Rainfall Runoff Experiment and Solar Farms Optimisation

Presented By

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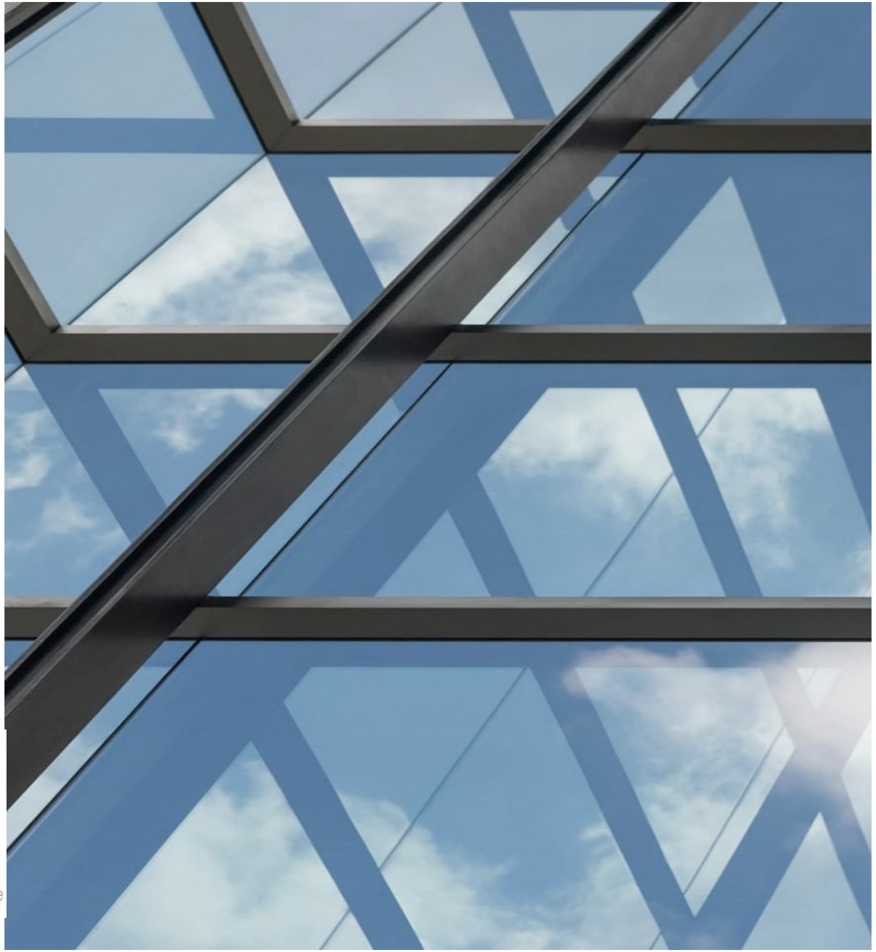
THE UNIVERSITY OF SYDNEY

Robert Bird Group
Member of the Surbana Jurong Group

Jacaranda Flame Consulting



Agenda

1. Team Introduction
2. Project Overview
3. Rainfall Runoff Experiment
4. Scouring Protection Design
5. Pavement Materials Optimisation
6. Questions

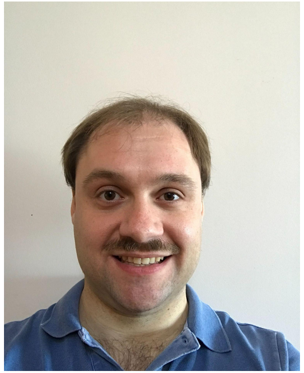
JFC Team Profile

Xiaoyi Xu
(Team leader)

Telecommunications

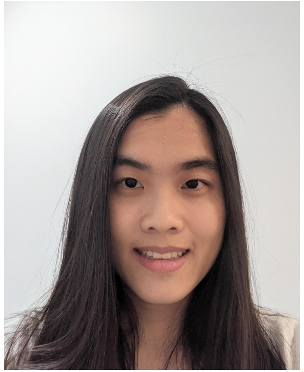
Vishant Prasad
(Client Liaison)

Mechatronic



Samuel G Doherty
(Team member)

Civil



Reaksmey Lim
(Team member)

Biomedical

Jiayu Wang
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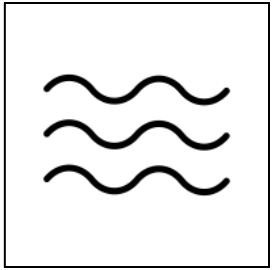
Civil

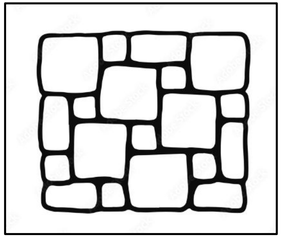
Hiu Fai NG
(Team member)

Civil

Agenda

- **Rainfall Runoff Experiment**
  - Aim & Context
  - Experimental Setup
  - Results
  - Conclusions
- **Scouring Protection Design Optimisation**
  - Context
  - Conventional Options
  - Alternative Options
    - Trade-off
  - Conclusion/Propositions
- **Pavement Design Optimisation**
  - Context
    - Geosynthetics
  - Conventional Options
  - Geosynthetics Options
    - Trade-off
  - Conclusion/Propositions
- **Questions?**





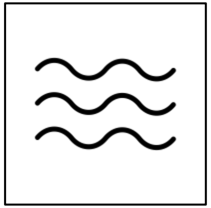
Project Overview

Robert Bird Group
Member of the Surbana Jurong Group

- Significant experience with design of Solar Farms.
- Research opportunity exists to optimise designs from civil engineering aspects.

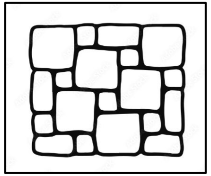
Rainfall Runoff Experiment

- Experimental investigation to evaluate and share findings of rainfall runoff effects.



Scouring Protection Design Optimisation

- Natural systems are used for drainage system.
- Standard Rock Protection



Pavement Design Optimisation

- Designed for minimal maintenance in high traffic areas.
- Current method is slightly conservative.
- Geosynthetic approaches.

Project Overview

- RBG has proposed the a review and optimisation of Solar Farm Civil Engineering aspects:
  - Pavements - Conservative after construction of a Solar Farm (Geosynthetics).
  - Stormwater - Drainage protection measures to combat scouring effects.

- Approached us with a proposal to undergo an experimental investigation to evaluate and share findings of rainfall runoff effects.

