Economic consequences of drought: Another view

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Some context

- I came to Berkeley in Fall of 1976 – for the winter of a severe drought.
  - It didn't concern me – I thought Northern California was supposed to be sunny year-round.
- I became interested in the economics of water, especially California water, and in 1981 I created a course on the economic of water, which I then taught until 2010.
- From Jan 1986 to Jan 1990 I served as the economics staff for California's water rights agency (SWRCB). I continued as a consultant on economics through 1993.
- In 2003 I established the California Climate Change Center at Berkeley.
  - The focus was economic modeling of climate impacts and climate mitigation policy.
- In 2011, I became emeritus at Berkeley and took up a regular position at ASU.
  - I still have an office at UC Berkeley and a home in Berkeley, and I work with Berkeley graduate students as well as ASU graduate students.
  - I still focus mainly on California water and – now – also the Colorado River Basin.

Today in California

- 2012-2015 was California's driest consecutive four years since records began in 1896.
- 2016, 2017 and 2018 were normal.
- 2019-2020 were the second driest pair of years on record.
    - 2020 was the third driest single year on record (after 1977, and 2014).
- This past winter was dry. Much of the state received less than half of the average rainfall this winter.
- The Sierra Nevada snowpack, which provides 1/3 of our water, is at 5% of average with the wet season now over, equaling the record low of 2015.
- Three fourths of California Counties are already experiencing extreme drought and, since two weeks, ago are in a state of drought emergency.
- This year's drought is steadily approaching the peak severity of the 2012-2015 drought.
    - This is still early – the hottest part of the year is yet to come.

I will talk from the perspective of California.

I will talk about:

1) What is wrong with how economists have generally modeled the demand for water and the economic losses if demand is not satisfied.

- This is an issue for modeling climate change and drought.
- It is also an issue more generally for modeling water without drought.
- I want to suggest some ideas for new lines of research and new modeling approaches.
  - I would be very interested in collaborations on implementing these ideas.

- 2) What things that are wrong with how California established and administers water rights, which make it especially vulnerable to climate change.
  - The significance of this is that badly functioning water institutions harm resilience.

Economic modeling issues

- We understate the flexibility in the responses of water users in the short run (on the scale of one, two, three,..? years).
  - We therefore overstate the immediate economic loss of shortage to water users.
  - However, we do not consider the short-term -- or long-term -- loss to ecosystems and, perhaps to small communities.

- But, we may understate the cumulative economic loss for water users if drought persist for a longer period of time.
  - Cumulative economic impacts are not well modeled.

- According to tree-ring evidence, prolonged dry periods were experienced in California during the middle ages, some more than 100 years in length.
- Climate change projections also show the likelihood of far longer runs of dry years than anything experienced in California over the last 200 years.

Understating the short-run flexibility in the system

The exaggerated role of optimization in economic analyses of water demand

- Optimization comes into economic analyses of users demand for water in two alternative ways:

1) User demand obtained by explicit optimization of a profit function
    - Programming models
    - Estimation of a crop-water production function combined with a profit maximization.

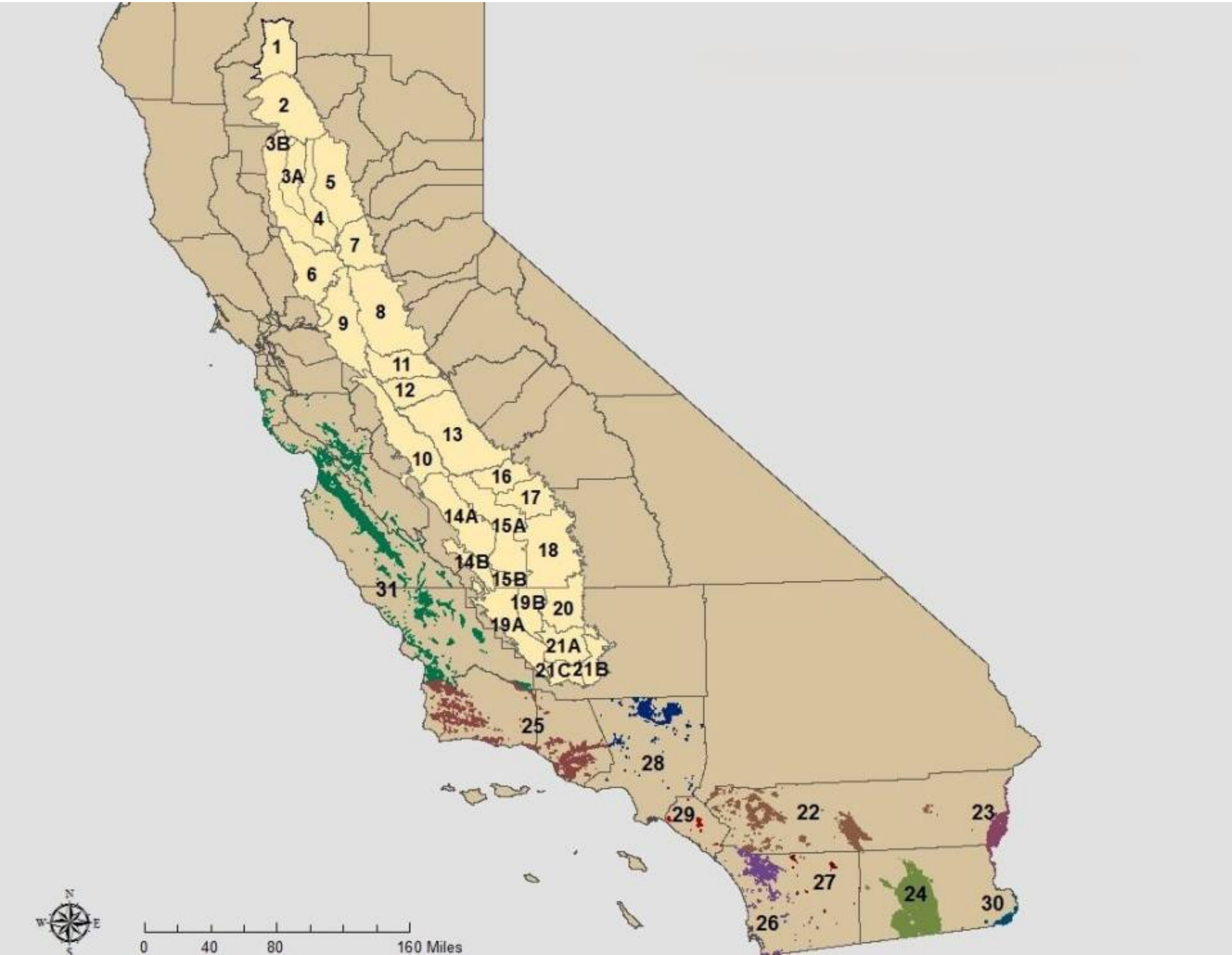
2) Statistical estimation of a demand function which is interpreted as being the solution of a profit maximization.
    - Invert the estimated function to obtain the marginal value product function for water as an input to production.

