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DECISION SUPPORT MODELING FOR NET-ZERO WATER BUILDINGS

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ABSTRACT

Net-zero buildings emphasize balance between the consumption and production of resources, resulting in structures that are not only more efficient, but potentially restorative. While historically applied to energy use, the net-zero framework is also relevant to water management. Both the building energy and water sectors consist of demand loads that must be met by available sources. Variations in load design, source allocation, and human interaction result in numerous arrangements that require evaluation to meet efficiency goals. Decision support systems aimed at building energy are abundant, whereas building water tools are limited. The dynamic nature of the building water cycle necessitates flexible modeling tools that can predict and assess future water consumption and production trends at varying resolutions and under fluctuating conditions. This paper presents opportunities for simulation modeling to support net-zero water achievement and introduces an integrated building water management (IBWM) model for on-site water balance decision support.

1 INTRODUCTION

The prevalence of net-zero projects is increasing in the building industry, especially regarding energy use (New Buildings Institute 2014). However, the application of net-zero evaluation has been expanded to other resource sectors where balanced consumption and production may be measured. Although less visible than net-zero energy objectives, net-zero water goals have been established by the Living Building Challenge certification program and the United States Army (International Living Future Institute 2012, United States Army 2014). The Living Building Challenge is an optional verification program, while U.S. Army net-zero piloting sites are mandated, but both recognize that net-zero accomplishment results in benefits regarding resource costs, predictions, flexibility, and conformance with emerging building standards (Booth et al. 2010).

Net-zero design and compliance requires analysis of resource use. Multiple integrated energy modeling tools exist for the design and analysis of building energy functions (Crawley et al. 2008). However, the complexity, flexibility, and dynamic capabilities found in energy simulation programs are generally lacking in the water sector (Table 1). Implementation of static values does not capture inherent variations in occupant behavior and produce limited water use results (CSIRO 2012, National Geographic Society, 2013, Pacific Institute 2010, POLIS 2010). Water models commonly output annual averages which dilute actual water profile outputs. The range of building types and water pathways are also restricted. Building water models often assume a specific building type and prevent connections between certain water sources and water fixtures. Water simulation tools must adapt to contain the features found in energy modeling programs for net-zero water analysis.

Table 1: Comparison of attributes found in energy and water simulation tools.

Attribute	Energy tools	Water tools
Prevalence	Prevalent	Limited
Inputs and outputs	Dynamic capabilities	Static
Results type	Detailed	Averages
Resolution	Detailed down to hourly	Annual
Building types supported	Flexibility for many types	Mostly residential
Sources	Alternative sources	Lack of alternative sources

Net-zero water projects require utilization of alternative water sources to offset potable water consumption. Integrated solutions are required that sustainably address all building water inputs and outputs for net-zero balance. Similar to energy load-matching, integrated building water management (IBWM) matches water demands (loads) to available sources based on a "fit-for-purpose" framework (Voss et al. 2010). Effects of different management schemes on all routes of water must be considered as part of an IBWM approach and to achieve water balance. The objective of this paper is to present a dynamic IBWM model framework capable of emulating various water demand and source interactions found in different building types that may be evaluated for net-zero compliance. The model must account for alternative water sources that allow for potable water offsets and accommodate variations in water demand and source profiles that result from occupant behavior, climate, and fixture usage. The IBWM model is applied to a case study to determine the feasibility of net-zero water compliance at a specific building site.

2 NET-ZERO WATER

Net-zero water assessment may be considered at various hydrologic levels (Figure 1). Water pathways within the building create a building water cycle unique to the interior structure. The physical building structure often consists of open space comprising the building site, which expands the hydrologic boundary. Infrastructure linkages connect the building to the urban water cycle, where municipal water and wastewater networks rely on natural water sources for water use and disposal. All water cycles are enclosed within the natural environment, and net-zero water projects aim to emulate the natural hydrologic cycle. The building, as a complete system and component of the larger hydrologic cycles, significantly affects the manipulation and distribution of water resources.