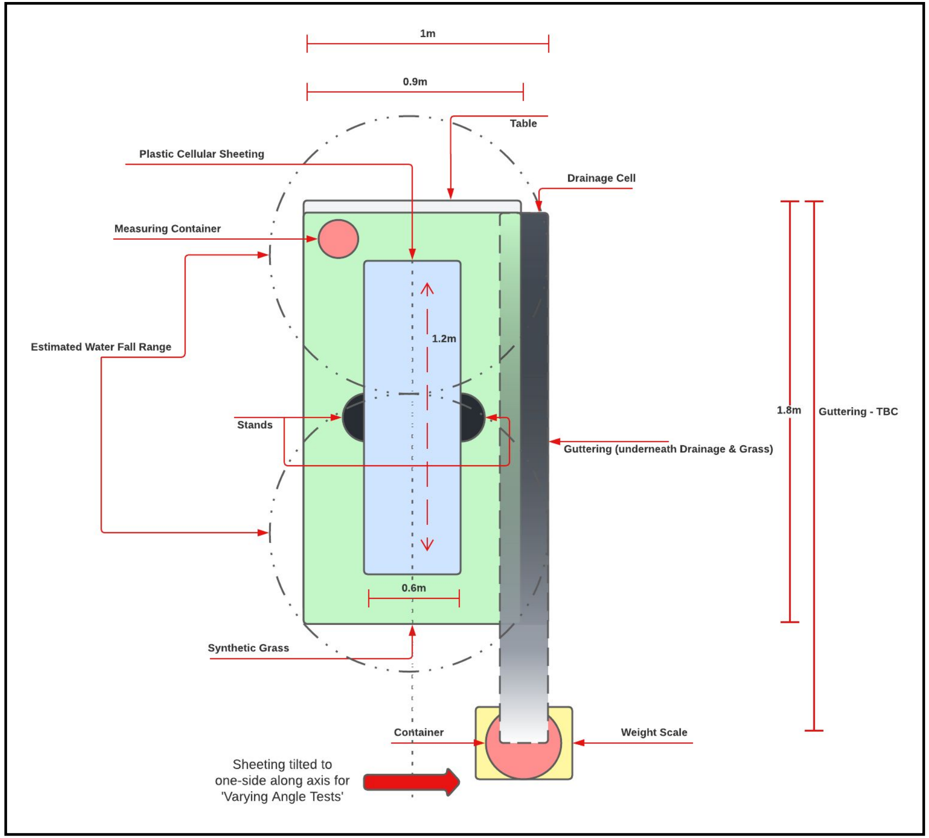
Rainfall Runoff Experiment

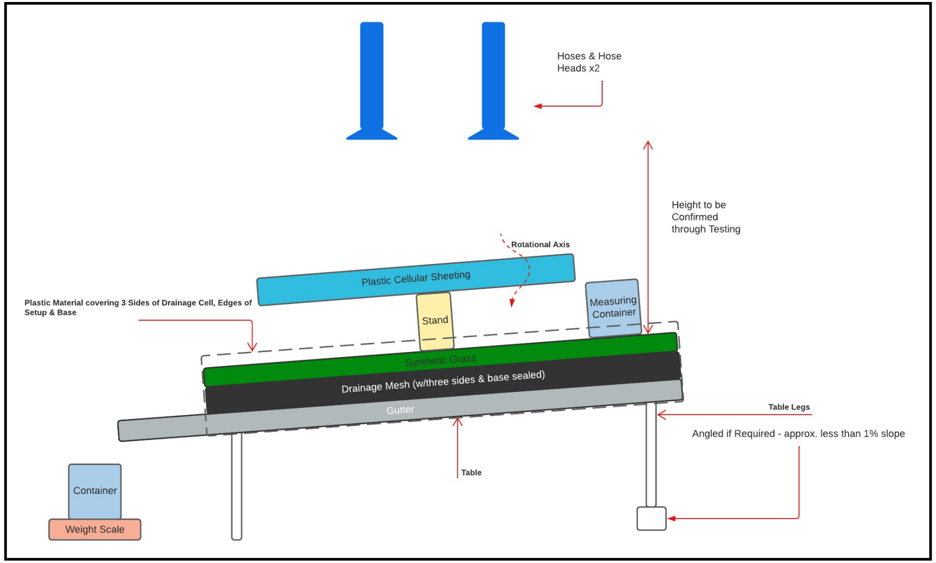
Aim & Background

- To find out if solar panel on grass would increase surface runoff during rainfall event compared to no solar panel on grass.

- To find out if the angle of solar panel would increase surface runoff on grass.

