three.
    - Upland reservoir source, significant shortage risk.
    - Gravity fed, no pumping costs.

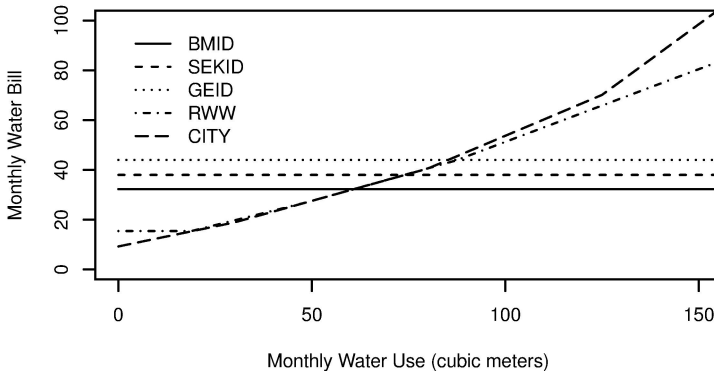
# Water Providers



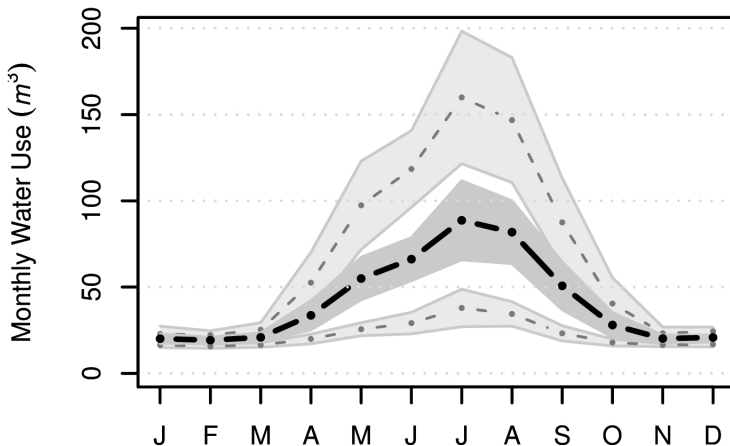


# Water Rates

## Kelowna Household Water Expenditure Schedules

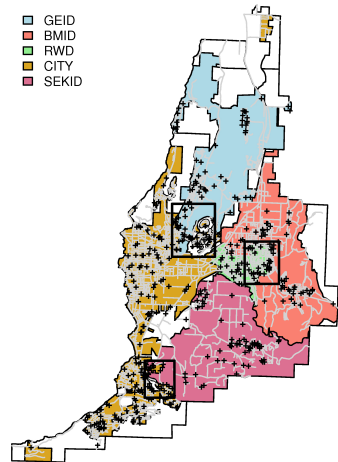


# Water Use



# Data Collection

- Mixed mode survey (telephone, internet, mail).
  - Initially telephone and internet, changed to mail and internet.
- Summer 2009 to autumn 2010.
- 2273 contacted, 512 completed.
  - Response rate ~25%
  - Not in service, respondent moved, etc.,



# Survey Elements

- 1 Household characteristics  
Ownership, type of house, occupants, ...
- 2 Water source  
Provider, treated, bottled, ...
- 3 Water quality  
Aesthetics, perceived risk, ...
- 4 Water conservation  
Indoor, outdoor, behaviors, message sources.
- 5 Water issue familiarity  
Knowledge about Okanagan water issues.
- 6 Views on the environment
- 7 Behavior of others
- 8 Perceptions of Okanagan water issues.
- 9 Demographics

