Water resilience:
What definition(s) for which implementation(s)?

Charles Rougé

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Resilience: an evolving history

1. Materials engineering, 1950s: getting back to original shape after disturbance
2. Holling (1973, ecology): ability to keep properties and functions after disturbance
3. “Resilience thinking” (Folke, 2006): embracing holistic view to adapt & transform system
4. Brand & Jax warning (2007): resilience could lose clear definition if too many different defs.

Is resilience like fighting climate change?

- ✓ Everybody agrees in theory that it is a good thing
- ✓ Scientists have done their work (from “resilience thinking” to the Safe and SuRe approach)
- ✓ Practical implementation is more difficult (complexity)
- ➢ What causes this complexity?

Example 1: flooding in Devon

Flood Risk Management

Protecting communities and increasing resilience

Devon County Council

You are here: Home > Flood resilience

- Home
- Who is responsible for local flood risk management?
- Who to contact if you experience flooding

Flood resilience

Community flood resilience – the response of people at risk of flooding – is important. Quite often simple actions by householders and communities can significantly reduce local vulnerability and the level of any damages from flood events.

The Flood Resilience Community Pathfinder Project was a partnership between Devon County Council, Plymouth City Council, Torbay Council and the Environment Agency. The DEFRA funding went towards a package of measures to improve local community resilience so that they are better prepared against the risk of flooding.

- Promotes processes that lead to better flood protection – but…

Measurable outcomes ?

How to allocate limited resources?

What should be achieved and who will really benefit?

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https://www.devon.gov.uk/floodriskmanagement/flood-resilience/

Example 2: drought in California

California Water Sustainability

Sustainability indicator framework to support water decisions

Home Overview Assessments Indicators Maps Regions Catalog About Us

California water sustainability indicators

Drought Resilience

Summary

The maximum severity of drought during which core water demands can still be met, including social and environmental minimum requirements

▸ General Information about this Indicator

- Clear quantitative definition – but…

What happens if a drought is more severe? (climate change)

Whose demands are most important? Count as minimum?

