2nd Seminar of the UsinoVerT Chair

"Planning Green Infrastructures for Industrial Cities"

ESALQ-Piracicaba, Brazil & UniLaSalle-Rouen, France

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Greening the Grey: Unlocking the Potential of Industrial Landscapes

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Green Infrastructure (GI) – Role in Industrial Areas

Multiple functions for Industrial Businesses

- **Flood protection**
- **Stormwater management and treatment options**
- **Potable water savings**
- **Improving the aesthetics, providing recreational opportunities**
- **Air quality improvement**
- **Temperature reduction**
- **Energy savings**

Eco Industrial Park

Businesses seek enhanced environmental and economic performance through collaboration in managing environmental and resource issues, including energy, water, and materials.

GI & Cost Savings in Runoff Management

Location	Description of GI Used	Cost Savings through GI
Parking Lot Retrofit Largo, Maryland	One-half acre of impervious surface. Stormwater directed to central bioretention.	$10,500–$15,000
Old Farm Shopping Centre, Maryland	Site redesigned to reduce impervious surfaces, added bioretention, filter strips, and infiltration trenches.	$36,230
OMSI Parking Lot Portland, Oregon	Parking lot incorporated bio-swales into the design, and reduced piping and catch basin infrastructure.	$78,000
Light Industrial Parking Lot, Portland, Oregon	Site incorporated bio swales into the design, and reduced piping and catch basin infrastructure.	$11,247
Point West Shopping Center, Lexana, Kansas	Reduced curb and gutter, reduced storm sewer and inlets, reduced grading, and used porous pavers, added bioretention cells, and native plantings.	$168,898
Vancouver Island Technology Park Redevelopment British Columbia, Canada	Constructed wetlands, grassy swales and open channels, rather than piping to control stormwater. Also used native plantings, shallow stormwater ponds within forested areas, and permeable surfaces on parking lots.	$530,000

Annual Cost Savings through Installing Green Infrastructure (GI) as Runoff Management Strategies in commercial and Industrial Developments (US and Canada)

(Jayasooriya et al., 2020)

SWOT analysis

Strengths (S)	Weaknesses (W)	Opportunities (O)	Threats (T)
Requires low initial expenses and operating costs.	Large physical footprint required.	Stakeholder participation opportunities.	Susceptible to seasonal/extreme weather.
Less sensitive to increasing material and power costs.	Needs proper site investigation and maturation time.	Partnerships with local landowners.	Unforeseen stresses over lifetime.
Appreciates in value as it connects to local environment.	Long time to mature fully.	Resource-efficient multifunctionality (cooling, air quality, flood protection).	Challenges obtaining permits and approvals.

SWOT analysis on applications of GI for industrial and/or brownfield sites

Optimizing GI for Industrial Areas

Residential Area

- Limited space
- i.e. : Bioretention/rain garden, Swales, permeable pavements

Industrial Area

- Considerably large surface areas
- High environmental demands
- Multiple functionalities for businesses
- i.e. : Wetlands, Bioretention/Rain garden, Retention ponds, Swales, Sedimentation Basins, Permeable Pavement, Green Roof, Green Walls

Optimal selection and sizing is complex

Problem: Runoff Treatment from Industrial Lands

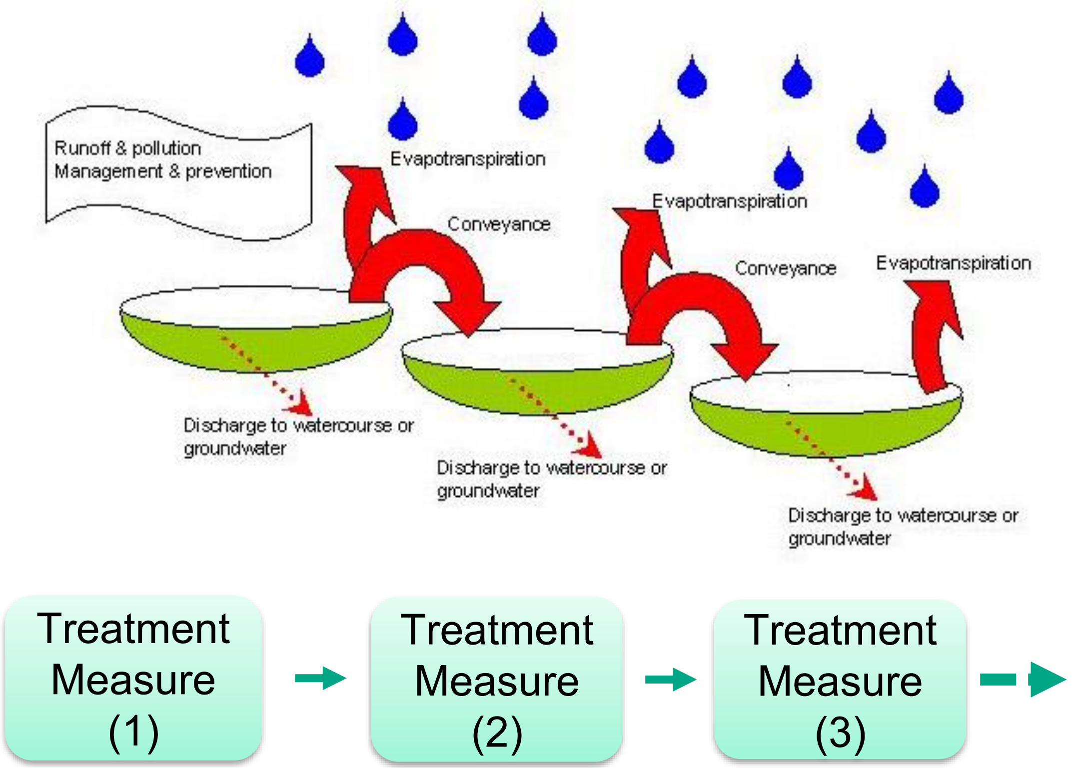
Industrial Runoff Pollution - Sources

- Outdoor Material Storage
- Loading and Unloading Operations
- Vehicle and Equipment Maintenance
- Fueling Areas
- Outdoor Industrial Processing
- Waste Handling and Disposal
- Industrial Cleaning and Washdown
- Chemical Handling and Spills
- Storage Tanks and Pipelines
- Industrial Yard Traffic
- Construction and Earthmoving
- Roof and Building Runoff
- Stockpiled Finished Products
- Accidental Releases

How GI can help?

