



Watershed Conservation as Climate Adaptation

Sustainability Science for Food, Forests, and
Floods: Integrating Climate Adaptation and
Pro-Poor Resource Management

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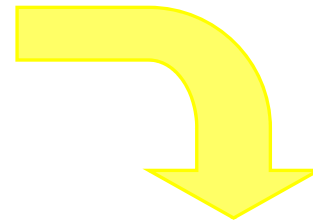
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Overview & Research Questions

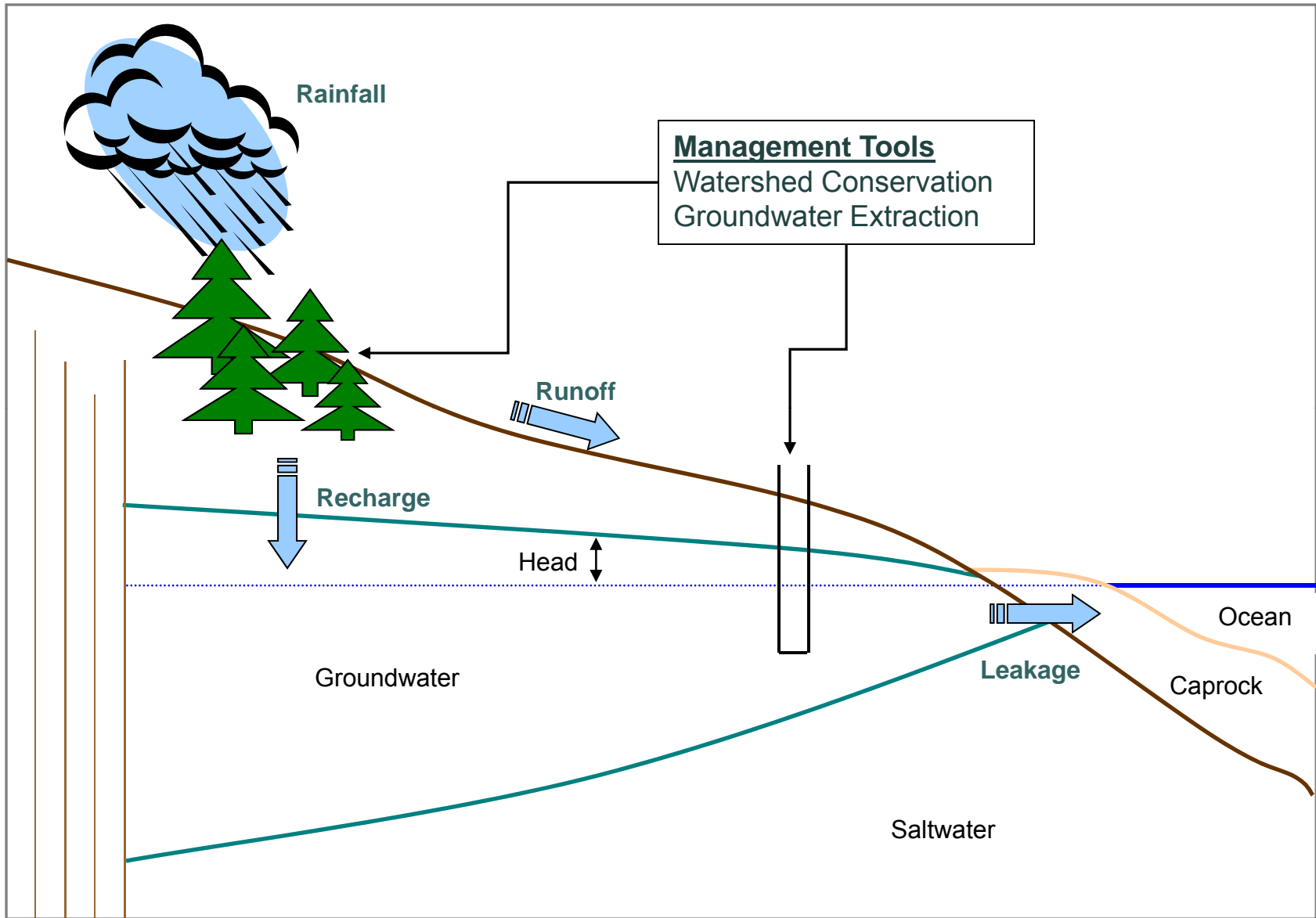
What do we know or suspect?

