# Improving ecosystem services through trade in the Murrumbidgee Catchment, Australia

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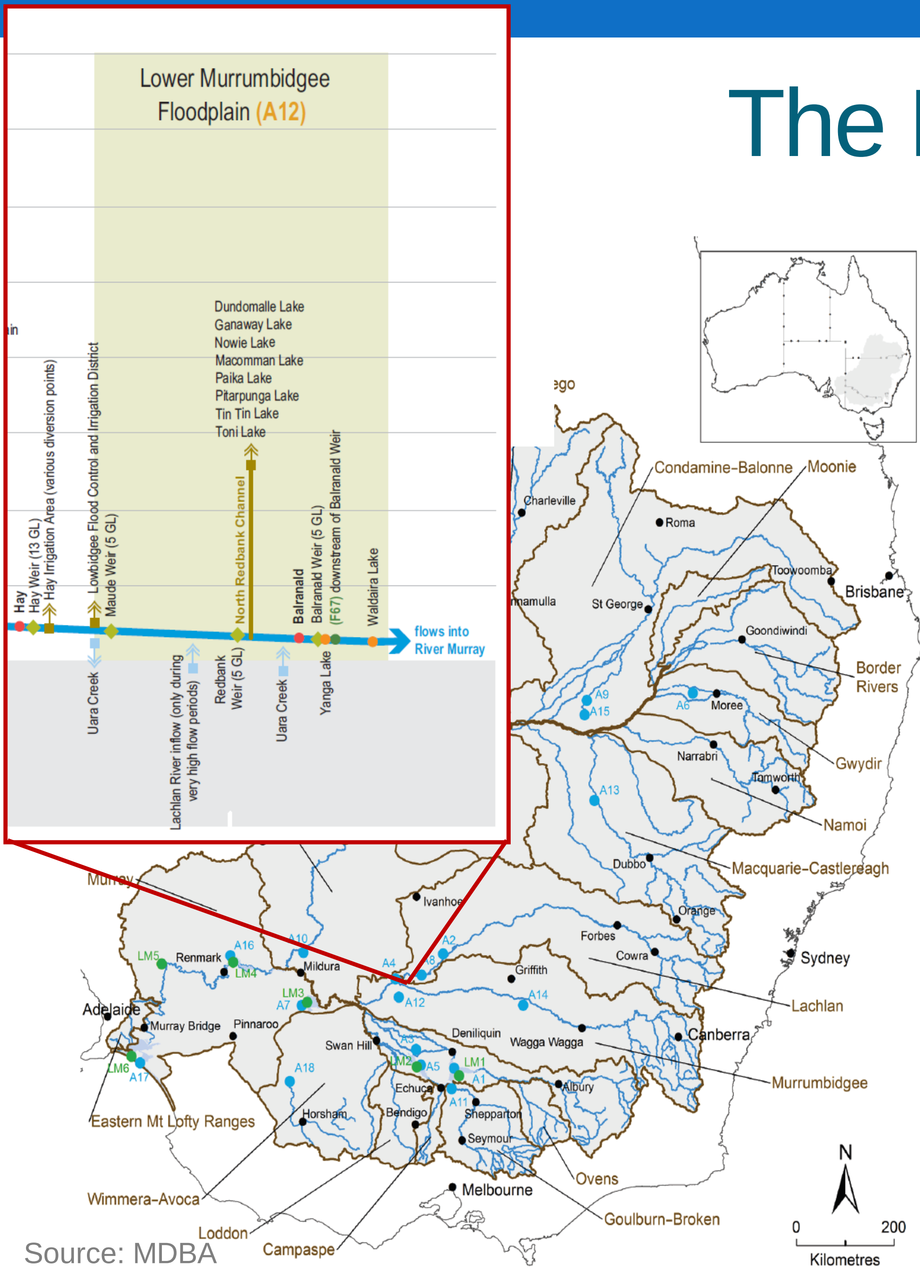
# The Lower Murrumbidgee




