Dynamic System Modeling for Achieving Net-Zero Water Building Design

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INTRODUCTION

Buildings are major water consumers, especially during the operational phase. Net-zero water buildings aim to (FEMP, DOE):

- Minimize total water consumption
- Maximize use of alternative water sources
- Reduce wastewater discharge and return water to the original source

However, achieving these goals is challenging due to:

- Fluctuating water demand
- Mismatch between supply and demand
- Storage and reuse system limitations

A **systematic modeling tool** is needed to support the design and planning of water-efficient buildings.

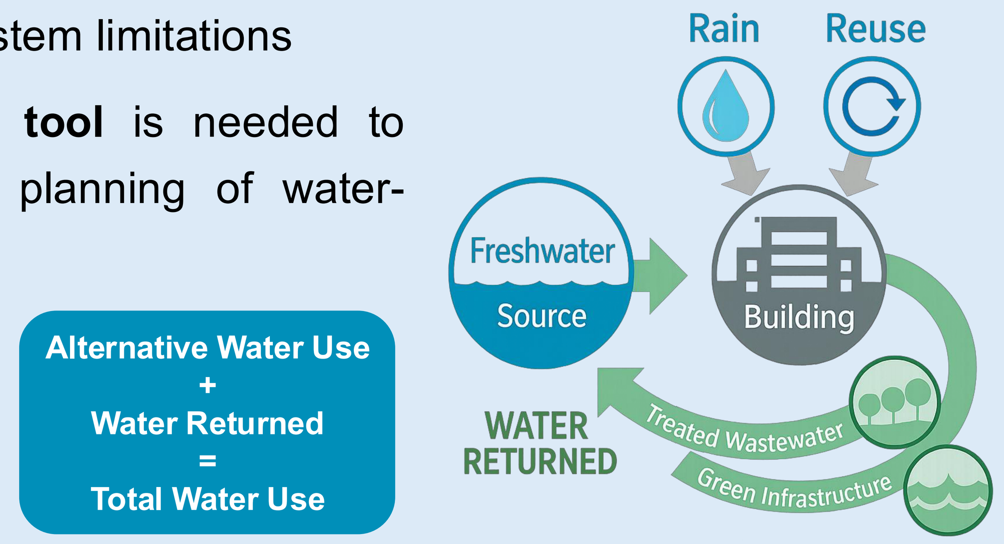

Fig 1. The Difinition of Net-zero Water Building (Redrawn based on FEMP, DOE)

METHODS

Step 1. Define Modeling Objective and Boundaries

Step 2. Establish the Building Water Model Framework

Step 3. Construct Building Water Dynamic Model Modules using VENSIM

Construct 6 main modules based on the framework and the water balance framework from Taiwan's industrial park water planning :

1.Water Sources
2.Storage Tanks
3.Green Infrastructure, GI
4.Water Demand
5.Treatment & Recycling
6.Evaluation Indicators

Step 4. Define Inter-Module Relationships

- Establish flow logic (e.g., supply priority, tank refill triggers, recycling paths)
- Incorporate:
  - Recycling efficiency
  - Treatment efficiency
  - Delay time for water availability after treatment
- Implement feedback loops and stock–flow logic using Vensim