- I have long been profoundly skeptical of (1). I am now skeptical of (2)

OPTIMIZATION MODELS

- The models I have observed most closely – primarily for California – grossly fail to predict the actual patterns of crop production, until artificially forced to do so crop by crop.
  - California represents a stress test for optimization models because of the enormous variety of crops grown here (85+ different crops grown statewide but only a handful of crops grown by any individual operator).
  - The California models "successfully" predict actual cropping models only through being constrained to grow minimum/maximum amounts for almost every individual crop. Crop constraints drive the model fitting.
- They almost certainly mis-represent farmers' decision making.
  - There are no economic constraints (e.g., contracts with processors) or behavioral constraints on what is grown or how it is grown.
  - They are generally static and deterministic. There is no uncertainty and no risk aversion.
  - Optimization is performed independently month by month across the year.
  - Fixed inputs are modeled as though they are all rented on a monthly basis.

=Model regions are treated as spatially homogeneous



STATISTICAL DEMAND RELATIONS TREATED AS THE OUTCOME OF A CORNER-SOLUTION MAXIMIZATION

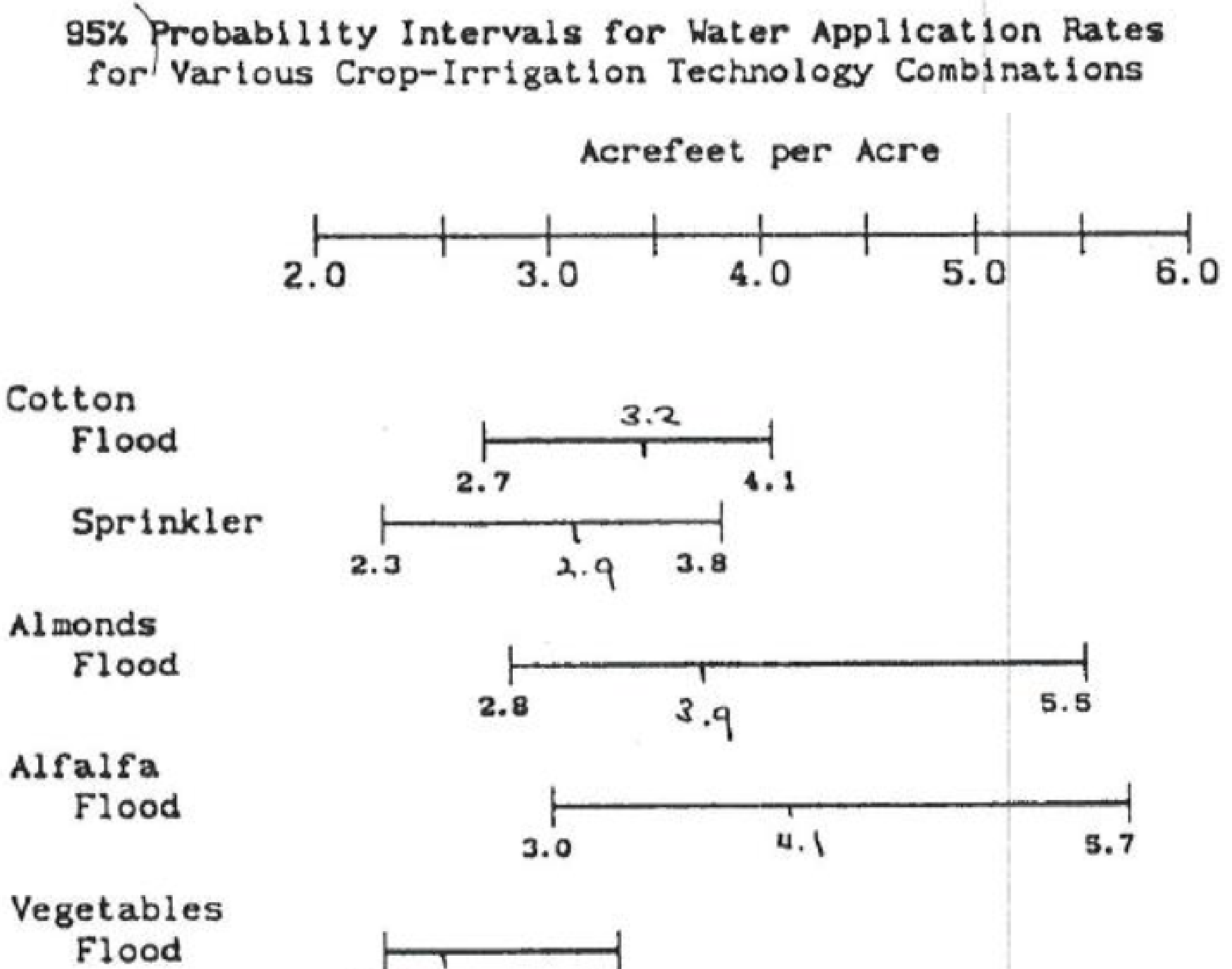
Whenever empirical data are available at the farm, they show that different farmers growing the same crop on the same type of soil with the same irrigation technology, and facing the same prices, nevertheless use very different quantities of key inputs.

Instead of a single input quantity, as predicted by programming models and conventional econometric models, there is a *probability distribution* of input quantities with a heavy right-hand tail.

The existence of a distribution of input use instead of a single quantity suggests that conventional approaches are missing something.

Data from a survey of ~45 farmers in Kern County, 1990

- They all face the same input/output prices, so there should be no variation in the amount of water applied for a given crop and irrigation technology
- There is evidence of X-inefficiency



The missing piece of the puzzle may be that (some) farmers are being inefficient in varying degrees

- At least in how much water they apply.
- After all, water is crucial – if you end up applying to little you compromise the yield obtained.
- Water is applied intermittently throughout the growing season. At any point in the season, you can't be sure about the crop ET and available water supply in the remainder of the season.
- While a crucial input, water may be a relatively small share of the total production cost.
- If you are risk averse, err on the side of over- rather than under-irrigation.

