THE UNIVERSITY OF MELBOURNE

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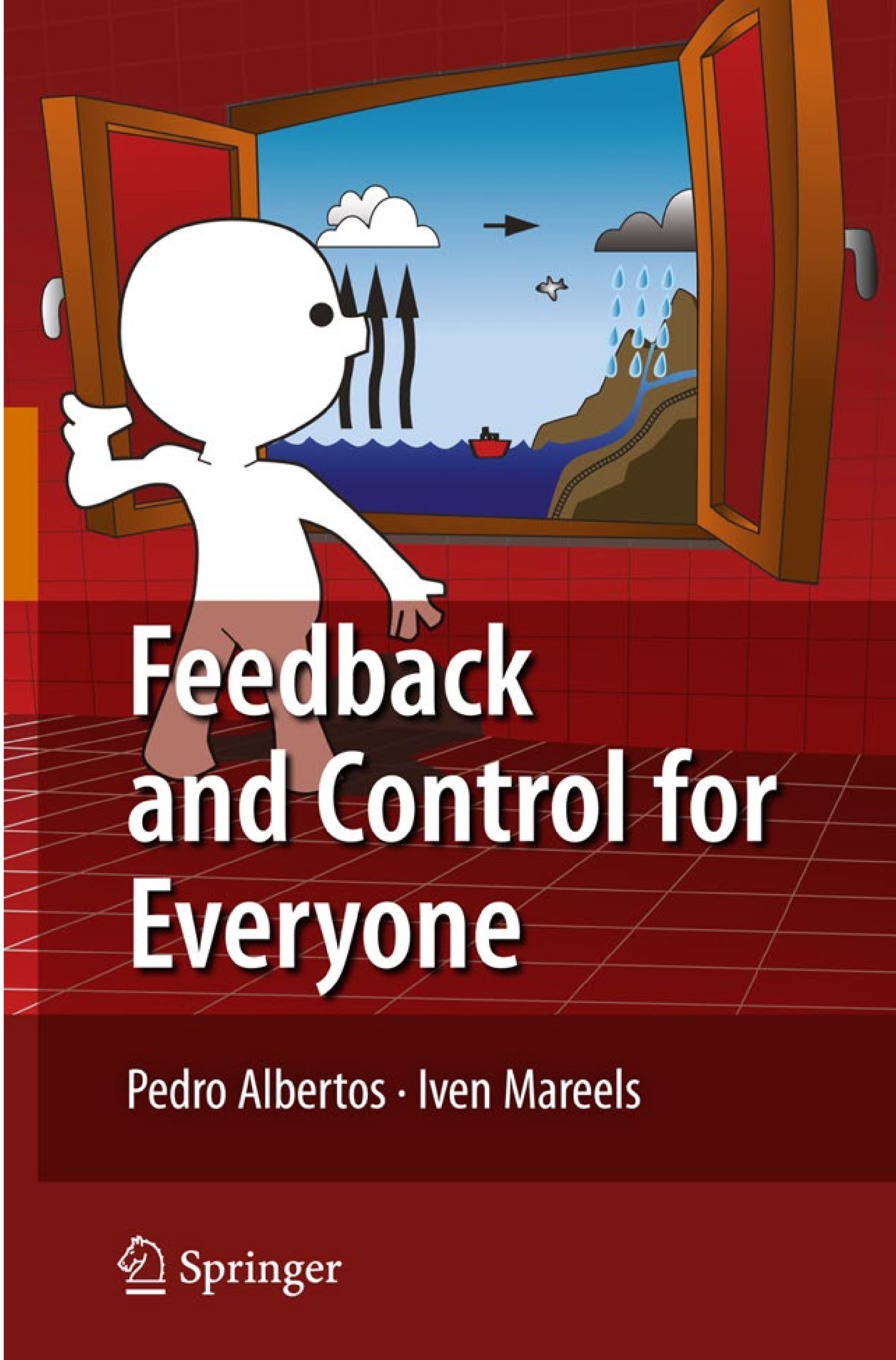
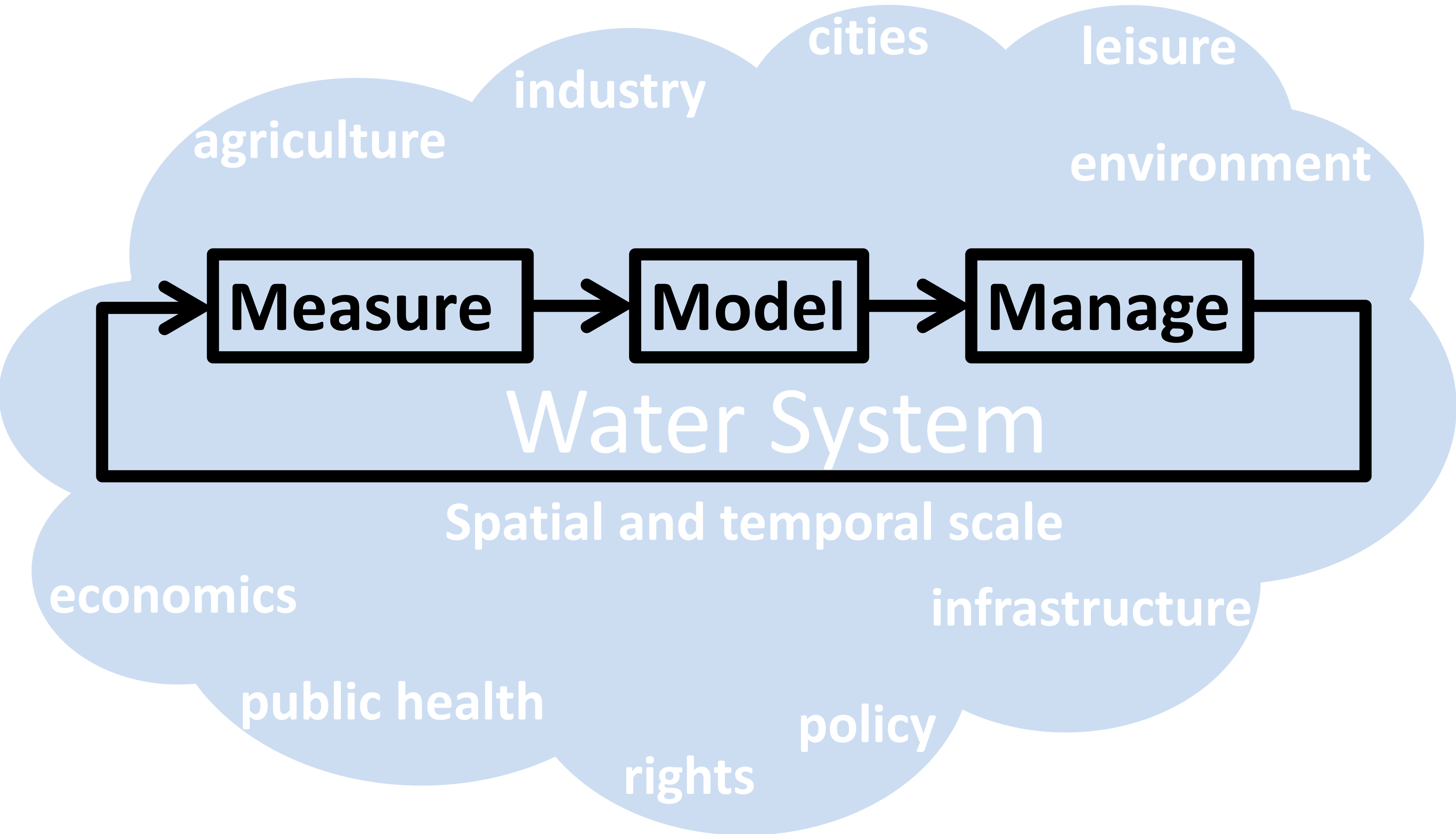


Objective

- Introduce the notion of "systems thinking"
- Illustrate the potential of "feedback & control"
- Demonstrate the role of mathematics and computation in engineering design

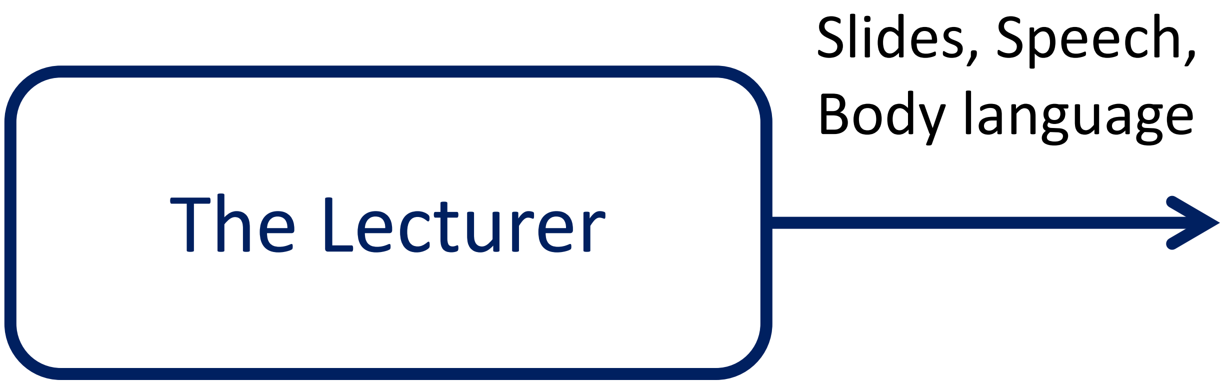
Example our water "system"



Outline

- **“Lecturing” from a systems point of view – introducing systems language**
- Models & prediction – modelling water flow in a channel
- Feedback & control for water distribution

"Lecturing" A Systems Point of View



System (box in a system diagram)
= Object that takes actions, produces, transforms "things"

Signals (arrows in a systems diagram, connected to systems)
= Things observed or used by a system (inputs); or produced by or measured from a system (outputs); the arrows matter!
= a function of "time"

Causality, precedence and time play key roles in the study of systems!

