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Optimising combinations of interceptive mitigations for cost-effectiveness in different landscapes

A flow-path and monte-carlo approach

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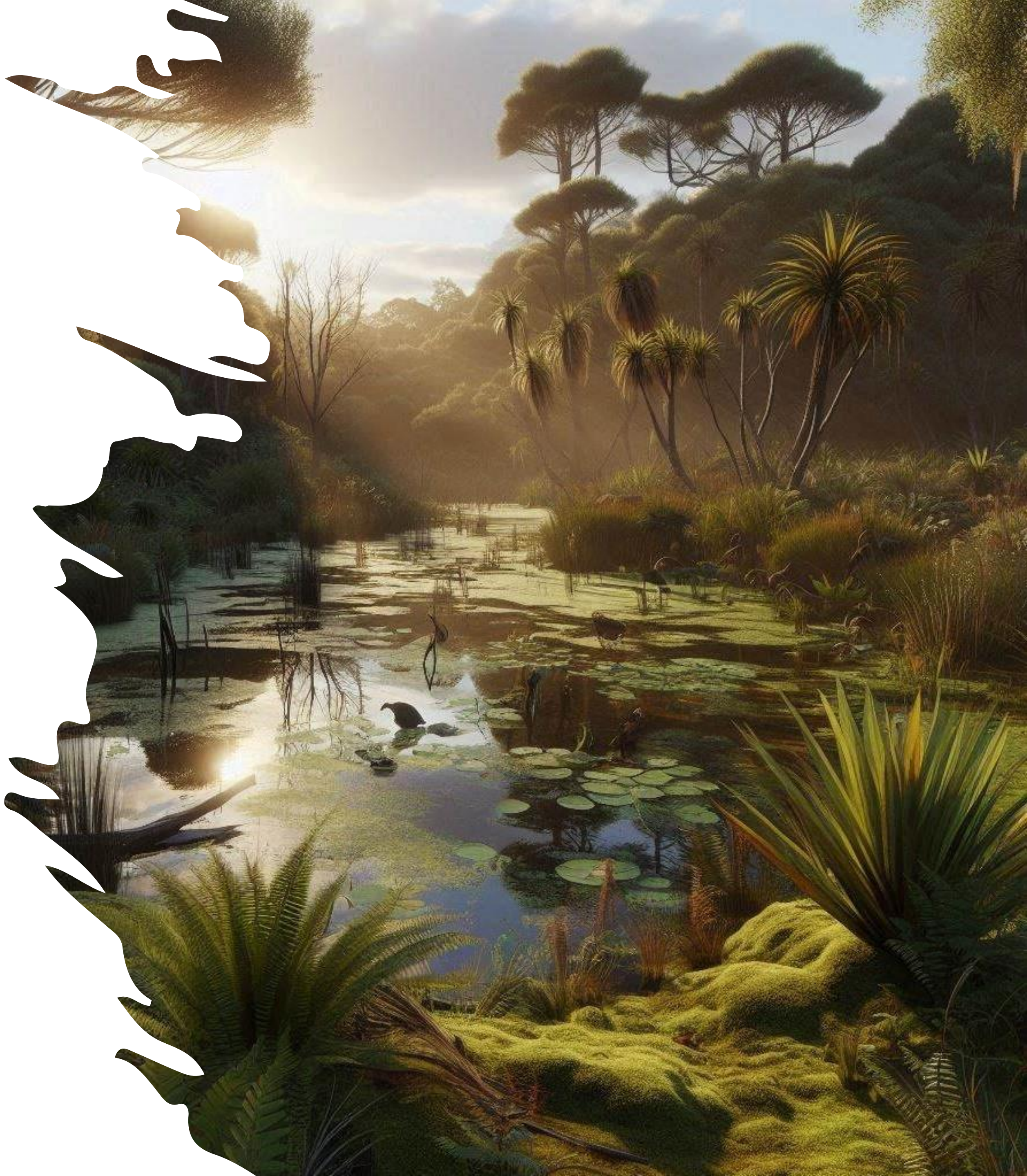
Motivation

- Cost-effectiveness depends on the farming system, the hydrologic landscape, and the scale of removal needed
- There is uncertainty around both costs and effectiveness, which may be an important consideration for individual landowners
- Previous economic analyses only considered the mean cost and did not account for the impacts of different landscapes or other mitigation systems



Approach

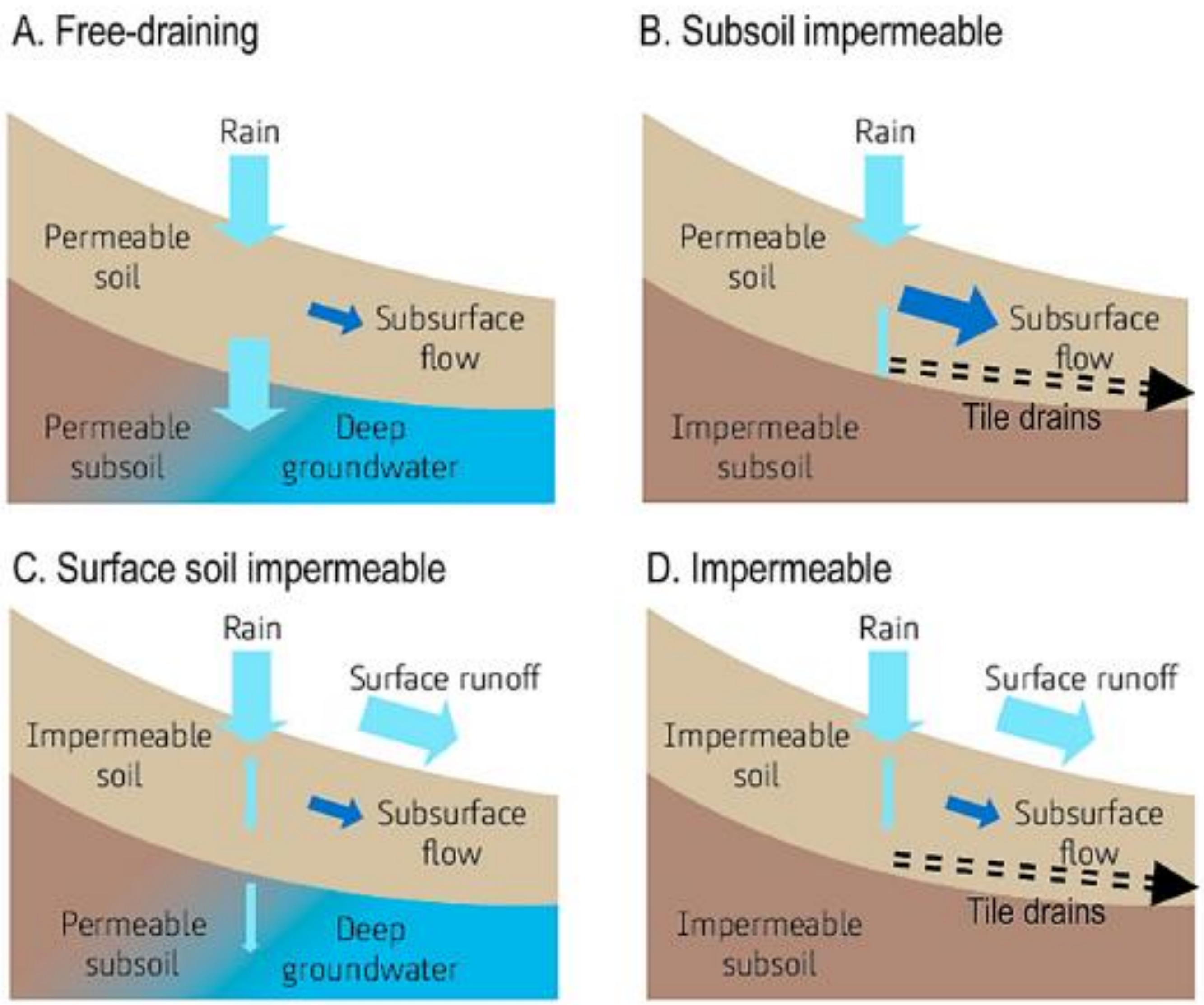
We developed a model to:

- Estimate cost and impacts for: riparian grass filter strips (RB), constructed wetlands (CW), woodchip bioreactors (WB), filamentous algal nutrient scrubbers (FANS), and detainment bunds (DB).
- Estimate the TN,TP and TSS flows through each interception point
- Use Monte Carlo simulation to estimate confidence intervals for a specified catchment type and area
- Calculate the overall cost effectiveness in terms of $ per unit of contaminant removed
- Used an optimisation algorithm to find the most cost-effective size and combination of systems for a given reduction target