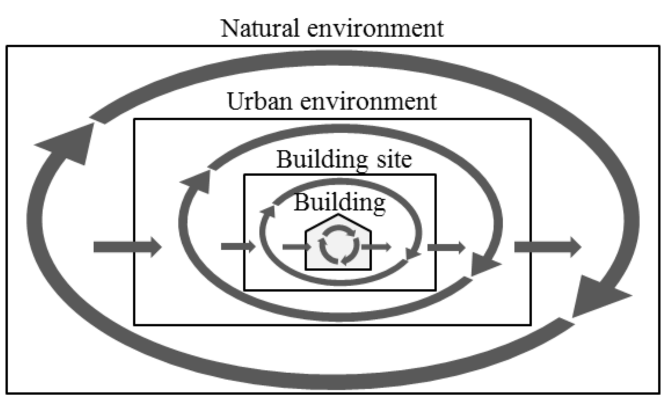

Figure 1: Nested hydrologic cycles for net-zero evaluation.

The nested water cycle boundaries which allow water transfer throughout them create multiple possible confines for net-zero water calculation. The varying boundaries for net-zero water balance are evident in the range of definitions found in Table 2.

Table 2: Definitions for net-zero water.

Definition	Source
"A net zero water installation limits the consumption of freshwater resources and returns water back to the same watershed so not to deplete the groundwater and surface water resources of that region in quantity and quality over the course of a year."	US Army, 2014
"One hundred percent of the project's water needs [except for regulated potable uses] must be supplied by captured precipitation or other natural closed loop water systems that account for downstream ecosystem impacts, or by re-cycling used project water. Water must be appropriately purified without the use of chemicals."	International Living Future Institute, 2012
"Annual potable water use is no greater than annual rainfall"	Olmos and Loge, 2013

Clarification among net-zero water definitions and associated boundaries may be achieved by applying net-zero energy concepts from the energy sector to the water sector (Hernandez & Kenny 2010, Sartori et al. 2010, Torcellini et al. 2006). The following definitions describe different evaluation techniques for water balance.

2.1 Zero Building Water

Zero water is synonymous with on-site net-zero water. For zero water compliance, the building must meet all water demands with water sources that originate within the building site boundary, such as precipitation. Municipal sources supplied by urban infrastructure, such as centralized potable or reclaimed water may not be used. The boundary for quantitative evaluation is drawn around the building site, but downstream impacts must also be considered. Reliance on natural precipitation water sources requires storage in order to take advantage of periodic rainfall events for year-round water demand fulfillment. Modeling of natural hydrologic patterns is necessary to ensure prolonged zero water achievement. Wastewater recycling is necessary in order to perpetuate the residence time of water within the building system, thereby limiting the amount of external water sources needed.

2.2 Net-Zero Building Water

Net-zero water expands the boundary to include urban infrastructure. Calculations allow for the net amount of water consumption to be offset by water production. The definition proposed by Olmos and Loge (2013) applies to this category. Precipitation falling within the project boundary and returning to the local watershed is considered water produced. Therefore, the precipitation offsets the water consumed from the municipal potable supply. However, true balance requires that both the originating and end locations of the water are within the same watershed. In addition, losses due to distribution networks should also be considered in the net-zero balance equation.

2.3 Life-Cycle Zero Water

A life-cycle zero water building calculates the embodied water cost for the project over its lifetime and offsets the consumption cost with water production. The feasibility of achieving life-cycle zero water balance based solely on quantitative calculations is unlikely. The embodied water within building materials may greatly exceed direct consumption (Crawford and Pullen 2011). Water is a natural resource that changes forms, but can generally not be created on a large scale. The creation of new water from hydrogen and oxygen requires a large energy input, which would increase the embodied energy needed to be offset. Life-cycle zero water achievement may become feasible if larger environmental impacts are considered within the evaluation.

2.4 Environmental Balance

Net-zero implies quantitative balance where the amount of incoming water equals the amount of outgoing water, but net-zero must also include balanced impacts. Quantitative water balance is possible while being detrimental to urban and natural environments. For example, a building discharging wastewater at a low quality to the natural environment may maintain quantitative water balance while reducing the health of the discharge environment. Maintaining the balance of water quality, but altering water origin and discharge locations or consuming and returning water at different times also has negative effects. Therefore, net-zero accomplishment requires proper management of water in terms of quantity, quality, location, and time.

3 BUILDING WATER CYCLE SIMULATION

3.1 Building Functions

Buildings fulfill specific functions such as shelter, protection, sanitation, and comfort. Water-related functions vary among buildings. Building water functions, or demands, must be identified in order to establish baseline water demand profiles for the building site. In addition, potential water sources that may meet the specified demands must be catalogued. The inventory of building demands and sources outlines the potential demand-source connections available within the building water cycle and capacity for water balance. Table 3 presents potential water demands and sources found in different building types and included in the IBWM model. Not all functions exist within all buildings, and the individual demands and sources may be excluded for simulations of various building water cycles.