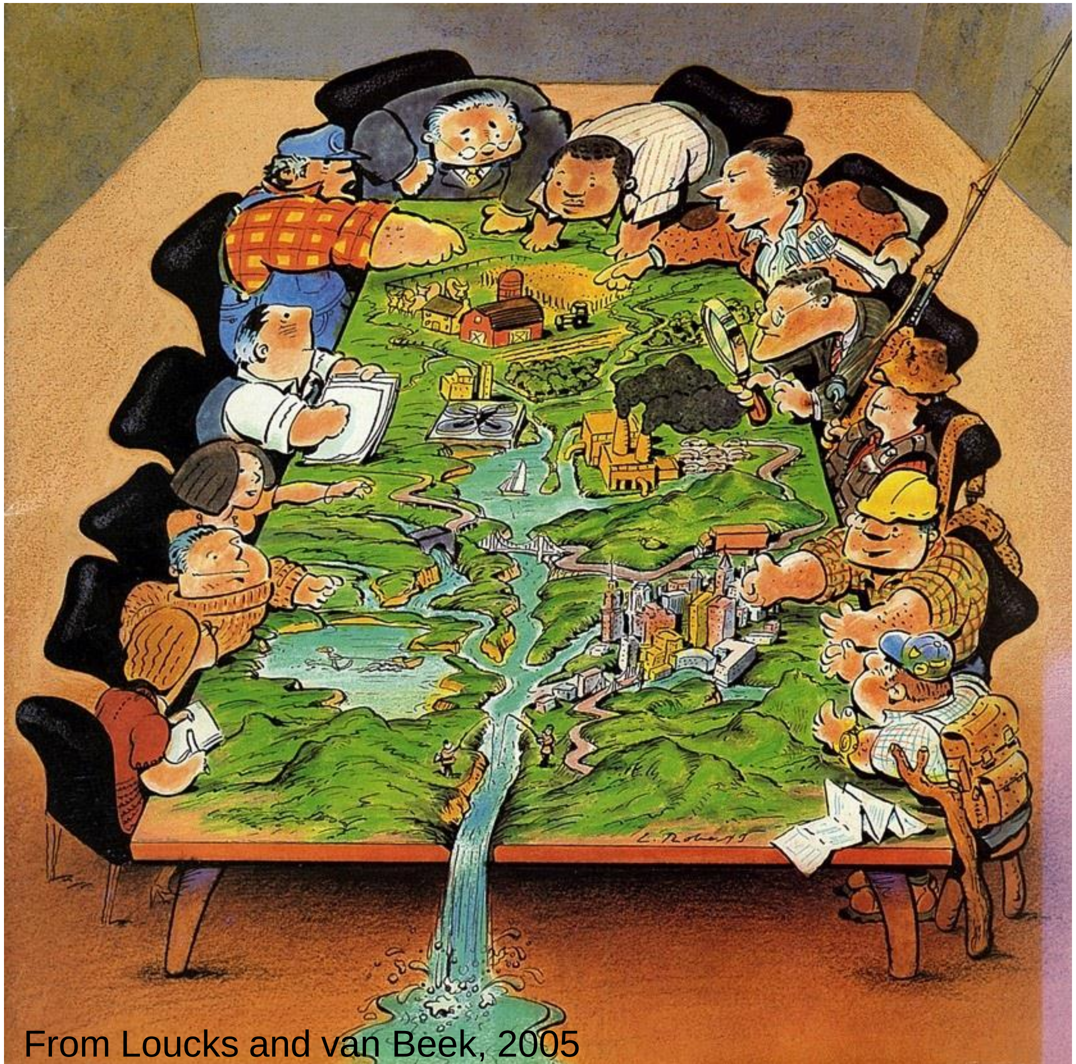
Resilience: challenges

1. Balancing holistic view & measurable indicators to identify actions for mitigation / adaptation

2. Representing and linking processes & outcomes (role of engineers!)

3. Understanding role of values, agendas, problem representations in shaping different meaning of resilience

Water resilience as a wicked problem



From Loucks and van Beek, 2005

Defining the problem is the problem!

- ✓ Stakeholders with their objectives, values
- ✓ Problem boundaries?
- ✓ What uncertainties?
- ✓ Confidence in projections?
- ✓ What is success?

Heavy consequences for failure!

- ➢ How do representations of resilience lead to actions?

Understanding resilience: a simple case

The example of lake eutrophication

Phosphorus inputs

Agriculture
Industry

DIFFICULT TO REVERSE

Oligotrophic lake
Clear water – High quality
Ecosystem services
High biodiversity