# Water Perceptions and Use of Alternatives

Variable	BMID	CITY	GEID	OTHER	RWW	SEKID
ABUND (516)	3.15 <sup>ab</sup>	3.08 <sup>ab</sup>	<b>3.31<sup>a</sup></b>	2.83 <sup>ab</sup>	2.88 <sup>ab</sup>	<b>2.71<sup>b</sup></b>
QUAL (516)	2.25 <sup>a</sup>	<b>1.62<sup>a</sup></b>	6.05 <sup>b</sup>	2.00 <sup>a</sup>	2.43 <sup>a</sup>	<b>8.30<sup>c</sup></b>
RISKS (516)	1.68 <sup>ab</sup>	1.26 <sup>ab</sup>	1.76 <sup>a</sup>	<b>0.44<sup>b</sup></b>	0.91 <sup>ab</sup>	<b>1.77<sup>a</sup></b>
ALT_WAT (516)	0.12 <sup>ab</sup>	<b>0.10<sup>a</sup></b>	0.13 <sup>ab</sup>	0.19 <sup>ab</sup>	0.11 <sup>ab</sup>	<b>0.33<sup>b</sup></b>

- In SEKID, more quality and scarcity fears, more likely to use alternatives.
- Own source, believe safe.

# Demographics, Knowledge and Attitudes

Variable	BMID	CITY	GEID	OTHER	RWW	SEKID
EDUC (483)	3.17 <sup>bc</sup>	<b>4.04<sup>a</sup></b>	3.51 <sup>ab</sup>	4.00 <sup>ab</sup>	<b>2.41<sup>c</sup></b>	3.74 <sup>ab</sup>
INCOME (423)	68.7 <sup>ab</sup>	89.0 <sup>a</sup>	78.1 <sup>ab</sup>	<b>132<sup>c</sup></b>	<b>52.0<sup>b</sup></b>	87.0 <sup>ac</sup>
KNOW (506)	0.34	0.31	0.31	0.35	0.28	0.37
NEP (516)	5.00	4.98	4.84	4.86	5.13	5.12

- Rutland, low education, income. Own source high income.
- No difference in local knowledge or environmental attitude.

# Indoor Conservation

<i>N</i>	Tap Aerator	<b>Low fl. Shower</b>	Low fl. Toilet
516	196	<b>366</b>	294
1.00	0.38	<b>0.71</b>	0.57

	Effic. Washer	Effic. D. Washer	<b>Grey System</b>
	245	212	<b>5</b>
	0.47	0.41	<b>0.01</b>

# Outdoor Conservation

<i>N</i>	Less Yard	Low wat. Grass	Moisture Probe	<b>Timed Irrig</b>	Rain Barrel
516	261	69	12	<b>356</b>	61
1.00	0.51	0.13	0.02	<b>0.69</b>	0.12
	<b>Grey System</b>	Soil Amend	Pool Cover	Gravel	Xeriscape
	<b>2</b>	200	58	164	134
	<b>0.00</b>	0.39	0.11	0.32	0.26



# Conservation Behaviors

<i>N</i>	Scrape Dishes	Wash in Basin	Off Teeth
516	257	203	414
1.00	0.50	0.39	0.80

<b>Shower Off</b>	Yellow Mellow	D. Washer Full	<b>Washer Full</b>
<b>74</b>	248	435	<b>455</b>
<b>0.14</b>	0.48	0.84	<b>0.88</b>

# Conservation Message Sources

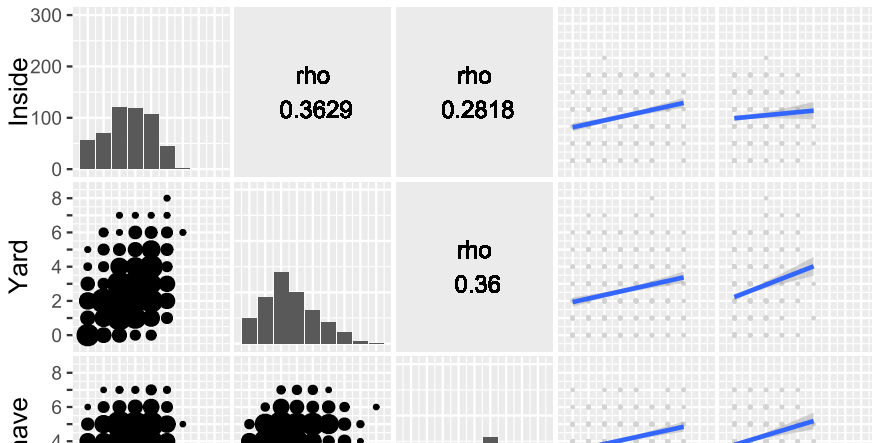
Private		Social	
Water bill	302	Community events	90
Utility bill	122	Place of worship	13
Unsolicited mail	152	School or public event	55
Ads in print	210	Neighbours or friends	187
News in print	334	Family members	117
Radio or TV	324		
Demonstrations	88		