Table 3: Potential water demands and sources in the IBWM model.

Water demands				Water sources	
Cooling	Landscaping	Firefighting	Process water	Greywater	Reclaimed water
Toilets	Green roof	Bathroom sinks	Drinking	Blackwater	Potable water
Urinals	Cooling	Kitchen sinks	Flexible stock 1	Stormwater	Condensate
Showers	Laundry		Flexible stock 2	Rainwater	

3.2 Water Allocation Prioritization

The inclusion of multiple water demands and sources within the building water cycle drives the need for prioritization. In order to reduce potable water use for net-zero water achievement, the use of alternative water sources must be assigned higher priority over potable or municipal sources. Previous work resulted in the creation of a prioritization framework in which ranked alternative water sources are allocated to demands based on priority (Joustra and Yeh 2014). Explicit prioritization is limited in current water models. Models that include water source prioritization often limit the number of potential ranking arrangements and exclude many demand-source connections (Makropoulos et al. 2008, Yates et al. 2005). Adaptable prioritization schemes are necessary in order to assess net-zero water projects. Therefore, the baseline prioritization within the IBWM model allows all demands to be met by all sources. In practice, the baseline prioritization framework is altered based on regulations, source availability, cost, and user-preference that dictate allowable water connections (Chung and Lee 2009, Yang et al. 2012).

4 IBWM MODEL

4.1 Software

All conceptualized building water aspects are networked using the *Systems Thinking Experimental Learning Laboratory with Animation* (STELLA) visual modeling software (www.iseesystems.com) to form a coherent system. STELLA was chosen as the development tool for the model due to its visual mapping, simulation features, and user-friendly interface. Utilizing STELLA provides a built-in dynamic aspect to the IBWM model, allowing trends in water demand and supply to be simultaneously plotted.

4.2 Model Overview

Development of the IBWM model is based on a generic framework that contains extensive demands that can be altered to represent most building types. The framework construction is generic in nature, and the control volume includes the building and adjacent landscaping. The IBWM model framework for water use and recycling includes the following features:

- Detailed supply and demand accounting for toilets, urinals, showers, bathroom sinks, kitchen sinks, laundry, drinking, cooling, landscaping, and green roof
- Flexible stocks for firefighting demands, process water, and two additional undefined demands separated based on the level of human contact
- Collection and storage of greywater, blackwater, rainwater, stormwater, and condensate
- Greywater and blackwater recycling for all demands
- Application of stored rainwater, stormwater, and condensate for all demands
- Control of fit-for-purpose water application options through the use of on-off switches
- Measurable tracking of all flows and volumes, visually and statistically

The IBWM model consists of various flows and volumes that can be separated into individual water demand and source subsections. Each section can be broken up into its own control volume with balanced and prioritized inflows and outflows. Once defined, all individual sections are connected in order to create a whole building system that defines all possible routes of water.

Each demand subsector consists of balanced inflows and outflows that are matched in order to fulfill the demand function and prevent accumulation in the demand volume stock. Therefore, for all demands

$$\int Q_{in} dt - \int Q_{out} dt = V = 0 .$$

The demand stock represents the point where water undergoes a quality transformation and may be divided into different pathways. No water may be created or destroyed at this intersection. Water losses from the subsector, such as leaks, human consumption, or runoff, are accounted for by an outflow pathway from the demand stock.

Unlike the water demands, water source subsectors must account for accumulation in the source volume stock. For all source stocks,

$$\int Q_{in} dt - \int Q_{out} dt = V \text{, where } 0 \leq V \leq V_{max}.$$

Outflows from the source volume stock cannot exceed the value of water available from the inflows and storage volume; therefore, the volume of the stock will always be a positive value.

Defining individual demand and source flows may be accomplished using graphs, tables, or static values. Applying static values has been the traditional method for water estimation, but results in static outcomes. The ability to vary water consumption or production parameters better emulates actual building water flows. All demand and source flows have the ability to accept graphical or tabular inputs which may be estimated or acquired from real-building data. Most demands and sources may also be calculated by the model based on user-defined parameters regarding usage and fixture design.