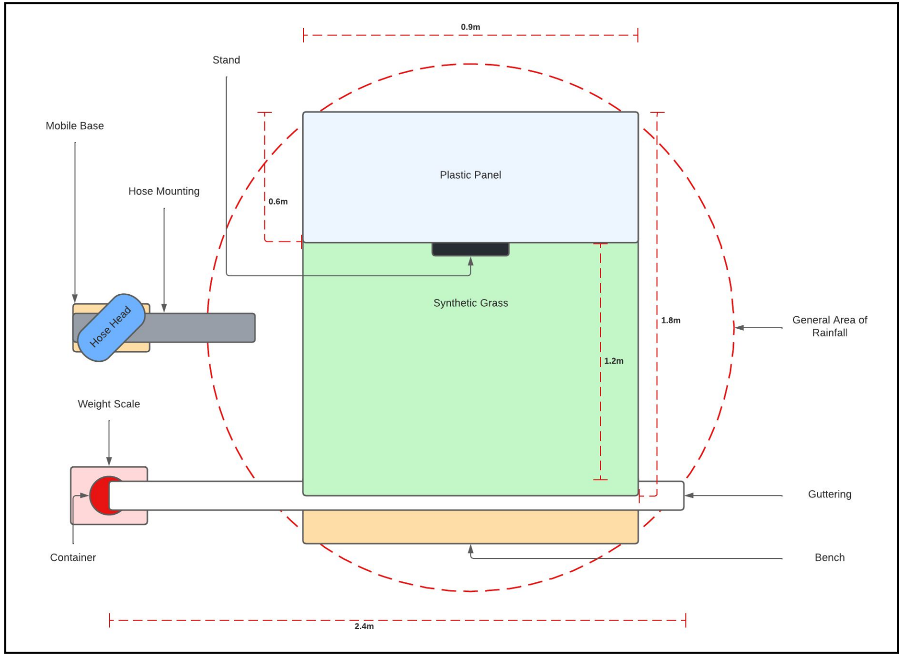
Experimental Setup



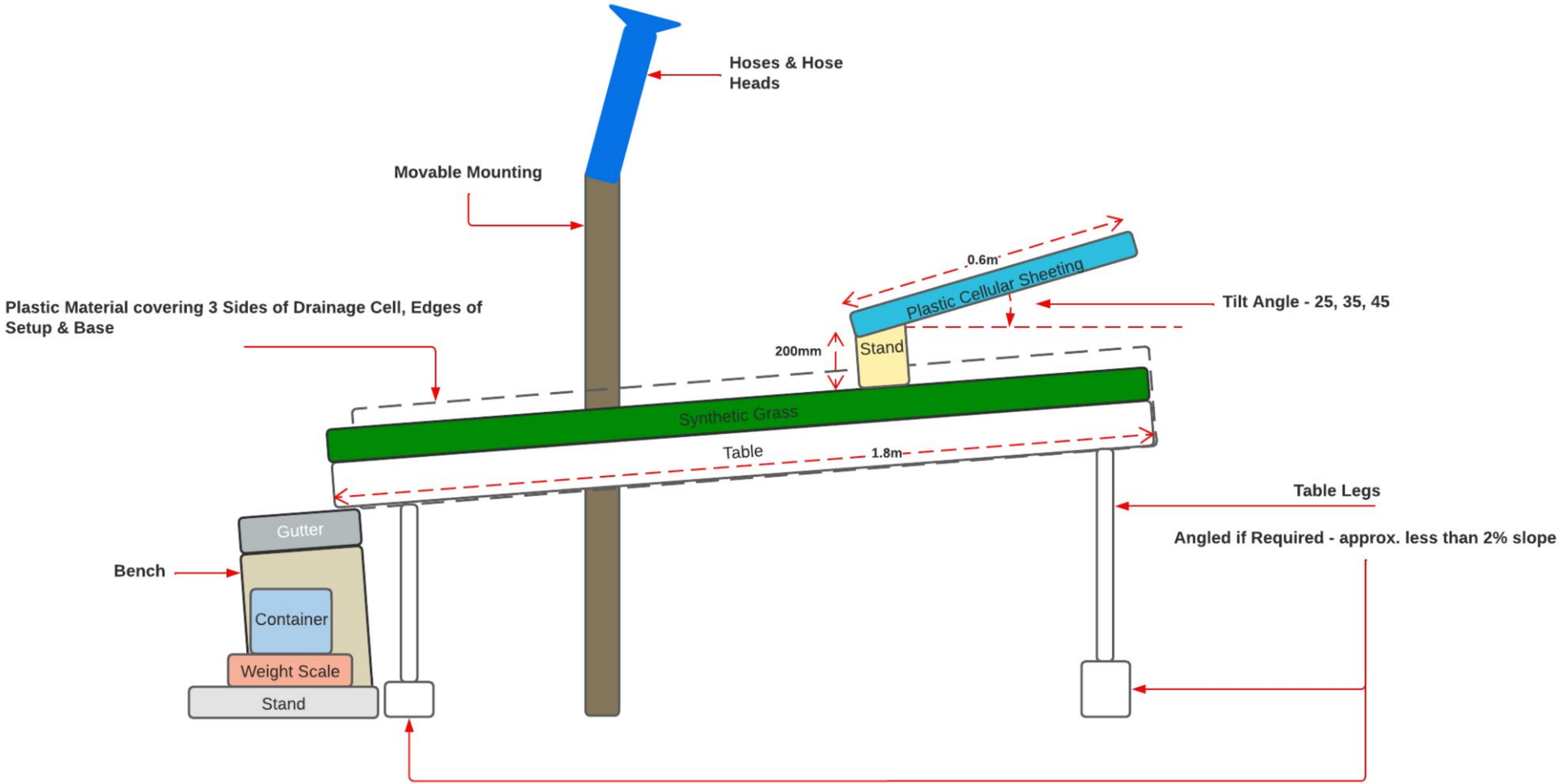


Experimental Setup

Experimental Setup



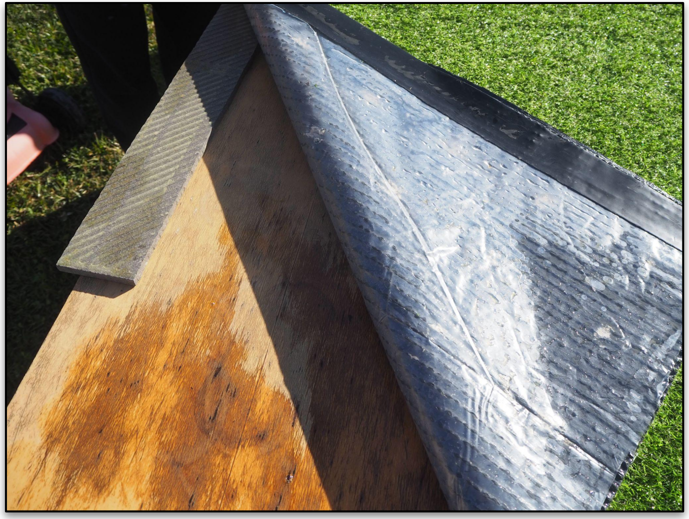
Experimental Setup



Experimental Setup

Making Grass Impermeable & Tiles on Edge

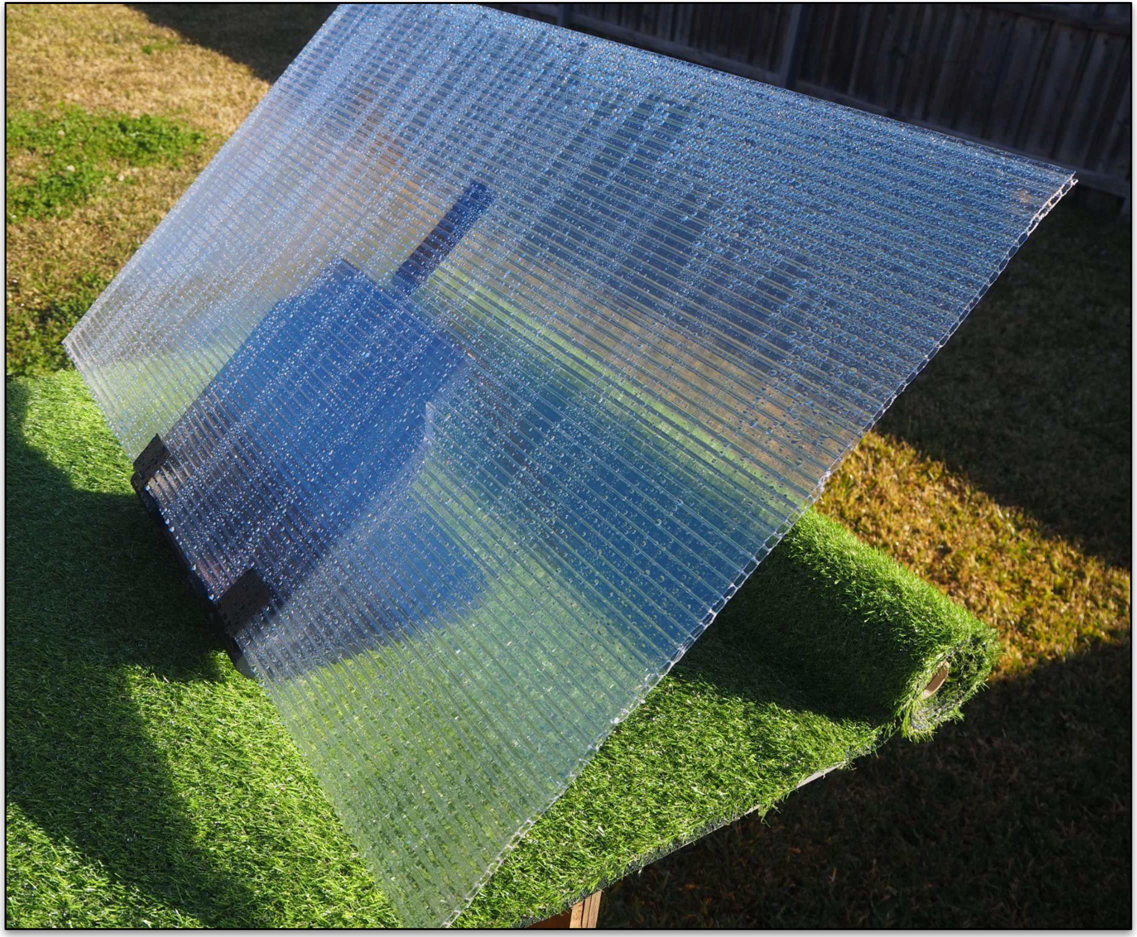
- Liquid nails & tiles used to ensure water flows on the surface.



