Climate Change and Water: What Have We Learned

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UC Riverside 3/09

Greenhouse Gases
IPCC 2007

- Greenhouse gases are emitted by burning fossil fuels and deforestation
- Deforestation has led to younger forests that now are absorbing carbon dioxide
- Oceans also absorbing greenhouse gases
- Greenhouse gases are accumulating in the atmosphere at slightly slower rate than emissions of fossil fuels

Climate
IPCC 2007

- Greenhouse gases act as a barrier to global heat loss
- Rising concentrations warm oceans (30 year lag)
- Warmer oceans lead to warmer climate
- Warmer climate increases hydrological cycle- more evaporation and more rain

Hydrology

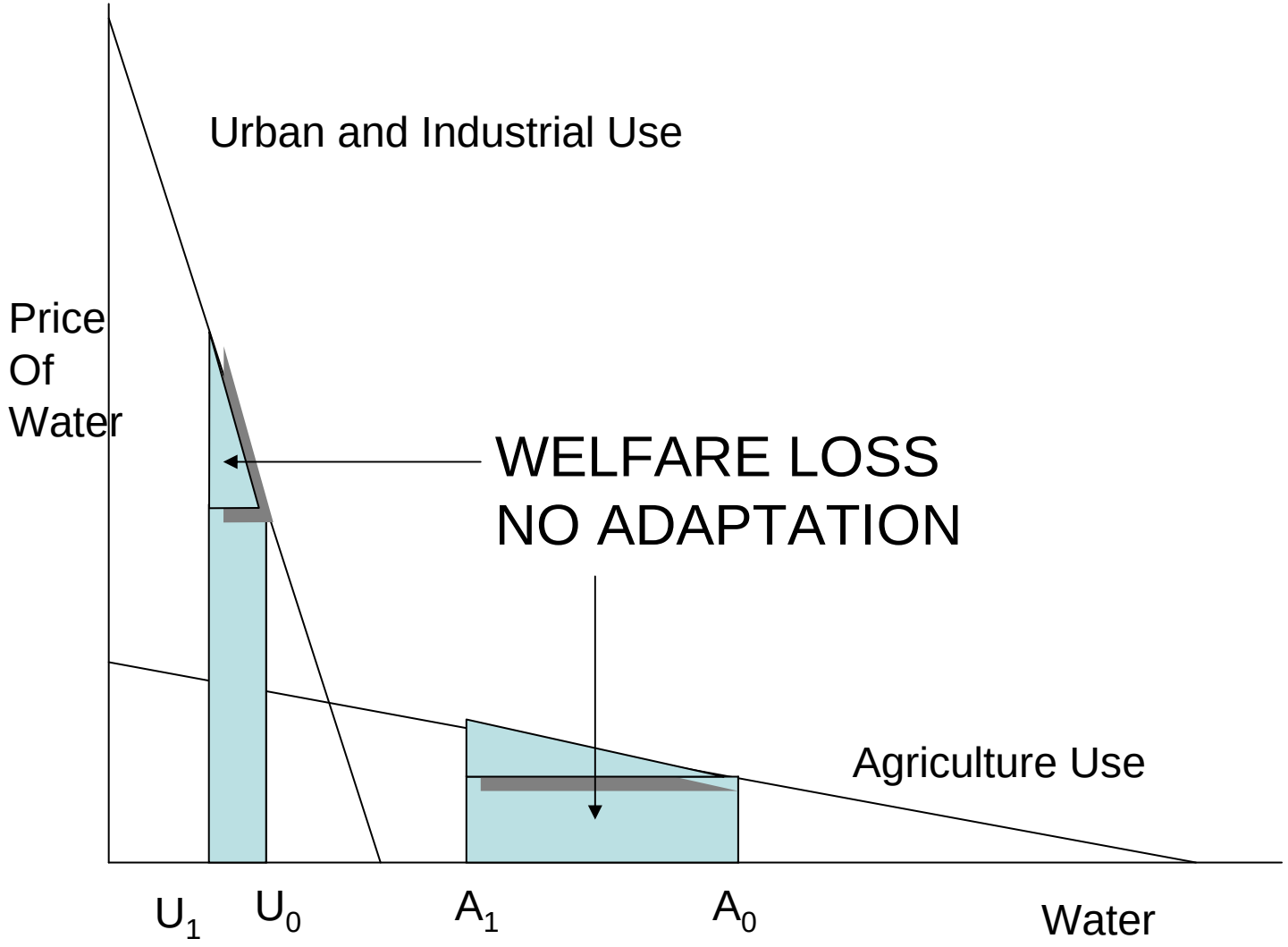
- Exact impact on hydrology is basin specific (e.g. Revelle and Wagner 1983, Gleick 1987, Lettenmeier et al 1992)
- Depends on change in local temperature and rainfall- both are uncertain
- Depends on characteristics of basin
- Global analysis implies need for basin studies around the world