Eutrophic lake
Turbid water
Improductive ecosystem
Low biodiversity

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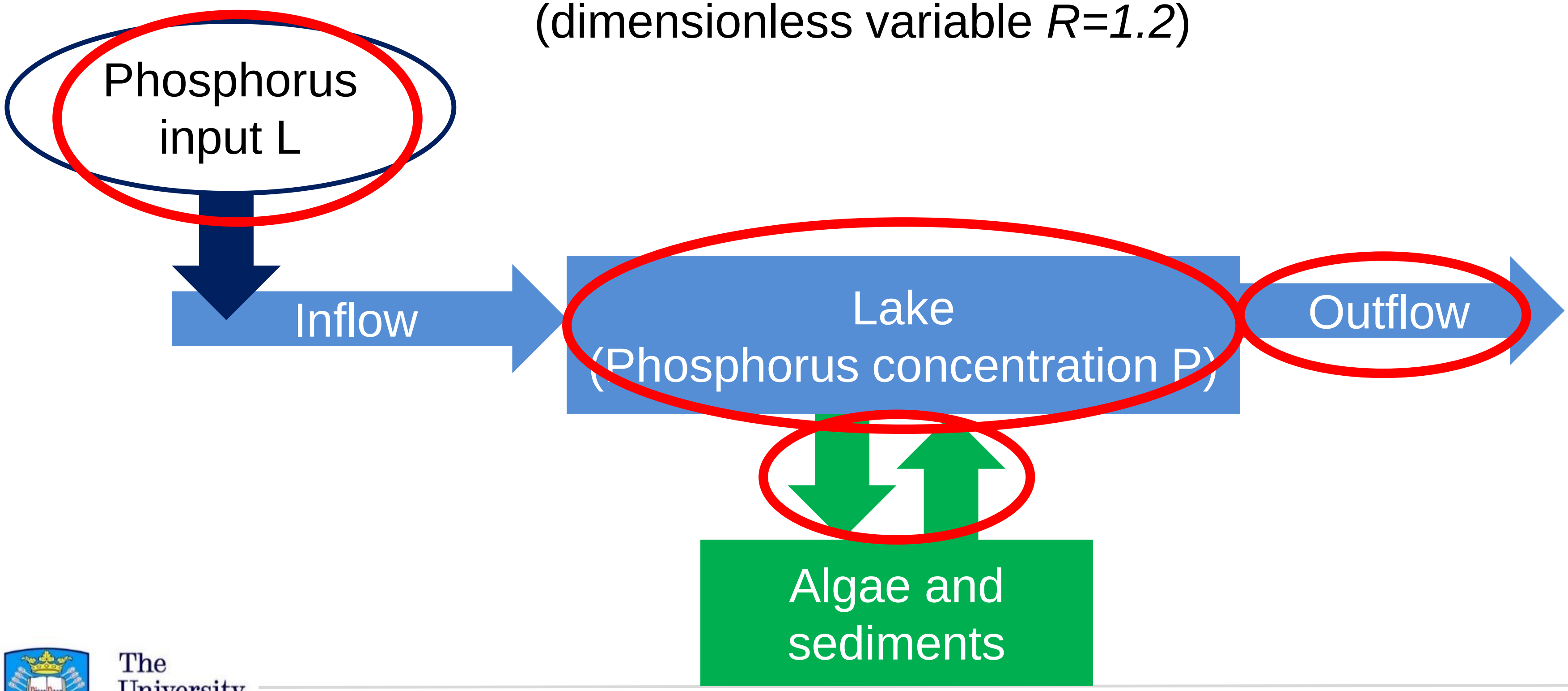
Dynamics of lake eutrophication

(Carpenter et al., 1999; Martin, 2004; Rougé et al., 2013)

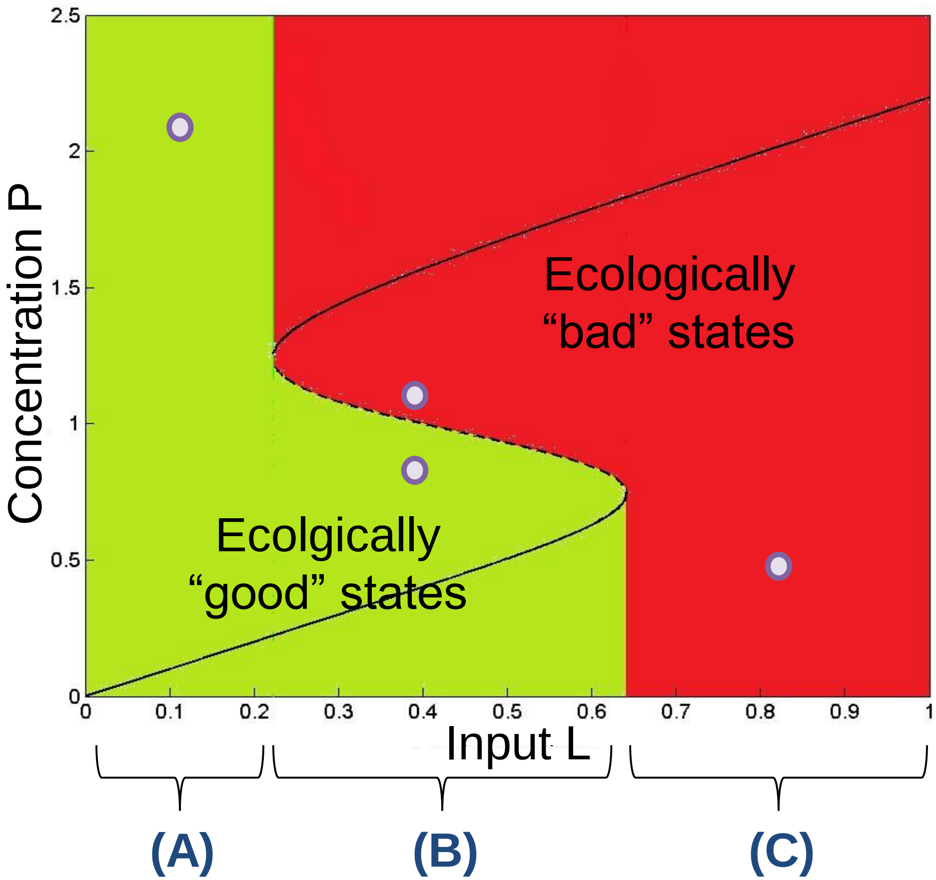
$$P(t+\delta t) = P(t) + \left[-P(t) + L(t) + R\frac{P(t)^8}{1+P(t)^8} \right].\delta t$$

