Sustainability Economics of Groundwater Usage and Management

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1. Sustainability concepts

Some representative definitions from the general literature:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

World Commission on Environment and Development (1987)

"We summarize the necessary conditions [for sustainable development] as 'constancy of the natural resource stock'. More strictly, the requirement as for non-negative changes in the stock of natural resources such as … ground surface waters and their quality, land biomass … and the waste assimilative capacity of the environment."

Pearce, D., E. Barbier, and A. Markandya. *Sustainable Development and Cost-Benefit Analysis*. 1988.

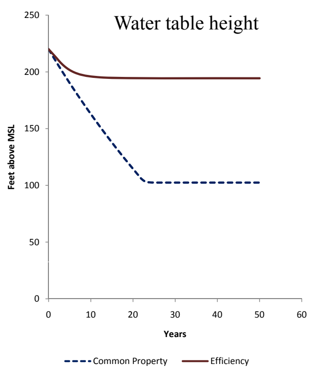
While these definitions likely point us in a useful direction, they can be very limited for quantitative policy analysis:

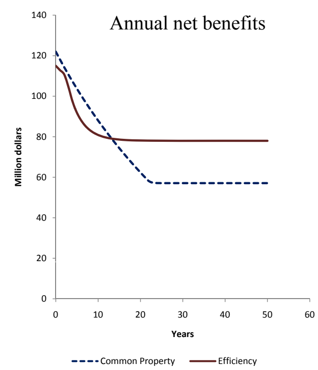
"Needs" type definitions:
- What are needs?
- Zero-one, all-or-nothing quality.

"Natural stock" definitions:
- Population and economic growth must inevitably draw down at least some natural resource stocks.
- How does one calculate the stock to maintain?
- Substitution possibilities.
- Nonrenewable resources.
- Natural capital is generating rents and incomes, this isn't necessarily consumption.
- Confuses means with ends.

Many studies don't define sustainability at all.

Groundwater economics: partial equilibrium analysis





Dilemmas:

- Drawing down natural resource stocks from an initial full level is inevitable. This means declining incomes for at least some time interval.
- An infinite number of steady-states, so how does one choose?
- Focusing on the resource alone ignores other possibilities for achieving end goals.

Way out:

What's coming off resource stock is income, not consumption, so investment can at least partially compensate for natural resource scarcity.

Consider socioeconomic and environmental systems jointly.

Environmental macro-economics literature

Capital/resource economy
Dasgupta and Heal (1979)

Can economies physically continue to grow with nonrenewable resources?
Solow (1974), Stiglitz (1974)

Will markets result in economic growth with nonrenewable resources?
Mourmouras

Social choice and sustainability
Asheim (2001)

What about PV-optimality?
Pezzey

Sustainability Policy:
Hartwick (1977), Solow (1974).

Sustainability: a proposed definition and framework from the environmental macro-economics literature.

Sustainability =

Intertemporal Efficiency [*Pareto-optimality*]

Intergenerational Equity [*Non-declining utility over time*]

Total capital =

Physical/human capital [Factories, roads, knowledge]

Natural resource stock [groundwater]

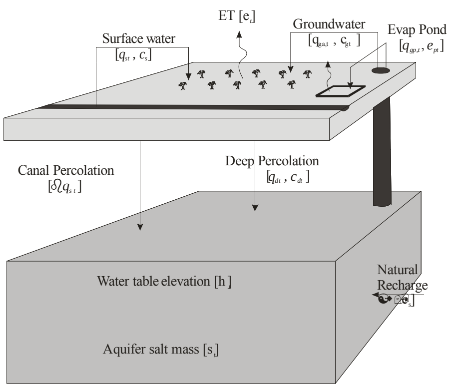
2. Model

Region with surface water supply and overlying a groundwater aquifer.

Households: consumption and savings/investment.

Production sectors = agriculture + manufacturing.

Kern county agriculture and water data.
U.S. growth data for manufacturing and capital stock data.



(a) Households

Utility function:

U[c(t)]=Log[c(t)]

Household utility depends on annual consumption

These are one determinant of intertemporal preferences.

Savings/investment rate = φ (constant rate).

This is consistent with Solow/Swan neoclassical growth model and U.S. empirical data.

(b) Regional output balance equation

Regional output (GDP) can be used for consumption or investment in the capital stock.

