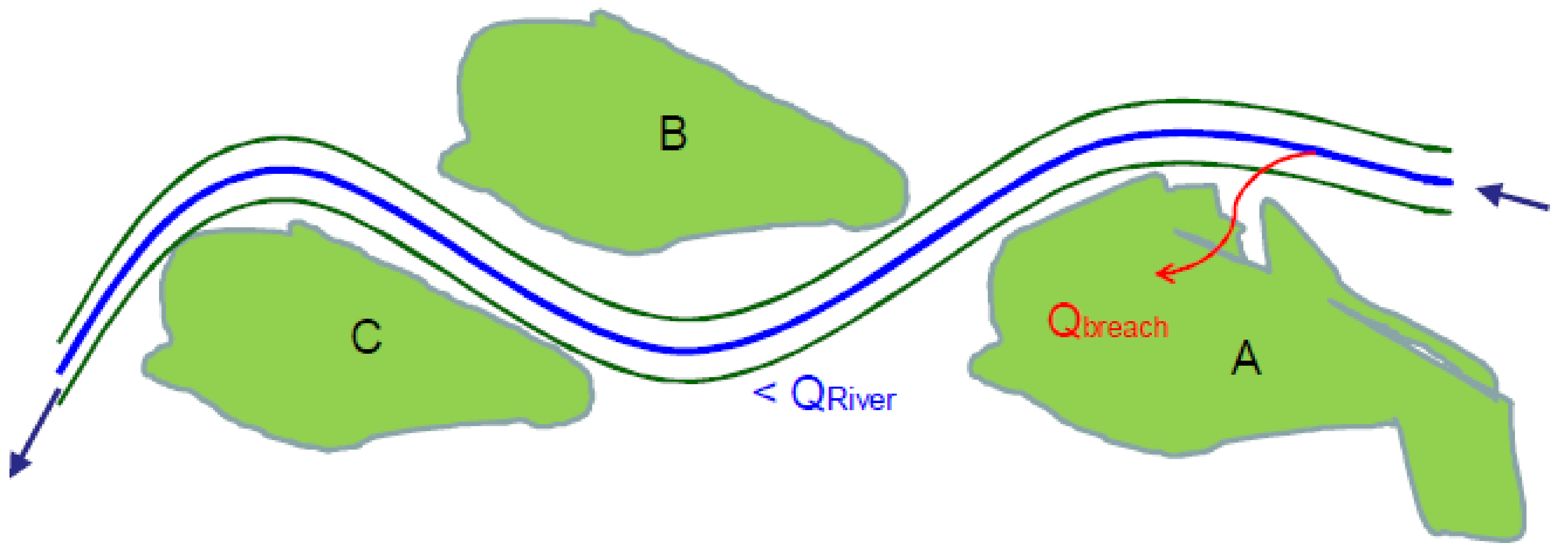
Developing flood risk management plans accounting for hydraulic system behavior

Alessio Ciullo, Karin de Bruijn, Jan Kwakkel, Frans Klijn

1. FRAMING THE RESEARCH PROBLEM

A system approach to flood risk management:



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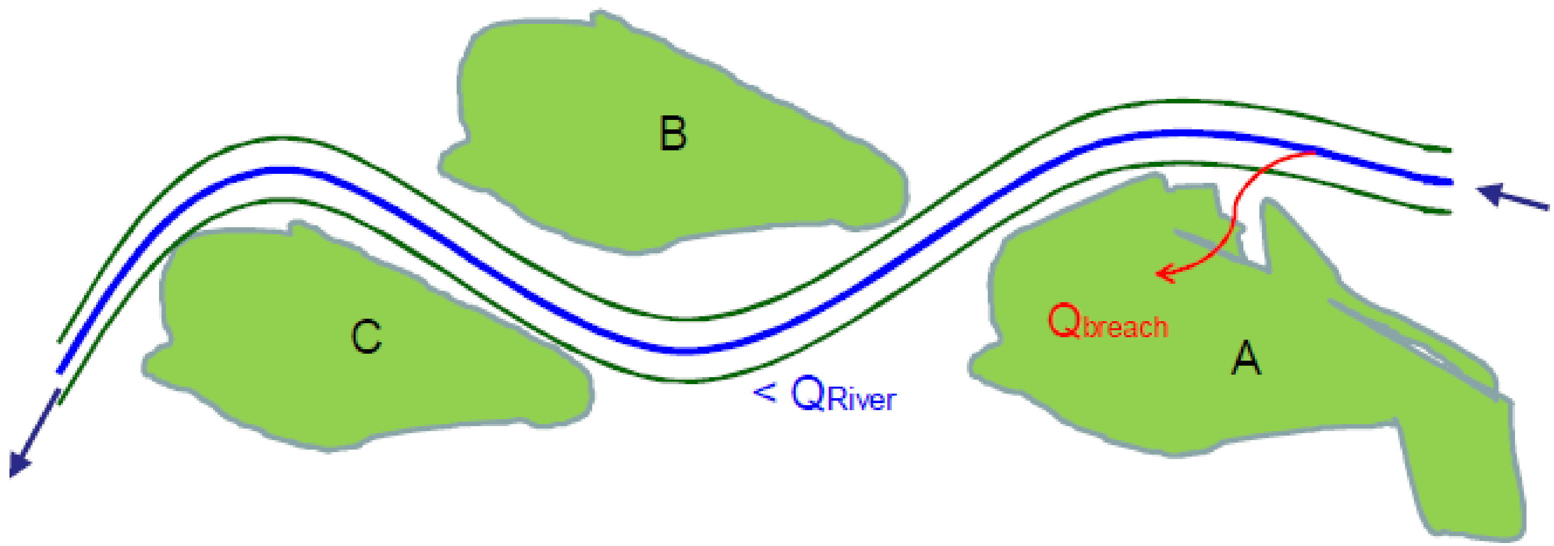

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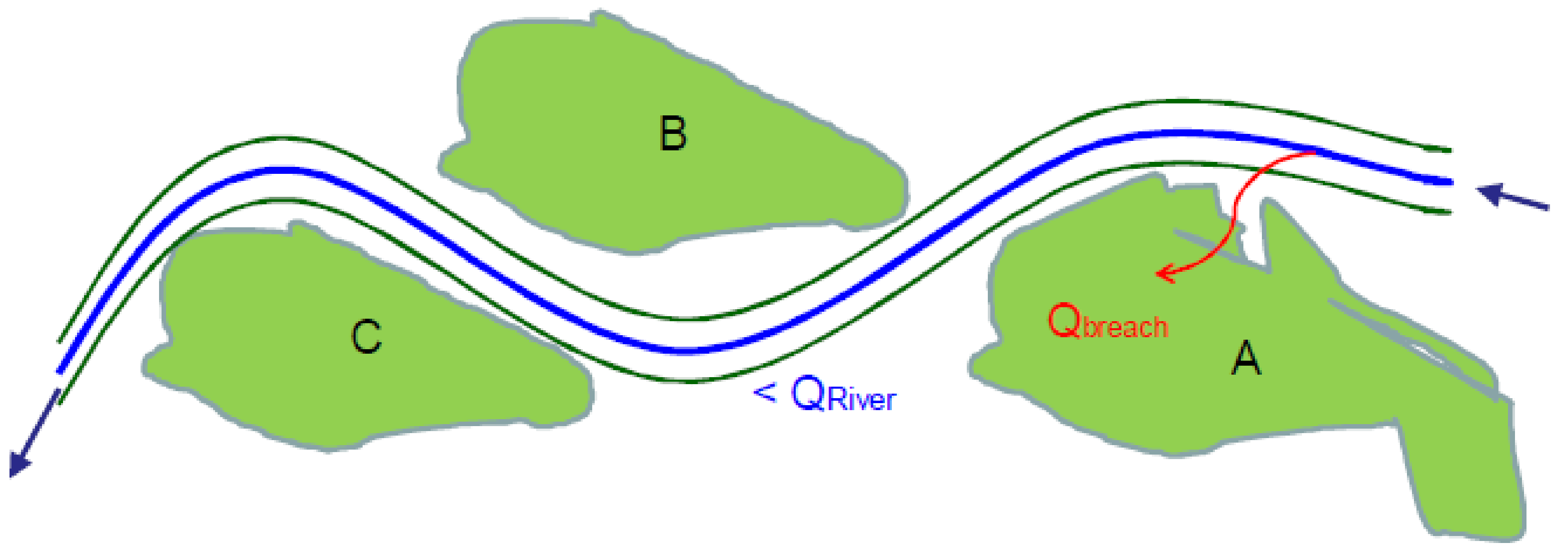

- Flood risk of the whole system ≠ sum of the single estimated risks
- Need to account for risk-transfers between locations

→ solidarity principle (EU Directive): plans '*shall not include measures which, by their extent and impact, significantly increase flood risks upstream or downstream*'

1. FRAMING THE RESEARCH PROBLEM

The challenges of a system approach to flood risk management:

1. Decisions regarding e.g. location A requires considering the effects on locations B and C
   - Complicates decision making
     - do we need new decision criteria?

2. Adds uncertain factors
   - breach locations
   - moment of breach
   - final breach width

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- Maximax
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- Regret-based
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Assess policy robustness in performing satisfactorily under uncertainty

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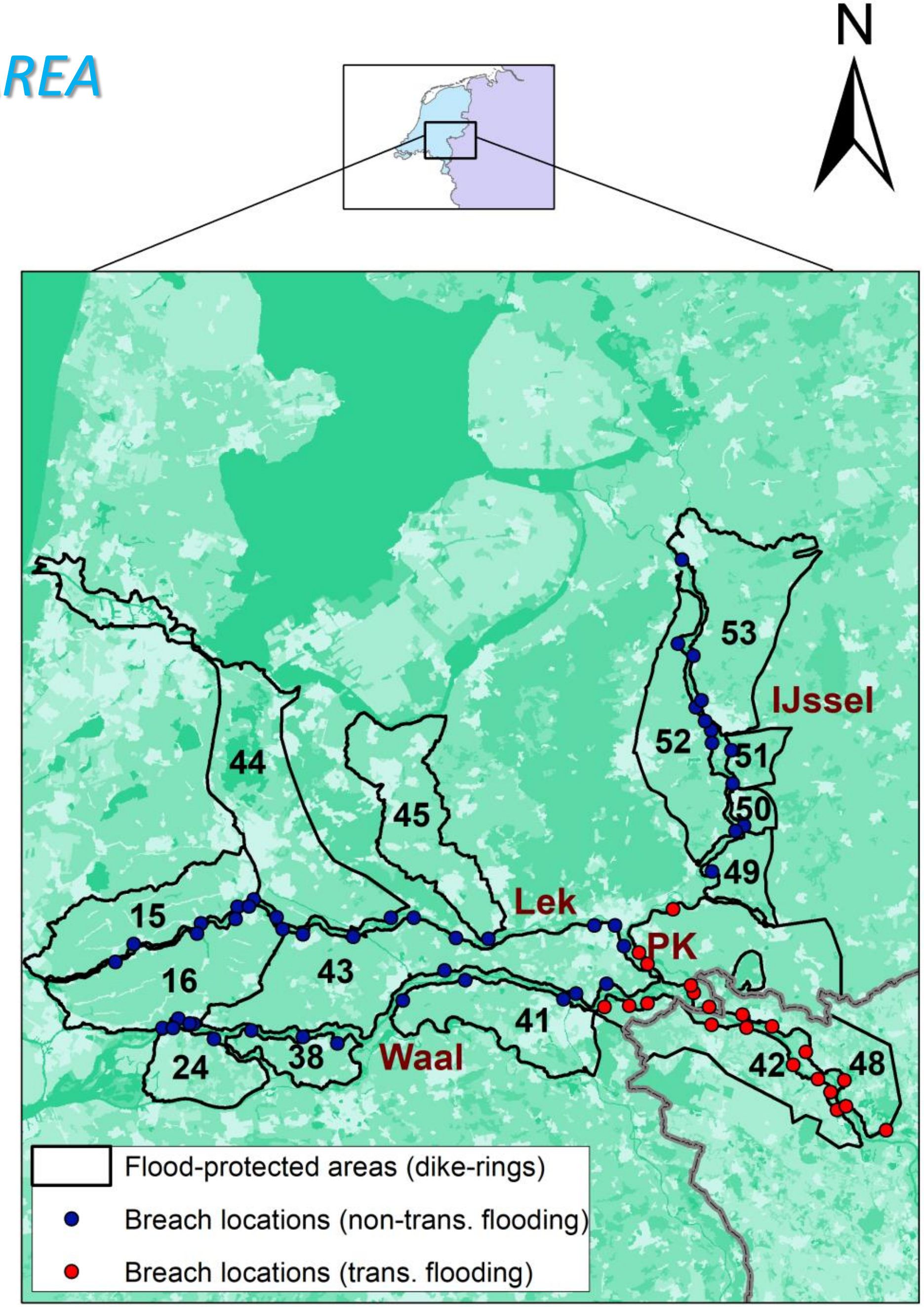
AIM:
Identify how alternative formulations of the policy problem influence the final set of optimal solutions