Information feeding into the model

- The catchment
  - Farm losses (we used farm typologies but could use individual farm data if available)
  - Categorize the landscape based on slope and permeability
  - Which paths each contaminant takes
  - Reduction target (assumed anthropogenic load)
  - What edge-of-field mitigations already exist (assumed none)
- The mitigation systems
  - Performance, lifecycle costs and uncertainty based on case study data
  - Detailed cost models to assess the impact of slope/remoteness
  - Interception points

Flow-path approach to categorising landscapes



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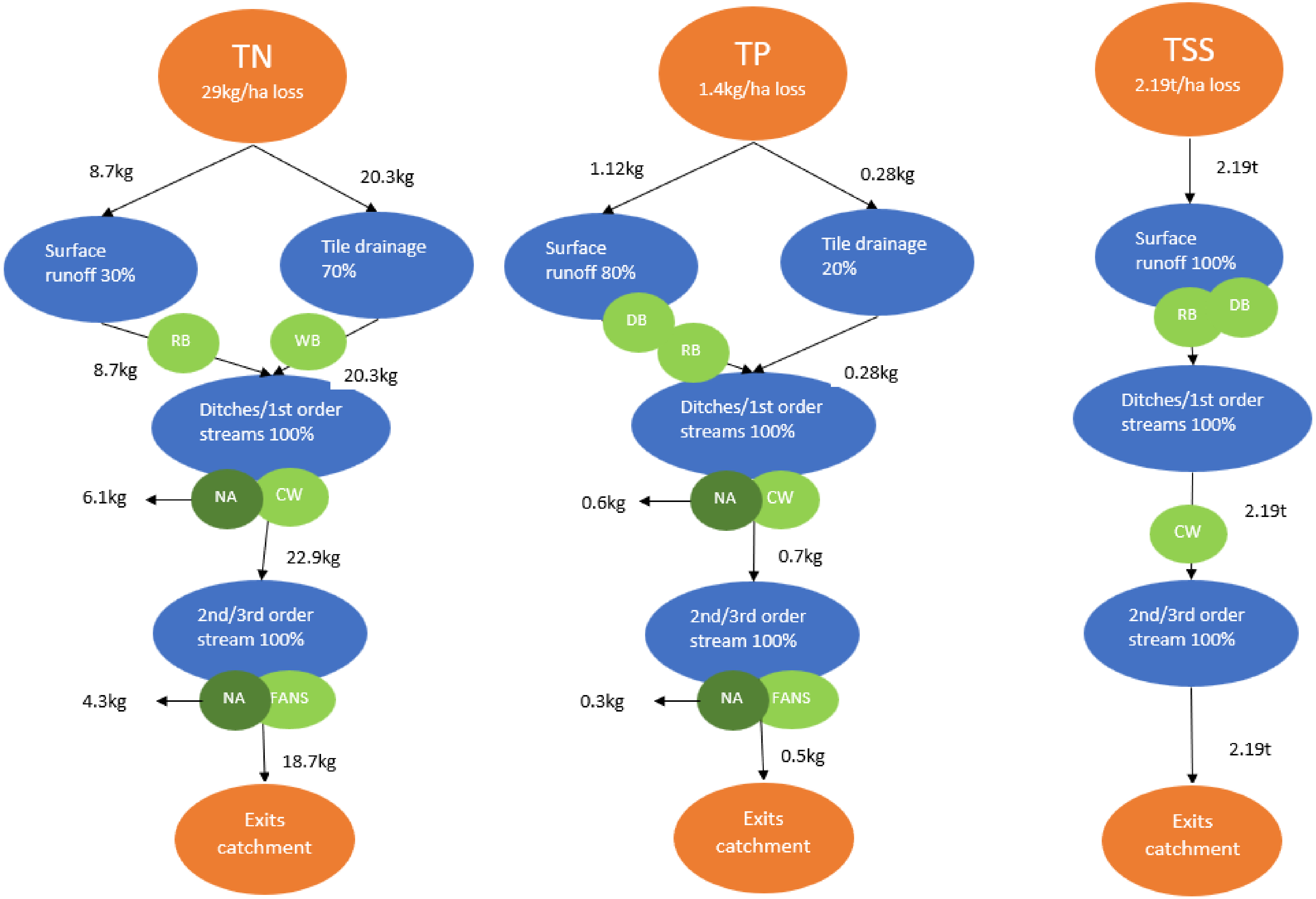
Contaminant interception

Mitigation	Contaminant	Surface run-off	Tile drainage	Shallow groundwater	Surface drains/ditches / first order streams	2nd/3rd order stream	Deep groundwater
Natural attenuation	N				x	x	
	P				x	x	
	S						
Constructed wetland	N	x	x		x	x	
	P	x	x		x	x	
	S	x	x		x	x	
Detainment bund	N						
	P	x					
	S	x					
Woodchip bioreactor	N	x	x				
	P						
	S						
Riparian grass filter strip	N	x			x		
	P	x			x		
	S	x			x		
Filamentous algal nutrient scrubbers	N				x	x	
	P				x	x	
	S				x	x	

Example:
flat dairy farm (D2) on type D (impermeable) landscape



Costing approach

- Inflation-adjusted to 2023 $
- Lifecycle costing (over 50 years)
  - includes both up-front costs, operations and maintenance, and replacement of components that have a shorter lifetime
- We used case studies and engineer cost models to estimate the average and ranges of each cost component
- Each systems has a maximum realistic size based on different constraints
- Some systems have a minimum size
- FANS has an economic benefit – the algae can be used for fertiliser
- We do not monetise other environmental or cultural benefits (e.g. habitat) though this is possible

The optimisation approach

- Is based on mean cost and impact but we could instead use % confidence.
- Tests each mitigation individually and find the smallest size that achieves the target, if at all
- Select the most efficient system and do a “gradient search” of adding or swapping small amounts of other systems
- Continue until no further improvement has been found after a full cycle.
- This is called a “Greedy Coordinate Descent”
- If the target is for multiple contaminants it converts to a weighted total but does check that each target is met (assuming it’s possible)

Use cases for this model

For landowners

- Provide guidance about the combination of mitigation systems they should investigate further
- Assess what could be achieved, or the likelihood of meeting a target with single or multiple systems

For councils:

- To assess how much it might cost to achieve specific reduction targets
- To help identify catchments where reductions could be achieved at a lower relative cost
- To assess the likelihood of targets being achieved given specified uptake of systems
- To assess the potential impact of a planned mitigation system