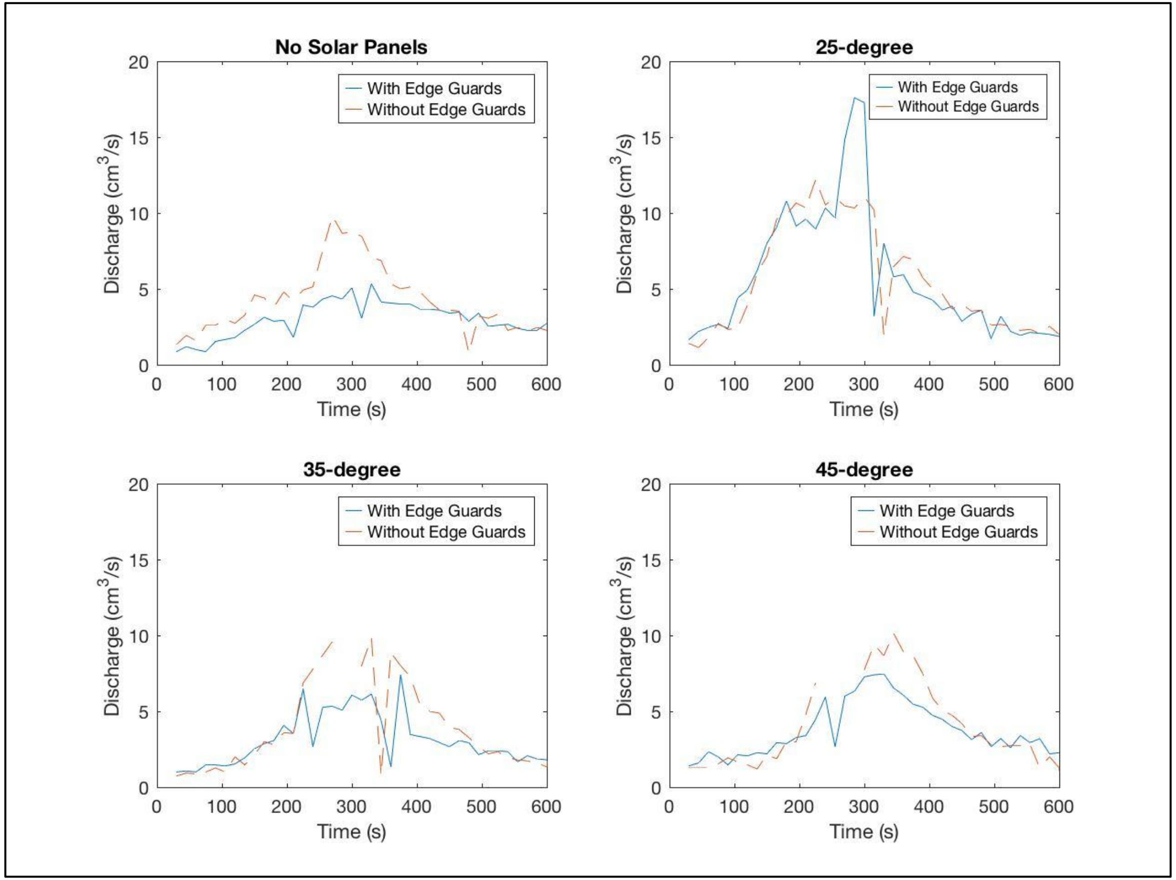
Gutter

Panal

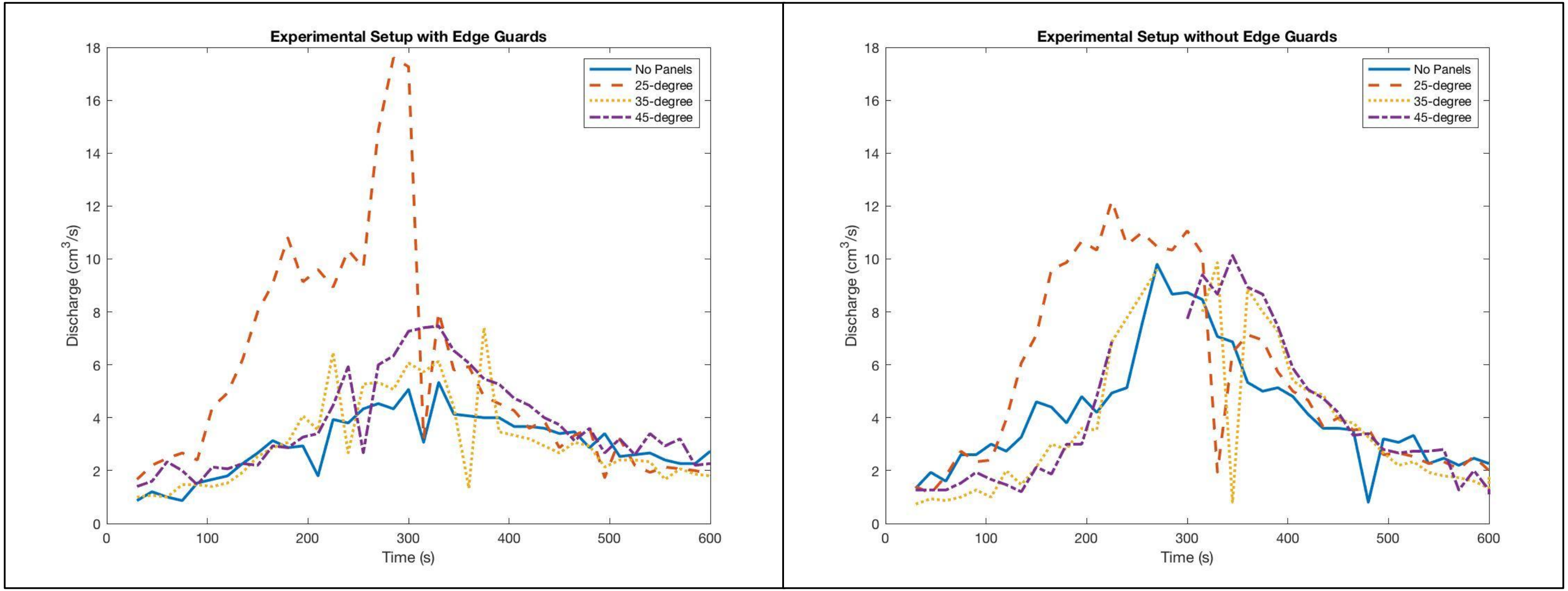
- Adjustable stand used to change angle.



Results for Edge Guards



Results



Experimental Setup with Edge Guards
Discharge (cm^3/s)
Time (s)
No Panels
25-degree
35-degree
45-degree
Experimental Setup without Edge Guards
Discharge (cm^3/s)
Time (s)
No Panels
25-degree
35-degree
45-degree

Conclusion

- Considerable effect on the surface runoff when having a solar panel at 25 degree angle.

- No significant effect on the surface runoff when having a solar panels at 35° & 45°.

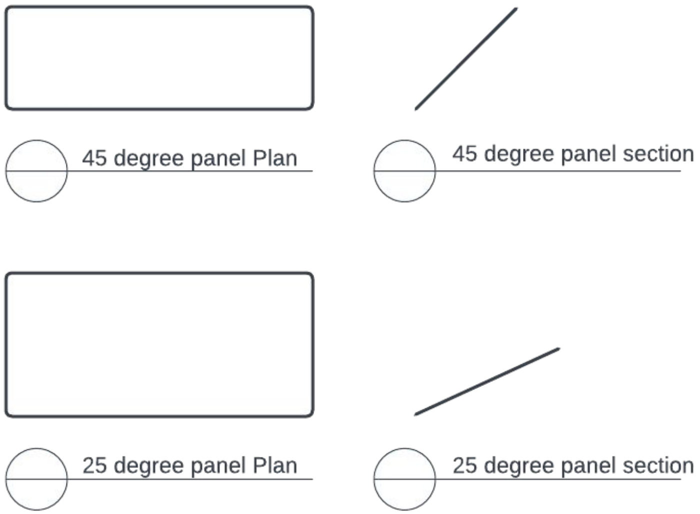
- Kinematic Wave Equation

$$T_c = \frac{6.94 n' L^{0.6}}{i^{0.4} S^{0.3}}$$

T_c	Time of concentration (min)
L	Overland sheet flow path length (m)
n'	Surface Roughness (Retardance Coefficient)
i	Rainfall intensity (mm/hr)
S	Slope (m/m)

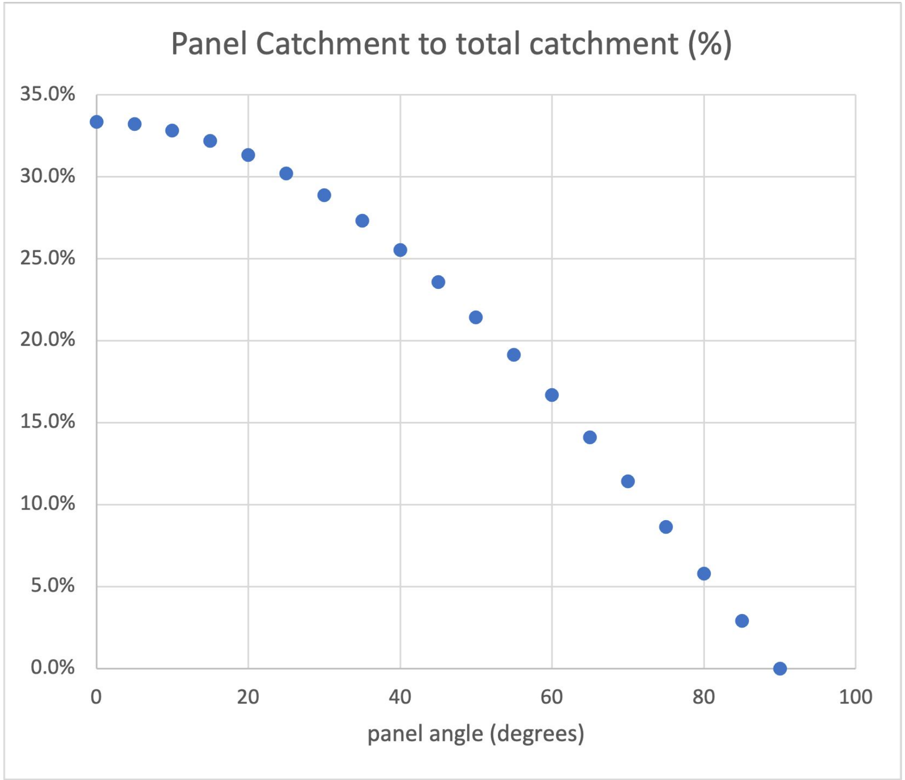
Result Explanation

- For why 25 degree has considerable effect
- Panel slope that changes the panel's 'catchment' area