- Watersheds provide many ecosystem services (e.g. biodiversity, flood control, recreation, groundwater recharge)
- The providing resource should be managed in conjunction with the downstream resource(s)
- Payments for ecosystem services should be informed by joint management



What do we want to know?

- How to jointly optimize a watershed and aquifer?
- How to finance investment in groundwater-recharge augmentation?
- How to adapt to declining recharge caused by climate change?





Groundwater System

- The aquifer head (h) is a measure of the groundwater stock
- Head increases/decreases over time depending on recharge (R), leakage (L) and extraction (q)

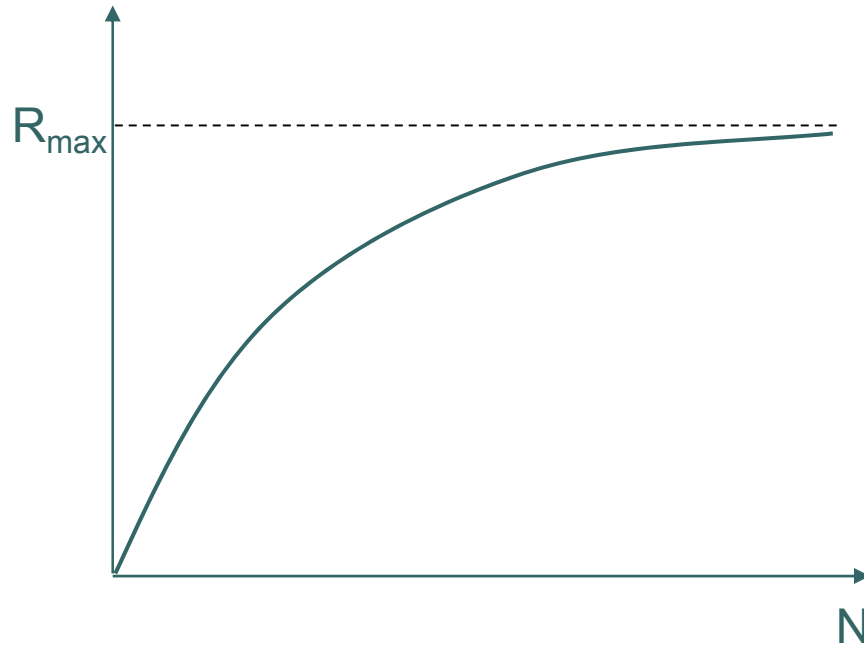
$$\dot{h}_t = R(N_t) - L(h_t) - q_t$$

- Recharge can be enhanced by watershed conservation, $R'(N) > 0$
 - N : stock of conservation capital



Recharge function

- In groundwater economics N is typically implicit and constant
- Here N is variable as is recharge:





Watershed

- Conservation capital increases recharge to the aquifer
 - Fencing: prevents pig wallows, which reduces runoff
 - Reforestation: reduces runoff; possibly reduces ET
 - Engineering structures: improve infiltration and reduce runoff
- The conservation capital stock is increasing in investment (I):

$$\dot{N}_t = I_t$$

- For simplicity, suppose zero depreciation



Optimal Joint Management

- In addition to groundwater, suppose desalination is another viable source of freshwater
- The resource manager chooses extraction (q), desalination (b), and investment in watershed conservation (I) to max. the PV net benefits to society:

$$\text{Max}_{q_t, b_t, I_t} \int_0^{\infty} e^{-rt} \left[B(q_t + b_t) - \underbrace{c_q(h_t)q_t - c_b b_t - c_I I_t}_{\text{Costs of extraction, desalination, and investment}} \right] dt$$