Illustrative results

For a single farm type

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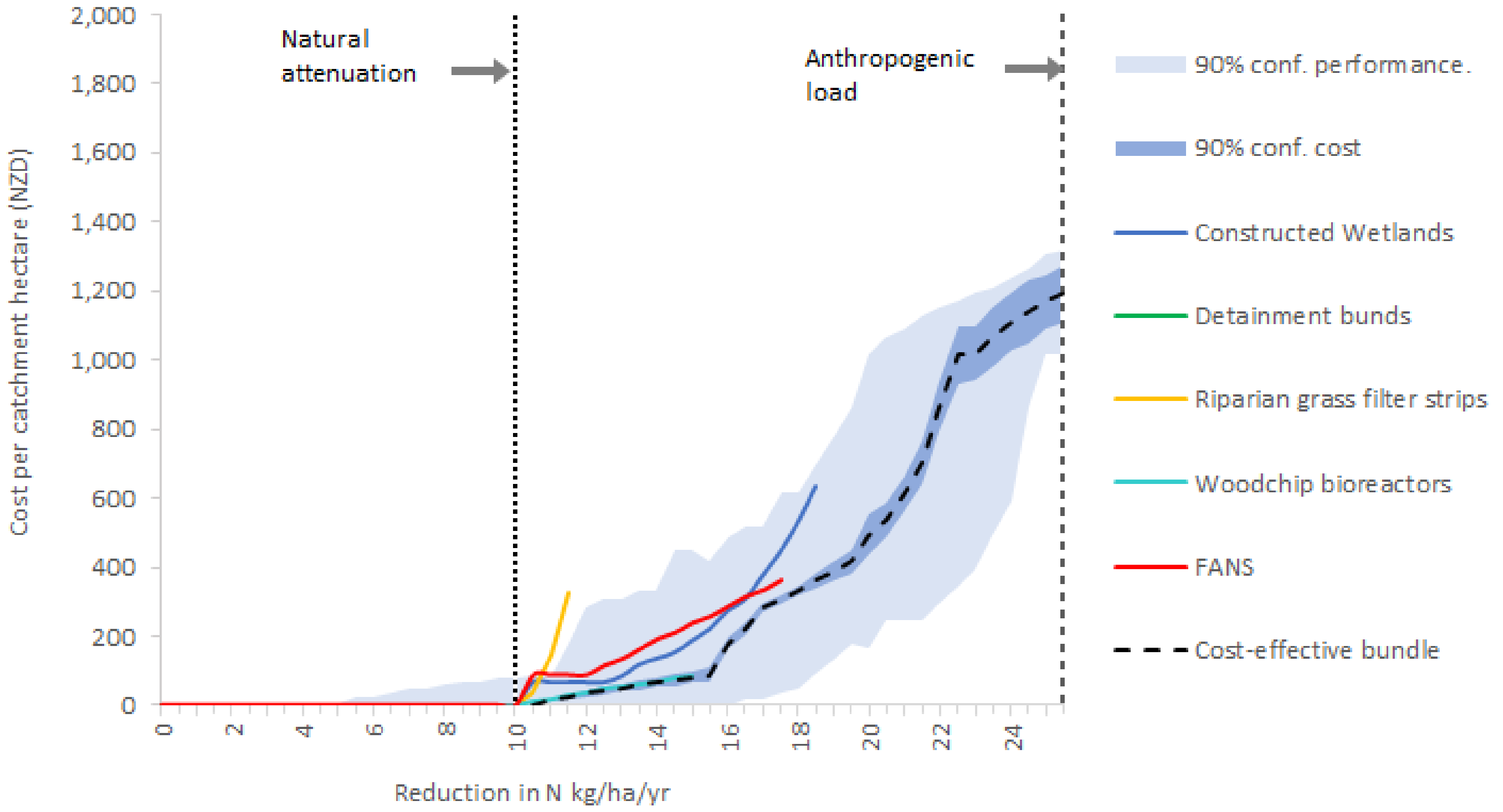
A flat dairy farm (type D2) on hydrologic landscape D (impermeable)

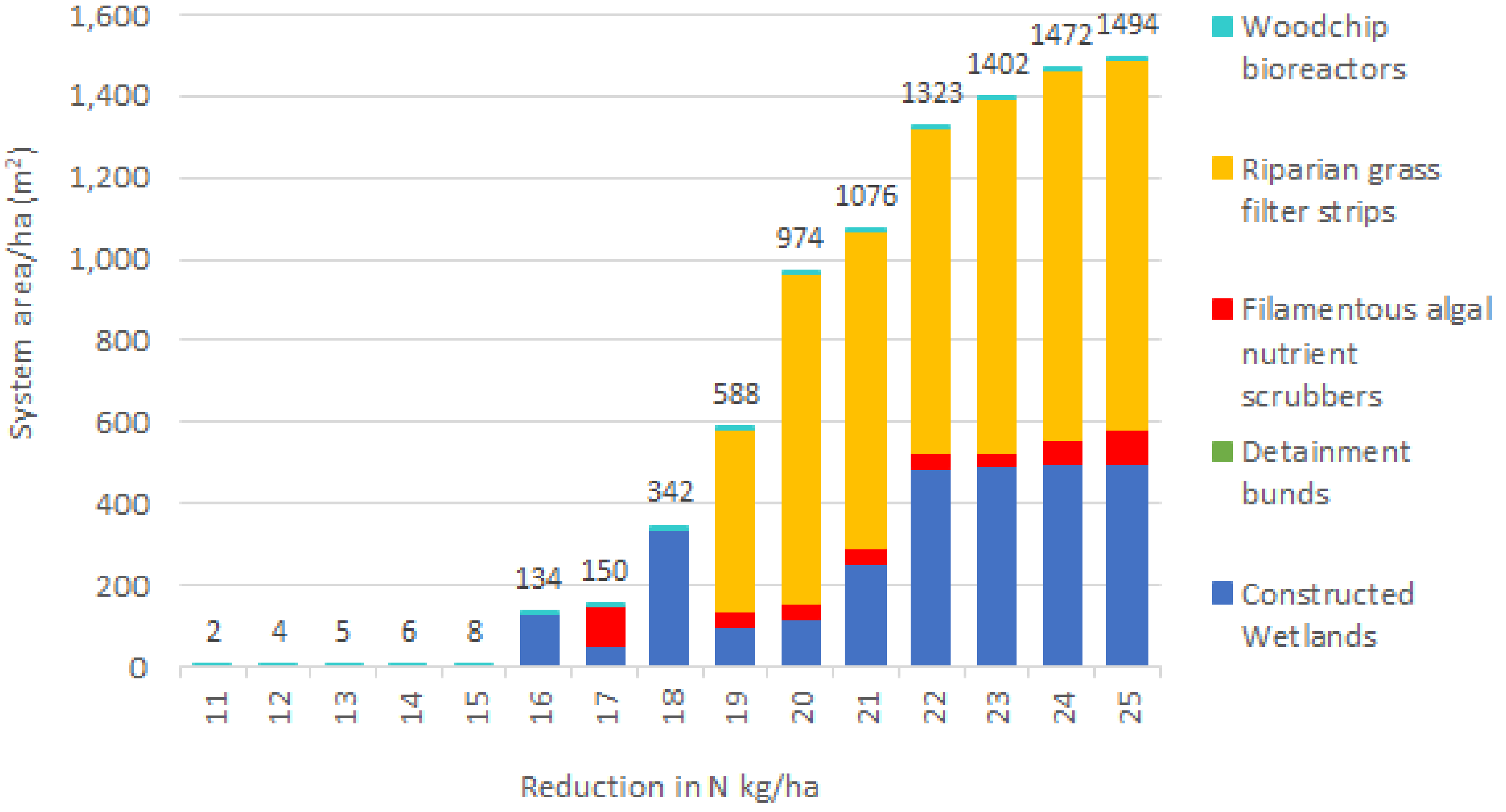
- Typical 67ha D2 dairy farm in the Waikato Region, not remote.
- Operating profit $2930/ha
- Farm losses: TN: 29 kg/ha/yr, TP: 1.4 kg/ha/yr, TSS: 2.19 t/ha/yr.
- Natural baseline loads: TN: 3.4-3.7 kg/ha/yr, TP: 0.21-0.34 kg/ha/yr, TSS: 1.4 t/ha/yr.
- 2,200 meters of waterways, including intermittent streams.
- Mostly flat with 25% undulating terrain suitable for detainment bunds (DBs).
- Low permeability, extensive tile drainage system.
- High clay content (>28.5%), affecting grass-filter riparian buffer (GRB) performance.
- Average Hillslope Length: 150 meters.
- Contains one second-order stream
  - mean daily flow 9,500 ± 2,000 m^3, MALF 2,200 m^3/day
  - TN 1.72 g/m^3, TP 0.07 g/m^3

TN mitigation costs and ranges

Could remove anthropogenic load for ~$1200/ha (41% of farm profit)