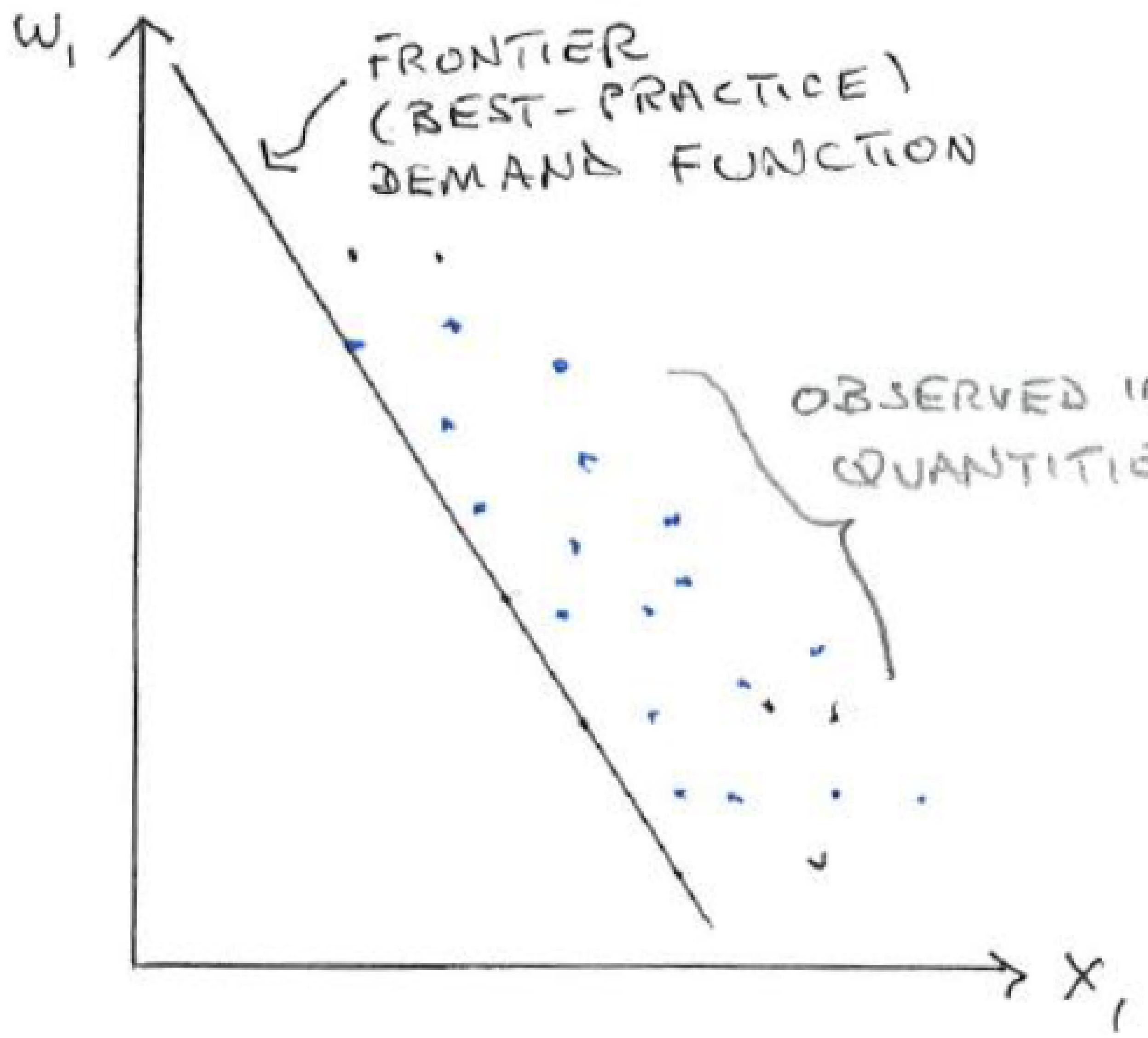
Frontier functions & X-inefficiency

- Technical (production) inefficiency
  - Not getting as much output as is technically possible, given the input quantities employed.
- Cost/Input choice inefficiency
  - Obtaining a given output at higher than minimum cost because the wrong combination of inputs is selected.
  - Shows up in the (conditional) input demand function
  - Also, in the cost-function
- Output supply inefficiency
  - Choosing a level of output that fails to maximize profit

These are estimated with statistical procedures to estimate *frontier* functions.

Economists have estimated cost functions as frontiers, but not input demand functions

Input demand function



Another version of the story

- $x = h(p,s,y) + \varepsilon$
- s = 1 if don't pay attention
- s = 2 if do pay attention

$h^1(p,y)$ if don't pay attention

$h^2(p,y)$ if do pay attention

$$E\{x\} = h^1(p,y) \cdot Pr\,\{\text{don't pay attention}\} + h^2(p,y) \cdot Pr\,\{\text{pay attention}\}$$

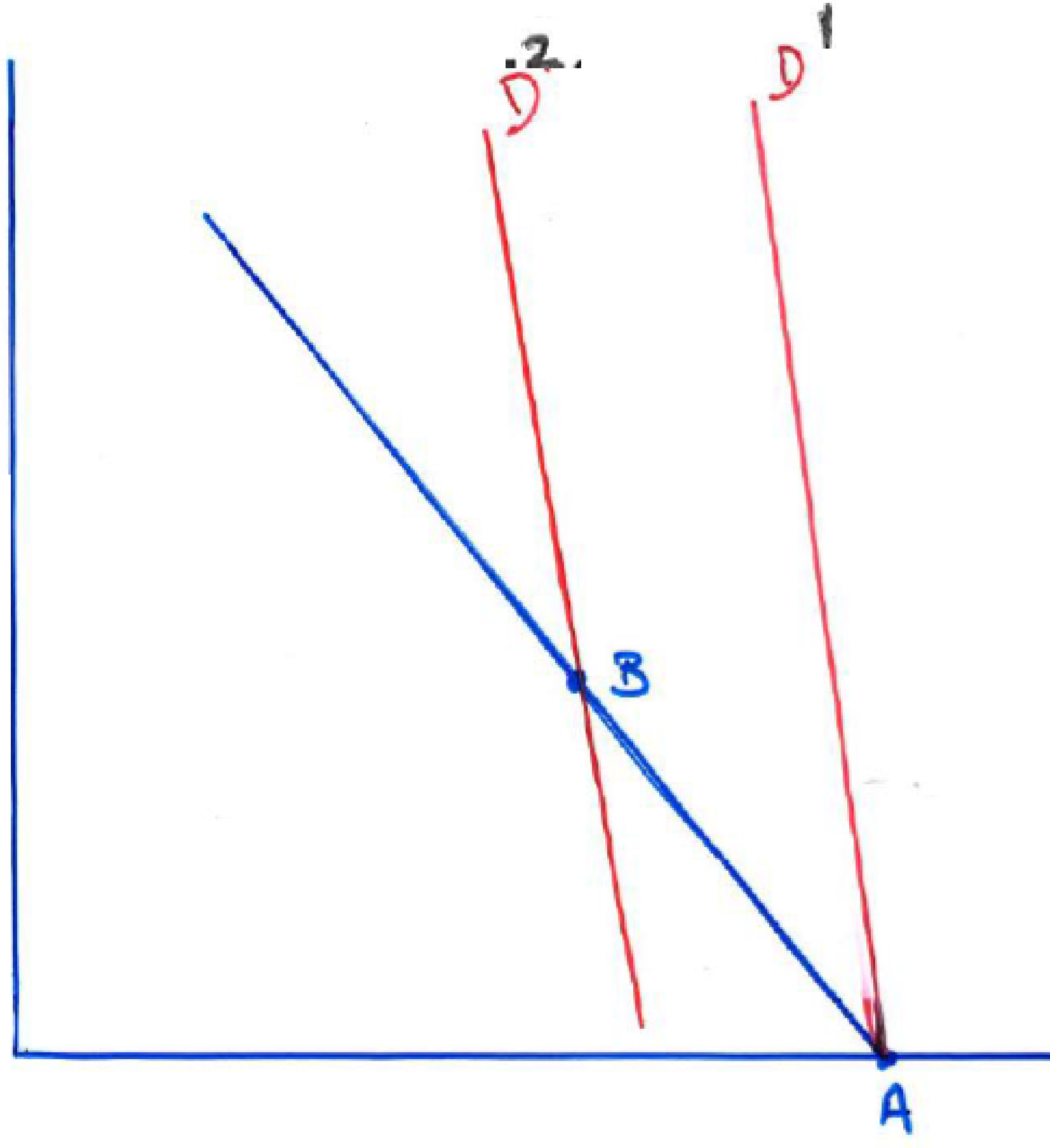
$$= h^1(p,y) - \Delta \cdot Pr\,\{\text{pay attention}\}$$

- $\Delta = h^1(p,y) - h^2(p,y)$

- When price rises, you start to pay attention.
- The response is a shift from A to B.
- Those lie on two separate demand curves.
  - The blue line is an imagined, but wrong demand curve.

$$dx = \frac{\partial h}{\partial p} \cdot dp + \frac{\partial h}{\partial s} \cdot ds$$

$$dx = \left[\frac{\partial h}{\partial p} - \Delta \cdot \frac{\partial \Pr\{\text{pay attention}\}}{\partial p} \right] dp$$



Broadview Irrigation District is a very small district of about 9,000 acres just north of Westlands water District. It has about a dozen farmers farming an average of about 2 fields each.

