Modeling Awareness & Decision Making: The Case of Climate Change & Water Resources

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Background

- Working on water resources in the MDB with Professor John Quiggin and Dr Thilak Mallawaarachchi since 2004.

- Model has had input into Garnaut Climate Change Review, SA to take VIC to high court, MDBC, MDBA, ABARES.

- I was brought into the Basin Plan process in 2011
  - My PhD changed to point out its flaws

- Initially my PhD was going to cover this topic as I was concerned that our results were misleading & that we hadn't explained the difference between SCA and existing approaches.

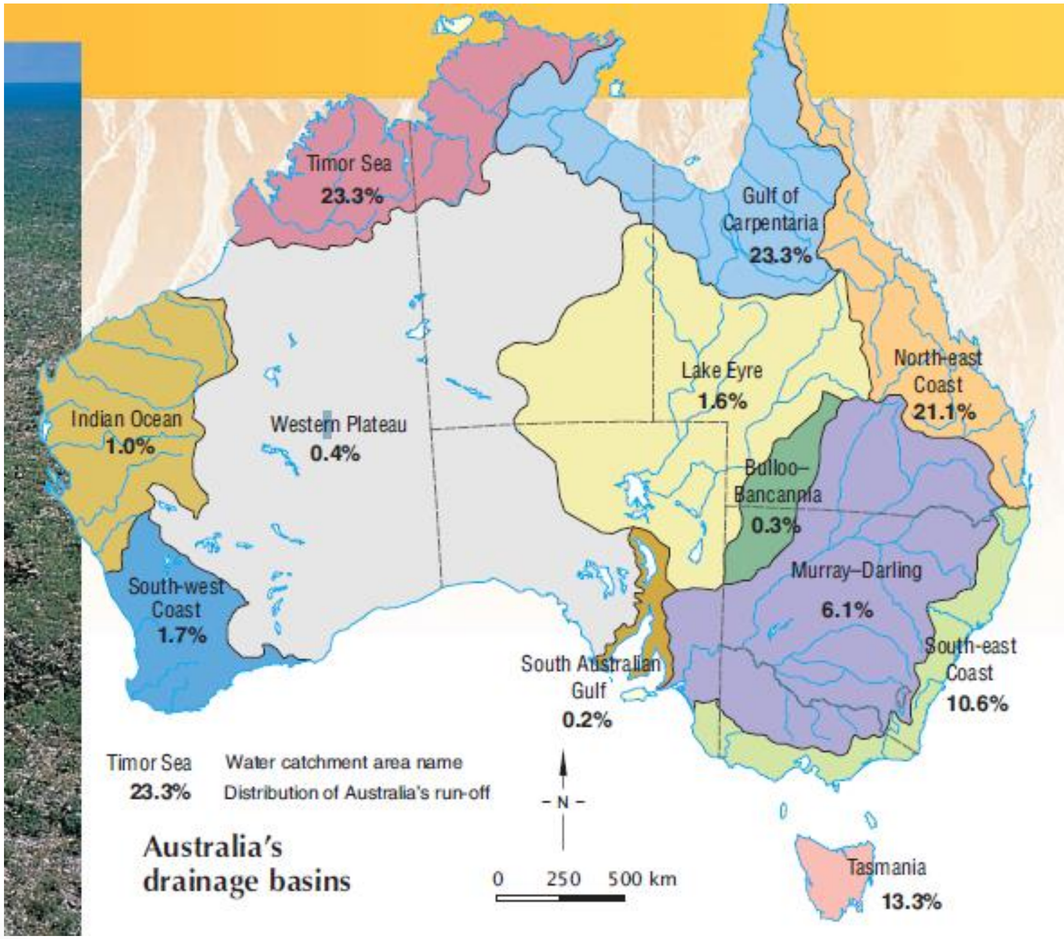
Issue

- Development of common water property rights increases economic welfare (private, public and environmental)

- But LR gains are threatened by uncertainty over the future supply of water (climate change)
  - Climate change alters total supply and the reliability of water supply but we have an incomplete description of the new problem set and the solutions to the new problem set

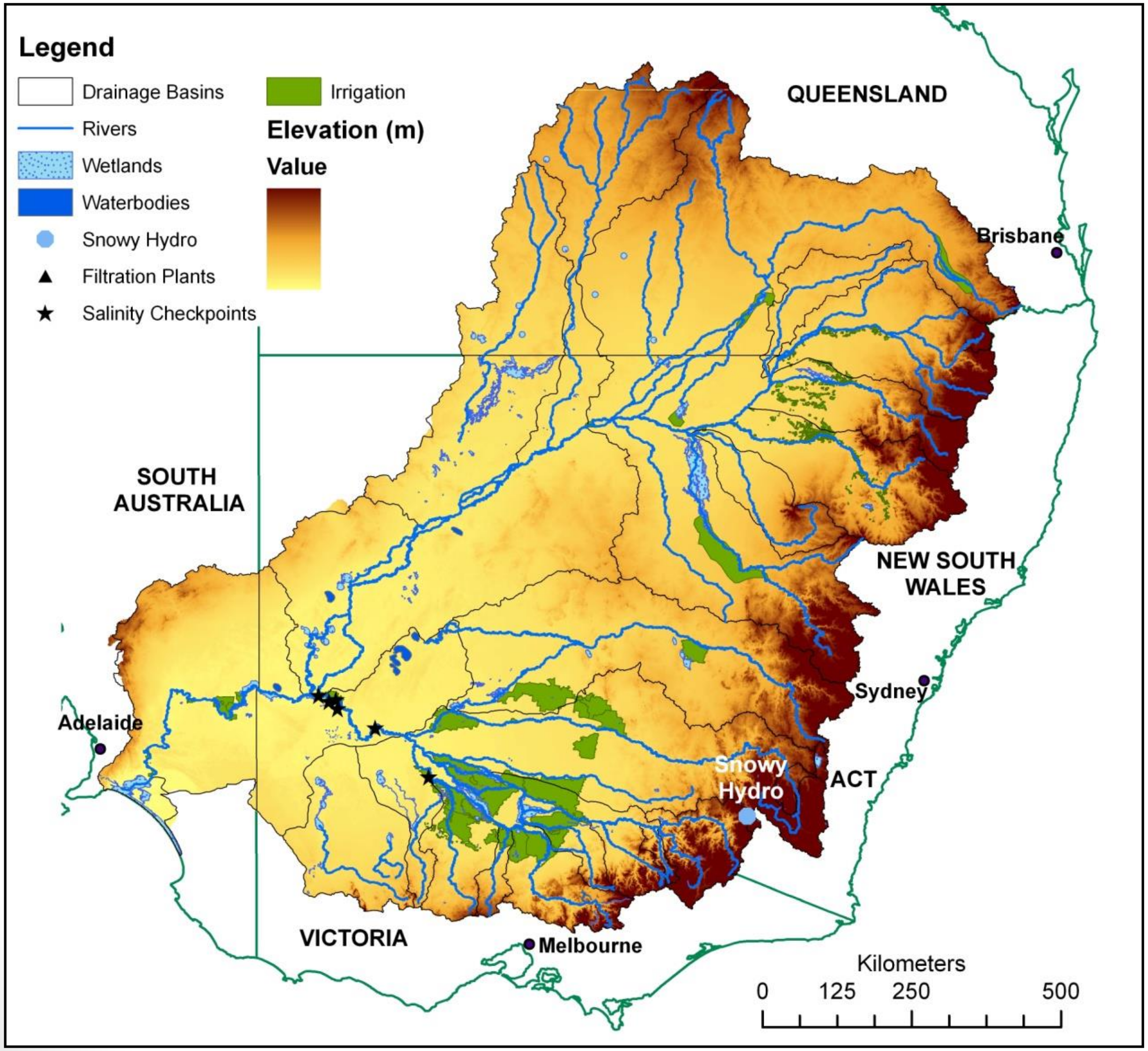
- How do we model irrigator and institutional adaption to rare or new events so that LR gains are maintained?

Murray-Darling Basin (MDB)



- 3rd largest river basin in Australia
- Yes it looks like a kidney and has the same function
- 440,000 Km^2 of river networks
- 14% of Australia's land mass

MDB



14 % of Aus but that is 1 million Km^2

- Italy 294,140 Km^2

Economic

- 40-50% GVAP
- 1/3 irrigation

Population

- 10% inside
- 5% Adelaide

Wetlands

- 30,000
- 16 Ramsar
- 25,000 Km^2

MDB Plan

- The MDB Plan aims to purchase 3,200 GL of water rights from irrigators to negate negative externalities
- But water supply in the MDB is highly variable
  - typified by drought and flood events
- Climate change is expected to reduce water supply and increase the frequency and severity of droughts.
  - Know that the problem set (water supply and reliability changes) and the solutions to that set will change but we don’t know how as yet.
  - How do we represent both institutional and private responses to new and rare events to inform policy?

Climate Change Problem

- Don't know the final emission path (or if the preferred goal of $\leq 2°C$ is possible)
  - Nov 2015 UN Climate Change Conference
  - Range of predicted outcomes for rainfall (errors, sensitivity)
  - Downscaling the rainfall predictions is complex
  - Rainfall to run off (10% decline in rainfall ≈20 - 30% reduction in runoff)
  - How realised climate variables (temperature, wind, humidity, etc) and climate patterns (La Niña and El Niño) will alter water supply and the demand for that water

- The water supply problem set will alter
  - Other factors also impact on supply

Management Response to Climate Change

- Water supply problem set alters
  - 3 outcomes: no change, more water, less water
  - Each outcome will influence the demand for water

- In a water deficient area
  - If water increases (benefit), but
  - If it become drier and freq & severity of droughts increase:
    - Placing pressure on maintaining gains from MDB Plan
  - Yes, it will still flood and we will still have good seasons

- So how do we model decisions makers (private and institutional) unawareness to the management practices in response to changing supply and demand for water

Increasing Unawareness (Taleb, 2007)

- **White Swan** = complete knowledge about future states and their contingencies (complete awareness).

- **Black Swan** = unforseen problems (complete unawareness). Can emerge from models due to bounded awareness heuristics and how tails of distributions are represented
  - Once they occur create non-linear responses

- **Grey Swan** = know the problem exists but the true definition of the problem and the appropriate contingencies are unknown.