Basin Changes That Lead to Impacts

- Changes in mean annual flow
- Increased evapotranspiration (increasing demand for water)
- Changes in seasonal flows (earlier runoff) Gleick 1987, Nash and Gleick 1993
- Changes in peak flows (floods)
- Changes in interannual variance

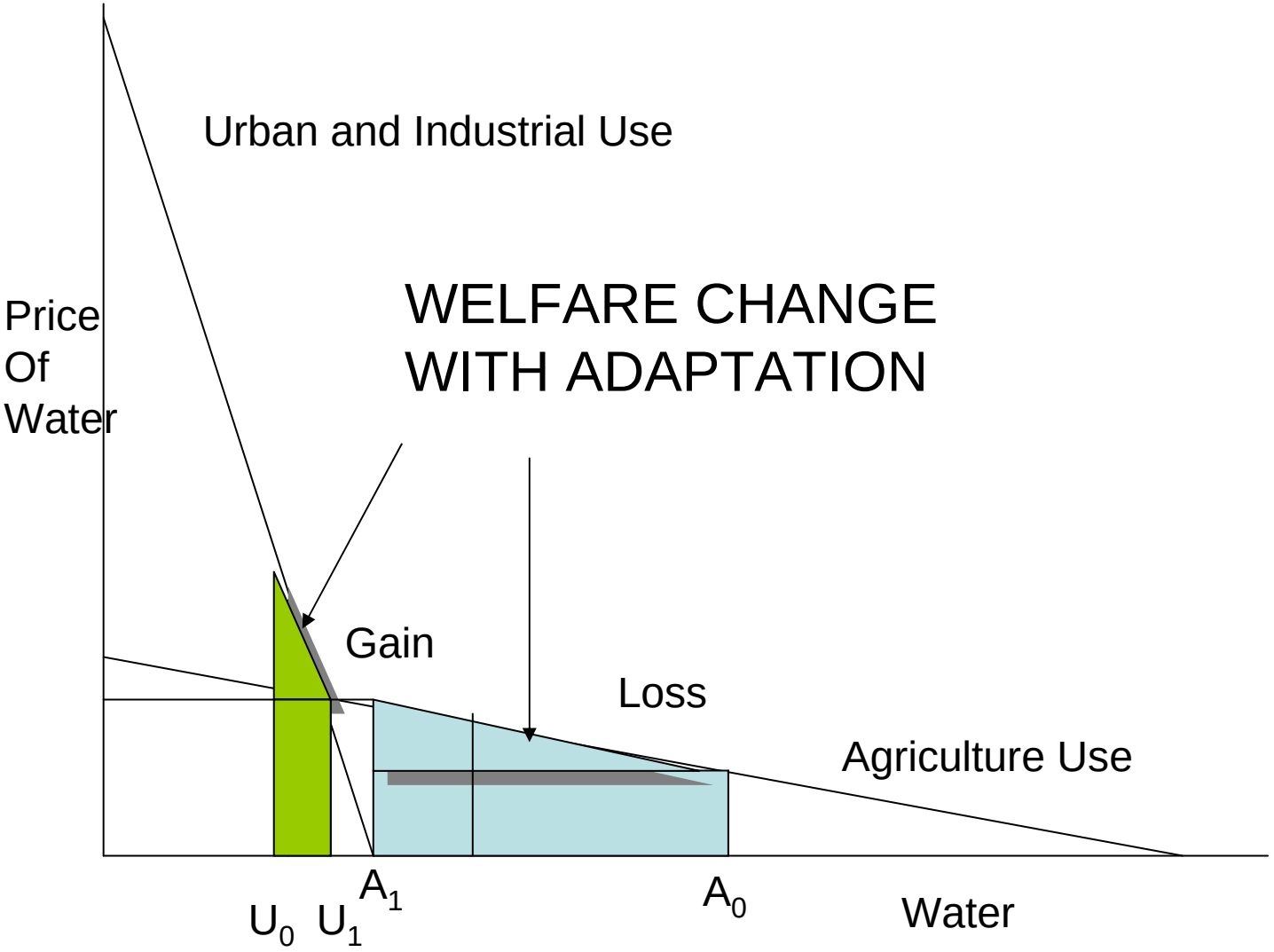
Measuring Water Impacts

- Need to value each water use
- Sum the values
- If there is no adaptation, the damages from changes can be large
- Reductions to high value users are worth much more than reductions to low value users


Urban and Industrial Use
Price
Of
Water
WELFARE LOSS
NO ADAPTATION
Agriculture Use
U1
U0
A1
A0
Water

Adaptation

- Reallocate water to best use
- Implies equating marginal value of water across users
- Reduces magnitude of loss
- Who pays for reductions depends on who owns the water, not on who reduces use


Urban and Industrial Use
WELFARE CHANGE
WITH ADAPTATION
Price
Of
Water
Gain
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Agriculture Use
A_1
A_0
U_0 U_1
Water

Colorado River Study
Hurd et al 1999

- VIC-hydrology model
- Examined projected conditions in 2060
- Includes 16 agricultural, 5 industrial and municipal, and 4 thermoelectric plants
- Includes 7 hydropower dams
- Includes recreation