Source: MDBA

- 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

# 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

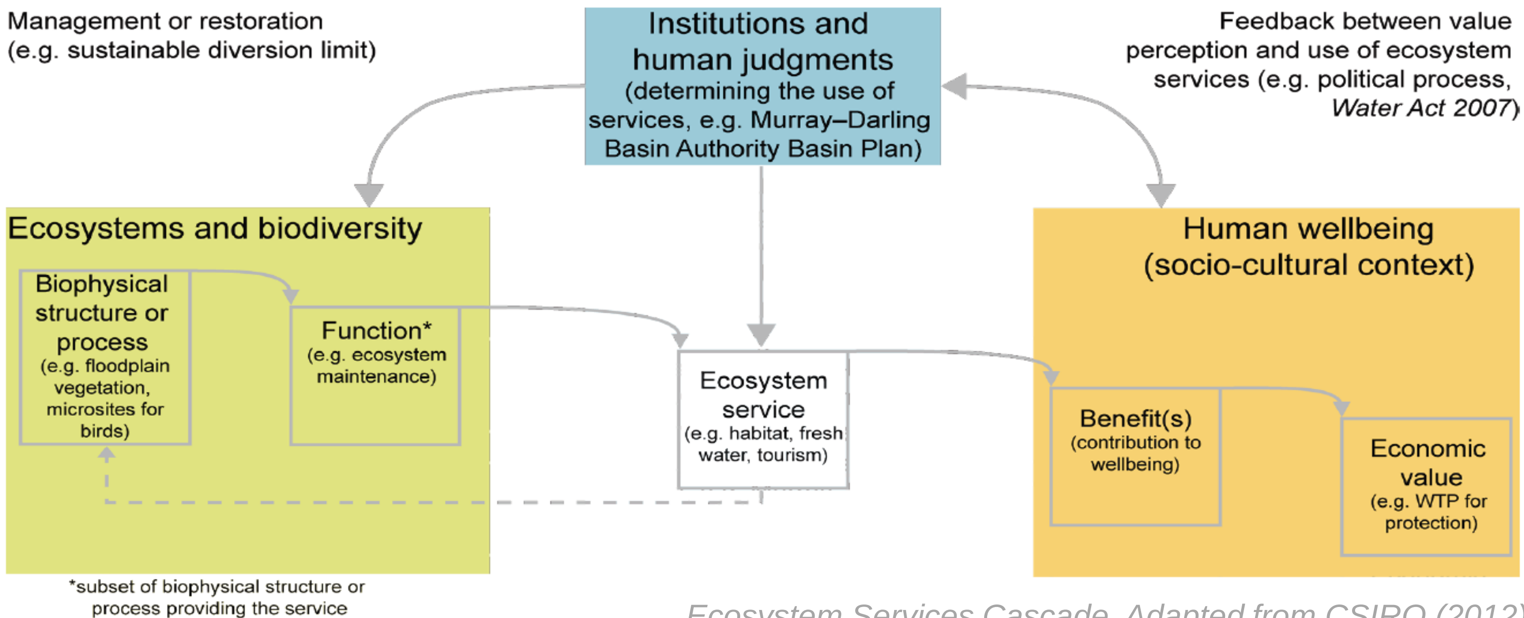
-thresholds

-trade-offs

-interactions

# Theoretical Basis: Ecosystem Services Cascade

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




*Ecosystem Services Cascade. Adapted from CSIRO (2012)*

For flow dependent ecosystems:

$\Delta$ hydrological $\rightarrow$ $\Delta$ biophysical $\rightarrow$ $\Delta$ ecosystem services $\rightarrow$ $\Delta$ economic value

# Ecosystem Service Dynamics

$\Delta$ hydrological $\rightarrow$ $\Delta$ biophysical $\rightarrow$ $\Delta$ ecosystem services $\rightarrow$ $\Delta$ economic value

Ecosystem service values are <u>not static</u>

- 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:

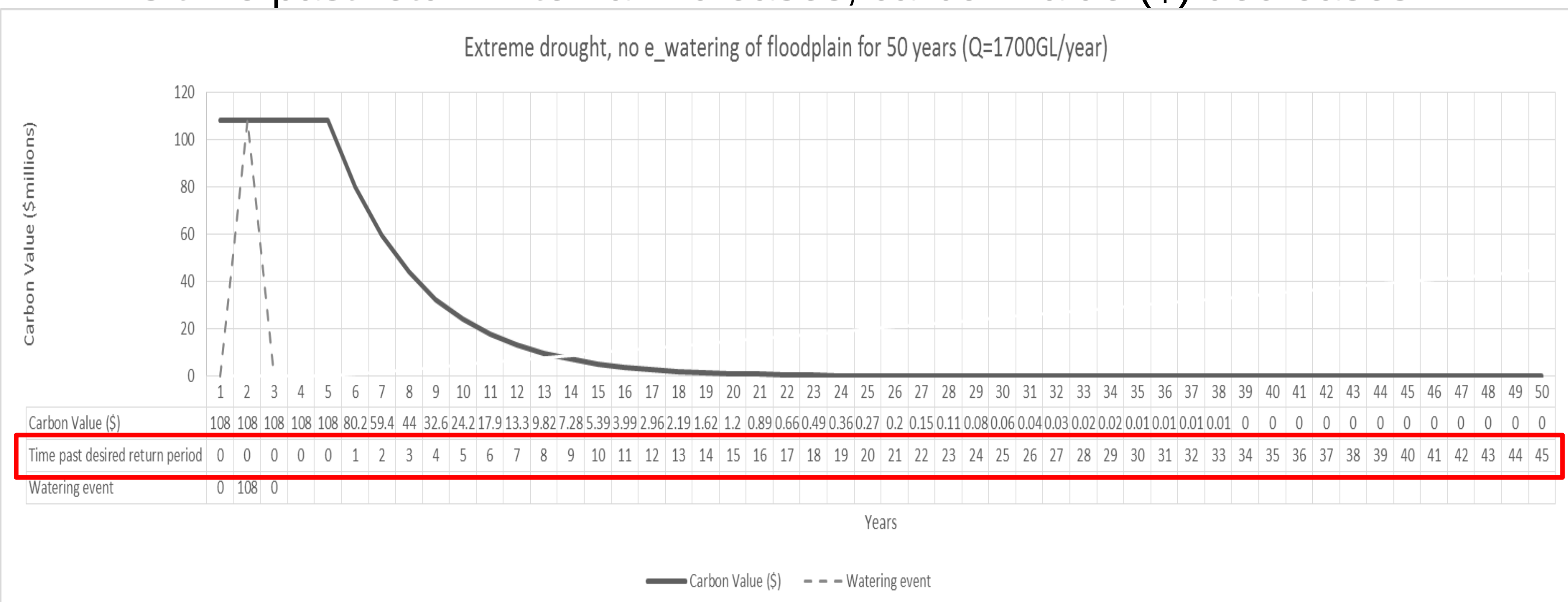
*Ecosystem services are <u>multiple</u> and they <u>change</u> across <u>time</u>, <u>space</u>, and with considerable degrees of <u>uncertainty.</u>*

We therefore need continuous descriptive functions to represent this.

# Example: Carbon Sequestration

- Market valuation technique
- $Value\ (\$) = f(area, tree\ health, market\ prices)$
- $Tree\ health = f(desired\ rerutn\ interval, actual\ return\ interval)$

