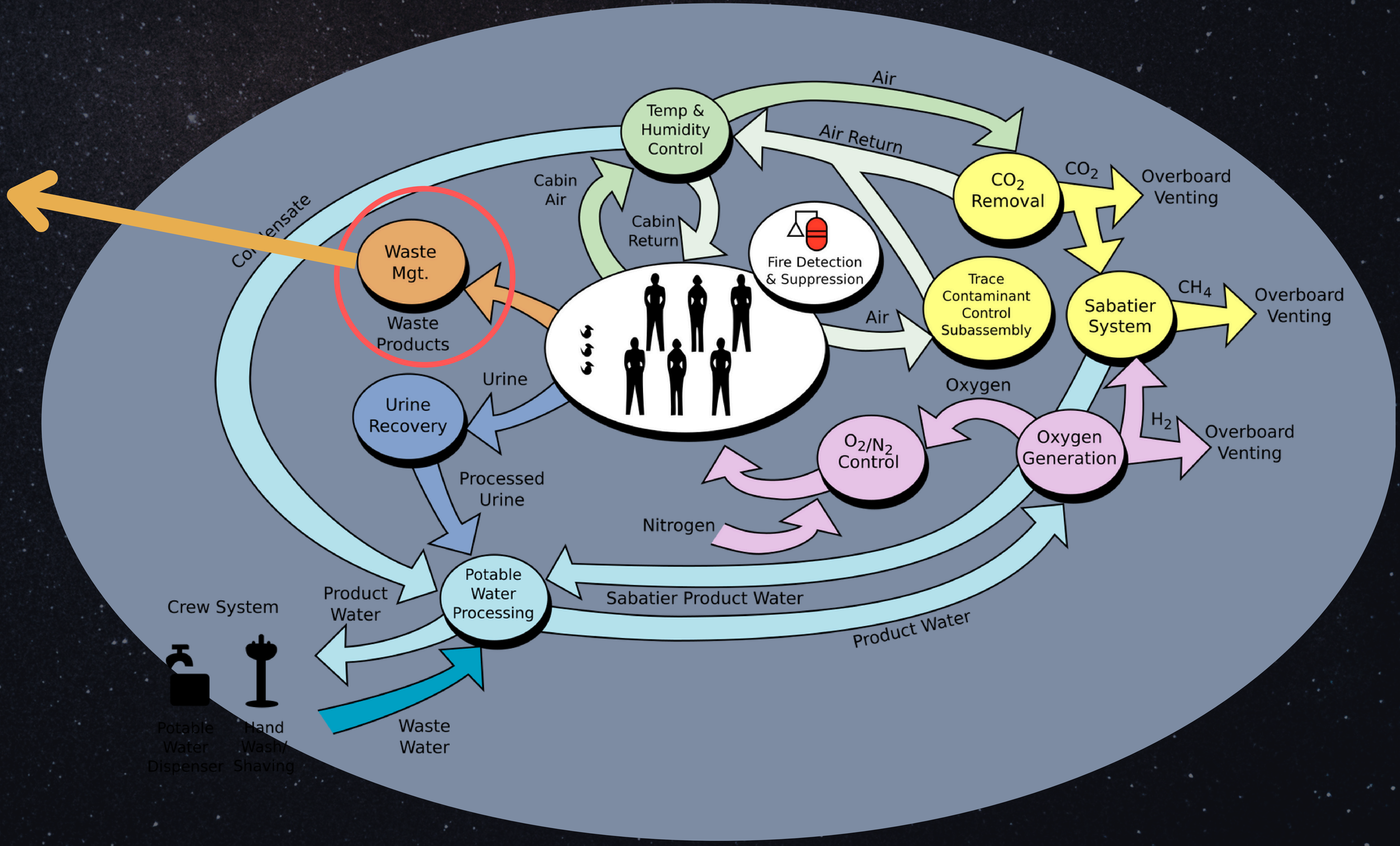
THE MARSHIAN:

SIMULATION OF A WASTE TREATMENT WETLAND FOR THE MOON OR MARS

The Spring Institute for Forests on the Moon

Problem



State of the art ECLSS ignores solid waste.

Cost of Waste

A HUMAN PRODUCES 128KG OF FECES/YEAR

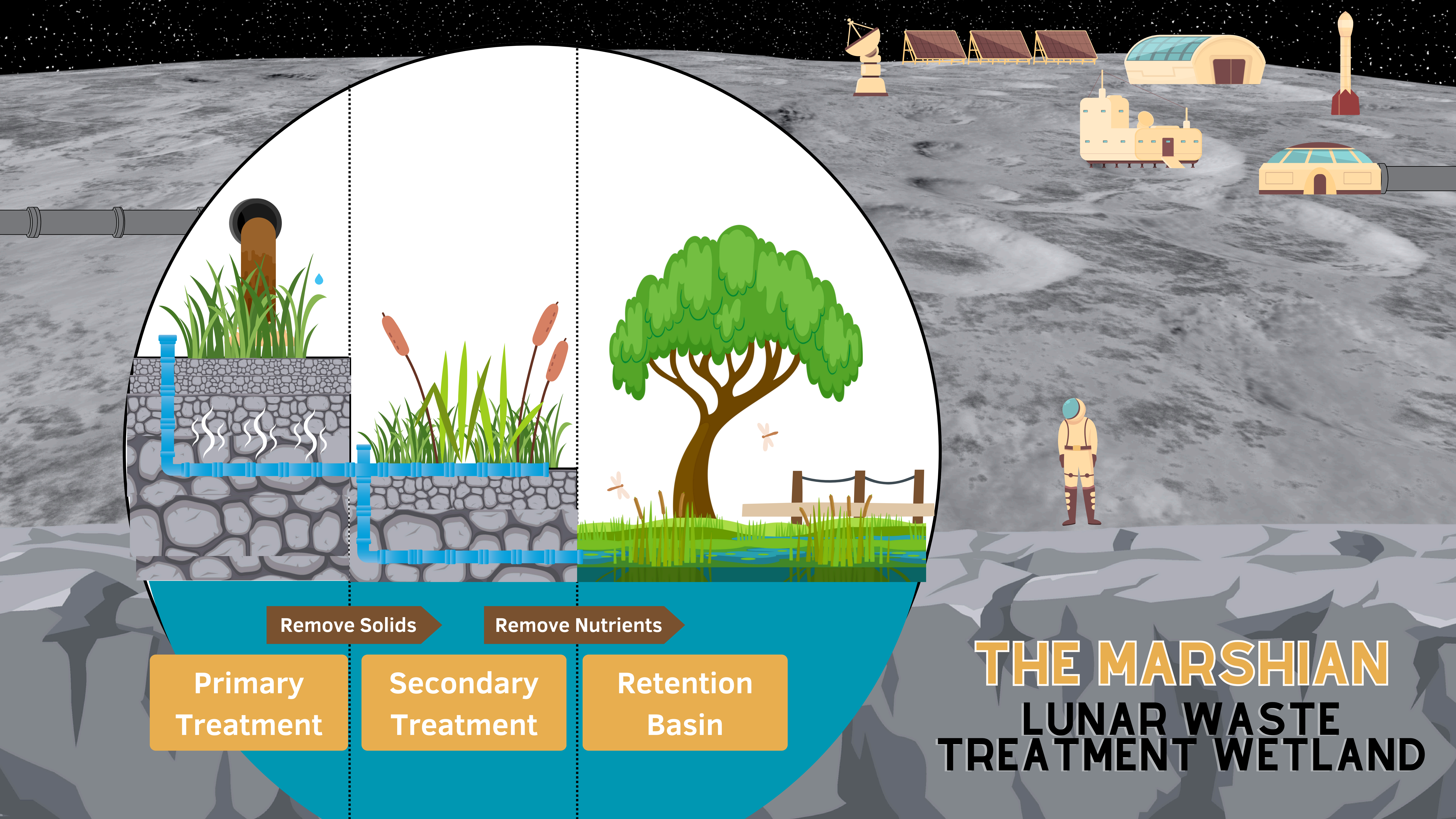
With an average of 7 ISS crew at a time, that's 896kg of upmass per year.