Lecturing: A Systems Point of View

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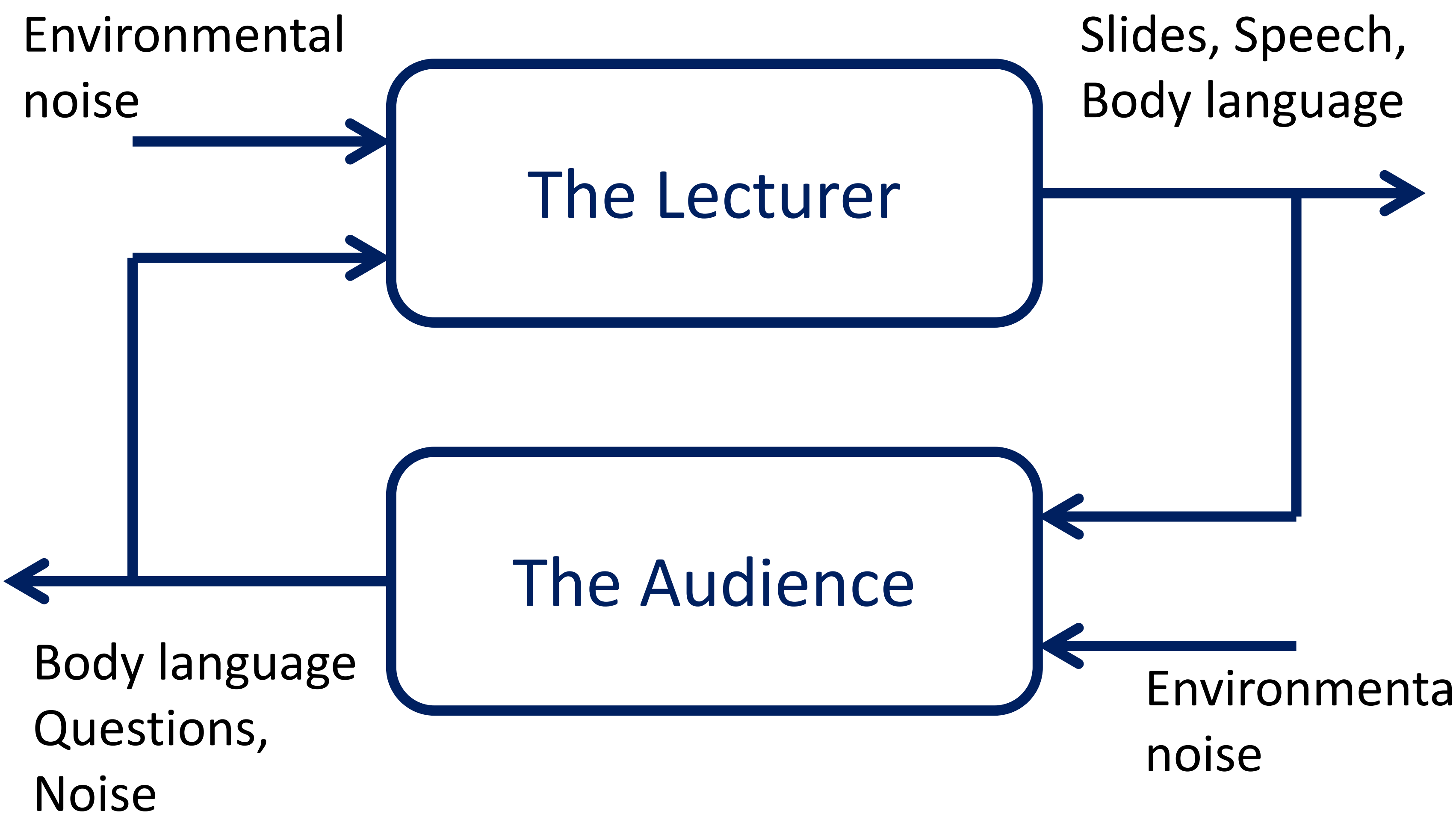
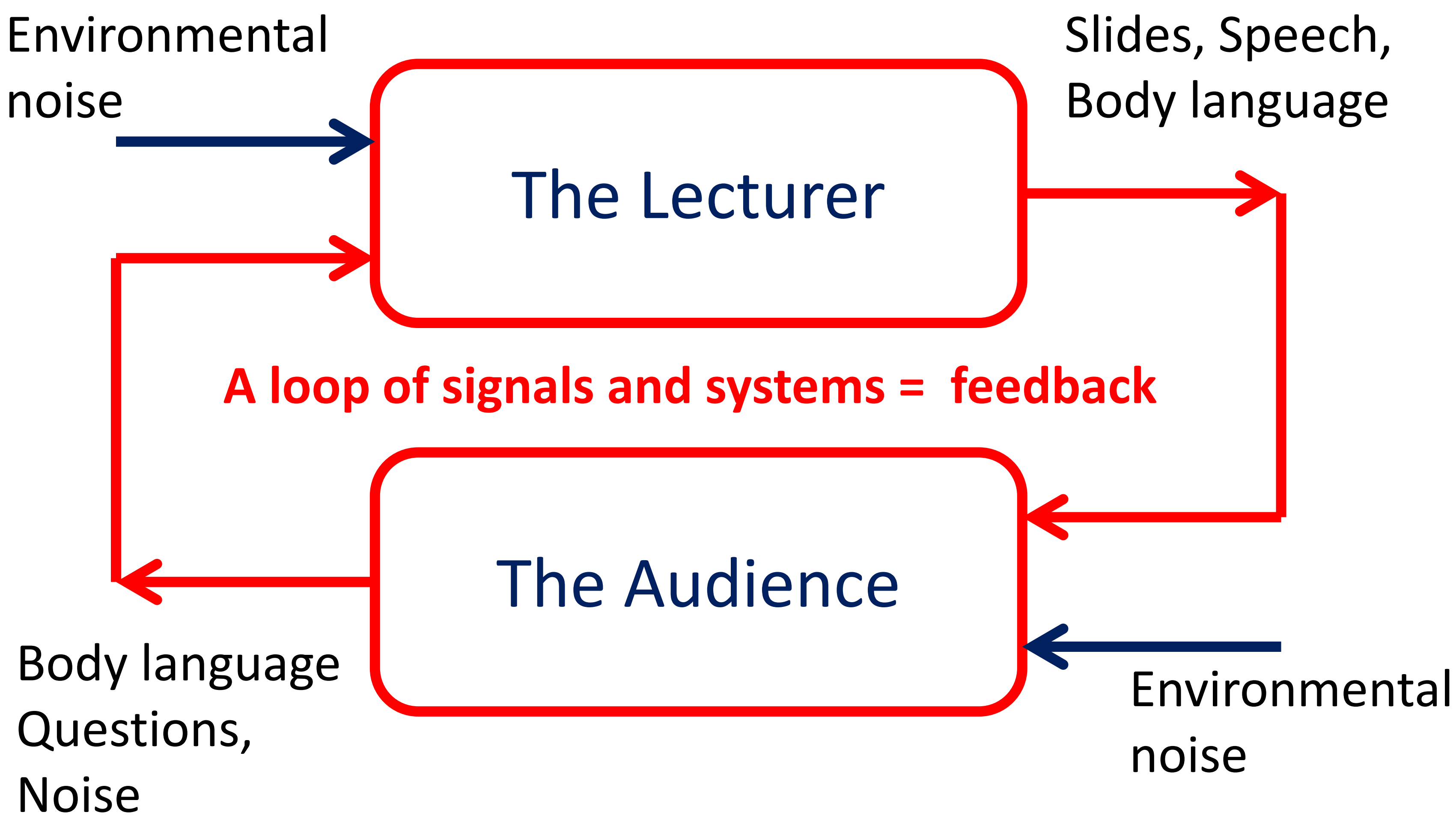
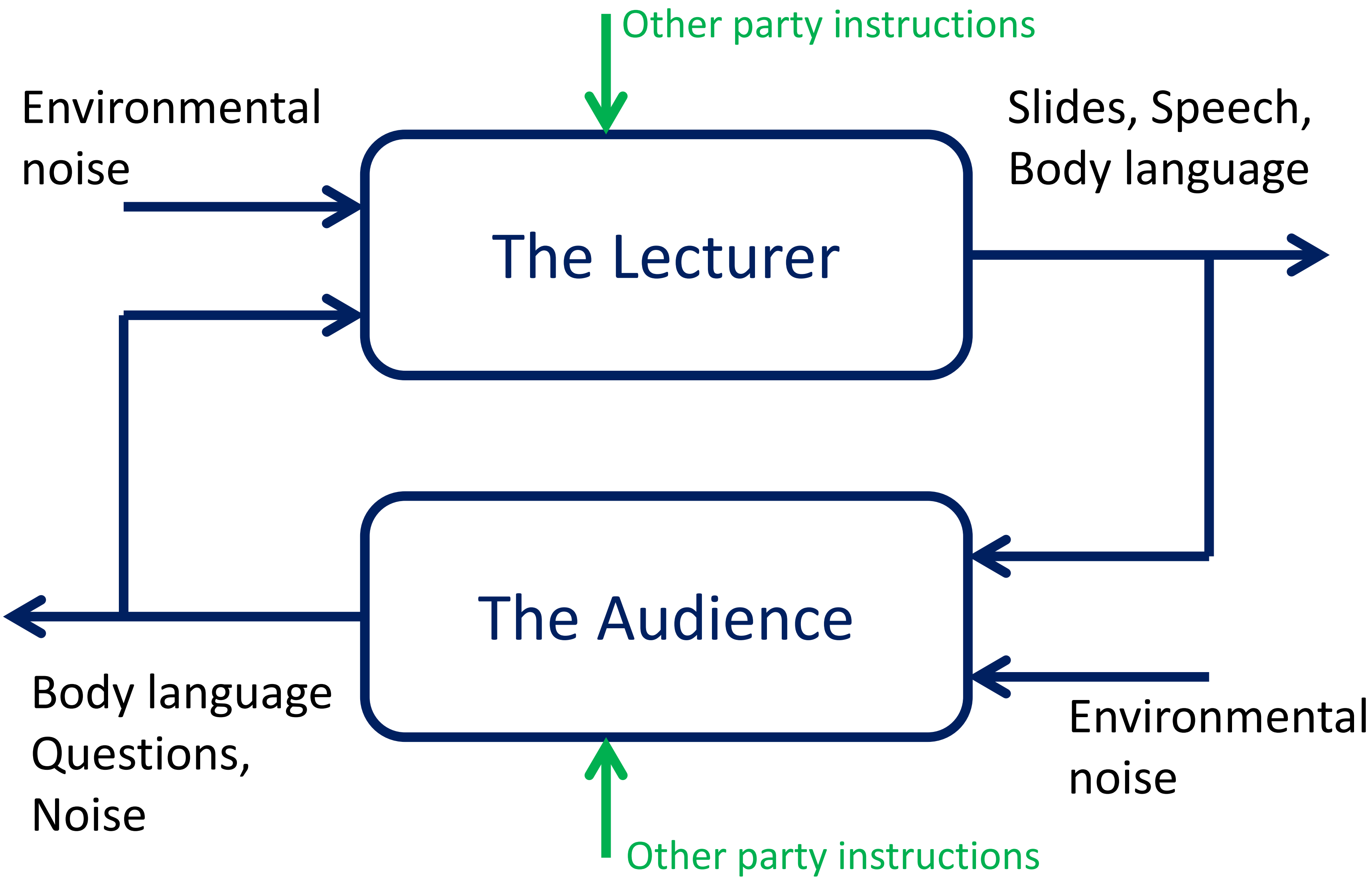


Lecturing: A Systems Point of View



Lecturing: A Systems Point of View



Signals & Systems

- A way of focusing on what matters (to you)
- *Signals* = functions of time, observable or measurable (by you)
- *Systems* = act on signals, produce signals (defined by, defining the signals)
- *System diagram* = a way of communicating, capturing the interaction, connectivity, relationships between systems and signals, separating the environment from “what matters”
- A system diagram is **always** a **partial** or incomplete **description**, there is no unique representation

Outline

- "Lecturing" from a systems point of view – introducing the language and the diagrams
- **Models & prediction – modelling water flow in a channel**
- Feedback & control for water distribution

Models, prediction, simulation

- **Systems** with their signals can be considered in isolation; to simplify, we divide and conquer; consider sub-systems with their signals

- **Models** (explaining the behavior; what is possible, and what is not)
  = mathematical or computational description for the (sub)system/signals
  = enables simulation & prediction (& further design)

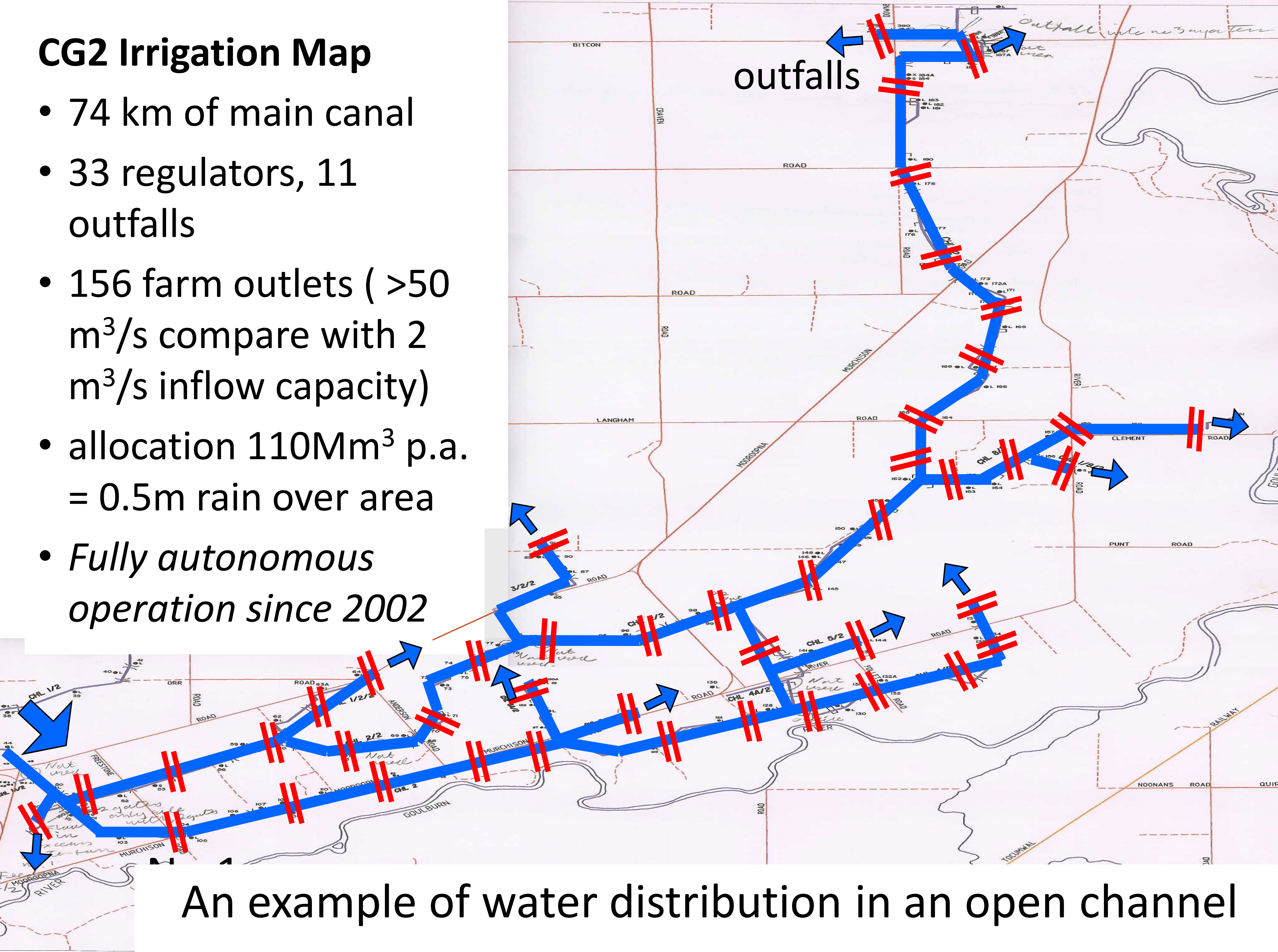
- **Modelling** – the art & science of obtaining a model
  Step 1 – what is the physical reality, system? Step 2 – what do I need to capture in the model? Step 3 – determine, validate model (for a purpose)

- **Control** – the art & science of designing a system's behavior

- **Example** manage water distribution in open channels (say for irrigation purposes) i.e. deliver water orders; a river is not a tap

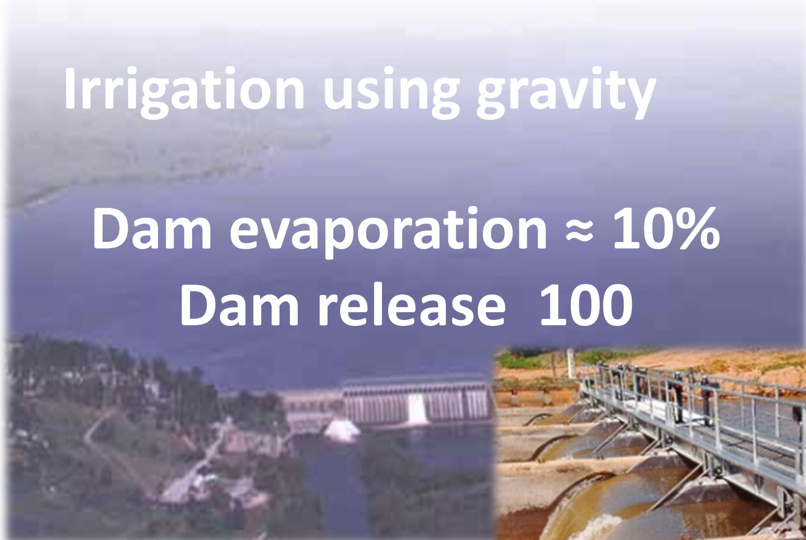
CG2 Irrigation Map

- 74 km of main canal
- 33 regulators, 11 outfalls
- 156 farm outlets (>50 m^3/s compare with 2 m^3/s inflow capacity)
- allocation 110Mm^3 p.a. = 0.5m rain over area
- *Fully autonomous operation since 2002*



An example of water distribution in an open channel

Irrigation using gravity



Dam evaporation ≈ 10%

Dam release 100

- Efficiency < 50%
- Over-irrigation leads to soil degradation
- Poor accountability

Channel to farm consumes >30

- Seepage ≈ 5
- Evaporation≈ 5
- Outfalls> 5
- Conservative over supply (due to the above ≈ 15)

Metering error ± 20%

Farm gate to plant consumes 30

- Outfalls ≈ 15
- Seepage ≈ 15
- Plants ≈ 40

Plants store (1%) 0.4

- Low energy footprint
- More productive, more reliable farming
- 50% of all farm profits (on a small area)
- Farmers take all risk, ask for more water