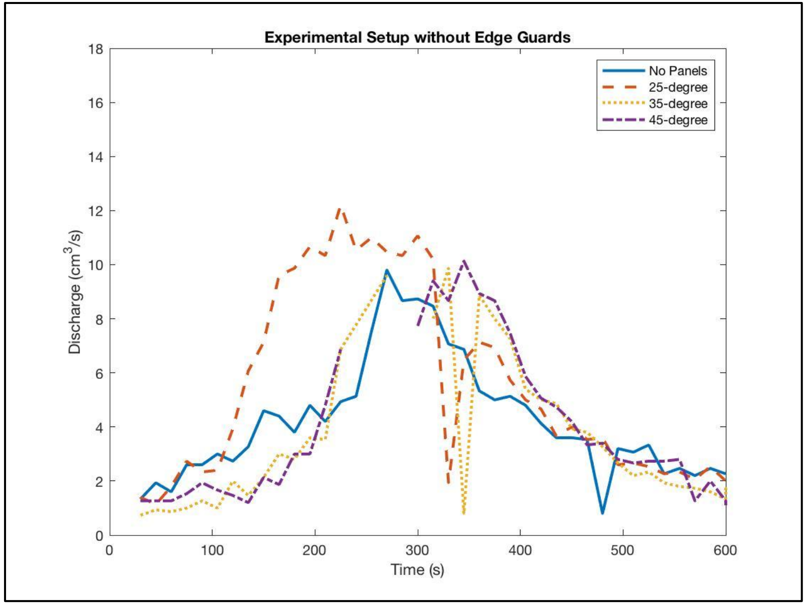
Changes of Panel Catchment

Panel width (m)	total grass length (m)	
0.6	1.8	
cases	projected distance (m)	panel catchment to total catchment (%)
no panel	na	0%
90	0.00	0.0%
85	0.05	2.9%
80	0.10	5.8%
75	0.16	8.6%
70	0.21	11.4%
65	0.25	14.1%
60	0.30	16.7%
55	0.34	19.1%
50	0.39	21.4%
45	0.42	23.6%
40	0.46	25.5%
35	0.49	27.3%
30	0.52	28.9%
25	0.54	30.2%
20	0.56	31.3%
15	0.58	32.2%
10	0.59	32.8%
5	0.60	33.2%
0	0.60	33.3%



Result Explanation Continued

- For why 35 and 45 degree have no significant effect.



- Due to the steepness of the panel, there are some panel catchment area but might not be sufficient direct runoff volume from the panel to make a difference.

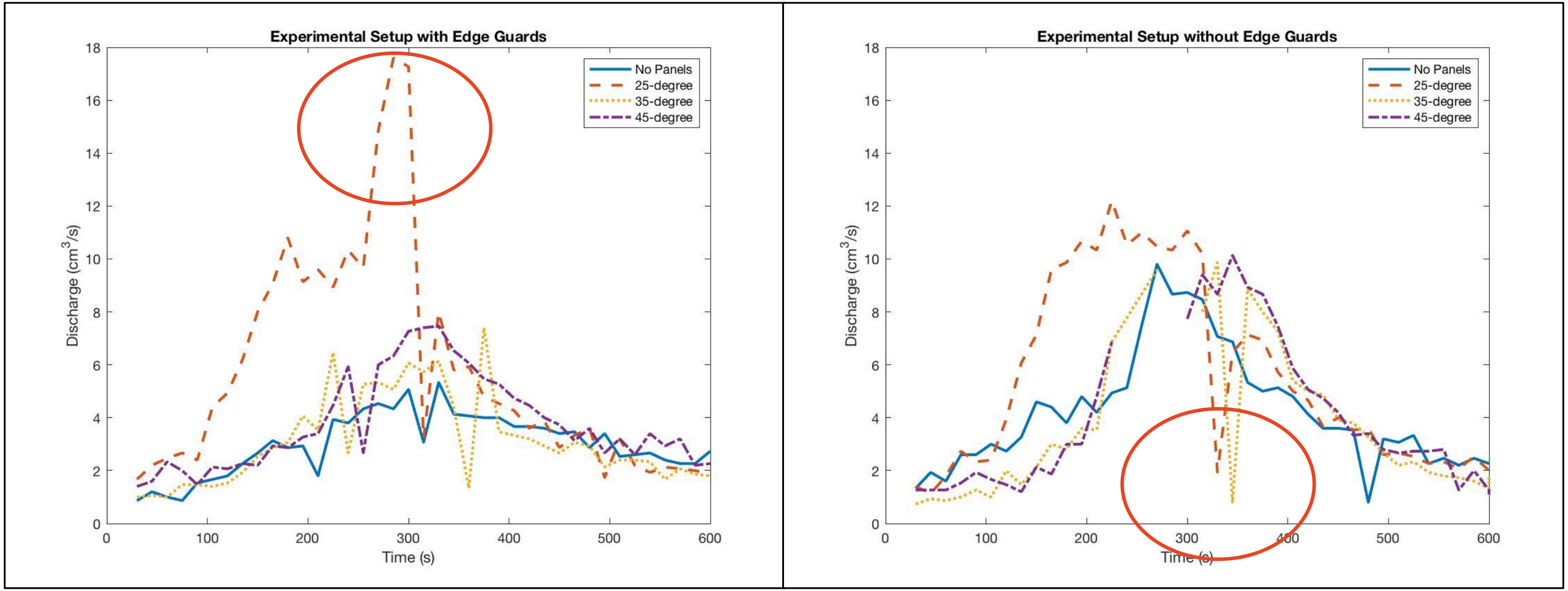
- Panel might be an interference since the panel is wide and rain comes in all direction.

- Many other variables.

Further Investigation

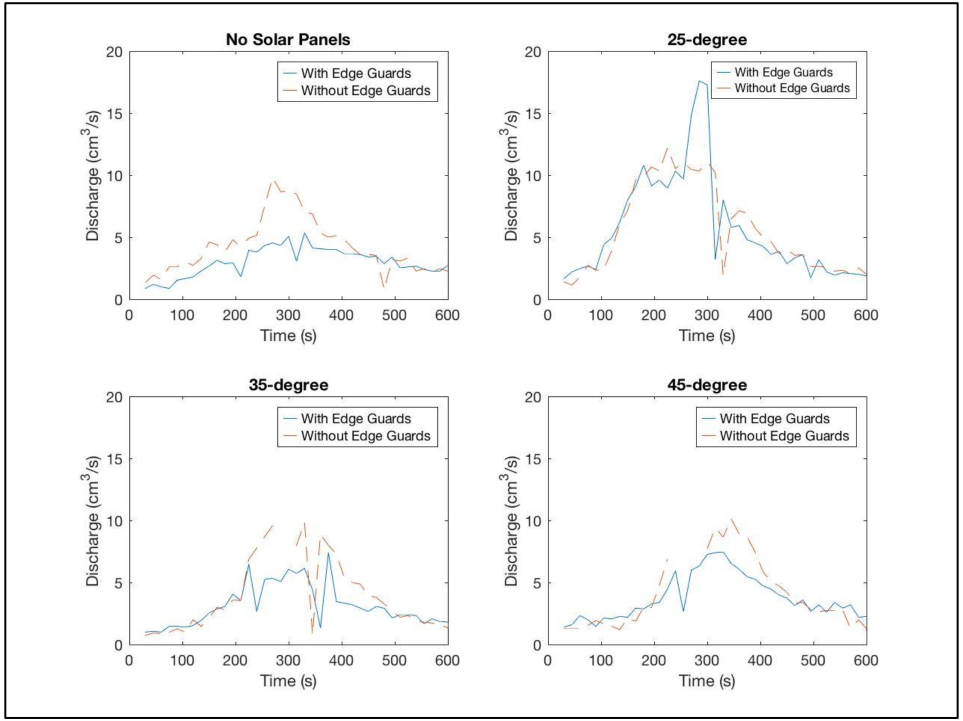
Angles	Investigation Reasons	Why this angle/details
90 (vertical)	- see if interference exist and decreases runoff	- presumably has most interference
25	- see if 25 degree slope itself makes difference in runoff	- concluded 25-degree panel has considerable effect but unsure of the critical variable - change the panel catchment to total catchment percentage to ~23.6% by using a longer grass, and compare to the 45-degree curve and no-panel curve from original dimensions
various	- see if 30% ”catchment percentage” is a hurdle to increase surface runoff	- keep the same 30% “catchment percentage” and change the angle compared to no-panel case
0-5 (horizontal)	- see if no slope increase runoff	- solar panel angle in extreme wind event - make sure water on panel flow in one direction
60	- see if it changes runoff	- solar panel night-time angle - can use same set-up

