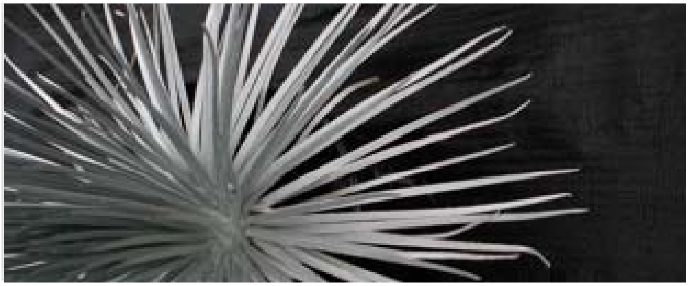

UHERO
THE ECONOMIC RESEARCH ORGANIZATION
AT THE UNIVERSITY OF HAWAIʻI

SUSTAINABILITY SCIENCE FOR FOOD, FORESTS, AND FLOODS: INTEGRATING CLIMATE ADAPTATION AND PRO-POOR RESOURCE MANAGEMENT

Managing coastal marine nutrient loads: point and non-point sources in West Hawaiʻi

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Session 4: Watershed Ecology, Mountain to the Sea

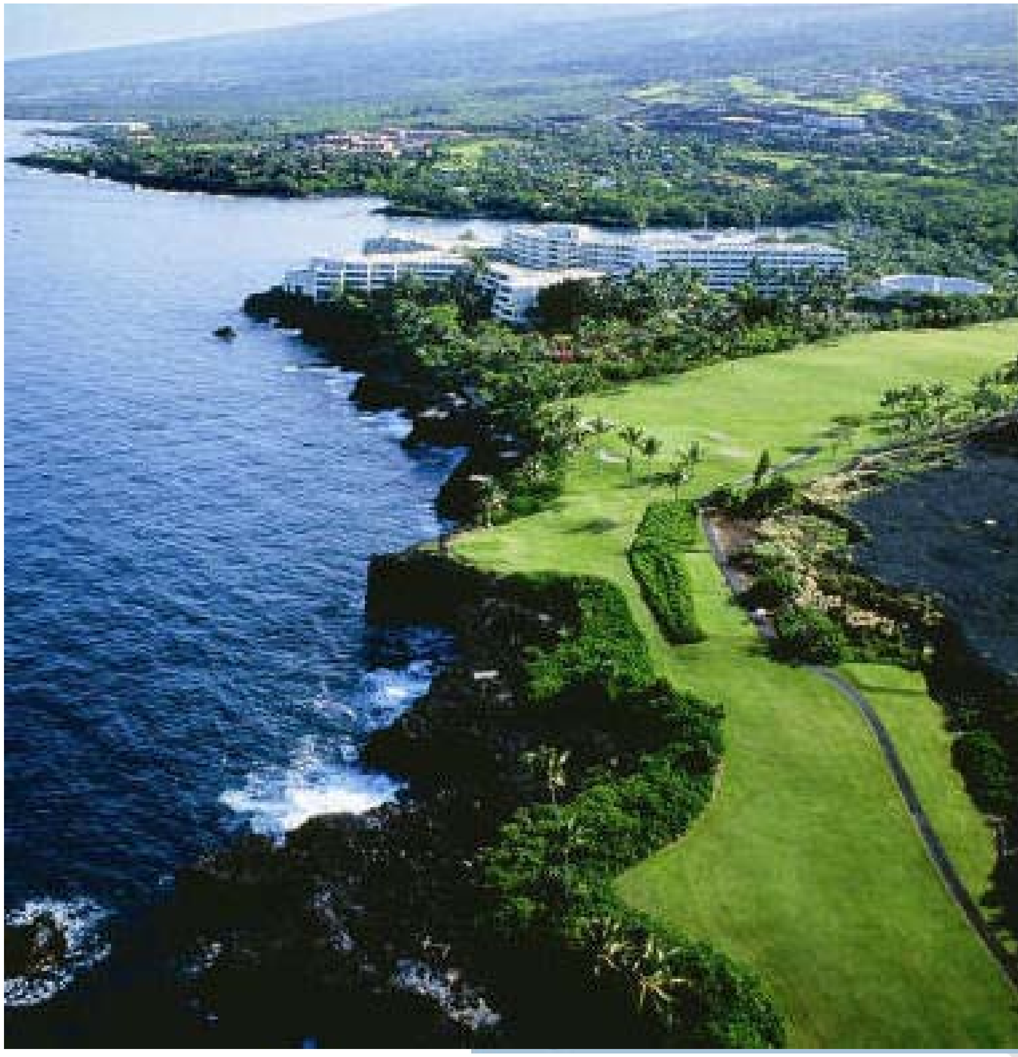
(a.k.a Jim’s groundwater posse)