Most cost-effective combination for TN



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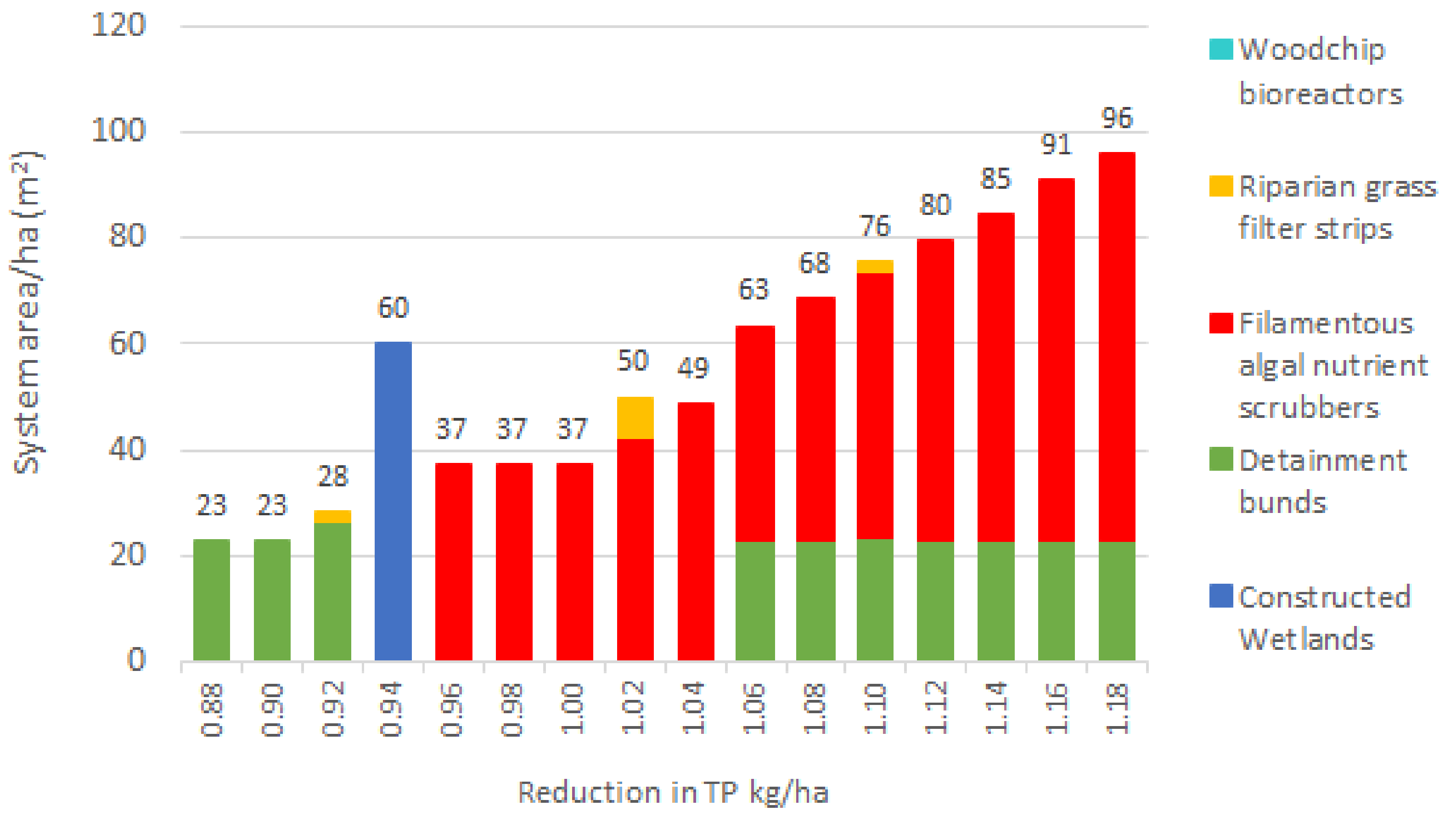
Most cost-effective combination for TP



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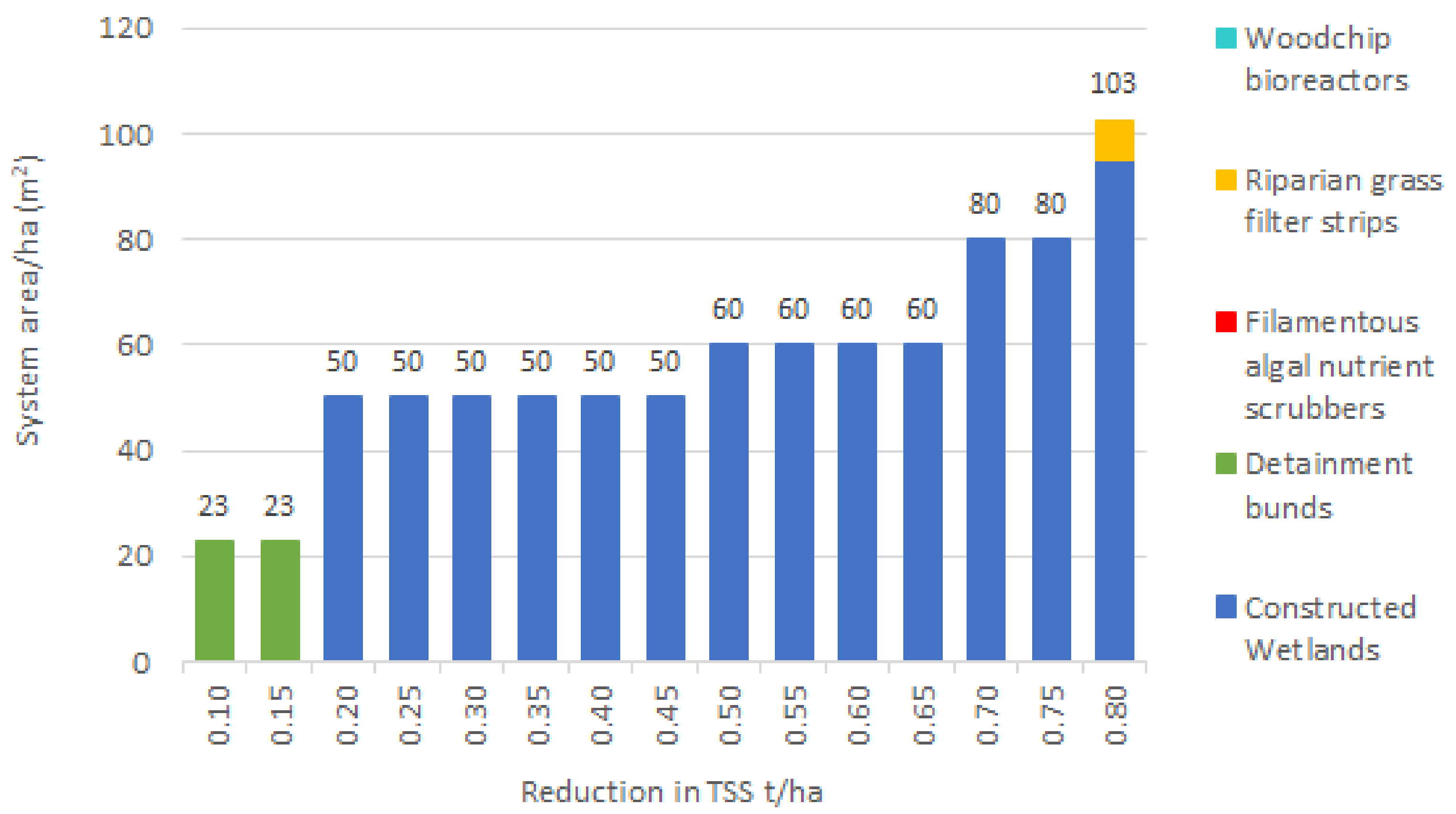
Most cost-effective combination for TSS