- Output balance equation

  c(t)+Δk(t)=q(a,t)+q(m,t) - γ(s,t) – γ(g,t)

- Surface water costs

$$\gamma_{st} = 15.47q_{st} + 1.365q_{st}^2 + 6.239q_{st}^3$$

$$\gamma_{st} = -22.03 + 84.89q_{st} - 70.69q_{st}^2 + 30.79q_{st}^3$$

- Groundwater pumping costs

$$\gamma_{gt} = \gamma^{pc}q_{gt} + \gamma^{e}(h^{l} - h_t)q_{gt} + \frac{\gamma^{e}q_{gt}^2}{2As^{y}}$$

(c) Agricultural production

Net returns from agriculture:

$$\Pi_t^a = \sum_i \sum_j \pi_{ijt}x_{ijt} \qquad \pi_{ijt} = p_j y_{ijt} - \gamma_{ij}$$

Crop yield production function:

$$y_{ijt} = \frac{\bar{y}_{ij}}{1 + \varphi_{1ij}\left(\frac{w_{ijt}}{w75_{ij}}\right)^{\varphi_{2ij}}}$$

Deep percolation production function:

$$d_{ijt} = \alpha_{1ij} + \alpha_{2ij}w_{ijt} + \alpha_{3ij}w_{ijt}^2$$

Water usage:

$$w_{ijt} = w_{ijt}^{g} + w_{ijt}^{s}$$

(d) Manufacturing sector

Production function: $\Pi_{mt} = k_t^{\beta}$

where β=0.2 is the capital share.

(e) Regional water and land usage.

Surface water:

$$q_{st} = \frac{1}{1-\beta_s}\sum_i \sum_j w^s_{ijt} x_{ijt} \le \overline{q_{st}}$$

Groundwater extractions:

$$q_{gt} = \sum_i \sum_j w^g_{ijt} x_{ijt}$$

Land constraint:

$$\sum_i \sum_j x_{ijt} \le \bar{x}$$

(f) Regional deep percolation and stock dynamics.

Deep percolation

$$q_{dt} = \sum_i \sum_j d_{ijt} x_{ijt}$$

Equation of motion for water table height:

$$h_{t+1} = h_t + \frac{1}{AS^y}(\omega + q_{dt} + \beta_s q_{st} - q_{gt})$$

Equation of motion for the capital stock:

$$K_{t+1} = K_t(1-\delta) + I_t$$

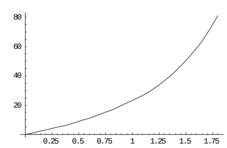
Kern County, California

Agricultural production

cotton, tomatoes

evaporation ponds

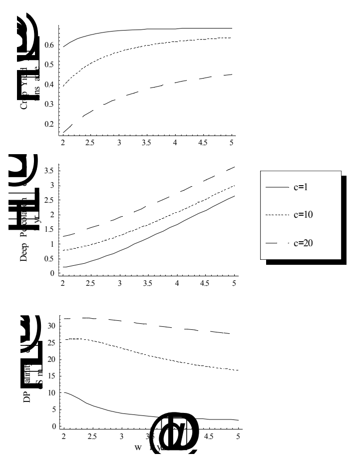
Surface water costs



Aquifer

area = 1.3 10^6 acres, h_{top} - h_{bottom} = 618 feet
specific yield = .13
natural recharge = .052 10^6 af/yr

Crop water production functions



U.S. growth data

Savings/investment rate = 0.2

Capital share = 0.2

Depreciation = .06

3. Common property usage.

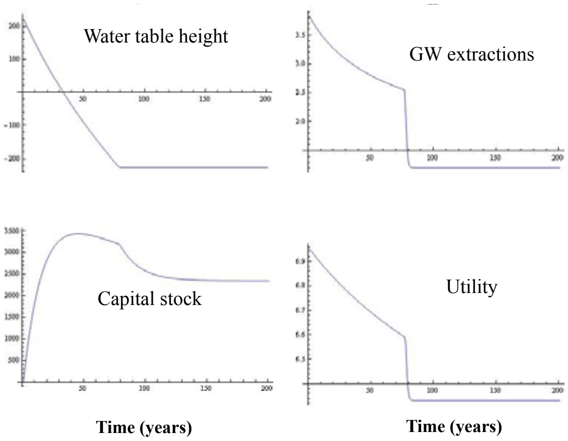
Unregulated usage
Users are essentially free to use the resource as they desire

Groundwater extractions
With many users in the basin it is reasonable to assume the following:

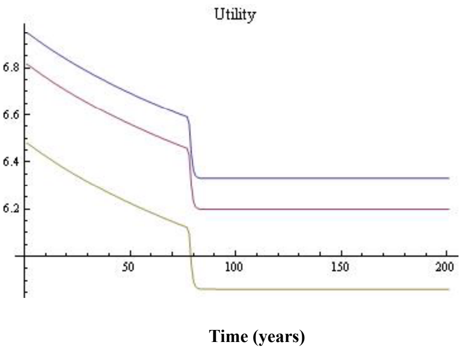
- *groundwater extractions are chosen to maximize current profits without regard to future levels of the water table level*
- *deep percolation flows and salt emissions to the aquifer are made as a byproduct of profit-maximization, again no explicit concern for future levels of aquifer hydraulic head or salt concentration*

Investment/savings
Neoclassical (Solow-Swan) model: Constant rate of savings/investment consistent With empirical facts.