4.3 Building Water Demands

The IBWM model developed is demand-driven. Each building water function exerts a demand which drives the allocation of sources to meet that demand. Therefore, building water demands must be defined first. Equation-based calculations are based on United States Green Building Council (USGBC) materials (USGBC 2009). Although the assumptions may not accurately represent the water usage for a specific projection, the IBWM model allows users to alter assumptions to values that feel more accurately portray water usage for their site or to apply direct graphical or tabular inputs.

4.3.1 Irrigation

The baseline amount of water demanded for irrigation is estimated based on the type of vegetation, area of the vegetation, vegetation characteristics, and evapotranspiration (ET). Water applied to landscaping is either utilized by the vegetation through ET processes or exits the subsystem as runoff. The water requirement for all irrigated landscaping requires the demand exerted by each vegetation type *i* to be considered. The total demand is calculated as

$$Q = CF \times ET_0 \sum_{i=1}^{n} \left(\frac{K_i A_i}{CE_i} \right)$$

where CF is a conversion factor, ET_0 is the baseline evapotranspiration rate for the site in inches or millimeters per desired time duration, K_i is the composite landscape coefficient between 0 and 1 for vegetation type *i*, A_i is the area of vegetation type $_i$, and CE_i is the controller efficiency between 0 and 1 for the irrigation system for vegetation type *i*.

4.3.2 Green Roof

A green roof, containing native and drought-tolerant landscaping, should optimally only require natural rainfall for sustainability. However, if irrigation is required, the inflows and assumptions follow the same format as the irrigation subsystem. Of this water, an amount is lost to the vegetation through evapotranspiration which varies seasonally. Additional water may exit the green roof as runoff. The option exists for runoff to be collected in a cistern or stormwater pond for use within the building system.

4.3.3 Cooling Tower

The cooling volume requires replenishment due to evaporation, drift, and bleed-off. Evaporation within the tower increases the concentration of dissolved solids; therefore, water from the tower is drained, or bled-off, into the sewer in order to return the concentration to a safe and reasonable value. Additionally, the model incorporates potential condensate capture from heating, ventilation, and air conditioning (HVAC) systems for reuse within the building.

4.3.4 Sinks, Showers, Laundry Machines, and Drinking Fountains

Sinks, showers, laundry machines, and drinking water fountains produce greywater. Generally, potable water is assumed to be the only appropriate source for these fixtures. However, the opportunity exists to utilize alternative sources for these needs. Water enters these fixtures before exiting as untreated greywater. The collected water can be sent through a treatment system, such as a MBR, and can then be reused within the building system for applications such as cooling, toilet flushing, urinal flushing, or irrigation. In a conventional setting, water exiting these fixtures is sent to the sewer system.

For flow-based fixtures such as bathroom sinks, kitchen sinks, and showers, the water demand is calculated as

$$Q = Q_i t N_i X ,$$

where Q_i is the flowrate for fixture *i*, *t* is the duration of each user-application of fixture *i*, N_i is the number of applications by occupants during the desired time period, and X is the number of occupants.

For volume-based fixtures, the $Q_i t$ expression is replaced by a single term for the volume of each fixture use event, V_i,.

4.3.5 Toilets and Urinals

Water used in toilets and urinals exits as blackwater. The resulting blackwater is tracked and collected as a separate possible recyclable source that is combined with greywater when this source is also active, or released and lost into the sewer system. Water demand can be decreased by installing fixtures that use fewer gallons per flush or utilizing waterless fixtures.

4.3.6 Flexible Building Subsections

The model incorporates separate sections that are not defined by a specific set of equations. Water demands can vary drastically from building to building, but additional subsections are included so that the model can be expanded to building sites with more intricate building cycles. Subsections exist for firefighting, process water, a generic demand with low human interaction, and a generic demand with high human interaction. The two generic stocks set aside for low or high human interaction demands have the potential for storage, such as an aesthetic water feature or swimming pool. Linkages also exist within the model to allow water exiting from all four flexible subsections to be defined and collected within the recycled wastewater, rainwater, stormwater, condensate, flexible stock or directed to the sewer.

4.4 Building Water Sources

Seven potential water source storage subsectors exist within the model. Blackwater and greywater collection share a recycled wastewater storage volume. The remaining sources are stormwater, rainwater, condensate, reclaimed water, potable water, and a flexible storage stock.

4.4.1 Municipal Sources

Municipal sources in the model include potable water and reclaimed water. Both sources have the ability to be stored in a storage stock, but the volume collection is turned off so that each source is simulated as a single pipe inflow by default.