- As time past return interval increases, carbon value ($) decreases

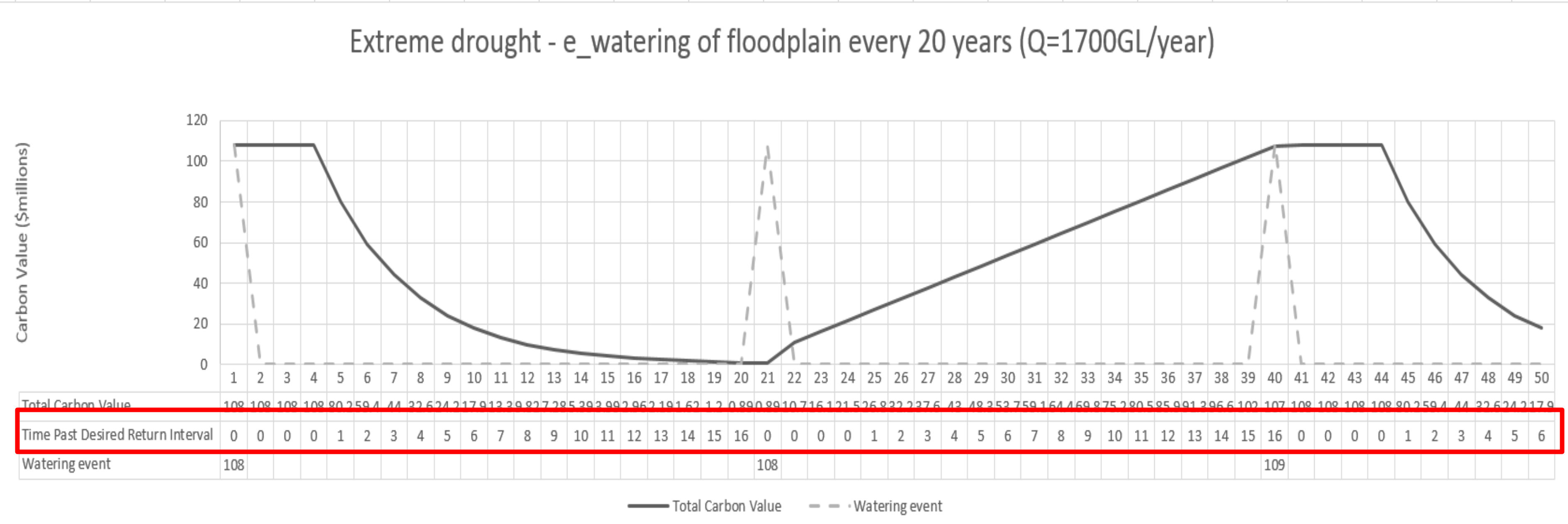



| Years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon Value ($) | 108 | 108 | 108 | 108 | 108 | 80.2 | 59.4 | 44 | 32.6 | 24.2 | 17.9 | 13.3 | 9.82 | 7.28 | 5.39 | 3.99 | 2.96 | 2.19 | 1.62 | 1.2 | 0.89 | 0.66 | 0.49 | 0.36 | 0.27 |
| Time past desired return period | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Watering event | 0 | 108 | 0 | | | | | | | | | | | | | | | | | | | | | | |

| Years | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon Value ($) | 0.2 | 0.15 | 0.11 | 0.08 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Time past desired return period | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| Watering event | | | | | | | | | | | | | | | | | | | | | | | | | |