Common property usage: Investment rate (φ) = 0.2



Common property usage: Investment rate (φ) = {0.2, 0.3, 0.5}



4. Present-value optimality (efficiency).

Present value is defined by

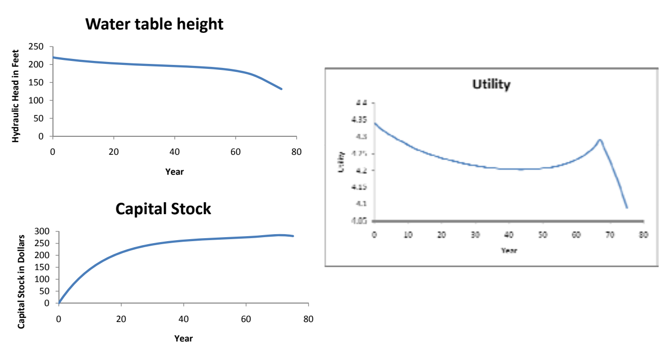
$$W = \Sigma_{t=1}^{T} u(c_t)$$

where α = 1/(1+ρ) is the discount factor, and ρ is the subjective rate of time preference.

Present-value optimality selects extractions to maximize W subject to the various definitions, equations and constraints in the model.

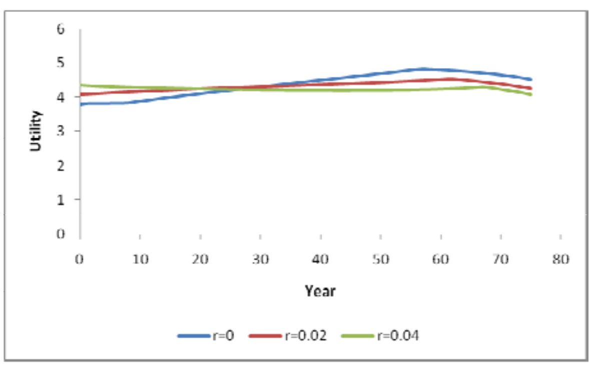
This generates an efficient outcome in terms of Pareto-optimality.

Efficient extractions.



Notes: investment rate (φ) = 0.2

Efficient extractions with different social discount rates.



5. Sustainability.

Market equilibrium (common property) and PV-optimality can lead To declining consumption over some time-frames.

Sustainability is defined by:

(a) Efficiency (Pareto-optimality/PV-optimality)

$$W = \Sigma_{t=1}^{T} u(c_t)$$

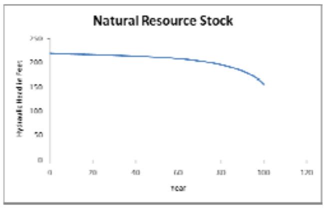
where α = 1/(1+ρ) is the discount factor, and ρ is the subjective rate of time preference.

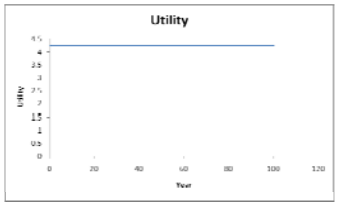
(b) Equity (non-declining utility over time)

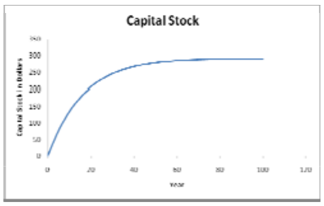
$$u[c(t)] \le u[c(t+1)]$$

Select extractions to maximize W subject to the various definitions, equations and constraints in the model.

Sustainable resource extractions





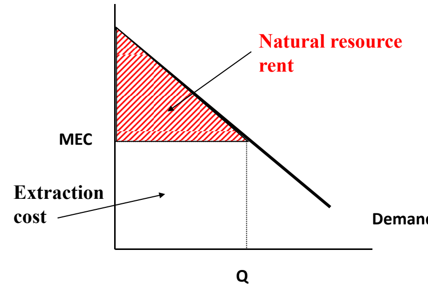


Investment rate (φ) = 0.2, interest rate = .04. Without sustainability, utility is declining over time.

6. Hartwick-Solow rule

Resource rents

(P – MEC) Q.



If we invest resource rents in capital stock, then we can maintain consumption forever.

Only holds under specialized conditions, but still useful insight.

7. Conclusions.

Concept of sustainability

- We need to define sustainability, otherwise we'll be talking past each other at some point.
- Existing definitions point in useful direction, but can't be basis for quantitative policy analysis.
- Can't just focus on natural resource stock alone, must consider socioeconomic and environmental systems jointly.

Sustainable groundwater management

Common property (market equilibrium) can lead to declining regional welfare after some point.

PV-optimality as commonly used in economic gw mngt studies doesn't guarantee sustainability either. Reason: this is about efficiency, sustainability also involves equity.

Utility-constraint: some theoretical limitations.

Future research

Further characterize when sustainability is achieved by the market and PV-optimality.

Improved sustainability criteria.

Scaling issues.

Sustainability policy instruments.