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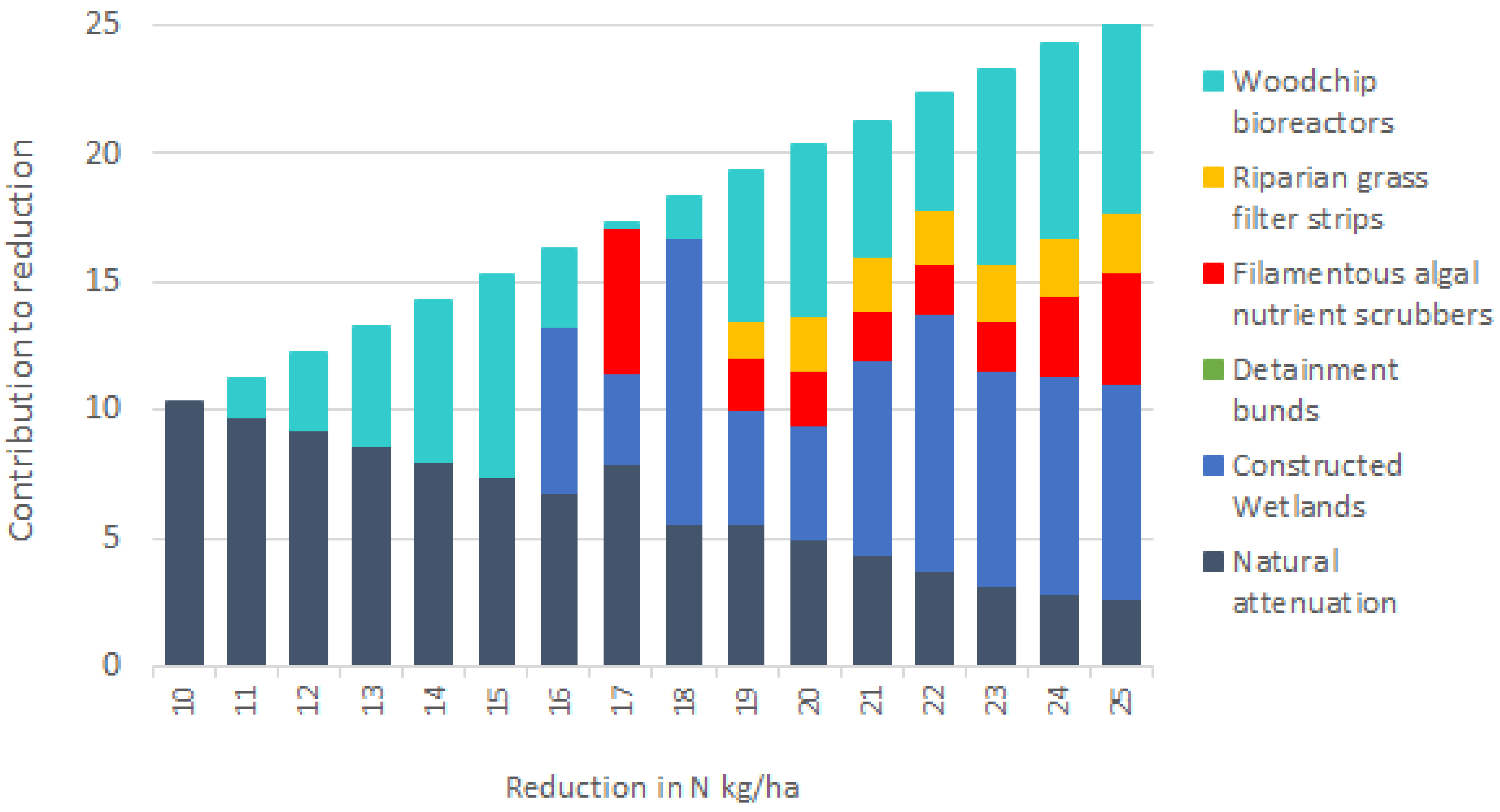
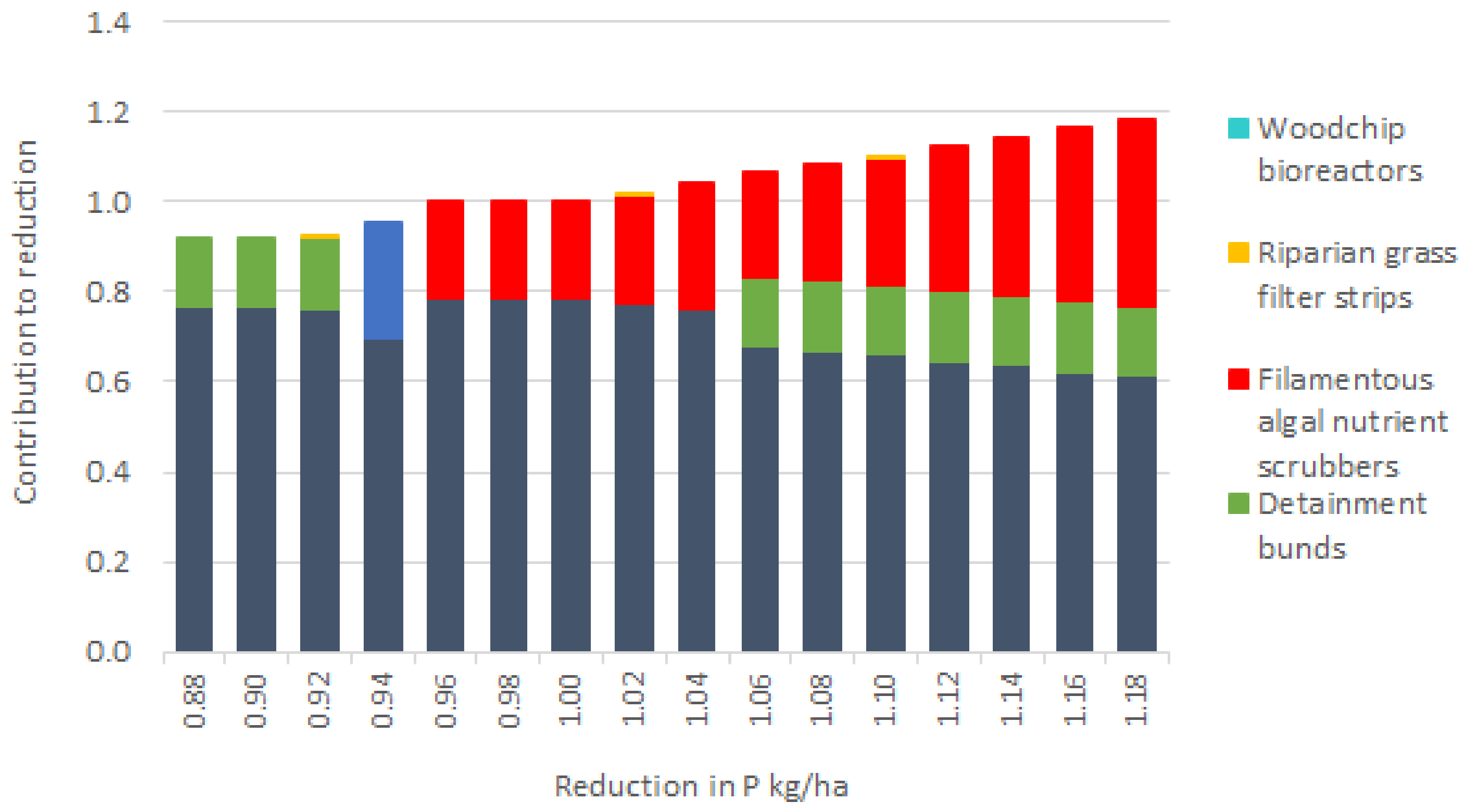
Contribution to TN reduction by each system



Contribution to TP reduction by each system



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Other farm types, HLTs and targets

How do results change?

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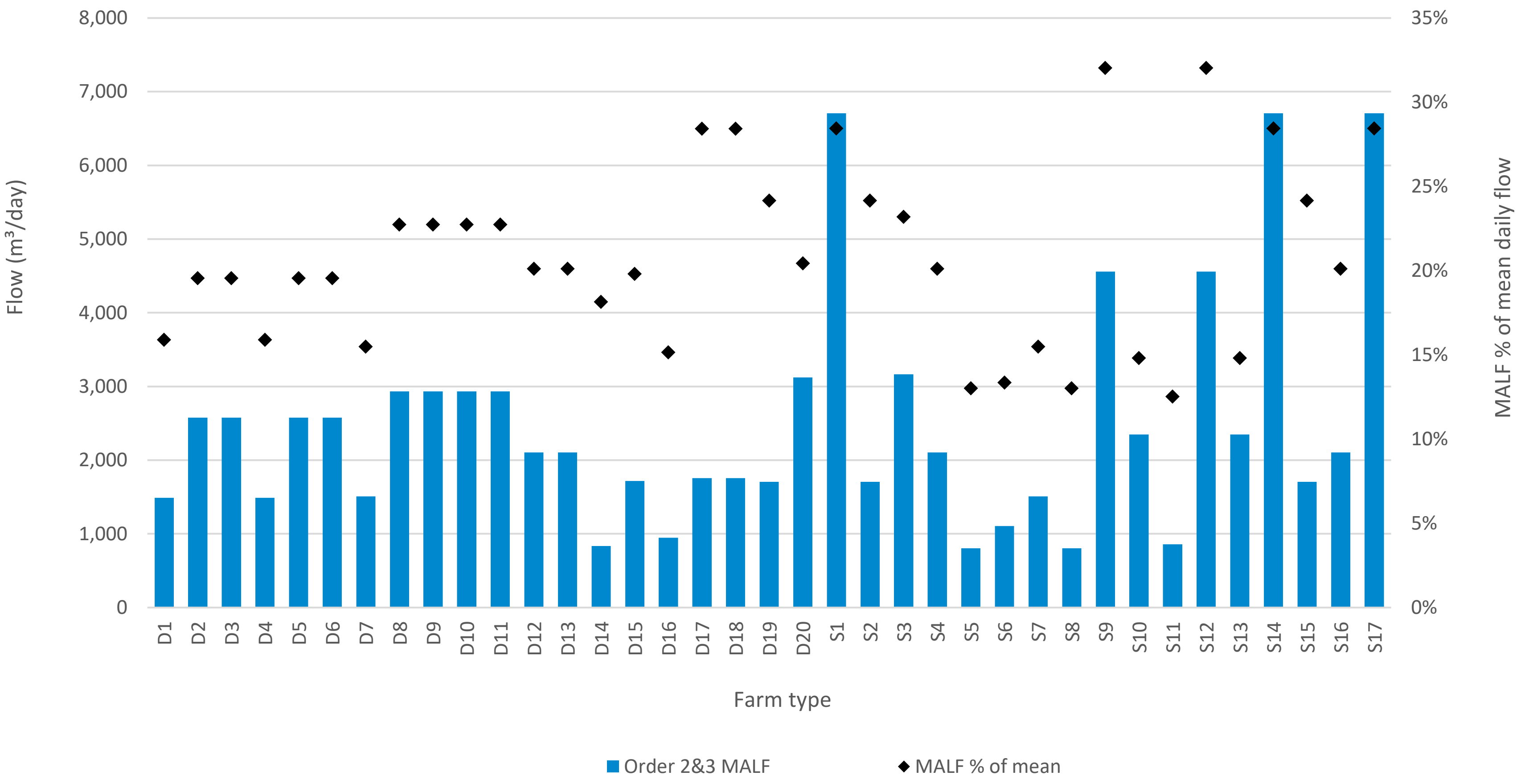
Approach for all-typology analysis