Typical manual control

In-Channel Actuator & Sensor The FlumeGate™

- Water tight, self cleaning, low head loss flow actuator (system)
- Accurate, repeatable self calibrating flow and level sensor (system) (SKM, THIESS 2009 <+/- 2%)
- Radio based internet, 1 PC on board (remote sensing, actuation)
- Solar powered, 4 day battery back-up
- 64 tagged variables per unit

Models, prediction, simulation

- Systems with their signals can be considered in isolation
  - Simplify: divide and conquer: consider sub-systems & signals

- Models
  = mathematical or computational description for the system/signals
  = enables simulation & prediction

- Modelling – the art of obtaining a model
  Step 1 – what is the physical reality, system? **Step 2 – what do I want to capture in the model?** Step 3 – determine, validate model

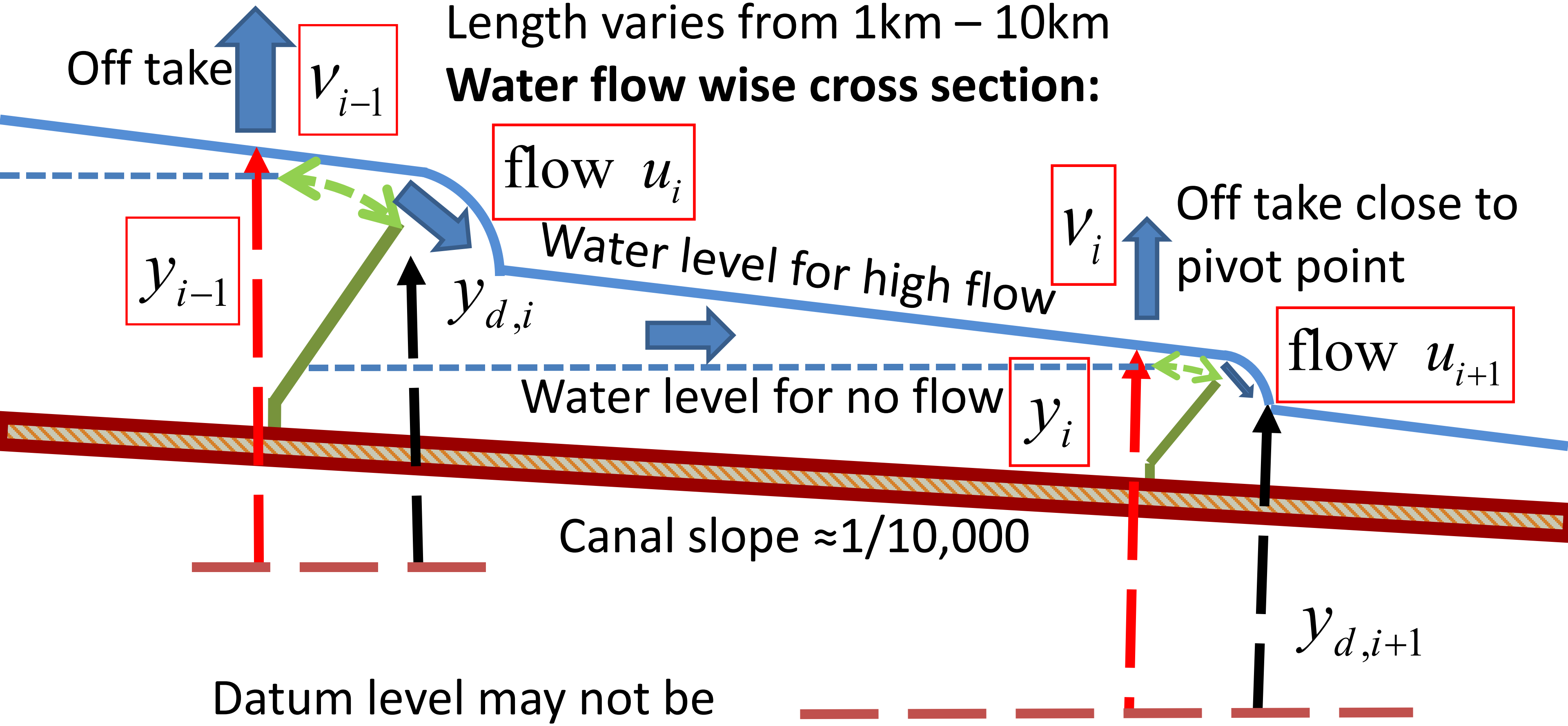
- **Example** manage water distribution in open channels (say for irrigation purposes) i.e. deliver water orders; a river is not a tap

Model: pool by pool, regulator by regulator

Pool = canal section between regulators

Length varies from 1km – 10km

Water flow wise cross section:

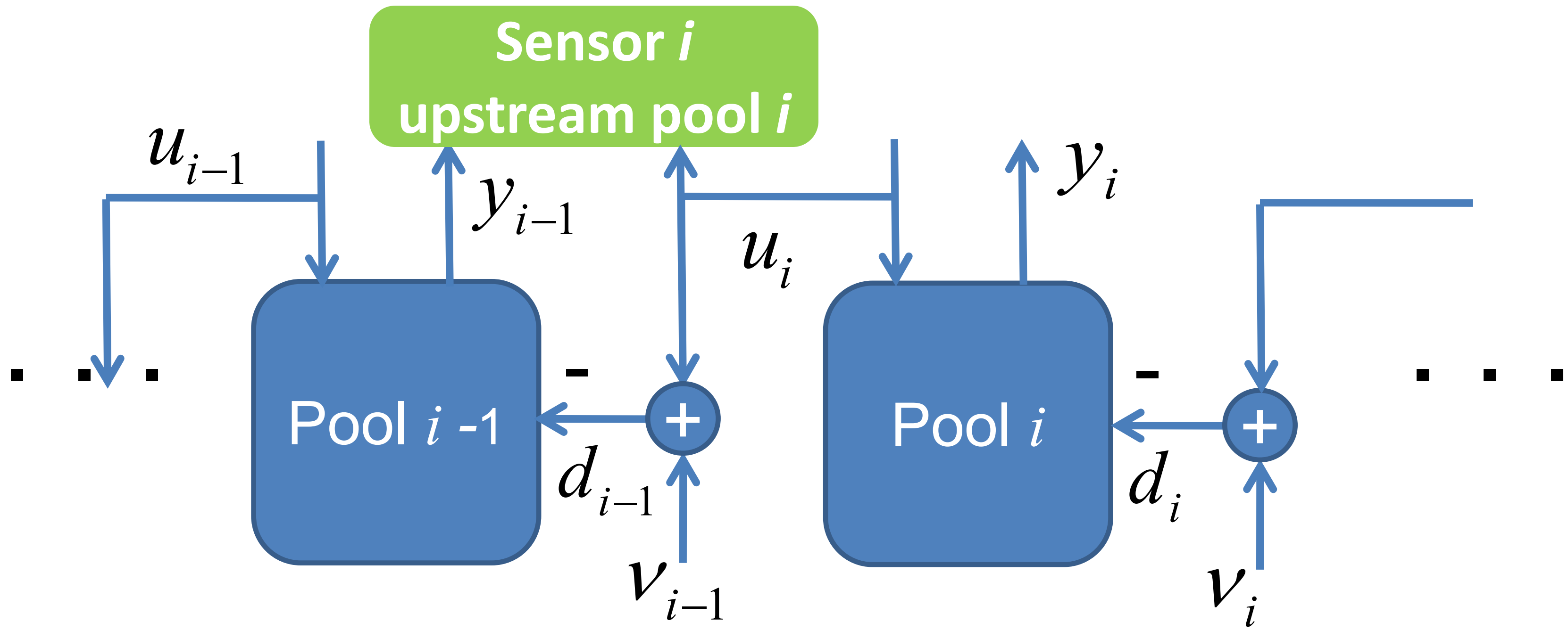


Datum level may not be unified across system

Building Large Scale Model

- Pool model = from up-stream inflow to down-stream water level, with a downstream flow disturbance (off-take)
- Inflow *u*, water level *y*, off-take *v*, *τ delay = actions travel time on pool – simple mass balance model is:*

$$\frac{d}{dt} y_i(t) = k_i\big(u_i(t-\tau_i) - u_{i+1}(t) - v_i(t)\big) \qquad u_i(t) = f_i(geometry)$$



Models, prediction, simulation

- Systems with their signals can be considered in isolation
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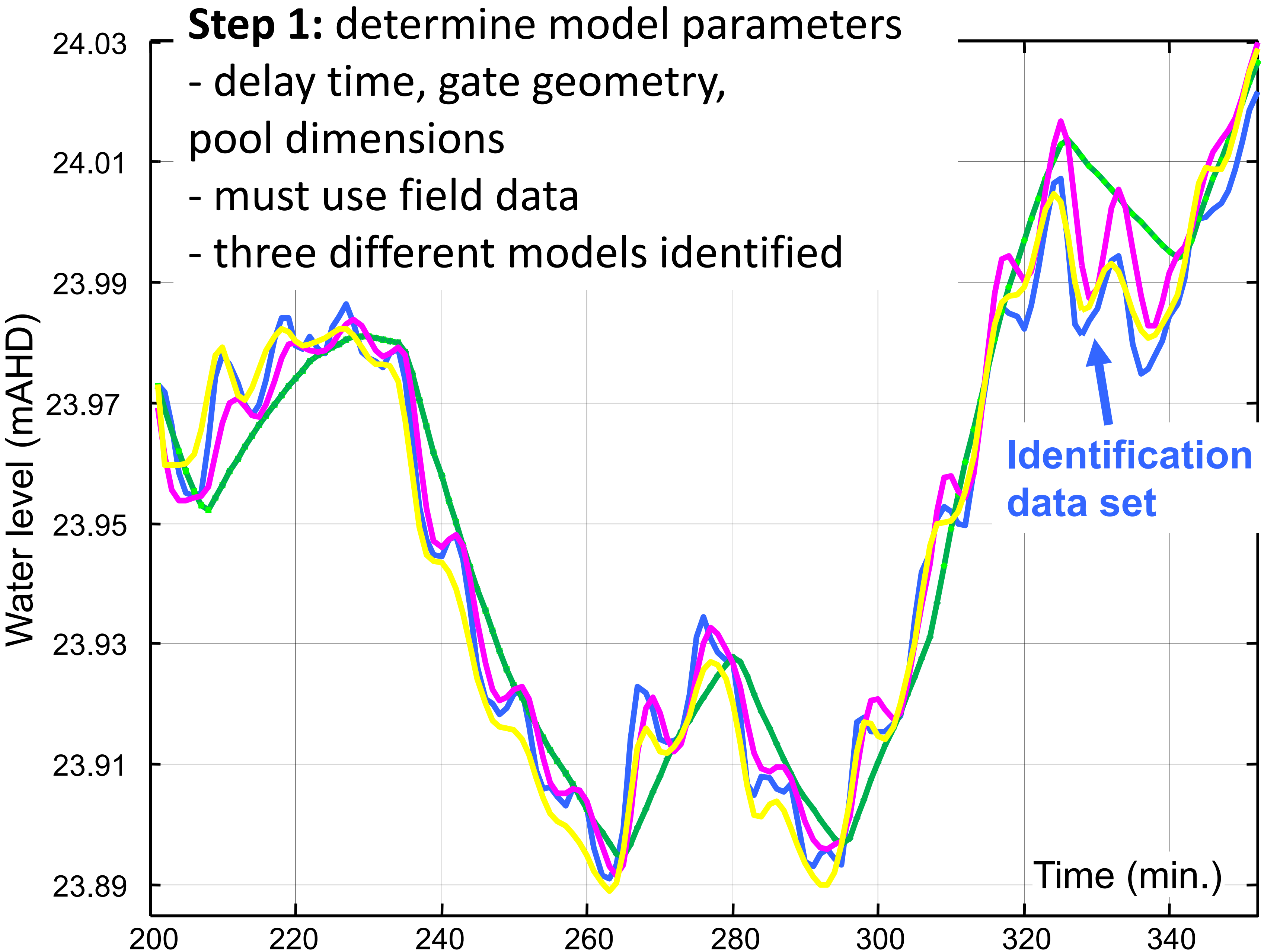
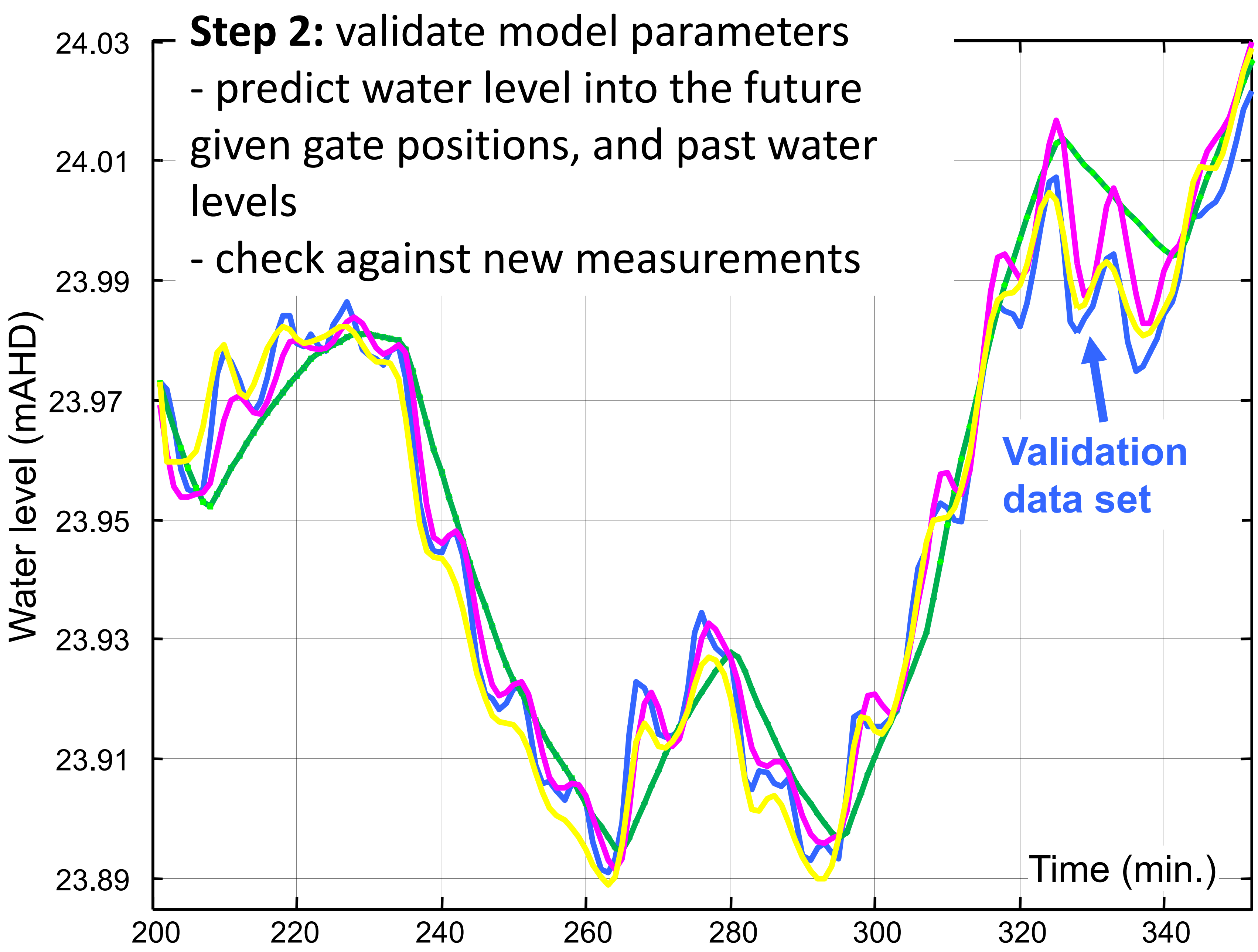
- **Example** manage water distribution in open channels (say for irrigation purposes) i.e. deliver water orders; a river is not a tap