Representing Grey Swans

- Decision makers have differential rates of learning (Grant & Quiggin (2012)
  - Aware & unaware individuals (agents) within a population (landscape)
  - Individuals do not have perfect recall
- Learning about known unknowns
  - incomplete data sets (problem & response) are best learnt about within bounds that are 'ecological rotational' (Goldstein & Gigerenzer, 2002)
- Their experience & learning about the outcomes of others can lead to rapid change (Inductive reasoning)
- Stochastic representation covers differential learning, induction reasoning & recall when these ecological rational states occur again
- But there are binding constraints which can prevent adaption

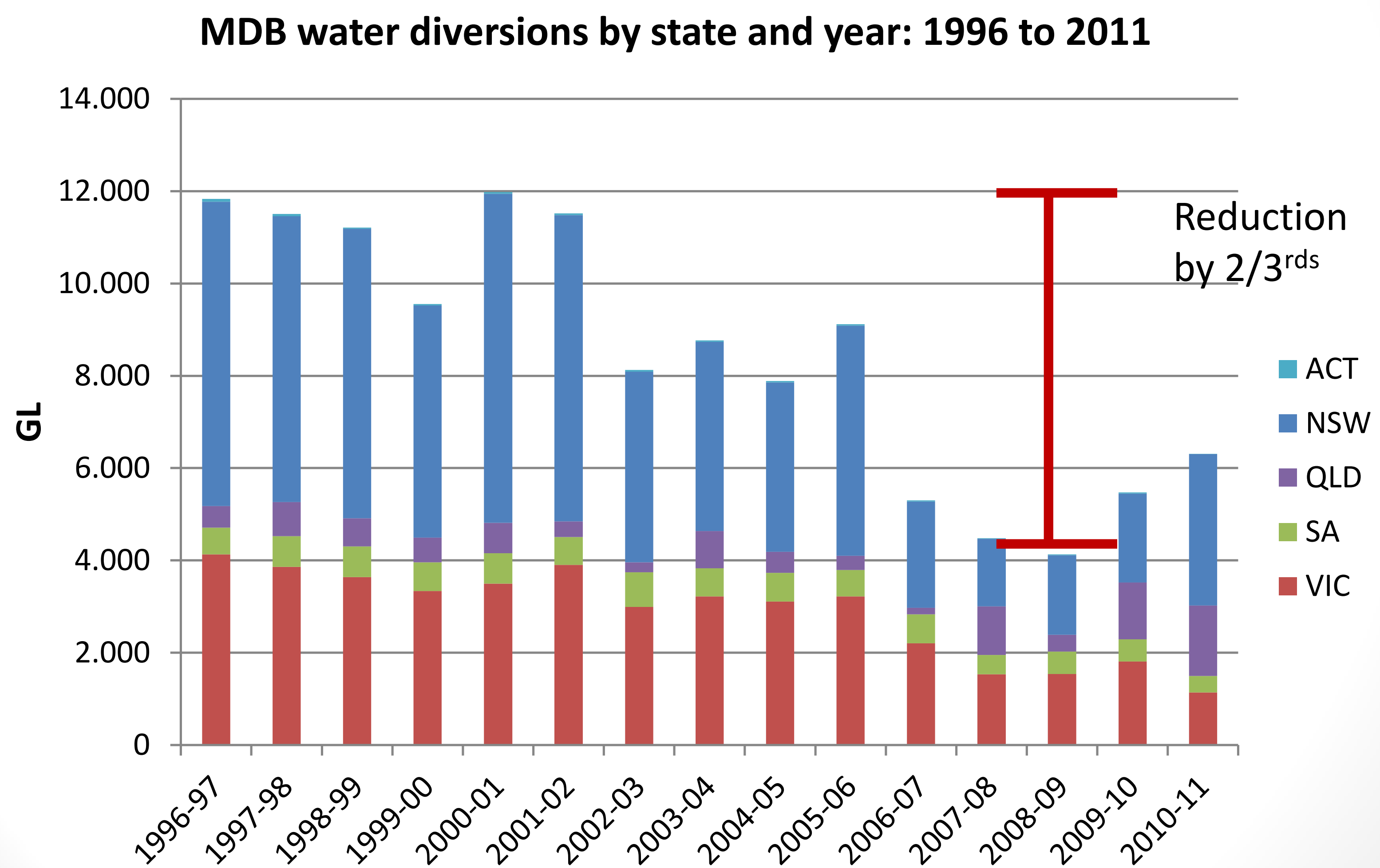
How do we model a Grey Swan

- If we represent a grey swan as a white swan we end up creating a black swan

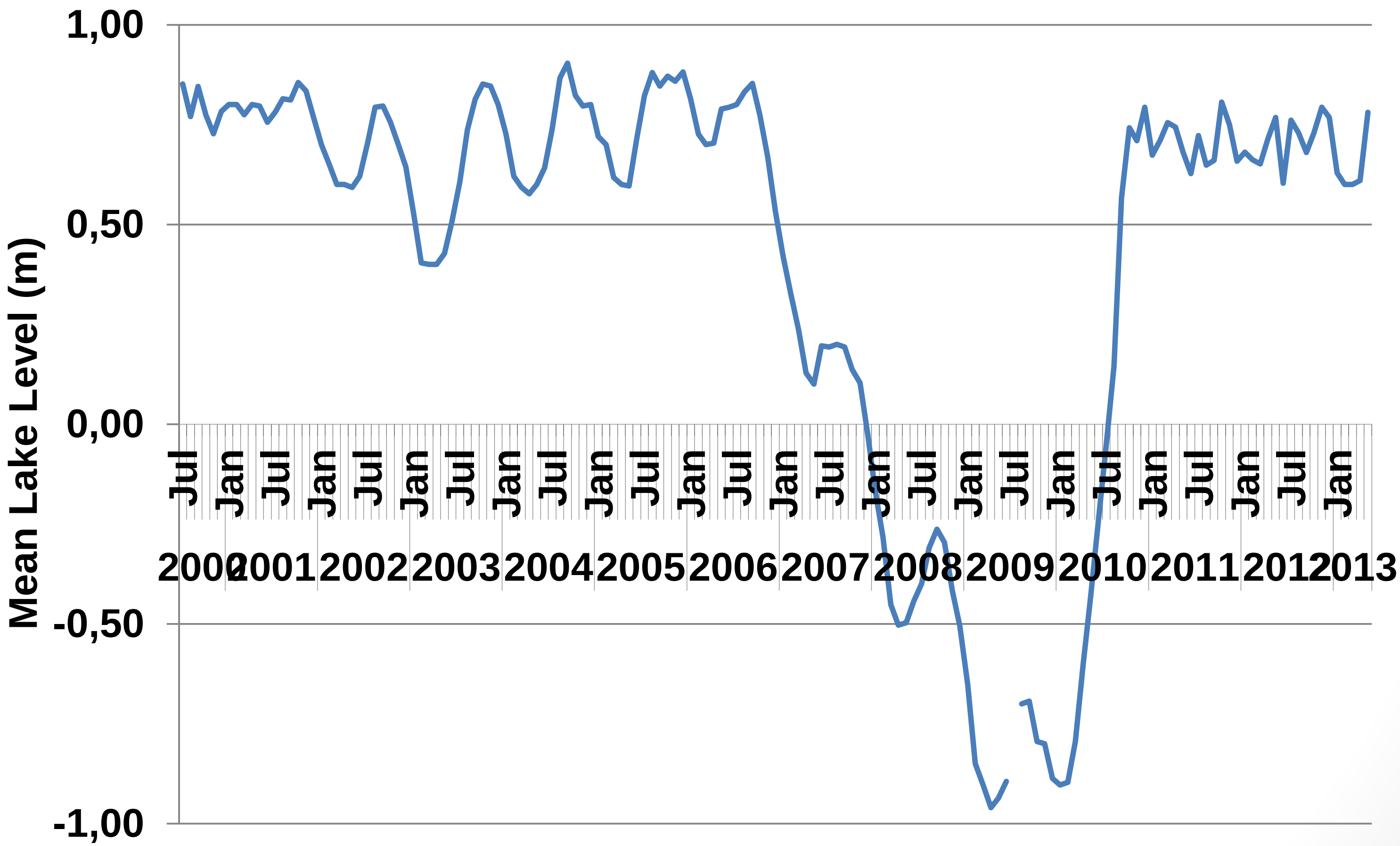
- For climate change in the MDB the Millennium Drought provided a natural experiment on adaption to climatic shocks (‘ecological rational’)

- Gained an insight into how and why people adapted as the drought unfolded
  - Value of water trade
  - Flexible production systems
  - Importance of annual commodities
  - Impact on the environment