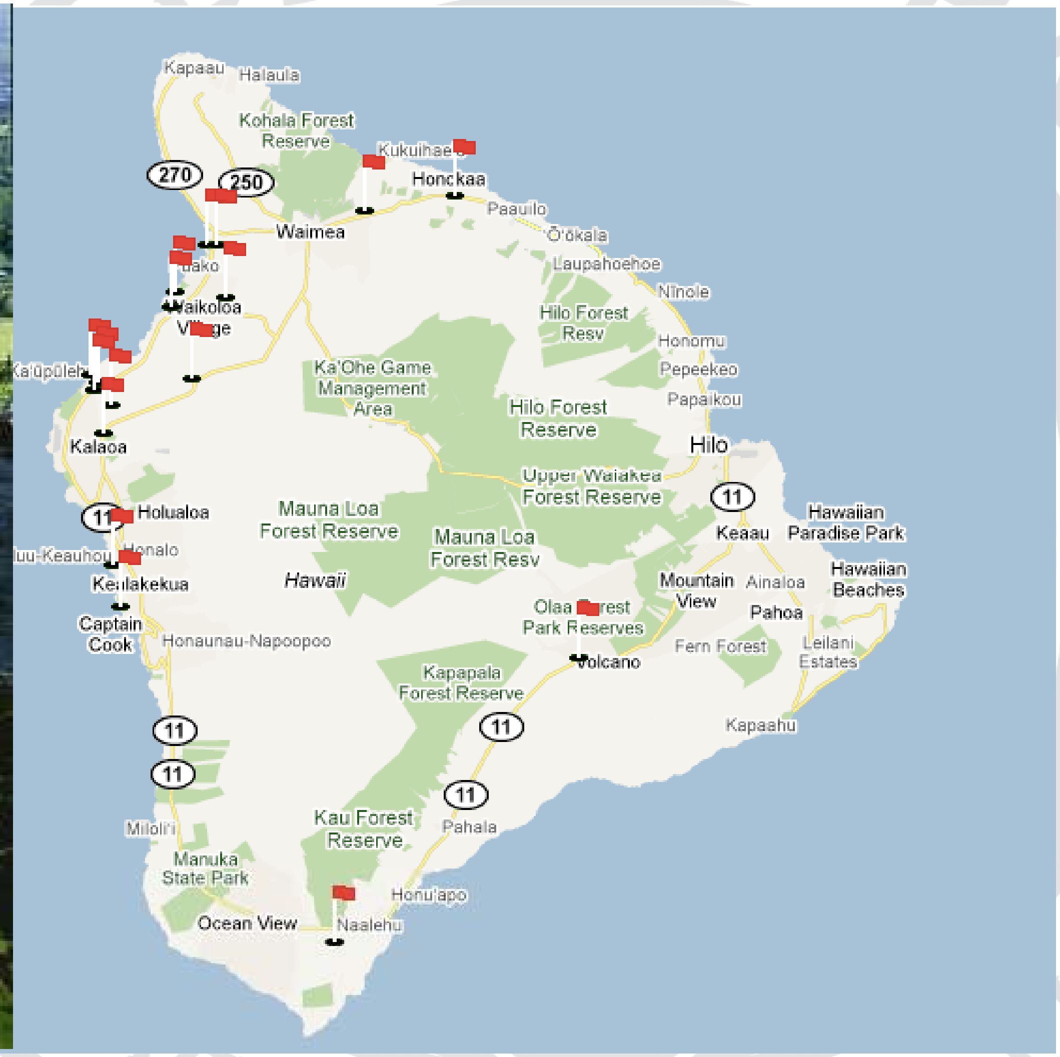
- **Kim: Managing nutrient loads to the nearshore that arrive via groundwater**
- **Pap: How groundwater management affects nearshore ecology**
- **Chris: How watershed conservation affects groundwater management**