3. CASE STUDY AREA



4. THE SIMULATION MODEL

INPUT:

Flood risk reduction measures:

- Dike heightening
- Making room for the river
- Flow diversion at bifurcation points

↓

MODEL:

Flood risk system model

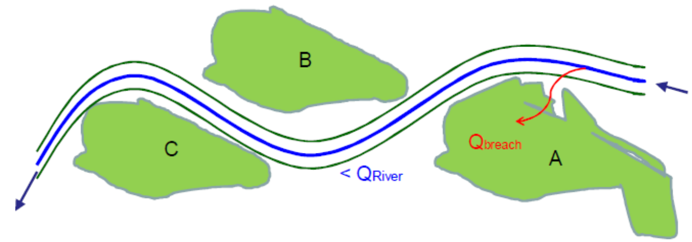
→

OUTPUT:

Investment Costs

Expected Annual Damage

5. THE POLICY OBJECTIVES



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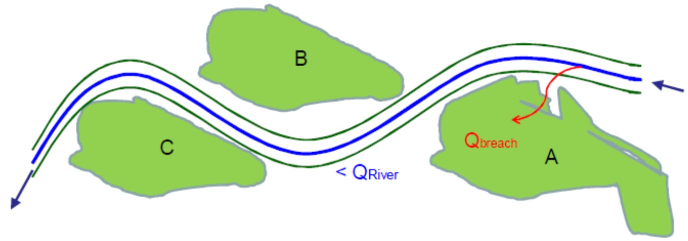
Optimize total costs



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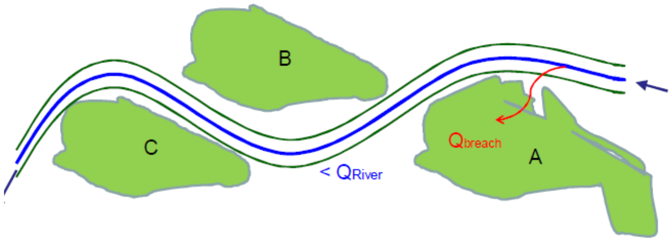

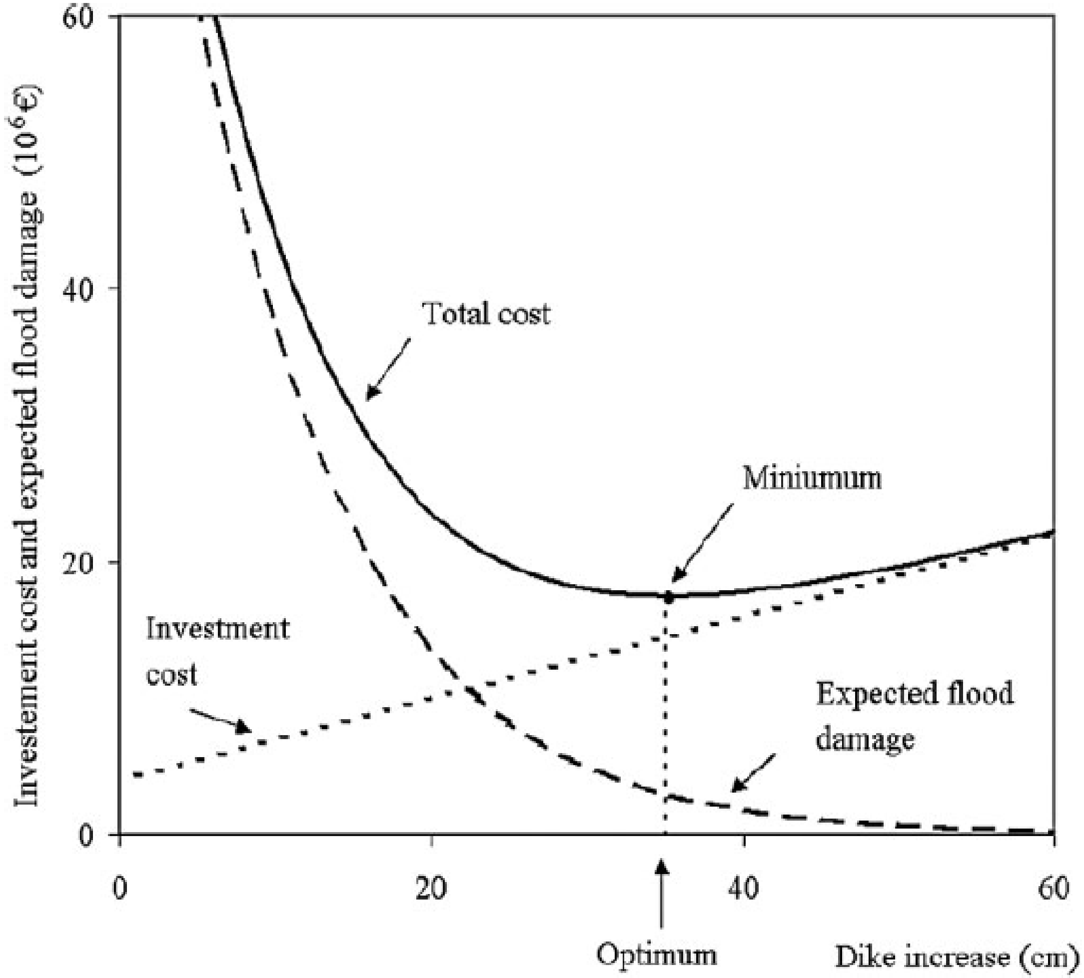

from Kind, 2010

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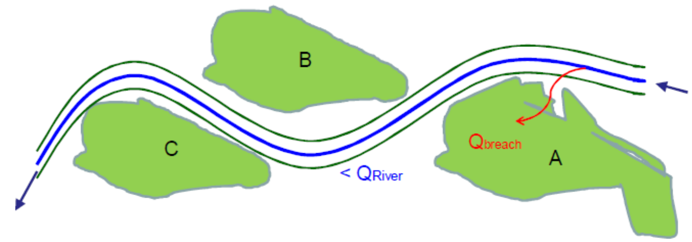
Optimize total costs…and equity



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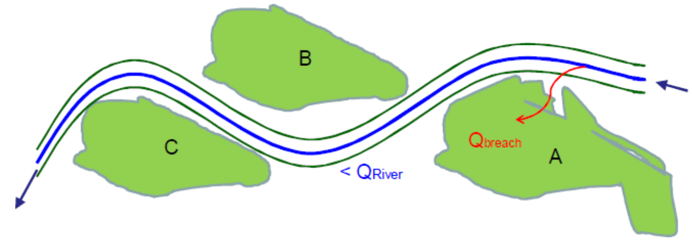

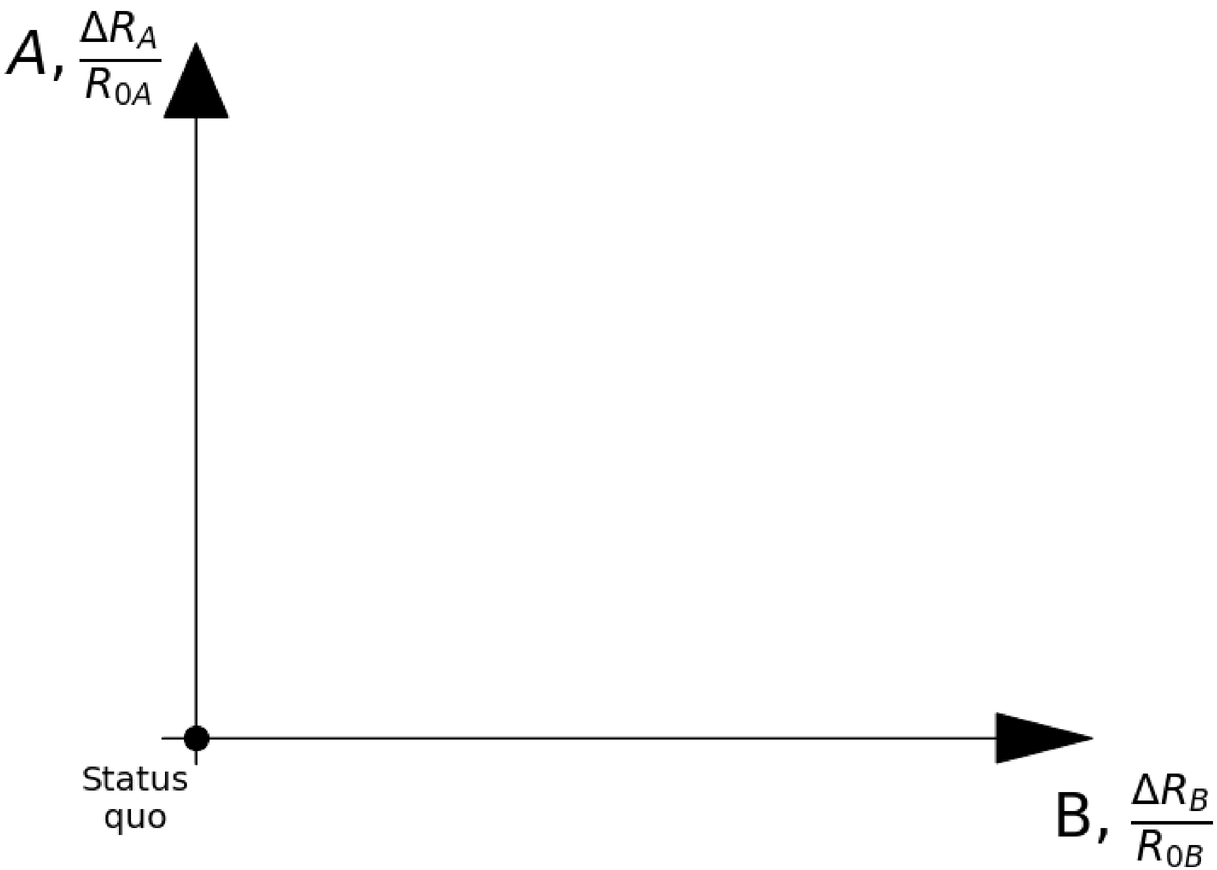

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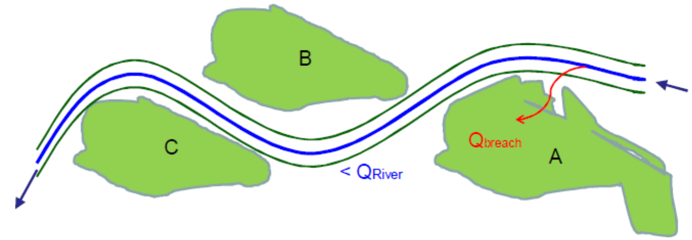

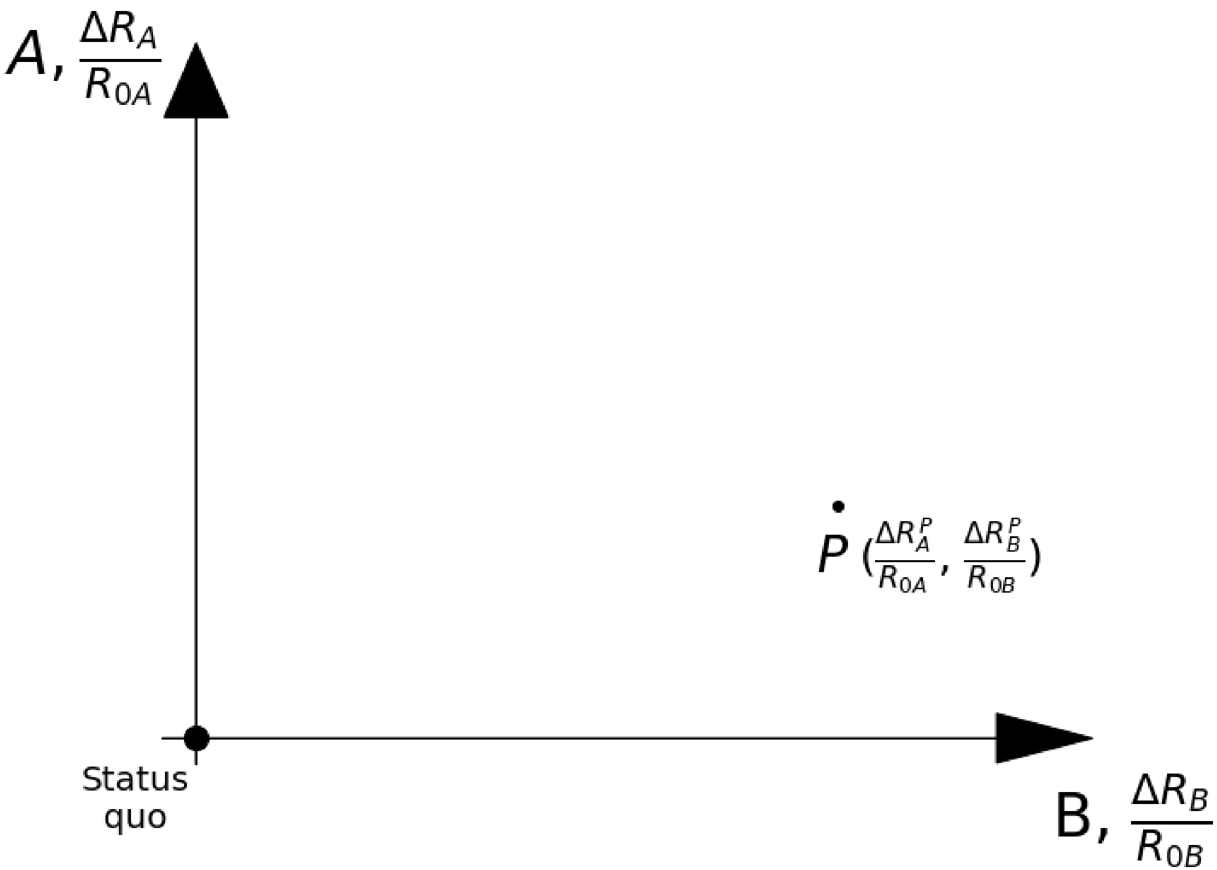

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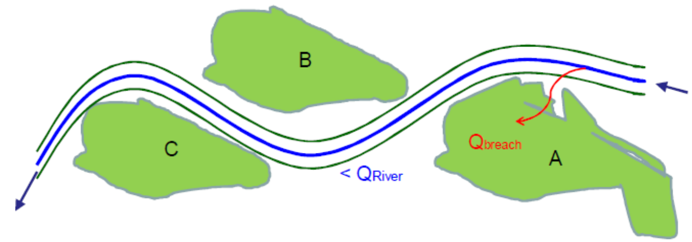