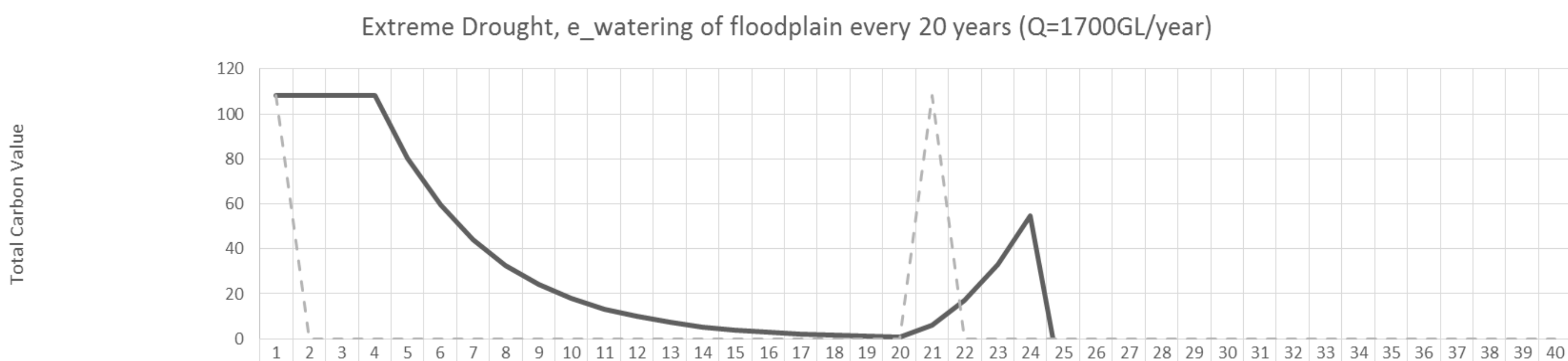
# Example: Carbon Sequestration

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



# 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)

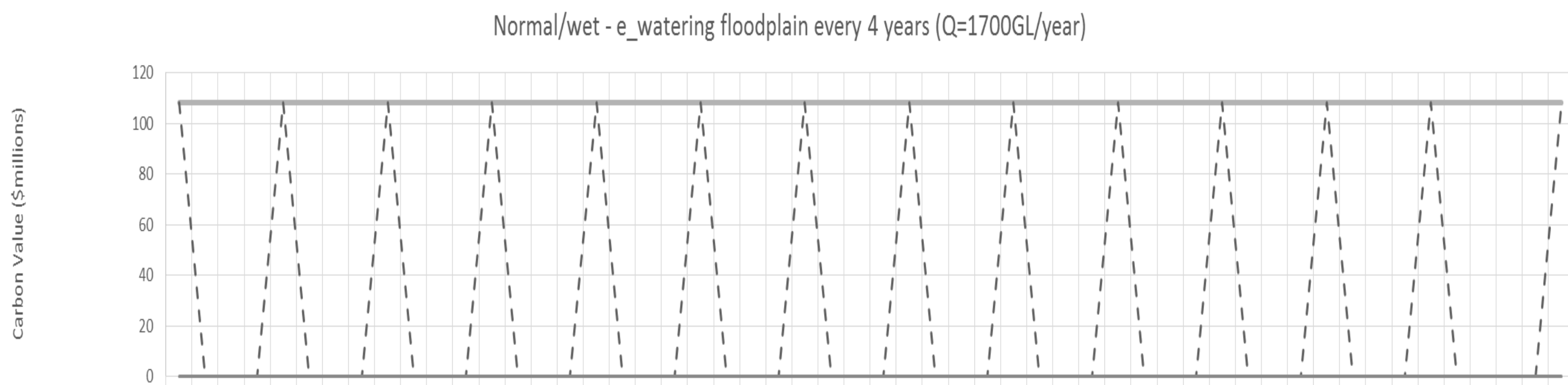



| Years | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Carbon Value | 108 | 108 | 108 | 108 | 80.2 | 59.4 | 44 | 32.6 | 24.2 | 17.9 | 13.3 | 9.82 | 7.28 | 5.39 | 3.99 | 2.96 | 2.19 | 1.62 | 1.2 | 0.89 |
| Watering event | 108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Time past desired return interval | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

| Years | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Carbon Value | 6.27 | 17 | 33.2 | 54.7 | -26 | -85 | -129 | -162 | -186 | -204 | -217 | -227 | -234 | -239 | -243 | -246 | -249 | -250 | -251 | -252 |