Treatment	Pollutants	Typical Treatment Measures
Primary Treatment	Gross pollutants and coarse sediments	Gross pollutant traps, Sedimentation basins, Vegetated swales
Secondary Treatment	Fine sediments and attached pollutants	Vegetated swales, Infiltration trenches, Permeable pavement, Bioretention
Tertiary Treatment	Nutrients and dissolved heavy metals	Bioretention, Bio-infiltration systems, Wetlands, Retention ponds

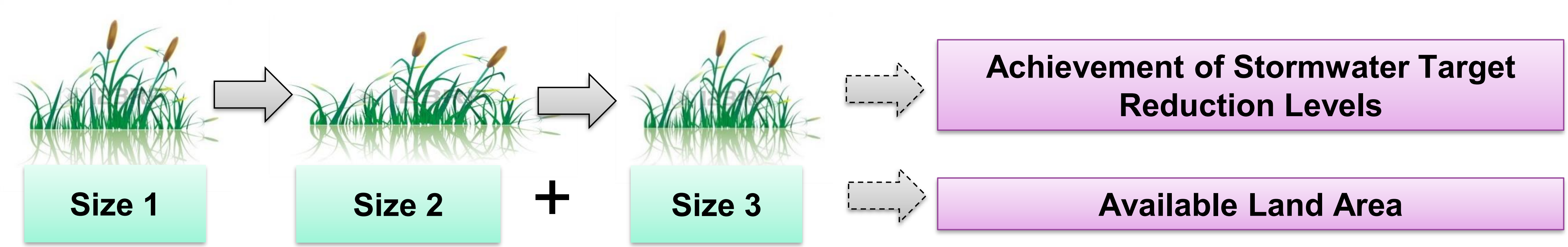
GI Treatment Trains



Advantages

- Enhanced pollutant removal with the number of different processes.
- Reduced risk of the system failure when one treatment device is failed.
- Ability of recreating the natural flow regime.
- Reduction of acute toxicity levels of stormwater for downstream aquatic ecosystems.
- Improvement of biodiversity.
- Improvement of liveability.

Challenges in Sizing of Treatment Trains



- Several treatment measures should be sized simultaneously.
- Different sizing combinations and difficulties in identifying which combination is the best.
- The availability of land.
- Costs associated with each of the treatment measures
- Achievement of target reduction levels.
- Other environmental, economic and social aspects.

Current Approach in Treatment Train Sizing

- Trial and Error
- Using Simulation Models
- Professional Judgment

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Case Study- Industrial Zone in Melbourne, Australia

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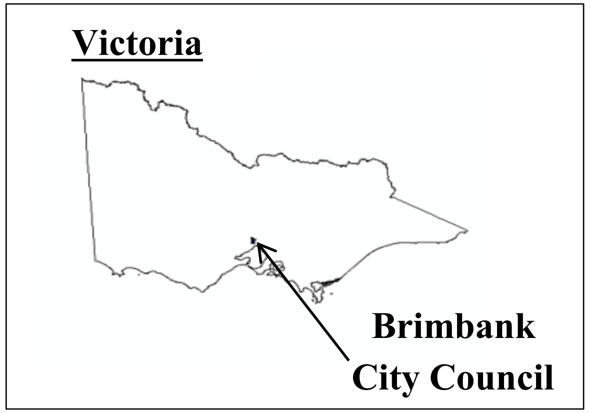
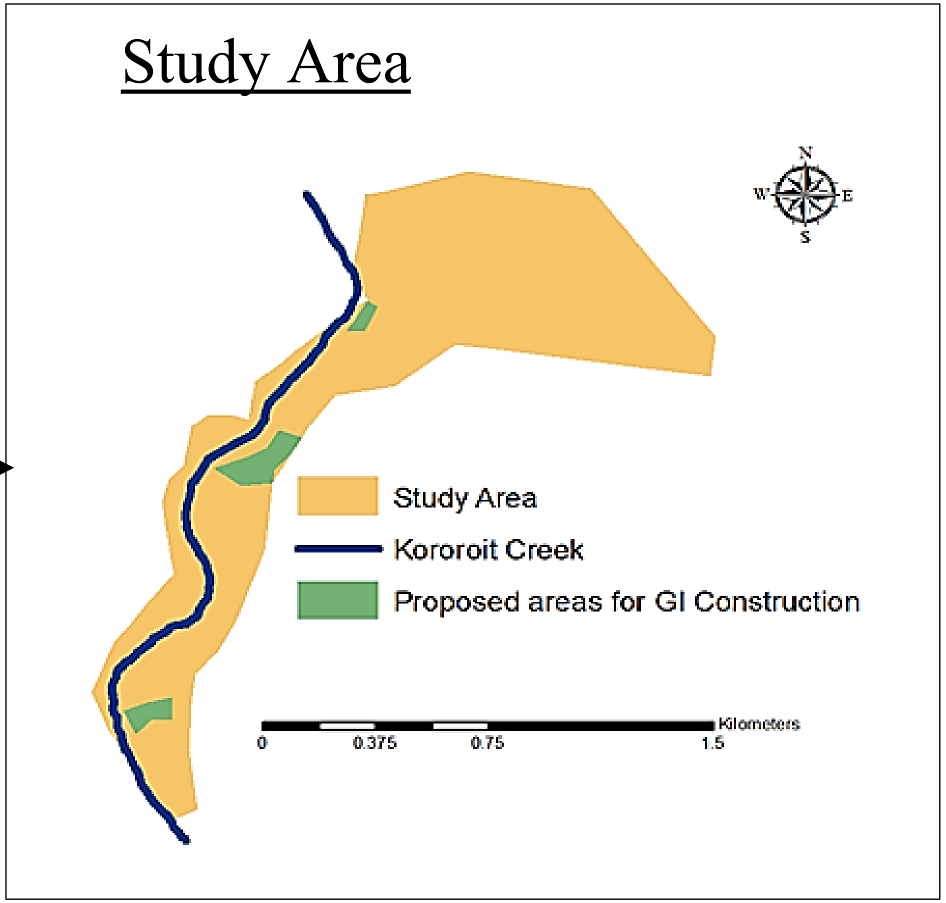
Study Area – Brooklyn Industrial Precinct





Potential GI practices

- ❑ Sedimentation Basin
- ❑ Vegetated Swale
- ❑ Bioretention
- ❑ Wetland
- ❑ Retention Pond

Treatment Trains

Combining Primary Secondary and Tertiary treatment measures

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Converting treatment train sizing into a mathematical optimization problem

Treatment Train Sizing as a Single Objective Optimization Problem

Objective Function

Minimizing the costs associated throughout the life cycle of the treatment train

Minimise $f(x_i)$ $i = 1.2, \ldots..n$

Subject to

$g_{TSS}(x_i) \geq TR_{TSS}$

$g_{TP}(x_i) \geq TR_{TP}$

$g_{TN}(x_i) \geq TR_{TN}$

$h(x_i) \leq LAA$

Where,

I = sizing combination
f(x) = Equivalent Annual Cost (EAC) of the treatment train
g(x) = treatment train effectiveness
TR = target reduction level
h(x) = land area required for GI to achieve target reduction level
LAA = land area available.