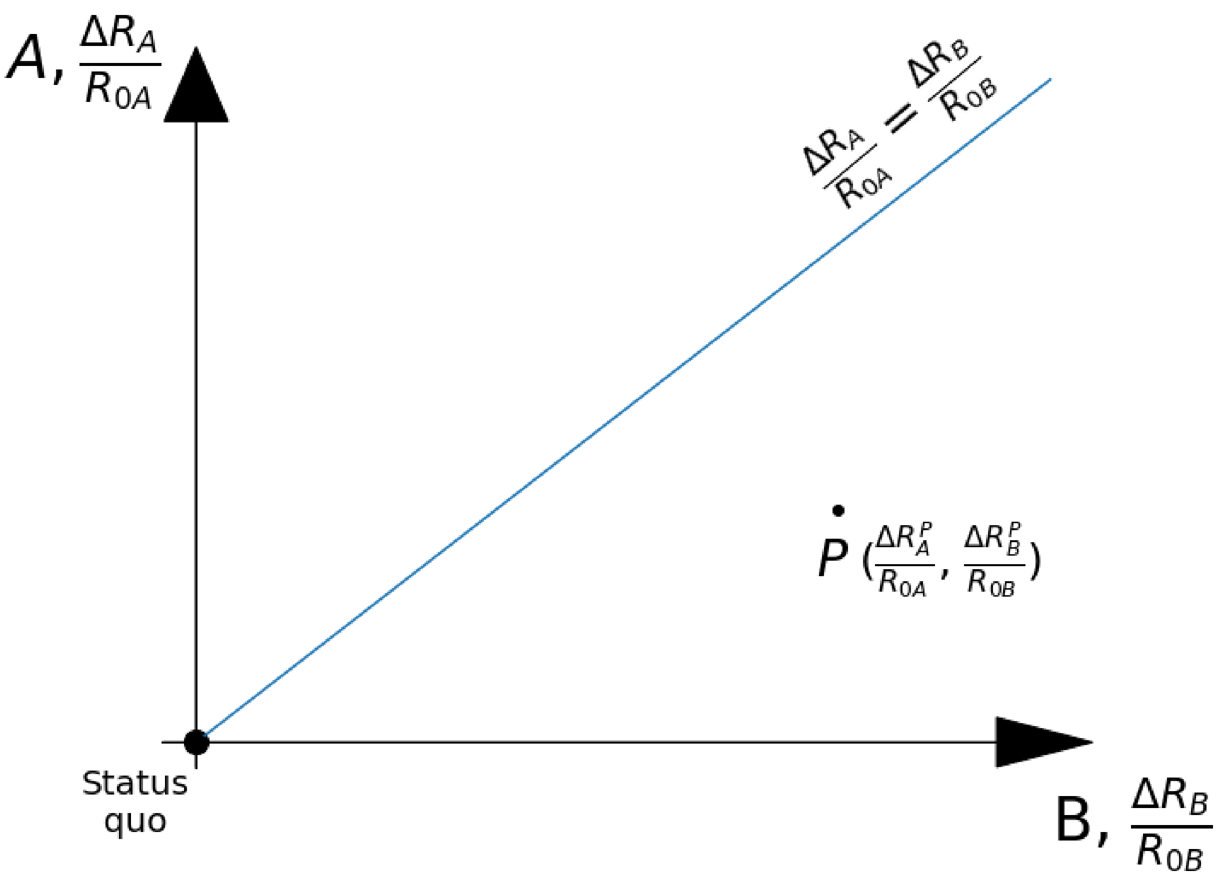

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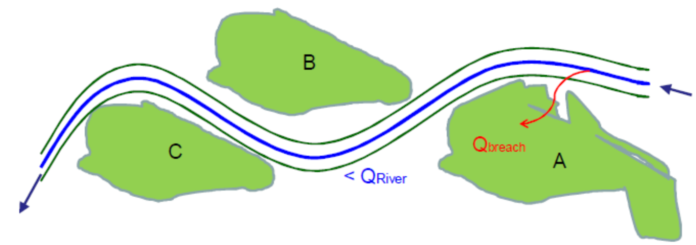

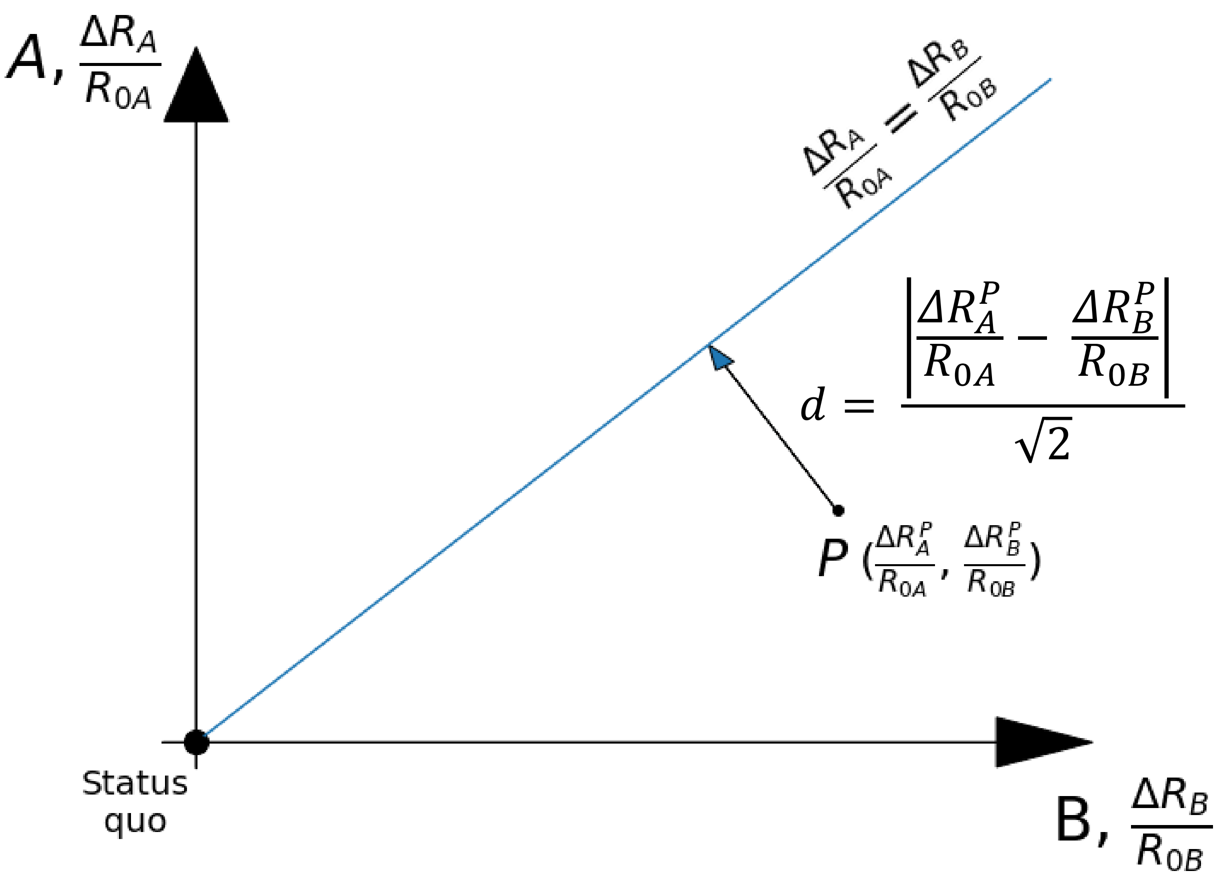

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First – current approach:

Optimize ***total costs*** *and* ***neglect*** *hydraulic system behavior*

minimize $\sum_i (I_i + EAD_i)$ $\forall\ i \in I$

$\sum_j (I_j + EAD_j)$ $\forall\ j \in J$

I and *J* are set of dike rings in the Dutch and German area respectively.

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minimize	$\sum_i (I_i + EAD_i)$	*∀ i ∊ I*
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Second:

*Optimize **total costs** and **consider** hydraulic system behavior*

Third:

*Optimize **total costs** and **equity** and **consider** hydraulic system behavior*

minimize	$\sum_i (I_i + EAD_i)$	*∀ i ∊ I*
	$\sum_j (I_j + EAD_j)$	*∀ j ∊ J*
	$\max_{x,y} \frac{\left\lvert \frac{\Delta R_x}{R_{x0}} - \frac{\Delta R_y}{R_{y0}} \right\rvert}{\sqrt{2}}$	*∀ x, y ∊ I U J, x ≠ y*
with	$EAD_{0,x} \geq EAD_x$	*∀ x ∊ I U J*

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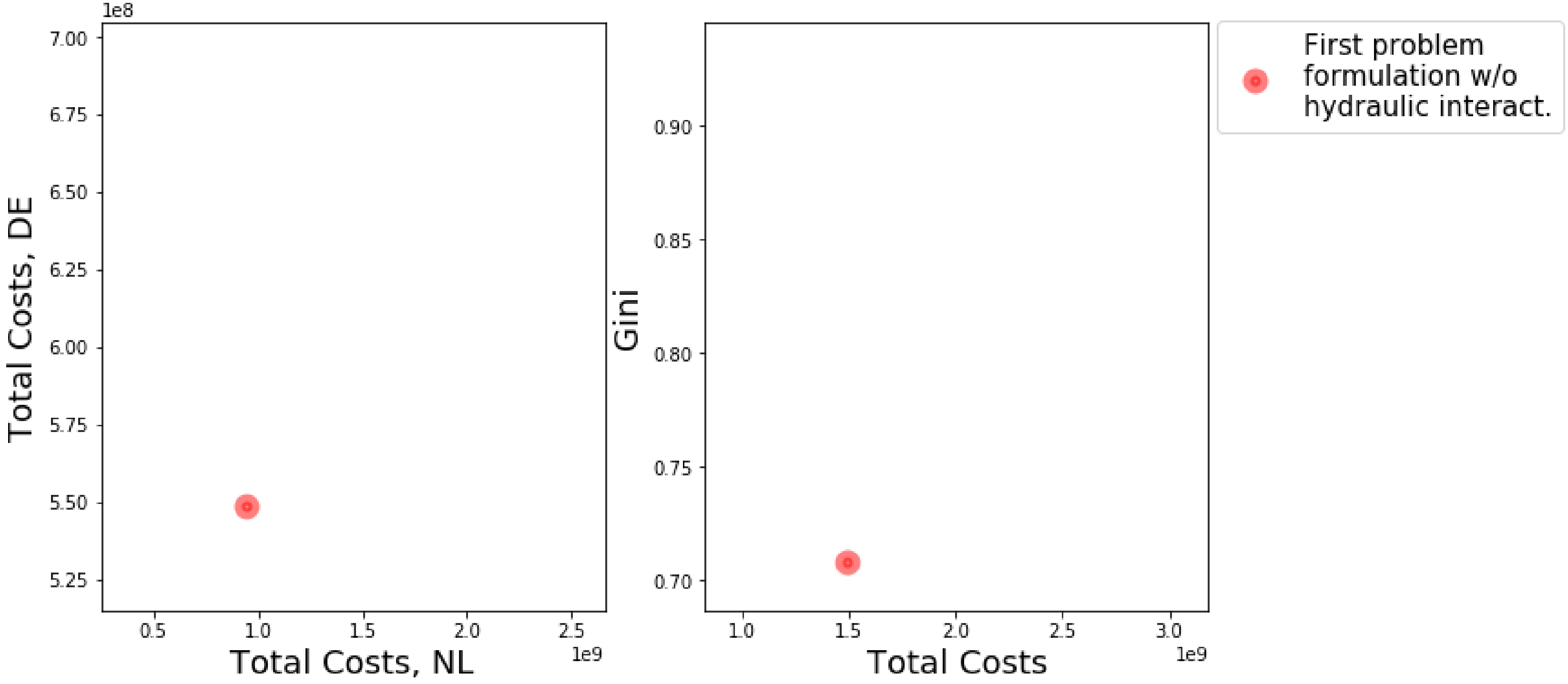
7. RESULTS



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Total Costs, DE
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2.5
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Total Costs, NL
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First problem formulation w/o hydraulic interact.