Discount factor Benefits from water consumption Costs of extraction, desalination, and investment

subject to the governing equations for N and h

Scarcity Value of Water

- Condition is the same whether investment is zero or positive, but the actual paths will differ (optimal paths of N and h will differ)

$$p_t = \underbrace{B'(q_t + b_t)}_{\text{marginal benefit}} = \underbrace{c_q(h_t) + \frac{\dot{p}_t - c'_q(h_t)[R(N_t) - L(h_t)]}{r + L'(h_t)}}_{\text{scarcity value or marginal opportunity cost (MOC)}}$$

- Optimal price determined where MB = MOC



Equimarginality Condition for Conservation Capital Stock

- Invest until the stock of capital satisfies the following condition:

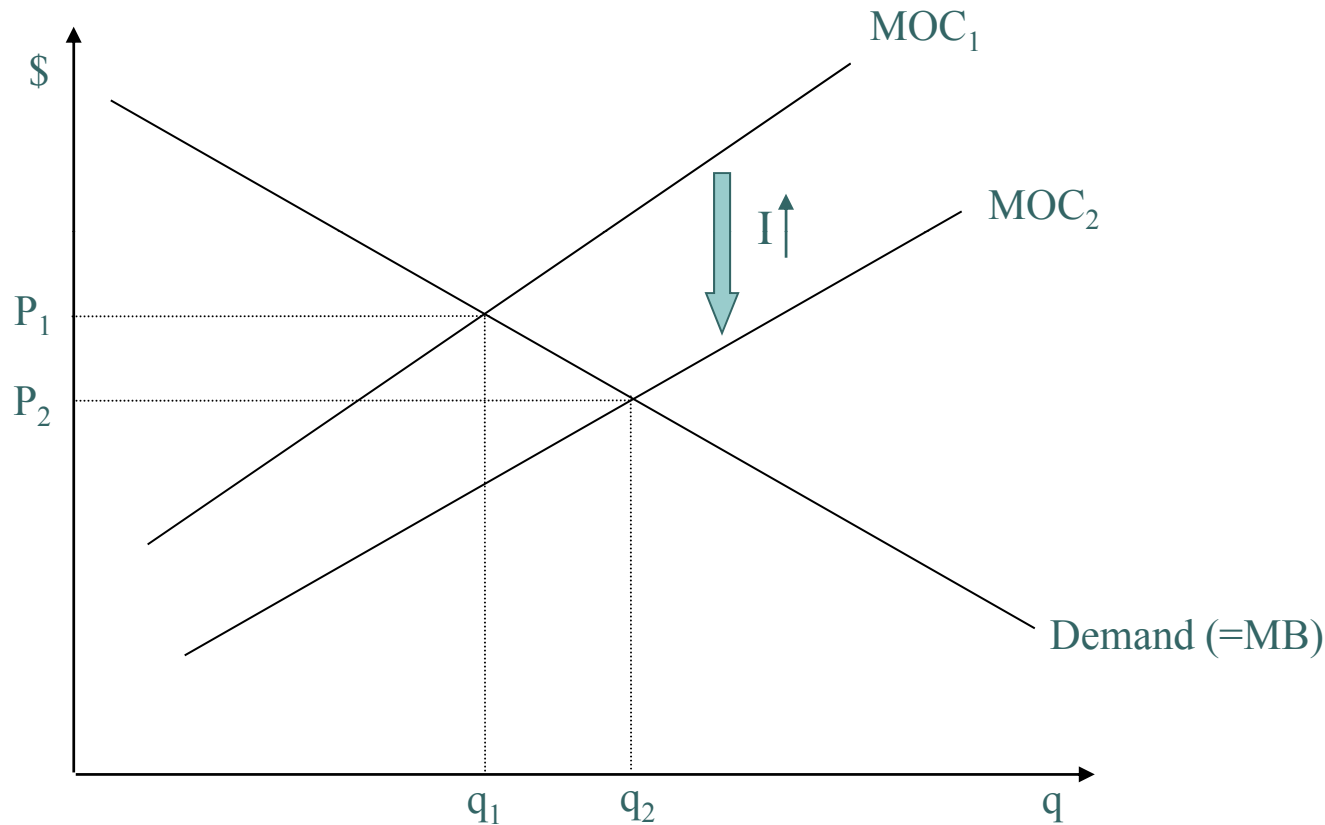
$$[p_t - c(h_t)]R'(N_t) = rc_I$$

Value of additional recharge

Forgone interest from investment cost

- Depends on optimized p and h just as optimal groundwater condition depends on optimized N

Scarcity Value of Groundwater w/ and w/o Investment



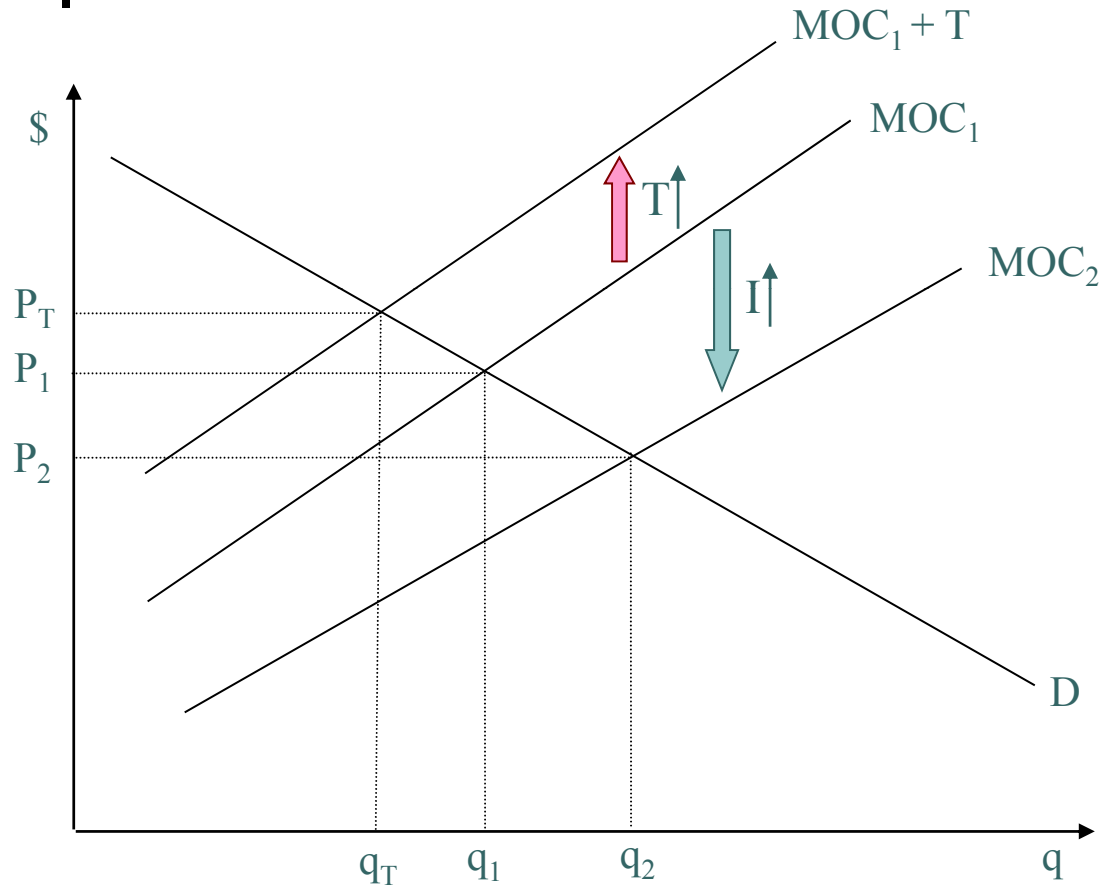
Investment tends to reduce the scarcity value of groundwater and hence the optimal price



Finance by Volumetric Surcharge?