Target Reduction Levels - TSS – 80% , TP -45%, TN- 45%

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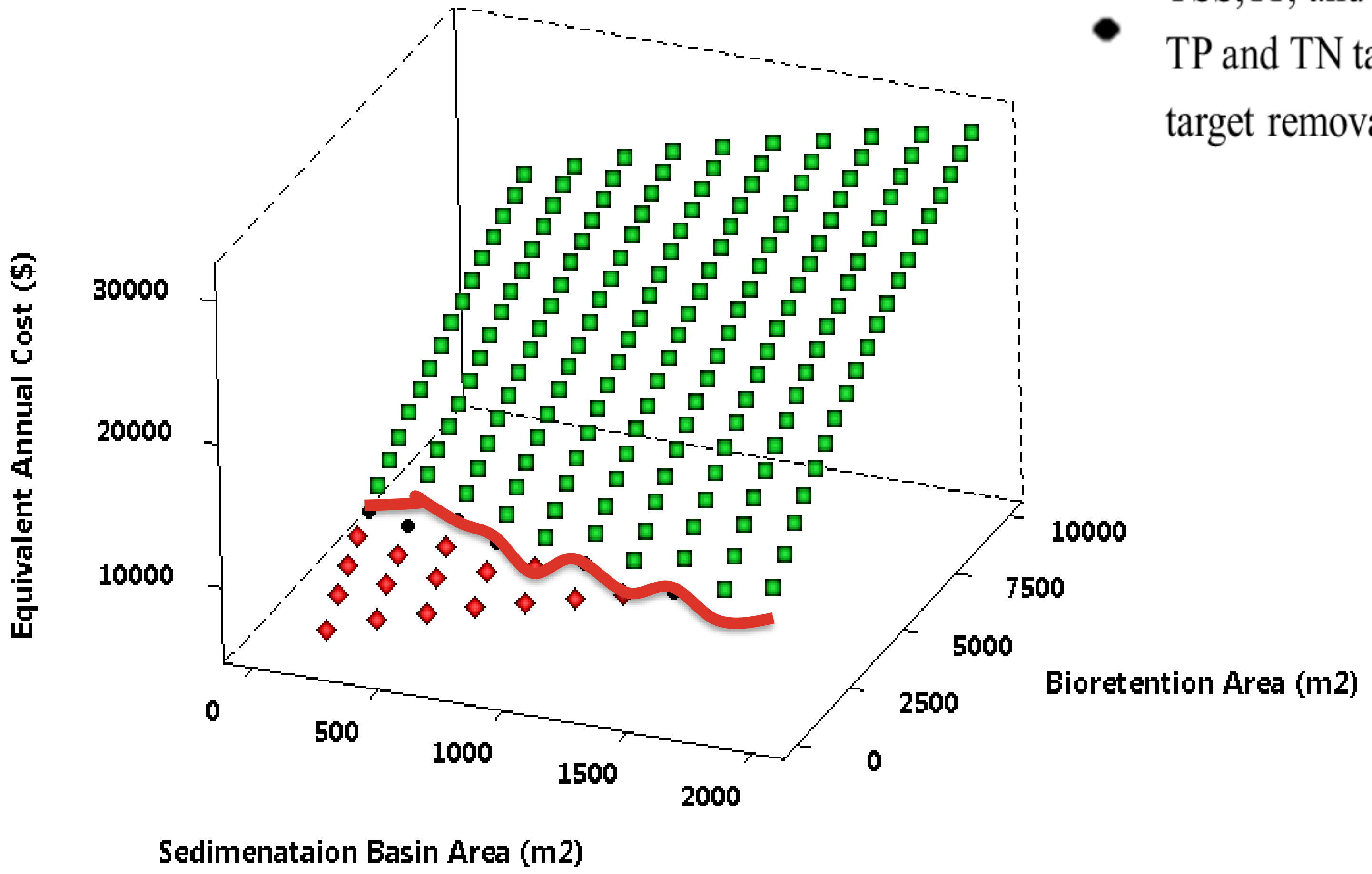
Treatment Train Configurations

Primary and Secondary Treatment	Primary and Tertiary Treatment	Primary, Secondary and Tertiary Treatment
❑ Sedimentation Basin and Vegetated Swale	❑ Sedimentation Basin and Retention Pond	❑ Sedimentation Basin, Vegetated Swale and Bioretention ❑ Sedimentation Basin, Vegetated Swale and Retention Pond ❑ Sedimentation Basin, Vegetated Swale and Wetland
❑ Sedimentation Basin and Bioretention	❑ Sedimentation Basin and Wetland	❑ Sedimentation Basin, Bioretention and Retention Pond ❑ Sedimentation Basin, Bioretention and Wetland
❑ Vegetated Swale and Bioretention	❑ Vegetated Swale and Wetland ❑ Vegetated Swale and Retention Pond	❑ Vegetated Swale, Bioretention and Retention Pond ❑ Vegetated Swale, Bioretention and Wetland

Results



TSS,TP, and TN target removal rates are achieved

TSS,TP, and TN target removal rates are not achieved

TP and TN target removal rates are achieved; TSS target removal rate is not achieved

Near optimal Solutions- Single Objective Optimization

- Treatment Trains with Two Treatment Measures
  - **66** Potential Sizing Combinations
- Treatment Trains with Three Treatment Measures
  - **219** Potential Sizing Combinations

Results

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Sample Treatment Train (Sedimentation Basin and Bioretention)

Near optimal Sizing Combinations for the treatment train – Sedimentation Basin and Bioretention