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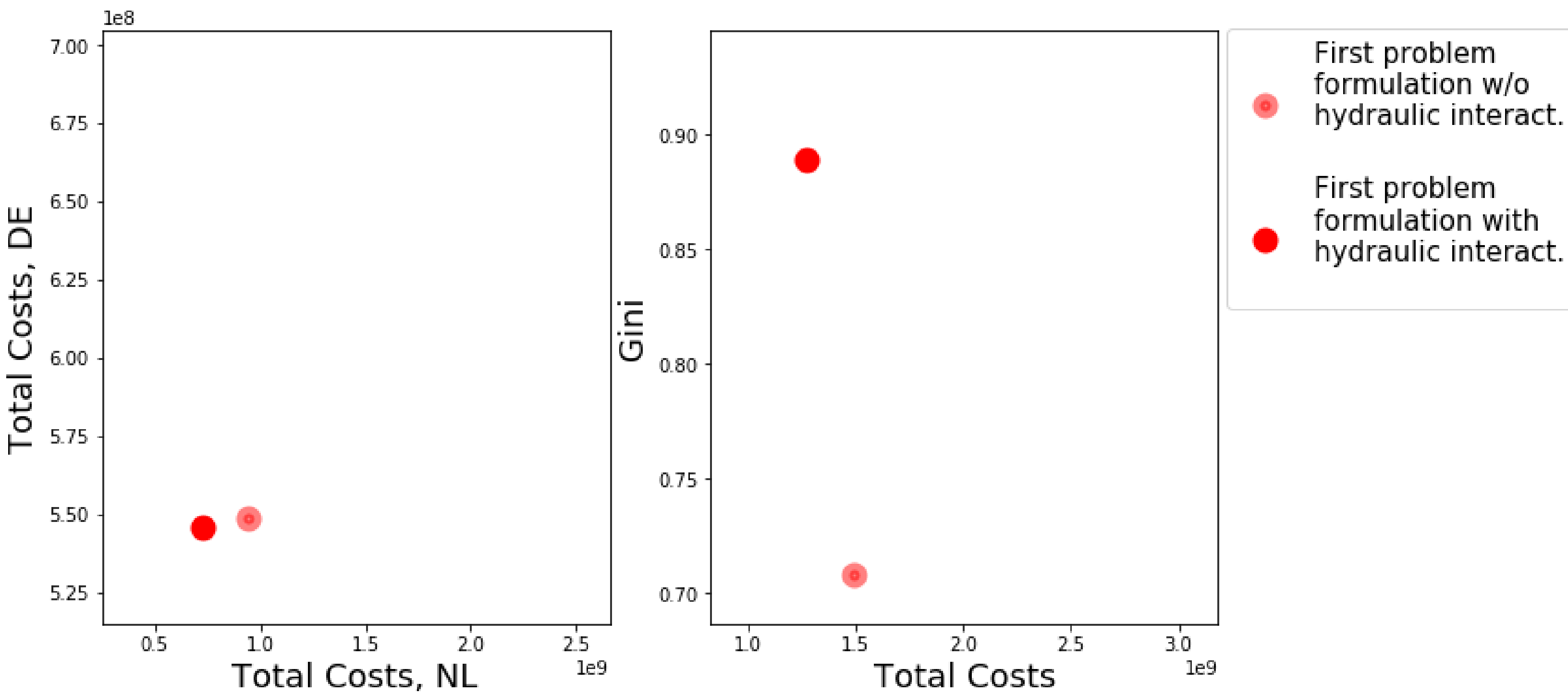
- Total costs overestimation in the Netherlands (upstream – downstream interaction)
- Same but much less for Germany (left-right interaction)



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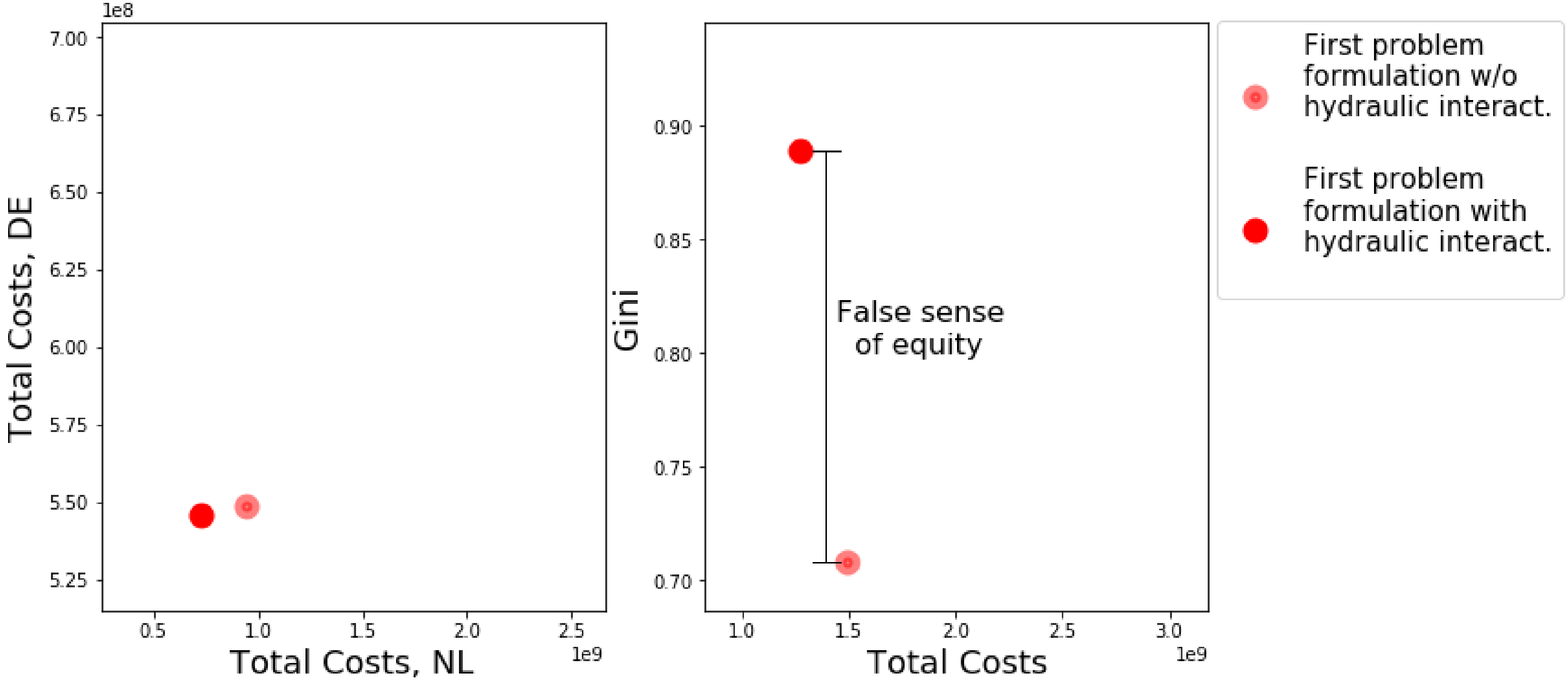
- False sense of equity (fewer damage downstream when interactions are included, thus more unequal risk distribution than expected without interactions)



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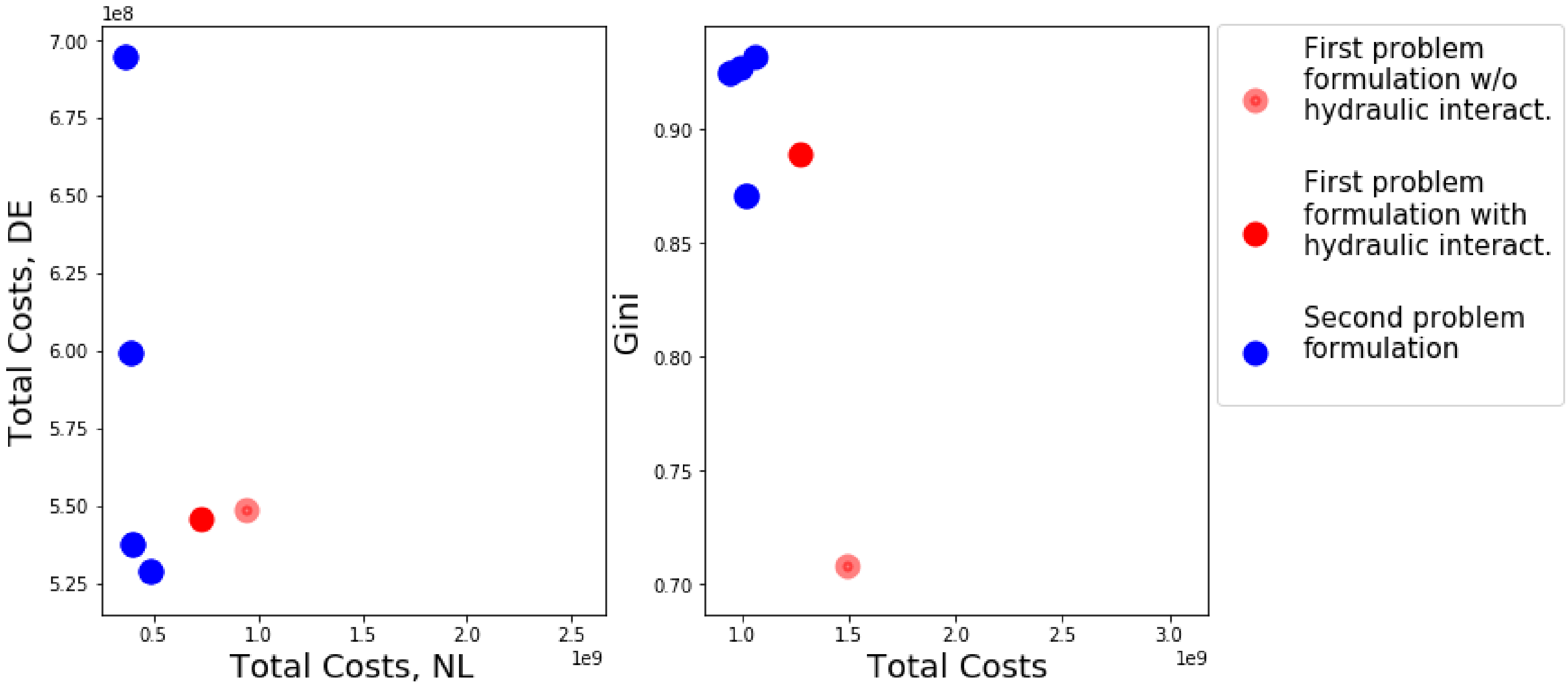