- Generally there may be competing land-uses, but Hawaii has conservation-designated land
- Landowners have no incentive to invest
- Then who should pay? Benefit taxation?
- Volumetric charge raises price faced by users while investment reduces the price
- With no economic objectives, volumetric charges may seem ideal: lower consumption + increased recharge capacity... but at what cost?

Effect of a Volumetric Tax



Optimal investment moderates water scarcity. Charging consumers more takes away part of benefits, exactly what we're trying to avoid



Win-Win Financing with Lump Sum Conservation Tax

- Optimize groundwater and watershed → PV cost and PV benefit of investment
- Proportion of benefits that balances the intergenerational budget is:
$$\alpha = (\text{PV costs}/\text{PV benefits})$$
- Calculate period- t benefits from consumption with (V_t) and without (W_t) optimal investment
- Optimal lump-sum tax for period- t is:

$$\tau_t = \alpha(V_t - W_t)$$

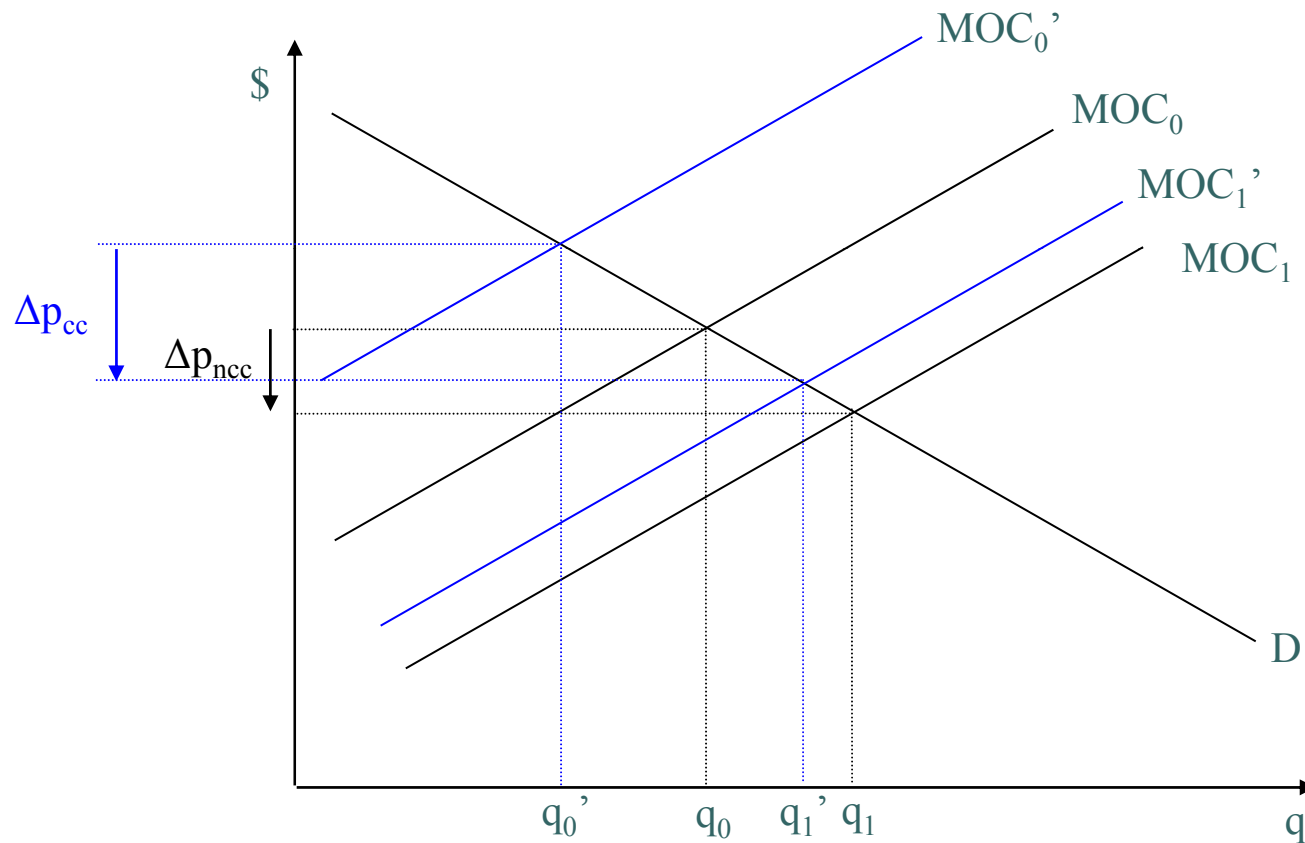
*This is for the case of proportional benefit taxation



