Improving ecosystem services through trade in the Murrumbidgee Catchment, Australia

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The Lower Murrumbidgee

- MDB sub-catchment
- Competing water demands
  - Agriculture (MIA, CID)
  - Domestic
  - Environment
  - Recreation
- Multiple ecosystem services in possibly competing or complementary combinations
- The Basin Plan (2012)
  - Reallocate water to environment and manage for maximum ecological benefit
- Additional option
  - Trading on the allocation market

Source: MDBA
Research Agenda:

1. Develop a model to assess how annual allocation trade by a hypothetical EWH can impact ecosystem services in the Murrumbidgee catchment.

2. Use the model to optimize strategic year to year water management decisions.

But first, need to describe mathematically how hydrological indictors (and water trade) impact ecosystem services and economic value:
  - thresholds
  - trade-offs
  - interactions
Theoretical Basis: Ecosystem Services Cascade

• “bridging the worlds of natural science and economics” (Braat and de Groot, 2012)

Δ hydrological → Δ biophysical → Δ ecosystem services → Δ economic value

For flow dependent ecosystems:

Ecosystem Services Cascade. Adapted from CSIRO (2012)
Ecosystem Service Dynamics

Ecosystem service values are not static
- Ecosystem services – and hence economic value – change with respect to hydrological conditions
  - Flow volumes (spatial dimension)
  - Flow frequencies (temporal dimension)
- It is not sufficient to say an asset is worth $x in all cases

Example: a wetland watered with a 1500GL flood in a timely manner provides more ecosystem services ($) than the same volume flood 5 years later
- By extension, the marginal value of water has a temporal dimension

Key point:

*Ecosystem services are multiple and they change across time, space, and with considerable degrees of uncertainty.*

We therefore need continuous descriptive functions to represent this.
Example: Carbon Sequestration

- Market valuation technique
  - $Value \in \mathbb{R} = f(\text{area}, \text{tree health}, \text{market prices})$
  - $Tree \text{ health} = f(\text{desired return interval}, \text{actual return interval})$

- As time past return interval increases, carbon value ($) decreases
Example: Carbon Sequestration

- When watering event occurs, tree recovery begins
  - Increase in carbon value ($)
  - Recovery rate proportional to tree health

Extreme drought - e_watering of floodplain every 20 years (Q=1700GL/year)
Example: Carbon Sequestration

- During recovery, time past watering still counting
- If desired return interval is exceeded, decay begins again from new, lower point
  - Gradual decrease over time until threshold reached (lost asset)

![Graph showing Extreme Drought, e_watering of floodplain every 20 years (Q=1700GL/year)]
Example: Carbon Sequestration

- Time past return interval is zero, carbon value ($) maintained at maximum
Relationship with EWH water trade

There is an opportunity for annual EWH water trade to influence the inter-annual distribution of overbank flooding and ecosystem service values.

Existing models:
• *Kirby et al.*, 2006
• *Connor et al.*, 2013
• *Ancev, et al.*, 2014

• Existing models are largely abstract and conceptual

• Contribution
  • Articulate multiple individual ecosystem services
  • Economic valuation of individual ecosystem services
  • Consideration of temporal thresholds, trade-offs and interactions
Ecosystem Services Considered:

Δ hydrological → Δ biophysical → Δ ecosystem services → Δ economic value

- Flow Frequency
- River Red Gum Health
- Carbon Sequestration
- Market Valuation
- Erosion Prevention
- Avoided Cost

- Flow Volume
- Habitat Suitability
- Recreational Fishing
- Marginal Expenditure

- Flow Velocity
- Thermal Mixing
- Blue Green Algae Prevention
- Avoided Cost
Objective Function: Sum of Ecosystem Services

Seek the best combination of yearly management decisions influencing $Q(\text{vol})$ and $Q(\text{freq})$ to maximize ecosystem service benefits

- Optimization algorithm to evaluate options:

$$\max P = \sum_{t=1}^{T} \sum_{n=1}^{q} ES_n, t$$

Where:

$ES_n$ is the number of ecosystem services
$T$ is the time horizon
$t$ is the time step in years

Subject to:

- Hydrological constraints (delivery, carryover, storage capacity)
- Fiscal constraints (budget, non-debt, non-profit, self-sufficiency)
Valuation Challenges

Uncertainties in market prices (water, carbon)

Avoid double counting by excluding willingness-to-pay for habitat services:
  • But monetary value of Basin Plan flow benefits dominated by habitat ecosystem services (non-use values)

Conceptual issues equating avoided cost, impacts, and value of ecosystem service benefits
  • e.g. avoided cost of erosion prevention
  • e.g. marginal expenditure of recreational fishing

Multiple management options each with different costs
  • e.g. cost of BGA prevention is cost of \((Q_1 - Q_0)\), when \(\frac{Q_0}{Ac} \leq 0.03 \frac{m}{s}\), such that \(\frac{Q_1+Q_0}{Ac} > 0.03 \frac{m}{s}\)
  • OR/ cost of dosing water with Chlorine
Uncertainties

Epistemological uncertainty:
• Market price of carbon
• Water price
• Ecological boundary conditions
• Groundwater conditions

Stochastic (natural) uncertainty:
• Spatial heterogeneity
• Stochasticity of flow
• Irrigation + domestic demands
Marginal Value of e_water

• The **Marginal Value** is the change in the total value created by the change in quantity of the control variable.

• Example: Horne et al., (2009).

![Figure 3. Possible total benefit curves for an environmental flow.](image)

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A. HORNE ET AL.

![Figure 4. Associated marginal benefit curves for an environmental flow.](image)
Example: Erosion Prevention

Avoided Cost ($MILLIONS) vs Years Past Desired Return Interval

- Q=50GL/year
- Erosion Rate Exceeds Allowable Sediment Yield
Example: Blue Green Algae Prevention

Avoided Cost ($MILLIONS)

Flow (GL/YEAR)

Avoided Cost

Minimum Velocity Threshold (m/s)
Example: Recreational fishing

Marginal Expenditure ($Millions)

Flow (GL/YEAR)

ES: Recreational Fishing

Baseline Flow Conditions (Q=1536GL/year)

Marginal Recreational Fishing Expenditure