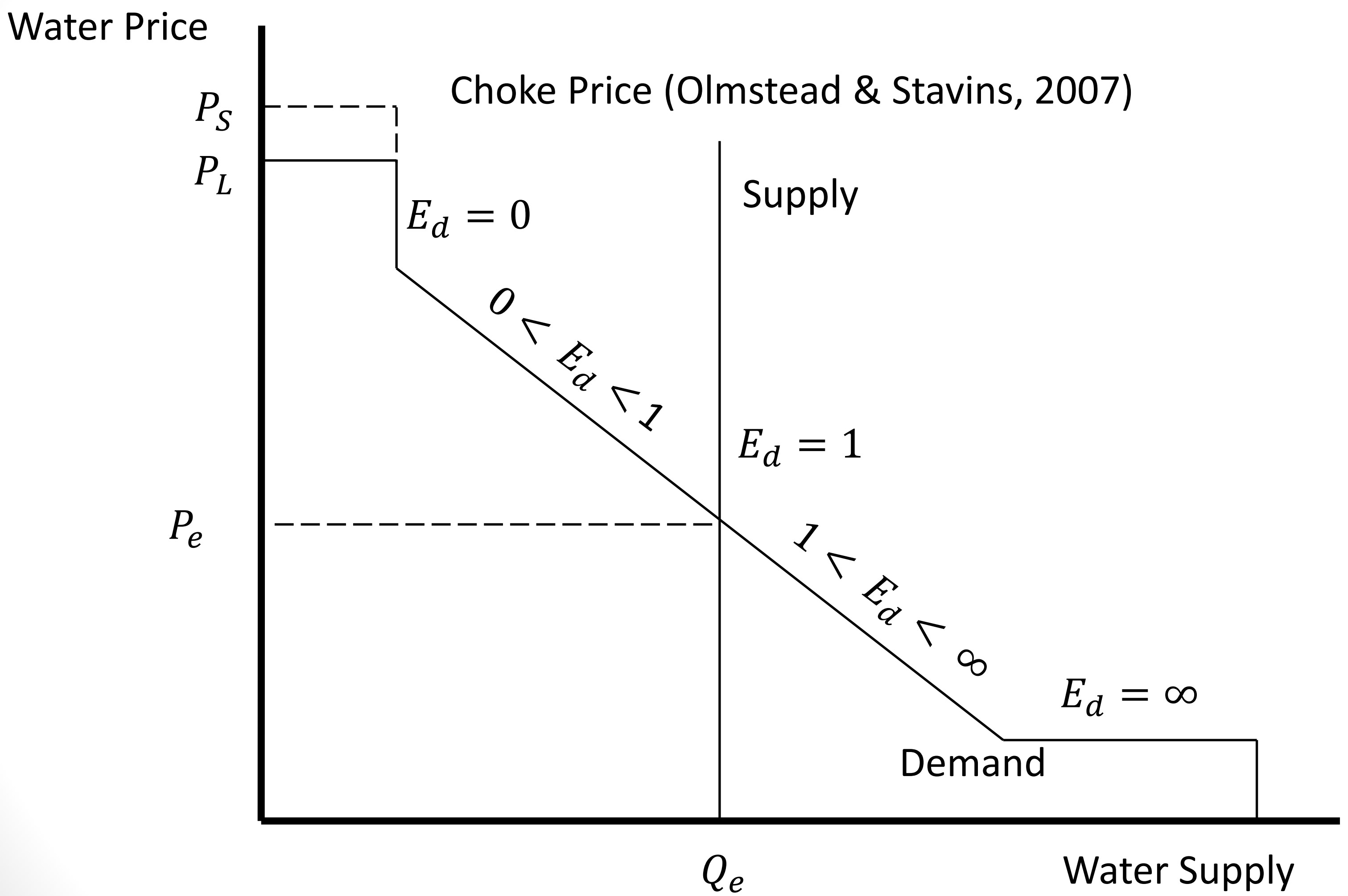
The Millennium Drought Black Swan Event



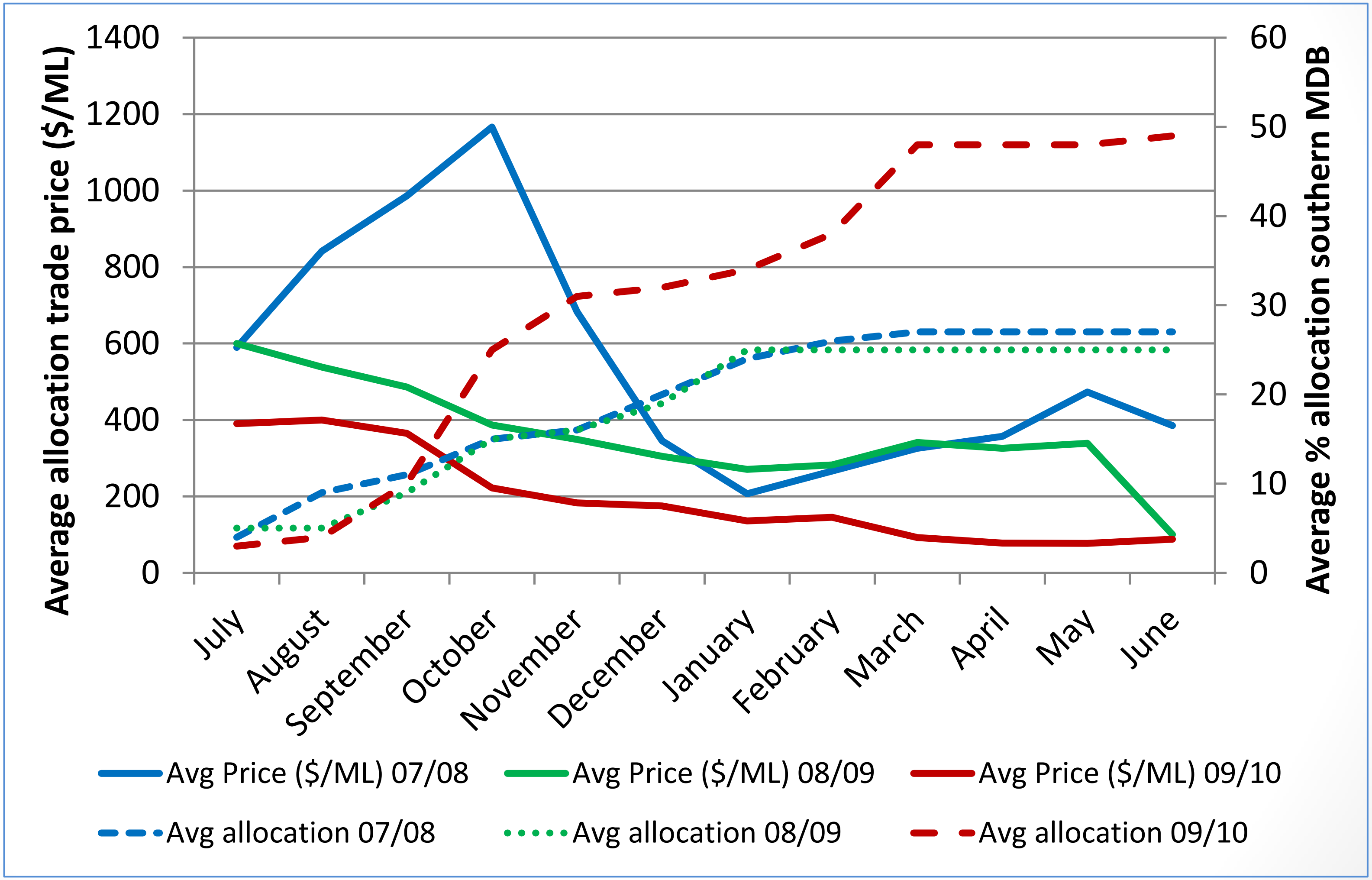
Lake Alexandrina (Coorong)



Private Demand for Water



How good is the last prior? (Inductive reasoning?)



Source: Loch (2011)

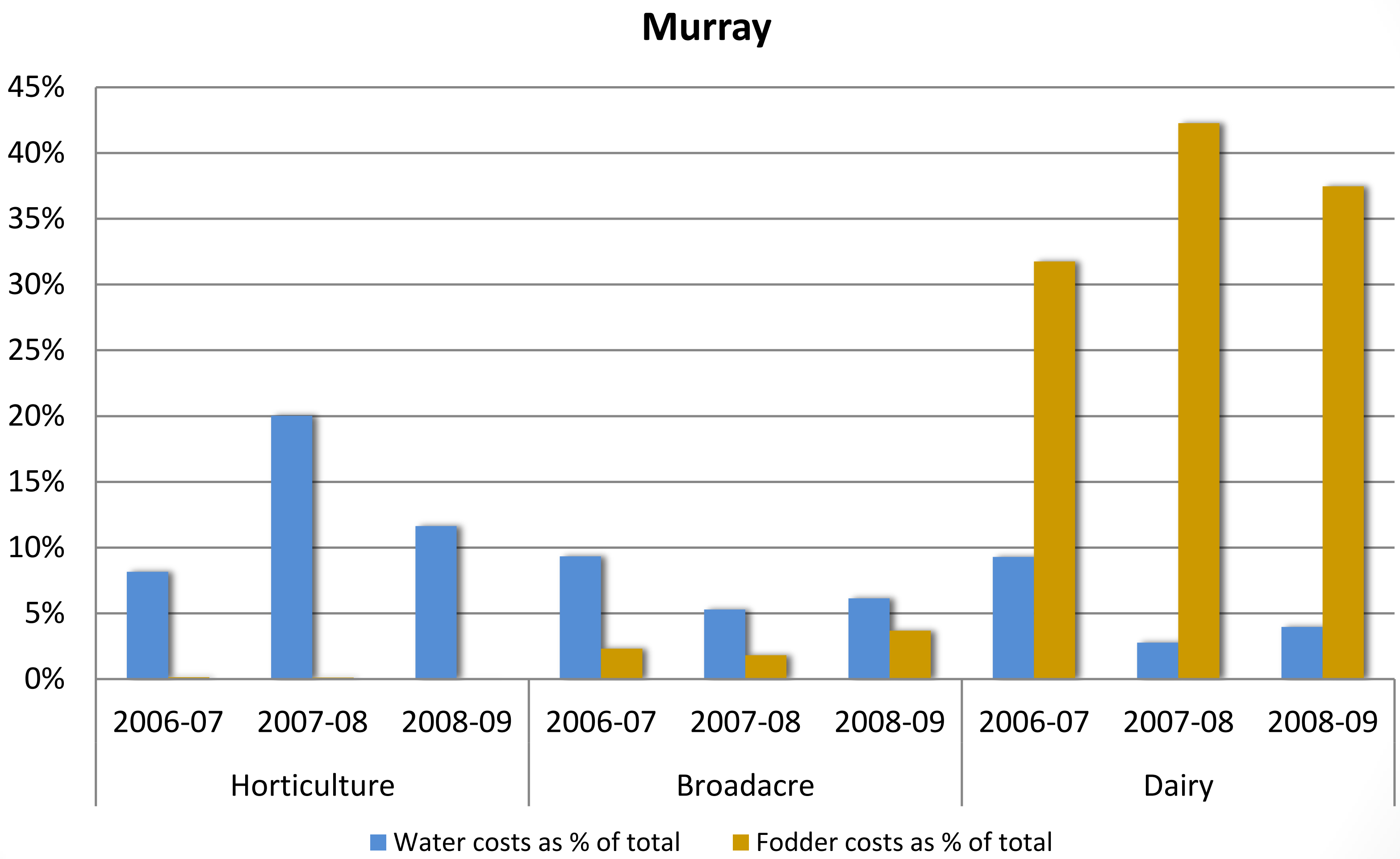
Change in Irrigated Area ('000 Ha)

Commodity group	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
Pasture for dairy and other livestock	760	707	551	669	703	717	446	365	272	393	375
Rice	178	145	44	65	51	102	20	2	7	19	74
Cereals (excl. rice)	260	354	416	340	324	329	266	291	245	216	165
Cotton	405	394	218	174	258	247	126	53	104	138	332
Grapes	84	86	89	87	92	106	112	106	101	96	94
Fruit (excl. grapes)	59	62	74	59	63	75	78	71	67	79	80
Vegetables	37	35	31	40	35	32	26	28	22	25	32
Other agriculture	41	34	43	67	62	46	52	42	111	8	3
Total Agriculture#	**1,824**	**1,817**	**1, 466**	**1,501**	**1,588**	**1,654**	**1,101**	**958**	**929**	**976**	**1,201**

Source: ABS (multiple years) Water Use on Australian Farms.