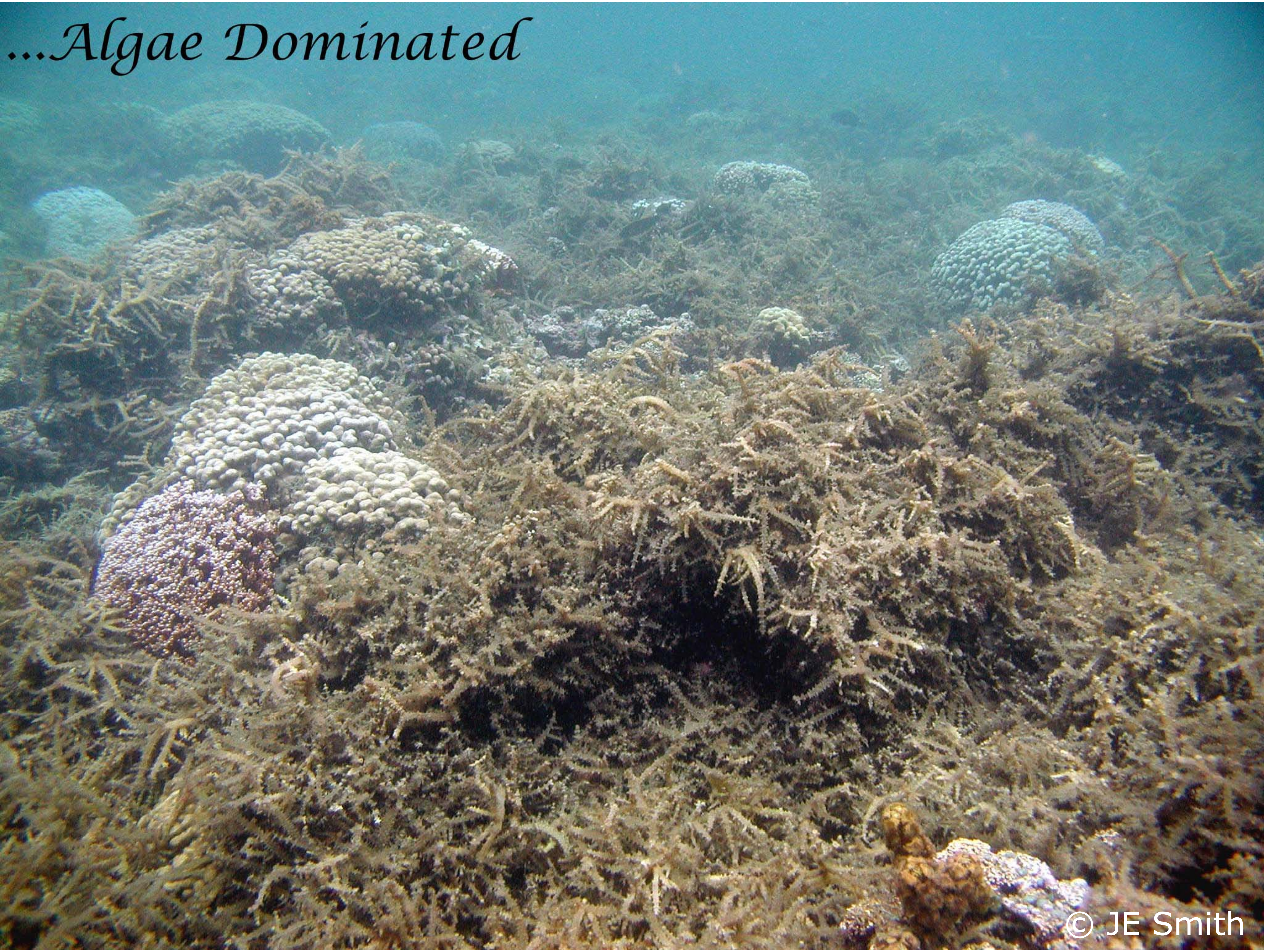
Nutrients? Wastewater Into Lava Tubes…

Invasive kiawe…

Golf Courses Galore…






...Algae Dominated
© JE Smith

The Problem

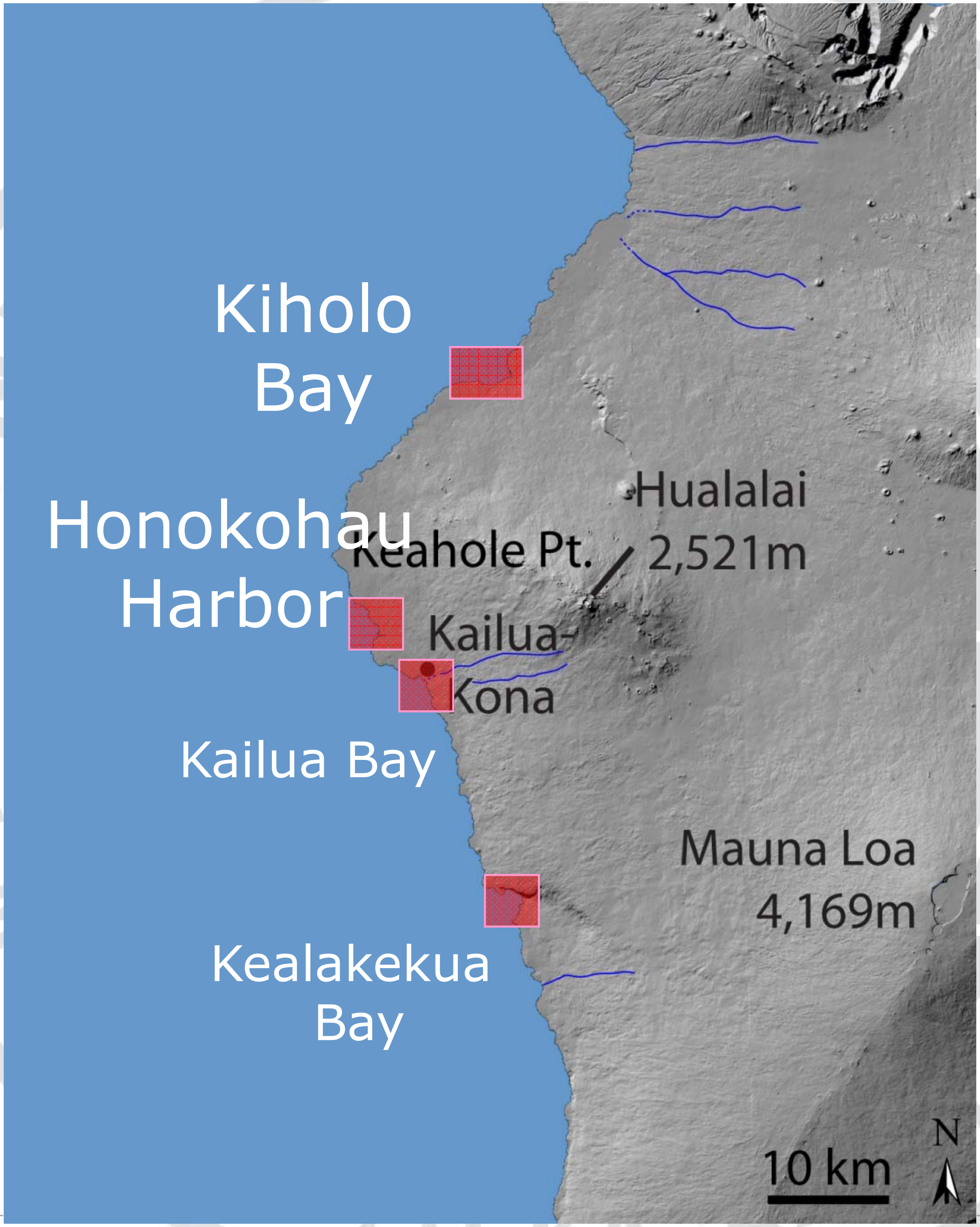
- **Nitrogen carried into nearshore waters by submarine groundwater discharge can result in ecological problems nearshore**
  - **Overtake native *limu* (seaweed)**
  - **Damage coral reefs**
  - **Diminish biodiversity**
- **Multiple sources**
  - **Natural: kiawe forests**
  - **Anthropogenic: sewage, golf course runoff**
- **What is the most cost-effective way of reducing nitrogen concentration in the bay?**

Management Instruments

- **Denitrification at sewage treatment facility (adding bacteria)**
  - **Converts ammonium and nitrate in effluent to harmless nitrogen gas (NH_4^+, NO_3^- --> N_2)**
- **Kiawe removal**
  - **Prevents nitrogen released by decaying plant material from infiltrating into the groundwater**
- **Nitrogen tax**
  - **Higher price for fertilizer would induce users (golf courses, landscaping) to substitute for other inputs**
    - **Increase frequency and decreases dose (substitute some labor for fertilizer)**
    - **Switch to a more "environmentally friendly" fertilizer**

Study Sites

- **Kiholo Bay: isolated and relatively pristine, though surrounded by invasive kiawe**
- **Honokohau Harbor: highly developed area, surrounded by sewage treatment plants and resorts**



What is Being Measured

- Groundwater flow (hourly)