Adapting to Declining Recharge

- Climate change threatens the condition of the watershed
- If we do nothing, recharge will decline
- Declining recharge means we have an even stronger case for investment (adaptation)

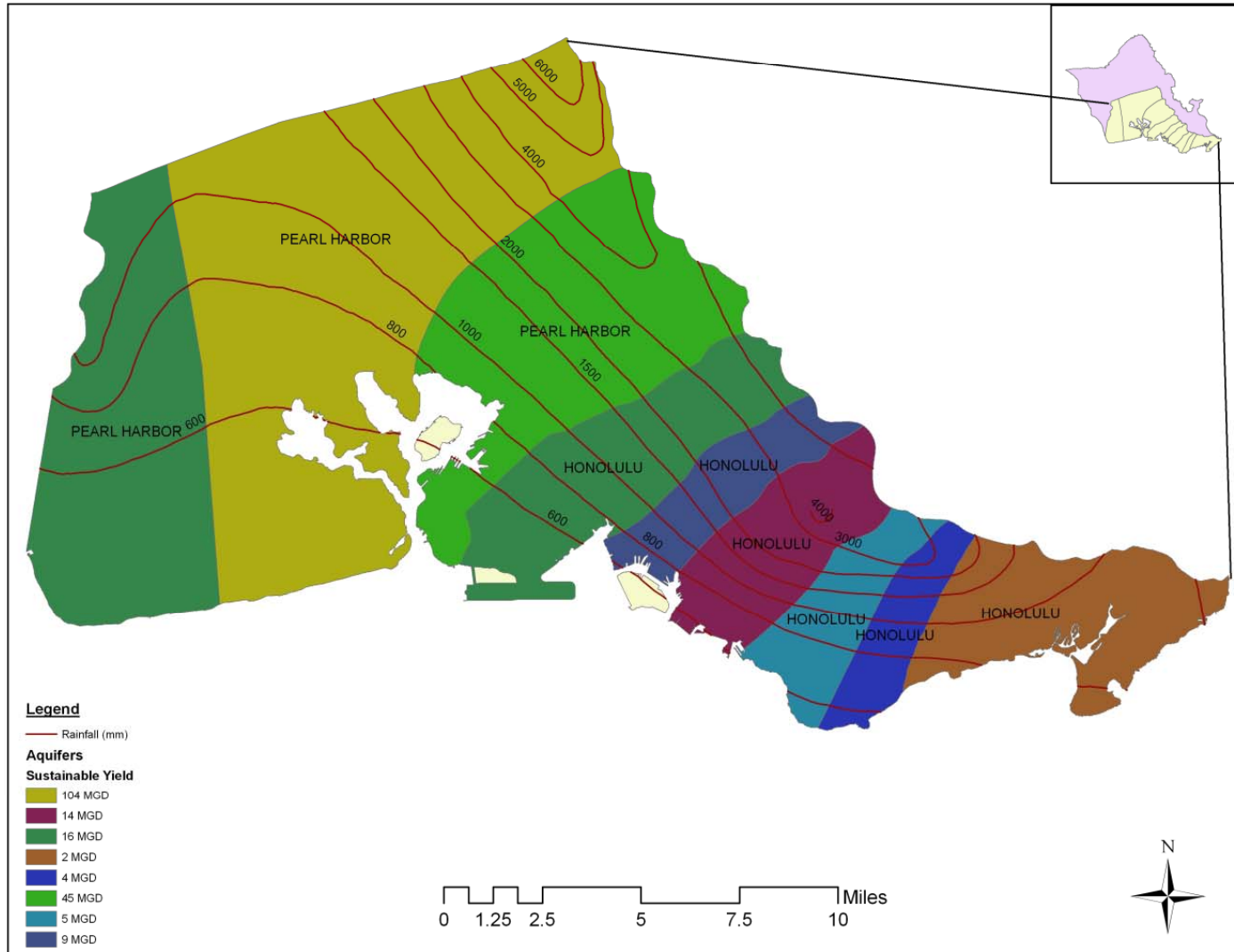
Impact of Declining Recharge