- Each REC2 catchment was associated with a farm typology and hydrologic class using a combination of region, land-use, topography, and geology GIS layers
- Set some feasible targets for each farm typology based on 50% reduction in anthropogenic load
- Baseline loads from predicted natural TN & TP yields (Snelder et al. 2018) and the sediment load estimator (Hicks et al. 2019)
- Cost adjustments for slope class and remoteness
- Extended the optimization algorithm to be multi-objective

Variability in flows



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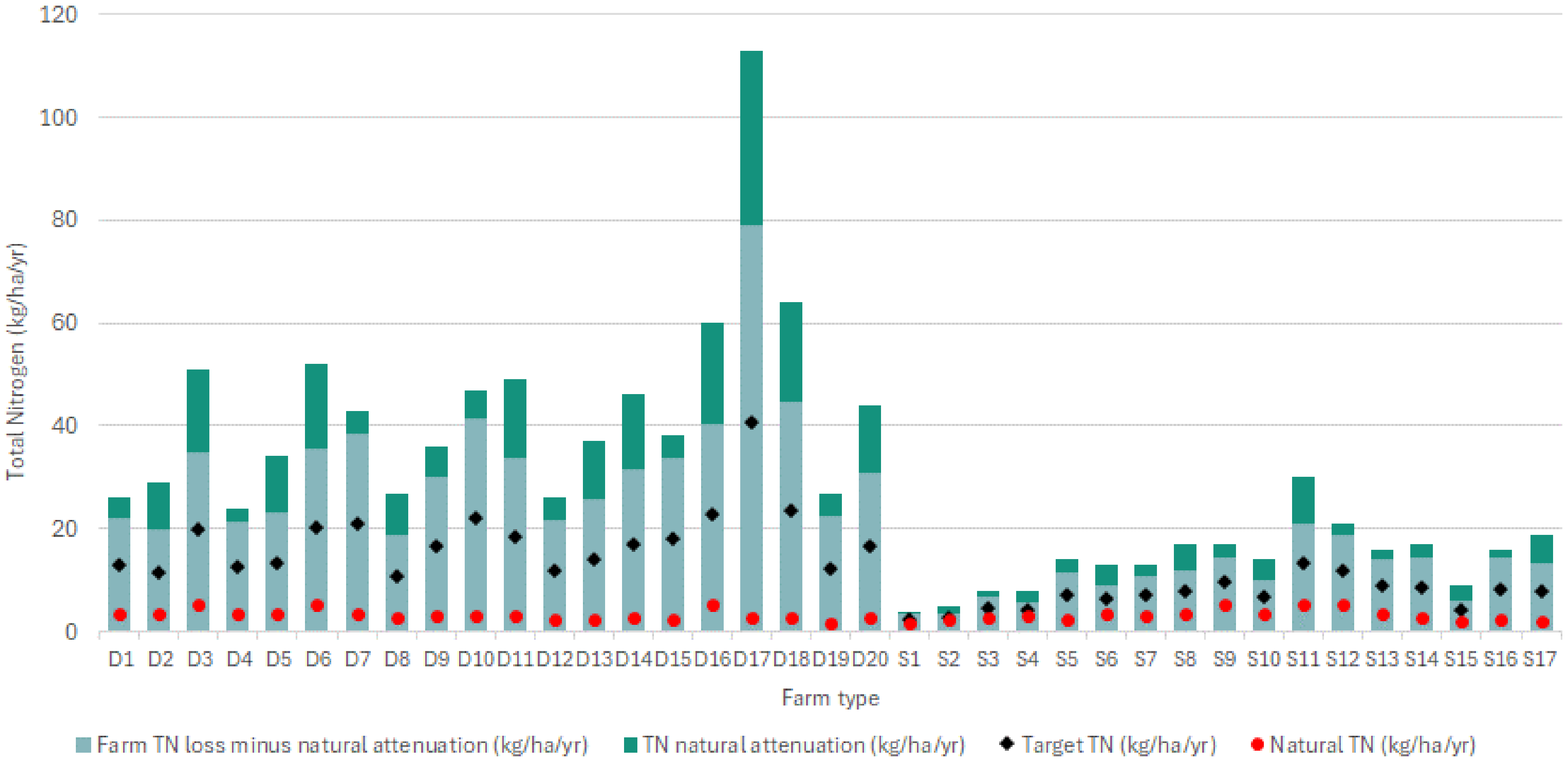
Variability in N losses and baselines



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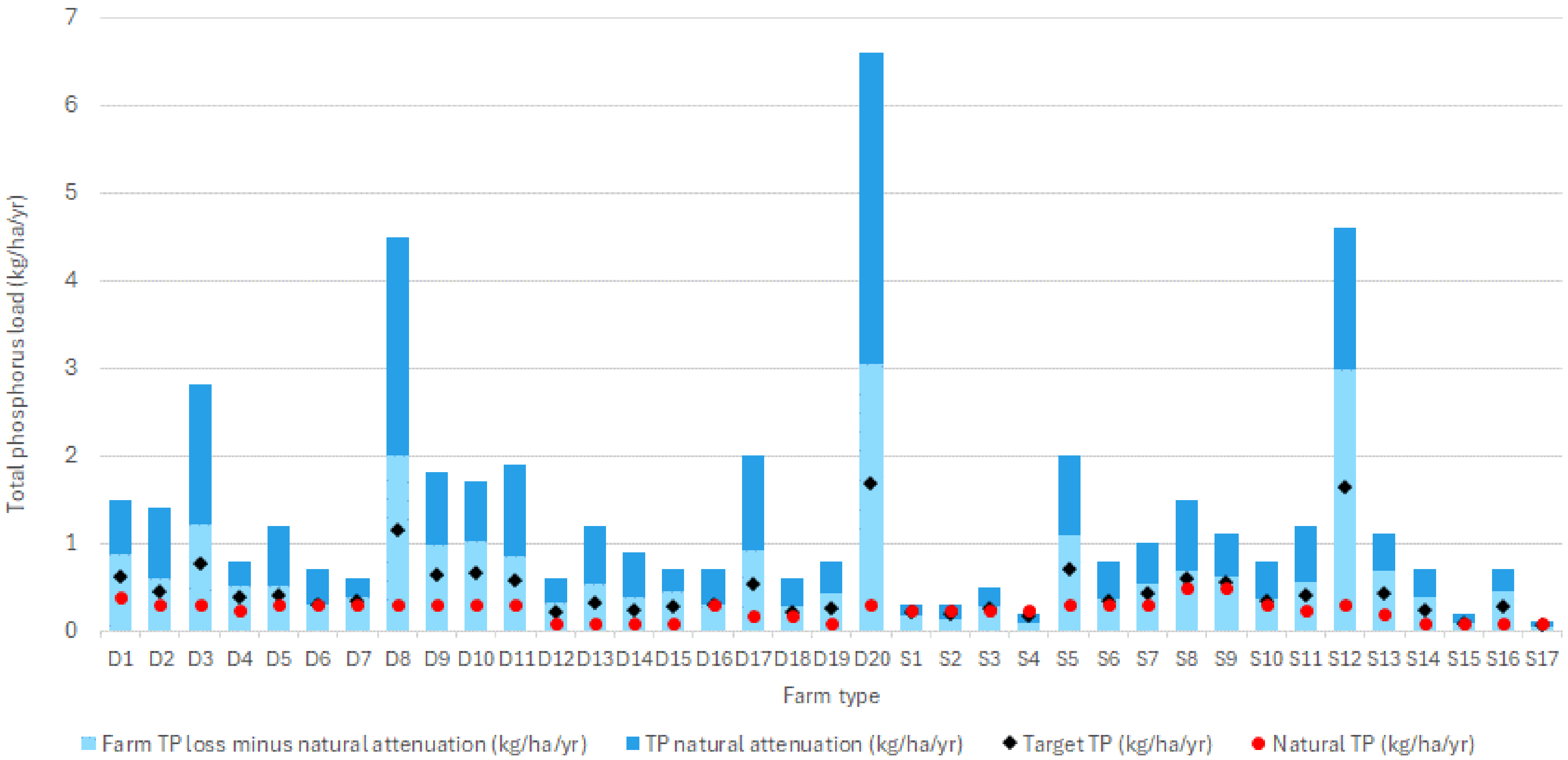
Variability in P losses and baselines