- Nutrient concentration
  - Isotopes (oxygen, nitrogen, hydrogen)
    - Anthropogenic vs. natural sources
    - Roughly source location: elevation of groundwater percolation
- What else we need to know
  - Disaster threshold for nitrogen concentration (how much until eutrophication)
  - Nutrient mixing/dissipation once transported into the ocean? Residence time?

How Much Nitrogen from Sewage?

- **The amount of nitrogen transported is directly proportional to the flow of effluent (E)**

$$N_t^S = d(n)E_t$$

- **The proportion can be reduced by increased spending on nitrogen removal (n) via denitrification**

How Much Nitrogen from Golf Courses?

- **The amount of nitrogen transported depends on both the quantity of "dirty" input (Z) and "clean" input (A) used for the production of golf courses**
  - **Dirty input: fertilizer with high nitrogen content (e.g. urea)**
  - **Clean input (higher cost):**
    - **labor - increased frequency of application and lower doses**
    - **fertilizer with lower nitrogen content (e.g. ammonium sulfate)**

$$N_t^G = M(Z_t, A_t)$$

Total Nitrogen Transported in Period *t*

$$N_t = N_t^S + N_t^G$$ (Nitrogen load in the bay)

- **More generally for multiple receptors and sources, we can imagine a matrix of transfer coefficients (for each period *t*)**

Receptor / Source	E (facility A)	E (facility B)	E (facility C)	…
1	d_{11}	d_{12}	d_{13}	…
2	d_{21}	d_{22}	d_{23}	…
3	d_{31}	d_{32}	d_{33}	…
…	…	…	…	

Demand for Fertilizer (nitrogen)