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Second problem formulation

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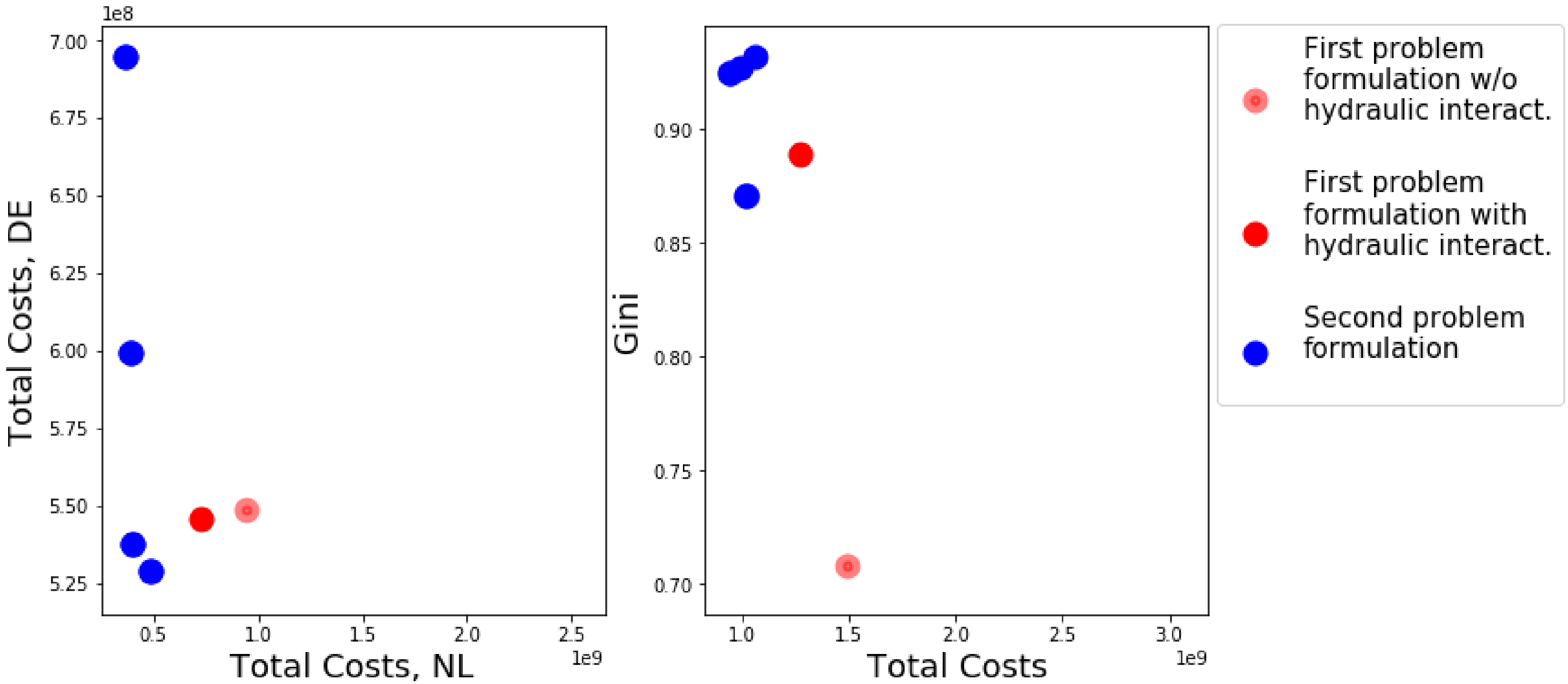
- Many more policies: Pareto set of solutions – Trade-offs are made explicit



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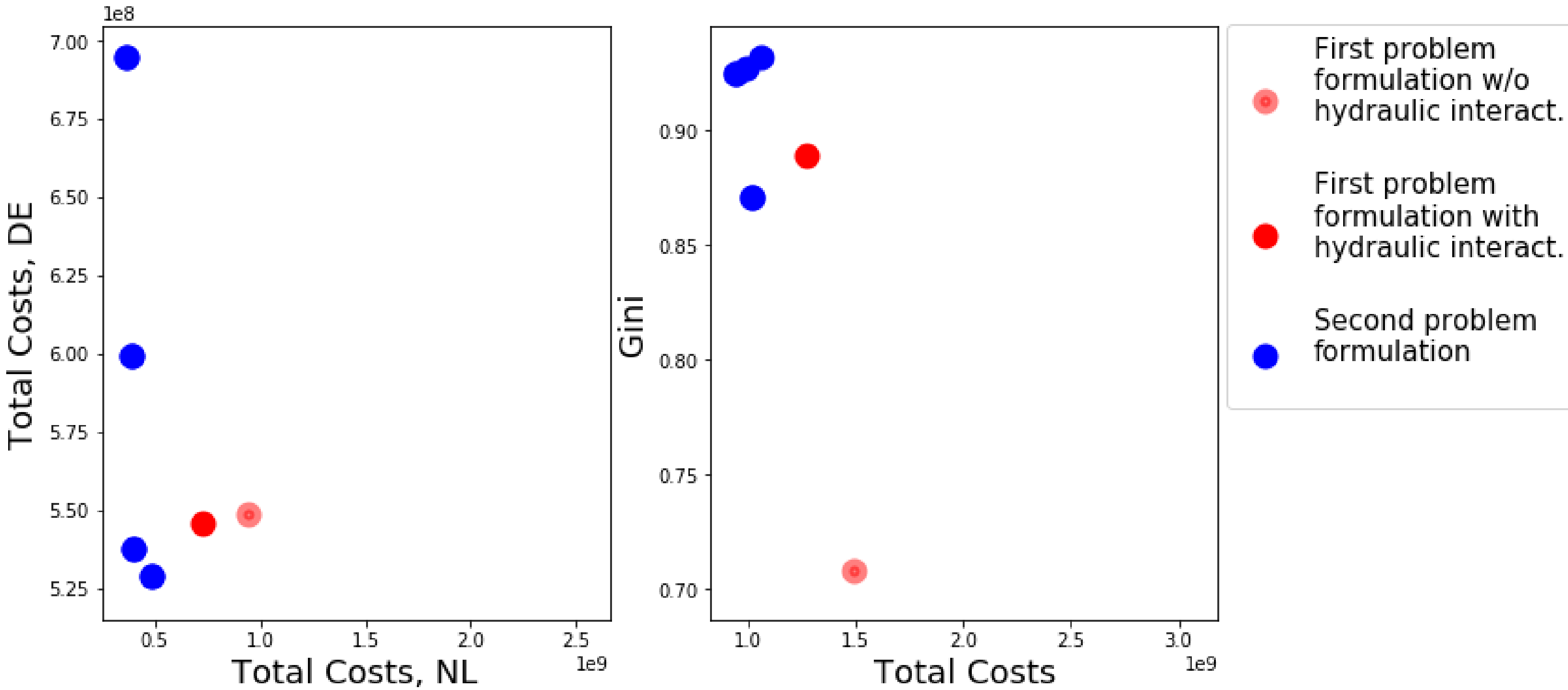

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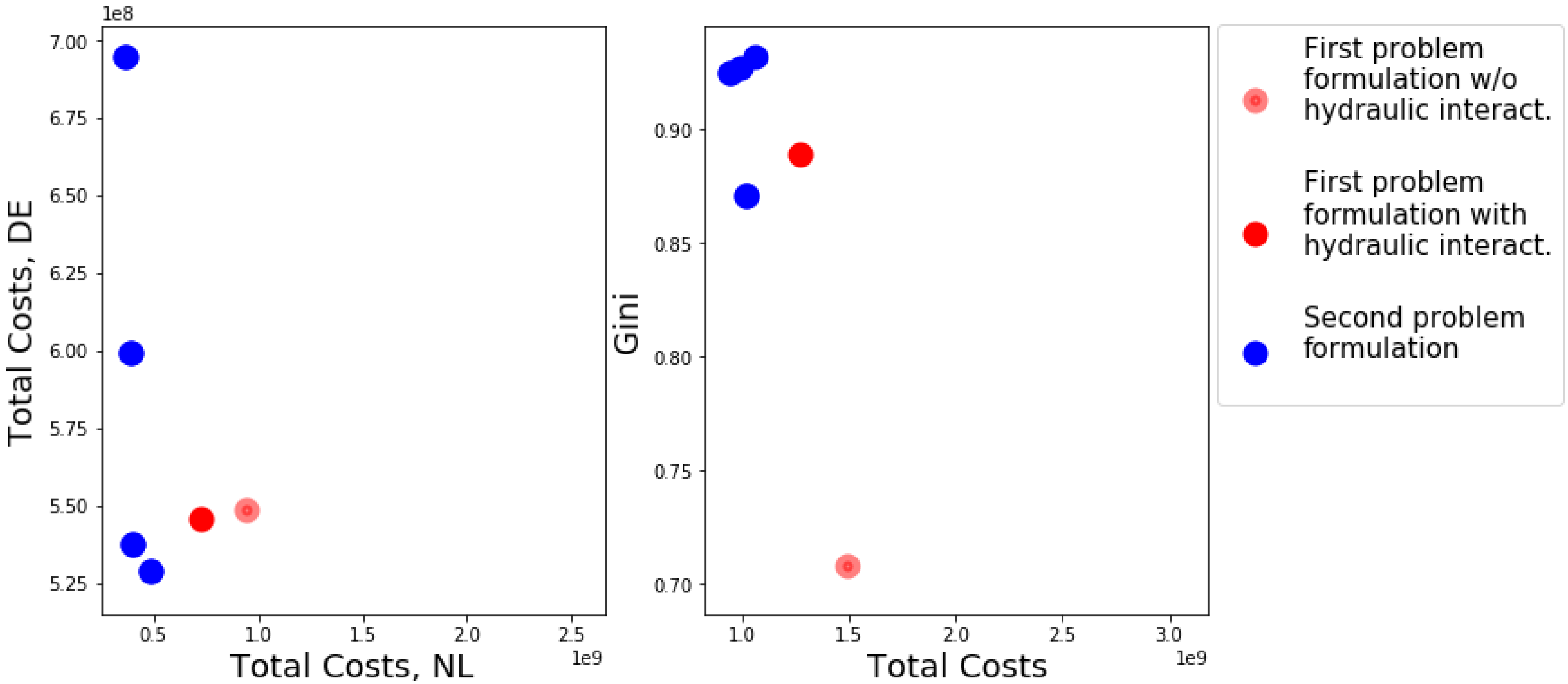

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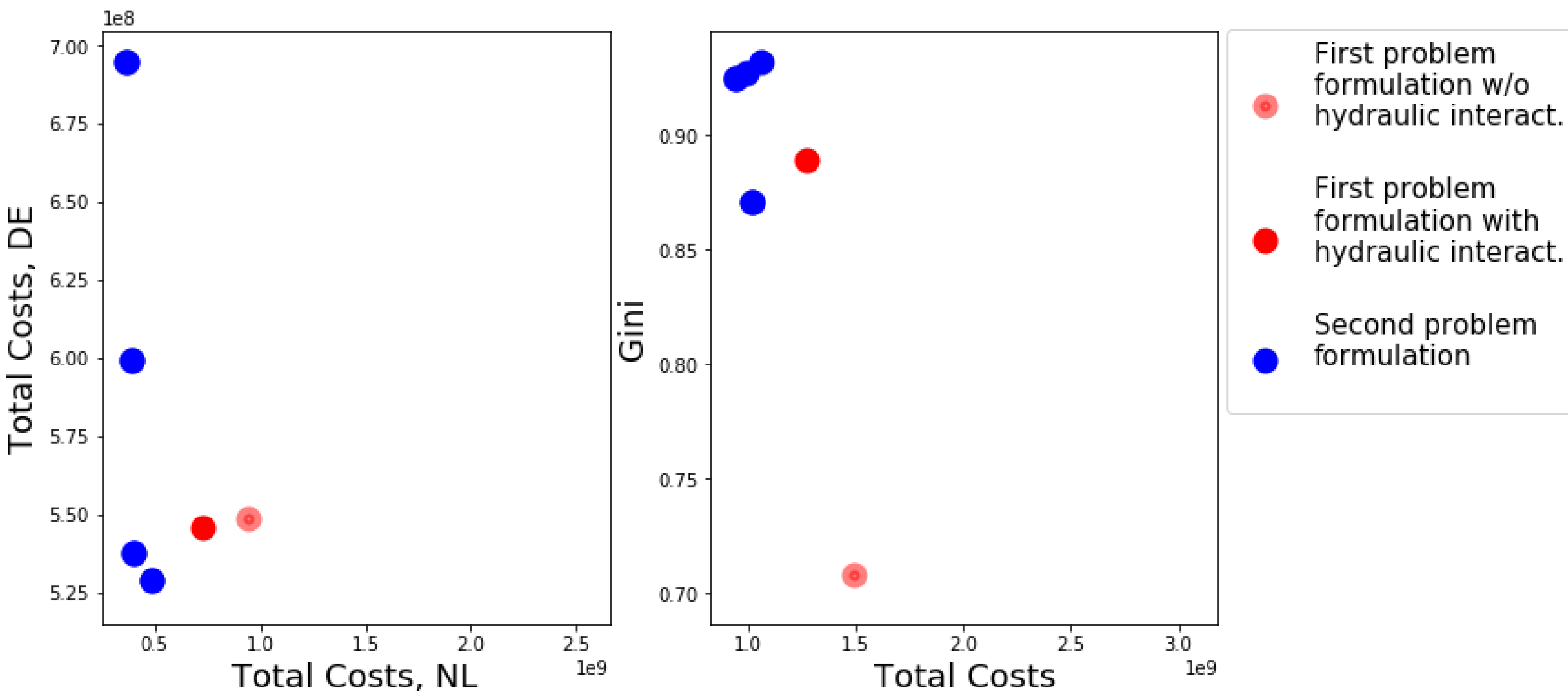
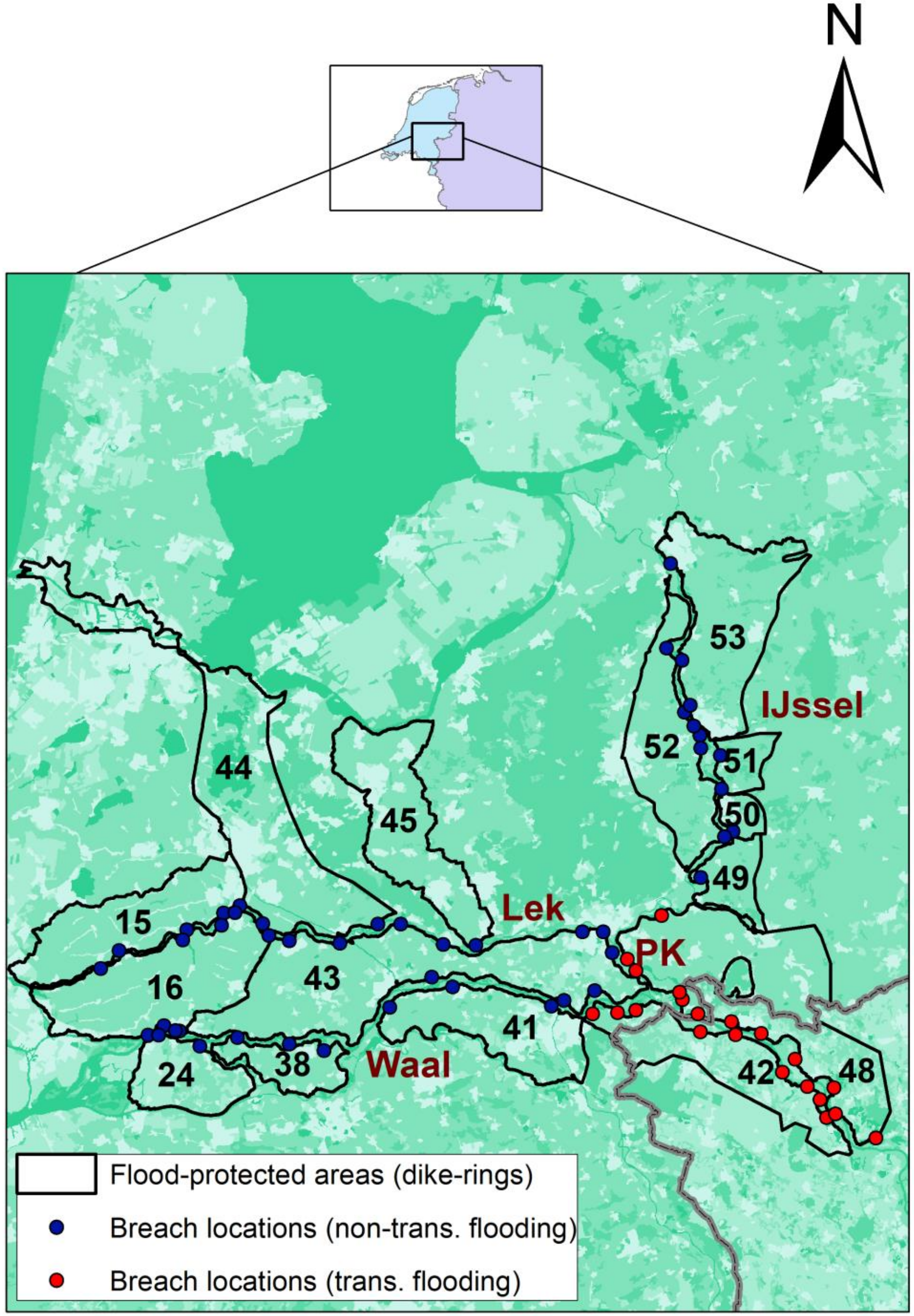
- For both approaches, the most unequal comparison in terms of relative risk reduction is between Lek areas and the Dutch part of dike ring 42