896kg to LEO
@ $93k/kg =
$83M

NASA 2018

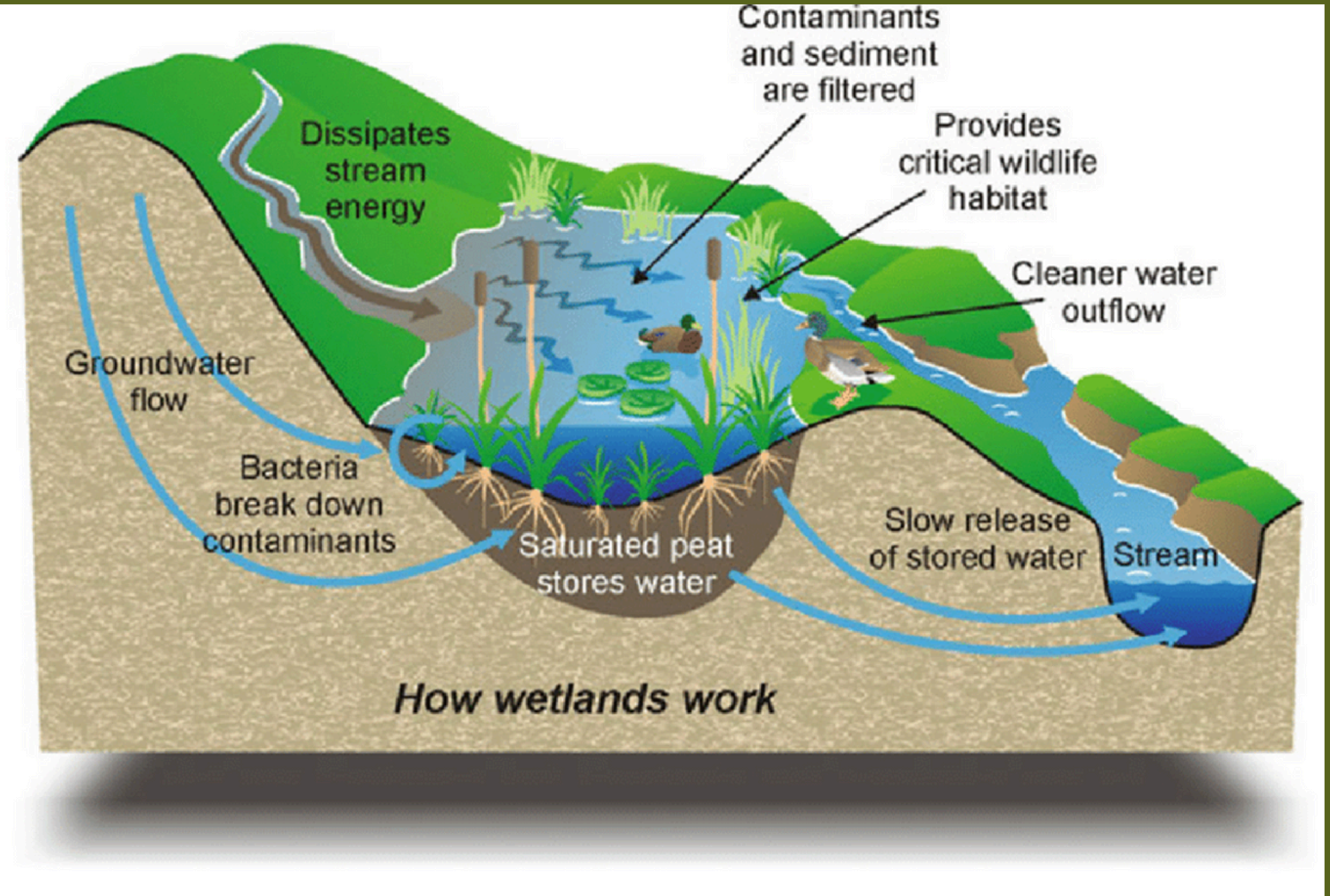
896kg to Lunar Surface
@ $1.2M/kg =
$1.1B

Astrobotics 2023


Remove Solids
Remove Nutrients
Primary Treatment
Secondary Treatment
Retention Basin
THE MARSHIAN
LUNAR WASTE TREATMENT WETLAND

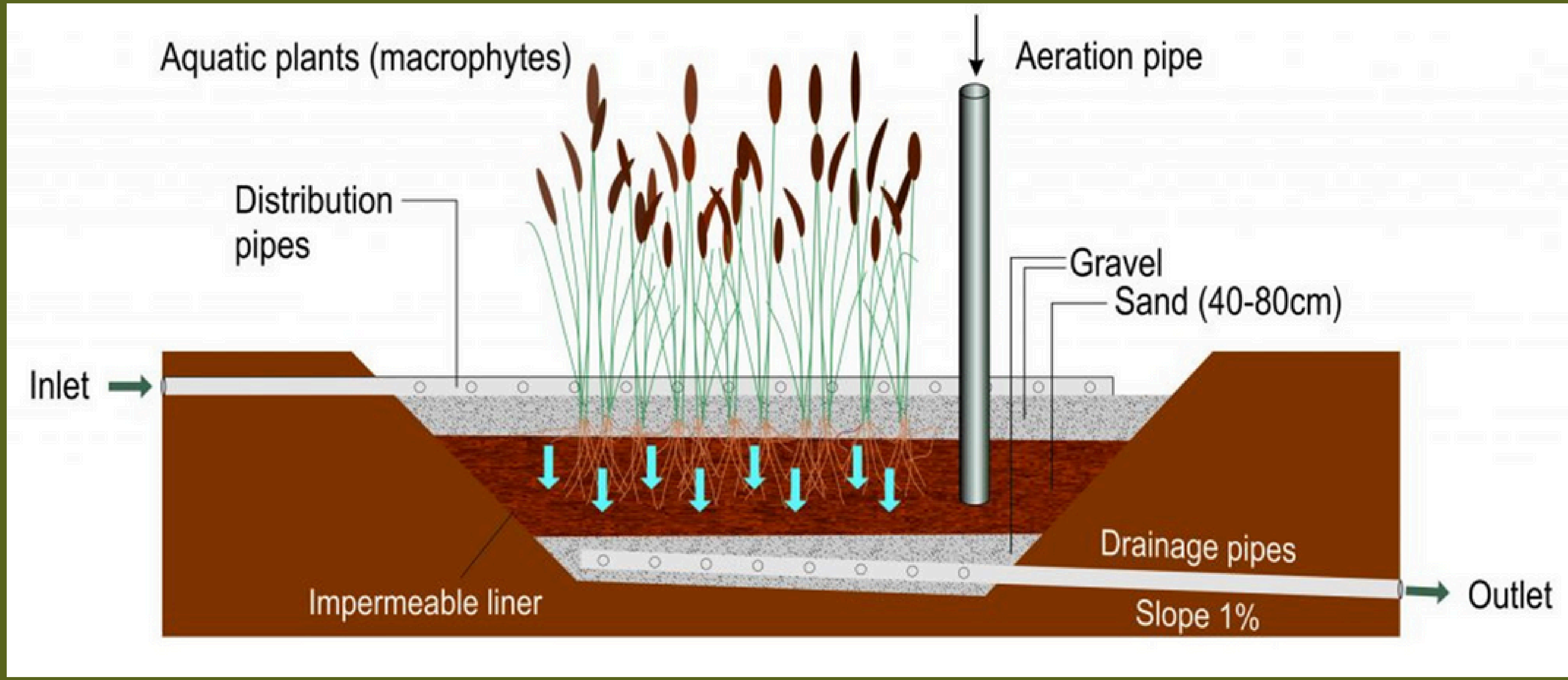
Wetland Removal Processes

Natural Wetland



Ma et al., 2018

Artificial/Constructed Wetland



Vymazal 2010

Simulation Objectives

Effect of Reduced Gravity

Compare performance of the same constructed wetland in Earth gravity and in lunar gravity.

ISRU Feasibility

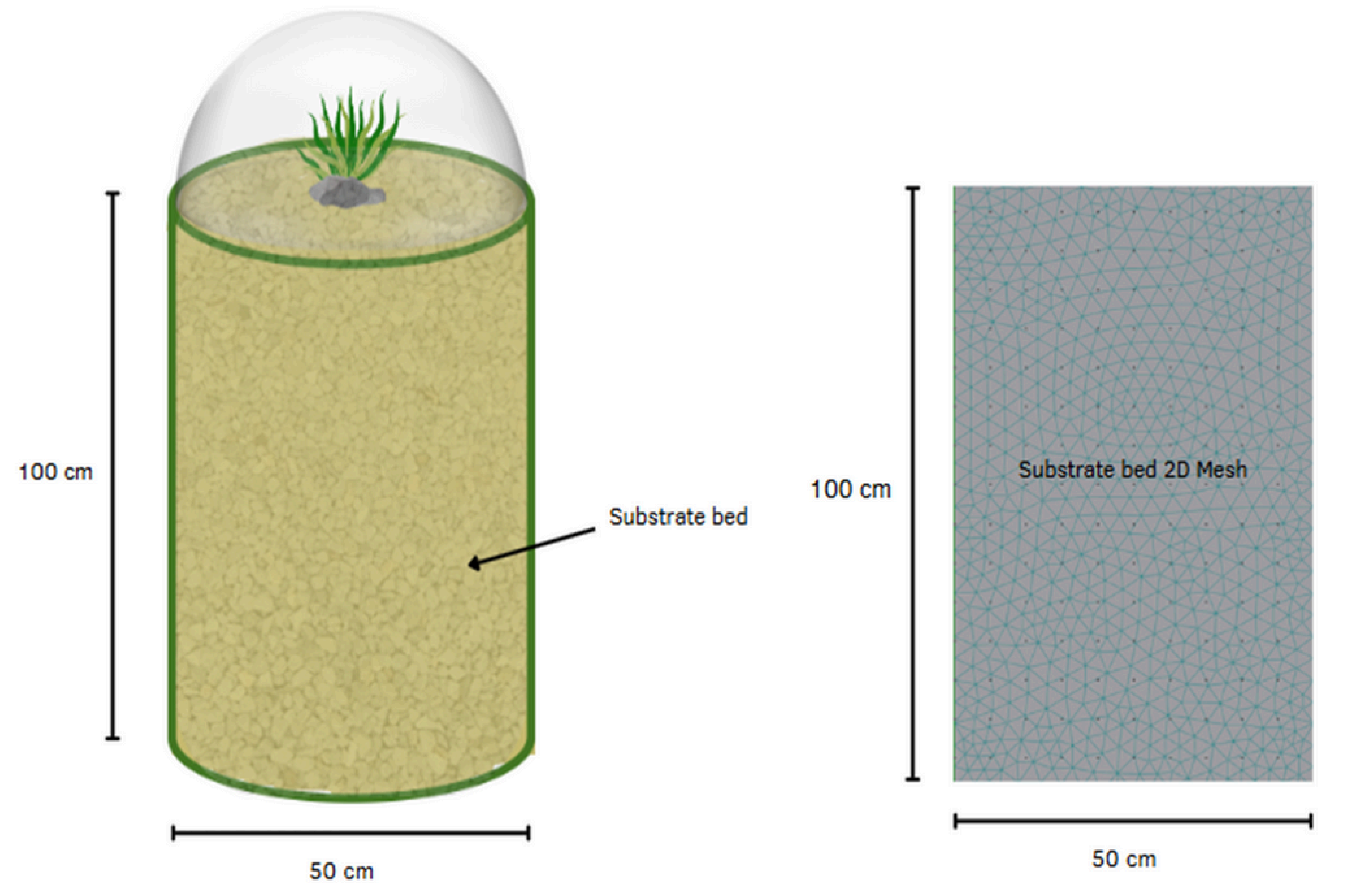
Compare the performance of the same contructed wetland built with conventional sand versus lunar regolith for the reactor bed.