Totals may not equal the sum due to multiple cropping practices and errors in estimates

Changing Inputs (Flexibility & Annuals)



Perennials v Annuals: SR v LR response: FC v VC

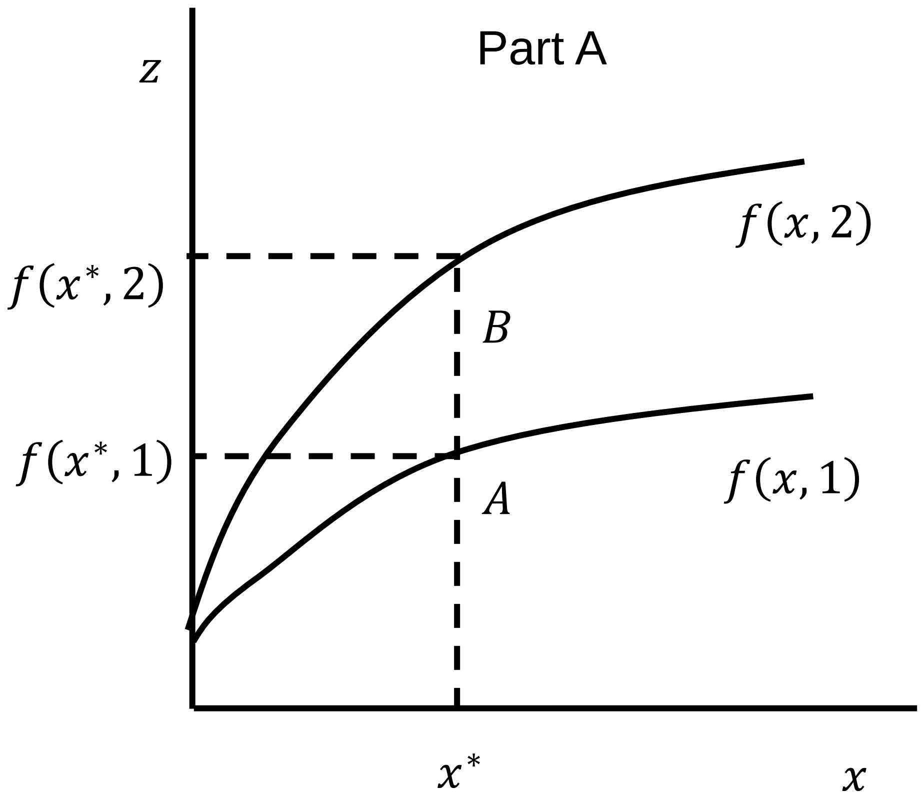
Decision Making & Uncertainty

- Just & Pope (1978) outlined the stochastic production function approach
  - Good to help explain the variation seen in nature
- Just & Pope (1979) argued that stochastic production function is
  - Very restrictive formulation as changes in inputs directly relate to variance in output; and
  - Consequently provides little help in understanding policies designed to reduce the risk to output
- But stochastic production functions dominates the literature of risk and uncertainty when allocating resources.
- "[w]e conclude that understanding of why risk response occurs is very limited. As a result, after decades of research, the profession remains in a weak position to offer definitive policy analyses in matters related to risk" (Just & Pope 2003, p. 1255).

Stochastic Production Function

Generalised Form $Z = f(x, \varepsilon)$

Z = output, x = input, ε is error used to defined to create distribution



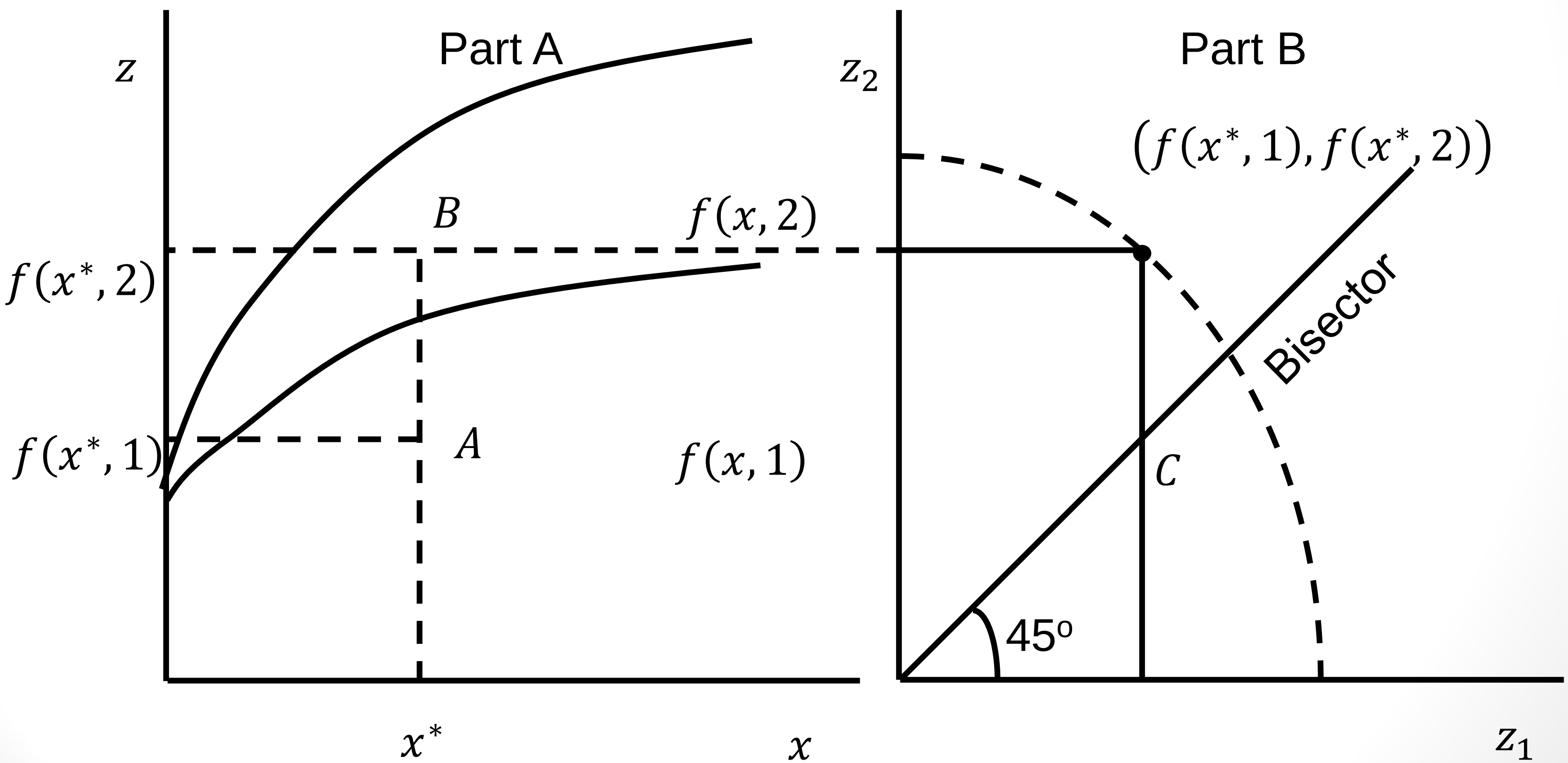
State Contingent Analysis

- Foundations are derived from Arrow (1953) and Debru (1959) work on state-space:
  - Nature = provides a complete description of the state-space of uncertainty $(S \epsilon \mathbf{\Omega})$
  - possible states (s) are exhaustive, mutually exclusive, and real
- Chambers & Quiggin(2000) expanded on this
  - dual optimisation
  - Decision maker has no ability to control what state occurs
  - Each s has unique management response, yields, prices, inputs and outputs
    - Grapes & dairy
  - Provides a mechanism for dealing with discontinuous functions (non-convexity)
  - Once a state is revelled all uncertainty disappears allowing for traditional approaches to deal with risk to be used
- Separates the environmental signal from the management action

Stochastic v SCA

Generalised Form $\boldsymbol{z_S} = \boldsymbol{f_s}(\boldsymbol{x}) \qquad \boldsymbol{s} \in \boldsymbol{\Omega} = \{\mathbf{1}, \ldots, \boldsymbol{S}\}$

Z = output, S = state of nature, x = input



But.. Can have Stochastic SCA

Clear rules associated for stochastic SCA

Both output derived from input use

- $X(z)$ is closed for all $\Re_{+}^{S}$

This provides defined upper and lower bounds to the output sets.

- $X(\mathbf{z})$ is closed for all $\mathbf{z} \in \boldsymbol{\Re}_{+}^{\boldsymbol{M}}$

- I will also argue that the SON is also stochastic as climatic signals are not the same for each producer.