Observation from the Experiment



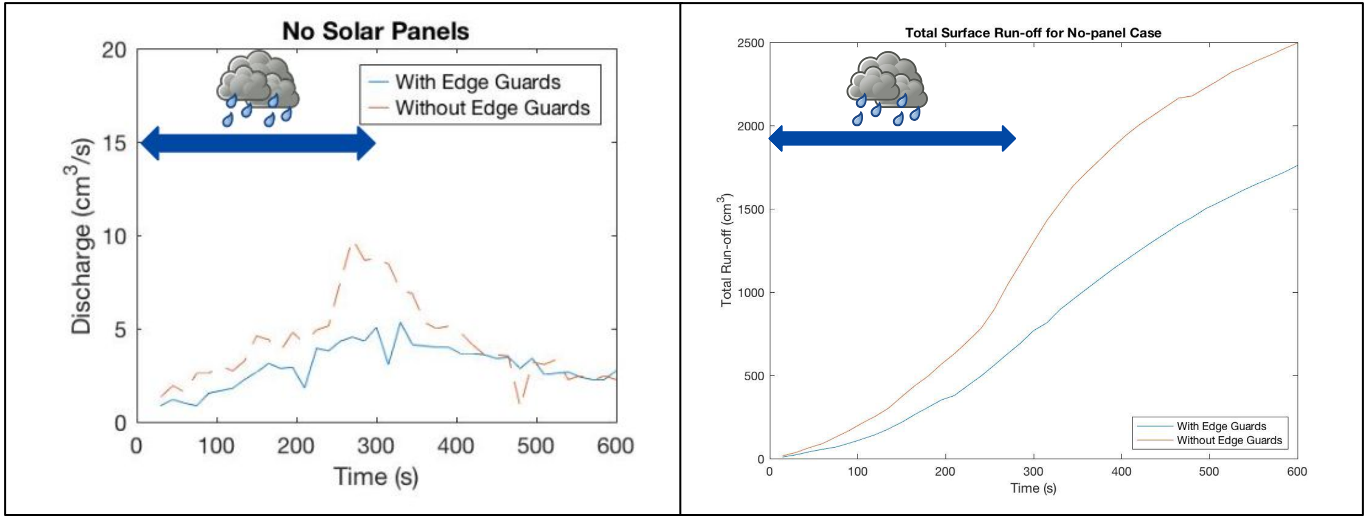
Edge Treatment Findings

- Edge treatment reflects cutting a section of a solar farm.
- Results for the “no solar panel case” denote the opposite of expectations.
- Other cases show similar results between edge guarding vs no guarding with given explanations providing possible reasoning.



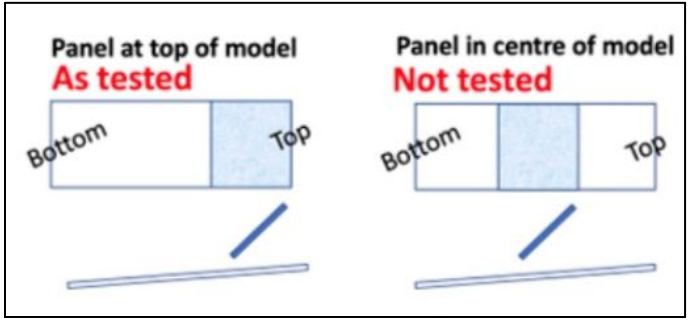
No Solar Panel Case

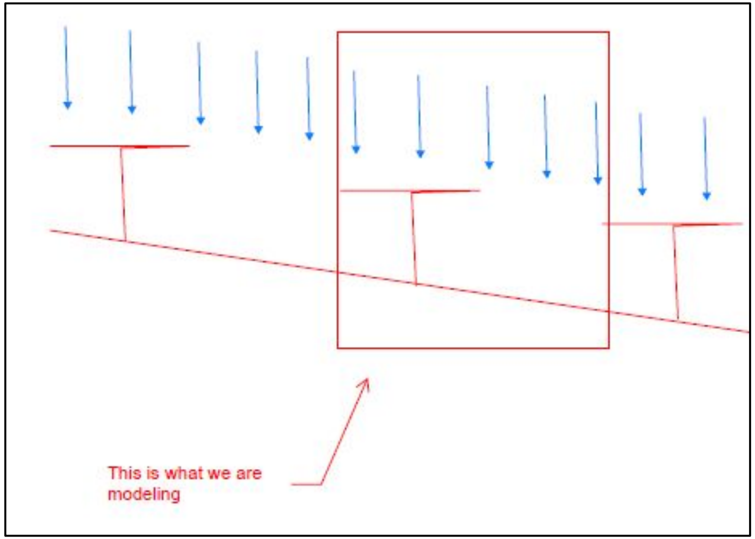
- Reasoning for the difference being as significant as indicated by results in the "no panel case" is possibly due to rainfall coverage fluctuations.
  - Rainfall coverage is critical.
  - Time of day & wind conditions as an important factor/variable.