Continuous vs Intermittent Operation

Investigate alternative feeding schemes to reduce the required footprint of the system.

First Conceptual Design

Hydrodynamic Modelling - Configuration



a) 3D Conceptual Model   b) 2D Finite Element Mesh Model

2D modeling of variably saturated flow through porous bed

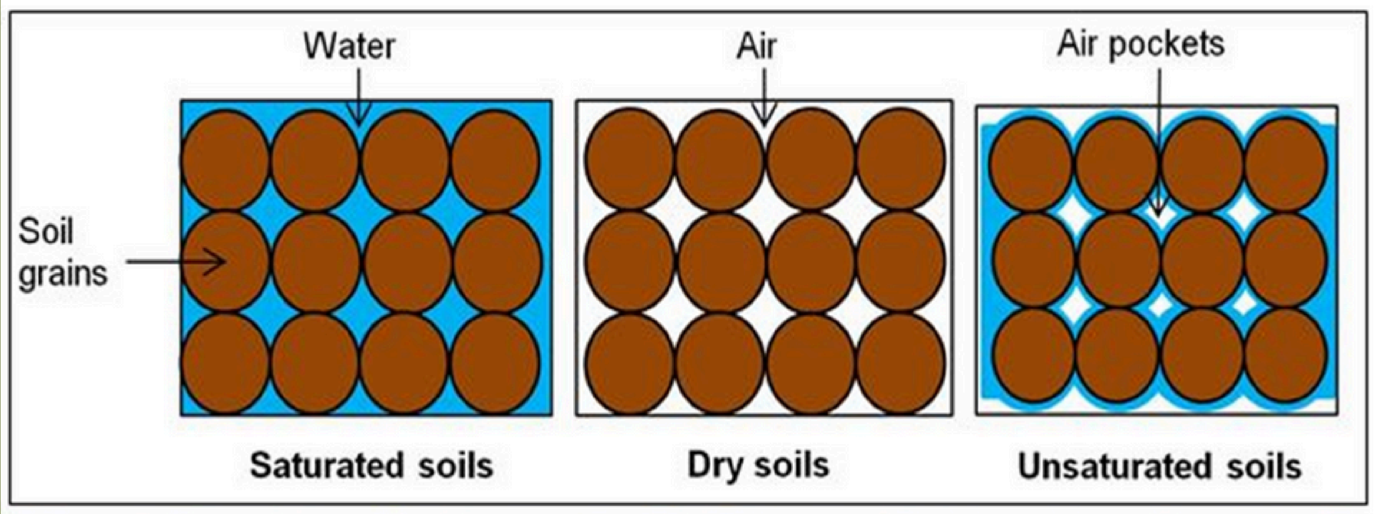
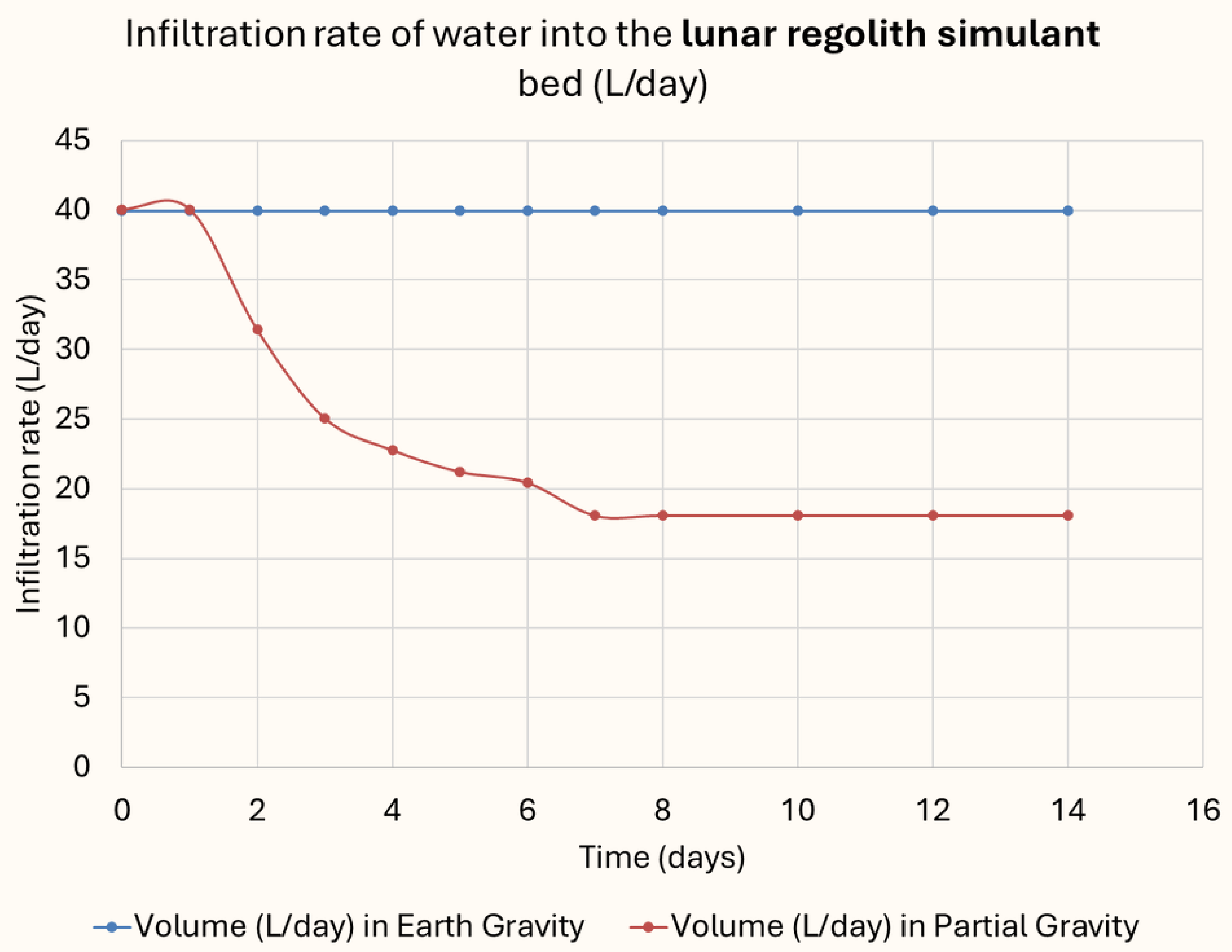
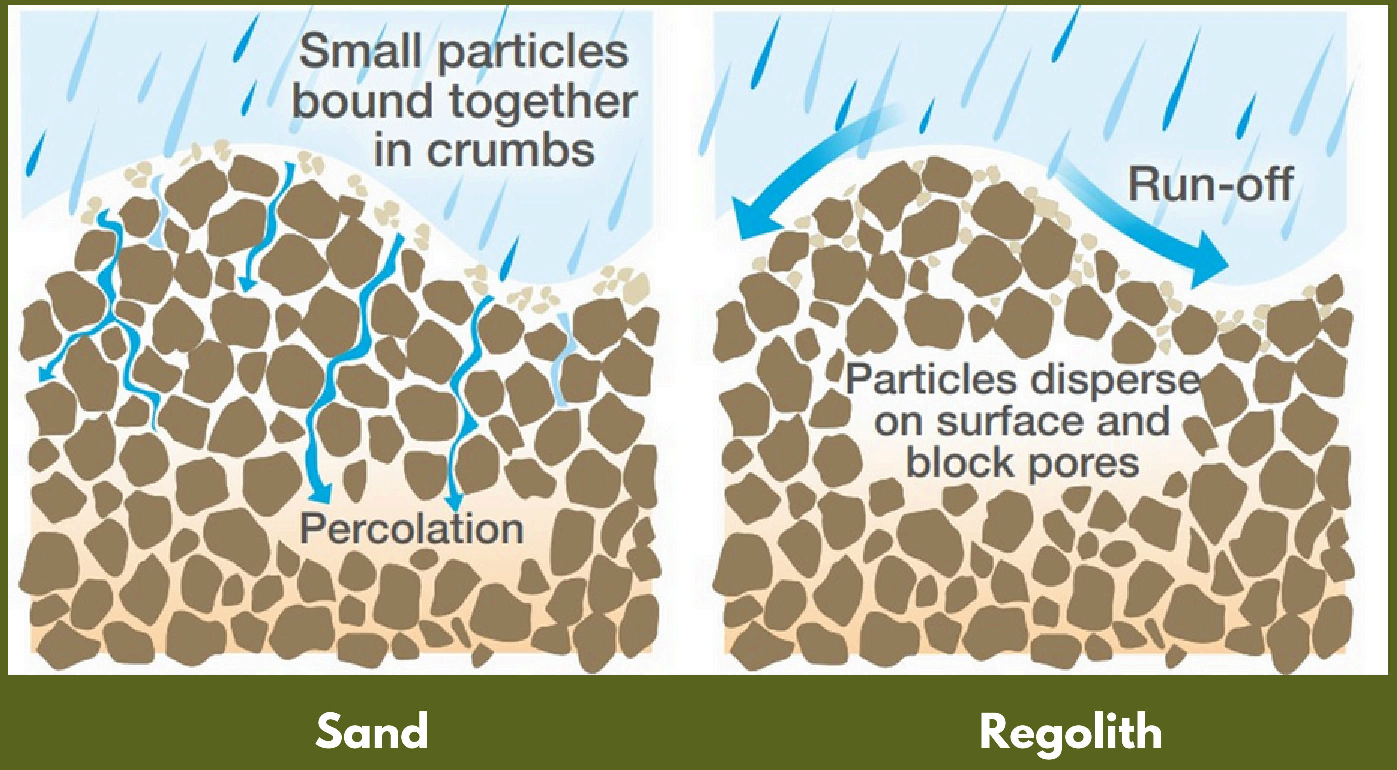