My Tasks

1. Need to examine and explain the difference between the
   - State Contingent Approach (SCA) versus Expected Value (EV)
   - Aware versus an unaware individual

2. Examine the outcomes from developing a stochastic SCA approach
   - Define the state of nature
   - Inputs required by that state of nature
   - What can we learn for policy (institutional goals of the MDB)

3. What is the predictive power of the alternatives to look at climate change
   - Current climate (D=0.2, N =0.5, W=0.3)
   - Climate change: 550 Avg, 2050 (Garnaut)
   - Current climate: Frequency of droughts (D=0.3, N =0.5, W=0.2)

Binding Constraints

- Water
- Water
- Water

- If water is still over allocated to Ag production then irreversible consequences (social, economic and environmental) will occur

- If a solution can not provide sufficient water to grow crops, meet human needs and environmental objectives then economic welfare is lost. Consequently the results looks at what happens in the Drought State of nature

Existing MDB Model

- Optimization framework (dangerous)

- Model
  - Connected river flow system (conveyance loss)
  - Water and salt interaction
  - 21 catchments (19 production + Adelaide + Coorong)
  - 25 regional production systems in each catchment
  - 3 states of nature (normal, drought & wet)

Optimization Problem

Maximise Economic return from water use

subject to

- Water flow
- Production constraints
- Institutional goals
  - SDL
  - Water to environment (Coorong 1,000 GL)*
  - Potable quality (Adelaide <800 EC)

- **Solved assuming that I'm a benevolent God, acting in the national interest!**

- * old target

Optimisation framework

$$MaxE[Y] = \sum_{K} \sum_{s \in \Omega} \pi_s \left(R_{s,k} - C_{s,k}\right)$$

Symbol	Definition
$E[Y]$	Expected [Income]
K	Catchments in the Basin ($K = 1 \ldots 21$)
S	States of Nature (where $S \in \Omega = 1..3$)
π	Probability of state occurrence
R	Revenue
C	Costs (FC+ VC+ Opp Labour + capital repayment as annuity)

See Ag Water Paper (Adam Loch)

Keeps going

- A lot of equations: But the objectives functions between the four models are:

- EV, discrete: $MaxE[Y] = \sum_K (R_k - C_k)$

- EV , stochastic : $MaxE[Y, \varepsilon] = \sum_K (R_k - C_k)$

- SCA, discrete: $MaxE[Y] = \sum_K \sum_{s \in \Omega} \pi_s \left(R_{s,k} - C_{s,k}\right)$

- SCA, stochastic:
  $MaxE[Y, \varepsilon] = \sum_K \sum_{s \in \Omega} \pi_s \left(R_{s,k} - C_{s,k}\right)$

SCA & EV Modelling

- Model set to the Adamson, Quiggin & Quiggin (2011) review on the Murray-Darling Basin (Basin)
  - Allows for a comparison with other published results

- EV model v SCA
  - Discrete Normal = 1
  - Constraints for Drought and Wet don't apply
  - Adjust the production systems
    - EV = Normal state – SCA specific productions systems why
    - EV is a passive response to the signal

Production Systems

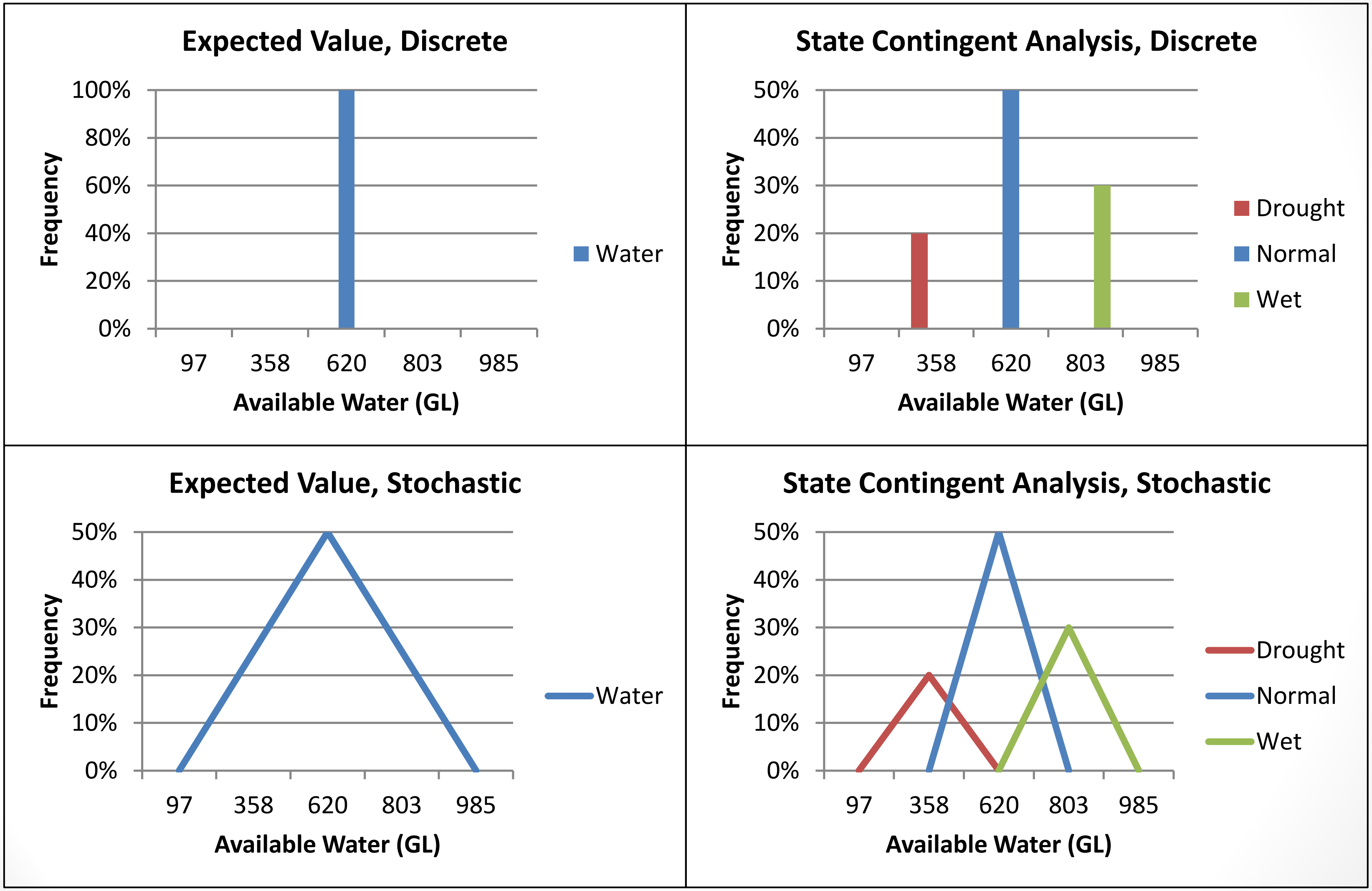
Production System Name	State Contingent Production Choice Set			Normal (EV)
	Drought	Normal	Wet	
Citrus-H	Citrus-H	Citrus-H	Citrus-H	Citrus-H
Citrus-L	Citrus-L	Citrus-L	Citrus-L	Citrus-L
Grapes	Grapes	Grapes	Grapes	Grapes
Stone Fruit-H	Stone Fruit-H	Stone Fruit-H	Stone Fruit-H	Stone Fruit-H
Stone Fruit-L	Stone Fruit-L	Stone Fruit-L	Stone Fruit-L	Stone Fruit-L
Pome Fruit	Pome Fruit	Pome Fruit	Pome Fruit	Pome Fruit
Vegetables	Melons	Vegetables	Fresh Tomatoes	Vegetables
Cotton Flex	Dryland Cotton	Cotton Flex	Cotton	
Cotton Fixed	Cotton Fixed	Cotton Fixed	Cotton Fixed	Cotton Fixed
Cotton/Chickpea	Chickpea	Cotton Flex	Cotton	
Cotton Wet	Dryland Cotton	Dryland Cotton	Cotton	
Rice PSN	Rice PSD	Rice PSN	Rice PSW	Rice PSN
Rice Flex	Dryland Wheat	Rice PSN	Rice PSW	
Rice Wet	Dryland Wheat	Dryland Wheat	Rice PSW	
Wheat	Wheat	Wheat	Wheat	Wheat
Wheat Legume (WL)	WL Dry	WL	WL Wet	WL
Sorghum	Sorghum	Sorghum	Sorghum	Sorghum
Oilseeds	Oilseeds	Oilseeds	Oilseeds	Oilseeds
Sheep Wheat (SW)	SW Dry	SW	SW Wet	SW
Dairy-H	Dairy-H	Dairy-H	Dairy-H	Dairy-H
Dairy-L	Dairy-L	Dairy-L	Dairy-L	Dairy-L

Discrete v Stochastic Modelling & Awareness

- Discrete (White Swan)