Panel Placement

- Two Arrangements:
  - Top
  - Centre

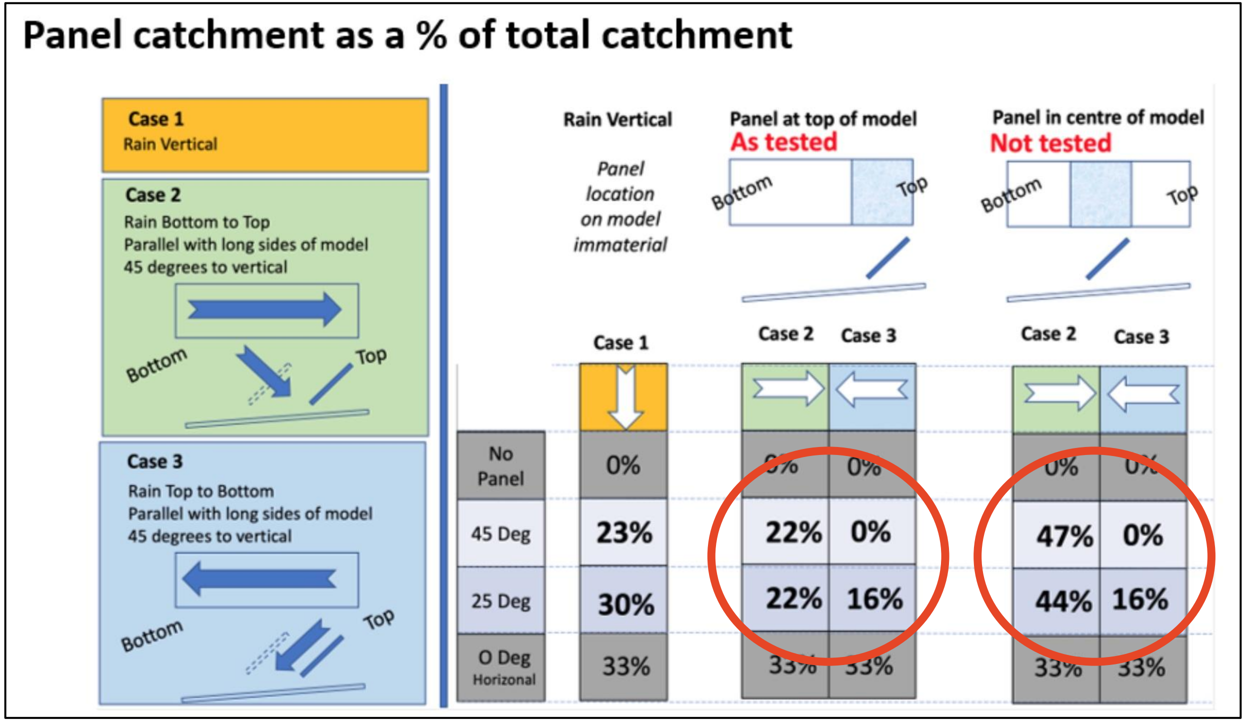




Panel Placement

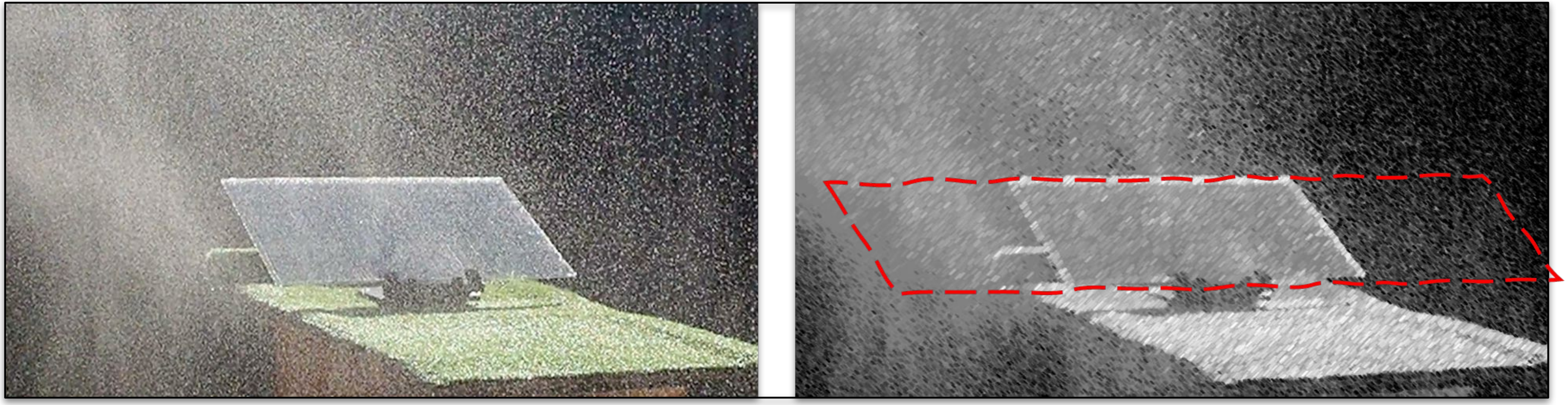
- Assuming the direction of rain and angle it is making with the vertical have the potential to affect the runoff data.

- Panel placement becomes an important factor.



Improvement for the Experimental Set-up

- Increasing the panel's span can reduce the rain swirling into the panels shade therefore, investigating runoff more closely.



Improvement for the Experimental Set-up

- Weather - Wind Conditions
- Consistent Rainfall Coverage
  - Secondary Container
- Consistent Saturation

- Synthetic Grass
  - Length & Density
  - Infiltration

- Secure Apparatus
  - Bucket
  - Scale
  - Gutter

Scouring Design Optimisation

Background

- The environment of solar farms in case of non-typical heavy rain - drainage can be overwhelmed with intense water flow.

- Counter the effects of water flow causing erosion within drainage within sites.

Products

- Geosynthetics
- Conventional Approaches
  - Concrete Blanket
  - Rock
- Mat & Mesh

Scouring Design Optimisation

Conventional Options

- Rock Protection
- Concrete Blanket
  - Higher Cost
  - Limited Sustainability Aspects
    - Sourcing Rocks
    - Transportation
    - Resulting Soil Effects
    - Production Process - CO_2
    - Machinery & Energy Demands
    - Permanent Removal of Soil

Scouring Design Optimisation

Alternative Options

Geosynthetic Clay Liners

Geotextile Tubing

Geocells

Geotextile Sand Containers

Articulated Concrete Blocks

Reinforced Turf Mat

Erosion Control Mat

Coir Mesh

Concrete Mesh

Scouring Design Optimisation – Evaluation Criteria

1. **Ease of Installation**
   - Material Density (Self-weight)
   - Required Construction Time
   - Feasibility
2. **Product Costs**
3. **Effectiveness**
   - Level of Erosion Control
     - Tensile Strength
     - Permeability
     - Flow velocity
4. **Maintenance**
   - Lifespan/ Durability
   - Maintenance Cost
5. **Environmental Impact**
   - Material Itself
   - Transportation
   - Construction

Scouring Design Optimisation – Evaluation Table

Criteria			Ease of Installation	Product Costs	Level of Scouring Protection	Maintenance	Environmental Impact
ID	*Options*	*Images*					
1	Reinforced Turf Mat (Enkamat)		Moderate	$8.99/m2	2.2 - 3.9m/s	Low	Low
2	Erosion Control Mat (TerraMat)		Simple	$16.6/m2	2-6m/s from Range of Products 7.2m/s w/Vegetation	Low	Moderate
3	Coir Mesh		Simple	$3.65/m2	4.8m/s	High	Low
4	Concrete Mat		Simple	$37-38.5/m2	5.79m/s	Low	Moderate
5	Articulated Concrete Blocks		Simple	$150-432/m2	4.3m/s & 6m/s w/Vegetation	Low	Moderate
6	Geosynthetic Clay Liners		Moderate	$0.10-$0.25/m2	Permability > 10^-12 to 10^-10 m/s	Low	Low to Moderate
7	Geotextile Tubing		Moderate	$950-$1200/m	22.22m/s	Low	Low
8	Geocells		Simple	$4.95/m2 or $9.43/m2 Depending on Grading	3-6m/s Depending on Infill Materials	Moderate	Low
9	Geotextil Sand Containers		Simple	$43/m2	2.5m/s	Low	Low