4.4.2 Rainwater and Stormwater

Rainwater and stormwater source flows may be defined by equations based on collection area (A), collection efficiency (CE), height of rainfall event (R). The natural rainwater inflow to a cistern is

$$Q = (CF \times CE \times A \times R) - V_{ff},$$

where CF is a volume conversion factor and V_{ff} is the first flush volume removed at the start of a rainfall event. Stormwater inflow into a pond storage system follows the same equation but lacks the first flush term. The model recognizes pond outflows, such as evaporation and infiltration, which are better estimated using detailed hydrologic models.

4.4.3 Condensate

High-quality condensate is ideal for offsetting potable water consumption in cooling towers and a plentiful source in hot and humid climates (Guz 2005, Licina and Sekhar 2012). Estimating condensate production is difficult due to fluctuating variables, including humidity, temperature, and equipment runtimes. Condensate source inflow may be defined by static of dynamic profiles provided by the user.

4.4.4 Recycled Wastewater

Recyclable wastewater sources include greywater and blackwater. Like all other source inflows, both may be statically or dynamically defined. However, these recycled sources may be calculated based on user-defined demand-source interactions. Wastewater from indoor building water fixtures may be directed to the recycled wastewater stock and re-allocated to demands within the building, thereby forming closed loop systems.

4.4.5 Flexible Storage Stock

An additional flexible source storage stock allows users to collect water from other sources or combination of wastewater from demands for model adaptability. The stock may represent a building water tower or additional alternative water storage facility.

5 CASE STUDY

The feasibility of achieving water neutrality is evaluated by applying the IBWM model to a hotel building site in central Florida. The basic hydrology flows for the site and region are presented on Figure 2. The building is currently serviced by potable from the city water treatment plant (WTP and reclaimed water supplied by the city wastewater treatment plant (WWTP). The city forms its own urban hydrologic system boundary. The 3-floor, 76-unit building structure is contained with a 6500 m^2 (70,000 ft^2) site. The hotel includes a swimming pool, landscaped areas, and central air conditioning.

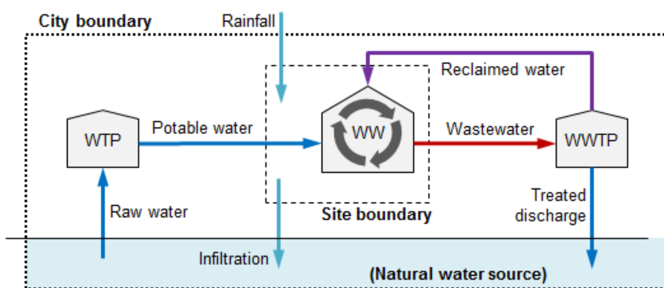

Figure 2: Basic hydrologic flows for the hotel site. Water use neutrality requires water cycles to be balanced. Net-zero fulfillment balances water flows at the larger urban scale, and zero water achievement requires balance within the building site.

Model runs take place over a year (from December 2011 through November 2012) with water allocation calculations occurring at a daily time step. Real-building water use data is used for total indoor and landscaping water consumption. Consumption by individual end-uses is estimated based on data from Gleick et al. (2003). The baseline water consumption for the building site is displayed on Figure 3.

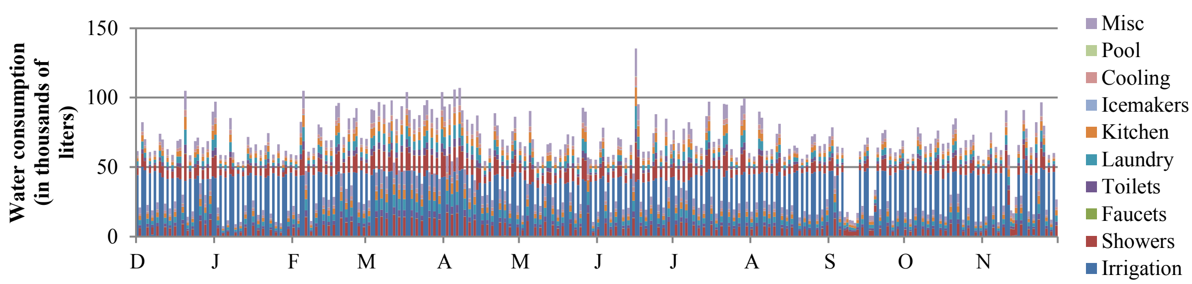

Figure 3: Water consumption for the hotel case study site separated by estimated end-use.