Sizing Combination	Sedimentation Basin Area (m^2)	Bioretention Area (m^2)	TSS Removal Efficiency (%)	TP Removal Efficiency (%)	TN Removal Efficiency (%)	Equivalent Annual Cost ($)
1	2000	500	80.6	69	52.6	14569
2	1800	500	80.2	66.3	50.1	13822
3	1600	1000	81.9	67.0	52.9	14680
4	1400	1000	81.2	63.9	50.3	13881
5	1200	1500	82.9	64.2	52.5	14365
6	1000	1500	80.6	61.6	49.5	13493
7	800	2000	81.7	60.6	51.7	13723
8	600	2500	82.7	60.0	53.5	13778
9	400	3000	82.7	58.8	53.8	13652
10	200	3000	80	55.4	50.7	12354

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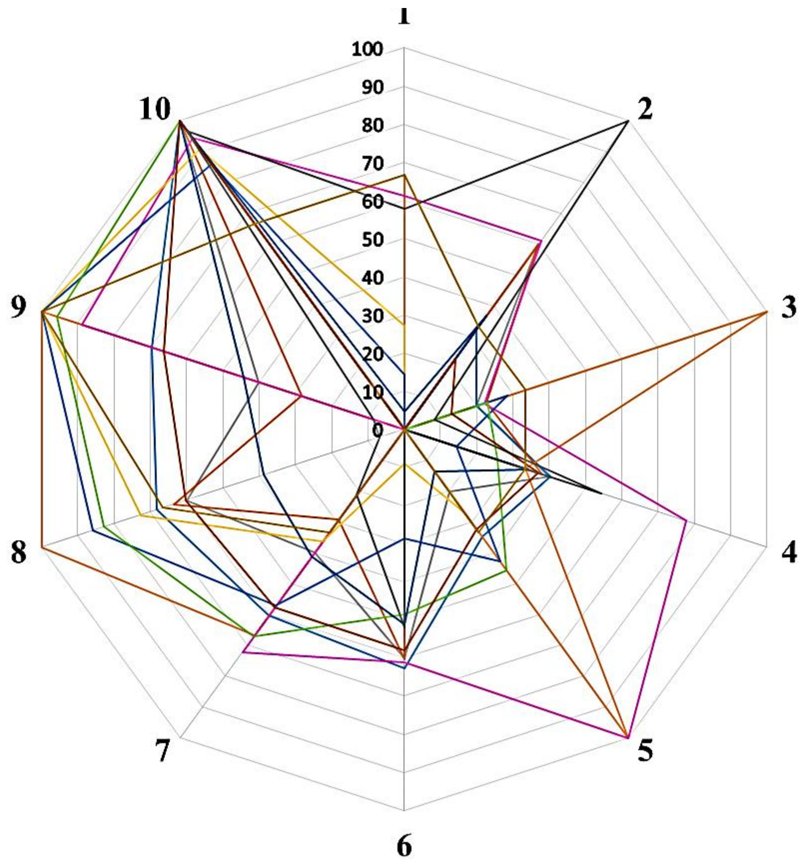
Results

Performance Measures- Sample Treatment Train (Sedimentation Basin and Bioretention)

X_{max} is better than X_{min} for maximizing - $\frac{(X - Xmin)}{(Xma_x - Xmin)} * 100$ When $X = X_{max}$, 100 and $X=X_{min}$, 0

X_{min} is better than X_{max} for minimizing - $\frac{-(X - Xmax)}{(Xma_x - Xmin)} * 100$ When $X = X_{min}$, 100 and $X=X_{max}$, 0



Sedimentation Basin and Bioretention

- Annual TSS Load Reduction (Kg/Yr)
- Annual TN Load Reduction (Kg/Yr)
- Zn Removal (%)
- Habitat Creation
- Equivalent Annual Cost ($)
- Annual Operation and Maintainace Cost ($)
- Annual TP Load Reduction (Kg/Yr)
- Cu Removal (%)
- Peak Flow Reduction (%)
- Portable Water Savings (ML/yr)
- Capital Cost ($)
- Improvement of Liveability

Stakeholder Preferences

Delphi Survey – 4 rounded iterative questionnaire series

Round 01
Identifying redundant/missing Performance Measures

Round 02
Finalize a set of performance measure for the GI selection for industrial areas

Round 03
Obtaining the weights for each of the performance measures

Round 04
Finalize the weights through gaining consensus of an expert panel

Rounds 3 and 4 - Obtaining the Weights

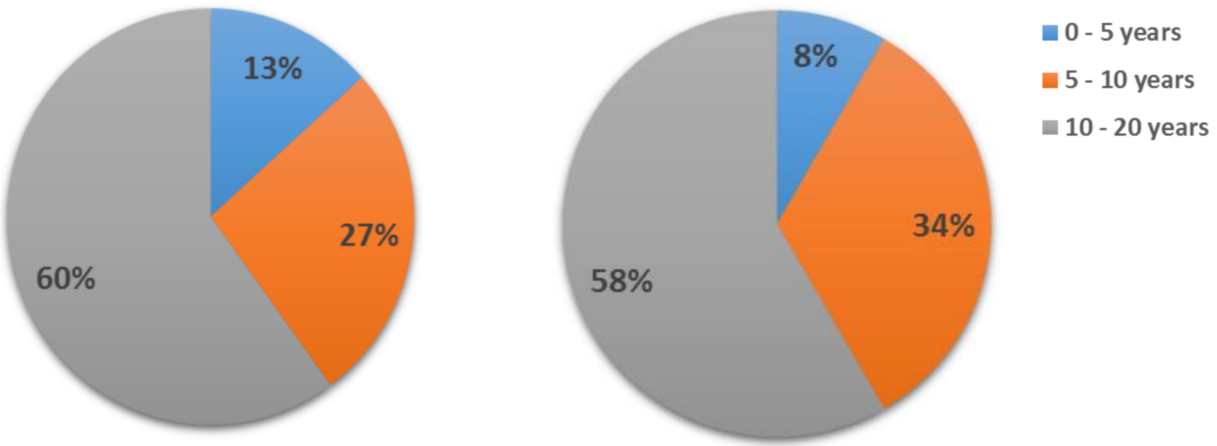
SWING Weighting Method

- Most Important Performance Measure – 100 points
- The weights for other performance measures – Based on this reference point

Expert Panel - Profile

ID	Expert Designation	Current Organization Type
1	Project Manager	Public Water Utility
2	Environmental Engineer	Consultancy
3	Senior Design Engineer	Local Government
4	Research Fellow	University
5	Water Resources Engineer	State Government
6	Strategic Supply Planner	Public Water Utility
7	Project Manager	Public Water Utility
8	Water Resources Planner	State Government
9	Senior Water Resource Analyst	Public Water Utility
10	Research Fellow	University
11	Senior Associate	Consultancy
12	Project Manager	Public Water Utility
13	Senior Drainage Engineer	Local Government
14	Technical Director - Water	Consultancy
15	Design Engineer	Local Government
16	Water Resources Engineer	Local Government