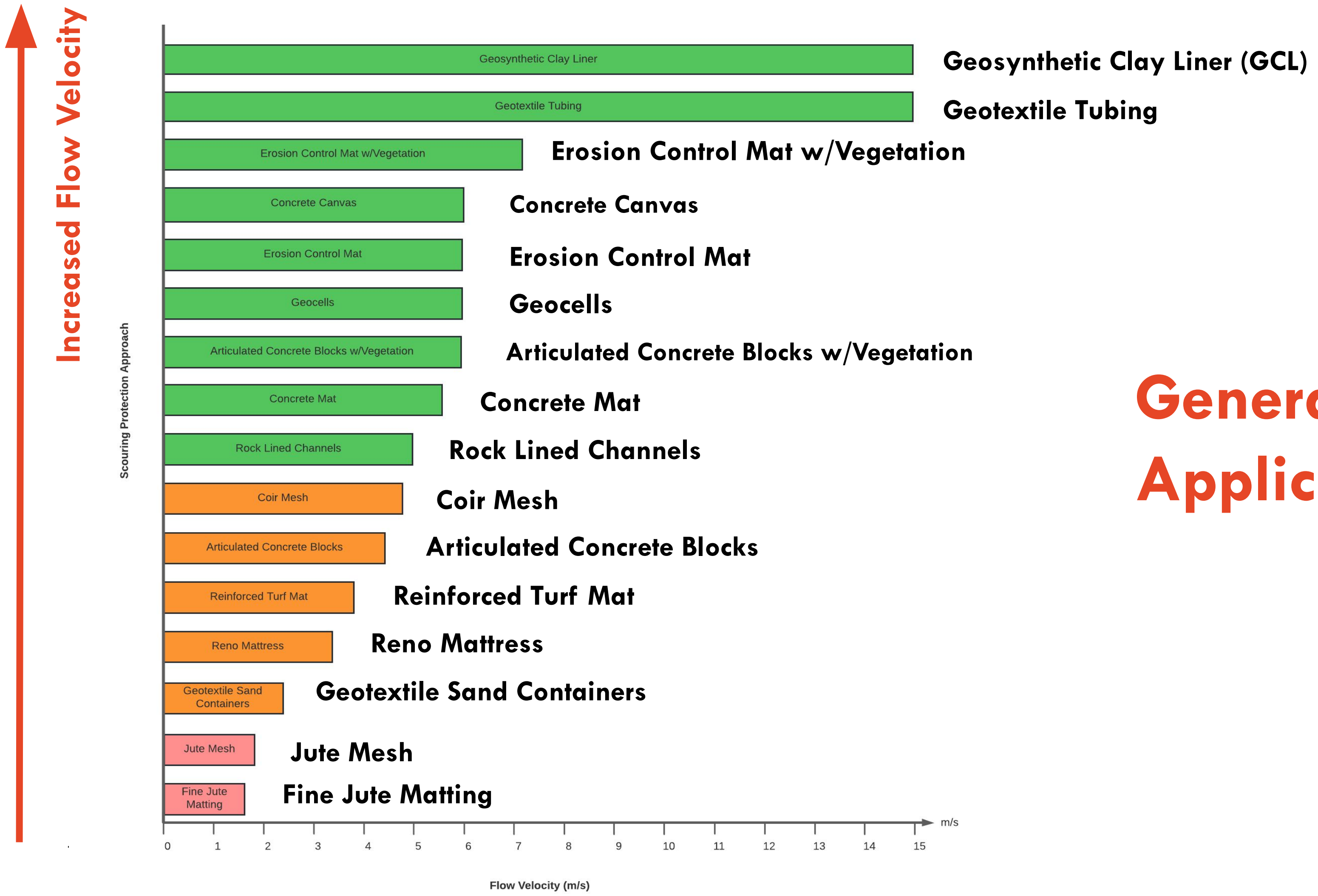
Acceptable

Moderate

Unacceptable

Scouring Design Optimisation – Proposition

Proposed Product	Reinforced Turf Mat	Geocell	Geotextile Sand Container
Key Benefits	Good resistance to weather and radiation, permanent erosion control	Cost-effective (product, transportation)	Environmental Friendly (product, transportation)
Limitations	Complex installation process	Lifespan 20 - 25 years	Higher Cost $43/m2



General Applications

Pavement Optimisation

Background

Post solar farms construction, traffic conditions are fairly light:

- Pre-existing pavements to be conservative
- Overall cost benefits and sustainability impacts

Products Availability

- Conventional Options:
  - Concrete
  - Asphalt
  - Gravel
- Alternative Options:
  - Geosynthetic Products

Pavement Optimisation - Conventional Options

Concrete

Pros:

- Longest lifespan
- Resist extreme weather conditions
- Used for low subgrade strength

Cons:

- Highest construction cost

Asphalt

Pros:

- Easy installation and implementing
- Good skid resistance

Cons:

- Shorter lifespan than concrete
- Amount of Maintenance: seal coating every 3 years

Gravel

Pros:

- Low cost
- Good drainage

Cons:

- Can be washed away
- Not suitable for heavy traffics
- Dust and road noise

Pavement Optimisation

Geosynthetic Options

Geosynthetic Clay Liner (GCL)

Geogrids

Geomembranes

Geocomposites

Geotextile

Geofoam

Pavement Optimisation – Evaluation Criteria

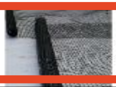
1. **Ease of Installation**
   - Machine Requirements
   - Steps needed

2. **Product Costs**
   - Mostly under $5

3. **Effectiveness**
   - Tensile Strength
   - 2% Strain

4. **Environmental Impact**
   - Material Itself (Eco Materials)
   - Carbon Emission
   - Transportation

5. **Maintenance**
   - Lifespan/ Durability
   - Maintenance Cost

Criteria				Ease of Installation	Product Costs	Effectiveness	Environmental Impact	Maintanence
ID	*Material Type*	*Options*	*Images*					
1	Asphalt	-		**Complex**	**$65-150/m2 Dependant on Mixtures**	**Tensile Strength: 120-1290kN/m2 Dependant on Mixtures**	**High**	**Moderate**
2	Geosynthetic Clay Liner (GCL)	Bentofix X2 BFG 5300		**Moderate**	**$0.05-0.10/m2**	**Tensile Strength: 14kN - Low Top Soil can Damage Material**	**Low**	**Moderate**
		Bentofix X5F BFG 5300		**Moderate**	**$0.05-0.10/m2**	**Tensile Strength: 14kN - Low Top Soil can Damage Materiall**	**Low**	**Moderate**
3	Geogrids	DuraGridX		**Simple**	**$3-6.02/m2**	**Tensile Strength: 7-14kN**	**Low**	**Low**
		TENAX® 3D Grid T		**Simple**	**$7.7-8/m2**	**550kN Modulus Radial Stiffness at 0.5% Strain is 321 kN/m - Suitable for Small-Medium Aggregates**	**Low**	**Low**
		mastaGRID® Poly Geogrid 40		**Simple**	**$4.41/m2**	**Tensile Strength: 17.5kN**	**Low**	**Low**
4	Geomembranes	HDPE		**Moderate**	**$1.50/m2**	**15000kN/m2**	**Moderate**	**Low**
		PVC			**$2.00/m2**	**5000kN/m2**	**Low**	**Moderate**
5	Geocomposites	LAMGRID® Green Non-woven (from Geofabrics)		**Moderate**	**$4.54-5.07/m2**	**8kN/m-37.5 kN/m Dependiing on Grading**	**Low**	**Low**
		ProGrid® GC/GB Compo (from GlobalSynthetics)		**Moderate**	**-**	**Ultimate Tensile Strength ≥ 50kN/m**	**Moderate**	**Low**
		GRIDTEX (from Cirtex Australia)		**Simple**	**-**	**Ultimate Tensile Strength: 30-40 kN/m**	**Low**	**Low**
6	Geotextiles	Bidim-Green Non-Woven		**Moderate**	**$1.46/m2**	**Tensile Strength: 8-37.5kN/m**	**Low**	**Low**
		TenCate- Mirafi RSI		**Simple**	**$4 - $4.40/m2**	**Tensile Strength: 1.5-2.1kN & Puncture Strength: 6.6-9kN**	**Moderate**	**-**
7	Geofoam	-		**-**	**$80/m2**	**-**	**Moderate**	**-**

Pavement Optimisation - Evaluation Table

Criteria				Ease of Installation	Product Costs	Effectiveness	Environmental Impact	Maintanence
ID	*Material Type*	*Options*	*Images*					
3	Geogrids	DuraGridX		Simple	$3-6.02/m2	Tensile Strength: 7-14kN	Low	Low
		TENAX® 3D Grid T		Simple	$7.7-8/m2	550kN Modulus Radial Stiffness at 0.5% Strain is 321 kN/m - Suitable for Small-Medium Aggregates	Low	Low
		mastaGRID® Poly Geogrid 40		Simple	$4.41/m2	Tensile Strength: 17.5kN	Low	Low
6	Geotextiles	Bidim-Green Non-Woven		Moderate	$1.46/m2	Tensile Strength: 8-37.5kN/m	Low	Low
		TenCate- Mirafi RSI		Simple	$4 - $4.40/m2	Tensile Strength: 1.5-2.1kN & Puncture Strength: 6.6-9kN	Moderate	-

Pavement Optimisation - Proposition

Proposed Product	Geogrids (DuraGridX)	Geogrids (masraGRID@ Poly Geogrid 40)	Geotextiles (Bidim Green Non-Woven)	Geotextiles (TenCate - Mirafi RSI)
Key Benefits	Simple roll out Installation; Cost Effective; Environment Friendly; Life Span - Over 100 years	Simple Roll-Out Installation; Cost-effective; Environment friendly; Design to reduce long-term creep	Cost-Effective; Environment friendly; Long life cycle (over 35 years)	Easy lay and align; Cost-effective;
Limitations	-	-	Spreader Bar Needed (Fully wrapped in rolls to 6 m)	Environment Impact

Application of the materials

Geogrid

- **Wall Structure**

  - A Geogrid reinforced Keystone® segmental retaining wall structure was designed for a large industrial project in Redbank, South-East Queensland, Australia.

- **Construction**

  - Working Platforms

  - SE Queensland

Geotextile

- **Flood Emergency Protection**
- **Construction**

  - Erosion control.

  - Bottom scour protection.

  - Scour fill artificial reefs, groynes, seawalls, breakwaters and dune reinforcement.

Questions

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