Broadview was under pressure to reduce the amount of irrigation water that its farmers applied,, because their excessive water use was causing contaminated drainage water to run off their fields; the contaminated drainage was actually causing a significant pollution problem. It was determined that if irrigation use fell by about 10% percent, the problem would be solved.

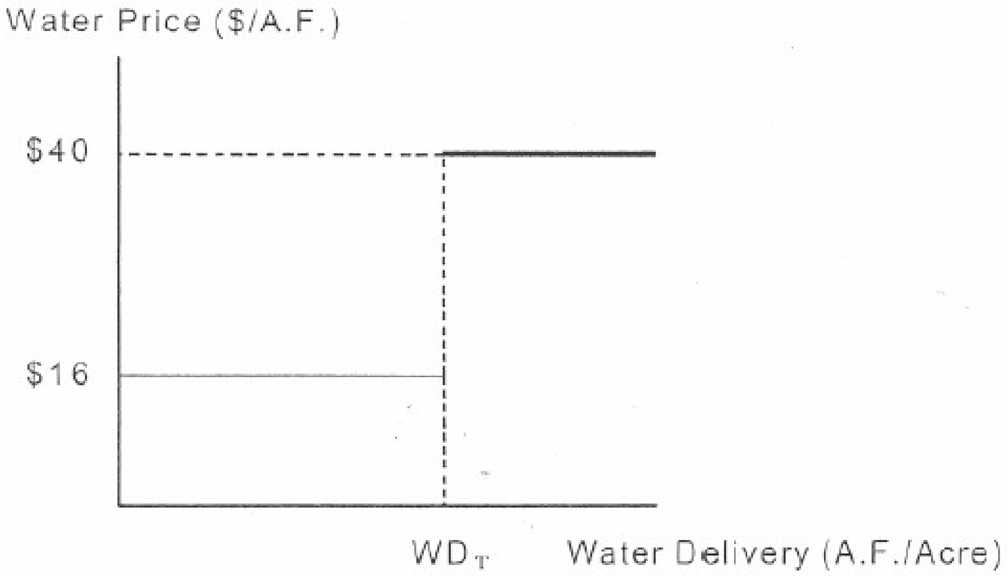


Figure 1. The tiered water pricing program implemented in the Broadview Water District in 1989

Table 1. Selecting crop-specific tiering levels for Broadview, based on empirical water delivery information (acre-feet per acre)

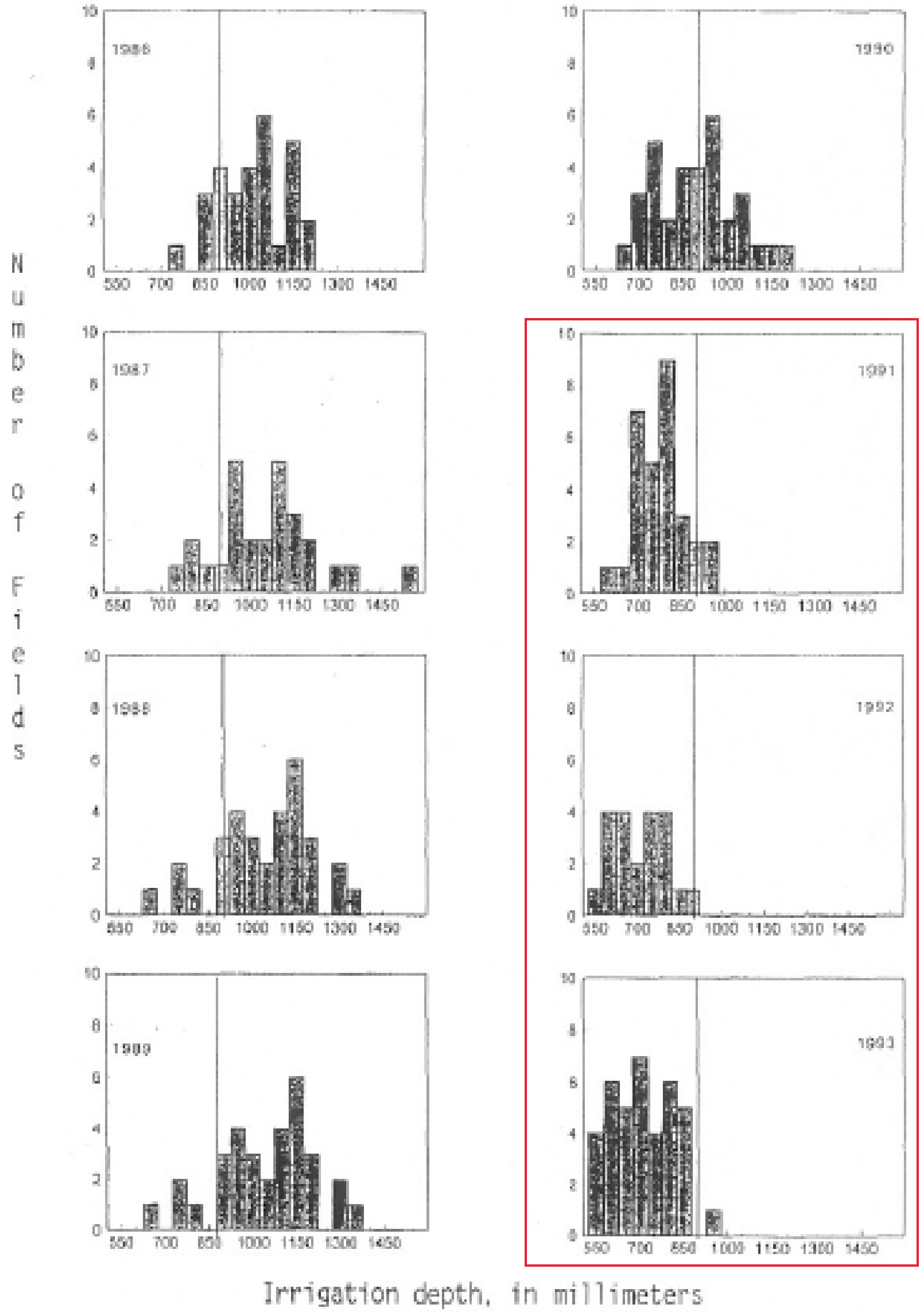
Crop	Average Field-Specific Water Deliveries 1986	1987	1988	Mean Value 1986 – 1988	Tiering Level (WD_T)
Cotton	3.21	3.13	3.27	3.20	2.9
Tomatoes	3.21	3.29	3.15	3.22	2.9
Cantaloupes	2.15	1.99	2.20	2.11	1.9
Wheat	2.01	2.55	2.35	2.30	2.1
Seed Alfalfa	2.13	2.24	1.80	2.06	1.9

There was a ~25% reduction in crop water use.