5.1 Net-zero Water Balance

For net-zero water balance, the building may utilize municipal water sources. Similar to the argument made by Olmos and Loge (2013), municipal potable water may be utilized if rainwater entering the site is managed so that it returns to the natural water source where the municipal supply originates. In this case, the urban water infrastructure creates another potentially balanced loop between the building and wastewater treatment plant, whereby wastewater is treated for reuse applications as reclaimed water. Climate is a fluctuating factor, and thus ten precipitation scenarios were considered for potential net-zero water achievement – three wet (W) patterns, four normal (N) patterns, and three dry (D) patterns. The model was used to calculate the annual on-site rainwater available for offsetting the potable water consumption. The model was also utilized to estimate the amount of wastewater exiting the building that could represent the amount of reclaimed water available for use in order to maintain balance.

Results for the ten precipitation runs are presented in Table 4. When all indoor and outdoor water demands are considered, net-zero balance cannot be met without the inclusion of reclaimed water sources; and even with the addition of reclaimed water, net-zero balance is only achieved for the model runs conducted under wet patterns. When outdoor demands are eliminated by implementing native and drought-tolerant landscaping, net-zero balance based solely on on-site rainwater is accomplished for the wet years. The addition of reclaimed water exceeds net-zero balance for all wet, normal, and dry years.

Table 4: Potential net-zero balance of potable water consumption (PW) compared to on-site rainwater (RW) and reclaimed water (RC) availability. Instances where the net-zero threshold has been exceeded are shown in **bold**. The percent potable water use reduction required (PW Red.) to reach net-zero is given for scenarios that do not meet the net-zero threshold.

Run	Annual RW		Indoor and outdoor use				Indoor use only		
	Inches	Liters	RW-PW	PW Red.	RC – (RW - PW)	PW Red.	RW-PW	PW Red.	RC – (RW – PW)
W1	69.59	11,494,988	-7,667,728	76%	**1,660,892**		**1,377,555**		**10,706,175**
W2	62.83	10,378,360	-8,784,356	87%	**544,265**		**260,927**		**9,589,548**
W3	61.92	10,228,045	-8,934,671	88%	**393,949**		**110,612**		**9,439,232**
N1	53.66	8,863,645	-10,299,071	102%	-970,451	10%	-1,253,788	12%	**8,074,832**
N2	52.03	8,594,399	-10,568,317	104%	-1,239,697	12%	-1,523,034	15%	**7,805,586**
N3	50.71	8,376,359	-10,786,357	107%	-1,457,736	14%	-1,741,074	17%	**7,587,547**
N4	48.03	7,933,673	-11,229,043	111%	-1,900,423	19%	-2,183,760	22%	**7,144,860**
D1	45.53	7,520,718	-11,641,997	115%	-2,313,377	23%	-2,596,714	26%	**6,731,906**
D2	42.75	7,061,514	-12,101,202	120%	-2,772,582	27%	-3,055,919	30%	**6,272,701**
D3	41.85	6,912,850	-12,249,866	121%	-2,921,246	29%	-3,204,583	32%	**6,124,038**

5.2 Zero Water Balance

Only on-site water sources may be utilized for zero water balance, and zero water analysis for the case study site only considered indoor water demands. From the net-zero water results, it is clear that the landscaping demand decreases the likelihood of water balance. Five alternative water use scenarios are considered (Table 5). Although Florida state regulations (Chapter 62-610) exist regarding the reuse of municipal reclaimed water for a variety of purposes (i.e., irrigation, fire suppression, laundry, toilet flushing), specific regulations regarding rainwater application are lacking. Rainwater harvesting is largely encouraged within the region in order to offset household irrigation water use. Routing rainwater to indoor water applications generally requires compliance with building codes, protection measures to prevent contamination of potable systems, and disinfection at a minimum. However, the lack of explicit regulation results in the interpretation of technical requirements for approval by local agencies. This study assumes that rainwater is allowed to meet the demands specified in each scenario and is treated accordingly. A collection area of 930 m^2 (10,000 ft^2) , cistern storage volume of 190,000 liters (50,000 gallons), collection efficiency of 0.90, and first flush volume of 76 liters (20 gallons) are used as model inputs for rainwater collection. The W1 precipitation pattern is used for the analysis.