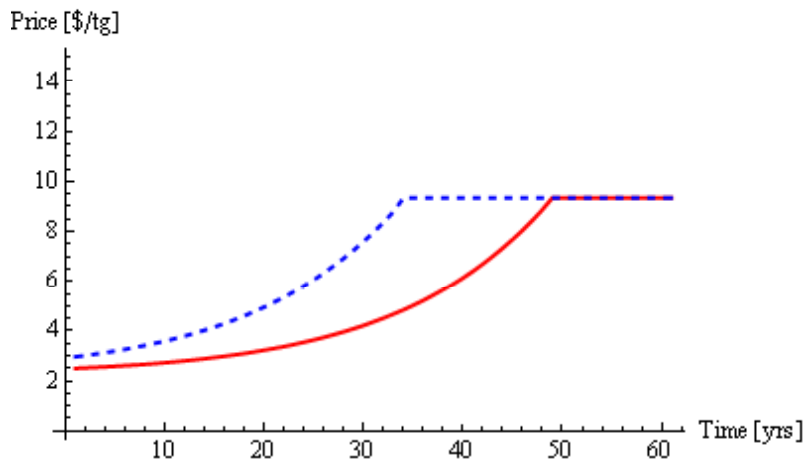
Solve the problem again but with declining recharge

Shift of MOC from investment is bigger with climate change than without

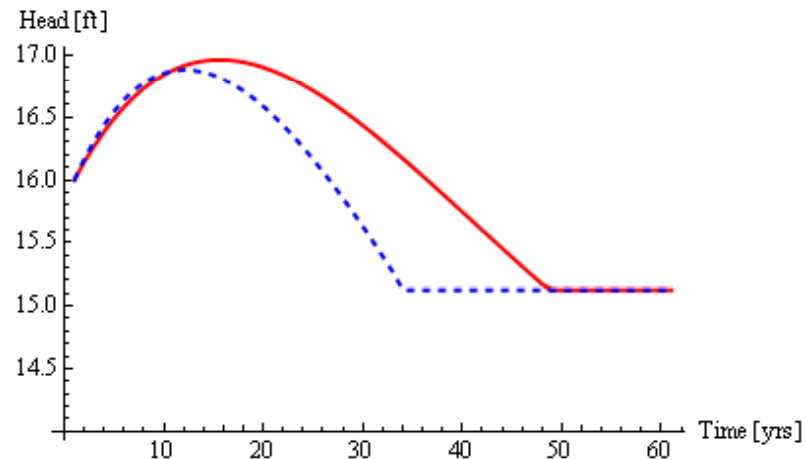
Example: Ko'olau Watershed and Pearl Harbor Aquifer