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Lek
PK
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Waal
Flood-protected areas (dike-rings)
Breach locations (non-trans. flooding)
Breach locations (trans. flooding)

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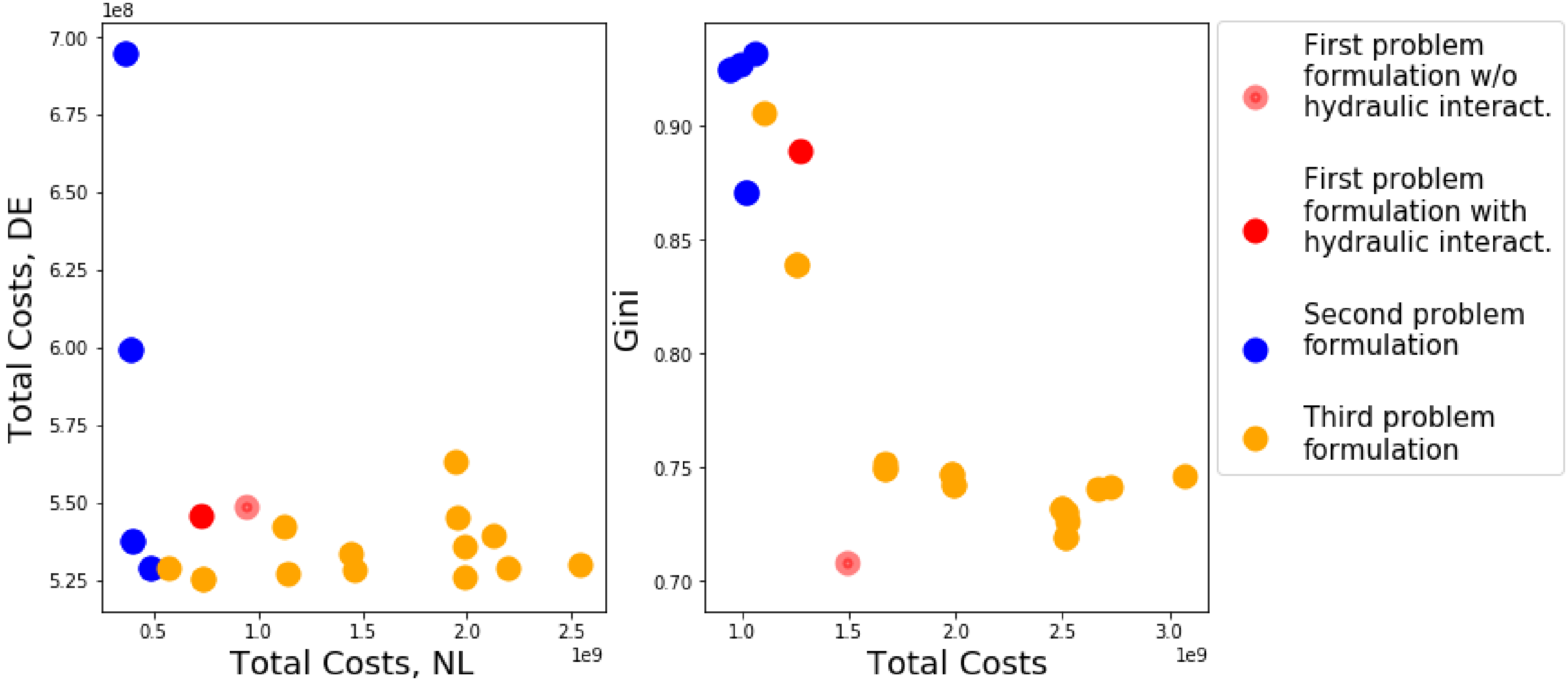

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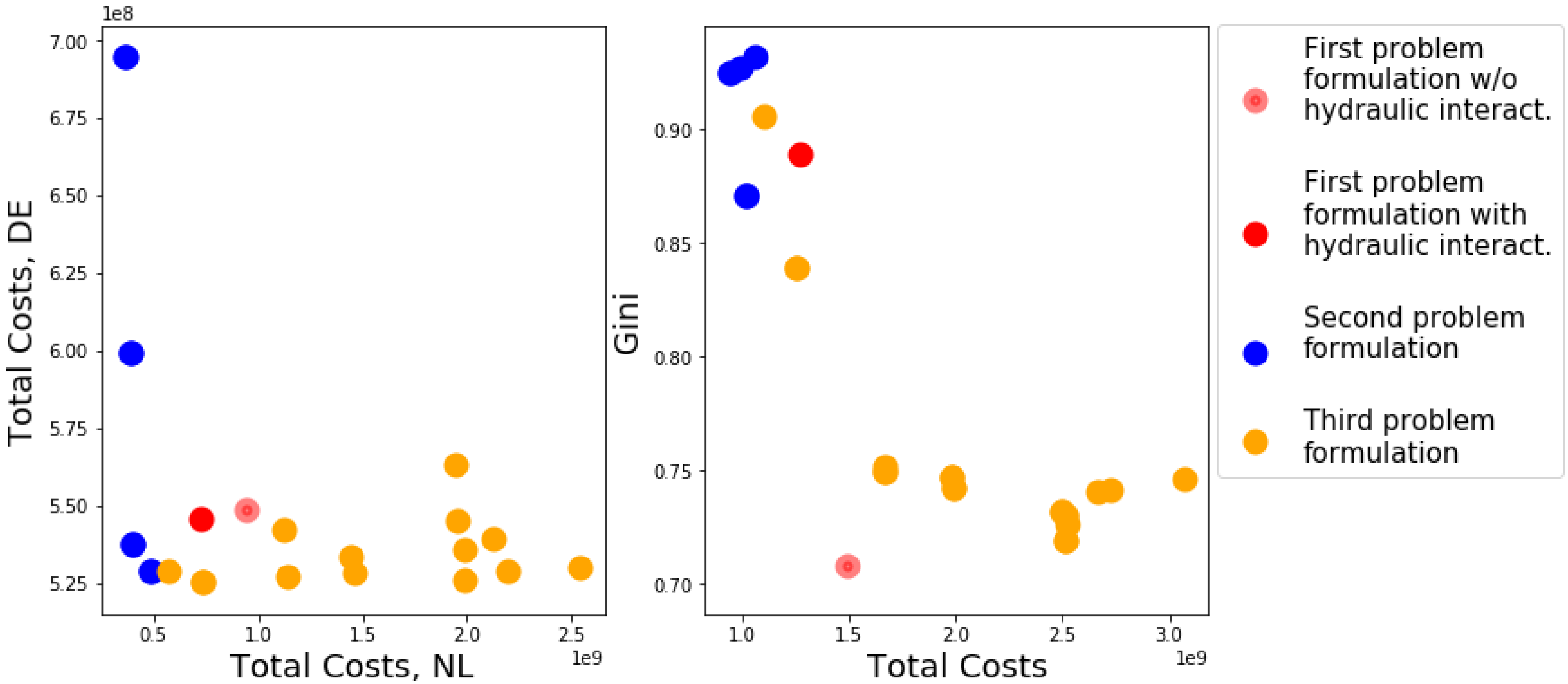
First problem formulation w/o hydraulic interact.
First problem formulation with hydraulic interact.
Second problem formulation
Third problem formulation

7. RESULTS

- Using the equity decision criterion in fact decreases the Gini Index (and it does so by acting on the two aforementioned issues)