Figure 1 – Illustration of microstructure for fully saturated, dry and unsaturated soils

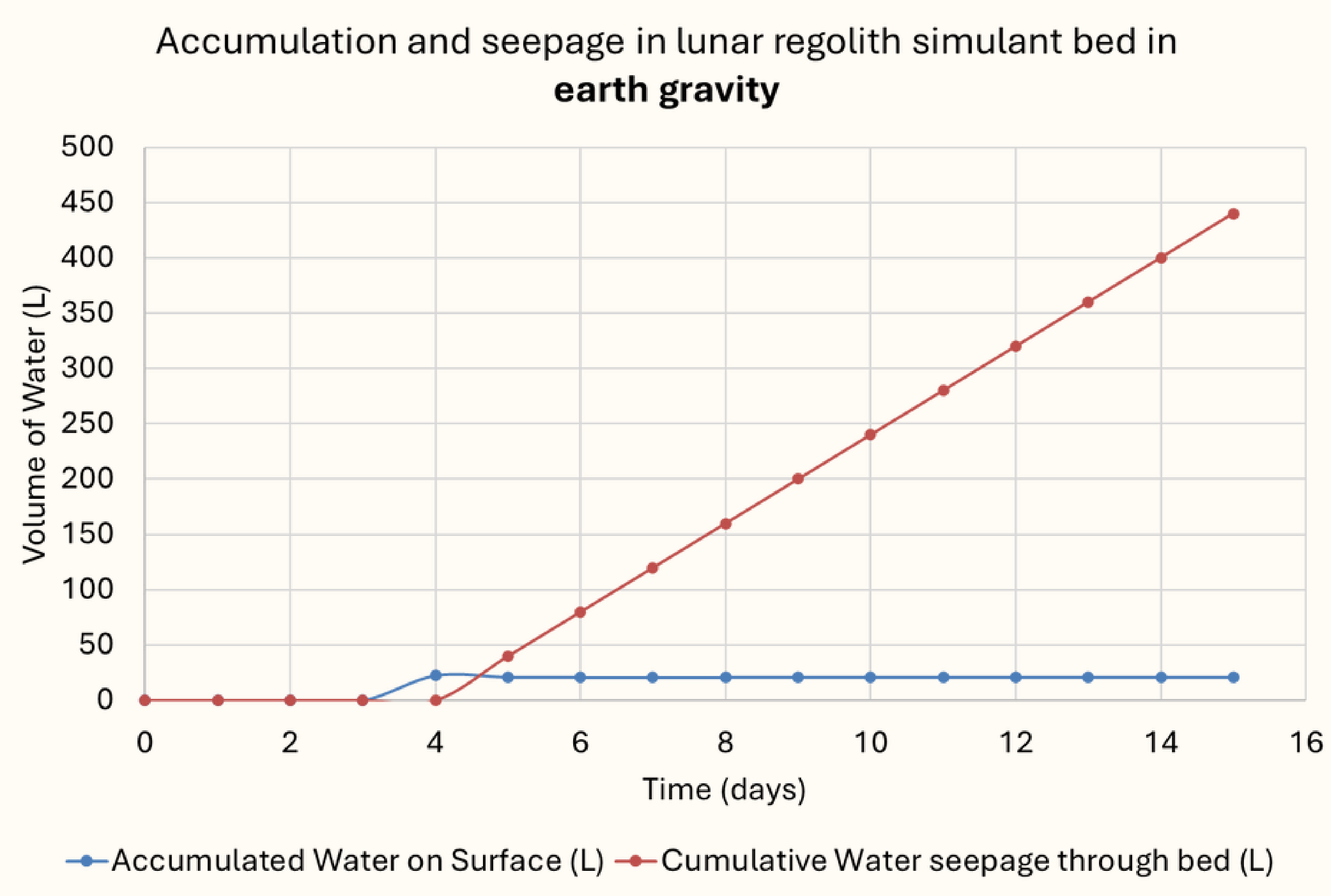
Hydrodynamic Modelling - Infiltration

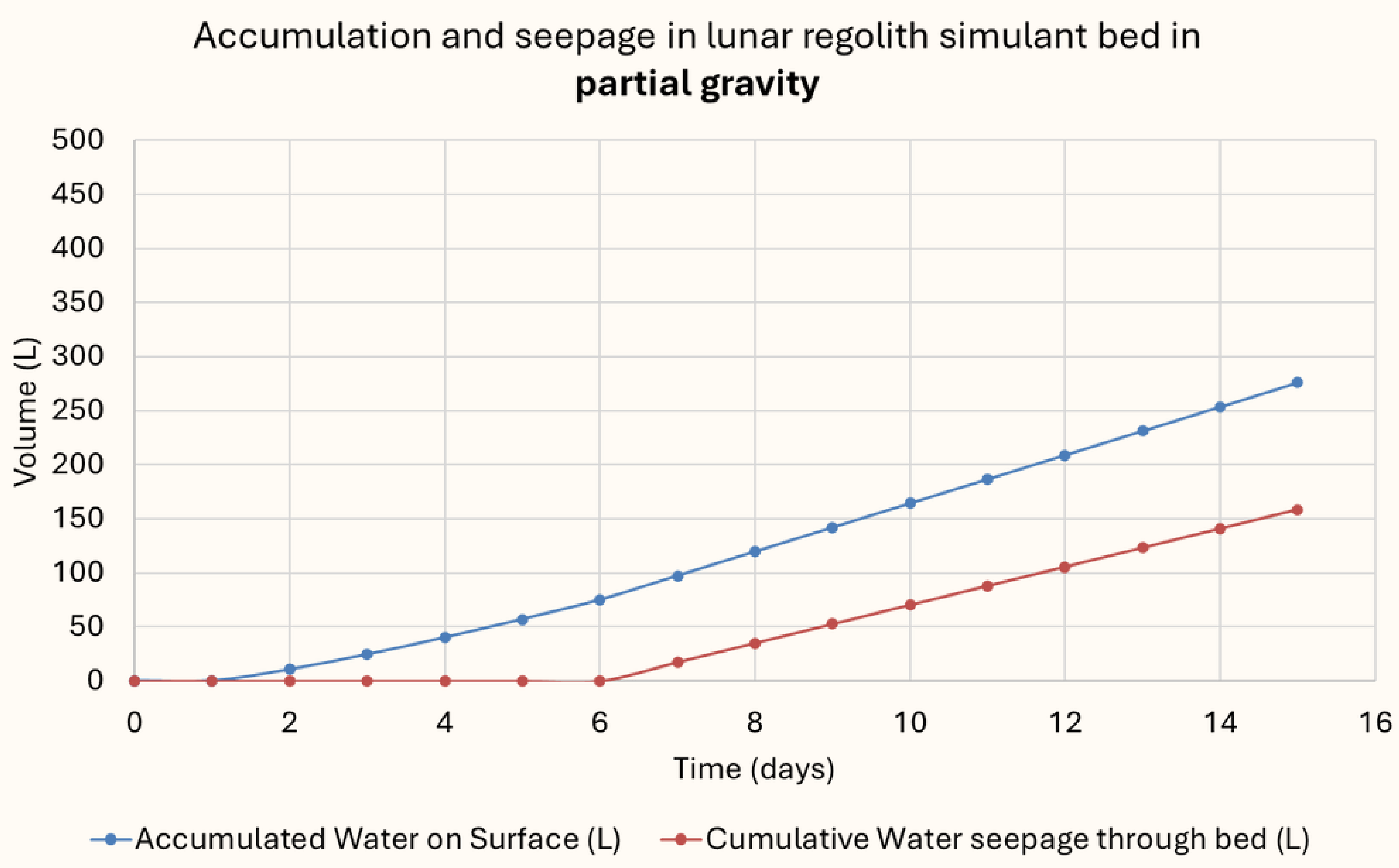




- **Reduced water infiltration rates over time in partial gravity conditions in lunar regolith simulant**
- **Not observed using sand**

Hydrodynamic Modelling - Runoff





No increase in surface accumulation.

Accumulation faster than seepage causes runoff of untreated sewage. Gross!