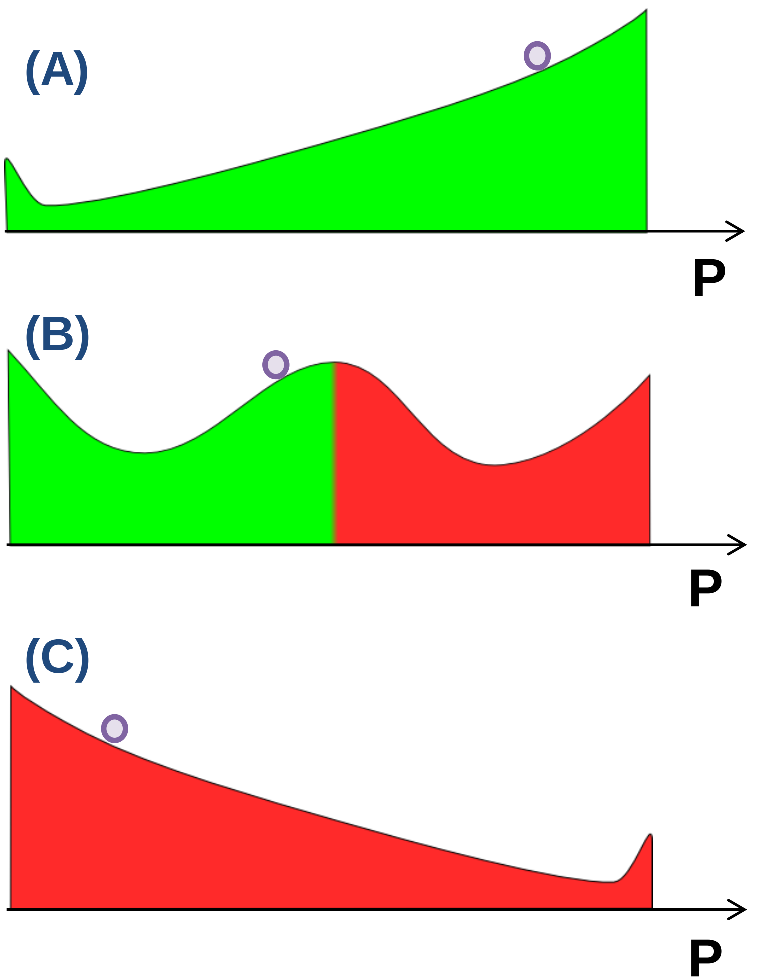
(dimensionless variable *R=1.2*)



