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Achieving Net Zero Water in Severe Drought Prone Areas: A Case Study of Catchment, Storage, and Infiltration Optimization

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Abstract

Net zero water or water independent buildings capture rainwater to meet potable water demand. These systems require a careful calibration between catchment size, storage capacity, and infiltration area to achieve performance goals. In severe drought prone areas with wider variability of rainfall and long periods of scarcity, the precision of the calibration between these three variables is more narrowly defined to reach system resiliency. This paper analyzes a case study of a midsize office project in the severe drought prone area of Los Angeles, California that aims to achieve net zero water. The interrelation of the three variables are analyzed against daily precipitation over the last 10 years to identify dependencies and critical break points. The study finds that in severe drought prone conditions, storage size is relevant only up to a threshold closely mapped with demand. Net zero water system resiliency is accomplished through the precise interrelation of catchment area and infiltration capacity.

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1. Introduction

An awareness of the need for expanded resiliency within the water system of Southern California has increased with recent severe drought conditions, yet integrated architectural and engineering building responses are few¹. Large municipal scale management systems have long held the focus of water system resiliency discussions, while, in relative order, less progress has been made with commercial building water systems². Commercial buildings account for up to 17% of publically-supplied water use³. In comparison with energy, which has well established benchmarks (e.g. EUI), building water use has thinly established benchmarks⁴.

This paper takes a case study of a midrise office building in Los Angeles County to address how individual commercial buildings can contribute to regional goals of water resiliency through an integrated architectural and engineering net zero water design. Rather than large scale infrastructural changes, this case study questions how water innovation can occur on a building scale. By creating a

water independent building that does not rely on the Southern California municipal supply, the building is removed from dependence on imported water with a high embodied energy⁵.

This paper addresses three main variables of net zero water design: capture, storage, and infiltration. The daily precipitation data from within 3 miles of the case study's project site⁶ over the last 10 years is used to model a range of catchment, storage, and infiltration sizes. Repeated severe drought years are simulated to establish system limitations under extreme conditions. Ultimately, break points and interdependencies are identified to create an optimal solution to achieve building water independence within a severe drought prone location. The variable amount of rainfall per year and inconsistent precipitation profile over the course of a year necessitate a system that can provide wide resilience.

1.1 Net Zero Water or Water Independence Definition

Net zero water, or water independence, is defined as meeting one hundred percent of a project's water needs through onsite capture, reuse, or other closed loop systems and managing one hundred percent of a project's storm water and water discharge. The outflow must be managed for ecological benefit⁷. There are few contemporary, commercial built examples of achieving net zero water in the world. The most publicized, documented examples are only a few years in existence and attached to the International Living Future's Living Building Challenge certification. The Bullitt Center in Seattle, Washington may be the most broadcasted example.

This definition of net zero water or water independence differs from common definitions of net zero energy (including the recent Department of Energy official statement⁸) in one fundamental way: there is no reliance on outside infrastructure. The building is disconnected from the municipal water supply (except for emergency fire suppression) and sewer and storm water outlets. Under this definition, net zero water is truly independent and provides resiliency outside of the functioning of a larger system, unlike the majority of net zero energy cases which are tied to the electrical grid.

1.2 Case Study: Site, Program, and Occupancy

The case study is a four story 49,000 square foot office building in Los Angeles County within the urban core. The 46,000 square foot site contains a thirty stall surface parking lot covered by a photovoltaic canopy, a public drive and service drive, landscaped public entrance, and landscaped public courtyard. The total Floor Area Ratio (FAR) is 1.1 and classifies the building as a L4 transect for density and location. Landscape areas exclusively contain urban agriculture with a drought tolerant irrigation profile. The ground floor of the building has a lobby and reception for public visitors with the upper two floors (levels 2 and 3) completely occupied by office space. The basement contains the showers, storage, various mechanical, electrical, composters (for the compost toilets), and water treatment rooms.

Occupancy numbers for the case study are presented as a Full Time Equivalent (FTE) value based on an eight hour work day. Fulltime employees are assigned an FTE of 1, whereas part time are given a fraction based on their hours within an eight hour work day assumption. Visitors are accounted for in the FTE with a half hour average visit to the building. In this case study, every other Friday is a non-working day. The calculated FTE for the building is 250.