- **For the case of a golf course, the production function could be represented as:**

$$Q_t = F(Z_t, A_t)$$

- **The golf course owner chooses a combination of inputs (amount of nitrogen to apply) to maximize profits:**

$$\underset{Z_t}{Max}\,[pF(Z_t, A_t) - w_z Z_t - w_A A_t]$$

$$\underbrace{Z_t(p_t, w_z, w_A)}$$ ← Changing over time

Factor demand function for fertilizer

Social Planner's Problem

- **The idea is to choose golf course inputs, and denitrification levels to maximize social net benefits:**

$$\underset{Z,A,n}{Max}[pF(Z,A) - w_Z Z - w_A A - D(N) - nc_s]$$

  - **p: price of golf course output**
  - **D: exogenous damage function**
  - **c_s: unit cost of denitrification**
  - **n: quantity of nitrogen removed by denitrification process**

Optimality Conditions

$$\frac{\partial V}{\partial Z} = pf_Z - w_Z - D'(N)M_Z \geq 0 \Rightarrow \underbrace{pf_Z}_{MB} = \underbrace{w_Z + D'(N)M_Z}_{MC}$$

$$\frac{\partial V}{\partial A} = pf_A - w_A - D'(N)M_A \geq 0 \Rightarrow \underbrace{pf_A}_{MB} = \underbrace{w_A + D'(N)M_A}_{MC}$$

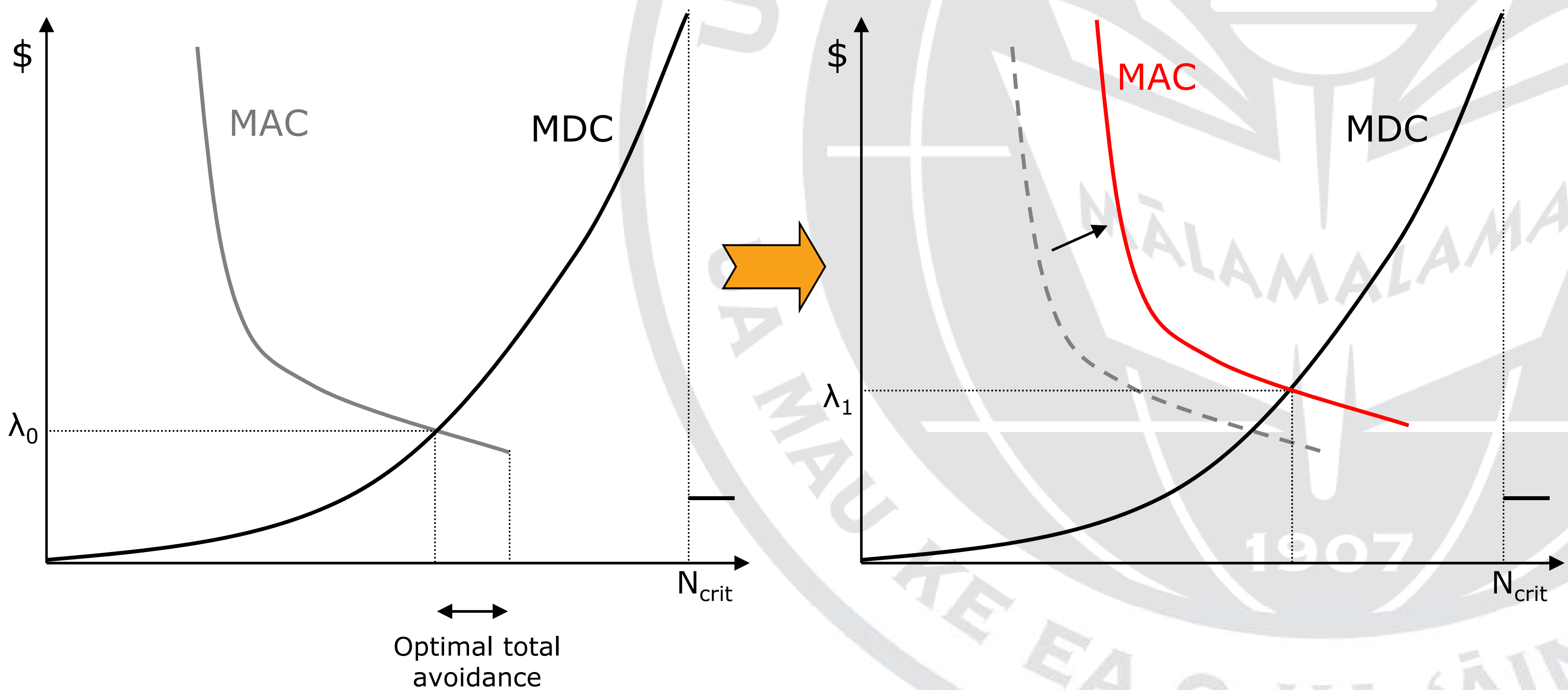
$$\frac{\partial V}{\partial n} = -D'(N)d'(n)E - c_n \geq 0 \Rightarrow \underbrace{-D'(N)d'(n)E}_{MB} = \underbrace{c_n}_{MC}$$