- Maximizes consumer surplus across all users subject to water constraints

Results

Climate Change	Runoff Change	Upper Price	Lower Price	Welfare Change
Baseline	17058 Kaf/yr	$77/af	$11/af	$7744 million
+1.5C +15%P	+23.5%	-$3/af	-$3/af	+$486 Million
+2.5C +7%P	-4.2%	+$2/af	+$2/af	-$102 million
+5C -10%P	-50.4%	+$180/af	+$60/af	-2087 million

Colorado River Conclusion

- Some climate scenarios increase runoff but most reduce it
- With reallocation, the damages are proportionally smaller than runoff changes
- Damages increase rapidly as runoff changes become larger

Rio Bravo
Mendelsohn 2008

- VIC hydrology model
- 3 Users: Agriculture, Industrial, Municipal
- Compared efficient vs proportional changes in allocations

Rio Bravo Prices (pesos/$m^{3)}$
No Adaptation

Climate Change	Runoff Change	Agriculture	Residential	Industrial
+1.4C +0%P	-5%	+0.05	+23	+48
+2.7C +0%P	-10%	+0.10	+46	+100
+4.1C -20%P	-20%	+0.30	+180	+201

Welfare effect (million pesos)
No Adaptation

Climate Change	Agriculture	Residential	Industrial	Total
+1.4C +0%P	5	1508	1061	2574
+2.7C +0%P	16	3228	2281	5526
+4.1C -20%P	69	7557	5338	12964

Welfare effect (million pesos)
Adaptation

Climate Change	Agriculture	Residential	Industrial	Total
+1.4C +0%P	7	0	0	7
+2.7C +0%P	20	0	0	20
+4.1C -20%P	86	0	0	86