2 Water Catchment

A building water system can be conceptualized in a similar way to a regional system: a watershed (the roof or catchment area), a reservoir (the cistern or storage volume), and a discharge site (the ground or infiltration area). The case study has two types of "water shed" areas: roof catchment suitable for potable water (represented in the model as supply) and surface runoff to be sent to a dry well (represented in the model as a component of total infiltration). Roof catchment is deemed to be of clean and consistent quality whereas surface runoff, in the view of regulatory authorities, is deemed to contain too much unpredictability in contaminants for a potable creation scenario.

2.1 Climate Uncertainty

Southern California experiences precipitation variability in two main ways that complicates modelling catchment potential: (1) annual seasonal fluctuation with winter rains and summer scarcity and (2) increased climatic deviation in drought and surge events for varying lengths of time⁹. In the face of climate uncertainty, resiliency of water systems has higher importance¹⁰ and net zero water design requires a wider view to optimize in this potentially greater variability.

2.2 Catchment Surface

All surfaces used for water catchment for treatment to potable water must be on a roof surface and fashioned from materials certified by the National Science Foundation (NSF) protocol 151 per California Plumbing Code, Appendix K. In this case study, catchment for potable use occurs on two surfaces within the project site: (1) the case study building roof and PV canopy over parking (19,000sf) and, to expand catchment potential, (2) one optional off-site surface, a neighboring building to be retrofitted with NSFp151 compliant roof membrane (24,000sf).

2.2 Water System Design and Water Budget Projections

The potable water demand projection is based on the 250 FTE occupancy. The potable water demand for the building includes: shower, lavatory, break room sink, drinking water, and maintenance (see Table 1.0). Grey water from showers and sinks is treated for reuse for onsite irrigation. Irrigation is needed to support an area of 15,000 square feet of urban agriculture and both tree species and low ground cover comprise the planting pallet.. These plantings are native and drought tolerant, thus adaptable to a wider variance of irrigation and rainfall. Storm water is addressed with an infiltration dry well, which is engineered at the lowest corner of the site to accommodate a 10 year peak 24 hour rainfall. Storm water from the site and a neighboring paved parking lot is treated through ecological means and infiltrated.

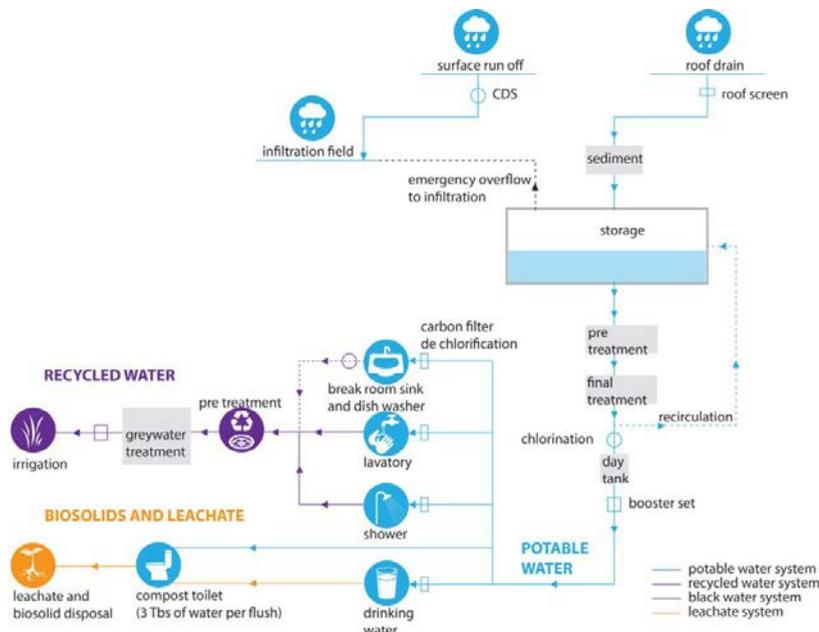


Fig. 1. Net zero water System Schematic of the Case Study

Toilet are compost units and their water usage is negligible (3 tablespoons per flush), but served by the potable water supply. The compost toilets have two outputs: (1) leachate and (2) biosolids. Leachate is pasteurized onsite and disseminated off site at a nearby constructed wetland. Biosolids are likewise pasteurized on site to a 'Grade A' compost classification, but spread on site.