| Watering event | 108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Time past desired return interval | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

# Example: Carbon Sequestration

- Time past return interval is zero, carbon value ($) maintained at maximum




| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon Value ($) | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 |
| Watering Event | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 108 | 0 | 0 | 0 | 0 | 108 |
| Time past return interval | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Years

Carbon Value ($) - - - Watering Event

# 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:

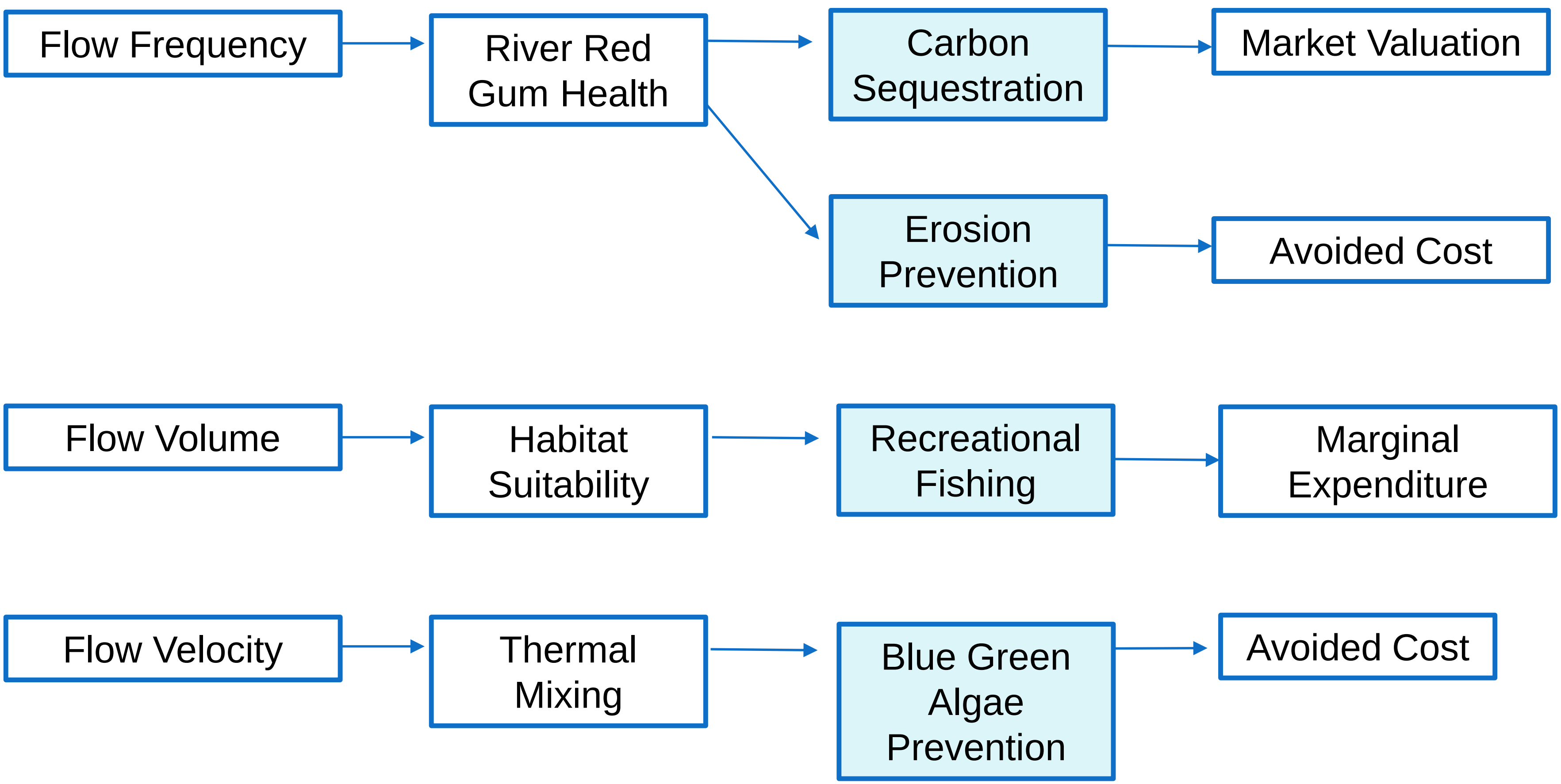
- *Kirby et al., 2006*
- *Connor et al., 2013*
- *Ancev, et al., 2014*