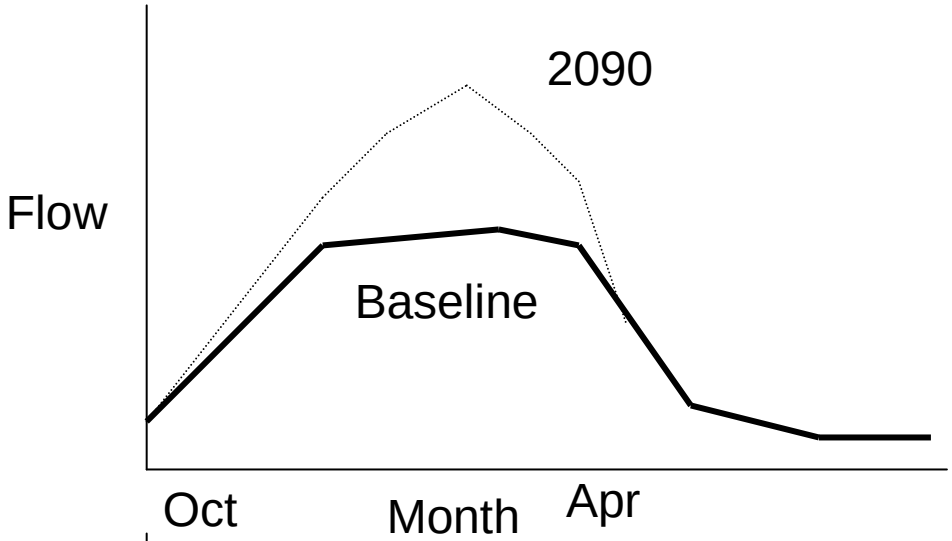
Rio Bravo Conclusion

- All the reductions in withdrawals should come from agriculture
- Losses fall by more than two orders of magnitude
- Costs do not have to be borne by farmers if system of tradable permits established-compensate farmers for losses

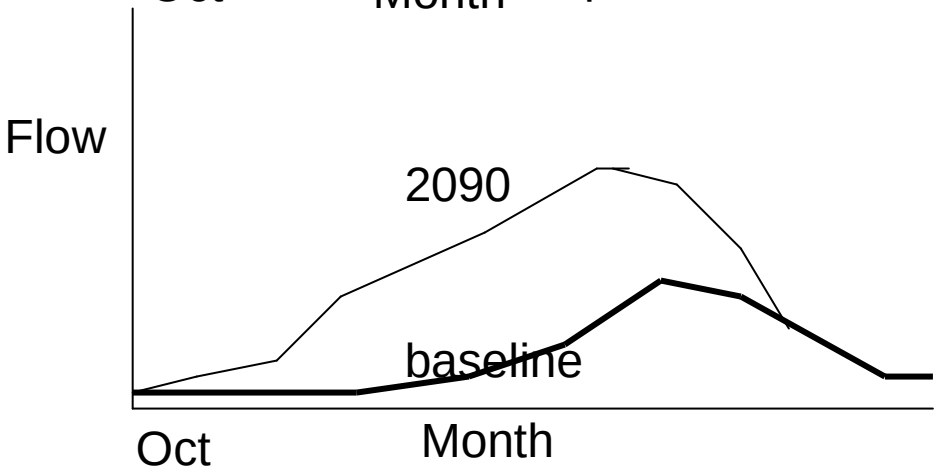
California Hydrology
Miller et al 2006

- SAC-SMA hydrology model
- 6 basins: Smith, Sacramento, Feather, American, Merced, Kings
- HADCM2 2090 (+3.3C, +58%P)
- PCM 2090 (+2.4C, -21%P)