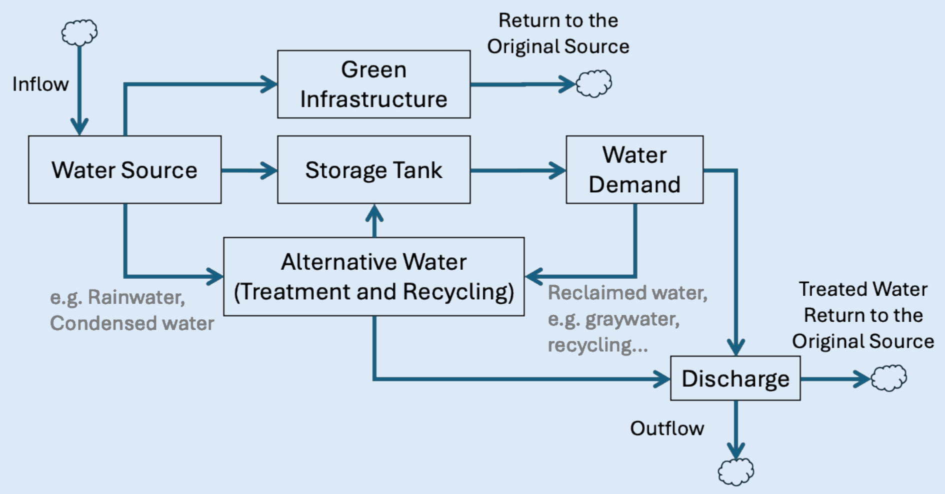

Fig 2. The Logical Framework of the Dynamic System Model

Step 5. Model Application: A Virtual Industrial Site in Taiwan

Input parameters included

- **Daily rainfall**
- **Demand profiles**
- **Recycle efficiency**
- **Treatment performance.**
- **SWMM** was used to simulate GI performance.

CASE STUDY- A Virtual Industrial Site in Taiwan

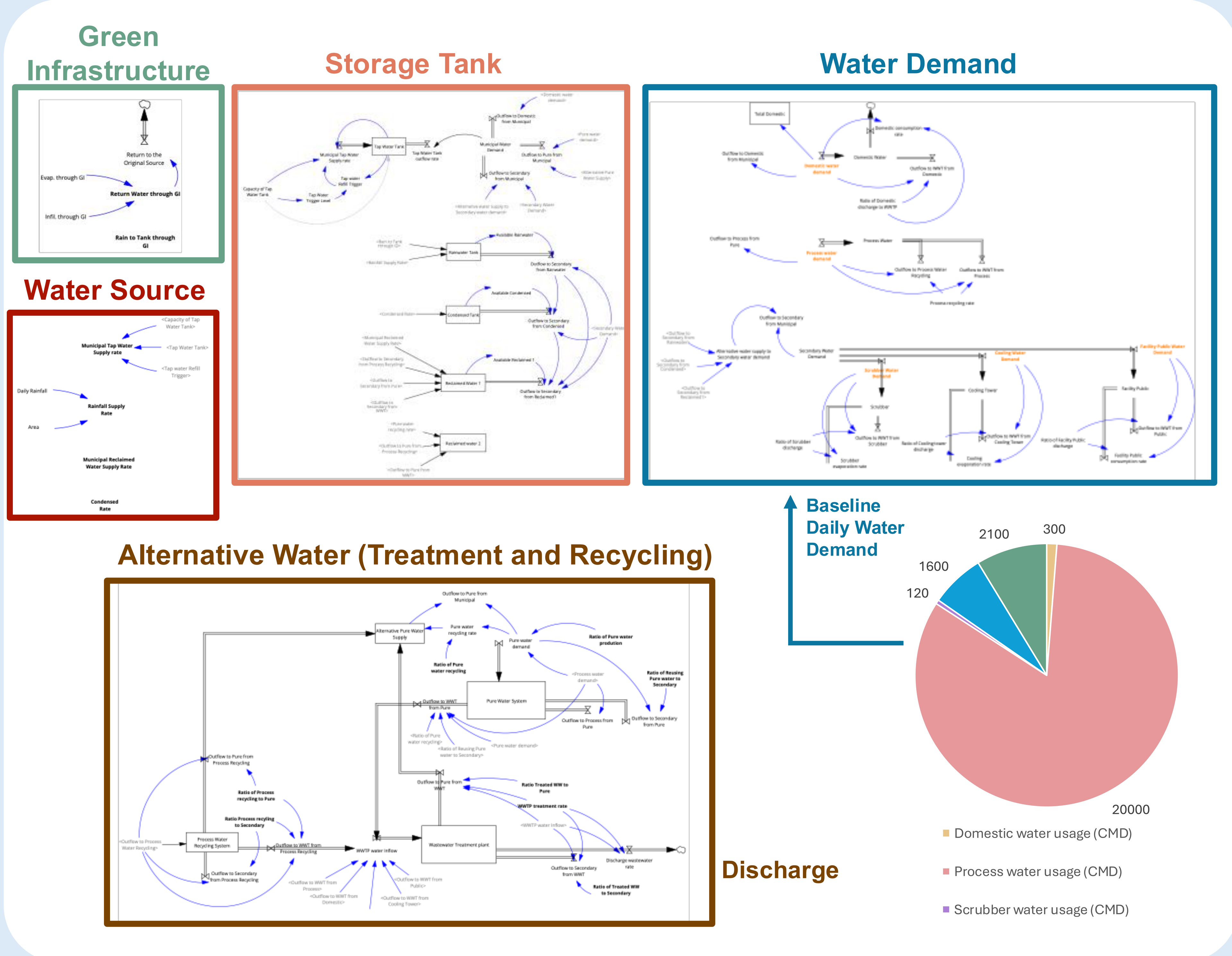

Fig 3. Dynamic system model for evaluating net-zero water performance in a virtual industrial site.