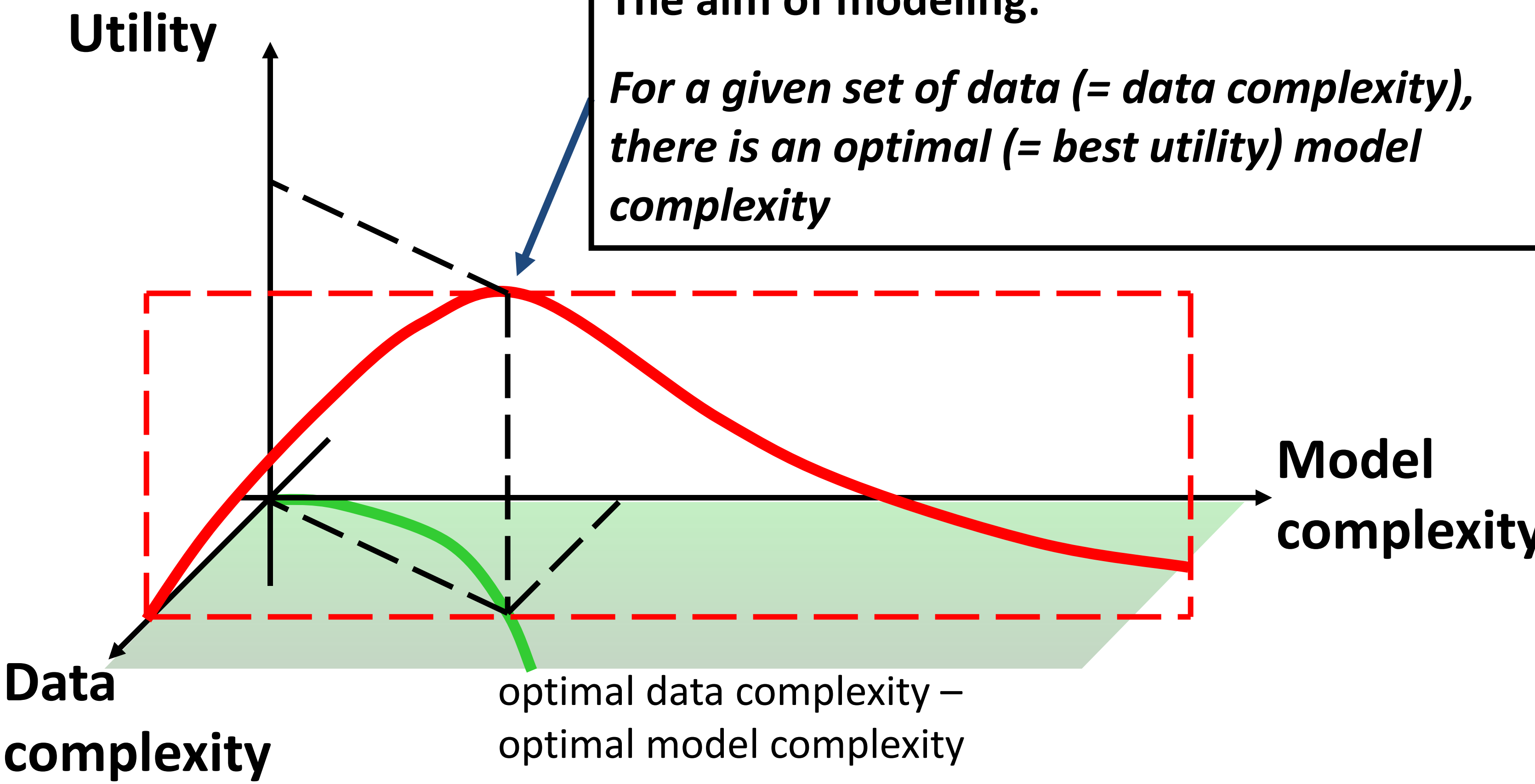

Step 1: determine model parameters
- delay time, gate geometry,
pool dimensions
- must use field data
- three different models identified
Identification
data set
Water level (mAHD)
24.03
24.01
23.99
23.97
23.95
23.93
23.91
23.89
200
220
240
260
280
300
320
340
Time (min.)


Step 2: validate model parameters
- predict water level into the future given gate positions, and past water levels
- check against new measurements
Validation data set
Water level (mAHD)
Time (min.)
24.03
24.01
23.99
23.97
23.95
23.93
23.91
23.89
200
220
240
260
280
300
320
340

The Art and Science of Modeling

The aim of modeling:

For a given set of data (= data complexity), there is an optimal (= best utility) model complexity



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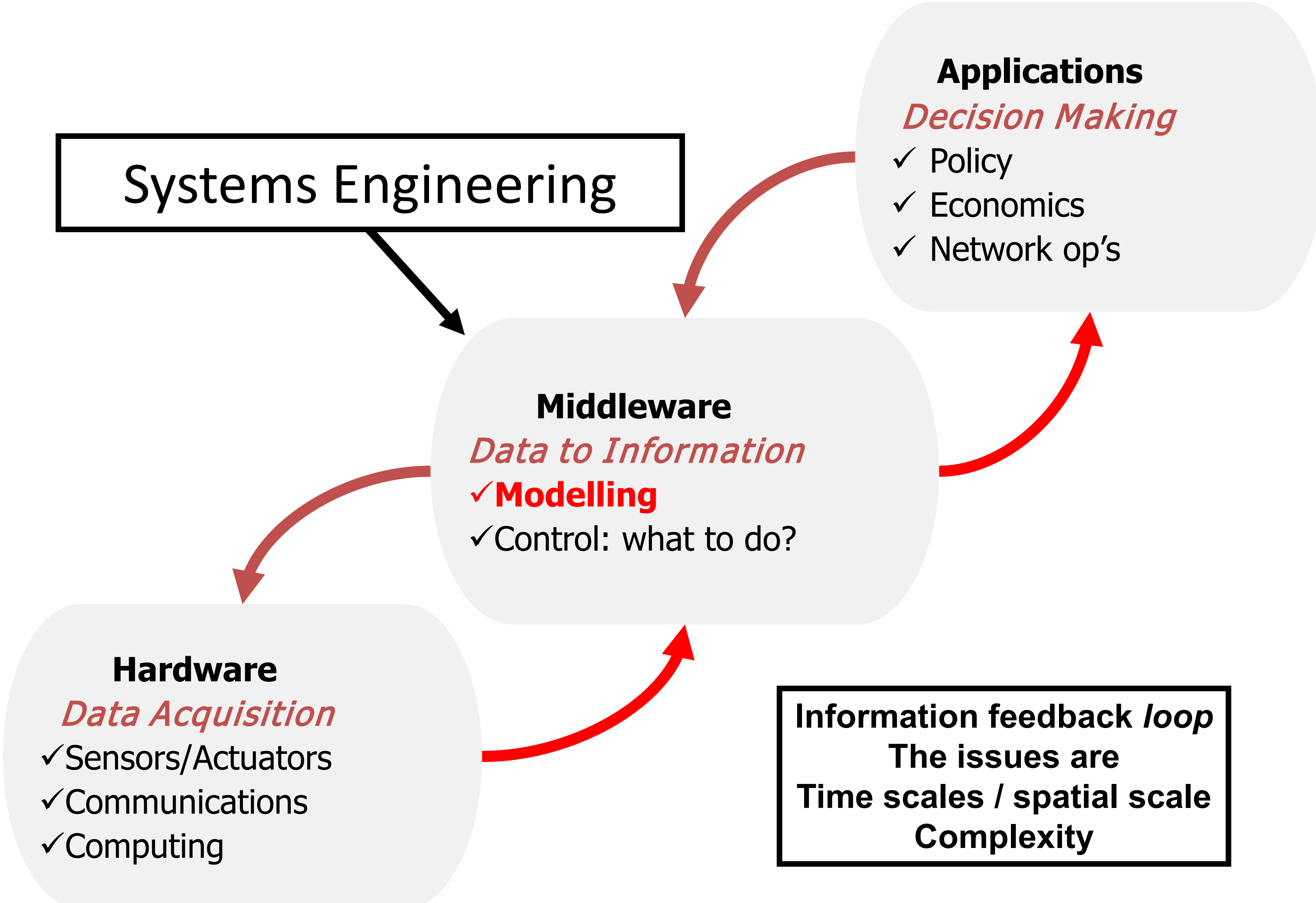
- **Feedback & control for water distribution**


Systems Engineering
Applications
Decision Making
✓ Policy
✓ Economics
✓ Network op's
Middleware
Data to Information
✓Modelling
✓Control: what to do?
Hardware
Data Acquisition
✓Sensors/Actuators
✓Communications
✓Computing
Information feedback loop
The issues are
Time scales / spatial scale
Complexity

The Ingredients of an Autonomous System

1. **Sensors** - monitor data; event driven, report by exception (distributed across the civil infrastructure)
2. **Actuators** - enable real time action, change topology of civil network (distributed across the civil infrastructure)
3. **Computers & storage** – combine prior knowledge with, sensor data, and decide actuation based on external objectives and present situation
4. **Communication system** – sensors to actuator via brain
5. **Design –** systems engineering & control, coordinate the assets to respond to management needs

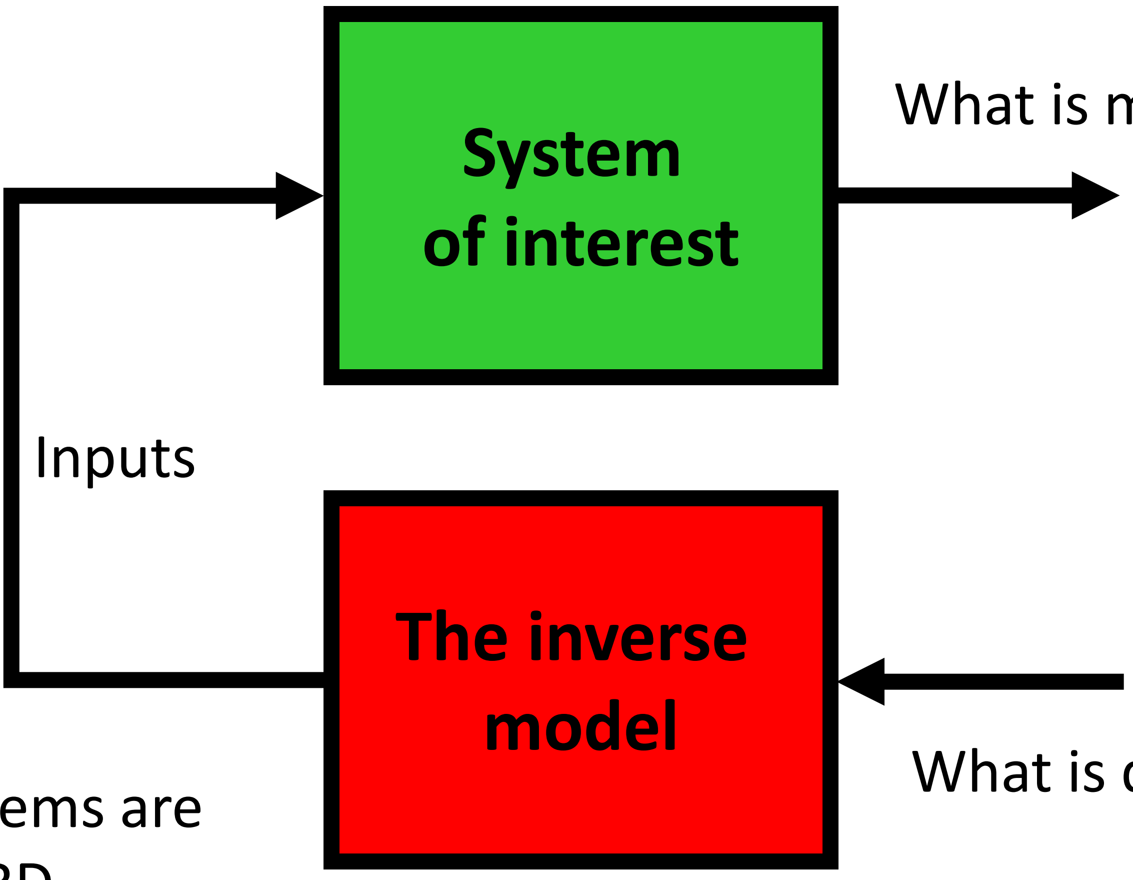
1 to 5 approximates autonomous system behaviour

similar to a "human body"