Optimization of water dynamics in partial gravity using lunar regolith

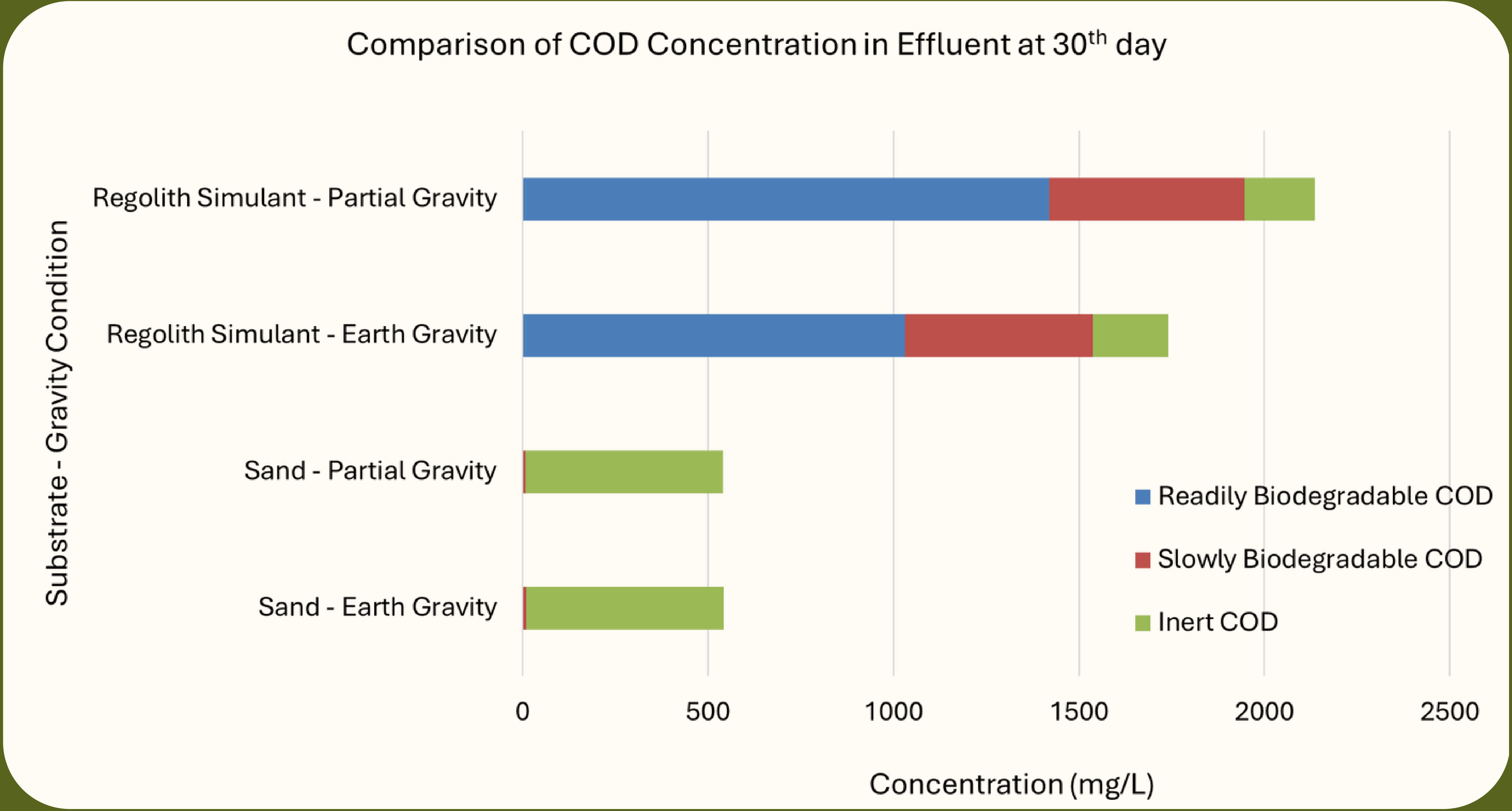
Condition	Volume (L)	Feeding Time (hours)	Saturation time (days)	Surface run-off (L/day)
1	11.8	7.2	**14**	0
2	19.9	12	9.5	2.4
3	23.6	14.4	7.5	5.9
4	39.3	24	6	22.3
5	80	48	6	62.8

No surface runoff!

Solution found? Not quite.

Contaminant Removal Modelling - COD Removal

Simulation results of contaminant removal in continuous feeding strategy (t < 1 day)

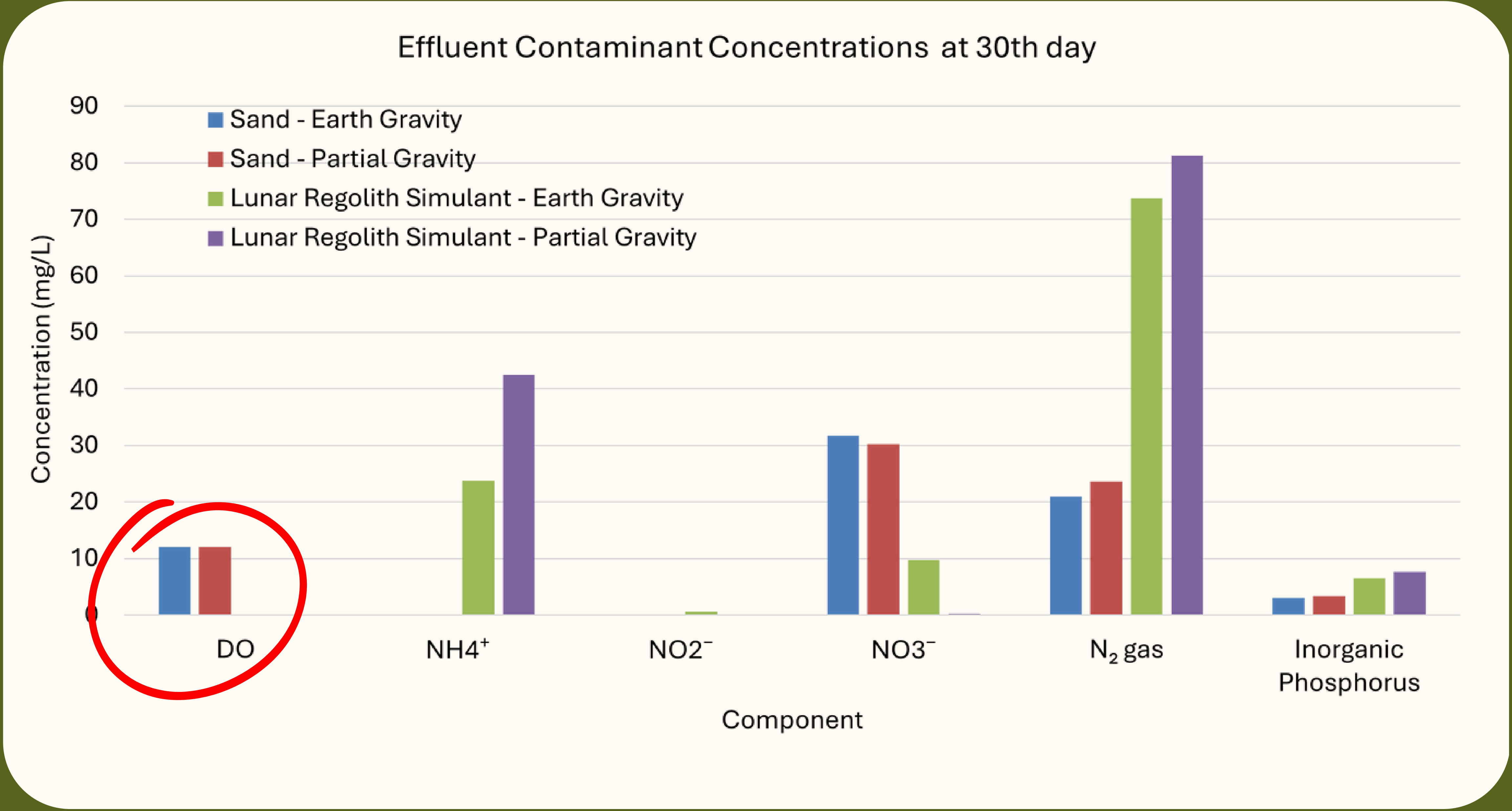


Contaminant removal requirement not met in lunar regolith under any gravity!

Earth Sand works in all scenarios, though.

Contaminant Removal Modelling - Effluent Composition

Simulation results of contaminant removal in continuous feeding strategy (t < 1 day)

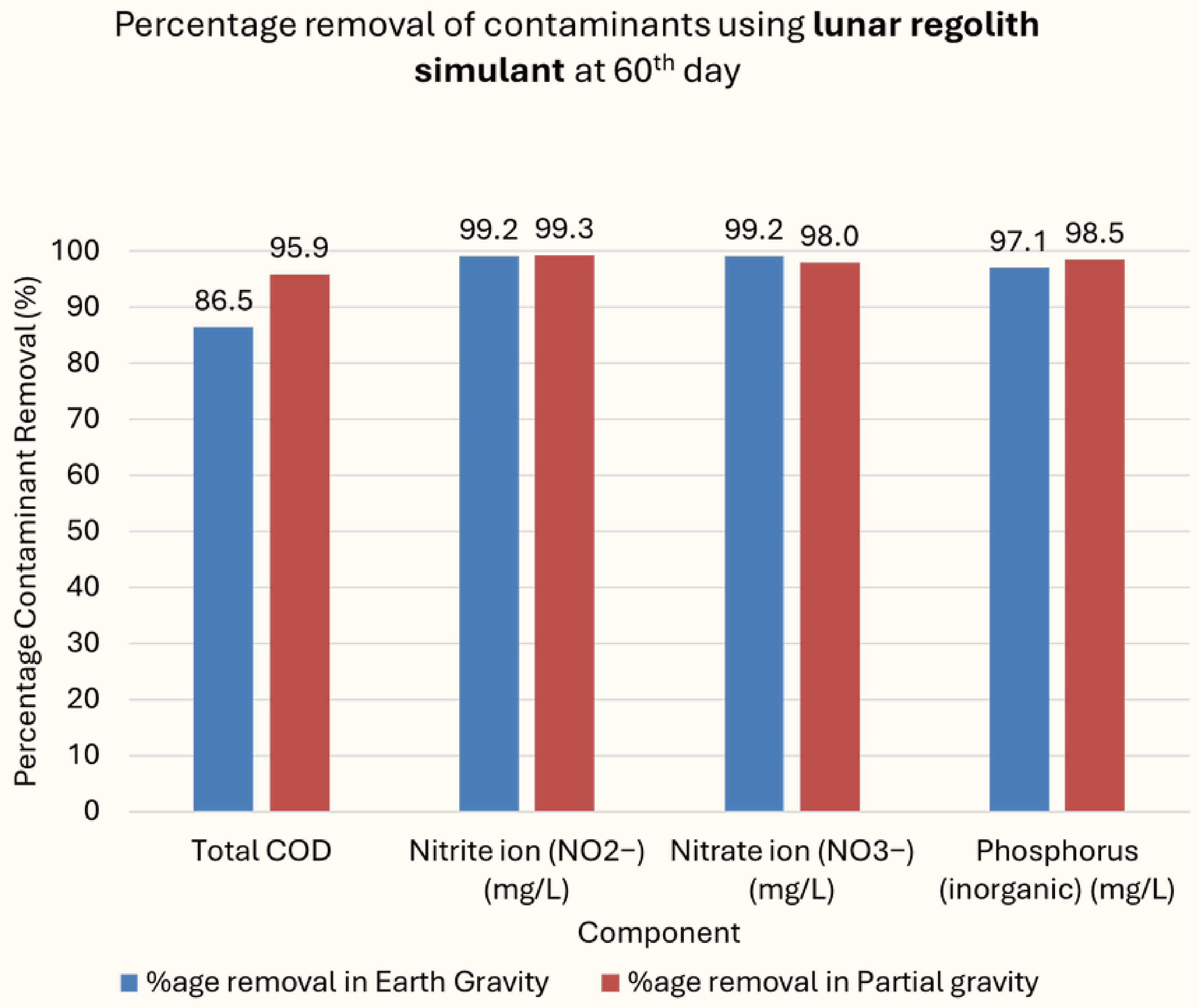


Lack of oxygen penetration into lunar regolith prevents aerobic metabolism (i.e. nitrification)