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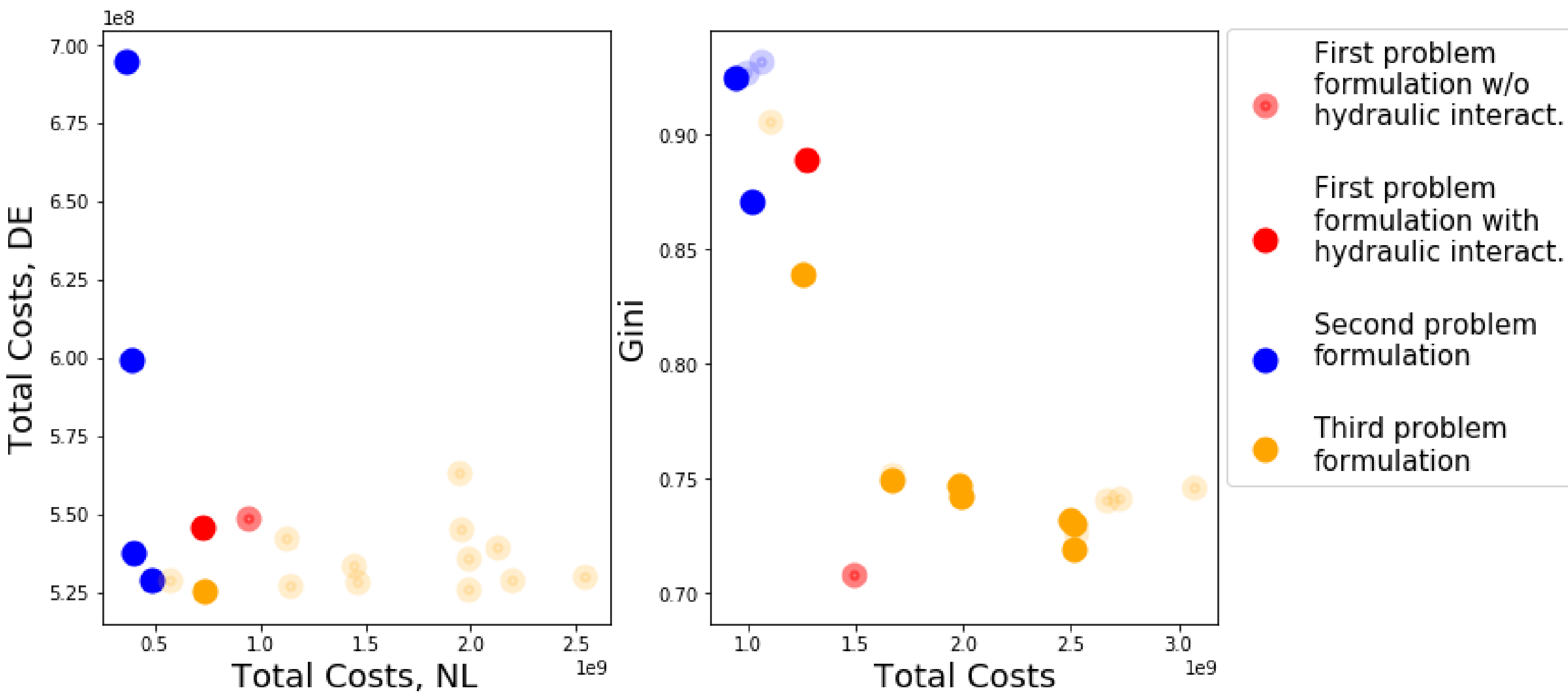
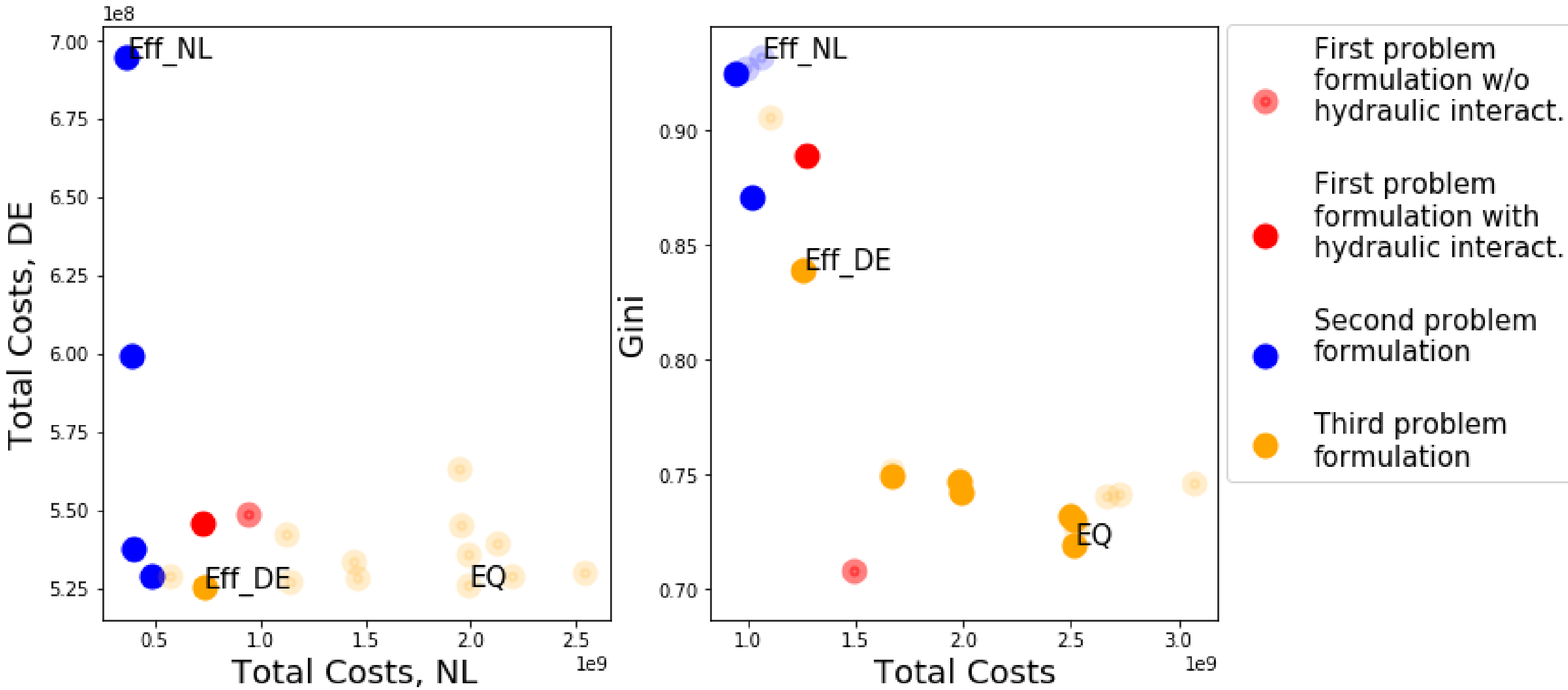
- Pareto front across formulations



7. RESULTS

- Pareto front across formulations
- Select few representative policies



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Neglects conflicts and trade-offs and it is suboptimal with respect to alternative formulations:

  - Too high investment costs downstream
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  - Leads some areas to benefit more than others (does not fix the second)

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Neglects conflicts and trade-offs and it is suboptimal with respect to alternative formulations:

- ➢ Too high investment costs downstream
- ➢ False sense of equity

- Accounting for hydraulic interactions:
  - ➢ Reduces too high downstream investment costs (fix the first problem)
  - ➢ Leads some areas to benefit more than others (does not fix the second problem)

- Adding a new decision criterion:
  - ➢ Increases equity in the system
  - ➢ ..but at higher investment costs, especially downstream

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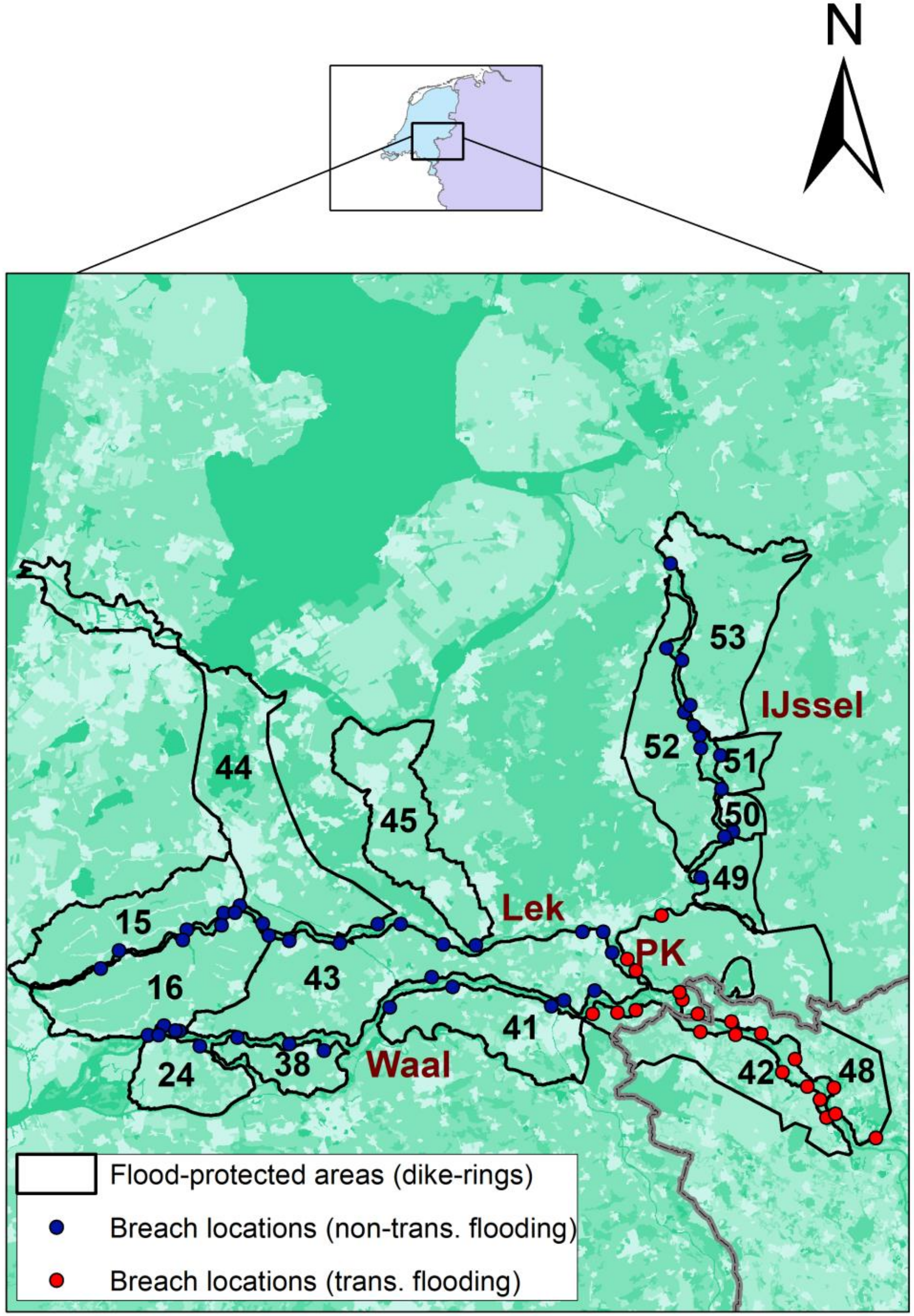
Deltares Enabling Delta Life

SYSTEM RISK ETN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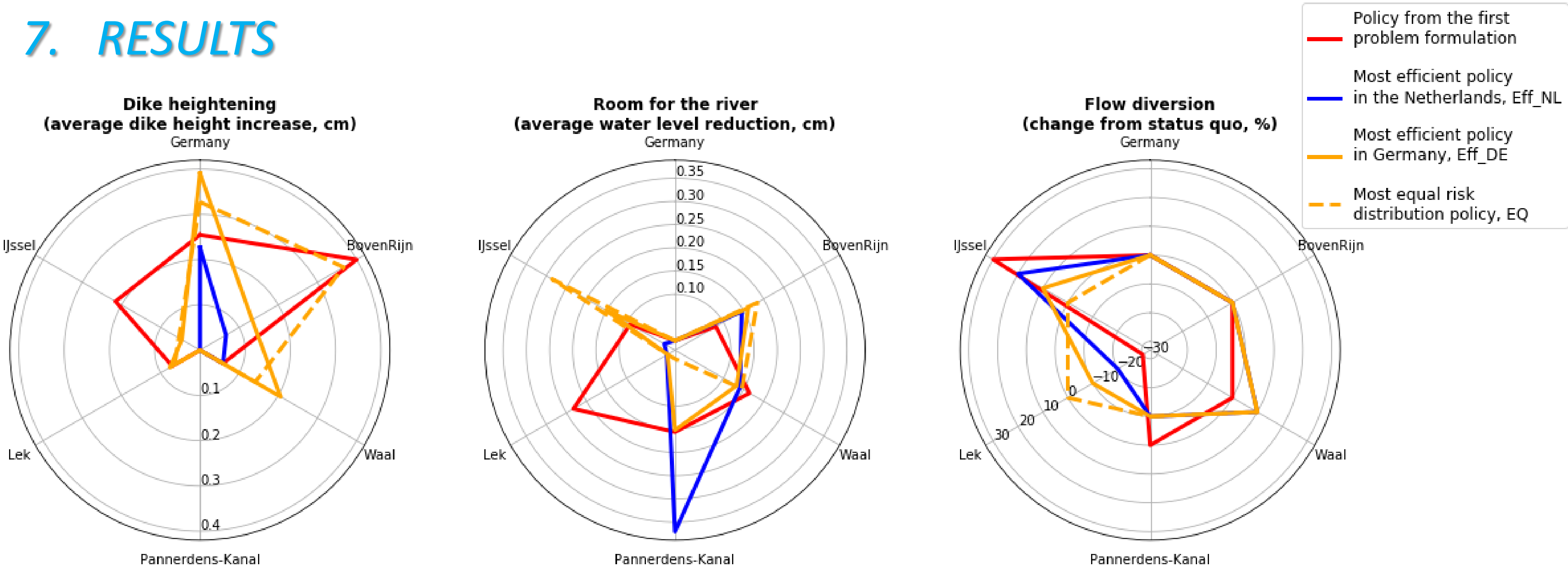
Dike heightening
(average dike height increase, cm)
Germany
BovenRijn
Waal
Pannerdens-Kanal
Lek
IJssel
0.1
0.2
0.3
0.4
Room for the river
(average water level reduction, cm)
Germany
0.35
0.30
0.25
0.20
0.15
0.10
BovenRijn
Waal
Pannerdens-Kanal
Lek
IJssel
Flow diversion
(change from status quo, %)
Germany
BovenRijn
Waal
Pannerdens-Kanal
Lek
IJssel
−30
−20
−10
0
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20
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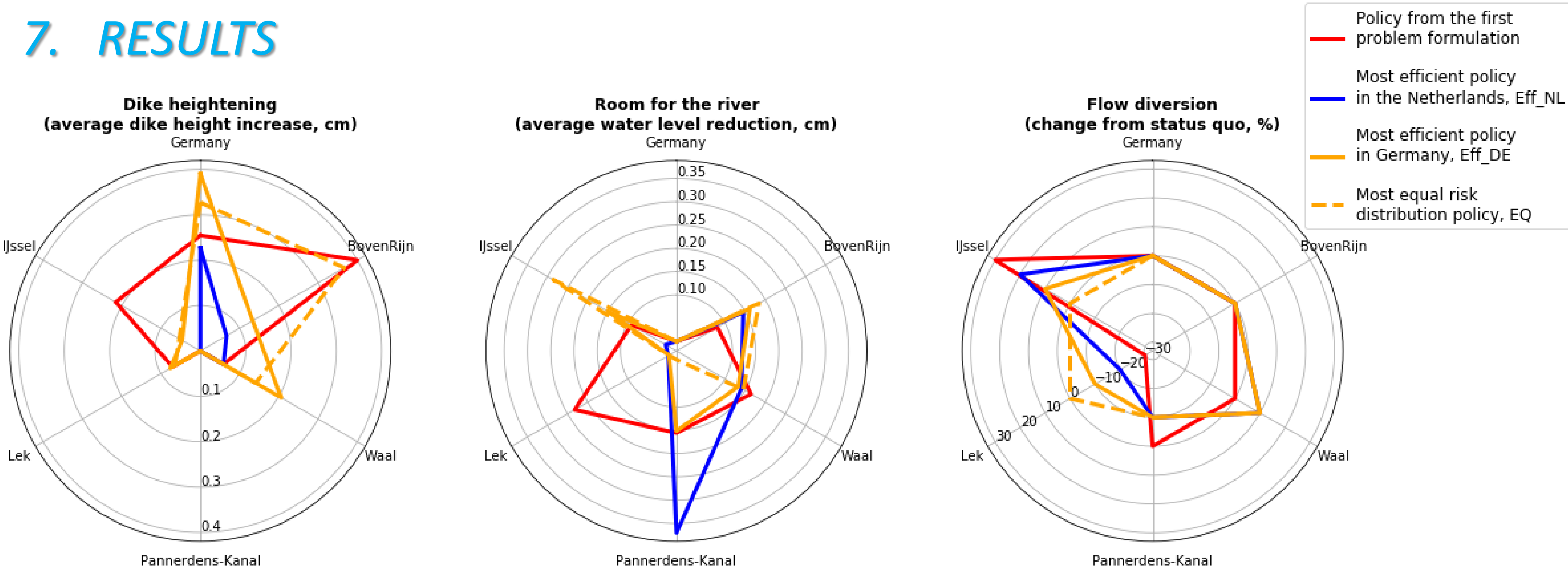
Policy from the first problem formulation
Most efficient policy in the Netherlands, Eff_NL
Most efficient policy in Germany, Eff_DE
Most equal risk distribution policy, EQ