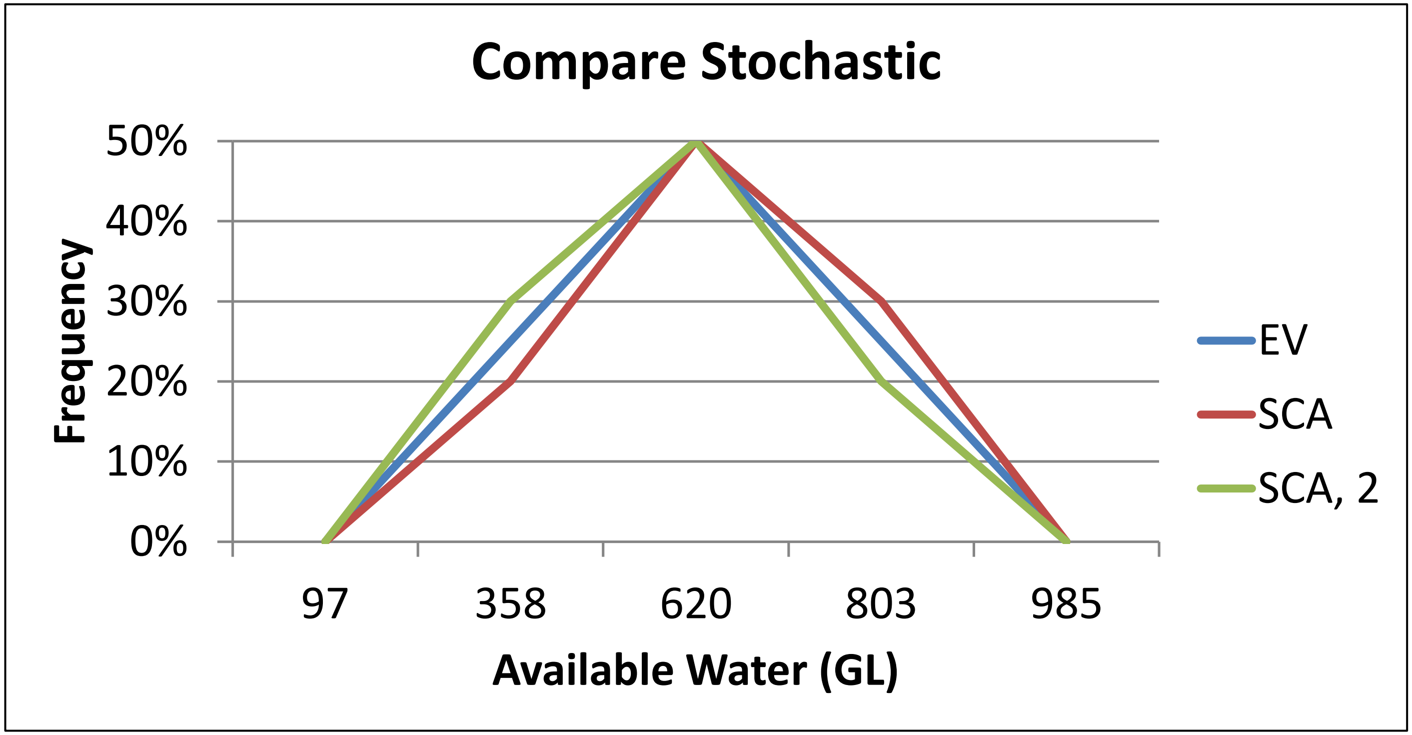
- Stochastic (Grey Swan)
  - Unaware (Ex-ante simulation) leave area set as per the Discrete Solution and then run the simulation
  - Aware (Ex-post solution) Monte Carlo optimisation using stochastic data
  - Stochastic function = triangular distribution to give hard bounds between states of nature ('ecologically rational')
  - EV model reports on the drought and wet states but is not constrained by them. Thus allowing for comparison.

Distributions, EV versus SCA



Water Data for Condamine Only

Compare Stochastic Range



- Condamine data again
- SCA, 2 change the Frequency of States
- Basically looks like noise

Discrete Results: EV v SCA

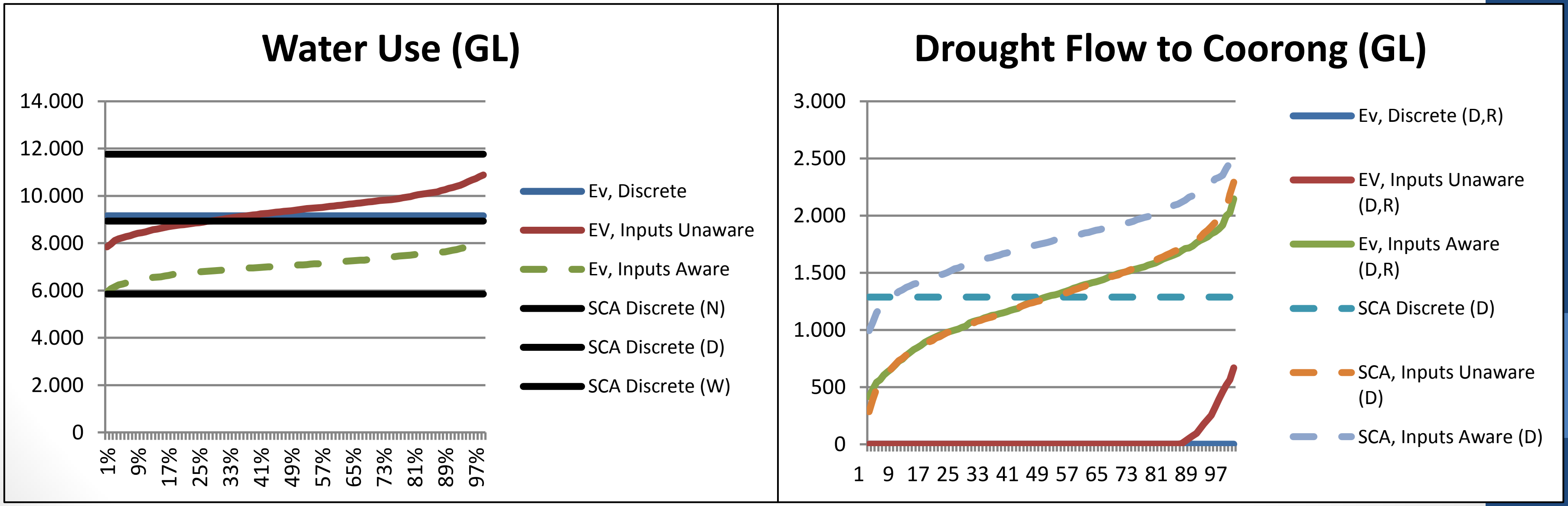
	Water (GL)		Coorong Flow (GL)		$ ('m)	
	EV	SCA	EV	SCA	EV	SCA
Drought		5,849	0	1,287		$1,085
Normal	**9,162**	8,930	6,221	6,383	**$2,591**	$2,644
Wet		11,757	11,753	10,482		$3,872
Average		**9,162**				**$2,502**

- One value for EV
  - Water on Average is the same but EV makes more on average but…

- EV solution has
  - 0 Flow in the drought = risk to capital invested in perennials
  - A lot of water not being used in good years

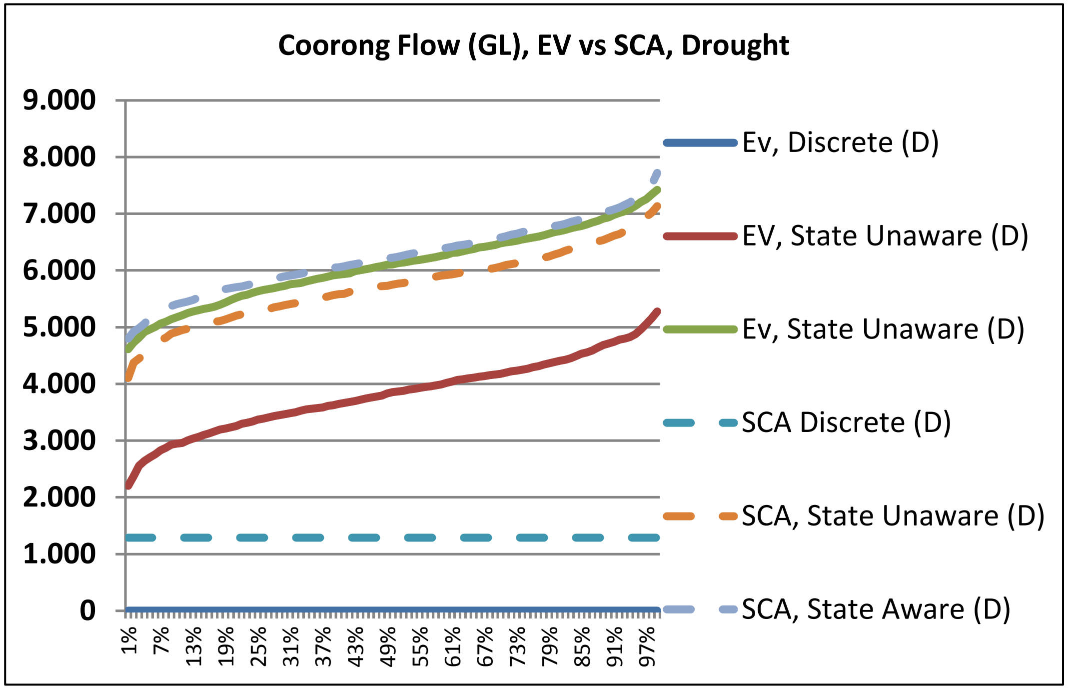
SCA v All EV: Inputs

- SCA discrete provides the bounds of the EV models stochastic water requirements
- But comes cost in the Drought
- Aware EV = Unaware SCA about input use