Table 5: Scenario descriptions for zero water IBWM model runs.

Scenario	Description
Scenario 1	Rainwater (RW) to toilets and pool
Scenario 2	RW to toilets, pool, cooling and misc.
Scenario 3	RW to showers, laundry and pool; Recycled wastewater (WW) collected from showers, sinks, and kitchen for use in toilets, cooling and misc.
Scenario 4	RW to showers and sinks; WW collected from showers, sinks, kitchen, toilets and laundry for use in toilets, cooling, misc., pool and laundry
Scenario 5	RW to showers, cooling, laundry, misc. and pool; WW from showers, sinks, kitchen, toilets, laundry and misc. for use in toilets, cooling, misc., pool, laundry and showers

The results show that potable water use decreases as water reuse and recycling connections are increased (Figure 4). Potable water was the only source considered acceptable to meet water demands associated with sinks, cooking, and ice-making. Only the most extreme water reuse and recycling scenario achieved zero water balance for the case study site, but balance did not occur throughout the year (Figure 5). The net-zero water evaluation shows that enough rainwater falls within the site to offset all potable water demands. However, the limited rainwater collection area and cistern storage greatly reduce the accessible volume. Potable water is required to meet the demands when stored rainwater and recycled wastewater streams are inadequate.

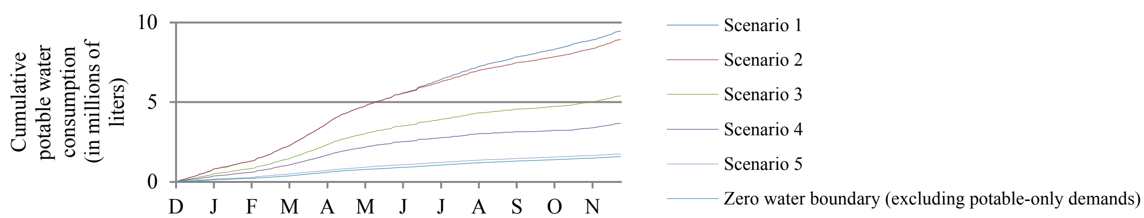

Figure 4: Cumulative potable water consumption for precipitation pattern W1 under the scenarios outlined in Table 5.

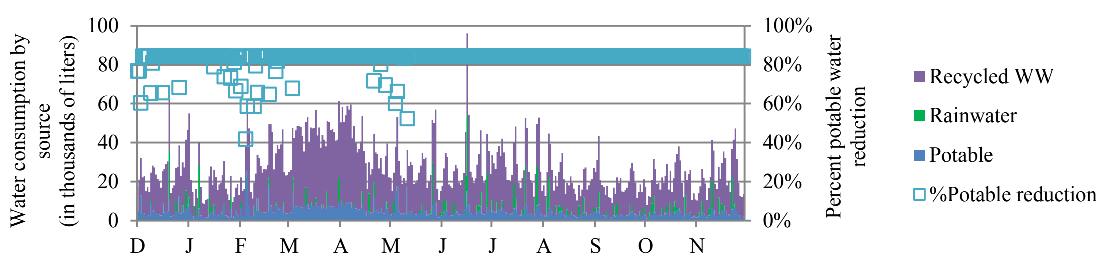

Figure 5: Total on-site water consumption by source and potable water offset for Scenario 5 in precipitation pattern W1.

6 CONCLUSION

An IBWM model has been introduced capable of evaluating the feasibility of net-zero water achievement for a building site. The control of water demand-source pathways within the model framework allows for the simulation of various building water cycles and evaluation of water neutrality within hydrologic cycles at distinct system levels. Although net-zero water and zero water evaluations of the case study site considered a limited number of variant scenarios, the IBWM model has the ability to address the variability introduced by climate, fixture design, and human behavior. Variations in both water demand and supply profiles are required in order to evaluate whether net-zero water or zero water goals are feasible under a range of possible conditions.

Water neutrality is currently based on quantitative evaluation. However, net-zero water balance must also consider environmental impacts associated with management scenarios that may result due to changes in water quality, spatial water relocation, or temporal water relocation. Furthermore, treatment of alternative water sources to meet end-use standards exerts demands for energy and materials. Net-zero water evaluation should be conducted as part of a whole-building net-zero analysis that considers balance within related sectors including energy, materials and emissions.

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