Components Modelled
Dissolved oxygen (DO)
Readily biodegradable COD
Slowly biodegradable COD
Inert COD
Ammonium ion (NH_4^+)
Nitrite ion (NO_2^-)
Nitrate ion (NO_3^-)
Dinitrogen gas (N_2)
Inorganic phosphorus

Contaminant Removal Modelling - Intermittent Feeding Alternative

Simulation results of contaminant removal in intermittent feeding strategy (t = 10 days)



- Higher COD removal compared to continuous strategy
- Increase the downtime of the system to 10 days
- Unfortunately also removes Nitrates and Phosphorus - still primarily anaerobic!

Meets treatment performance goal, but not daily load requirements.

Conclusion

CW offer effective lunar waste treatment using conventional sand.

Water movement is significantly slower in lunar G, but it helps improve microbial performance.

Lunar regolith as a wetland substrate is possible, but requires significant accommodations.

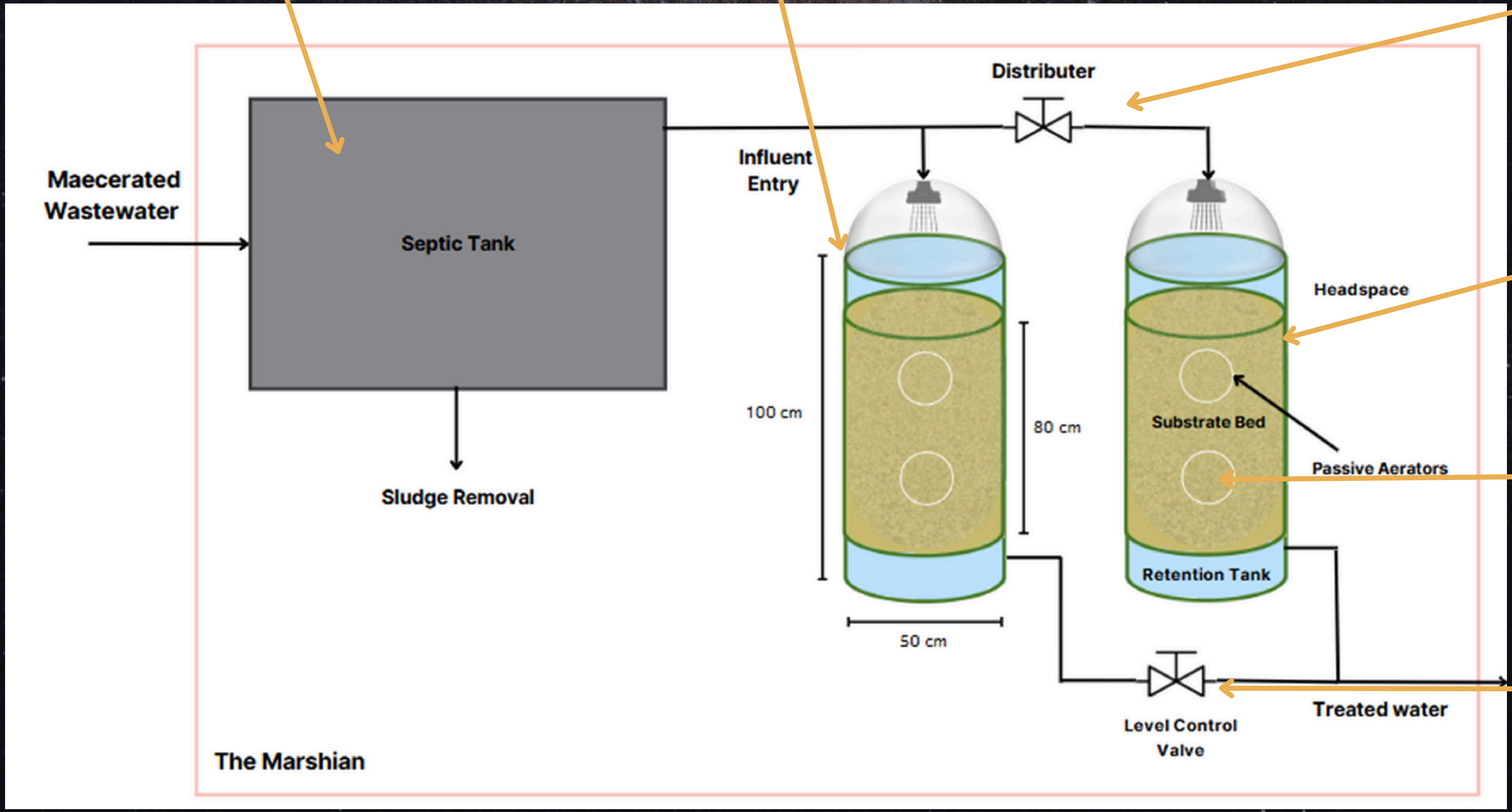
A CW can treat 4 astronauts' daily wastewater, though it would require support infrastructure.