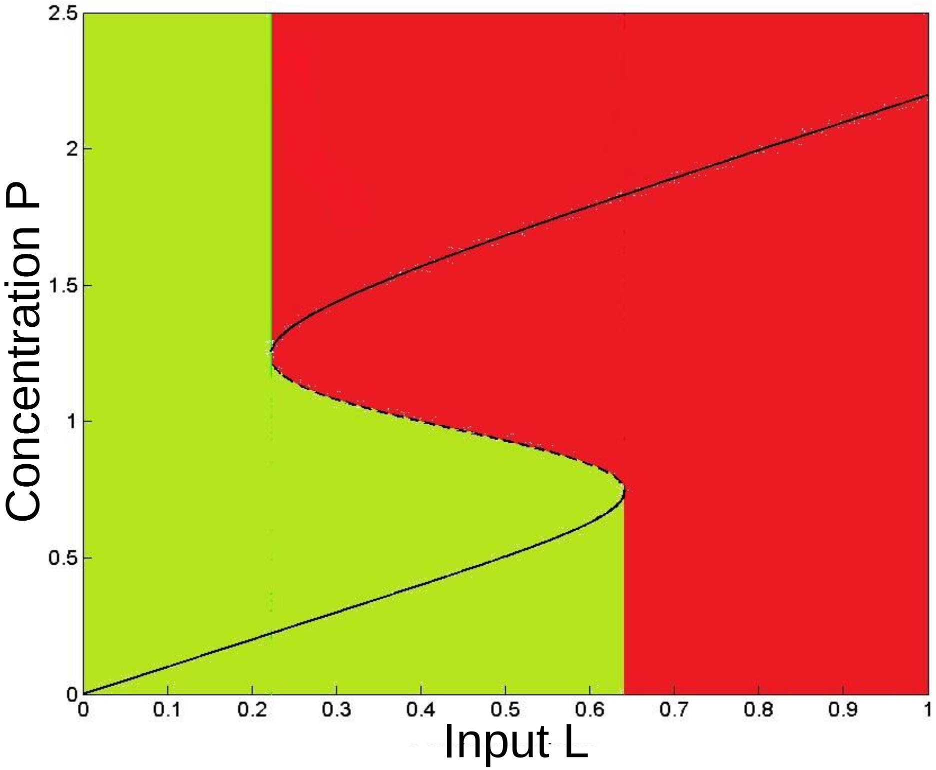
Eutrophication dynamics: illustration

Interest in keeping the lake oligotrophic





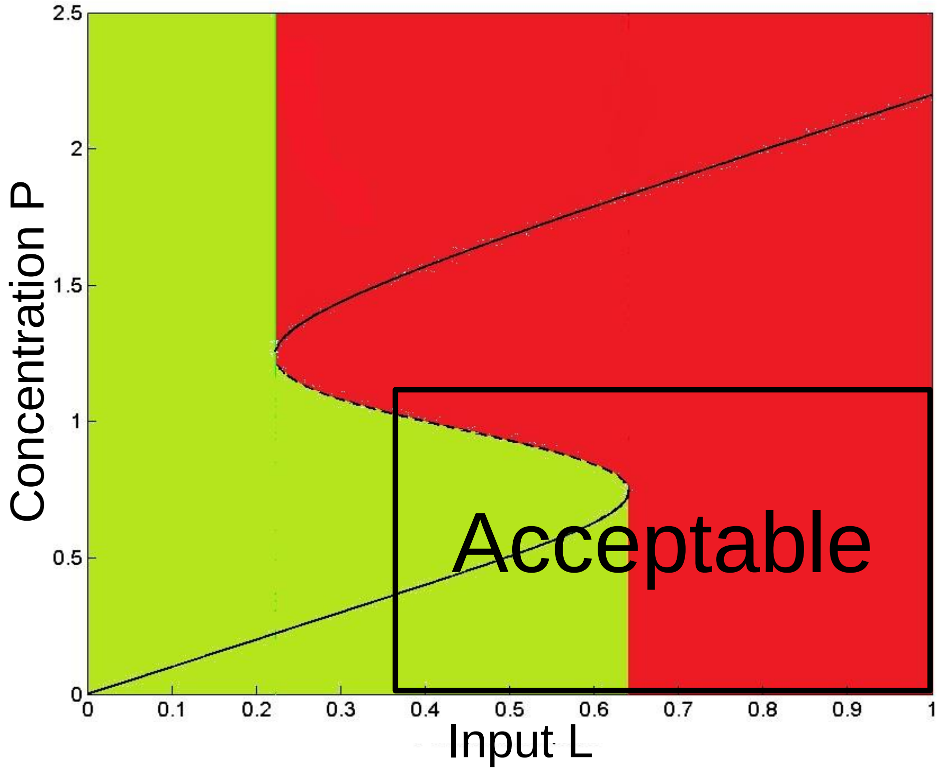
Management objectives



- Keeping the lake in a clear state
  - Minimise *P*
  - Minimise inputs
- Economic profits
  - Maximise inputs

> ➢ Clear trade-offs between ecological and economic objectives

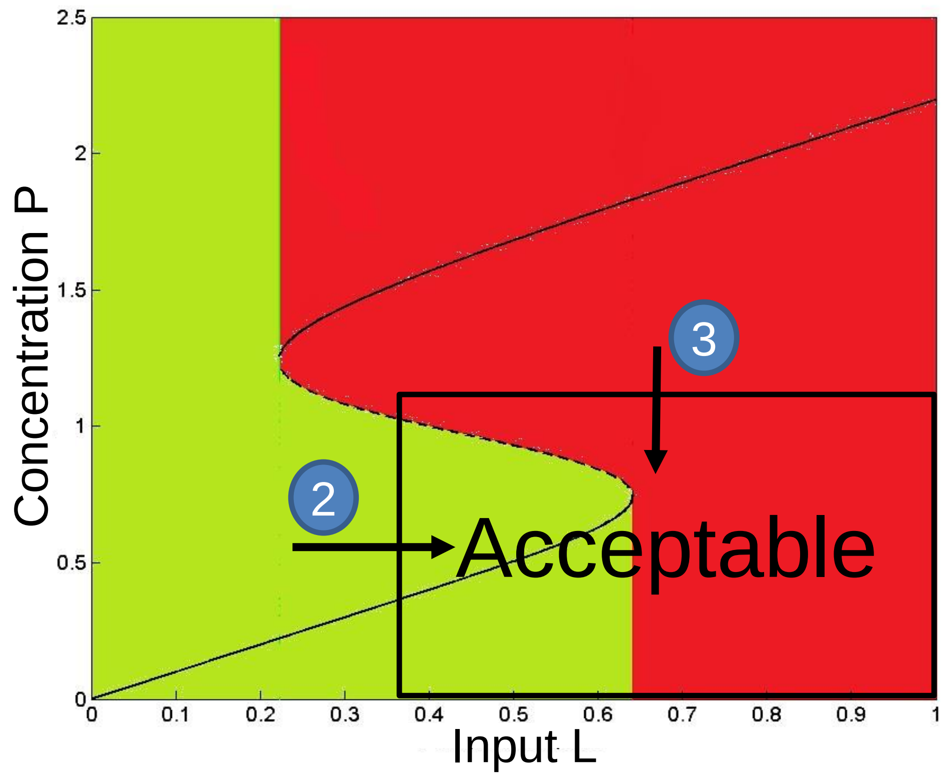
Resilience: define the acceptable



- Keeping the lake in a clear state
  - ➢ Maximum threshold for *P*
- Economic profits
  - ➢ Minimum threshold for *L*

➢ Where exactly do we put the thresholds?

Lake resilience objectives



1. Maximise economic benefits from phosphorus use
2. Maximise threshold for minimum *P* inputs
3. Minimise threshold for maximum *P* concentration

➢ What do the thresholds mean?