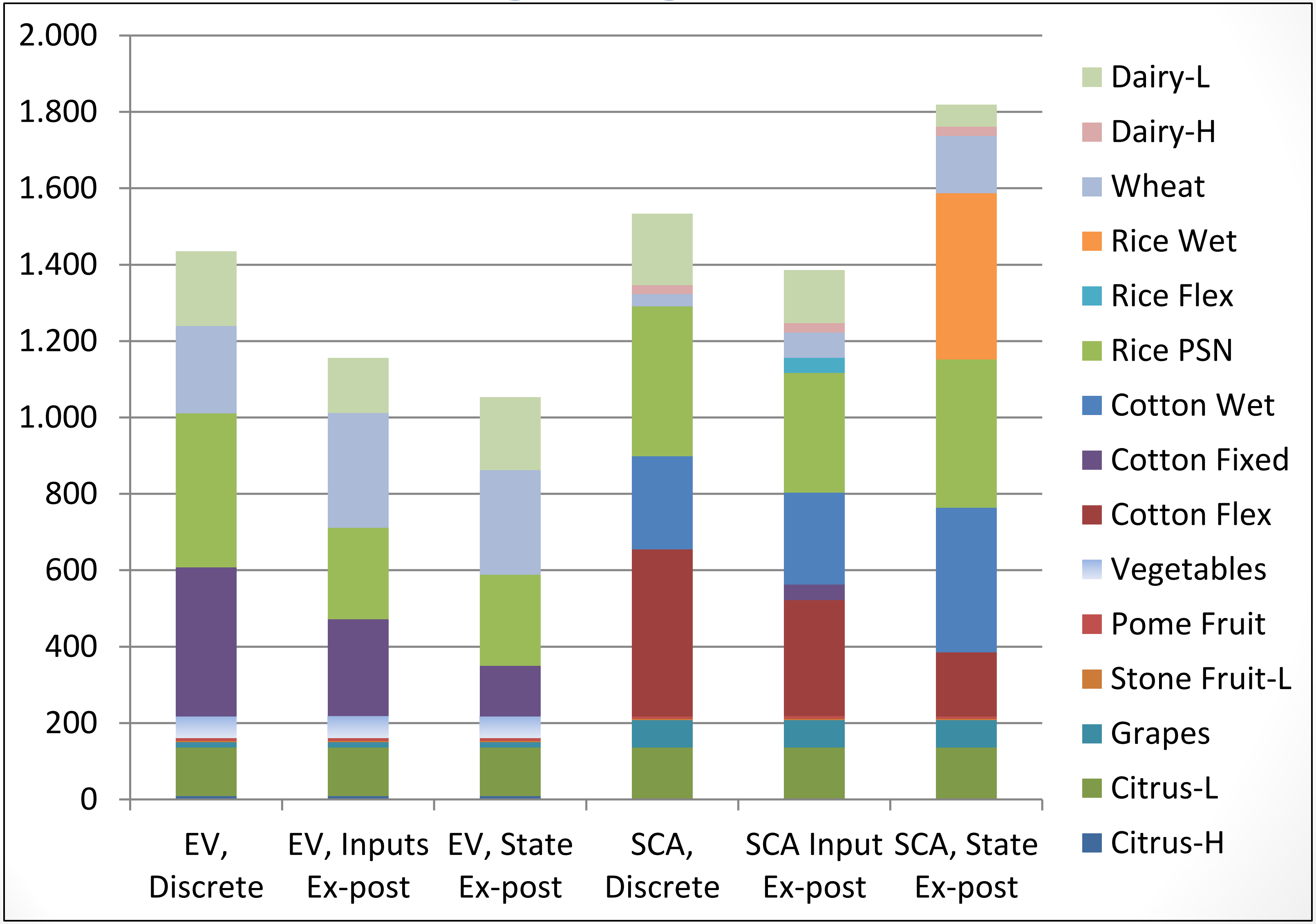


EV v SCA: State of Nature

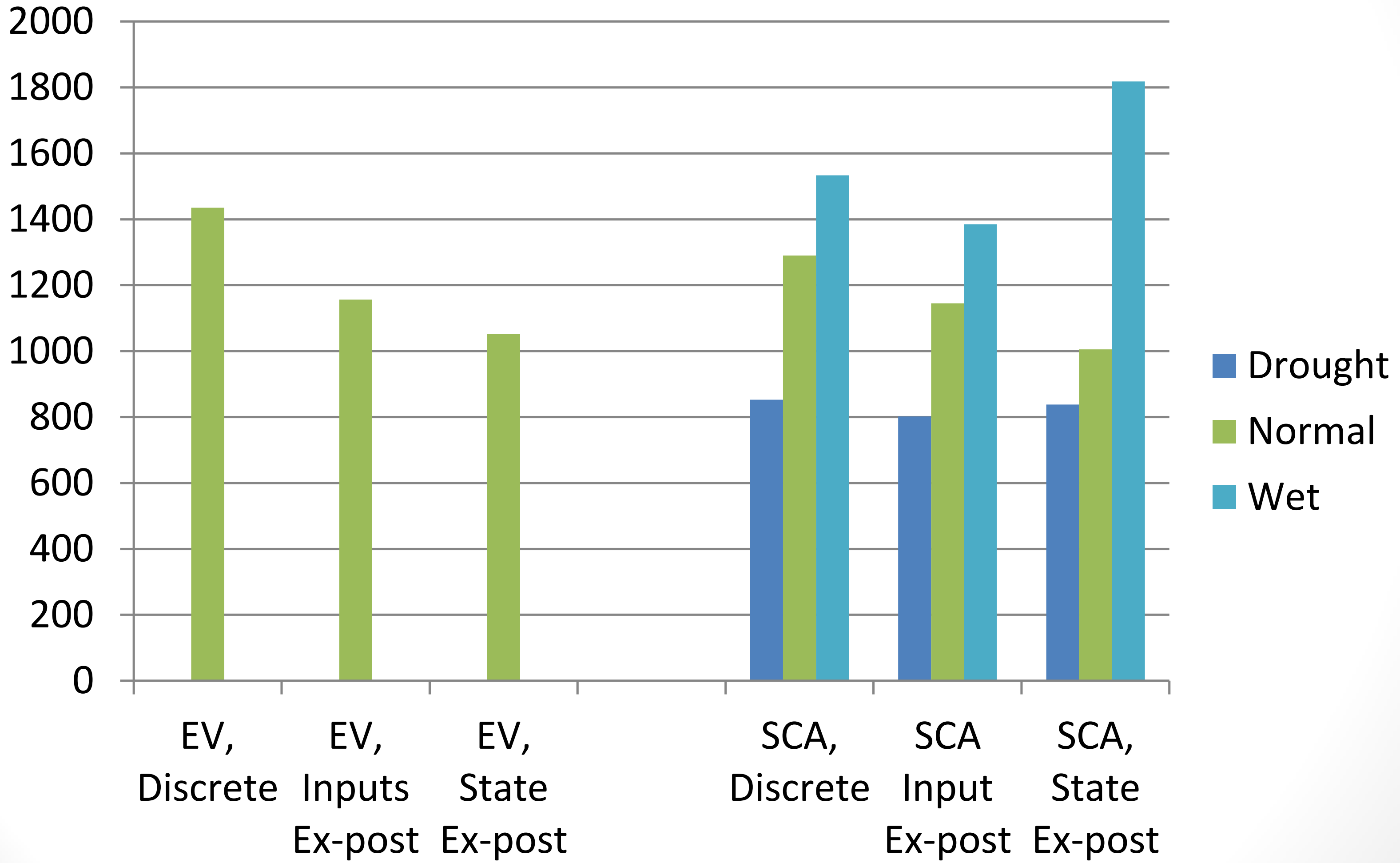
- Drought State = scarcity = constraint in the model.
- Discrete: EV= 0, SCA > constraint
- Aware: EV & Aware SCA basically the same
- Unaware: EV about 2,000 GL less than SCA



What's really going on (Area '000Ha)



Ability to Use Water



Implications: Inputs

- Inputs = how much water needed by commodity

- Both EV & SCA
  - Unaware violate constraints = capital loss
  - As awareness about the required inputs occurs, use less water, as understand the risk associated to capital (Kingwell & Farre, 2009)

- SCA aware transition more flexible production systems and management options:
  - cognitive heuristics allow for rapid adaptation & adoption if learning is are 'ecological rotational' (Goldstein & Gigerenzer, 2002)

Implications: Inputs

- EV doesn’t allow for this and gets stuck by the trails
- Increasingly gets worse as climate changes
  - creates Black Swans
- Problem increases as awareness increases creating perverse outcomes from stochastic EV analysis (Just & Pope 1978)
  - Large flows in wet???

Implications: State of Nature

- Defines total water supply

- As awareness increases production is reduced in the drought state and opportunistic cropping

Awareness & States of Nature

- State of Nature
  - EV uses less water than SCA
  - SCA reallocation of resources away from Normal and Drought states to opportunistic.
  - EV fixed production systems = stupid farmer assumption

- In this case uncertainty about water supply reduces the economic returns when compared to inputs but
  - SCA values > EV as farmers reallocate resources to maximise returns when water is not a binding constraint

Modelling Climate Change

	Reduction Compared to Current Climate		
	550 Avg	Frequency	Difference
Discrete	$71	$155	$84
Inputs-Unaware	$301	$384	$83
Inputs-Aware	$273	$333	$60
State -Unaware	*$71*	*$155*	*$84*
State - Aware	$179	$217	$37

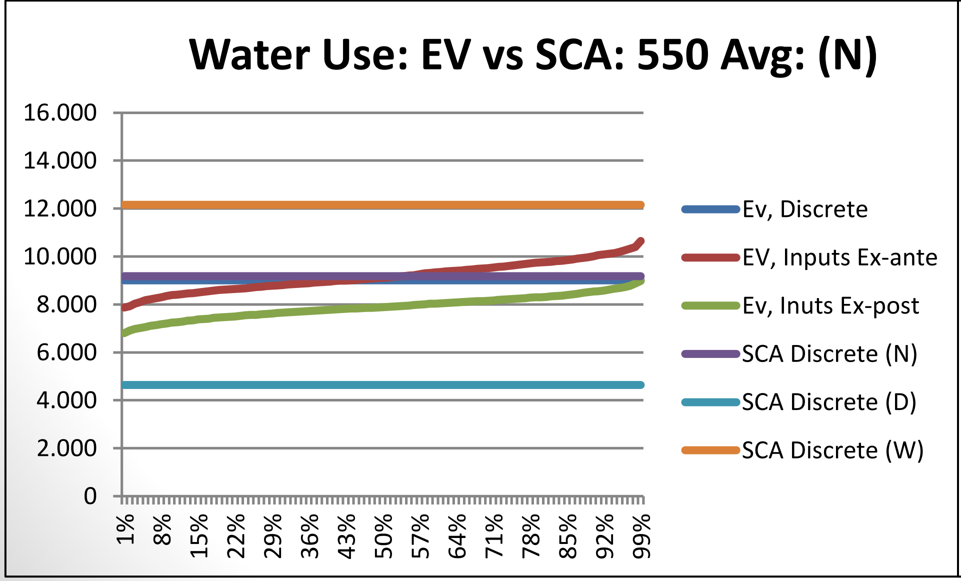
- Frequency > 550 Avg
- Inputs have the greatest impacts (unaware)
- State flips to being aware having the greatest impact
- As awareness increases the loss reduces
- State radically alters the production response

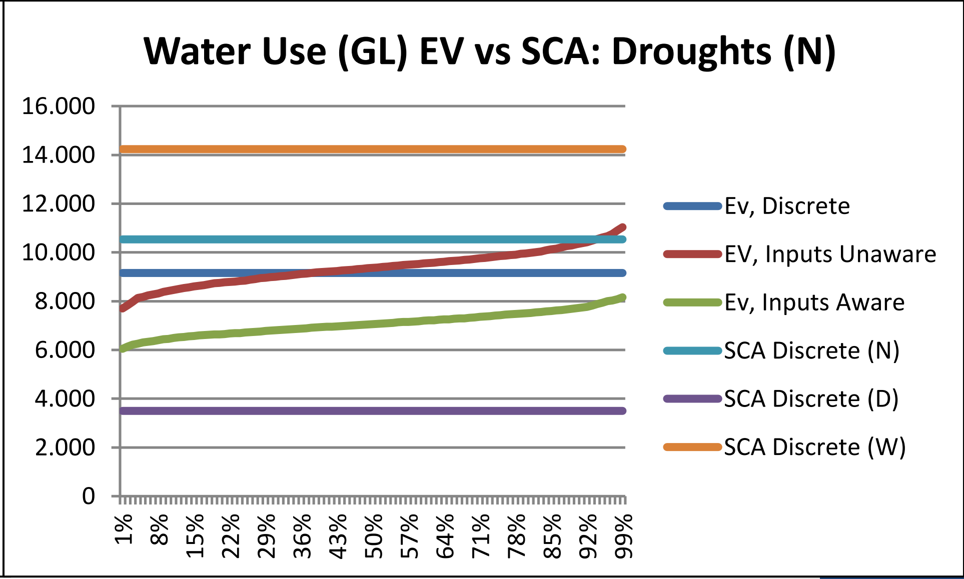
Modelling Climate Change

- 550 Avg really needs to be modelled with a difference data set (aware). If this was to occur the difference between the EV and SCA model would reduce
- Increasing Droughts forces the EV to reduce area and lack of ability to adapt
- Inputs (awareness) = encourages flexibility leading to robust outcomes to deal with other shocks. Therefore EV (both aware & unaware) policies designed to increase efficiency will cause capital loss the next time a drought occurs.