Round	Invited	Completed	Response Rate (By round)
Round 1	16	15	94%
Round 2	15	15	100 %
Round 3	15	13	87%
Round 4	13	12	92%



Start of the Survey

End of the Survey

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Delphi Survey- Measuring Consensus of the Expert Panel

Rounds 1 and 2

Objectives

- Investigating the environmental, economic and social performance measures important in GI selection for industrial areas
- Identify redundant or missing performance measures

Certain Level of Agreement – Two thirds of the panel

- Not Important (1)
- Slightly Important (2)
- Moderately Important (3)
- Very Important (4)
- Extremely Important (5)

Rounds 3 and 4

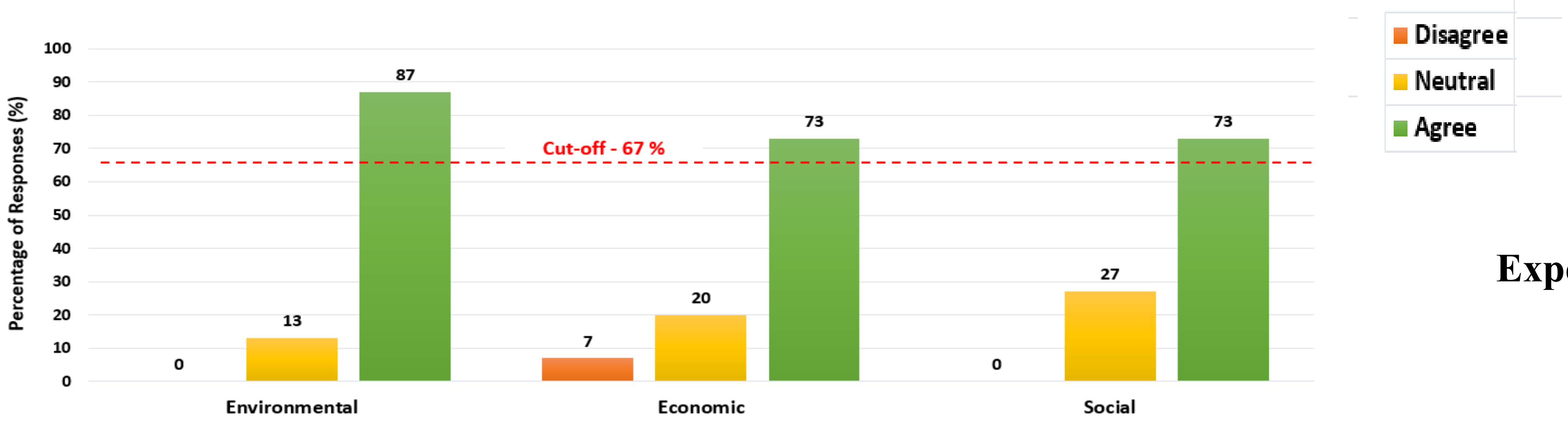
Objectives

- Weight elicitation for finalized performance measures
- Obtaining SWING weights for Performance measures

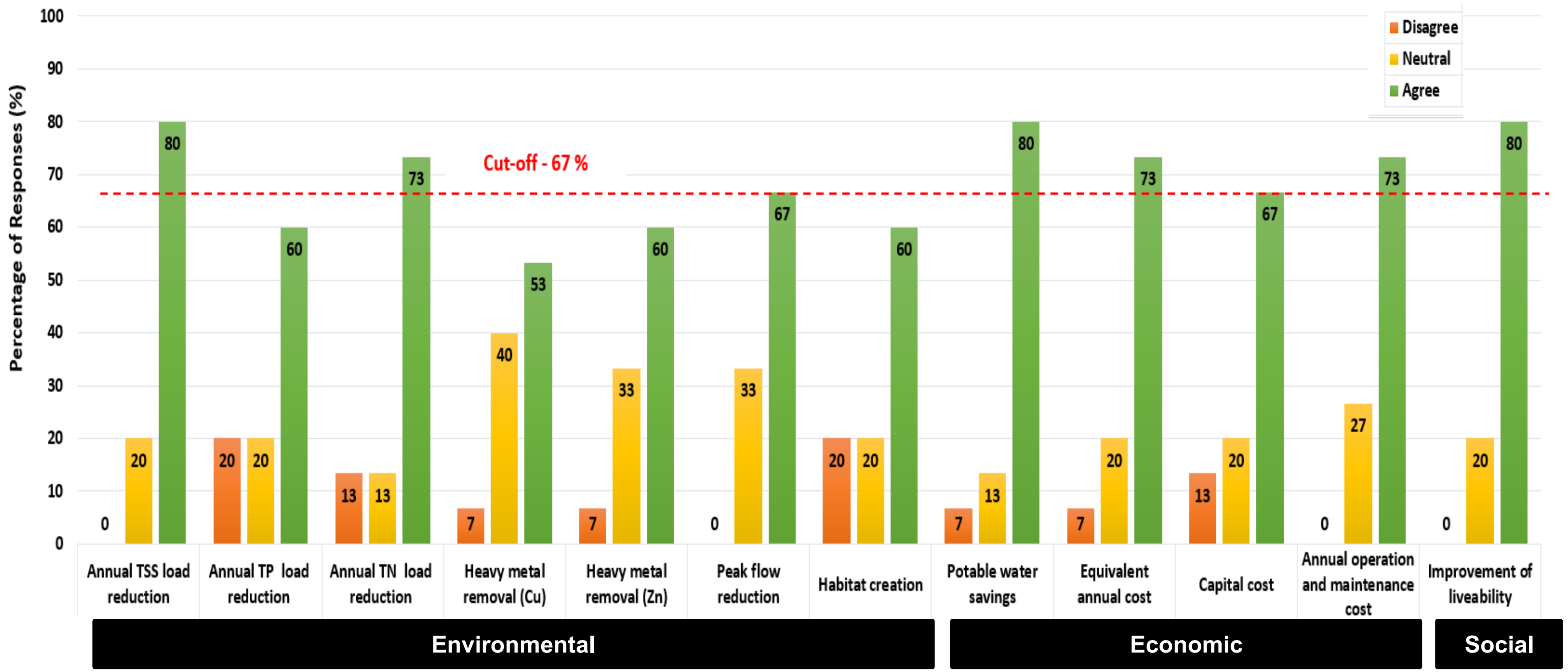
Coefficient of Variation of Weights

Coefficient of Variation (C_V)	Decision Rule
$0 < C_V \leq 0.5$	Good degree of consensus. No need for additional round.
$0.5 < C_V \leq 0.8$	Less than satisfactory degree of consensus. Possible need for additional round.
$C_V > 0.8$	Poor degree of consensus. Definite need for additional round.