Control for Water Distribution

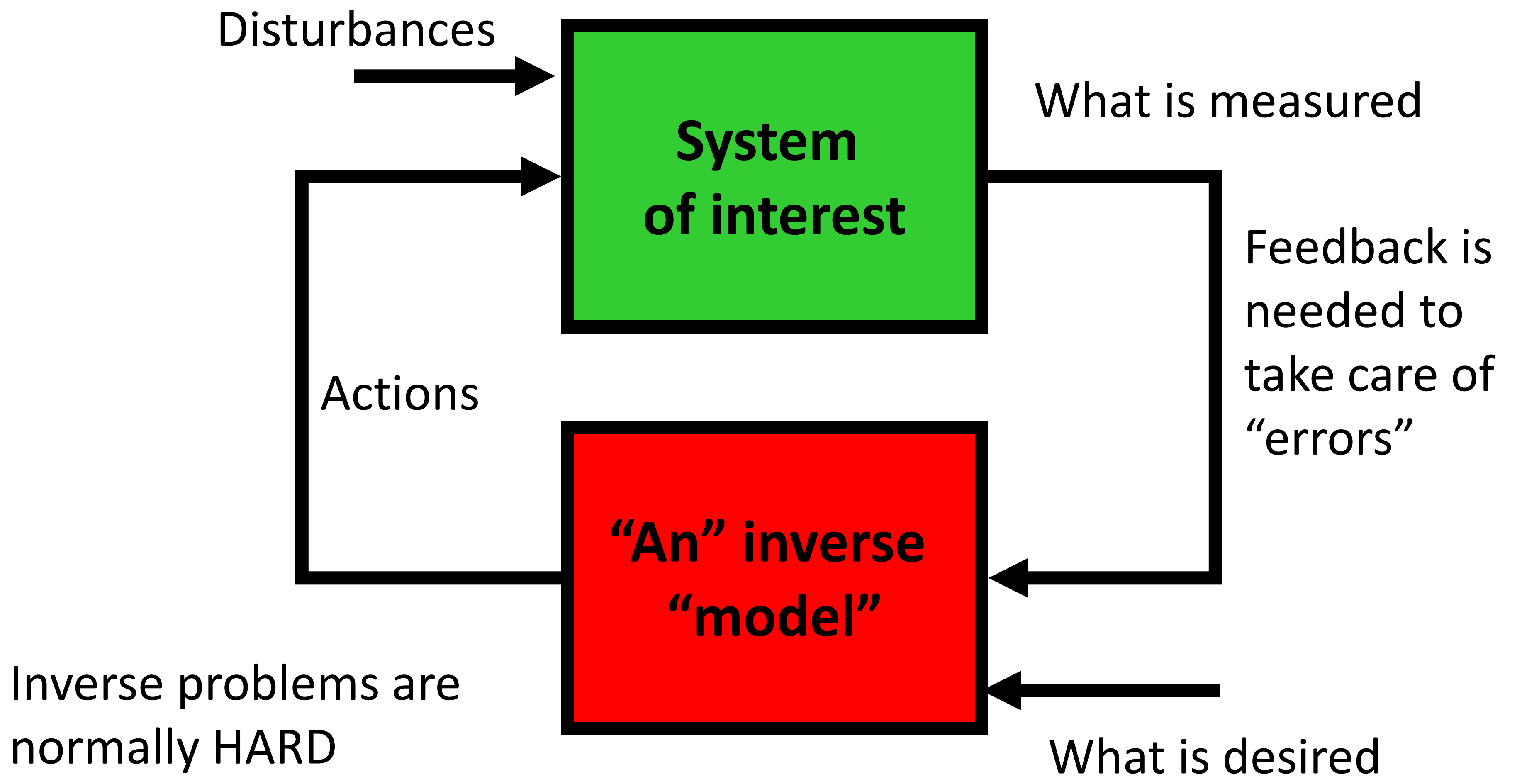
- Maintain water levels, deliver water orders, minimise outfalls, cope with the weather, seepage, evaporation losses …
- An irrigation district in Australia = 30,000 pools with 10-15 action events/h ≈ 7M "SMS" per day
- Need to integrate these data with weather data, crop data, asset condition data, economic data (value of crop) to provide *decision support for best result for irrigation*
- "actuator/sensor infrastructure" + "telecommunication infrastructure" + "software" = control system in support of the civil infrastructure, the whole delivers a "water service"

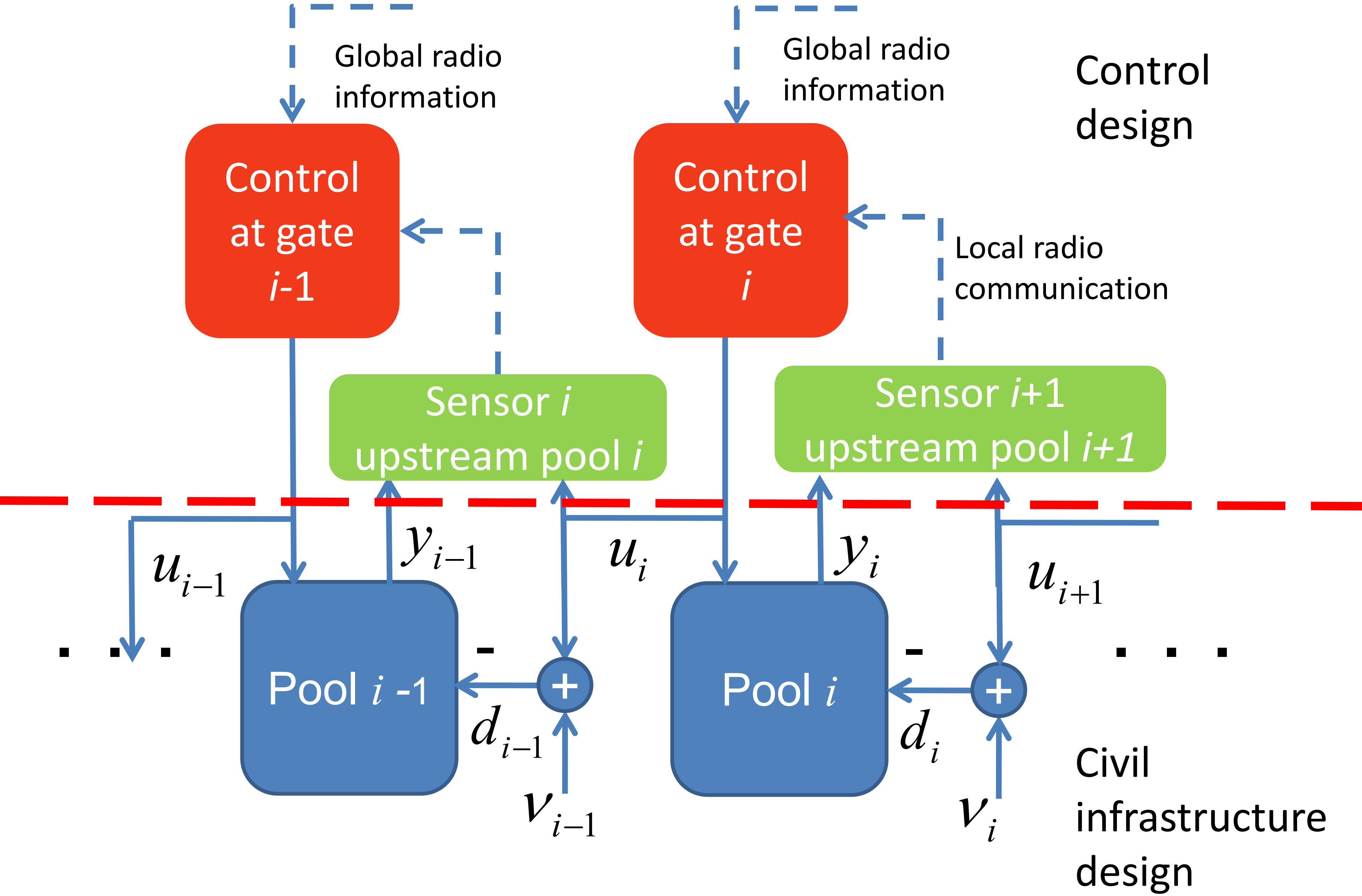
System thinking: how to do control



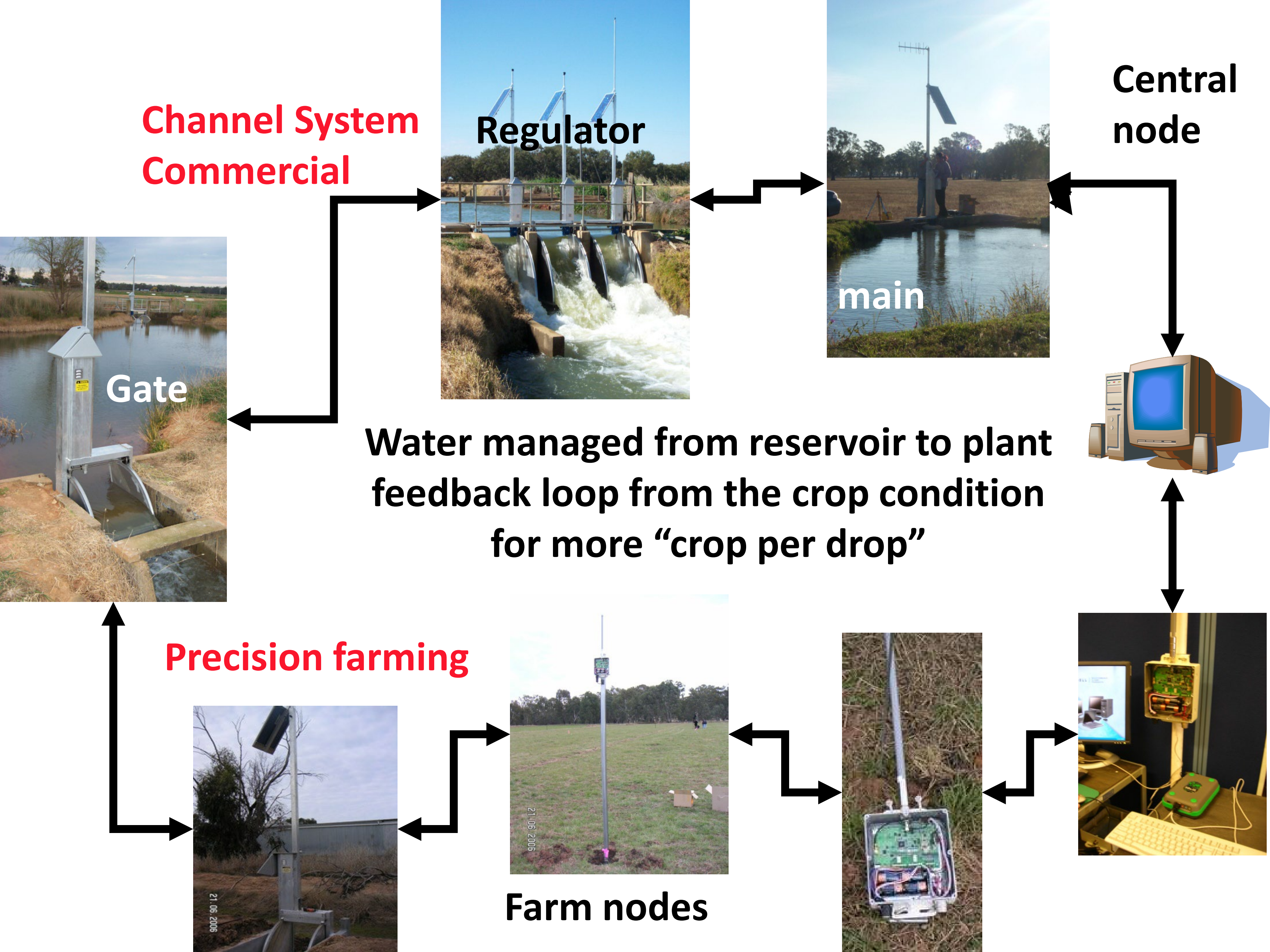
Inverse problems are normally HARD

System thinking: how to do control

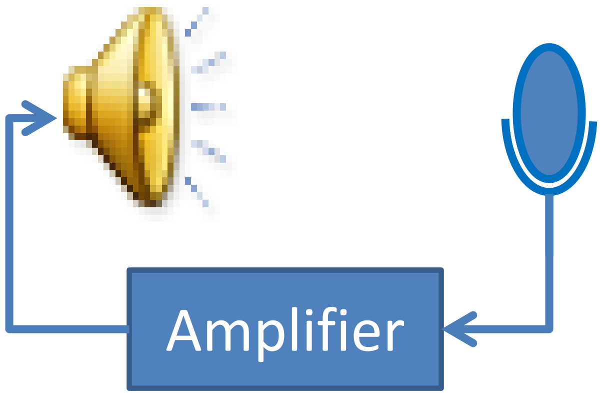




Global radio information
Global radio information
Control design
Control at gate i-1
Control at gate i
Local radio communication
Sensor i upstream pool i
Sensor i+1 upstream pool i+1
y_{i-1}
u_i
y_i
u_{i-1}
u_{i+1}
Pool i -1
Pool i
d_{i-1}
d_i
v_{i-1}
v_i
Civil infrastructure design


Channel System
Commercial
Regulator
Central
node
main
Gate
Water managed from reservoir to plant
feedback loop from the crop condition
for more “crop per drop”
Precision farming
Farm nodes