- **It is optimal to use both instruments simultaneously only when the following condition holds:**

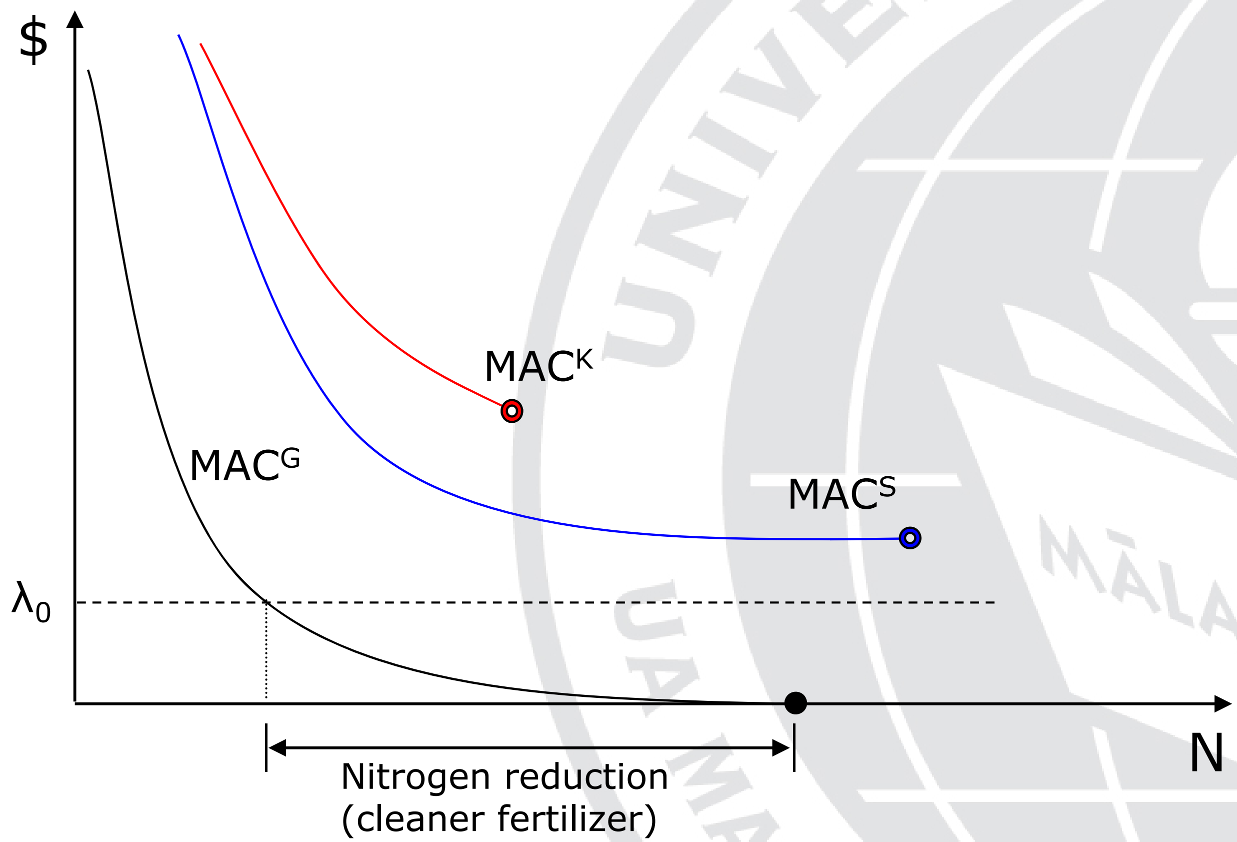
$$\underbrace{-D'(N)}_{\text{MB of abatement}} = \frac{w_A - pf_A}{M_A} = \frac{w_Z - pf_Z}{M_Z} = \frac{c_n}{d'(n)E}$$