- 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



# Objective Function: Sum of Ecosystem Services

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

- Optimization algorithm to evaluate options:

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

Where:

$ESn\ is\ q\ number\ of\ ecosystem\ services$

$T\ is\ the\ time\ horizon$

$t\ is\ the\ time\ step\ in\ years$

Subject to:

$Hydrological\ constraints\ (delivery, carryover, storage\ capacity)$

$Fiscal\ constraints\ (budget, non-debt, non-profit, self\ sufficiency)$

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*River Red Gums along the Murrumbidgee. Source: NSW National Parks and Wildlife Service (2016)*

# 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)

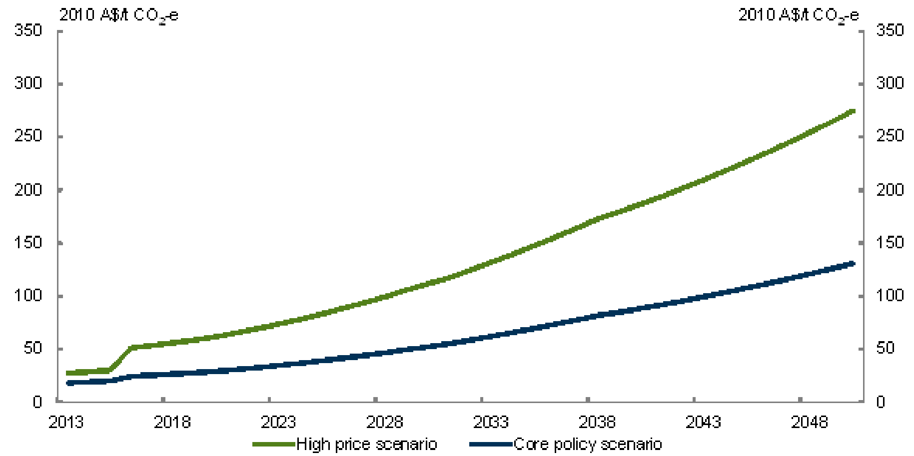
Conceptual issues equating avoided cost, impacts, and value of ecosystem service benefits

- 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 $(Q1 - Q0), when\, \frac{Q0}{Ac} \leq 0.03\frac{m}{s},\ such\ that\, \frac{Q1+Q0}{Ac} > 0.03\frac{m}{s}$
- 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).

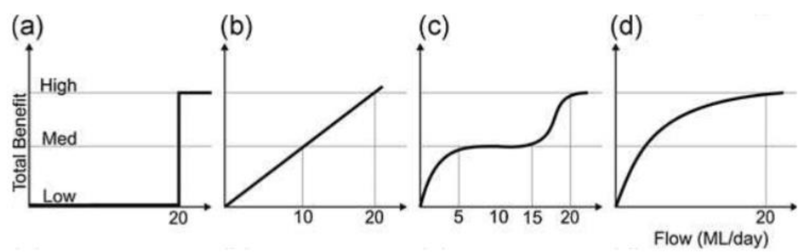



Figure 3. Possible total benefit curves for an environmental flow. (a) Trigger response to flow, (b) Linear response to flow, (c) Staged response to flow and (d) Significant initial response to flow, diminishing benefit of additional flow