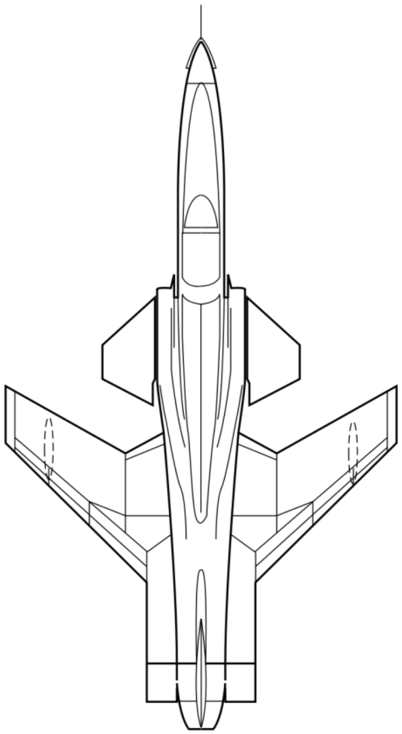
Feedback needs design

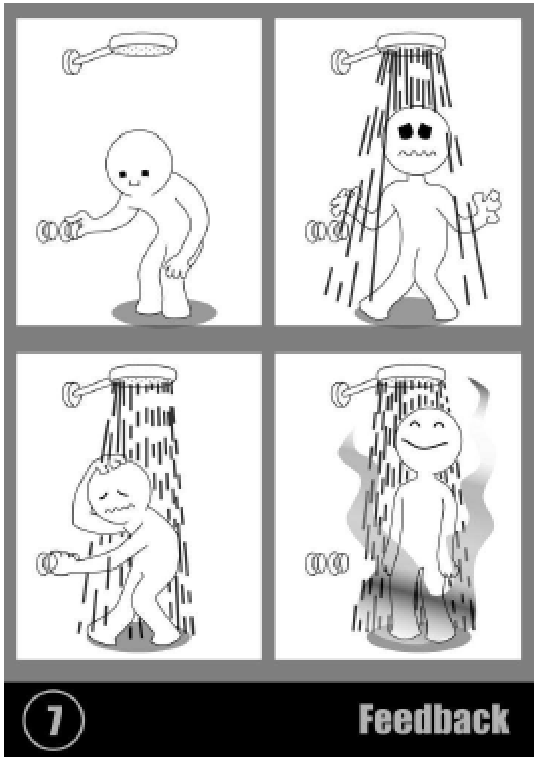


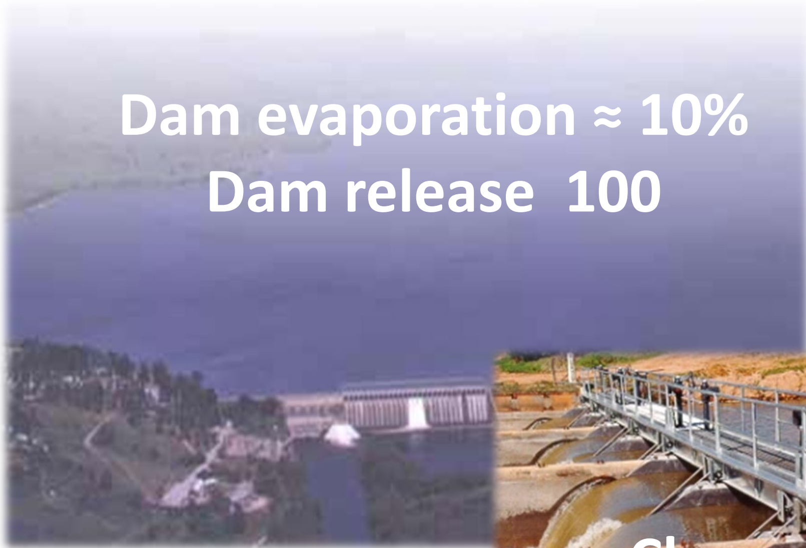
Unpleasant feedback experiences
- Acoustic feedback
- Hot/cold shower

Abandoned feedback experiences
- Forward swept wing aircraft

Disastrous feedback experience
- Chernobyl runaway reactor







Dam evaporation ≈ 10%

Dam release 100

- **Efficiency > 80% not < 50%**
- **Improved accountability**

- Seepage ≈ 5
- Evaporation ≈ 5
- ~~Outfalls ≈ 5~~
- ~~Conservative management ≈ 15~~

Channel to farm consumes 10 ~~30~~

Meter error ± 2%

Farm gate to plant consumes 10 ~~30~~

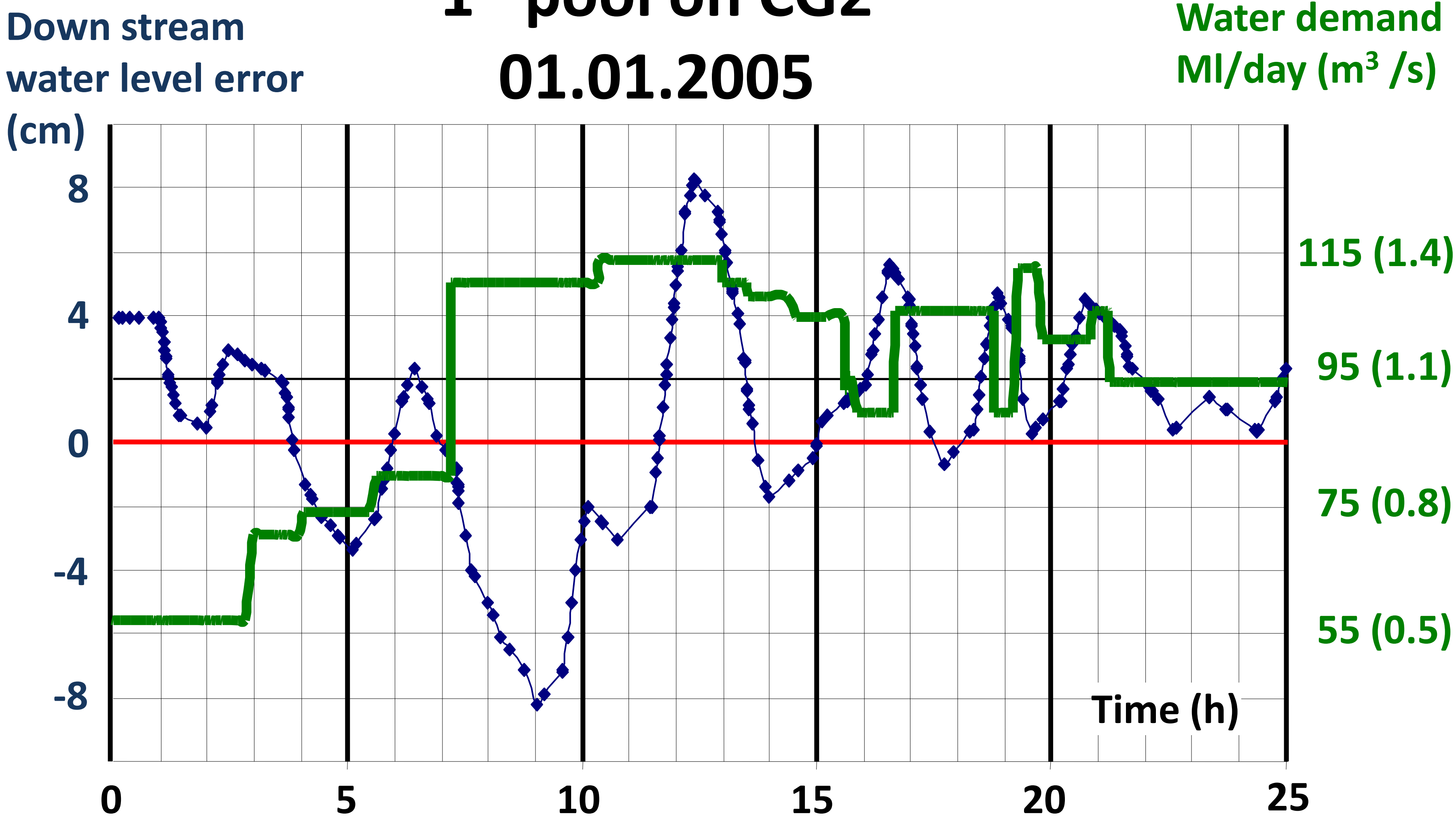
- Outfalls ≈ 0 ~~15~~
- Seepage ≈ 10 ~~15~~
- Plants ≈ 80 ~~40~~

Plants store (<1%) <0.8

Double the production for the same water volume

Farmers ask for less water

1st pool on CG2 01.01.2005



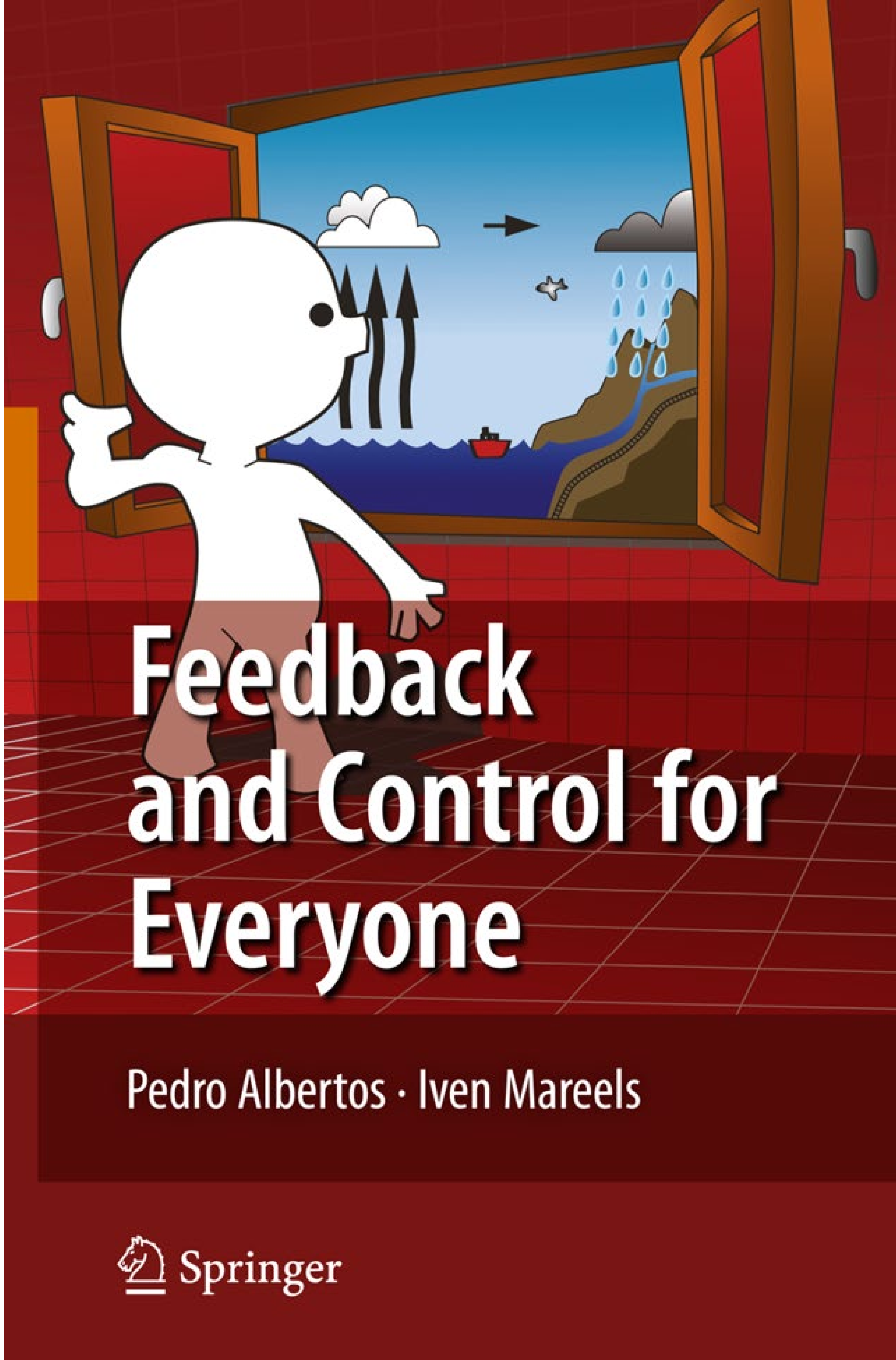
287 “measurement events” ≈ 5min between measurements