Shadow Price of Nitrogen

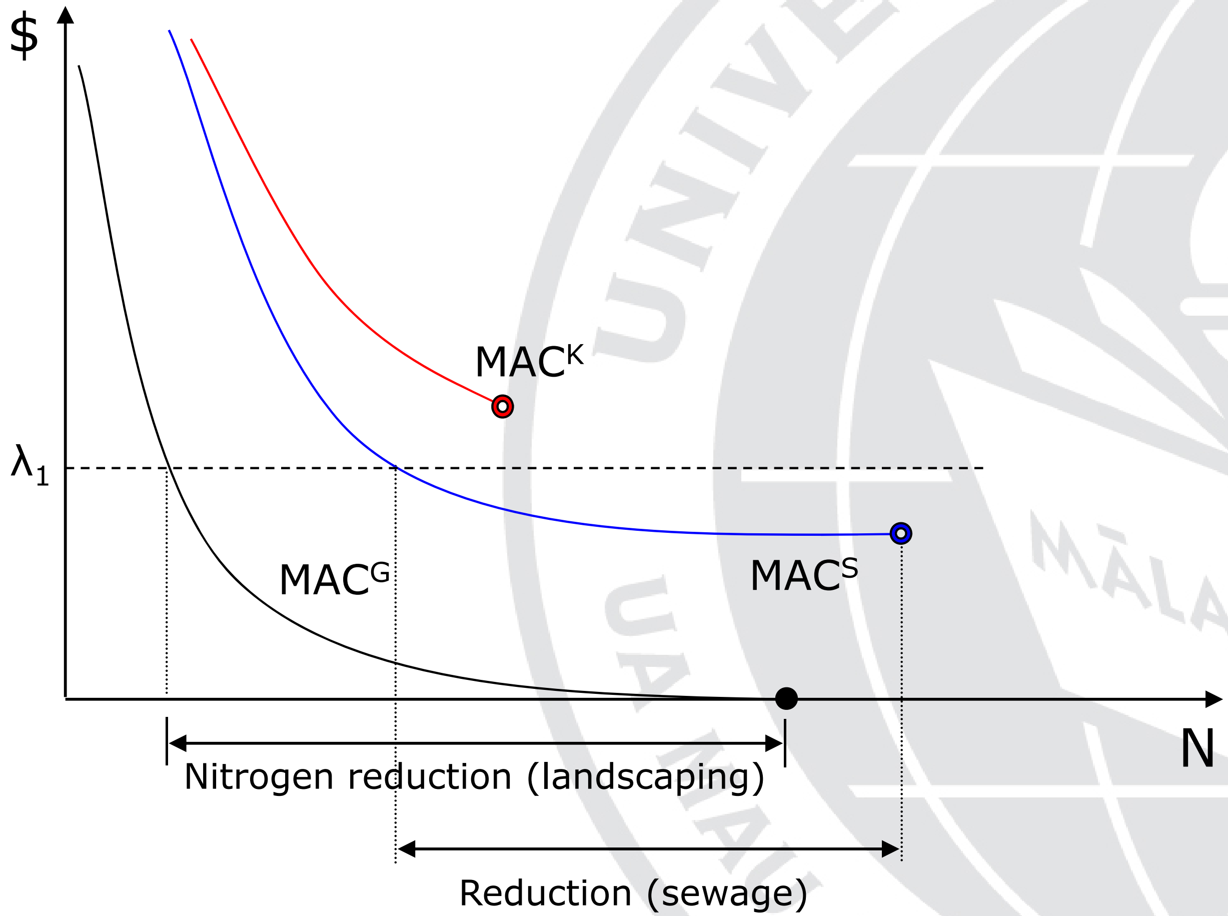
- **Each management instrument yields an avoidance cost function**
- **Summing of the MACs horizontally gives an aggregate MAC**
- **Shadow price of nitrogen (λ) determined by the socially optimal equimarginality condition: MDC = aggregate MAC**