550 Avg vs. Droughts: Inputs

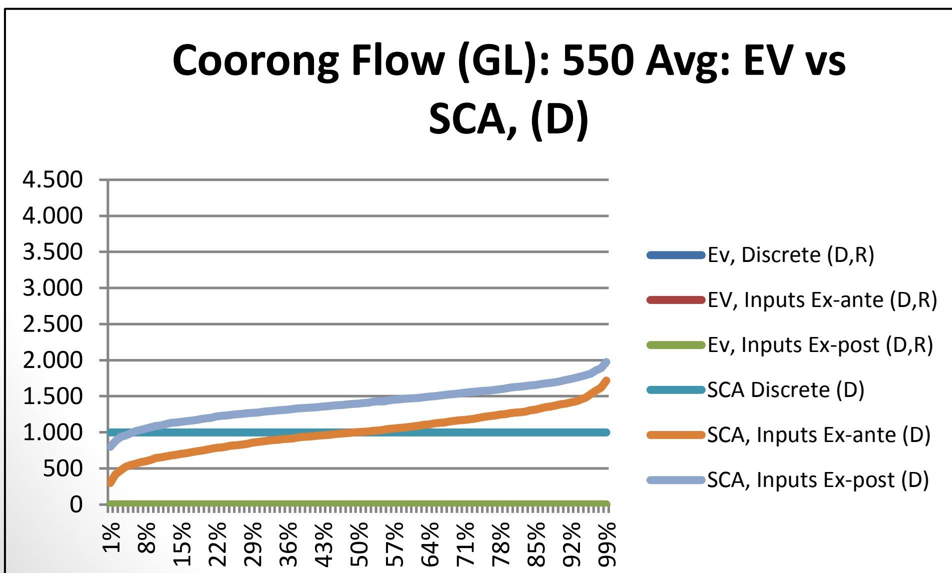
- EV contracts within the SCA discrete bounds compared to current climate
- 550 Avg SCA Normal = EV
- Increased Drought forces
  - SCA & EV apart
- 550 v Drought = forces opportunistic irrigation

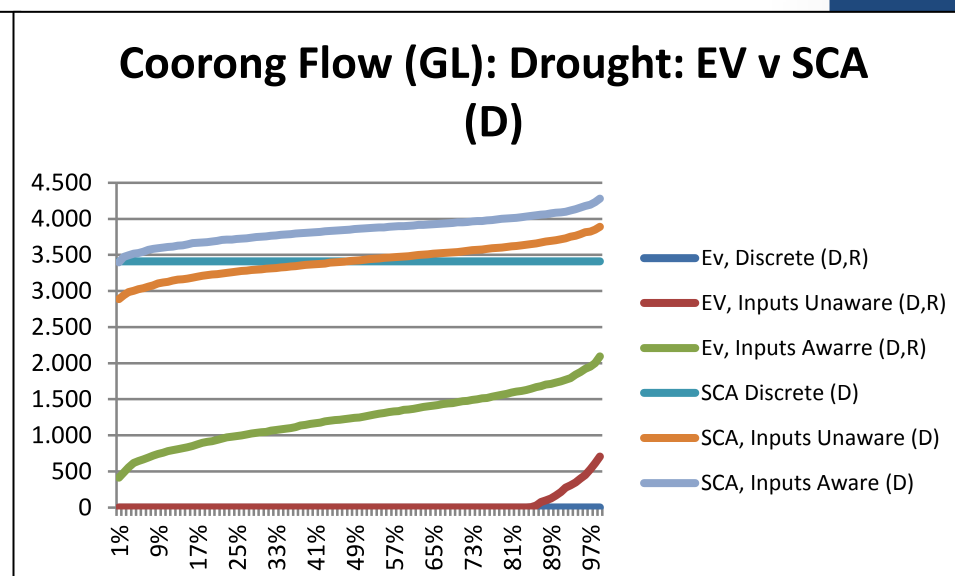




550 Avg vs. Droughts: Inputs

- 550 Avg
  - EV cannot deal with the drought
  - SCA hit the constraints
- Drought
  - EV Aware has flow
  - SCA a lot more water flowing (production system adaptation)

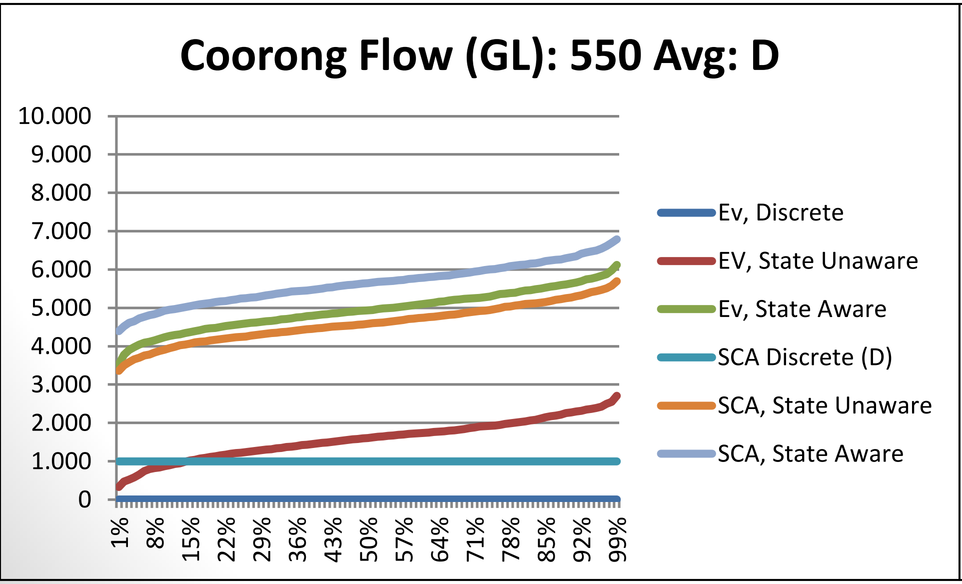


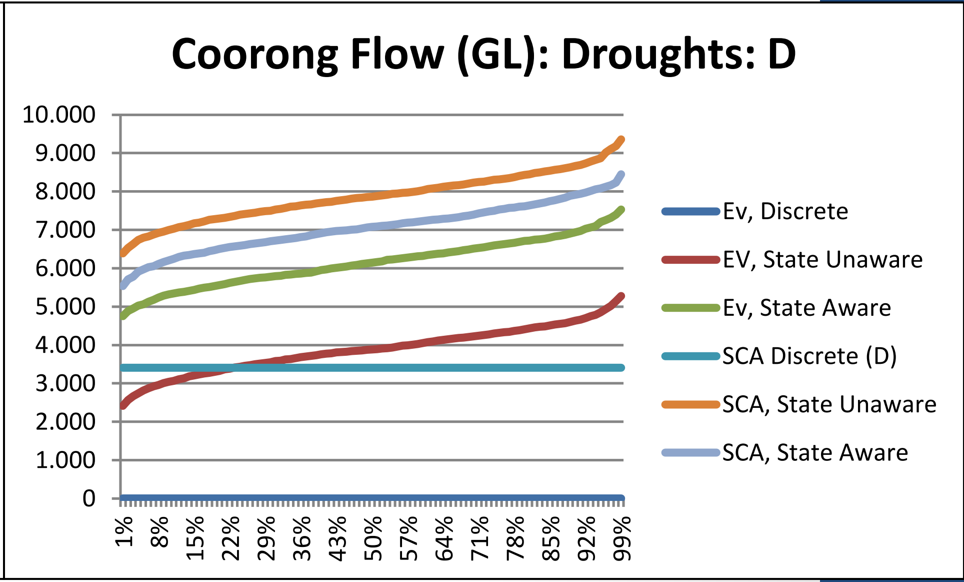


550 Avg vs. Drought: State

- 550 Avg
  - EV Aware > SCA Unaware

- Drought Frequency
  - SCA Aware less flow than SCA Unaware





Natural systems & data

- Natural systems always experience new events.
- Not a draw from the previous known data
- You can get new highs, new lows that are outside known records (or models)
  - Lows = scarcity
- The mean is a dangerous beast.

Conclusion

- If we continue to model passive decision makers, then policy makers are assuming they not respond and resources will continue to be wasted
- EV discrete works only if you have complete certainty
- EV stochastic can only be as good as a SCA discrete
- SCA stochastic helps understand why decision makers don't use all of their resources
- And once this is understood

Conclusion

- These signals then help policy makers understand issues such as:
  - Capital investment in efficiency
  - R&D
  - Management options
  - Role of how the Commonwealth Entitlement Water Holder (CEWH) needs to manage water resources
  - Property rights

- This then provides capacity to design incentives and regulations to transition society along new growth paths