1 gate movement / 10min

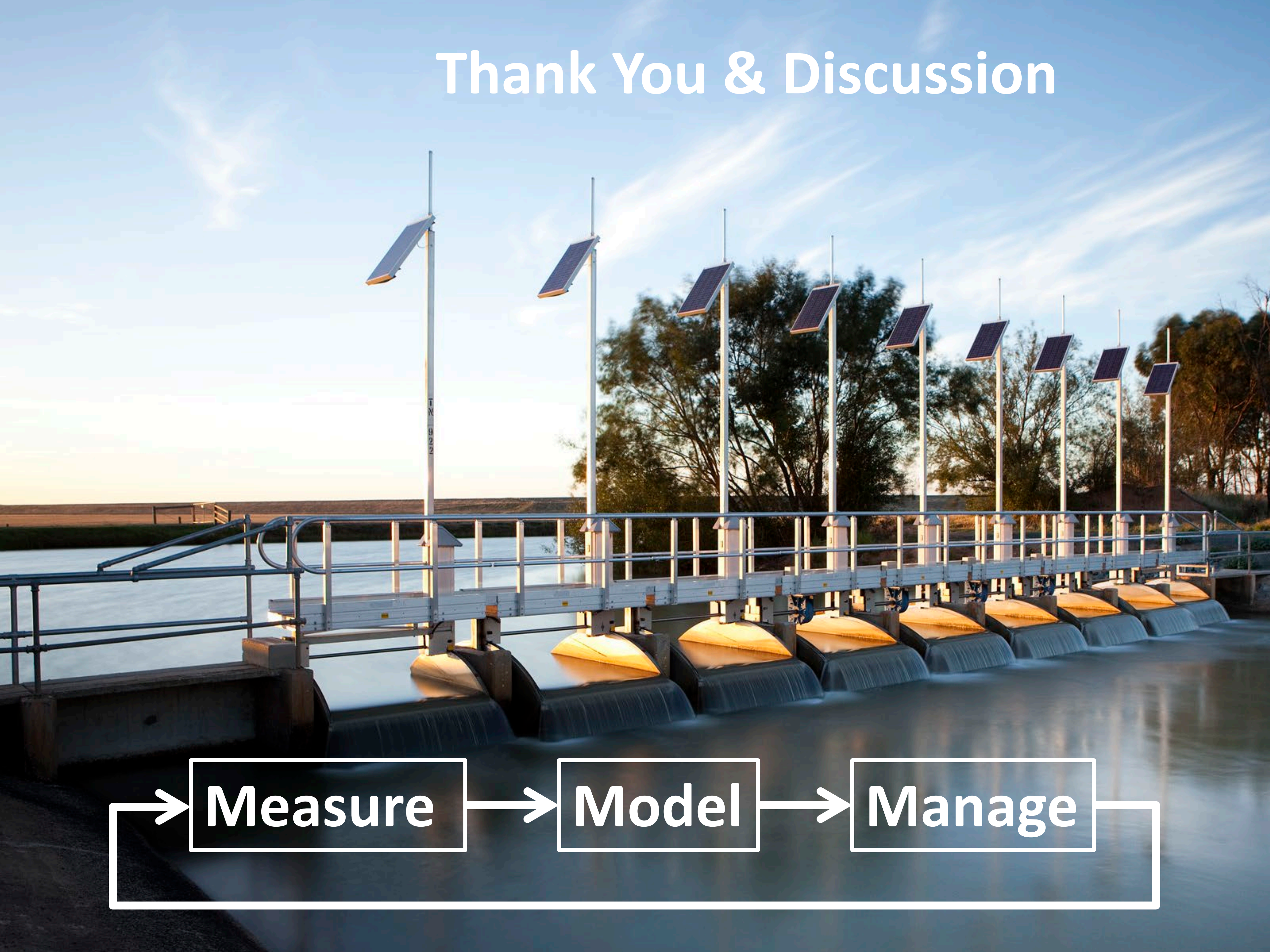
To probe further

- Systems & signals: properties, classify, order, construct, design for…

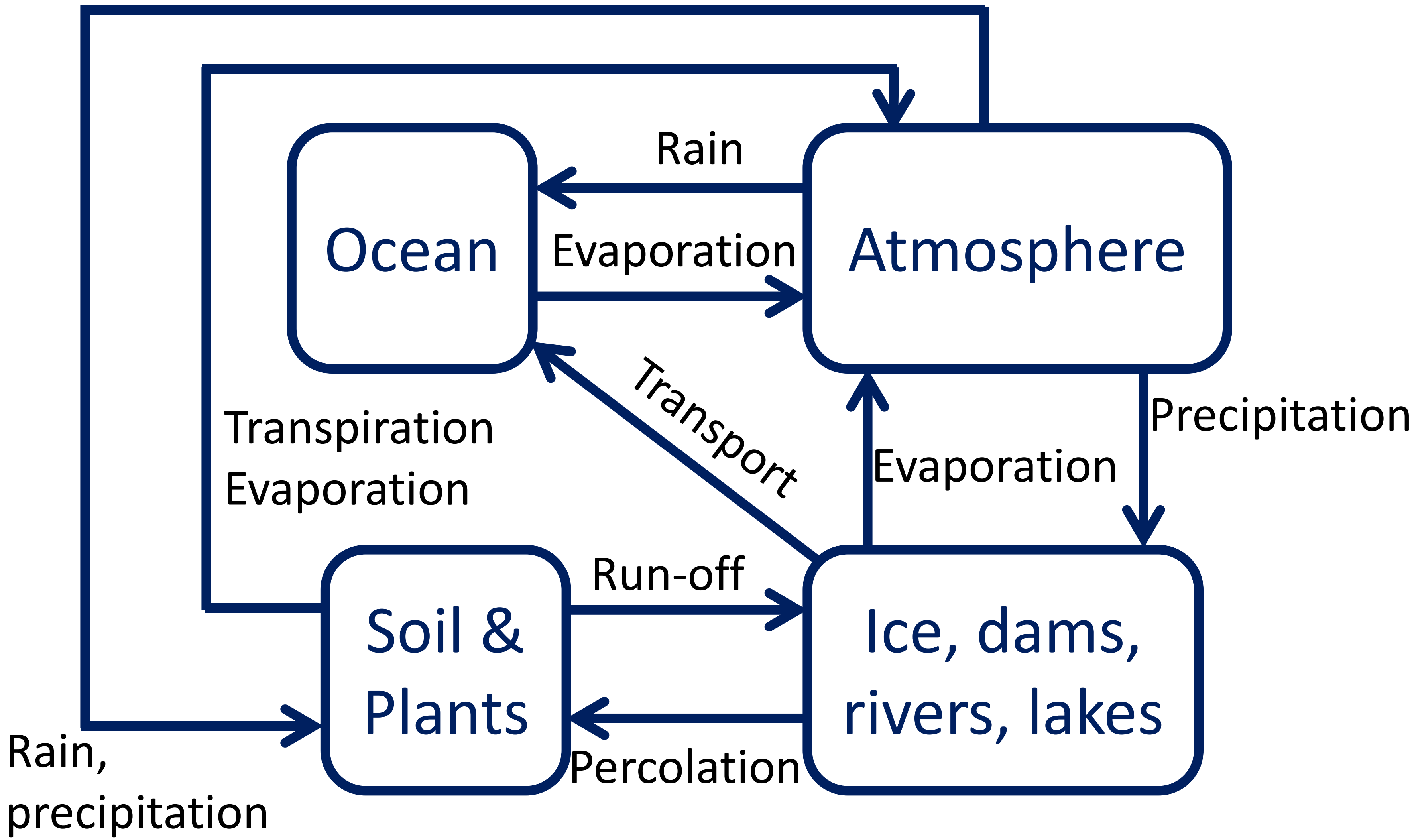
- Control design = augmenting systems, use feedback, design by optimization (find best possible)



Thank You & Discussion



Another example: the hydrocycle



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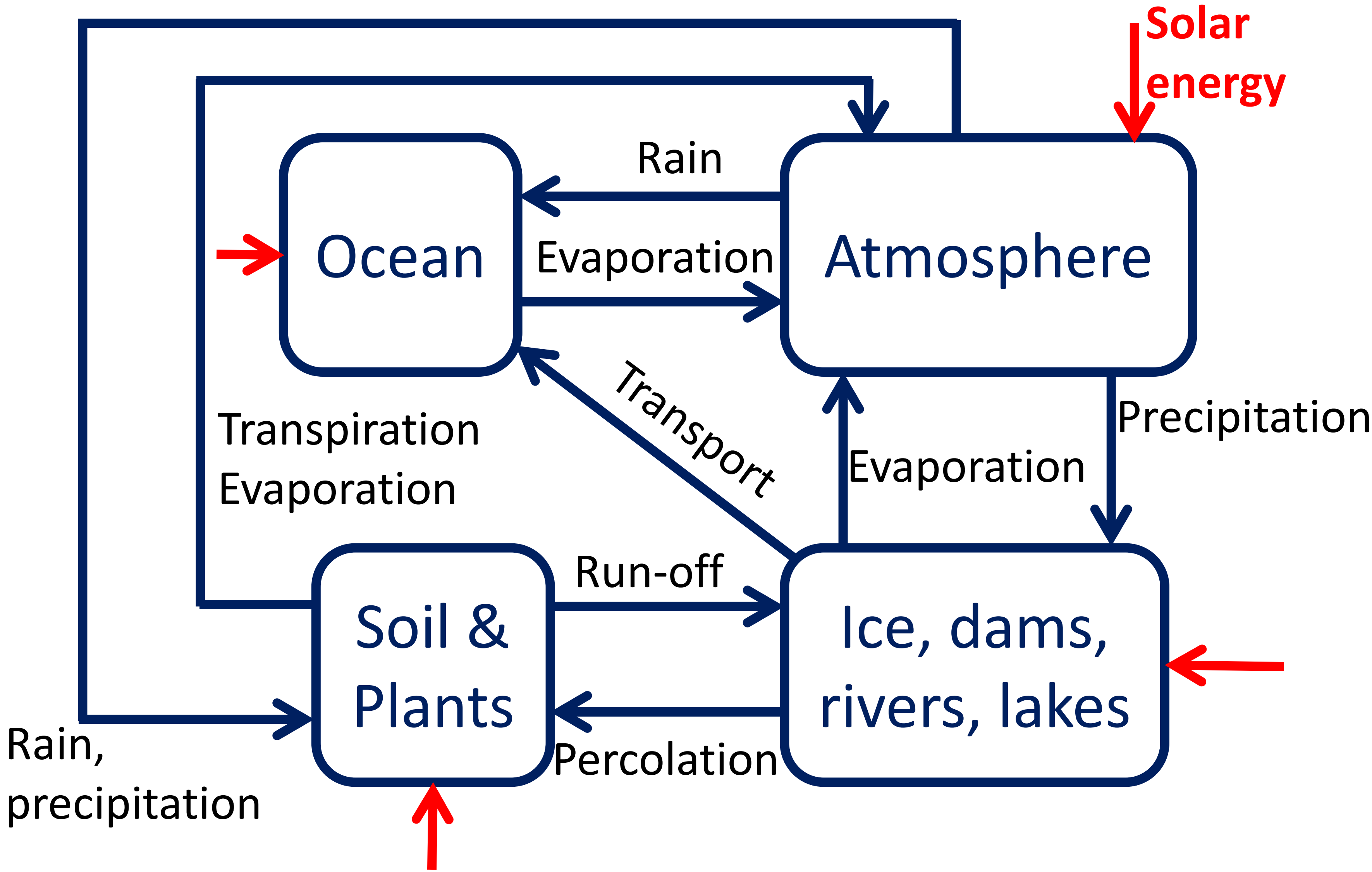

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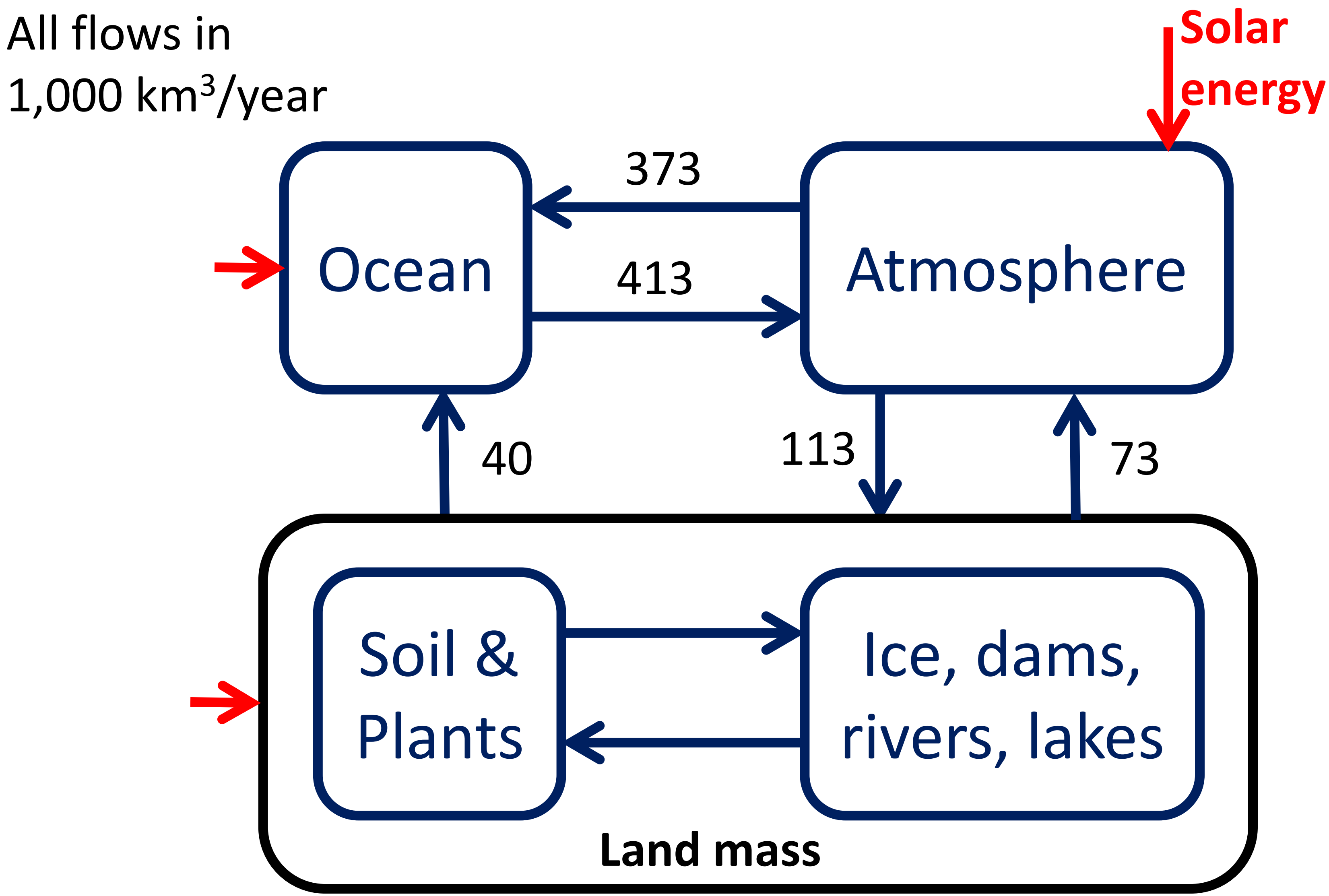
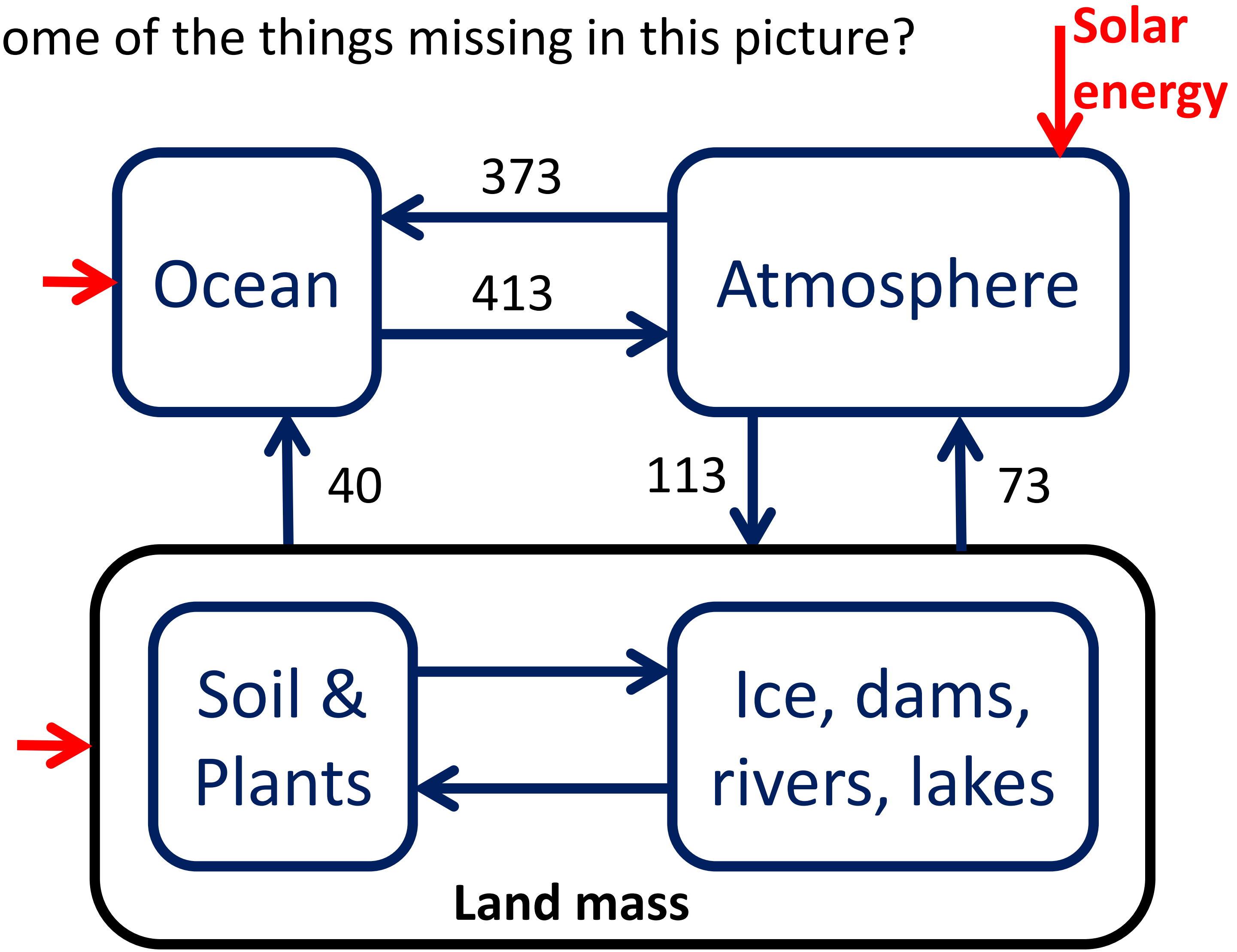
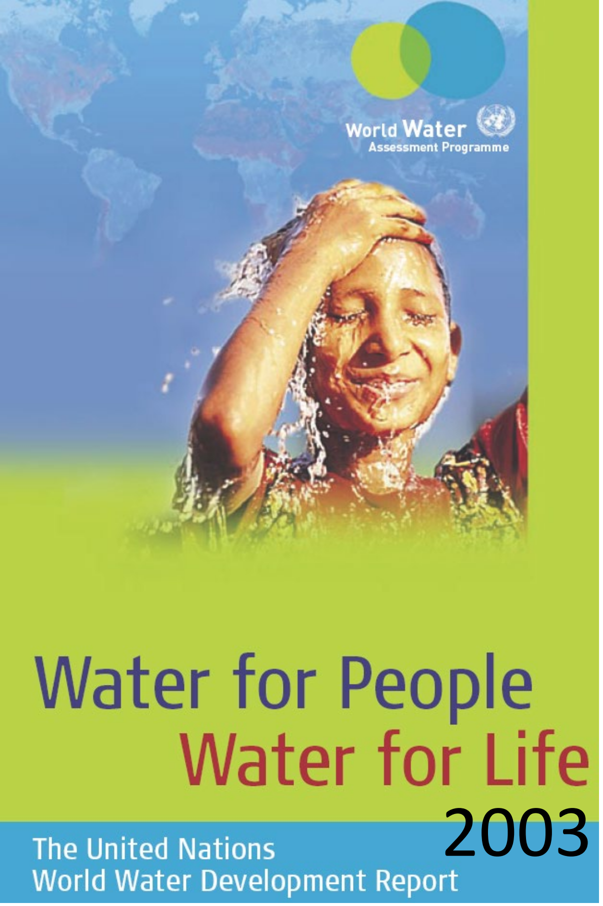
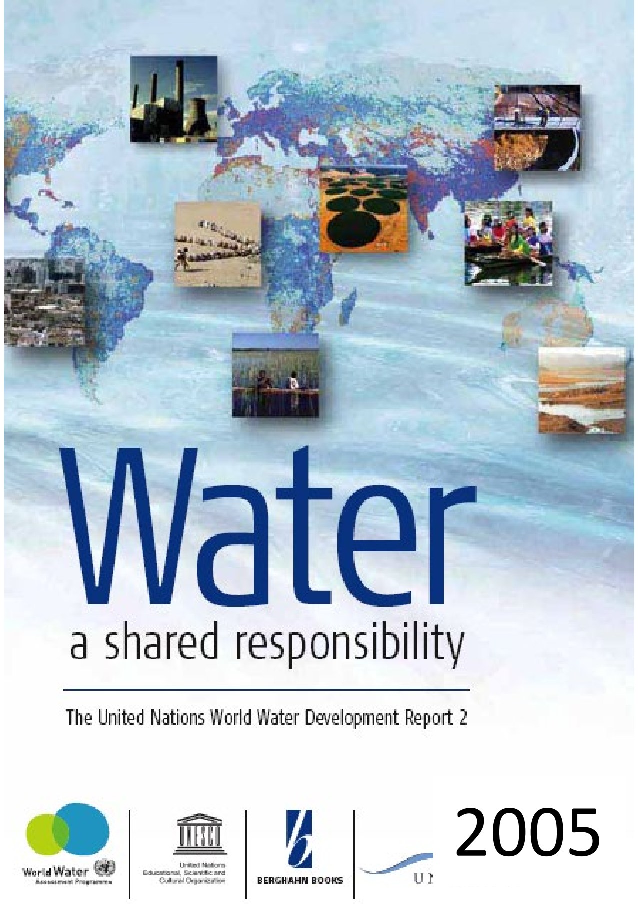