# Conservation Choices and Conservation Messages

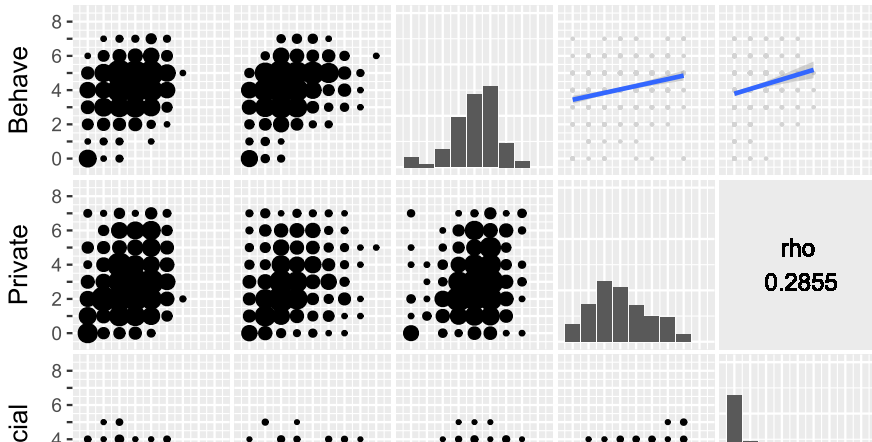
Variable	BMID	CITY	GEID	OTHER	RWW	SEKID
IN_HSE (516)	2.75	2.62	2.44	2.25	2.43	2.66
ON_YRD (516)	2.52	2.59	2.51	2.69	2.49	2.80
BEHAVE (516)	4.29	4.02	4.01	3.88	3.71	4.29
MSG_PRI(516)	3.12	3.06	2.93	2.75	3.03	3.10
MSG_SC (516)	0.97	0.89	0.84	1.06	1.00	0.94

- Investments (IN\_HSE, ON\_YRD), no difference.
- Behaviors, no difference.
- Noticed messages, no difference.

# Conservation Choices and Conservation Messages



# Conservation Choices and Conservation Messages



# Research Question

- Does water provider (water price) influence conservation investments and behaviors?
- Are there other variables that influence conservation investments and behaviors?
- Are there correlations between conservation investments and behaviors?

# Water Demand

- Renwick and Archibald [1998], Renwick and Green [2000]
  - Nonprice policy ubiquitous
  - Difficult to disentangle price and nonprice influence
  - Reduce demand and invest in conservation technology
- Campbell et al. [2004], Ferraro and Price [2011]
  - Free fixtures ineffective - rebound effect.
  - Ordinances effective.
  - Messages may be effective.

# Water Conservation

- Hamilton [1985]
  - People do not know own water use.
- Millock and Nauges [2010], Grafton et al. [2011]
  - Price volumetric, more likely to invest
  - Behaviors predict investment
- Dupont and Renzetti [2013]
  - Price influences conservation
  - Non-price doesn't.
  - Water conserving choices correlated



# Regression

- Identifying predictors for conditional mean

$$E(y_j | \mathbf{x}_j) = h(\mathbf{x}_j, \beta)$$

- Describe by a probabilistic relationship

$$\Pr(z \leq y_i | \mathbf{x}_j, \beta) = F(y_i | \mathbf{x}_j, \beta)$$

- Select relationship between  $\mathbf{x}_j$  and  $\beta$  and role in  $F()$ .