Was there any loss of profit?

If the growers had been maximizing profit before the change, there should have been some loss of profit.

But, I suspect there was not any loss.



Some evidence to this effect from Kansas

Drysdale and Hendrick (D&H) study what happened in Sheridan County 6 LEMA

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Adaptation to an irrigation water restriction imposed through local governance☆

Krystal M. Drysdale [a], Nathan P. Hendricks [b,*]

- Sheridan County 6 LEMA. The LEMA is a 99 square mile area that contains 185 wells for irrigation and 10 non-irrigation wells (Figure 1). The goal of the LEMA is to reduce groundwater pumping by approximately 20% relative to historical use. This is accomplished by restricting irrigators to a five-year allocation of 55 inches each.
  - This implies they were using on average 13.2" per year. Cutting this back by 20% means using 11" per year.
  - But, they are allowed to carry savings over from one year to another over the 5-year window of the program. They are allowed to use 55" over 5 years.

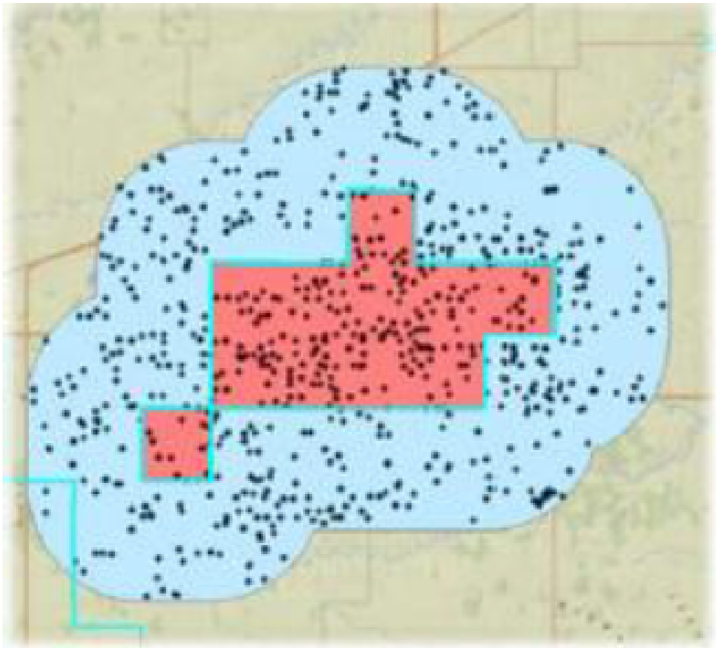
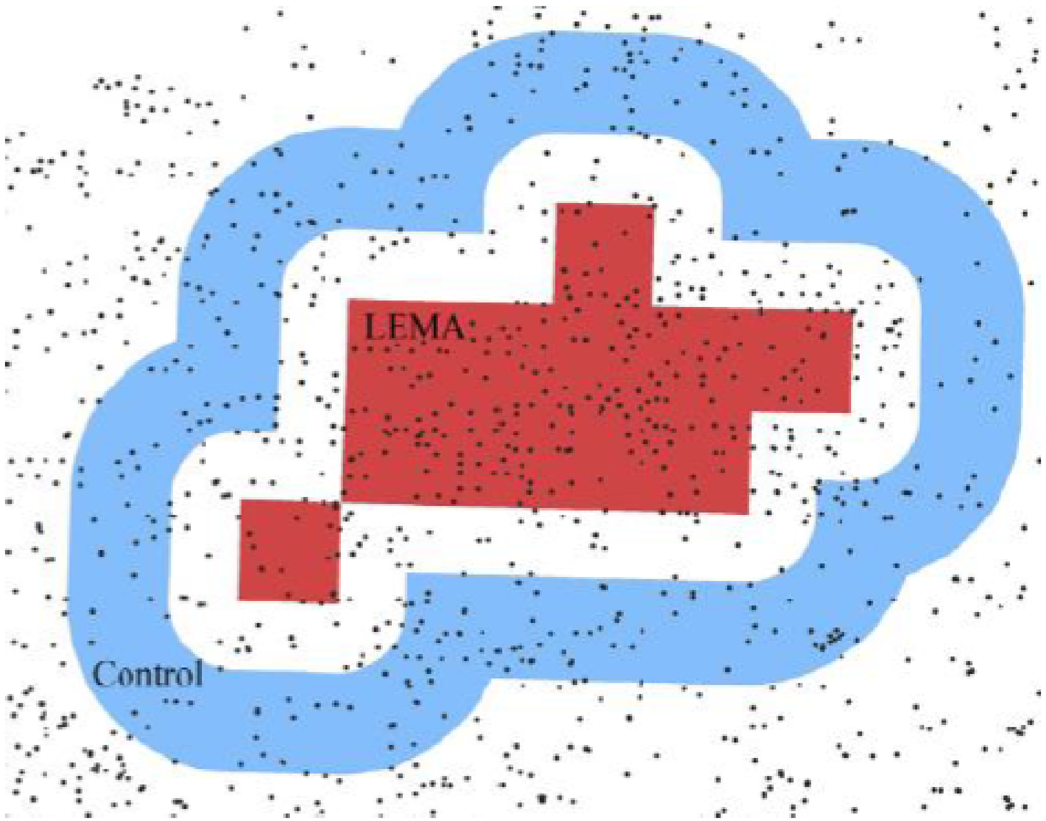


Figure 1: Number of Irrigation Wells in Sheridan County 6 LEMA (red) and Surrounding 5 Mile Boundary (blue)

D&H analysis

- The LEMA period is 2013-2017. They do a field-level analysis (like H&P) for the period 2007-2016, before and after the LEMA.
    - Often a water right is associated with a single point of diversion, but in certain cases multiple points of diversion have the same water right number. Because the water use restriction was placed on water rights, we aggregate all the data to the water right ("field") level.
- Instead of just comparing LEMA fields before 2013 and after, they compare both LEMA and non-LEMA fields before 2013 and after – a *difference in difference* analysis -- using a non-LEMA control group.
- The control group (blue) includes all water rights between 2 and 5 miles of the LEMA boundary.
    - Don't include water rights < 2 miles from the LEMA boundary due to concerns about spillover of the water restriction—water rights just outside the LEMA boundary may have changed water use due to changes in their aquifer conditions.