Delphi Results – Round 1

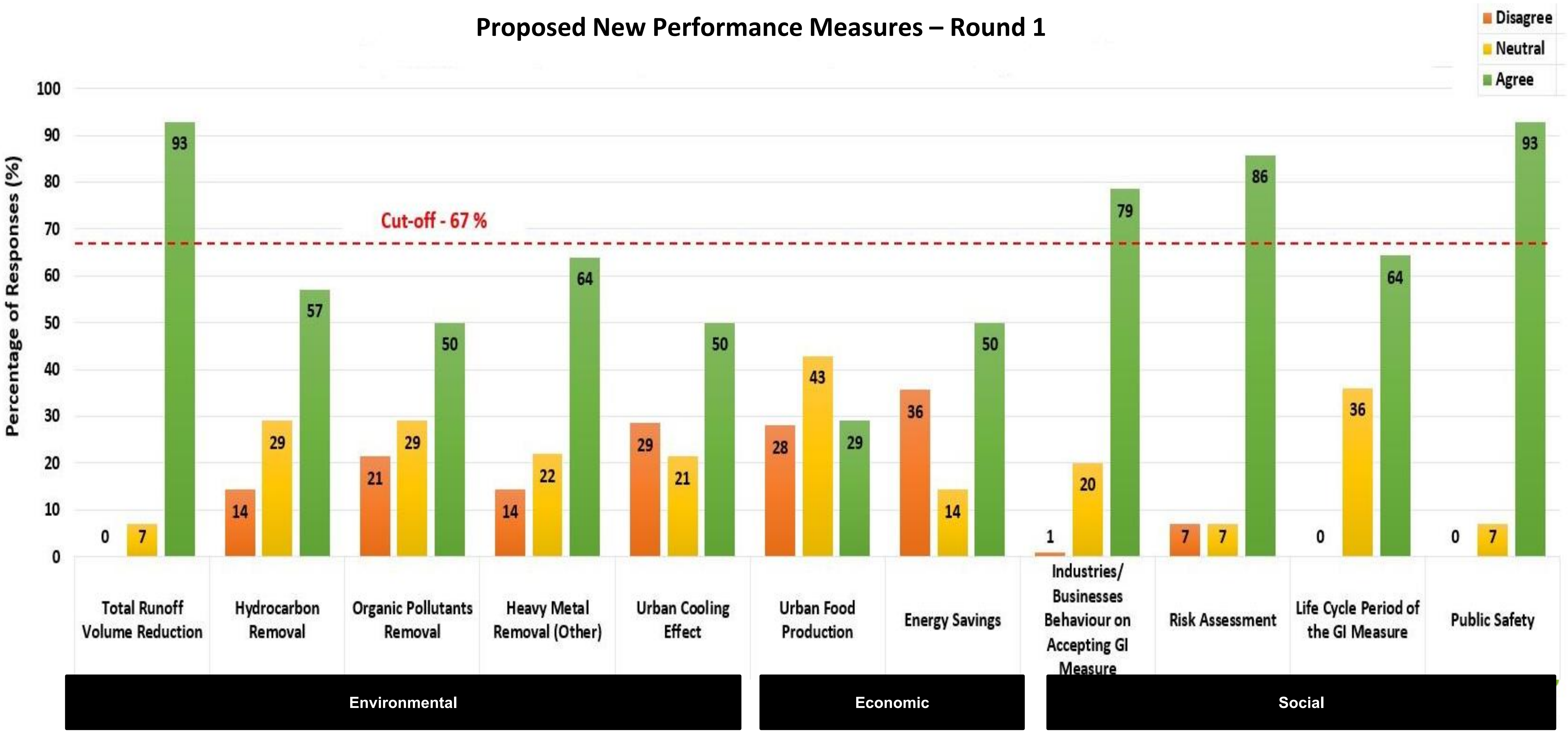


Expert ratings for Objectives – Round 1

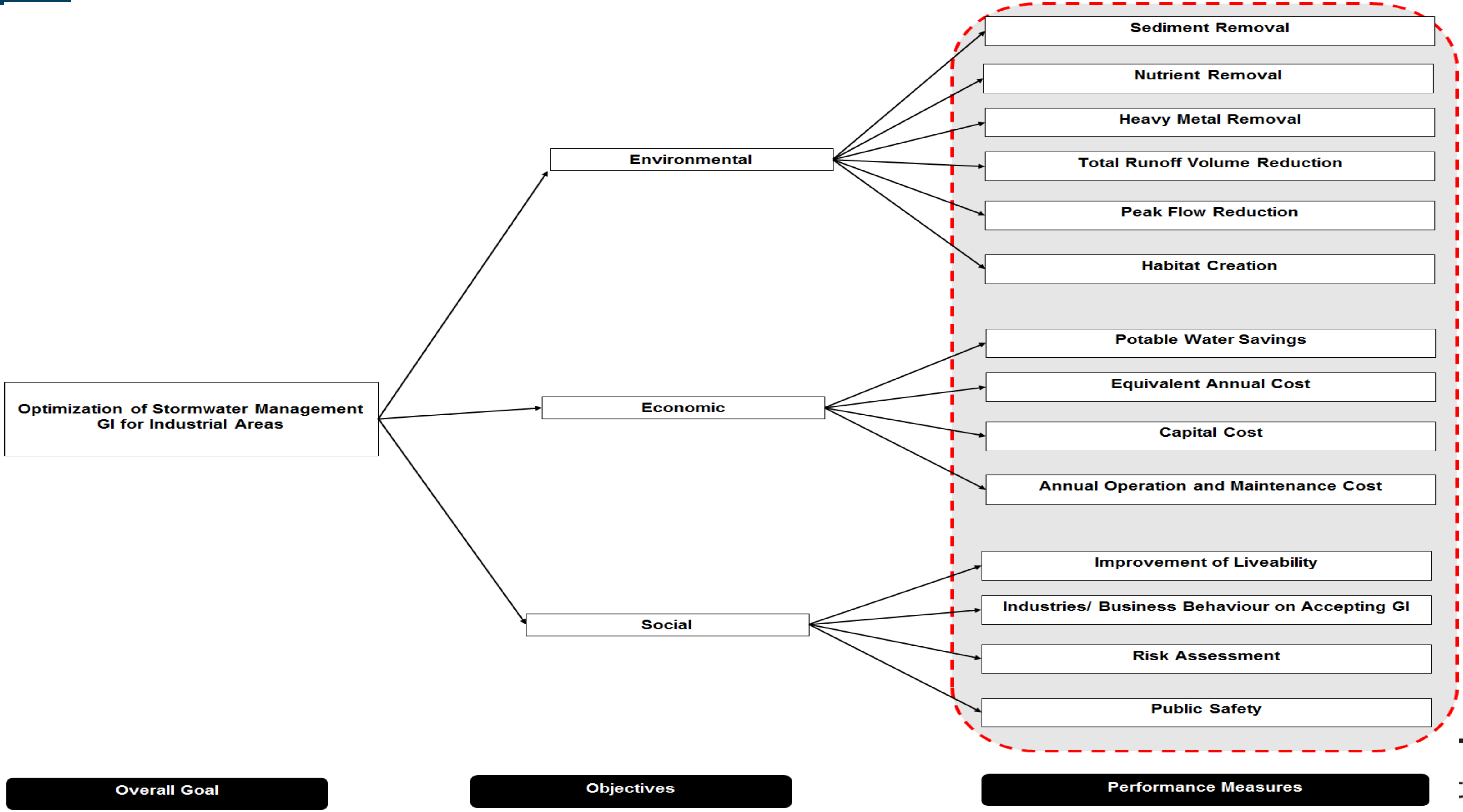


Expert Ratings for Performance Measures – Round 1

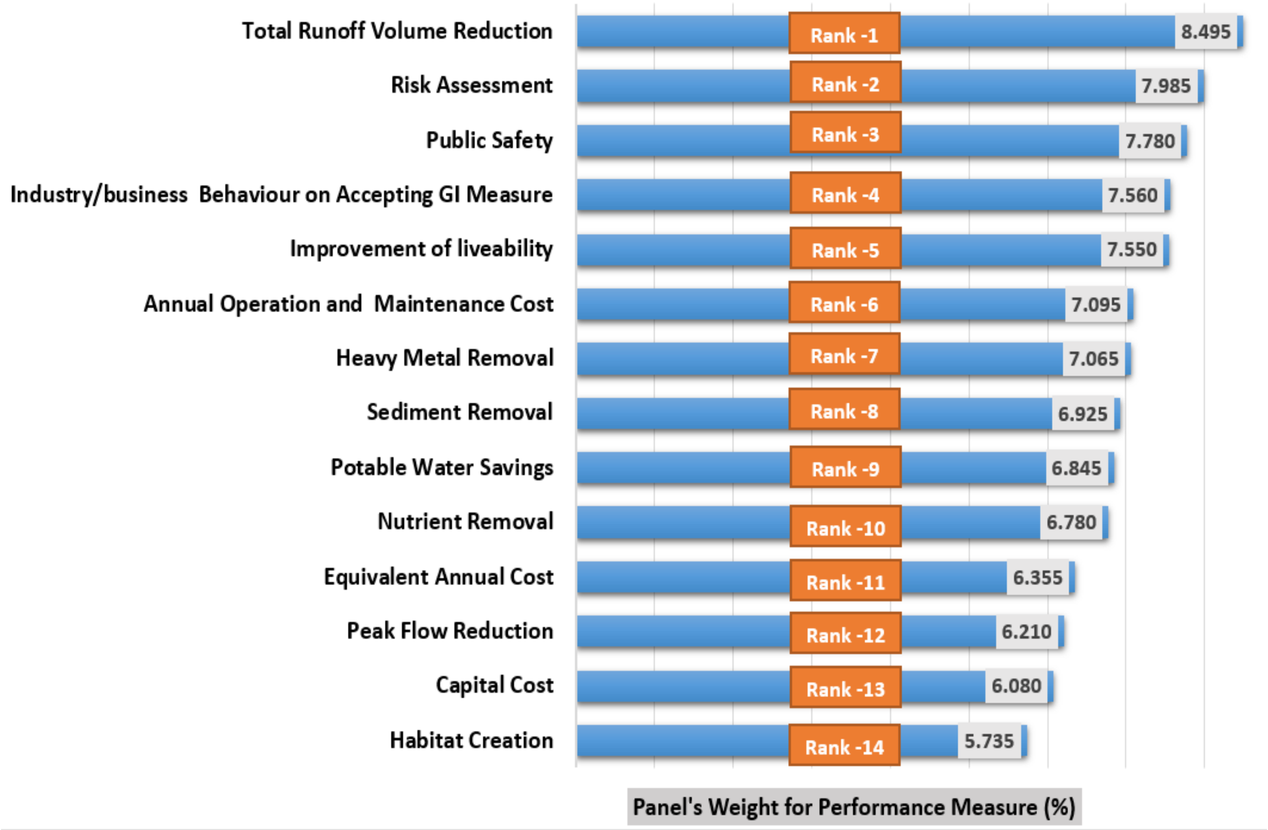
Delphi Results – Round 2



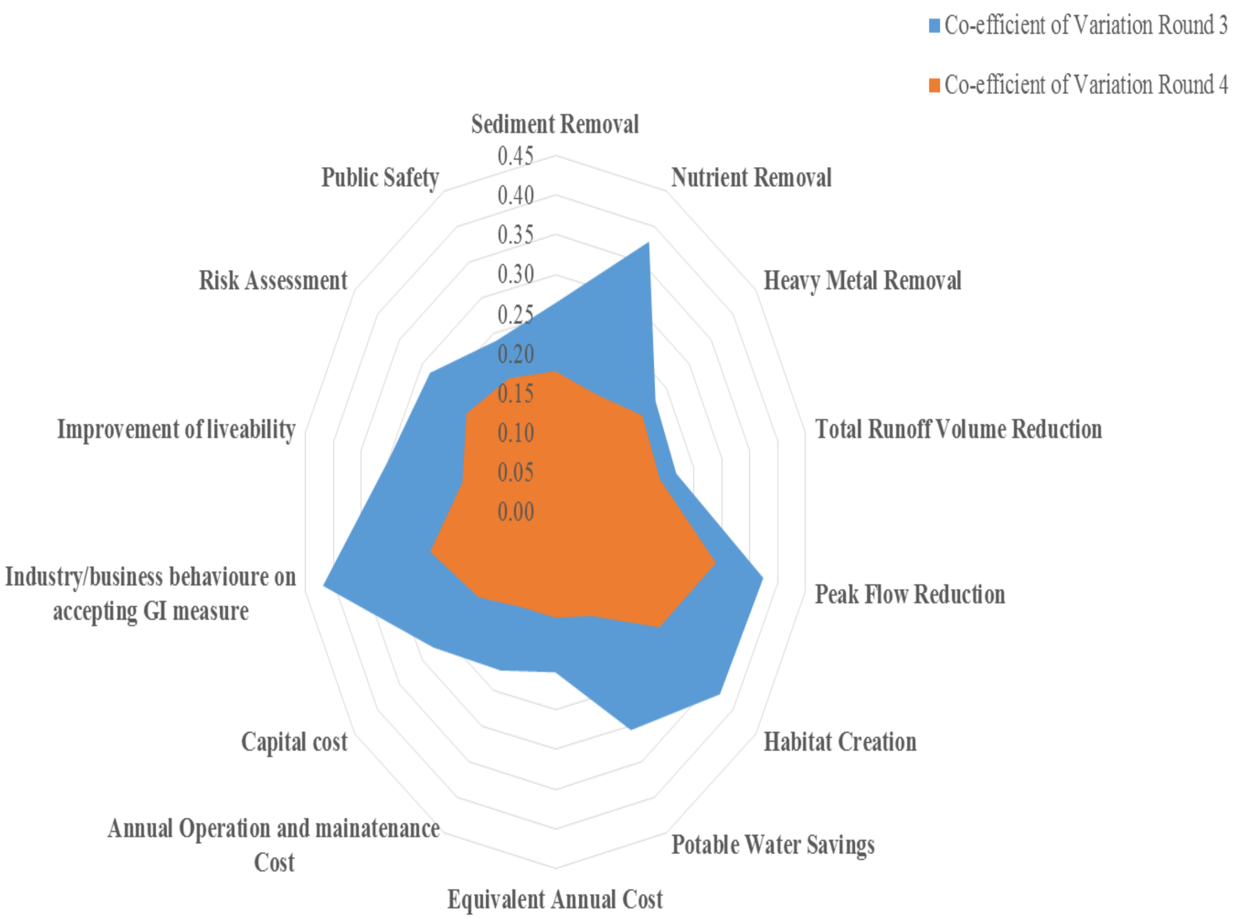
Delphi Results – Round 2



Delphi Results – Weight Elicitation (Rounds 3 and 4)



Final Weights and Ranks for Performance Measures – Round 4



Consensus Measurement – Rounds 3 and 4

Multi Criteria Decision Analysis

TOPSIS - The Technique for Order of Preference by Similarity to Ideal Solution

Positive Ideal Solution - The solution that maximizes benefit criteria and minimizes cost criteria

Negative Ideal Solution - The solution that maximizes the cost criteria and minimizes the benefit criteria

Closeness Coefficient - Separation Measure from the Positive ideal Solution

Results

Optimum Treatment Train Configurations and Sizing Combinations – Treatment Trains with Two Treatment Measures

Treatment Train Sizing Combination	Area of the Treatment Measure (m^2)		Separation Measure of the Group		Relative Closeness	Rank
	Treatment Measure 1	Treatment Measure 2	Positive Ideal	Negative Ideal	Closeness Coefficient	