3.0 Water Storage and Treatment

The case study proposes to use a series of three underground, fiberglass cisterns for water storage. In multiples, the storage becomes more robust as there is a backup if one storage unit needs to be maintained (eg cleaned, repaired) or if piping to one of the storage units ruptures.

Treatment options for a net zero water system are prevalent and established for greywater treatment, but largely unestablished and under-tested for the rainwater to potable water system component. In the United States, all potable water must comply with the Safe Drinking Water Act by the Environmental Protection Agency (EPA) standards¹¹. At this time, for a commercial building to create potable water, it must be operated under an existing water agency license or apply for a new one.

In this case study, greywater treatment is accomplished through a standard skid and used for subsurface irrigation. Potable water is created through the use of a sediment separator, sand filter, Ultra Violet (UV) disinfection, and chlorination (as an active treatment for pipe conveyance to point of use where it is de-chlorinated with a carbon filter per Living Building standards).

3.1 Permitting

In Southern California, the systems necessary to meet net zero water do not currently have a legally instituted pathway for permitting. The barriers currently presented by the California Health and Safety Code and Plumbing Code, Environmental Protection Agency protocols, and California Water Resource Control Board protocols make net zero water system permitting onerous if not impossible. For urban water reinvention to occur, institutional innovation will be as important as technological innovation¹³. There are three critical areas of institutional innovation needed to bridge with existing technological innovation: rain water to potable, zero discharge sewer, and onsite black water treatment.

4.0 Water Infiltration

Infiltration demand is primarily dependent on the amount and variation of rainfall on the site, area of the site, and soil capacity. The daily output from the building water use and storage capacity affect infiltration on a daily time scale. Infiltration can be accomplished through an array of options from natural to more engineered approaches. The appropriate strategy depends on location, geotechnical information, state and local regulation, and percolation information. Outside of onsite urban agriculture, the case study relies on a dry well to manage onsite infiltration due to the constrained urban location with minimal open space. The irrigation profile of the case study is directly defined by the amount of grey water produced over the course of a week (taken as the available irrigation water). Stated another way, grey water the only irrigation water provided for the project.

Percolation and geotechnical tests for the site revealed a high water table (between 30-40 feet below the surface) and sandy soil. For this case study site, there is favorable soil capacity, yet constrained area (given the urban site). Due to this constrained density, a dry well is needed to handle the full storm water ten year, 24 hour event.

4.1 Cistern Overflow

Cistern overflow occurs when several high quantity and long duration rain events occur, causing the cistern to reach its storage capacity. In the cases of cistern overflow, there is a valve channeled to the dry well infiltration area. With a large capture area and small cistern volume, the cistern will always be full, but the greater pressure will be placed on the infiltration field. With a smaller capture area and large cistern, the cistern may never be full while there will be minimal if any pressure placed on the infiltration field.

5.0 Methodology

The three components of the case study water system under study were: catchment area (sqft), cistern storage volume (gallons), and infiltration area (sqft). The catchment area and cistern volume were modelled as independent variables with infiltration area being the resultant dependent variable. The interrelation of the three variables are analyzed against daily precipitation in severe drought over the last 10 years to optimize for net zero water. Ultimately, when designing for resilience in times of extreme deficit, the reciprocal result in the model is a heightened overflow in times of heavy rains. The definition of achieving net zero water was no days within the 10 years where the cistern was empty. Table 4 provides a summary of the limits of the three variables that were modeled.

5.1 Modelling Daily Water Precipitation

Data collected within 3 miles of the project site was employed in order to show true variations and repeat drought occurrence from 2005-2014. The data was available at no cost from the Los Angeles County database. The methodology of modelling the system in response to real daily rainfall data (R) rather than an averaging of years was employed to test extreme data points of surplus and deficit within the year and over large climatic cycles of drought and El Nino events. The real data naturally provides deviations in intensities, durations, and frequencies.