Design and Operation Recommendations

Septic Tank halves initial COD

High freeboard to protect against surface accumulation

Parallel beds with alternating rest periods

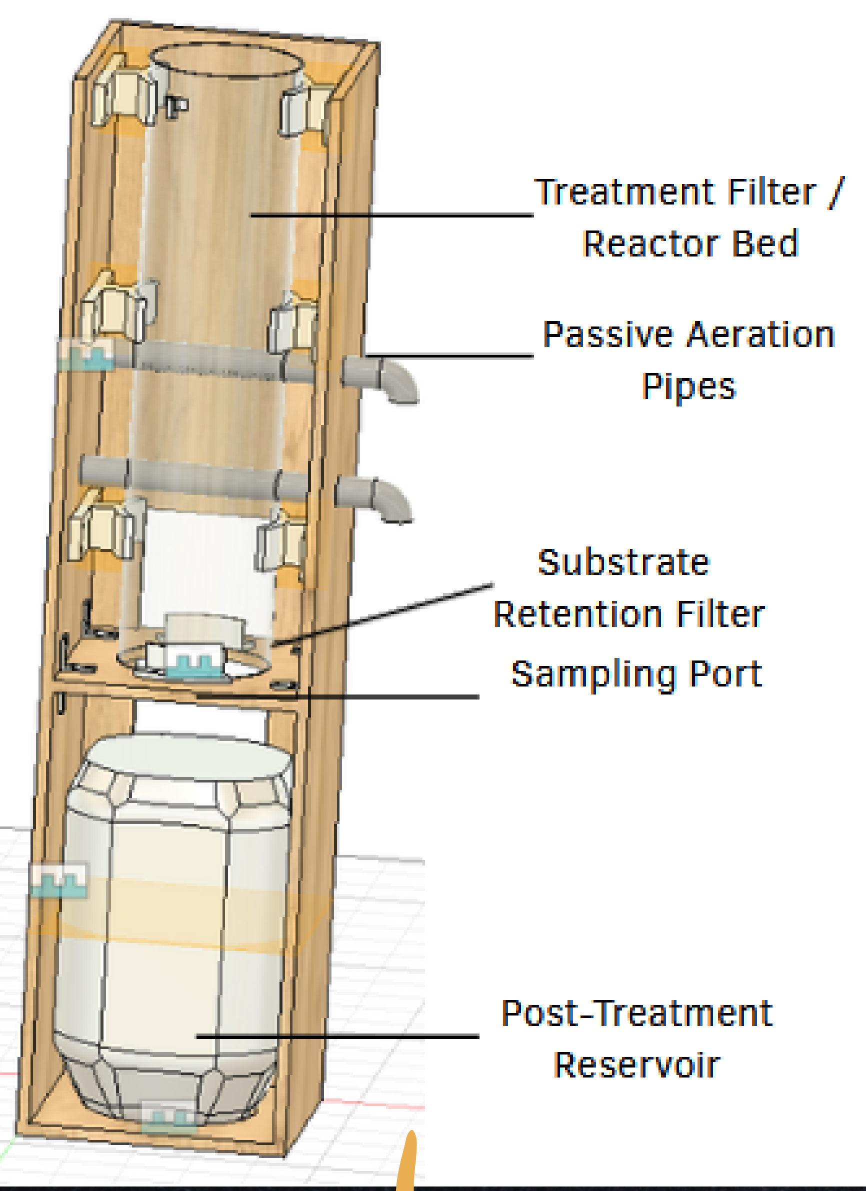


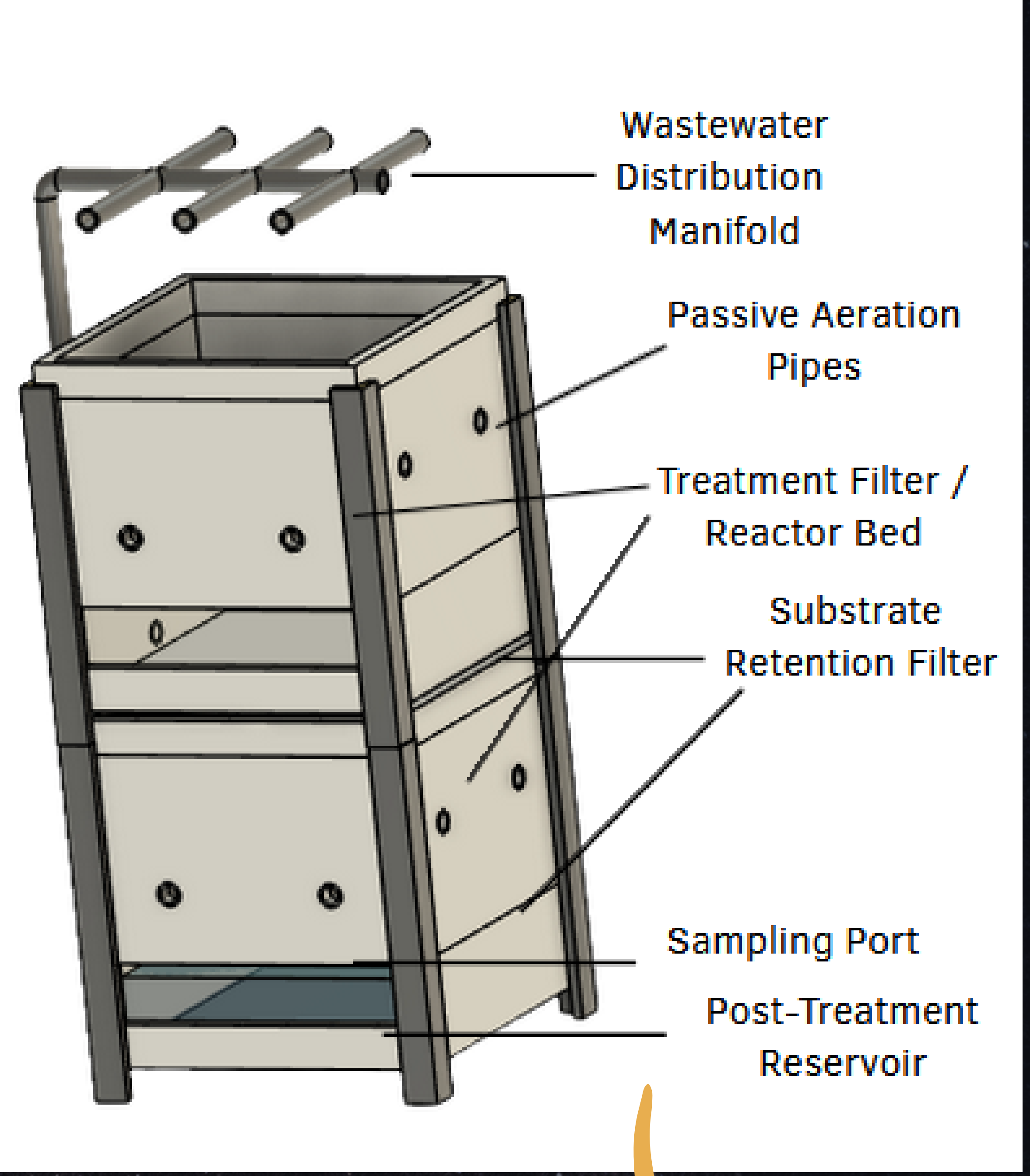
Sieve regolith to larger particle size (1-2mm)

Passive oxygen injection via pipes

Process feedback control loop for automation of the system

Current Status





“Bench” scale protoypes for simulation validation

Full scale model TBD (To be deployed)

?

THANK YOU

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APPENDIX

Simulation framework for water dynamics

- van Genuchten model for **hydraulic properties**
- Hydraulic parameters for lunar regolith simulant (LMS-1) have already been estimated

Parameter	Interpretation
θr (Residual Water Content) [-]	Minimum water content left in the bed after drainage
θs (Saturated Water Content) [-]	Maximum water content when the soil is fully saturated
α (Air Entry Suction Pressure) [1/cm]	**Determines the pressure at which air enters the soil pores**
n (Pore-size Distribution Parameter) [-]	Describes how uniform the pore sizes are
Ks (Saturated Hydraulic Conductivity) [cm/day]	**The rate at which water moves through fully saturated soil**
l (Pore Connectivity Parameter) [-]	Empirical parameter influencing hydraulic conductivity under unsaturated conditions

Effect of reduced gravity

Simulation framework for water dynamics

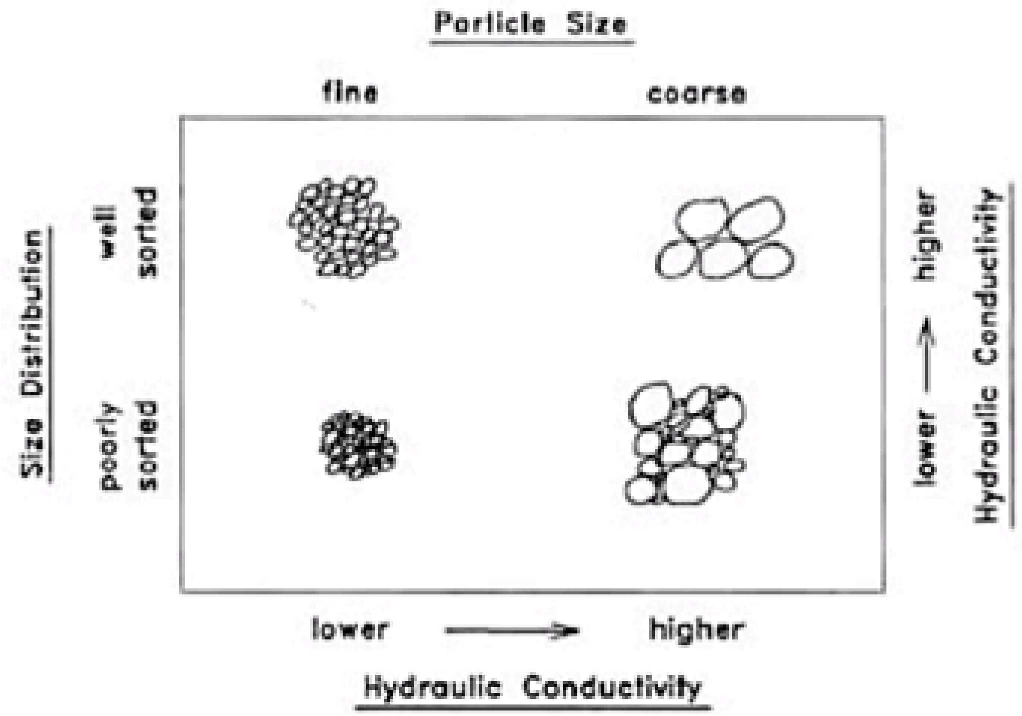
Water dynamics through porous wetland bed in partial gravity conditions

Richard's equation:

$$Q = -K(\theta)(\nabla \mathrm{h} + \nabla \mathrm{z})$$

Total height = $(\nabla h + \nabla z)$
Hydraulic conductivity = $K(\Theta)$

(Bonan et al., 2019)



Estimation of hydraulic conductivity for partial gravity conditions

Using Karmen-Cozney's correlation for hydraulic conductivity: $K_{sat} = k\,(\frac{\rho g}{\eta})$

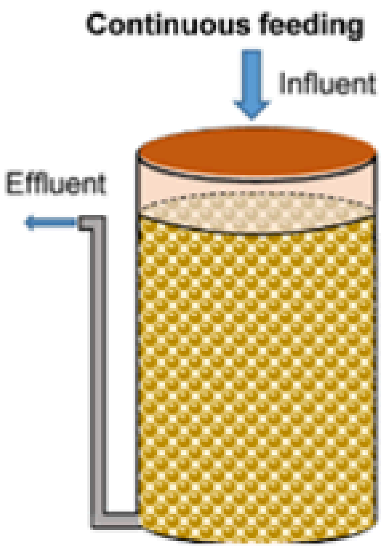
Where k is permeability (m^2), g is gravitational acceleration (m/s^2), η is dynamic viscosity (kg/ms), and ρ is the liquid density (kg/m^3)