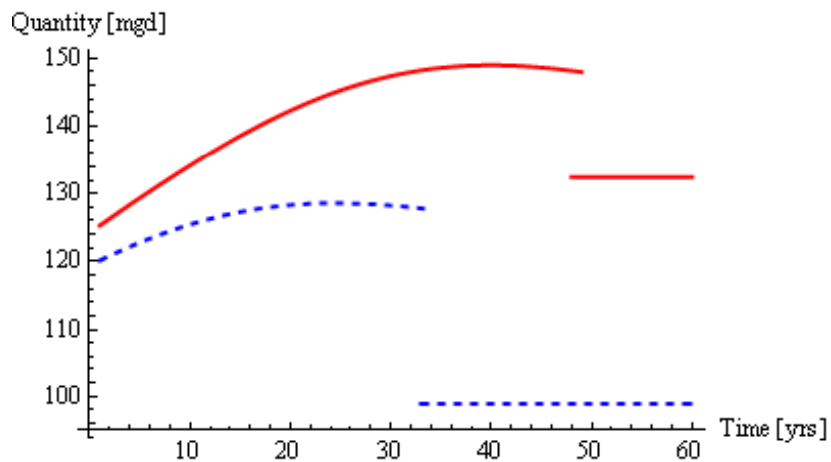
Efficiency Price Paths



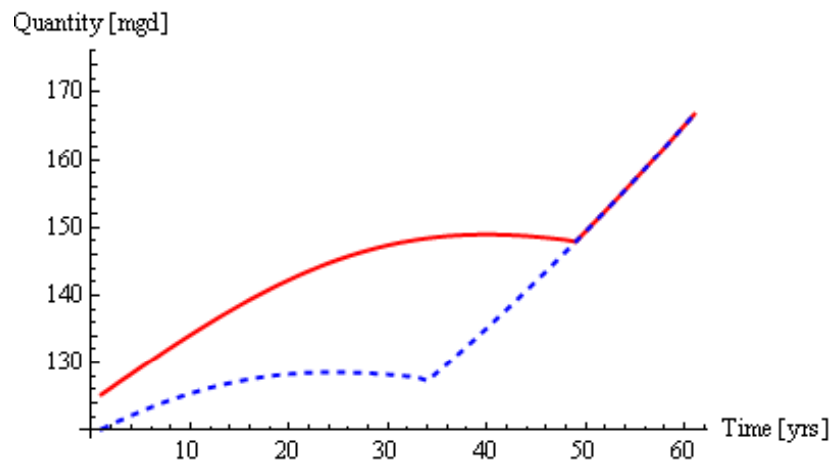
Optimal Head Paths



Optimal Groundwater Extraction Paths



Optimal Consumption Paths

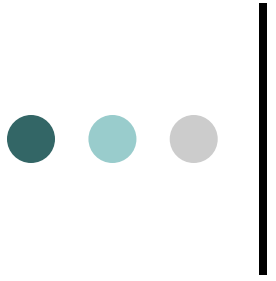


Key: — Watershed Partnership Plan (0.3% annual recharge reduction)
..... Status Quo Conservation (1% annual recharge reduction)

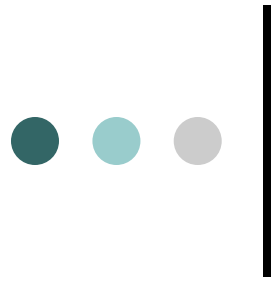


Conclusions

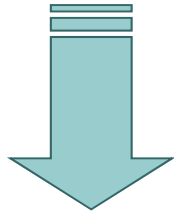
- Watershed conservation ameliorates upward pressure on scarcity
- Fixed, not volumetric, surcharges
- Solving adaptation is doing the same problem over again with declining recharge
- Enabling legislation
 - How should improvements to natural capital be financed?
 - Same as debt for capital improvements.
- Big research challenges remain
 - Establish link between investment dollars and recharge



Mahalo!



Pearce Equation



$$p = c + MUC + MEC$$



David Pearce
(1941-2005)

(Unifying resource, environmental, and micro economics)

- True for flow externality (MEC separable)
- Stock (capital) to flow (recharge) externality captured with the MUC (MEC not separable)