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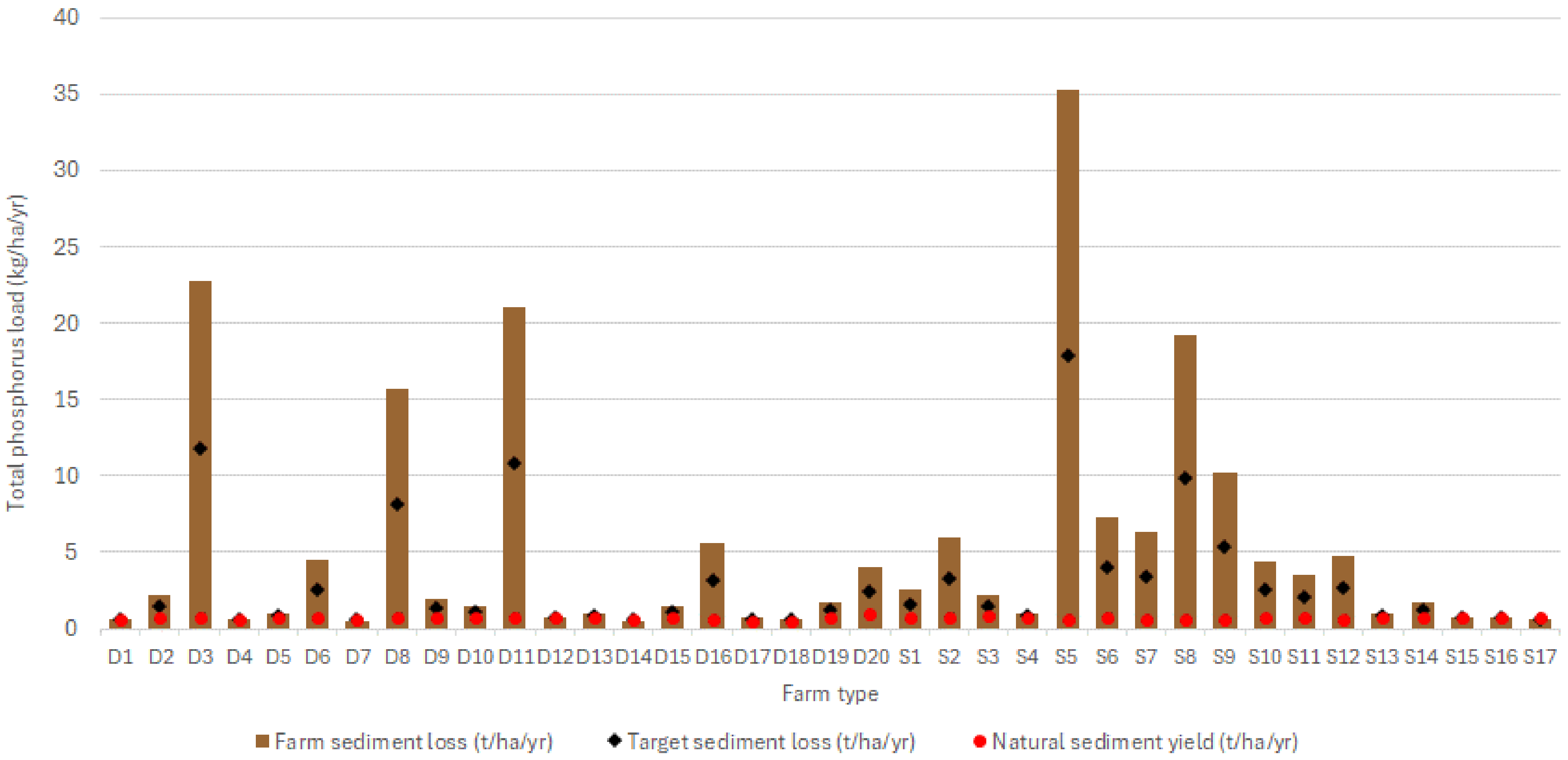
Variability in S losses and baselines



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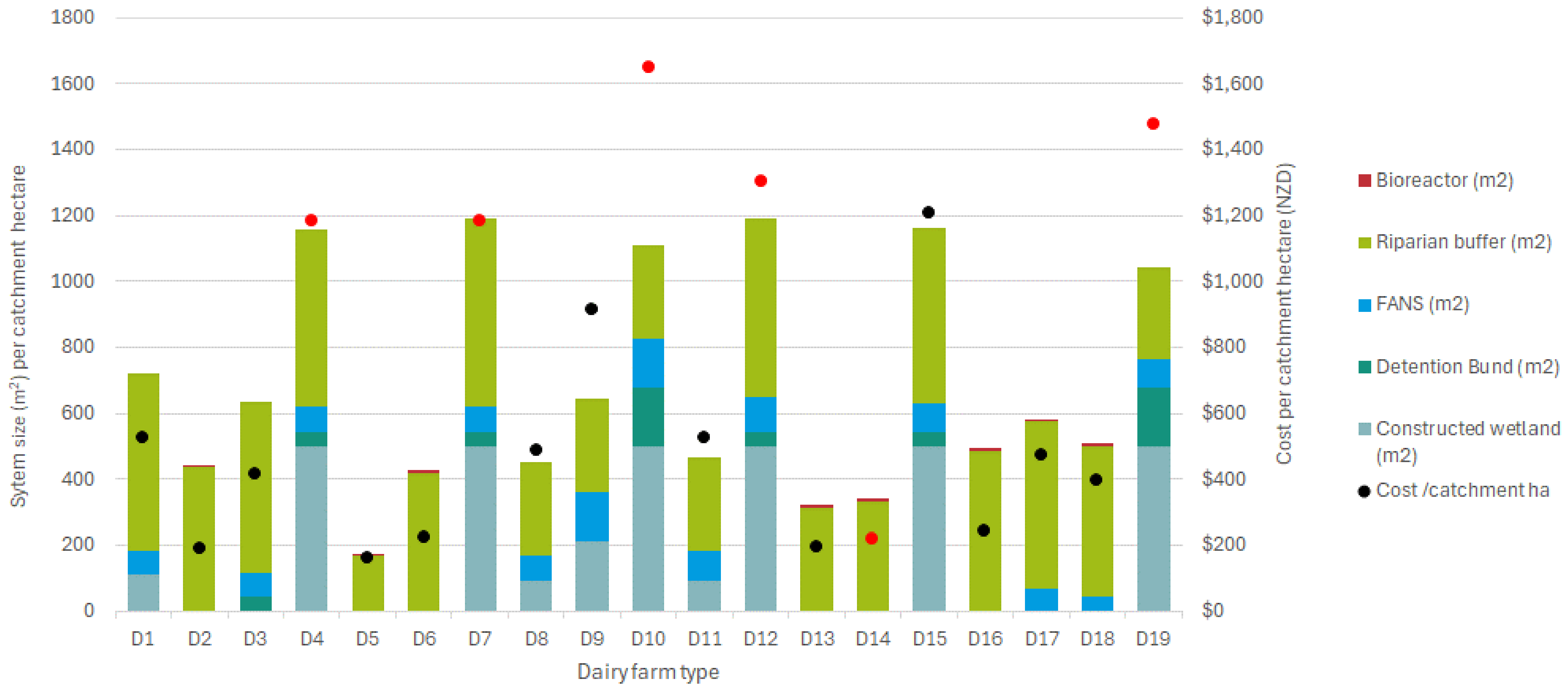
Least-cost bundles for dairy farms