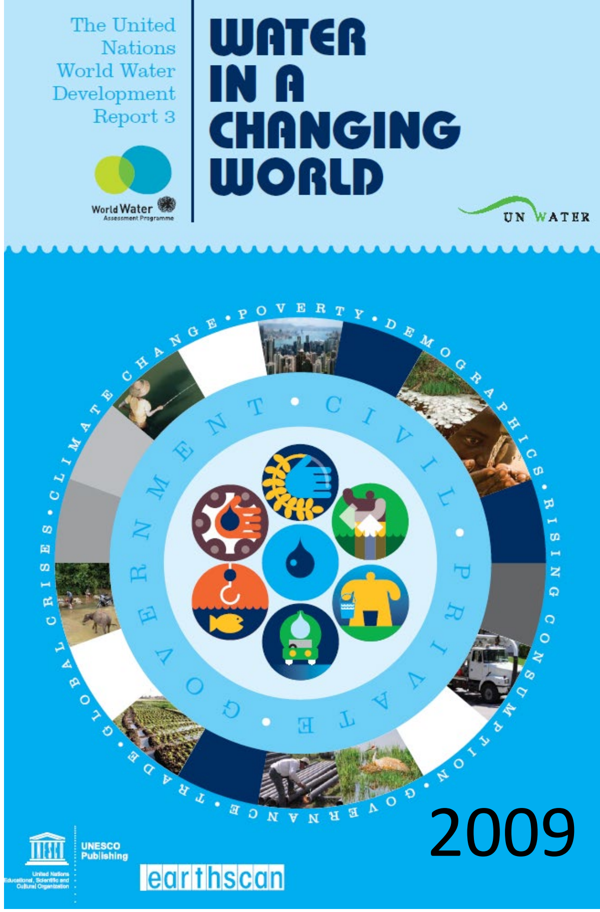
Another example: the hydrocycle

What are some of the things missing in this picture?







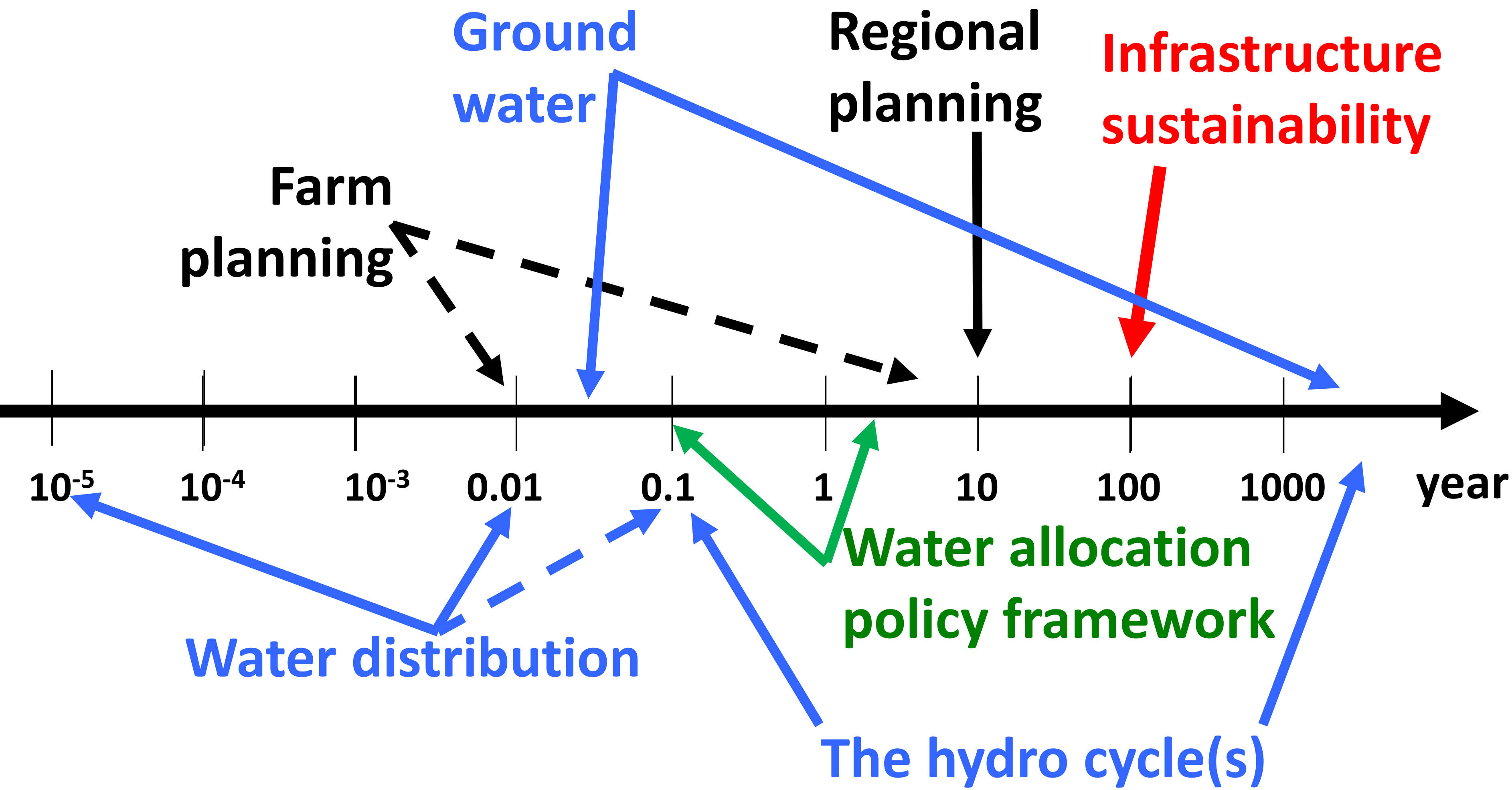


- **Crisis** "Water management crisis", "Water efficiency < 50%", "Paucity of data", "Poor quality data - everywhere"
- **Getting worse**: equity, industrialisation, food & irrigation (70% of all water), climate change, *population growth*, environmental needs
- 60% of "easy" (run-off) water is in use
- 95% of all river basins are severely over-exploited

Water Time Scale Complexity: 12 orders of magnitude

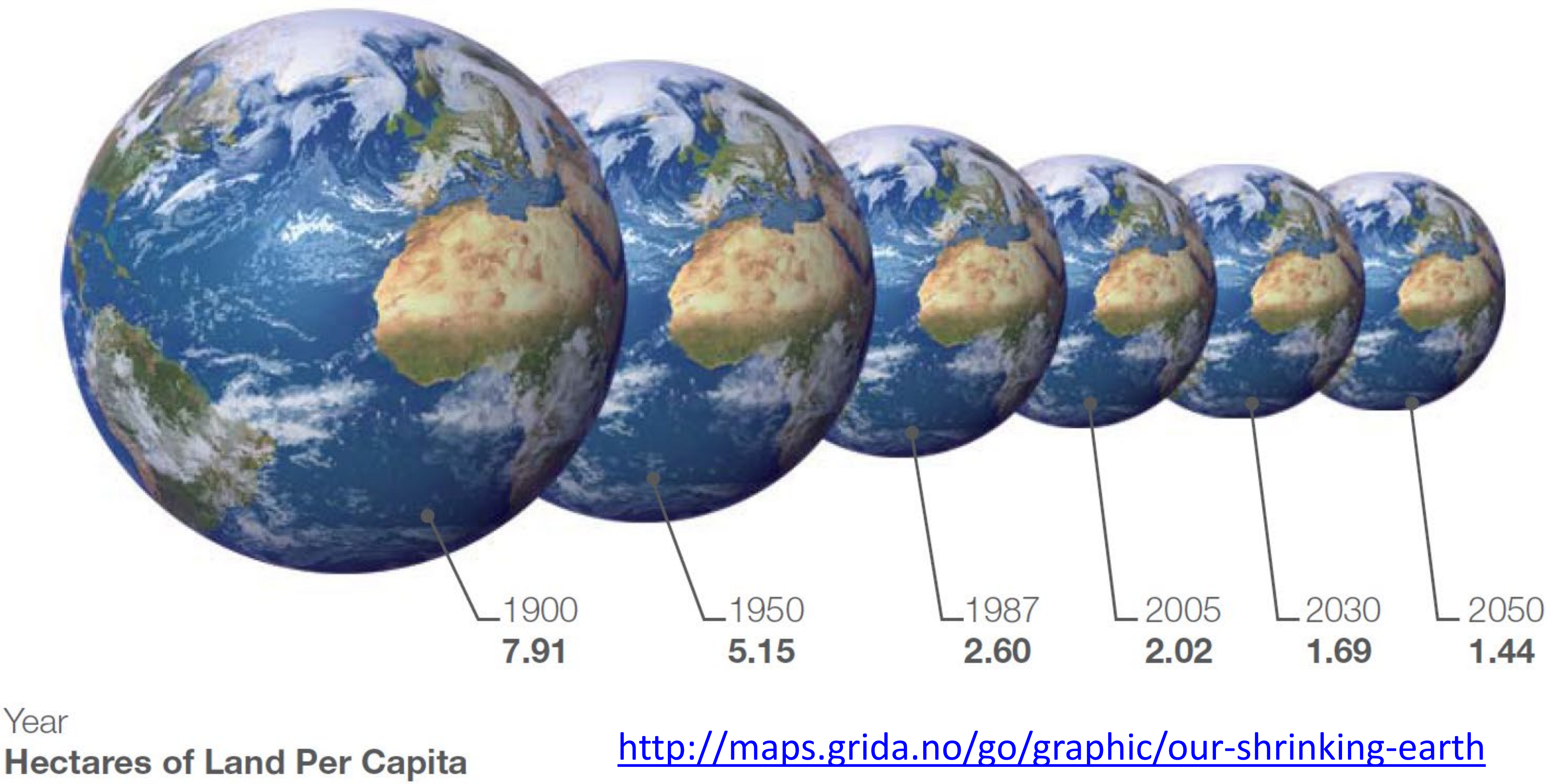
From seconds to millennia

but we do not know much about it!



Human activities are "earth-sized" processes
We should manage on this scale

Water Spatial scales from the molecular to the planetary
= 16 orders of magnitude



http://maps.grida.no/go/graphic/our-shrinking-earth