To demonstrate the applicability of the developed model, a **virtual industrial site** was constructed based on the typical layout and water use patterns of a science and technology park in Taiwan. Key scenario settings applied in the simulation are summarized in Table 1 and 2.

Table 1. Assumed Scenario Settings for the Virtual Industrial Site

Category	Setting
Water Demand Functions	Process, domestic, public/facility, cooling, scrubber
Alternative Water Sources	Rainwater, condensate, reclaimed water
Treatment Systems	Wastewater treatment, pure water system, process water recycling; internal recycling ratios assumed based on typical operational conditions.
Green Infrasrtructure	Green Roof, Bio-retention, permeable pavement, retention pond
Data Type *(Assumed scenario)*	Baseline demand with ±5% daily fluctuation (RANDOM UNIFORM); internal recycling ratios assumed fixed; daily rainfall and condensate supply estimated based on representative site conditions.

Table 2. Low Impact Development (LID) Design and Allocation by Subcatchment

Subcatchment	Area (m^2)	LID	LID % area(designed)
A	6400	Green Roof	50
B	7400	Green Roof	10
C	1000	Green Roof	10
D	1300	Green Roof	80
M	8300	Green Roof	80
KL	8600	Green Roof	20
Green1	1200	Bio-retention	80
Green2	3000	Bio-retention	80
Green3	700	Bio-retention	95
Green4	100	Bio-retention	90
Green5	1700	Bio-retention	95
pond	-	-	-
parking1	900	permeable pavement	100
parking2	1100	permeable pavement	100

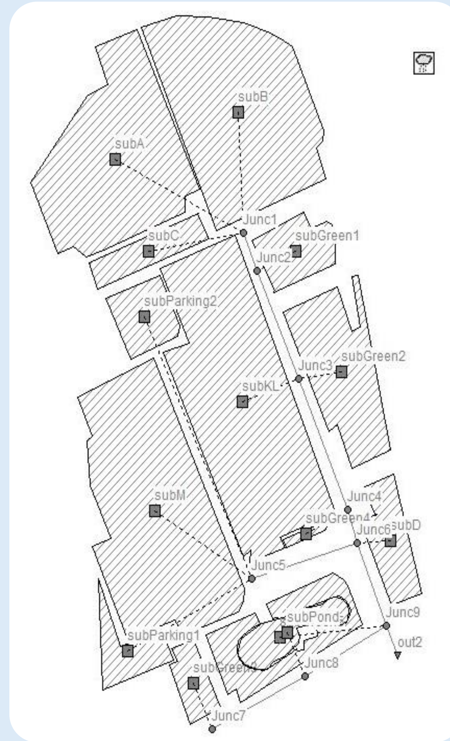

Fig 4. Subcatchment Layout of the Virtual Industrial Site

RESULTS

Net-Zero Water Performance Evaluation

- The **Net Zero Water Achievement Index** provides a quantitative evaluation of how effectively alternative water sources and return flows offset freshwater demand, where Index = 1 indicates full achievement of net-zero water, defined as:

$$Net\ Zero\ Water\ Index = 1 - \frac{Municipal\ Tap\ Water\ Intake\ - Return\ Water}{Alternative\ Water\ Used + Municipal\ Tap\ Water\ Intake}$$

- Simulation results showed the index stabilized at approximately **69%** (Fig 5.), meaning **69% of total water demand was met by alternative water sources and return flows**.
- The initial fluctuation of the index reflects the system startup phase, primarily due to storage tank filling.