# Regression

- Normal  $(\mu_j, \sigma^2)$ ,  $y_j \in (-\infty, \infty)$ :

$$f(y_j) = \exp \left[ -(y_j - \mu_j)^2 / 2\sigma^2 \right] / \sqrt{2\pi\sigma^2}$$

$$\mu_j = \mathbf{x}_j^T \boldsymbol{\beta}$$

- Poisson  $(\lambda_j)$ ,  $y_j \in \{0, 1, 2, \dots, \infty\}$ :

$$\Pr(y_j = k) = \lambda_j^k \exp(-\lambda_j) / k!$$

$$\lambda_j = \exp(\mathbf{x}_j^T \boldsymbol{\beta})$$

- Negative Binomial  $(m_j, r)$ ,  $y_j \in \{0, 1, 2, \dots, \infty\}$ :

$$\Pr(y_i = k) = \left( \frac{r}{r + m_j} \right)^r \left( \frac{m_j}{r + m_j} \right)^k \frac{\Gamma(r + k)}{\Gamma(r)k!}$$

$$m_j = \exp(\mathbf{x}_j^T \boldsymbol{\beta})$$

# Copulas

- Multivariate continuous distributions can be uniquely represented by marginal distributions and a copula function (Sklar, 1959).
- A copula is a multivariate distribution function defined over a multidimensional unit simplex.

$$C(u_1, \dots, u_n) \quad u_i \in [0, 1]$$

$$C(u_1, \dots, u_n) \geq 0$$

$$C(u_1, \dots, u_n) \leq 1$$

$$C(1, \dots, 1) = 1$$

$$C(0, \dots, 0) = 0$$

# Copulas

- Any cumulative distribution function (CDF) satisfies

$$0 \leq F(y_1) \leq 1$$

- The combination

$$C(F_1(y_1), \dots, F_n(y_n))$$

is then a multivariate distribution function for  $(y_1, \dots, y_n)$ .

- The corresponding multivariate density function is

$$c(F_1(y_1), \dots, F_n(y_n))$$

# Copula Regression

- Single observation  $j$  likelihood function

$$l_{ij} = f_i(y_{ij} | \mathbf{x}_{ij}, \beta)$$

- Single observation CDF

$$F_i(y_{ij} | \mathbf{x}_{ij}, \beta_i) = \int_{-\infty}^{y_{ij}} f_i(y_{ij} | \mathbf{x}_{ij}, \beta)$$

- Multivariate distribution function

$$C(F_1(y_{1j} | \mathbf{x}_{1j}, \beta_1), \dots, F_n(y_{nj} | \mathbf{x}_{nj}, \beta_n) | \theta)$$

- Multivariate likelihood of single joint observation

$$c(F_1(y_{1j} | \mathbf{x}_{1j}, \beta_1), \dots, F_n(y_{nj} | \mathbf{x}_{nj}, \beta_n) | \theta) \prod_{i=1}^n f_i(y_{ij} | \mathbf{x}_{ij}, \beta)$$

# Implementation

- Multiple observation likelihood

$$\prod_Y \left\{ c(F_1(y_{1j}|\mathbf{x}_{1j}, \beta_1), \dots, F_n(y_{nj}|\mathbf{x}_{nj}, \beta_n)|\theta) \prod_{i=1}^n f_i(y_{ij}|\mathbf{x}_{ij}, \beta) \right\}$$

- Multiple observation log likelihood

$$\sum_Y \left\{ \log c(F_1(y_{1j}|\mathbf{x}_{1j}, \beta_1), \dots, F_n(y_{nj}|\mathbf{x}_{nj}, \beta_n)|\theta) + \sum_{i=1}^n \log f_i(y_{ij}|\mathbf{x}_{ij}, \beta) \right\}$$