Thresholds: two broad visions of resilience

"Hard" threshold

Resilience is all about **not crossing** the threshold

Dam Safety

Ban on all water uses (Max level restrictions)

Domestic water supply <99.9% of the time in normally wet conditions

"Soft" threshold

Resilience is all about **recovery** if / when threshold crossed

Floodplain buildings damaged

Hosepipe ban / Permit restrictions

Burst pipe

Lake resilience objectives: 2 visions

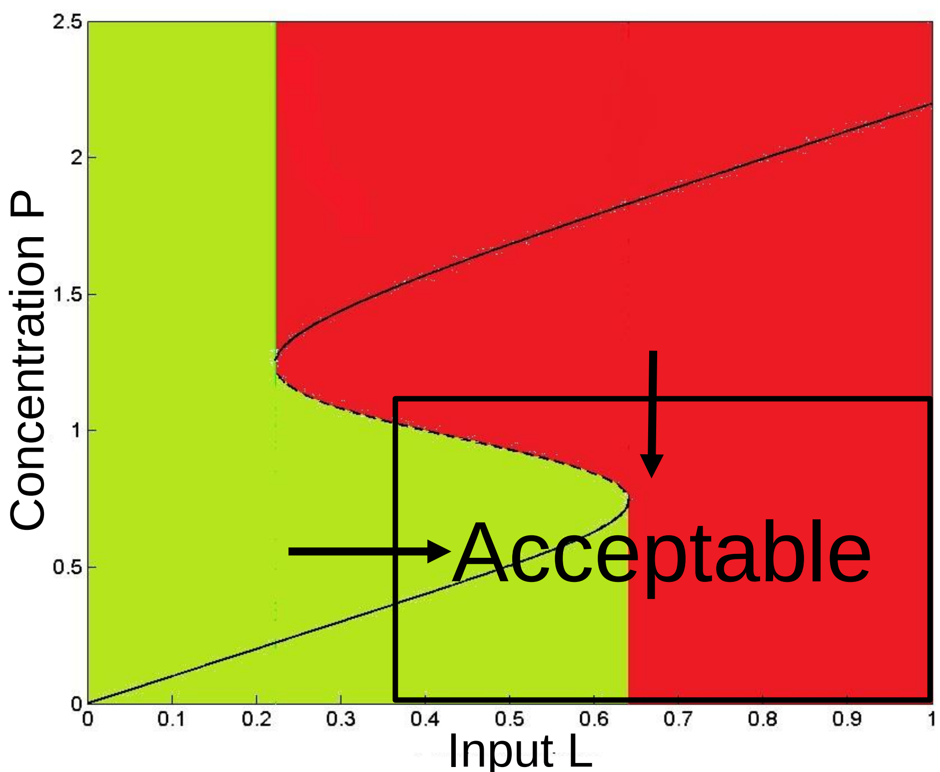
"Hard" threshold

1. Maximise economic benefits from phosphorus use
2. Maximise threshold for minimum *P* inputs
3. Minimise threshold for maximum *P* concentration
4. **Minimise probability of crossing thresholds**

"Soft" threshold

1. Maximise economic benefits from phosphorus use
2. Maximise threshold for minimum *P* inputs
3. Minimise threshold for maximum *P* concentration
4. **Minimise time spent beyond thresholds**

Experiments



- Multi-objective evolutionary algorithm (Borg-MOEA) to find policy *L=f(P)*
- Compare “hard” and “soft” threshold definitions
- Examine the impact of:
  1) input uncertainty
  2) extreme events
  3) parameter uncertainty

- Results are an **ensemble of solutions** trading-off ecology and economy

- Examining policies and if they can lead into the eutrophic (red) zone, especially under 2) and 3)

Preliminary takeaways

1. Very little difference between "hard" and "soft" resilience definitions in low-uncertainty conditions (emphasis on respecting thresholds in both cases)

2. Depending on the ecology-economy trade-off, in high-uncertainty conditions **"hard"** thresholds lead to **risk averse, low flexibility** policies:
   a) Very stringent economic policies (ecology favoured)
   b) High minimal *P* input even when events are leading to eutrophication (economy favoured)

3. **"Soft"** thresholds allow for a **greater diversity** of policies, including **flexible policies** balancing ecology and economy by breaching the economic threshold when needed.

Conclusions

1. Resilience definitions shape management objectives and policy decisions

2. Resilience definition choice should promote out-of-the-box thinking about solutions

3. Current proof-of-concept work on idealised model, but maximal impact on real-world applications!