g = 9.81 m/s^2 for Earth

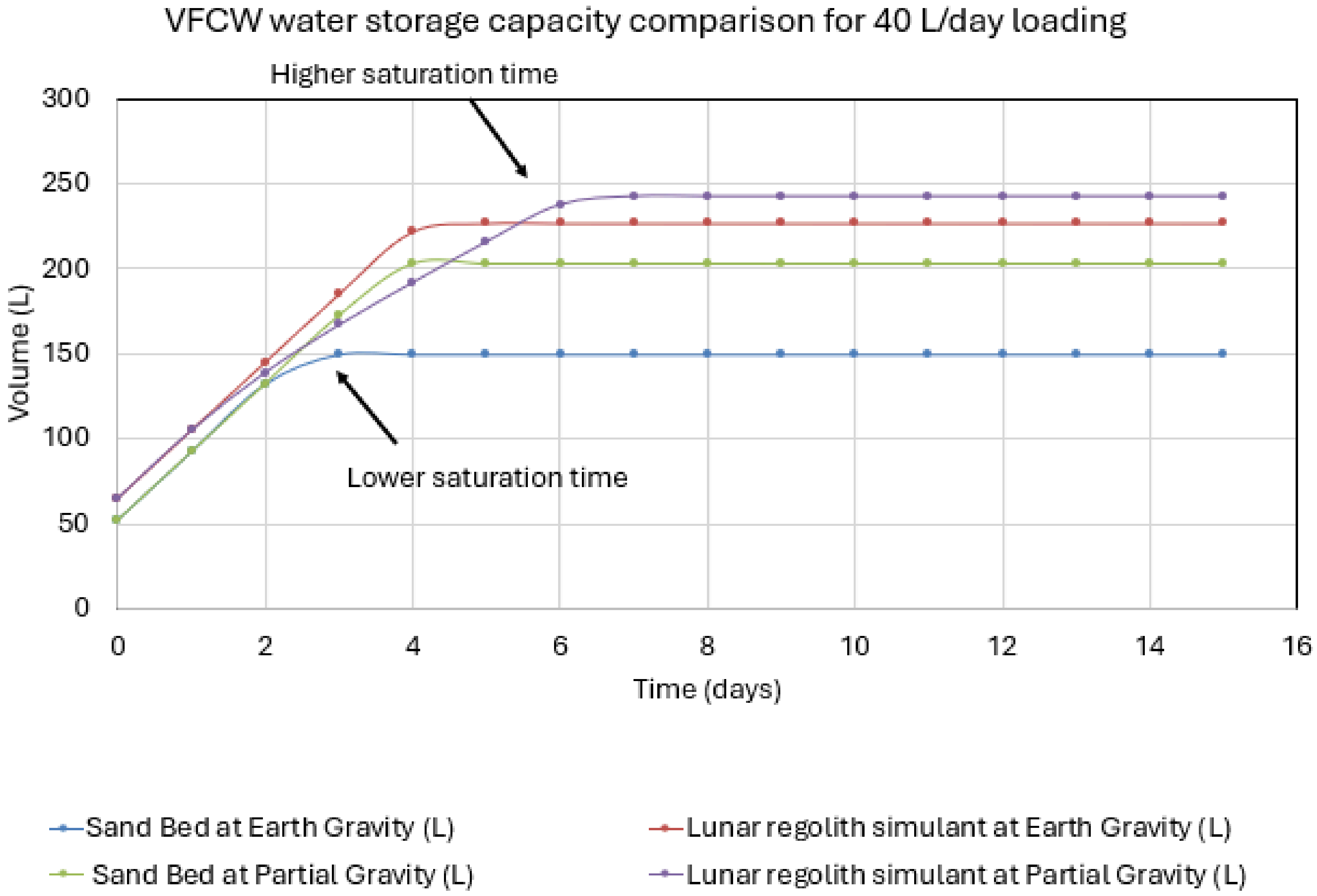
g = 1.62 m/s^2 for Moon

Simulation results of water dynamics using 40 L/day

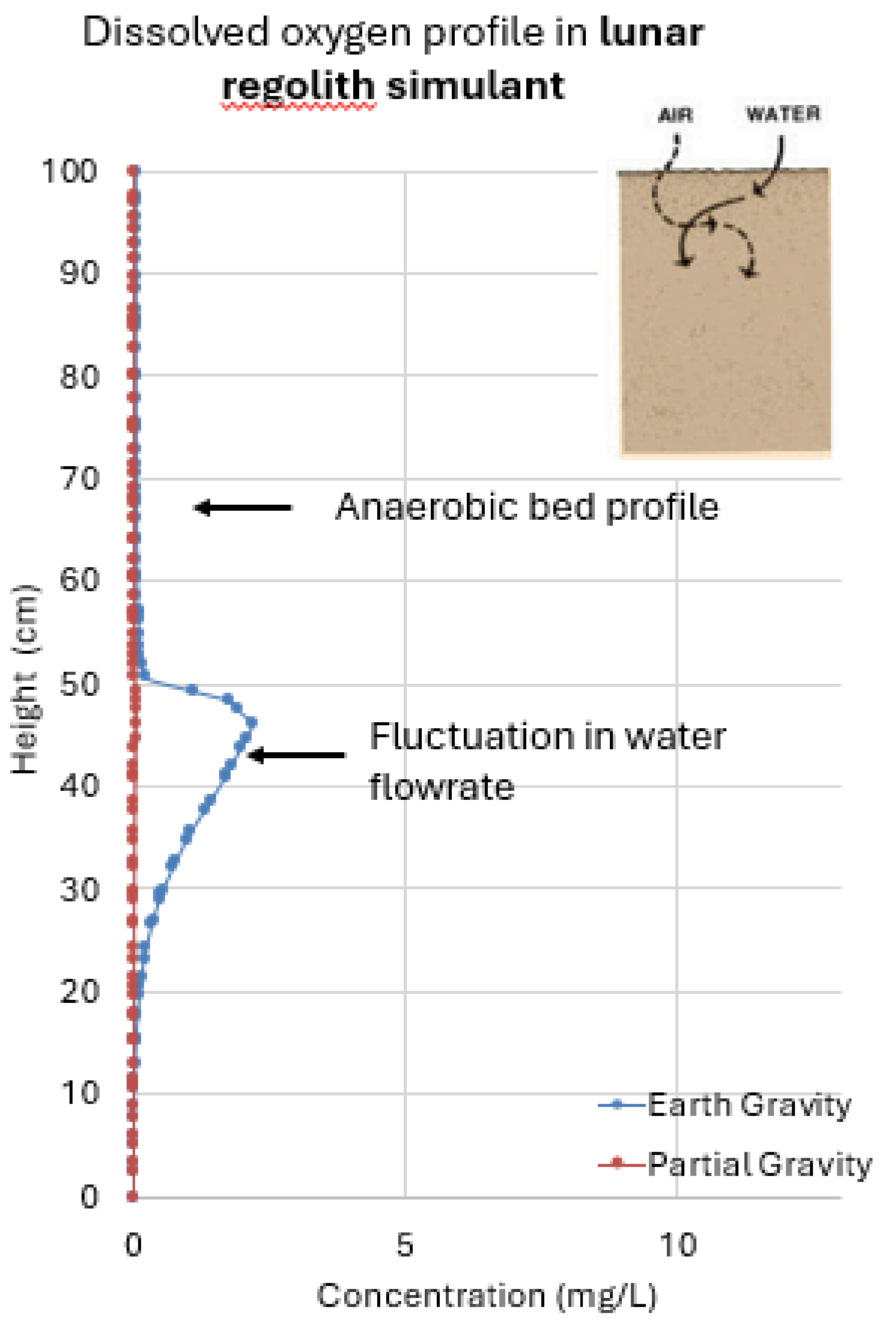
- Inherent difference in water storage capacity due to **substrate nature**
- Higher saturation time in partial gravity conditions

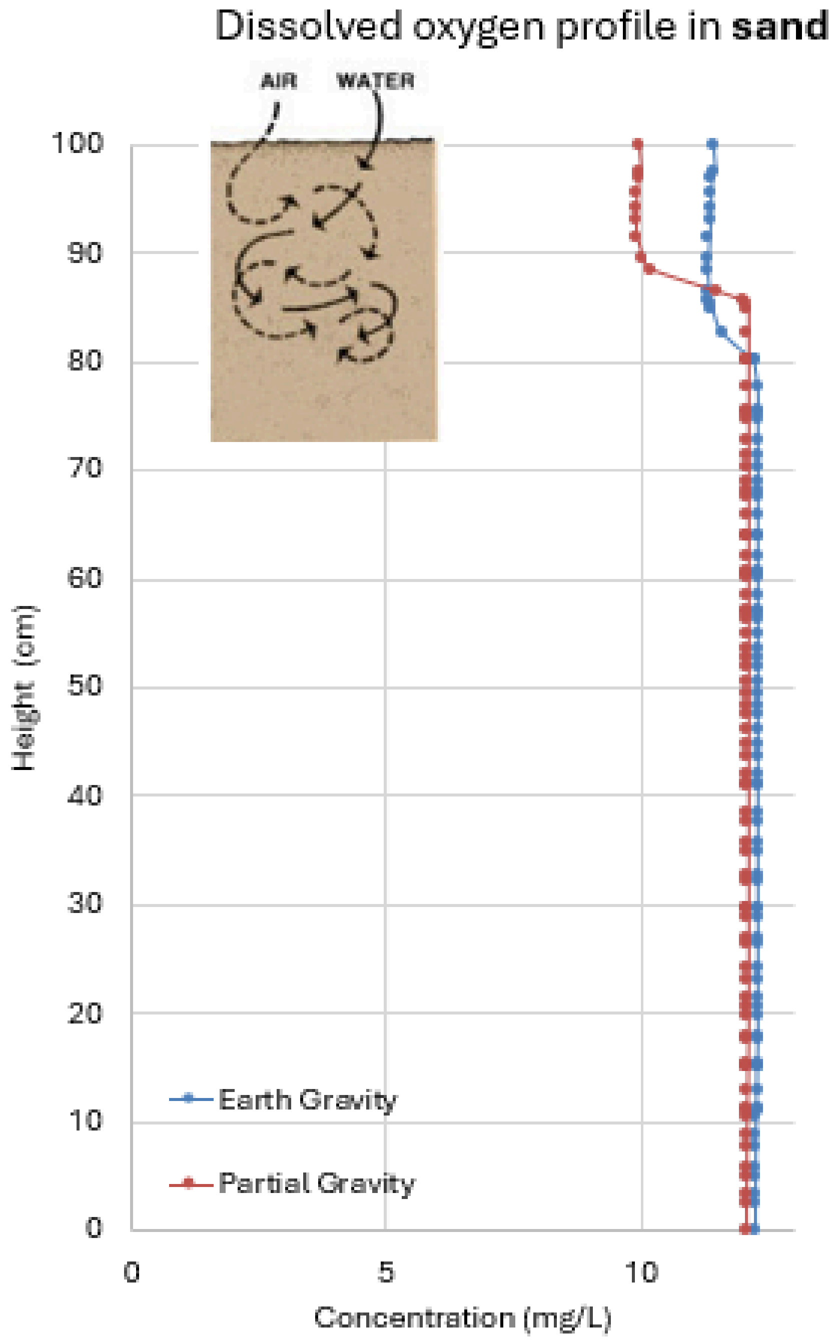


Feeding interval <1 day



Simulation results of contaminant removal in continuous feeding (t < 1 day)





Possible Causes

- **Higher entry suction pressure** of lunar regolith simulant