7. RESULTS



- Current approach:
  - ➢ high dikes (esp. Boven-Rijn, IJssel), substantial RfR - no load reduction
  - ➢ extensive change 2nd discharge distribution (in favour of Lek) – only tot. costs

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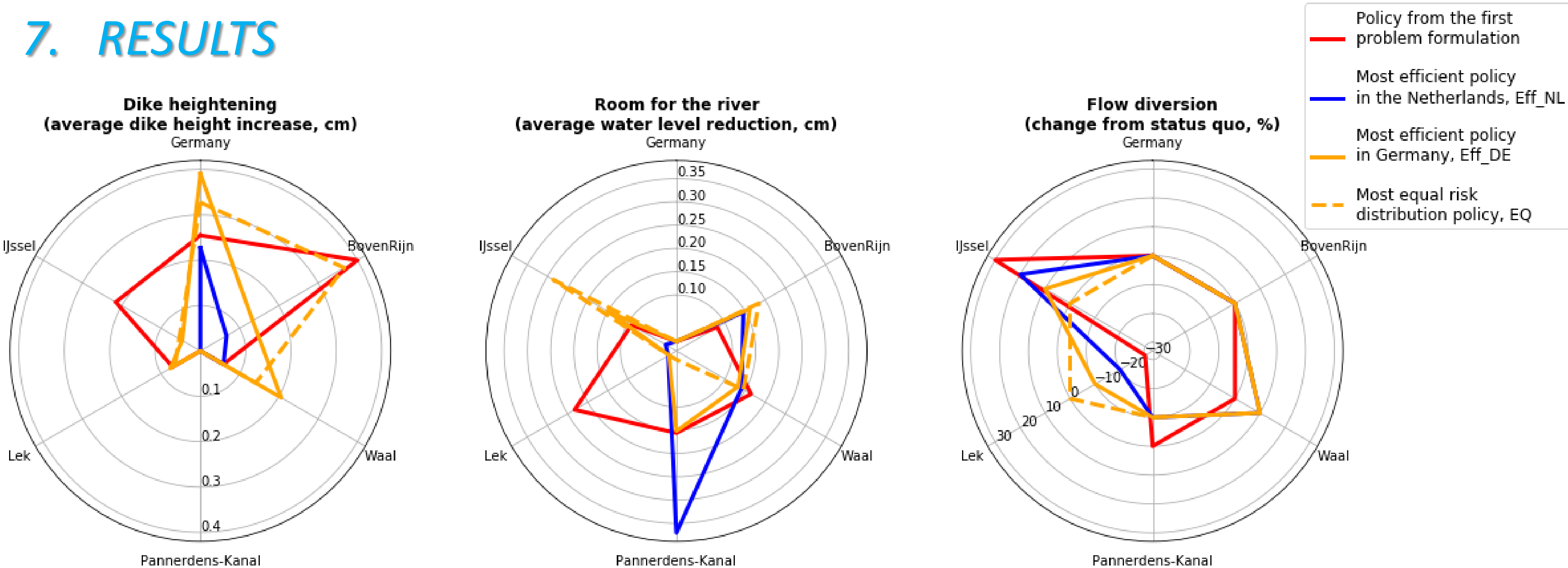

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  - ➢ Much less structural measures – yes load reduction
  - ➢ Slightly lower degree of (both) discharge distributions – only tot. costs but with load reduction

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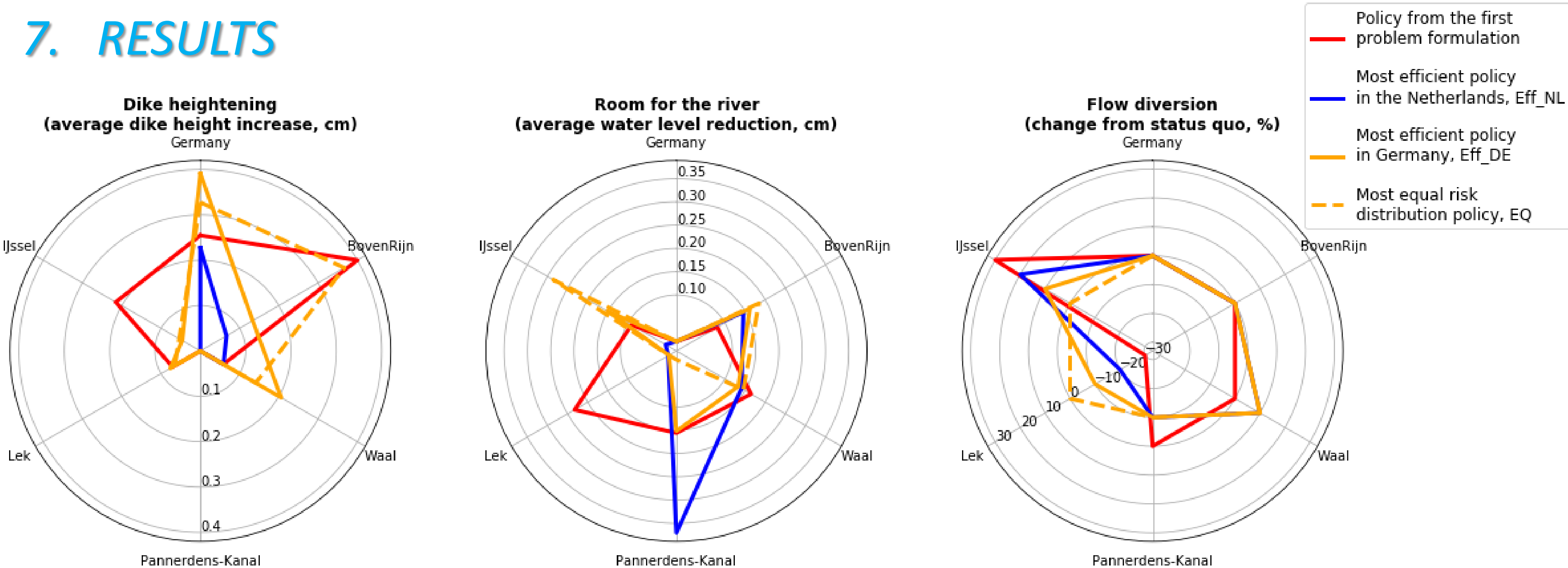

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- Eff_DE:
  - ➢ Much higher dikes in Germany

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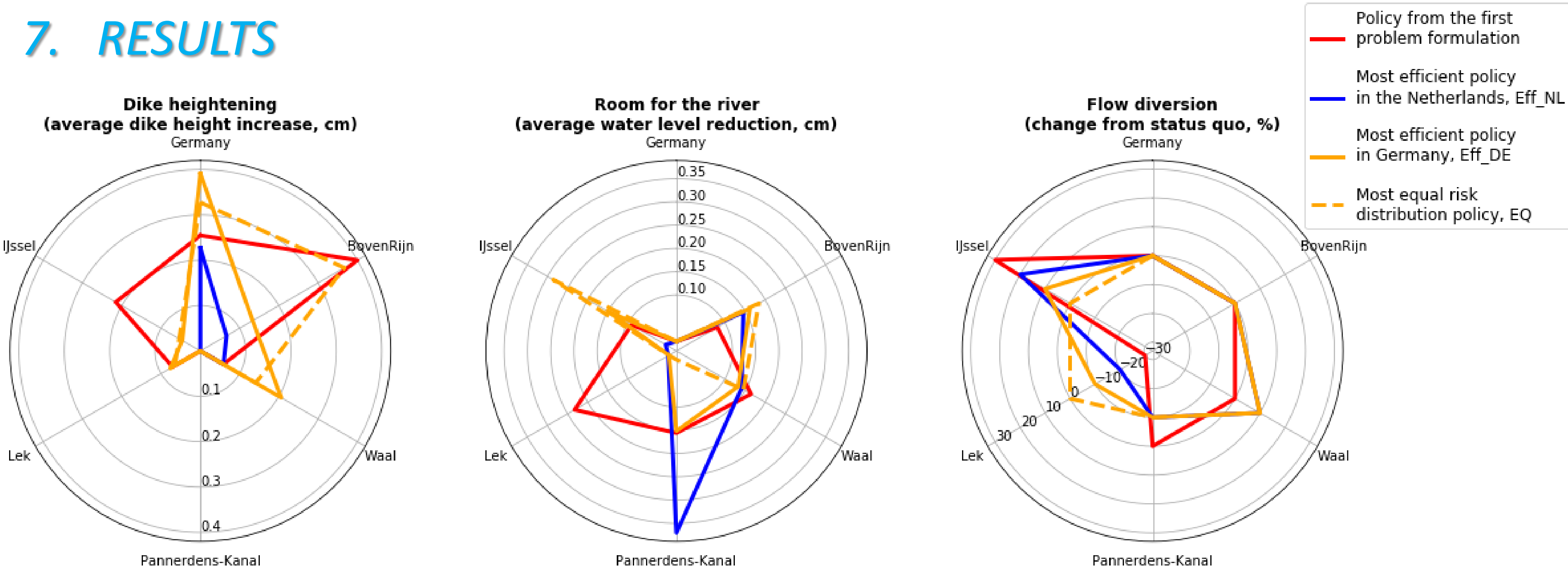

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- Eff_DE:
  - ➢ Much higher dikes in Germany
- EQ:
  - ➢ high dikes (esp. Boven-Rijn, Germany, Waal), RfR (Boven-Rijn) – protect Dutch part DK42 more
  - ➢ much lower change of the discharge distributions (although done) – no risk increases IJssel

PRE-PROCESSING:

1. Calibration of the Muskingum parameters
2. Adjustment of the fragility curves to the flood protection standards

EVENTS GENERATION:

1. Sample upstream high discharge events and generate a flood wave
2. Sample the degree of embankment raising, the discharge distribution and the Room for the River project to implement
3. Sample embankment maximum breach width, breach growth rate and failure probability

EVENTS SIMULATION:

Flood wave routing of each event from one location to the other following a Muskingum scheme. At each location:

1. Discharges are translated into water levels
2. Embankment failure is evaluated by comparing water levels with critical water levels
3. In case of failure, discharge through the polder is estimated through a weir formula

DAMAGE ESTIMATION:

Losses are estimated using the JRC global flood-depth damage model and the CORINE Land Cover dataset

- Cost function
- Probability distribution function

- Expected Annual Damage
- Investment Costs