- Irrigated acres decreased slightly inside the LEMA and acres remained about constant in the control group, implying a 6% decrease in irrigated acreage due to the restriction. Applied water intensity decreased substantially inside the LEMA while it remained about constant in the control group resulting in a 28% decrease in intensity.
- Total water use fell by 26%.
  - They exceeded the target of a 20% reduction in total use.
- The reduction in water use was due mainly to lower water use intensity per acre rather than changing crop.
  - Crop switching alone only decreased water use by about 3%.
  - This has a lower economic cost that cutting back the total irrigated acreage (H&P).
- Here we have a significant reduction in water use triggered *not* by raising the price of water but by imposing a quantity regulation on the total amount of water used per water right

So, what was the economic cost? It isn't clear there was much of an economic cost.

- This is addressed by D&H 2016 Ag Extension fact sheet, not by their 2018 JEEM article.
- The dropped nozzle irrigation was already in place – no indication of any change in irrigation technology in Sheridan 6 LEMA.
- D&H 2016: "Our estimates assume that farmers had the same expenditures for corn before and after the LEMA was implemented so the only change in input expenditures is due to changes in cropping patterns. For farmers within the LEMA, seed and chemical expenditures dropped significantly, especially for corn. The overall reduction was nearly 20 percent. Herbicide and insecticide expenditures each fell by 16 and 23 percent, respectively. The largest estimated drop was fungicide applications plummeting more than 30 percent.
- Changes in corn acreage led to seed and fertilizer expenditures falling roughly 20 percent. "
- Overall, it appears that there was a 26% reduction in total water use with no major change in profit.

The crucial question:

- How was it possible for farmers to have made a substantial reduction in their water use without incurring the loss in profit implied by a conventional economic analysis?
  - The loss as measured by the change in area under their demand function for water as an input.
- Could it be that they were not operating on a (profit-maximizing) demand function in the first place?

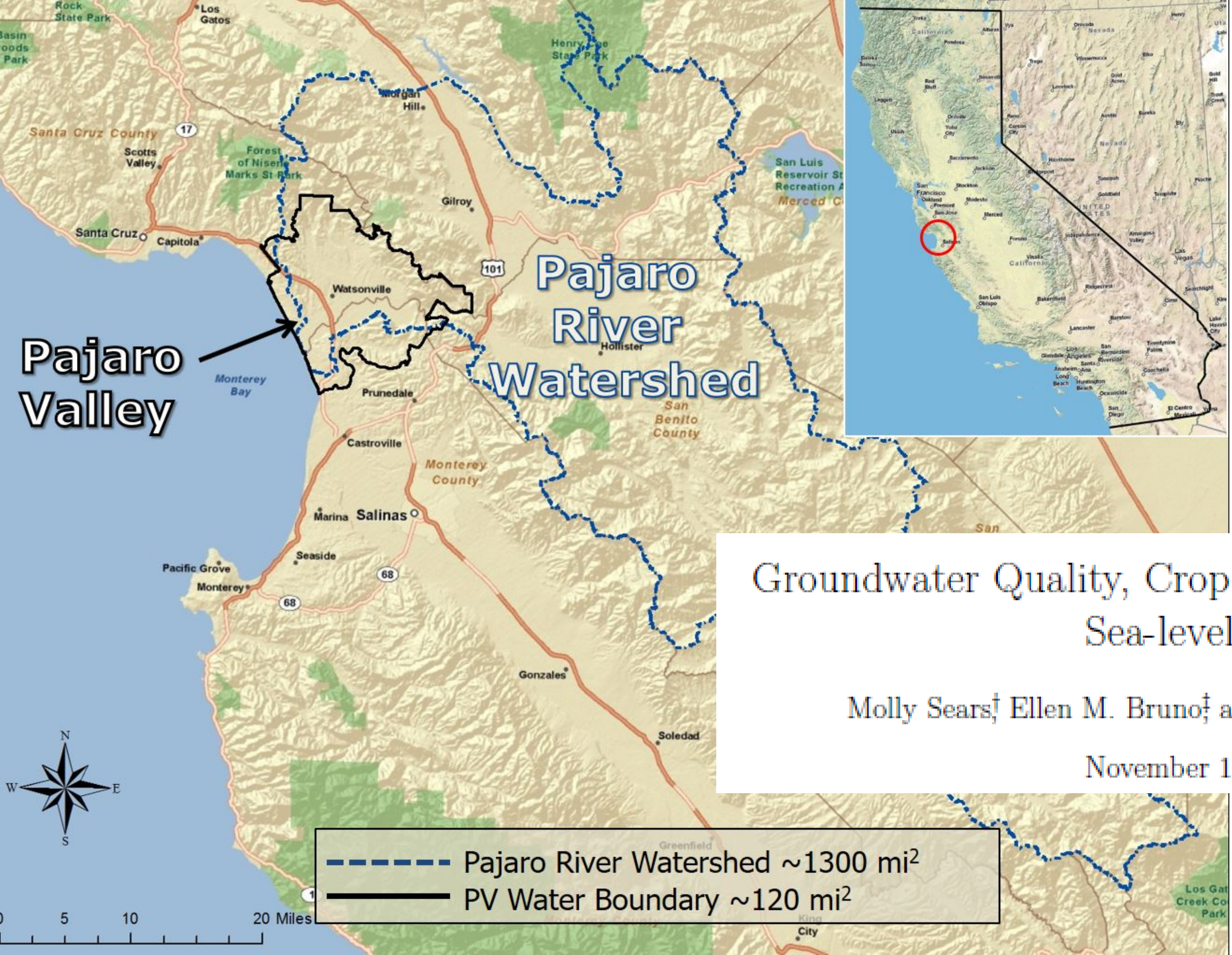
- Why might be?
- A possible answer: water is an essential input to production. But it accounts for a **tiny** fraction of the total cost of production.
- So, why not err on the side of caution and over-irrigate?

The small share of water in total production cost

- If you apply 50% more water per acre, that raises the total cost of production by only $26!

2017 CROP BUDGET CENTER-PIVOT IRRIGATED CORN NW KANSAS

	UNIT PRICE	QUANTITY	AMOUNT
REVENUE	$ 3.70/bushel	239 bushels	$883.40
DIRECT EXPENSES			
Natural gas	$51.35	= 12.84 mcf @ $4.00/mcf for pumping 18 acre-inches	
Well maintenance	$ 5.94		
Fertilizer	$92.22		
Other chemicals	$62.46		
Labor	$204.87		
Seeds	$128.00		
Crop insurance	$32.43		
Other	$16.50		
Interest on operating capital	$17.81		
TOTAL DIRECT EXPENSE			$611.59
Depreciation on well, center pivot, power unit			$76.67
Interest on durable equipment			$59.22
Land rent			$152.00
TOTAL FIXED EXPENSE			$287.89
TOTAL EXPENSE (DIRECT + FIXED)			$899.47
NET RETURN ABOVE DIRECT EXPENSE			$271.82
NET RETURN ABOVE TOTAL EXPENSE			-$16.07



Groundwater Quality, Crop Choice, and the Cost of Sea-level Rise*

Molly Sears[†], Ellen M. Bruno[‡], and W. Michael Hanemann[§]

November 18, 2020

Two major challenges:

1. Depletion of groundwater. **Sustainable yield is 24,000 AF/year**. Current pumping:
   - 59,000 AF/year agriculture
   - 12,000 AF/year urban
   - 71,000 AF/year total
2. Salinity of groundwater

- **pre-1940s:** High groundwater levels; some waterlogging
- **1940s:** Deep well turbine pumps introduced
- **1953:** Seawater intrusion recognized as an issue in basin
- **1964:** Seawater intrusion flagged by USBR
- **1976-1977:** Drought exacerbates decline in groundwater table
- **1980:** DWR recognizes overdrafted basins: PV near top of the list
- **1984:** PVWMA established

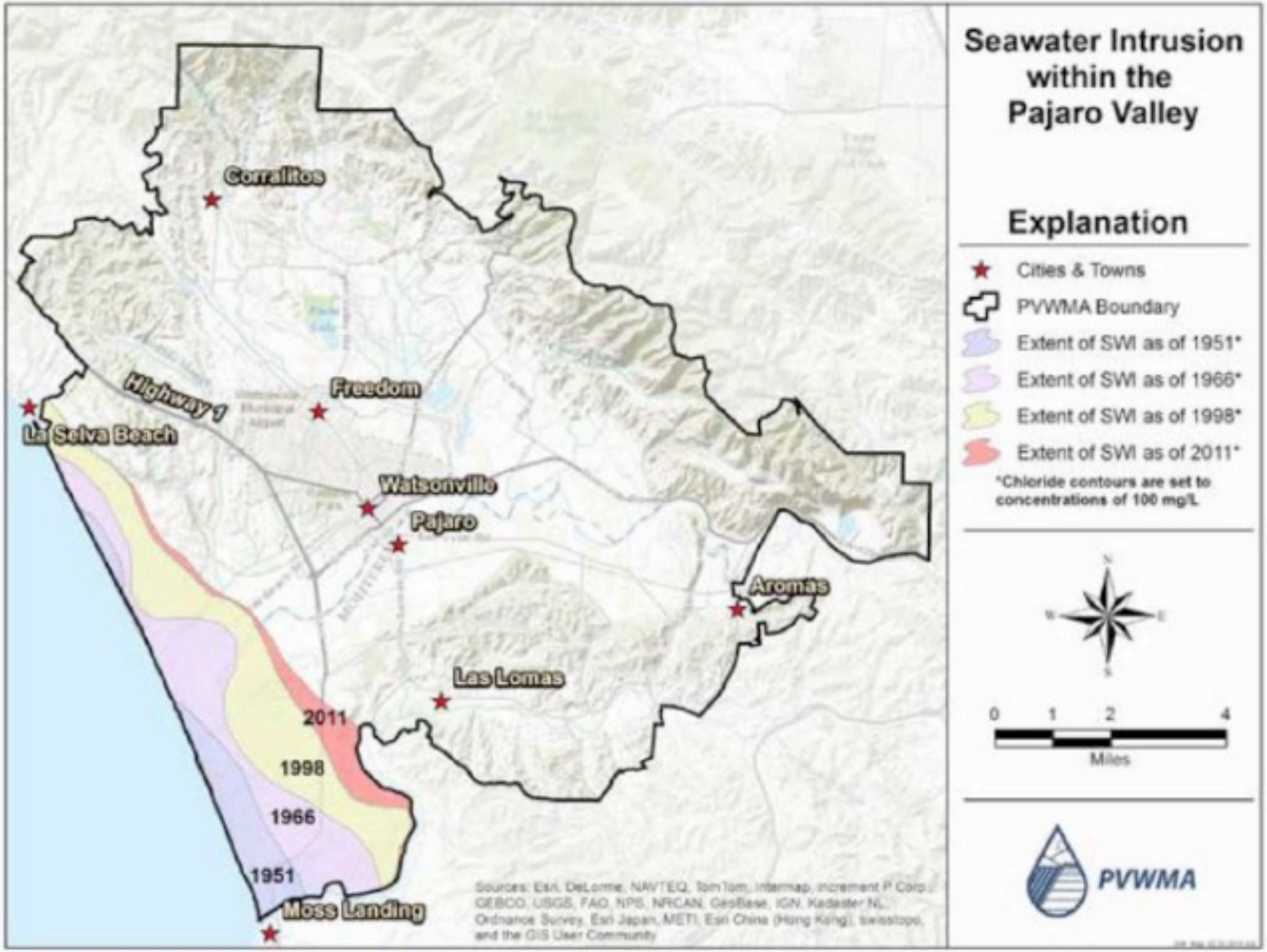


Figure ES-2. Seawater continues to degrade groundwater along the coast.

Astronomical price of ground water in Pajaro Valley

Year	Metered (DWZ)	Metered (not DWZ)	Unmetered	Delivered
2002/03	80	80	80	
2003/04	120	120	120	
2004/05-2006/07	160	160	160	
2007-2009/10	80	80	80	
2010/11	195	162	92	306
2011/12	200	166	92	313
2012/13	200	166	92	313
2013/14	210	174	99	329
2014/15	215	179	101	338
2015/16	235	191	92	348
2016/17	258	203	97	359
2017/18	282	217	103	369
2018/19	309	231	109	381
2019/20	338	246	115	

- Old-line districts in the San Joaquin Valley with their own surface water rights typically charge $20-40/AF
- Districts pumping groundwater $40-60/AF
- Districts receiving Federal CVP water $100-200/AF
- Districts receiving State Water Project water $60-180/AF

- We find a small effect of price in reducing the amount of groundwater pumped.
- But, the main behavioral response is crop switching rather than reduction of water use, and the main driver of behavior is salinity, not water price.
- Why might the price of water not matter so much?
- At 3 acre-ft/acre, they are spending ~$1,100/acre on water.
- But they are growing very valuable berries – strawberries, raspberries, blue berries.
- Depending on the crop, gross revenue is $35-60,000/acre.
- Profit is ~ $10,000 -13,000/acre
  - The crucial constraints are labor for picking the berries and pest control.
  - Who bothers with p_i = VMP_i for water??

What happens in a drought – in the short run

- In a drought, farmers tighten up their operation.
- They plant less than the full acreage.
- They harvest less than the full area planted.
- They may deficit irrigate.
- In California, where there is groundwater, they pump far more groundwater.
- They preserve water for high value crops, and reallocate it away from lower value crops.
- Programming models and statistical models fail to capture all of these adjustments. They overstate farmers' loss of profit.
  - But, they also fail to account for the increase in groundwater pumping costs in future years due to the groundwater overdraft.