Alternative Water Utilization& Return Water via GI

- Alternative water contributed 68.67% of total water use in the modeled scenario.
- Return flows through GI, contributed 0.23% of total water use :
  - Evaporation through GI: 16,110.65 m³/year (0.18%)
  - Infiltration through GI: 4,076.10 m³/year (0.05%)

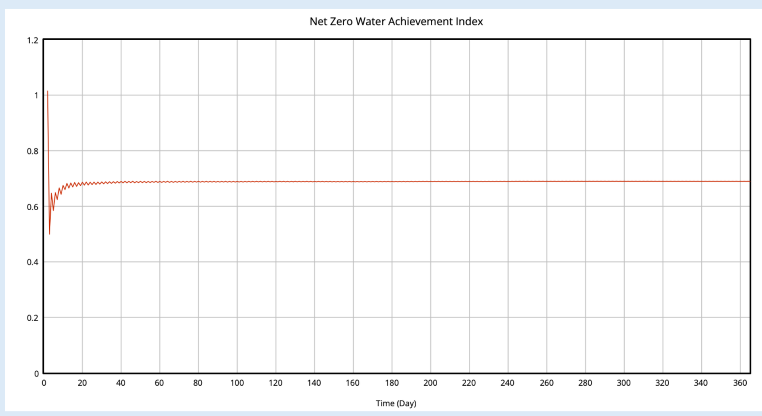

Fig 5. Net Zero Water Index performance over the simulation period.

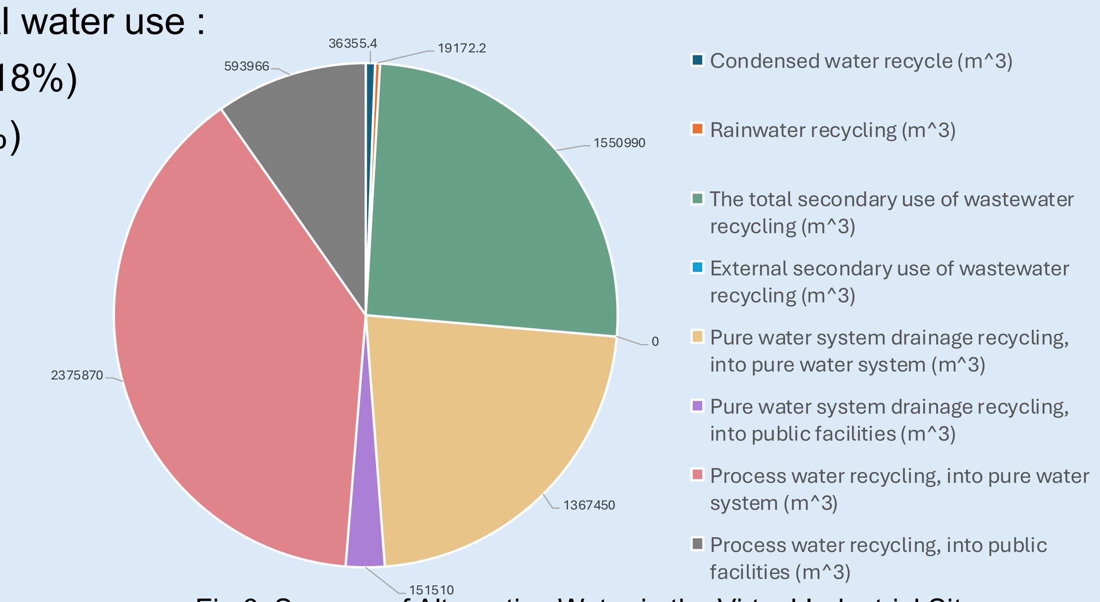

Fig 6. Sources of Alternative Water in the Virtual Industrial Site

CONCLUSION&DISCUSSION

- A dynamic system model was developed to evaluate net-zero water performance for a virtual industrial site.
- The model achieved **68.67% alternative water utilization**, with the **Net Zero Water Index stabilized at approximately 0.69**.
- The framework enables scenario analysis and can be applied to assess different **water management strategies, infrastructure configurations, or climate conditions**.
- To address remaining gaps toward net-zero, companies may consider adopting **water neutrality strategies** (e.g., replenishing water through ecosystem restoration or supporting water access projects beyond the site).
- Future work may include **sensitivity analysis, seasonal rainfall variations, or multi-year evaluations** to enhance model robustness.

REFERENCE & CONTACT

Reference

Definition of net-zero water building adapted from U.S. Department of Energy, Federal Energy Management Program (FEMP).

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