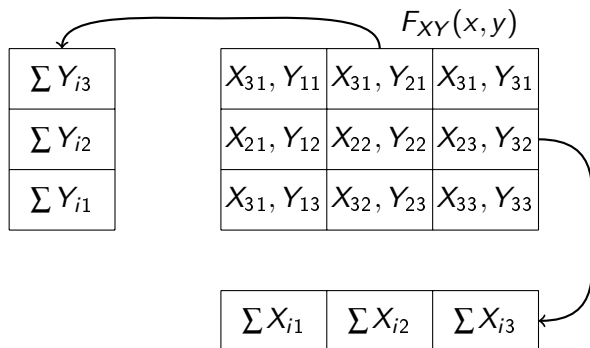
- Let a numeric optimizer do the work!

# Example

$$F_{XY}(x, y)$$

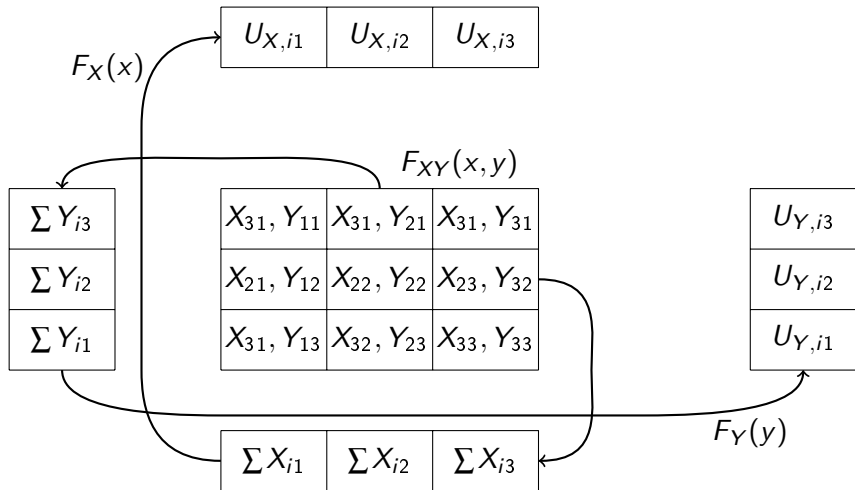
$X_{31}, Y_{11}$	$X_{31}, Y_{21}$	$X_{31}, Y_{31}$
$X_{21}, Y_{12}$	$X_{22}, Y_{22}$	$X_{23}, Y_{32}$
$X_{31}, Y_{13}$	$X_{32}, Y_{23}$	$X_{33}, Y_{33}$

# Example

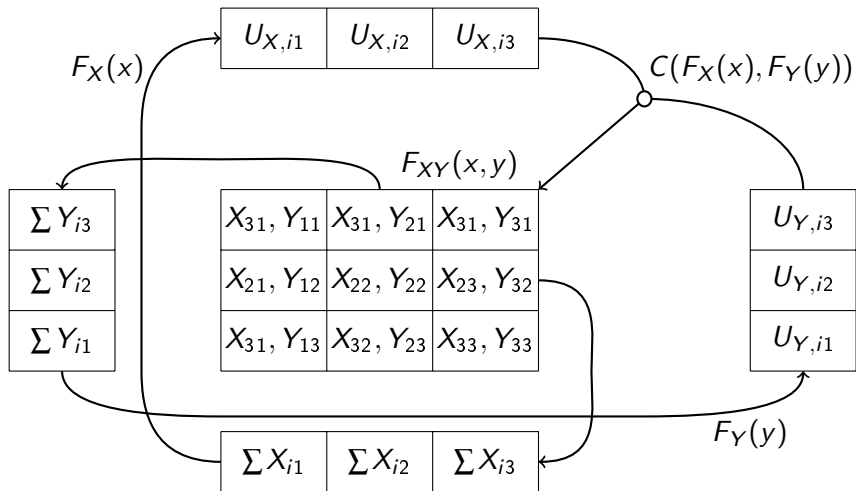




## Example



## Example



# Instrumental Variables

- Do message sources predict conservation investment, or is the correlation spurious?
  - Are those who invest in conservation also more attuned to conservation messaging?
- Use an instrument for suspect variables.
  - Instrument correlated with messages, but not correlated with source of spurious correlation.
- Build instrument from collection of other observed variables.