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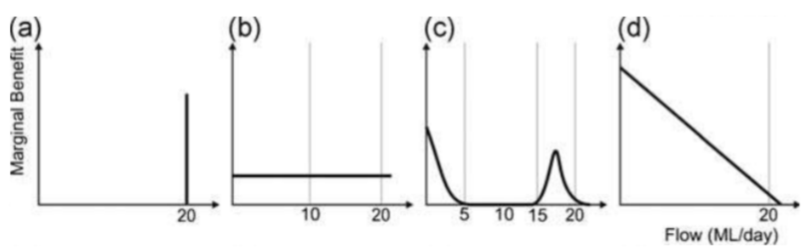
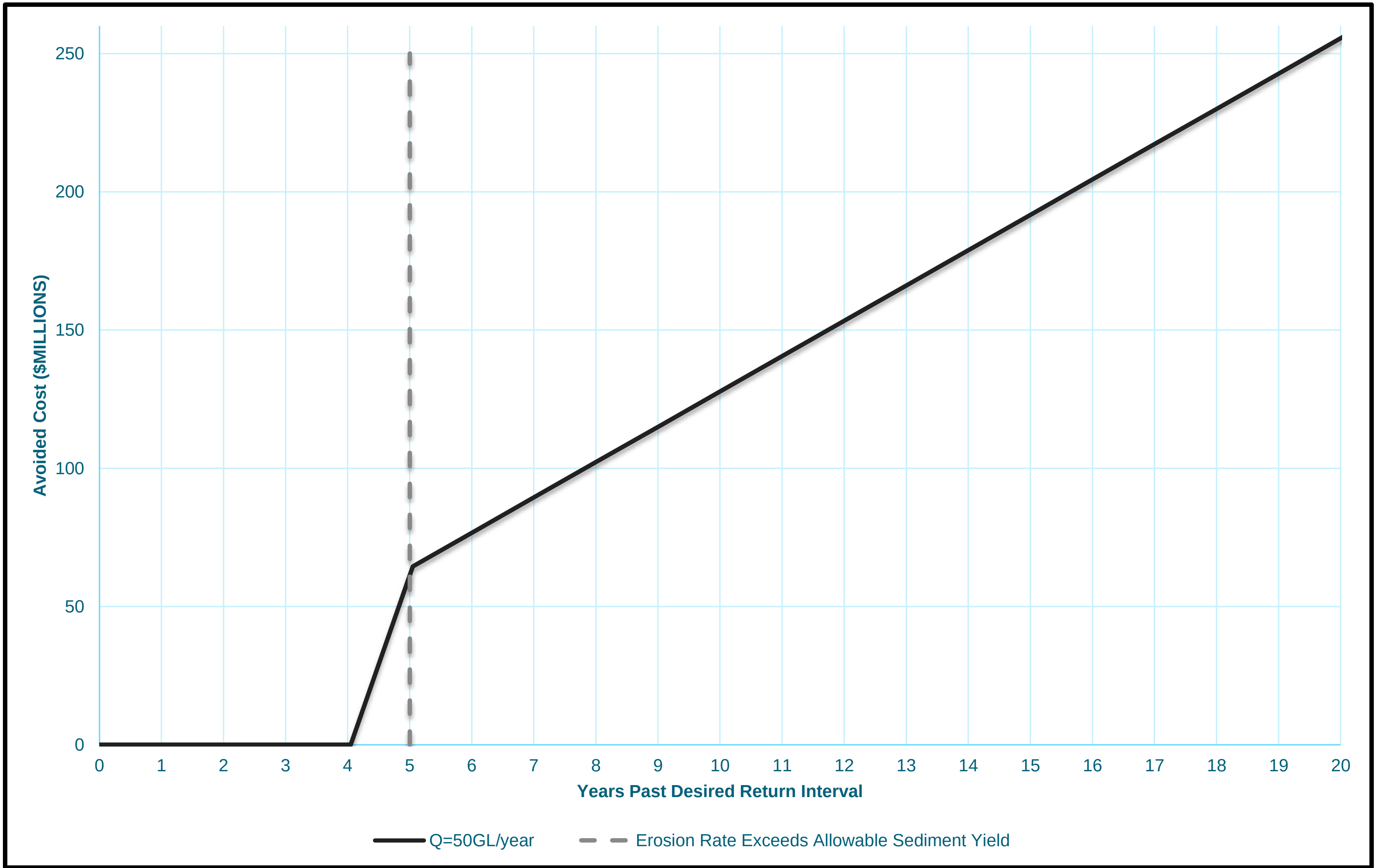
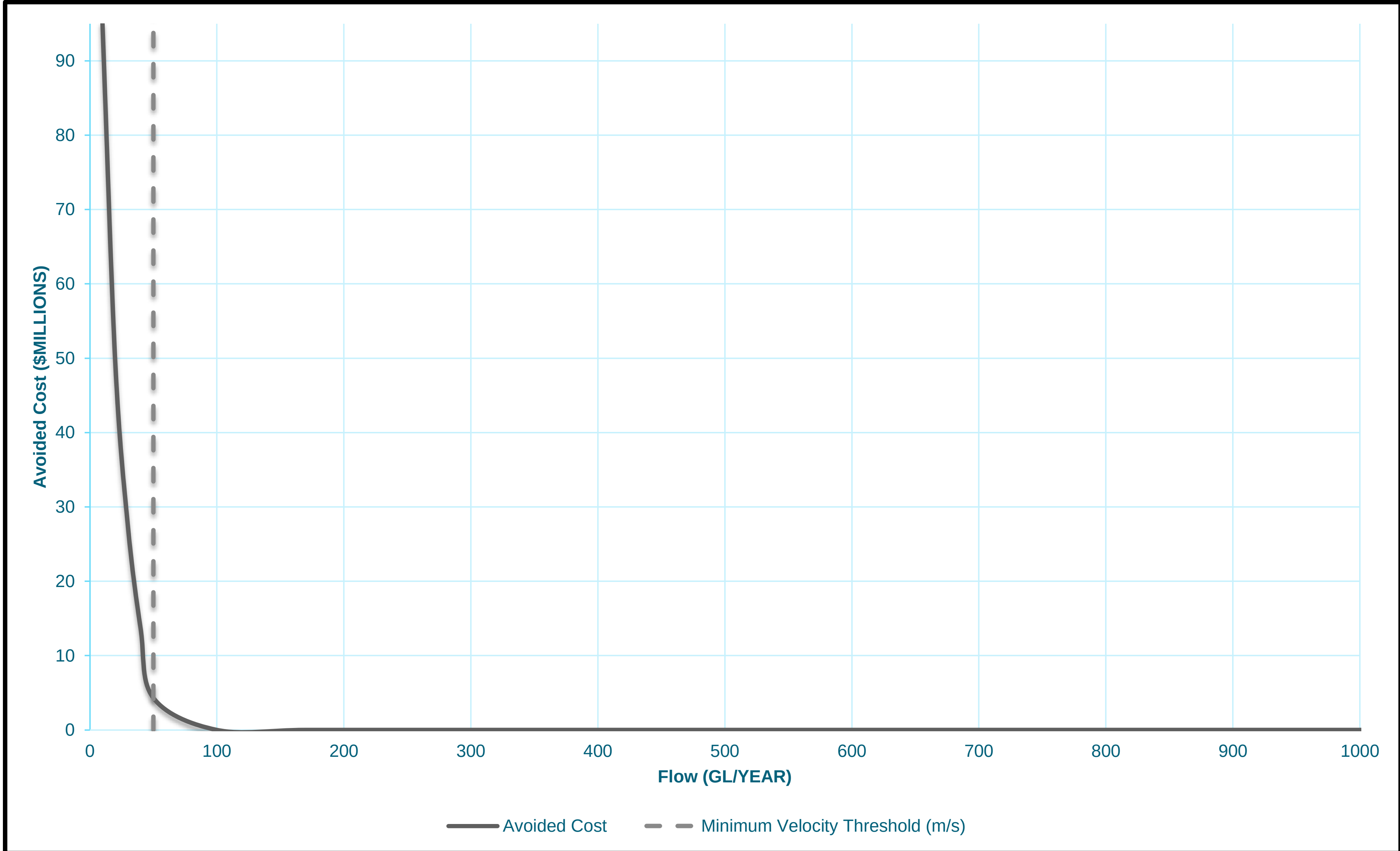



Figure 4. Associated marginal benefit curves for an environmental flow. (a) Trigger response to flow, (b) Linear response to flow, (c) Staged response to flow and (d) Significant initial response to flow, diminishing benefit of additional flow

# Example: Erosion Prevention



# Example: Blue Green Algae Prevention



# Example: Recreational fishing