Runoff Results
Hadley

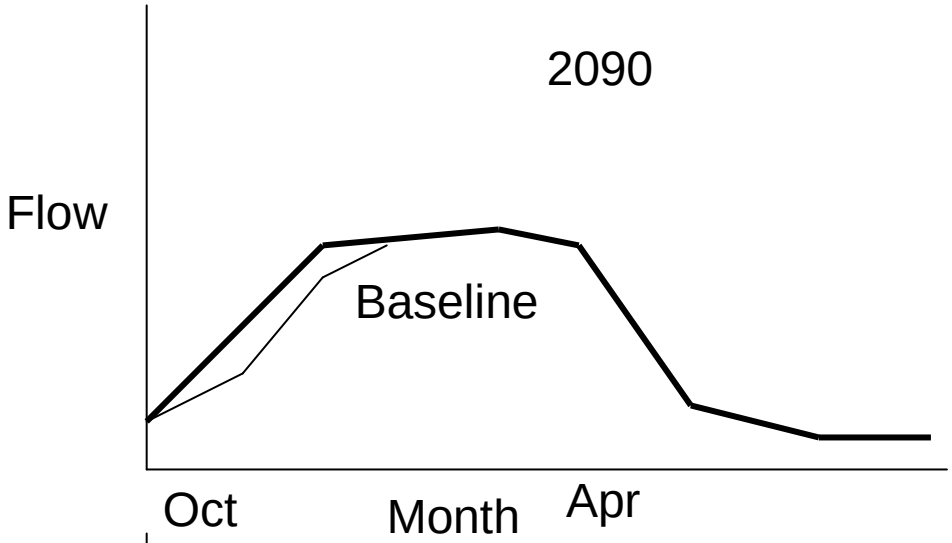


Smith, Sacramento,
Feather, American

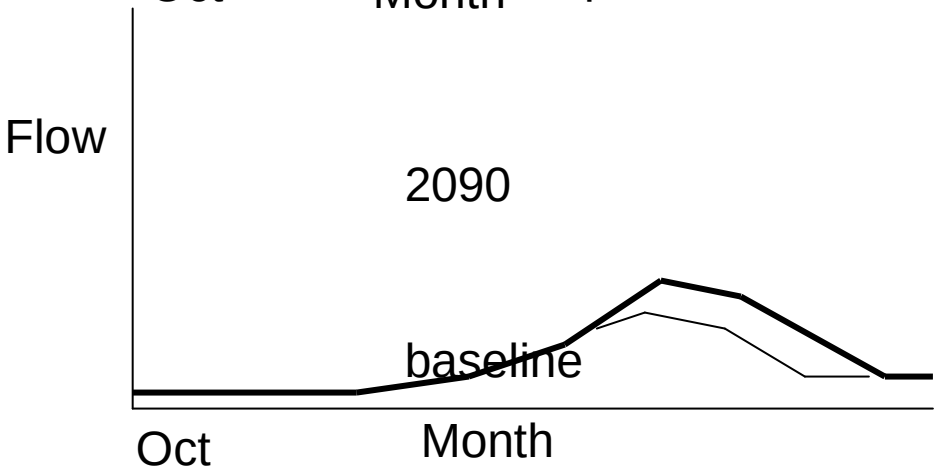


Merced, Kings

Runoff Results
PCM



Smith, Sacramento,
Feather, American



Merced, Kings

Runoff Conclusions

- Hadley- 2090- increase of 11%- mostly winter flow
- PCM- decrease of 9%- some Nov-Dec and some May-July

Change in Water Demand
Adams 2006

Region	PCM 2090	HAD 2090
Sacra Delta	+17%	+19%
San Joaquin	+7%	+15%
Northeast	+9%	+16%
Coast	+19%	+32%

CALVIN
Lund et al 2006

- Reallocates water to maximize economic benefits
- Flow constraints, dams
- Urban values of water
- Operating costs
- Does not consider changing infrastructure
- Assumes perfect foresight

CALVIN Results
(Million $/yr)

Costs	PCM2090	HAD2090
Urban	87	-3
Agriculture	1476	-18
Operating	147	-237
Total Losses	1809	-259

CALVIN CONCLUSION

- Wetter climate scenario leads to benefits and dryer scenario leads to damages
- Reallocating water to highest use reduces welfare effects
- Institutional and infrastructure constraints keep costs high

Agricultural Economic Analysis Howitt and Pienaar

- SWAP
- Changes crops to maximize profit given climate, land, and water
- Accounts for reduction in future farmland
- 21 Regions in California
- 12 Categories of crops: cotton, field crops, fodder, grain, grapes, orchard, pasture, tomatoes, rise, sugar beets, subtropical, and truck

SWAP Results

CROP	Baseline	HadCM2	PCM
Field and rice	11.5	11.4	5.9
High Value	70.2	70.1	78.4
Pasture-Fodder	11.8	12.1	9.4
Cotton	6.5	6.4	6.3

SWAP Conclusion

- HadCM2: more water, little change
- PCM: switch out of low valued crops
- Welfare effect with PCM: 24% reduction in agr water supply, 14% reduction in agr land, welfare effect only 6% loss in agr

What is still to be done?

- Explore uncertainty of climate scenarios, hydrology, baseline changes
- Add flooding
- Add water quality
- Extend models to more places
- Explore infrastructure changes- dams, canals, pumping

Water Institutions

- Need to be more efficient today
- Climate change likely to increase urgency of reforms
- Two major approaches to allocation: Improve centralized control or strengthen water rights and allow water trading
- Two major approaches to water quality: stricter regulations of behavior or taxes on pollution