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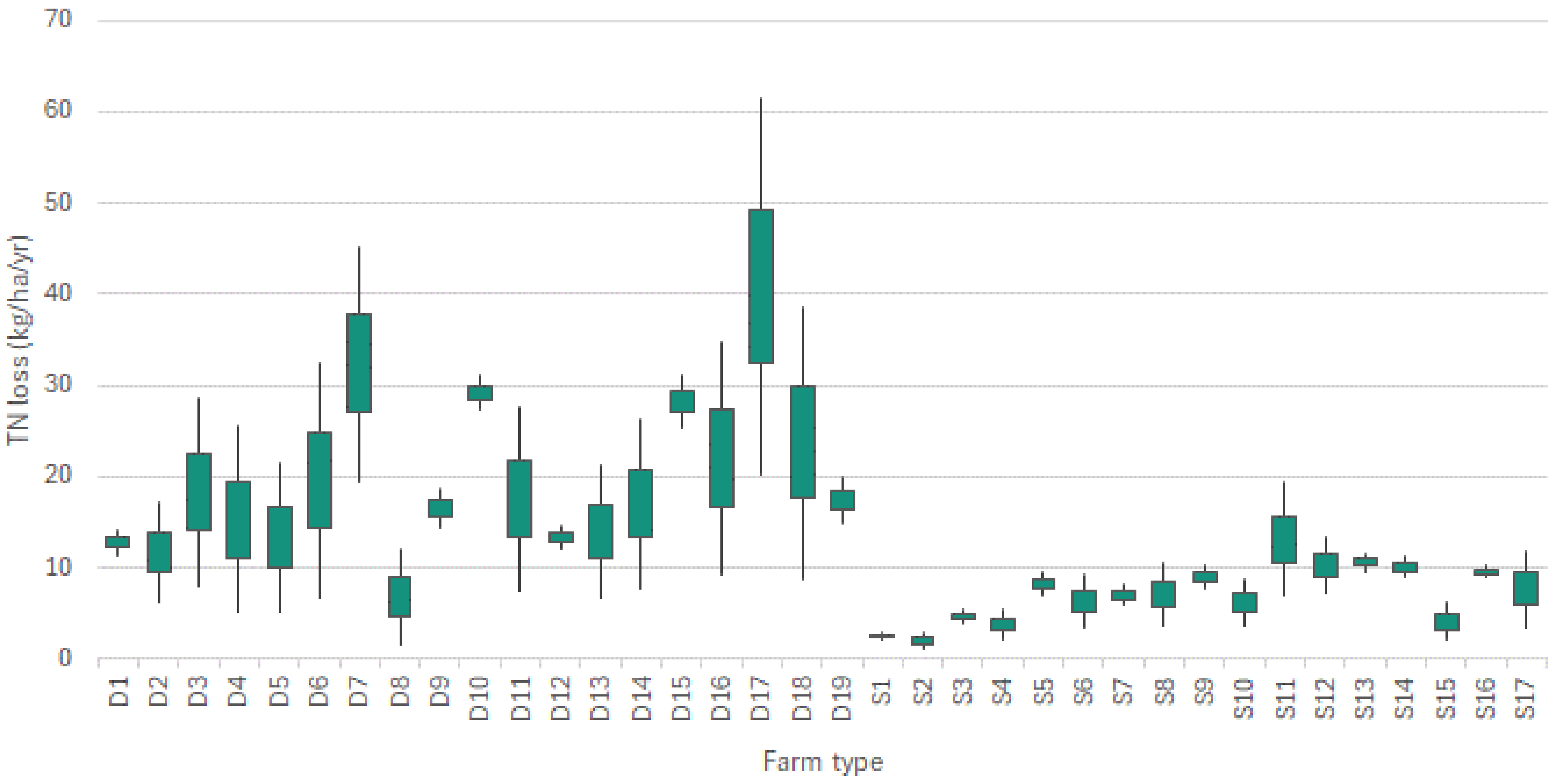
Uncertainty

There are wide confidence intervals around outcomes due to flow variability and epistemic uncertainty



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Summary

- We can run this model for any of the 20 dairy farm and 17 SNB farm typologies and 8 HLT/slope classes
- For a catchment with multiple farm systems, we would split the catchment
- Output includes:
  - Cost and impact confidence intervals for specific combinations of mitigations
  - The expected most cost-effective combination for a specified target or range of targets

Potential next steps

- Find opportunities to apply the model to specific catchments
- Port the model to a user-friendly online format (R Shiny) for typical use cases?
- Add other mitigation systems?
- Quantify ancillary benefits?
- Include *E.coli?*
- Look to improve the model by:
  - adding more case studies to the costing database
  - adding seasonal variation (would need more data)
  - obtain information about what systems already exist in catchments

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Kia ora rawa atu – Thank you

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Farm types

Typology	Farm type	Predominant region	Slope	Drainage	Wetness	N Loss (kg/ha/yr)	P Loss (kg/ha/yr)	Sediment loss (t/ha/yr)
D1	Dairy	Waikato	Flat	Poor	Dry	26	1.5	0.59
D2	Dairy	Waikato	Flat	Poor	Moist	29	1.4	2.19
D3	Dairy	Waikato	Flat	Poor	Wet	51	2.8	22.78
D4	Dairy	Waikato	Flat	Well	Dry	24	0.8	0.57
D5	Dairy	Waikato	Flat	Well	Moist	34	1.2	1.03
D6	Dairy	Waikato	Flat	Well	Wet	52	0.7	4.47
D7	Dairy	Manawatu	Flat	Light	Dry	43	0.6	0.55
D8	Dairy	Waikato	Moderate	Poor	Moist	27	4.5	15.68
D9	Dairy	Waikato	Moderate	Well	Moist	36	1.8	1.96
D10	Dairy	Waikato	Moderate	Well	Wet	47	1.7	1.5
D11	Dairy	Waikato	Moderate	Light	Moist	49	1.9	21.02
D12	Dairy	Southland	Flat	Poor	Dry	26	0.6	0.69
D13	Dairy	Southland	Flat	Poor	Moist	37	1.2	1.03
D14	Dairy	Canterbury	Flat	Poor	Irrigated	46	0.9	0.53
D15	Dairy	Southland	Flat	Well	Moist	38	0.7	1.46
D16	Dairy	Taranaki	Flat	Well	Wet	60	0.7	5.58
D17	Dairy	Canterbury	Flat	Well	Irrigated	113	2	0.76
D18	Dairy	Canterbury	Flat	Light	Irrigated	64	0.6	0.59
D19	Dairy	Otago	Moderate	Poor	Dry	27	0.8	1.72
D20	Dairy	Waikato	Moderate	Well	Wet	44	6.6	4.02
S1	High country	Marlborough-Canterbury	Moderate			4	0.3	2.57
S2	High country	Otago/Southland	Moderate			5	0.3	5.95
S3	Hill country	Marlborough-Canterbury	High			8	0.5	2.16
S4	Hill country	Otago/Southland	High			8	0.2	1.03
S5	Hard hill country	East Coast	High			14	2	35.3
S6	Hard hill country	Northland-Waikato-BoP	High			13	0.8	7.31
S7	Hard hill country	Taranaki-Manawatu	High			13	1	6.28
S8	Hill country	East Coast	Moderate			17	1.5	19.24
S9	Hill country	Northland-Waikato-BoP	Moderate			17	1.1	10.17
S10	Hill country	Taranaki-Manawatu	Moderate			14	0.8	4.44
S11	Intensive finishing	East Coast	Flat			30	1.2	3.49
S12	Intensive finishing	Northland-Waikato-BoP	Flat			21	4.6	4.74
S13	Intensive finishing	Taranaki-Manawatu	Moderate			16	1.1	0.95
S14	Finishing breeding	Marlborough-Canterbury	Flat			17	0.7	1.73
S15	Finishing breeding	Otago/Southland	Flat			9	0.2	0.76
S16	Intensive finishing	Otago/Southland	Flat			16	0.7	0.76
S17	Mixed finishing/arable	Marlborough-Canterbury	Flat			19	0.1	0.58