R=Daily Rain Fall

5.2 Modelling Daily Water Capture

Water capture is established by taking the total catchment area (C) and multiplying it by the runoff coefficient (Ro) and the daily historic rainfall for that day (R). The runoff coefficient is established as an average for the particular roofing membrane material used.

$$C * R * Ro = \text{Daily Catchment volume}$$

- C=Catchment Area
- Ro=Runoff coefficient
- DC= Daily catchment volume

5.2 Modelling Daily Water Use

Occupancy usage over the 10 years was modelled taking into account weekends, governmental holidays, and the company policy of having every other Friday off. The assumed fixture type and usage duration pattern are outlined in Table 1. These assumptions were established through either study of current employee usage patterns or a survey of current employees projecting usage in the new building.

$$S + L + Br + DW + D + M = \text{Gallons of Water Demand per Day}$$

- S= Shower demand
- L=Lavatory demand
- B= Breakroom sink demand
- DW= Dishwasher demand
- D= Drinking water demand
- M= Maintenance demand

Table 1. Potable Water Demand Projection

Fixture Type/Use	Flow	Duration	Usage	Amount (Gal/day)
Shower	1.8 gal/min	5 min	20FTE 1x/day	180
Lavatory	0.5 gal/min	12 sec	250FTE 4x/day	75
Breakroom Sink	2 gal/min	20 sec	240FTE 1x/day	160
Dishwasher	8gal/run	n/a	5 machines 1x/day	40
Drinking Water	0.5 gal	n/a	100% FTE 1x/day	125
Maintenance	.003gal/sf	49,000 sf	1x/day	147

5.3 Modelling Irrigation Demand

Daily irrigation demand was calculated using the area planted, the plant factors (PFs) and the evapotranspiration (Eto) coefficient for each plant species based on average daily temperature data. Ultimately, the planting palate was developed as a response to the projected treated greywater output that needed to be consistently infiltrated through irrigation usage. Thus, although the irrigation calculations were refined with the below equation, the rough outline was dictated by the building grey water output available.

$$(Eto * PF * SF * 0.62) / IE = \text{Irrigation Demand}$$

- PF= Plant factor
- SF= Area of planting
- IE= Irrigation Efficiency
- ID=Irrigation demand
- Eto= Evapotranspiration factor for the site location

5.3 Modelling Daily Water Availability

Available water to meet the daily potable building water demand is defined as the amount of water in the cistern at the beginning of a day. Daily cistern volume is solved by taking the volume of the day before and adding it to the volume of catchment that day. On the first day of the model, the cistern starts full. Past day one, cistern volume is established by subtracting the daily catchment volume from the sum of that day’s building water demand.

$$[C * R * Ro] - [S + B + L + D + M] = \text{Cistern Volume}$$

$$CV_x + CV_{x-1} = \text{Daily Cistern Volume}$$

CV= Cistern volume
 DCV= Daily cistern volume
 x= given day

Table 2. Days empty of modelled cisterns with 19,000 sf catchment area

Year	80,000 gallon cistern (days)	100,000 gallon cistern (days)	150,000 gallon cistern (days)	500,000 gallon cistern (days)
2005	25	0	0	0
2006	101	81	0	0
2007	220	220	0	0
2008	129	129	0	0
2009	173	173	74	74
2010	57	57	57	57
2011	24	0	0	0
2012	211	195	148	148
2013	250	250	250	249
2014	209	209	209	210

Table 3. Days empty of modelled cisterns with 43,000 sf catchment area

Year	80,000 gallon cistern (days)	100,000 gallon cistern (days)	150,000 gallon cistern (days)	500,000 gallon cistern (days)
2005	0	0	0	0
2006	23	0	0	0
2007	156	131	20	0
2008	78	31	0	0
2009	37	0	0	0
2010	0	0	0	0
2011	0	0	0	0
2012	18	0	0	0
2013	80	35	0	0
2014	73	71	0	0

5.3 Modelling Daily Infiltration

The daily cistern volume is limited to the defined capacity of the cistern. When the daily cistern volume exceeds the cistern capacity, cistern overflow occurs and infiltration of the overflow volume is required. Infiltration requirement is defined as the sum of daily irrigation demand, site storm water, and any cistern overflow.

$$DCV - CC = \text{Cistern overflow, when } DCV > CC$$

$$ID + SS + CO = \text{Infiltration Required}$$

CC= Cistern capacity
 CO=Cistern overflow
 SS= Site Stormwater

6.0 Application

When the three variables are modeled against the 10 year daily water records, various breaking points are discovered for this particular building given the location and daily water demand and weekly usage profile.