What happens in a drought – when there is a prolonged drought

- This is the part that we don't know much about.
- In California, we had been spoiled with droughts involving two consecutive critically dry years.
  - 1976 - 1977; 1990 - 1991; 2008 - 2009.
- In each of those cases, state water managers reacted by pulling water from storage, gambling that there would not be a third consecutive critically dry year.
- That gamble failed in the drought of 2013-2014-2015

The economics of a long-run drought

- This is a chapter waiting to be written.
- It is about risk aversion, more specifically, about **downside** risk aversion.
- It also involves what might be called the **Inverse** Le Chatelier Principle

The Inverse Le Chatelier Principle

- In economics the Le Chatelier Principle is invoked to imply that the short-run response to a price change is smaller than the long-run response.
- The corresponding implication is that the economic cost (lost profit, lost utility) is lower in the long run than in the short run.
- But, the opposite can be the case:
  - If the reservoir contains water, in the short run you can cheaply pull water out of the reservoir. But, when the reservoir is empty, the cost skyrockets.
  - Similarly with groundwater: in the short run you can overdraft. In the long run this becomes very costly.
- Herbert Stein quote (Chairman of Council of Economic Advisors in 1970s): **If a thing can't go on forever, it will eventually stop.**

Risk aversion

Downside risk

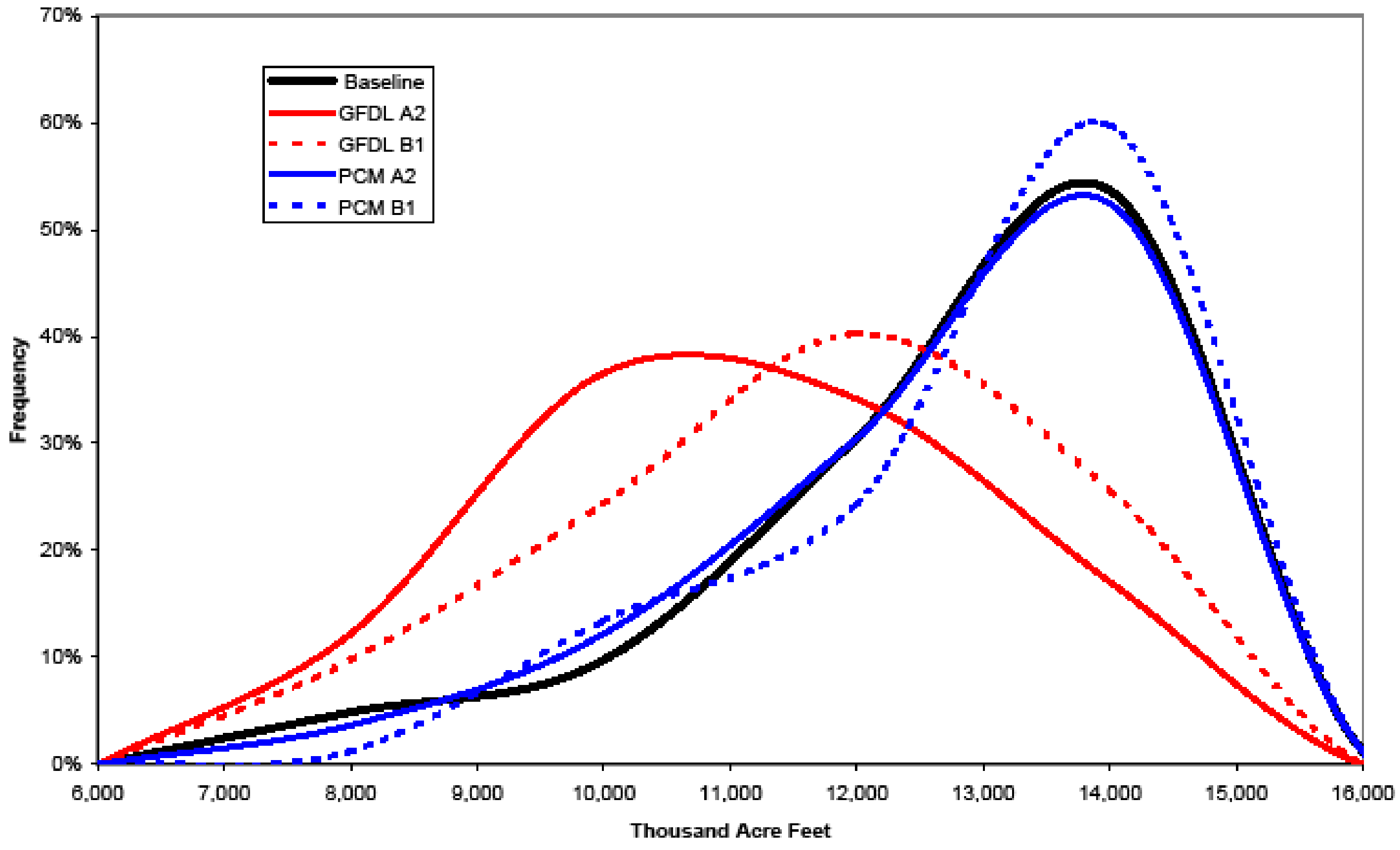
- This is a modification of the conventional theory of risk aversion.
- It is based on the notion that there is some asymmetry in risk attitudes towards outcomes.
- Downside outcomes (defined relative to some point) are weighed more heavily than upside outcomes.
- The concept was first applied in the financial literature in the 1970s – going broke is viewed differently than making a profit.
- It is likely to apply to many physical outcomes of climate change – e.g., asymmetry between having too little water and having too much.
- Water resource management is all about downside risk (Kiparsky, 2009; Hanemann et al., 2016)

Example of downside risk analysis (Hanemann et al. 2016)

- Under the downscaled projections from the GDFL model (a medium-sensitivity GCM), but not the PCM model (a low-sensitivity GCM), there is a significant increase in downside risk with respect to water deliveries for agriculture in California's Central Valley.
- With downside risk aversion there is a significant risk premium associated with that change.

Annual deliveries to Central Valley agriculture, 2085

- Under the GFDL (red) scenarios, there is a major increase in downside risk.
  - Less so with the PCM scenarios (blue)
- The variance of deliveries barely changes; the semi-variance increases greatly.



Downside risk-adjusted impact

CENTRAL VALLEY AGRICULTURE ANNUAL NET REVENUE 2085 ($ million)			
	MEAN	DOWNSIDE RISK FACTOR	ADJUSTED VALUE
BASELINE	$415	$132	$283
GFDL A2	$314	$178	$136
GFDL B1	$349	$163	$186
PCM A2	$397	$130	$267
PCM B1	$413	$126	$287
	LOSS COMPARED TO BASELINE		
GFDL A2	$101	$46	$147
GFDL B1	$66	$31	$97
PCM A2	$18	-$2	$16
PCM B1	$2	-$6	-$4

For GFDL, consideration of downside risk increases the estimate of loss by about 50%.
For PCM, consideration of downside risk reduces the estimate of loss.

The economics of a long-run drought

"The universal truism is that by the time you react to a drought it's too late to react to a drought," said Jeffrey Mount, a senior fellow at the Public Policy Institute. "The majority of things you have to do to mitigate impacts have to be done before the drought."

- Doing things in advance is essentially a form of insurance.
- The economics of investing in insurance depend crucially on risk preferences – and, for water -- downside risk aversion.
- For water, a key adaptation to climate change in California is sorting out water rights in this state.
    - That will be the subject of a separate seminar.

Modeling a choice as a short-run decision versus as a long-run decision

- These are different choices, and involve different trade-offs.
- We tend to ignore the distinction and conflate the two types of decisions – we model them as though they were the same thing.
- But, this is an important distinction for many issues in water economics.
  - Response to a current drought vs response to a prolonged drought.
  - Water marketing as short-run flexibility versus long-run re-allocation.