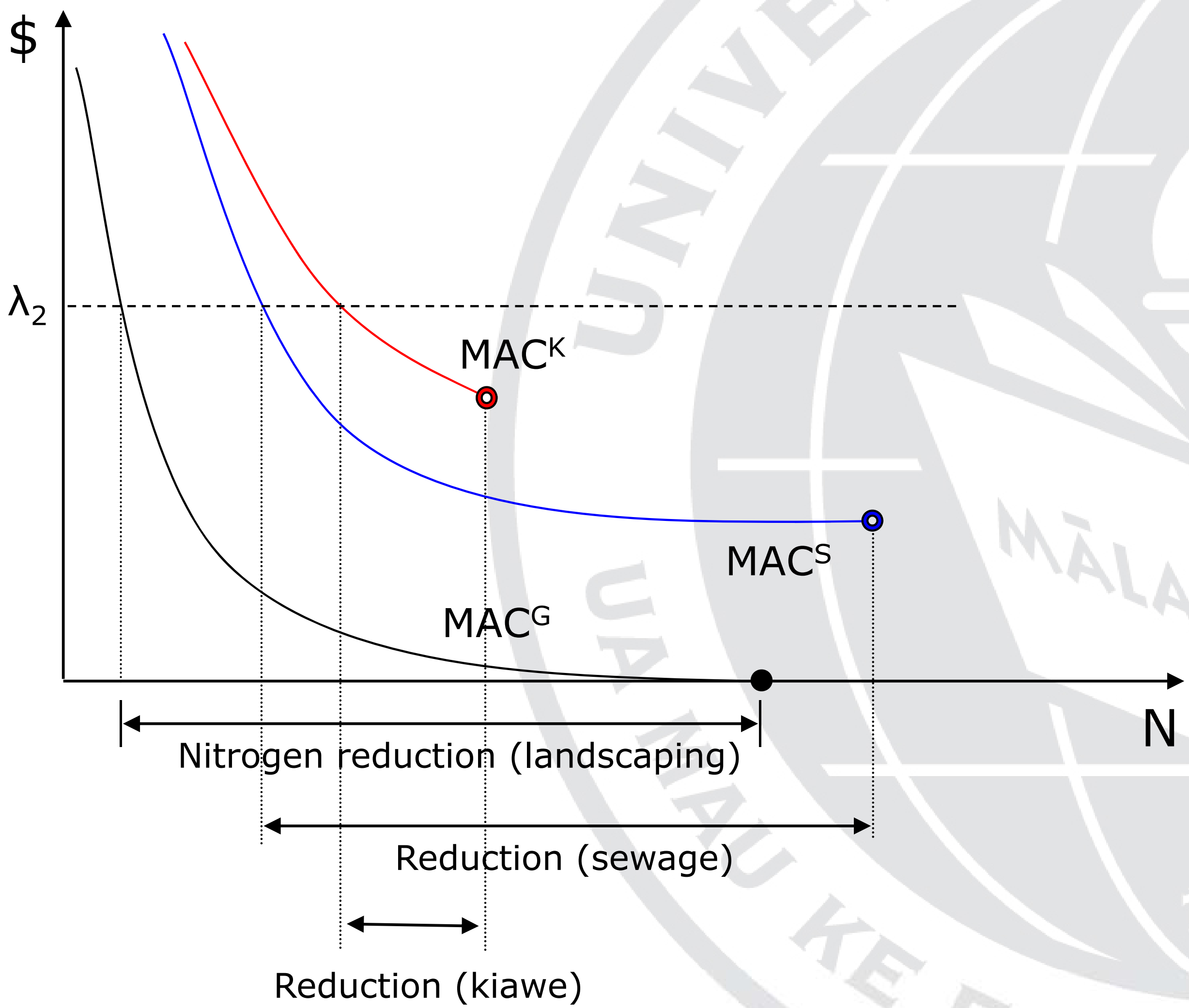
Avoidance Plan Depends on Shadow Price



As Shadow Price Increases, Avoidance Changes



If High Enough, Use All 3 Instruments



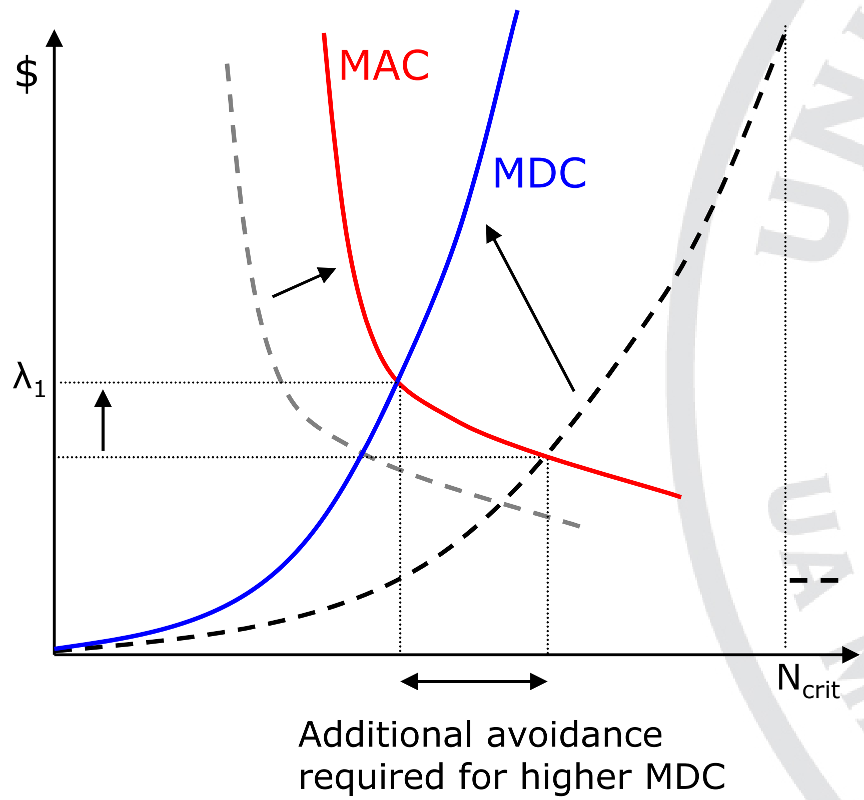
Avoidance Plan

- **Determine optimal time for denitrification, fertilizer substitution, kiawe tree removal**

- **Premature implementation of any of these wastes resources that could have been more cost-effectively used (e.g. restore recharge of aquifers)**

- **As development depletes groundwater, nitrogen transported by kiawe and fertilizer will decline (reduced SGD)**

- **Increases the MDC**
- **Accelerates the optimal avoidance plan**



Sustainability Science in Action

1. Objective: determine cost-effectiveness of nitrogen removal
2. Collaboration: what is being measured? How does the physical system work?
3. Economics: develop model to achieve objective, using info from step 2 + adding management instruments
4. Add climate change