# Instrumental Variables

- Instruments:
  - Five dimensions of NEP
  - Behavior of others
  - Principle components for perceptions of Okanagan water issues
  - Knowledge about Okanagan water issues
  - Time living in Kelowna
  - Months of year in Kelowna
  - Alternate source or treating drinking water
  - Water quality and perceived water risk
  - Education
  - Why move to / stay in Kelowna
  - Household composition

# Variables

Name	Description
Priv	# private message sources
Soc	# social message sources
Assess	log of assessed value
Lot	log of lot size
Bld	log of building size
Baths	number of bathrooms
Beds	number of bedrooms
Age, Age <sup>2</sup>	age of building (and square)
Purv	water purveyor

# Bivariate

- IV case:
  - Univariate Log Likelihood  $(-721.05) + (-730.93) = -1,451.99$
  - Multivariate Log Likelihood  $-1443.787$
  - Likelihood ratio test  $2(LLF_R - LLF_U) \sim \chi_1^2, P < 5.113 \times 10^{-5}$
  - Correlation

$$\begin{bmatrix} 1 & 0.817 \\ 0.817 & 1 \end{bmatrix}$$

## Bivariate: Indoor

	Uni	Multi	Uni IV	Multi IV
Intercept	-0.1047	-0.1535	0.0761	0.1030
Private	0.0632***	0.0658***	0.0091	0.0107
Social	0.0027	0.0093	0.0191	0.0499
Assess	-0.0092	-0.0046	0.0060	0.0033
baths	-0.0799	-0.0601	-0.0841	-0.0763+
beds	0.0135	0.0009	0.0176	0.0106
Bld	0.1677	0.1438	0.1494	0.1303
Age	-0.0151*	-0.0138**	-0.0167*	-0.0137***
Age2	0.0002+	0.0002**	0.0002.	0.0002*
RWW	-0.0017	-0.0304	0.0582	0.0430
BMID	0.0487	0.0136	0.0556	0.0442
GEID	-0.0377	-0.0335	-0.0272	-0.0284
SEKID	0.0906	0.1196	0.1169	0.1603+
FUTURE	0.1698	0.0727	0.1260	0.1176



# Bivariate: Outdoor

	Uni	Multi	Uni IV	Multi IV
Intercept	-2.2287*	-2.1970+	-1.7921+	-1.7907
Private	0.0434*	0.0466*	0.0247	0.0528
Social	0.1156***	0.1198***	0.2562***	0.2750***
Assess	0.1806*	0.1747+	0.1734*	0.1626+
Lot	0.0610	0.0506	0.0533	0.0537
RWW	0.1126	0.1324	0.1209	0.1051
BMID	-0.0355	-0.0503	0.0288	0.0072
GEID	-0.0434	-0.0181	0.0402	0.0202
SEKID	0.0589	0.1095	0.1285	0.1579+
FUTURE	-0.0327	-0.0585	-0.0359	-0.0204



# Trivariate

- Univariate log likelihood  
 $(-721.05) + (-730.93) + (-741.53) = -2193.52$
- Multivariate Log Likelihood  $-2067.28$
- Likelihood ratio test  $2(LLF_R - LLF_U) \sim \chi_1^2$ ,  $P < 1.907 \times 10^{-54}$
- Correlation

$$\begin{bmatrix} 1 & 0.640 & 0.677 \\ 0.640 & 1 & 0.684 \\ 0.677 & 0.684 & 1 \end{bmatrix}$$