SW_BR (10)	500	3500	0.03174	0.01998	0.6137	1
SW_BR (1)	5000	1500	0.03661	0.02354	0.6086	2
SW_BR (4)	3500	2000	0.03327	0.02266	0.5949	3
SW_BR (2)	4500	1500	0.03427	0.02404	0.5877	4
SDB_SW (1)	1000	4500	0.03200	0.02314	0.5803	5
SW_PD (1)	5000	1500	0.02999	0.02186	0.5783	6
SW_BR (9)	1000	3000	0.03011	0.02199	0.5780	7
SW_BR (7)	2000	2500	0.03042	0.02283	0.5712	8
SW_BR (5)	3000	2000	0.03111	0.02362	0.5684	9
SW_BR (3)	4000	1500	0.03202	0.02481	0.5634	10

SW – Vegetated Swale **SDB – Sedimentation Basin** **BR – Bioretention** **PD – Retention Pond**

Results

Optimum Treatment Train Configurations and Sizing Combinations – Treatment Trains with Three Treatment Measures

Treatment Train Sizing Combination	Area of the Treatment Measure (m^2)			Separation Measure of the Group		Relative Closeness	Rank
	Treatment Measure 1	Treatment Measure 2	Treatment Measure 3	Positive Ideal	Negative Ideal	Closeness Coefficient	
SW_BR_PD (9)	5000	500	1000	0.0109	0.0173	0.6128	1
SDB_SW_BR (42)	200	4500	1500	0.0122	0.0179	0.5946	2
SW_BR_PD (16)	3500	1000	1000	0.0110	0.0157	0.5887	3
SW_BR_PD (23)	500	2500	1500	0.0105	0.0149	0.5856	4
SW_BR_WL (1)	5000	500	1000	0.0118	0.0160	0.5764	5
SDB_SW_BR (39)	200	4000	1500	0.0125	0.0165	0.5691	6
SDB_SW_PD (20)	400	5000	1000	0.0120	0.0157	0.5667	7
SW_BR_PD (8)	4000	500	1000	0.0118	0.0152	0.5632	8
SDB_SW_BR (1)	200	500	3000	0.0114	0.0147	0.5618	9
SW_BR_PD (22)	1000	2000	1500	0.0112	0.0142	0.5583	10

SW – Vegetated Swale **SDB – Sedimentation Basin** **BR – Bioretention** **PD – Retention Pond** **WL- Wetland**

Conclusions

- Green infrastructure transform industrial landscapes from "**grey liabilities**" into productive, resilient spaces.
- The real challenge is smart design with balancing space, cost, and performance.
- Combining engineering tools with stakeholder insights leads to practical, adoptable solutions.
- Multi-criteria approaches help cities and industries choose GI options with confidence.

Thank you..!

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Open for discussions...

- ***Horizon Europe Collaborations***
- Cluster 5: **Climate, Energy and Mobility**

  Areas of interests: Urban Sustainability, Green Infrastructure, Urban Analytics, GeoAI and Smart Cities
- **France – Canada Research Fund (FCRF)**
- **For students – Mitacs Globelink Research Award** (3-month research internship in Canada)

HORIZON EUROPE

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