# Trivariate: Indoor

	Uni	Multi	Uni IV	Multi IV
Intercept	-0.1047	-0.0958	0.0761	0.0793
Private	0.0632***	0.0688***	0.0091	0.0128
Social	0.0027	0.0144	0.0191	0.0422
Assess	-0.0092	-0.0168	0.0060	-0.0037
baths	-0.0799	-0.0683	-0.0841	-0.0966*
beds	0.0135	-0.0058	0.0176	0.0126
Bld	0.1677	0.1500	0.1494	0.1444
Age	-0.0151*	-0.0160**	-0.0167*	-0.0193***
Age2	0.0002+	0.0003**	0.0002.	0.0003*
RWW	-0.0017	0.0058	0.0582	0.0564
BMID	0.0487	0.0423	0.0556	0.0458
GEID	-0.0377	-0.0612	-0.0272	-0.0340
SEKID	0.0906	0.1114	0.1169	0.1459
FUTURE	0.1698	0.1471	0.1260	0.1195



## Trivariate: Outdoor

	Uni	Multi	Uni IV	Multi IV
Intercept	-2.2287*	-2.2343+	-1.7921+	-1.7766
Private	0.0434*	0.0536**	0.0247	0.0401
Social	0.1156***	0.1280***	0.2562***	0.2970***
Assess	0.1806*	0.1658+	0.1734*	0.1603+
Lot	0.0610	0.0531	0.0533	0.0444
RWW	0.1126	0.1297	0.1209	0.1299
BMID	-0.0355	-0.0509	0.0288	0.0312
GEID	-0.0434	-0.0689	0.0402	0.0568
SEKID	0.0589	0.0828	0.1285	0.1579
FUTURE	-0.0327	-0.0293	-0.0359	-0.0628

# Trivariate: Behavior

	Uni	Multi	Uni IV	Multi IV
Intercept	0.6280	0.6590	0.8722	0.8875
Private	0.0419**	0.0467**	-0.0953	-0.1203
Social	0.0546*	0.0702**	0.1483**	0.1859**
Assess	0.0439	0.0240	0.0514	0.0379
RWW	-0.0284	-0.0334	-0.0385	-0.0435
BMID	0.0604	0.0525	0.0723	0.0734
GEID	-0.0080	-0.0325	0.0057	0.0013
SEKID	0.0610	0.0826	0.0829	0.0983
FUTURE	0.0299	0.0157	-0.0132	-0.0244

# Instruments

- New Ecological Paradigm
- Perceptions about other's behavior
- Attitudes towards water supply and use
- Knowledge about local water issues
- Affiliation with Kelowna
- Drinking water perceptions and choices
- Household composition
- Voting behavior
- Education

# Instruments

- Attitudes towards water supply and use.
  - Principle components reduction from 13 to 5 components
    - 1 Plenty of water, can use what I want.
    - 2 Water is scarce, urbanites should not be punished.
    - 3 Wrong to sell, pay too much now.
    - 4 In face of climate change, agriculture the priority.
    - 5 We are making things worse, but water is a basic right.

## Instruments

		Estimate	Private Std. Error	Estimate
(Intercept)		0.8274*	0.3616	-1.1620
Limits to Growth		0.0514	0.0321	0.0924
NEP	Antianthropocentrism	-0.0793*	0.0323	-0.0875
	Balance of Nature	-0.0957*	0.0409	-0.2247**
	Antiexceptionalism	0.0299	0.0349	0.0625
	Ecocrisis	0.0514	0.0356	-0.0379
	Better than Average	0.0737**	0.0277	0.0908+
Others	Others Waste	0.0041	0.0210	-0.0237
	Residents hit First	-0.0258	0.0197	-0.0458
	Most not Serious	0.0283	0.0262	0.0646
	Know a Champion	-0.0215	0.0212	-0.0880*
	Attitude #1	0.0205	0.0153	0.0491+
	Attitude #2	0.0042	0.0171	0.0338

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