6.1 Usage and Cistern Size Threshold

The model showed a threshold of effectiveness of storage capacity at a 125,000 gallon volume. Past this amount, the daily water demand did not draw down the cistern (with adequate capture) quickly enough to throw the building system outside of the net zero water parameters. The model proves that for net zero water design, an established storage threshold for a given water usage can be determined.

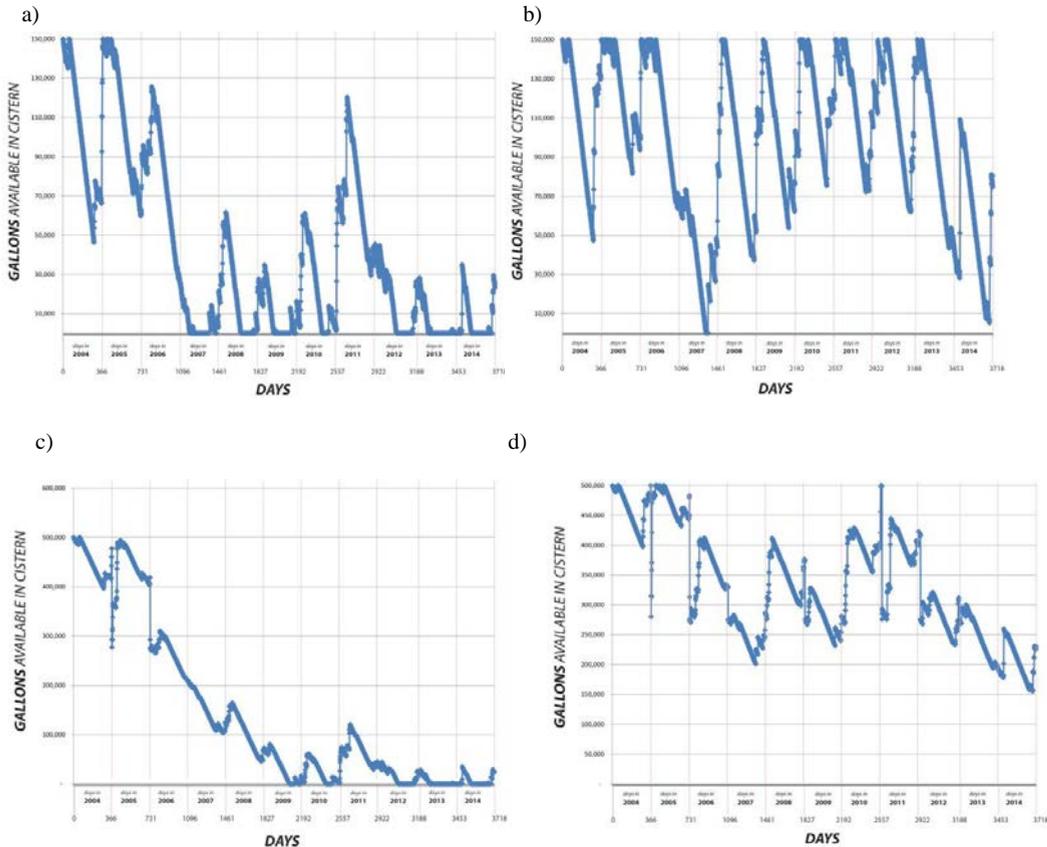


Fig. 2. (a) 150,000 gal storage and 19,000sf catchment; (b) 150,000 gal storage and 43,000 sf catchment; (c) 500,000 gal storage and 19,000sf capture; (d) 500,000 gal storage and 43,000 sf capture.

6.2 Rainfall, Cistern Overflow, and Infiltration

The water system is optimized to function in the extreme case of severe drought (represented in the model in years 2012, 2013, 2014). The reciprocal result of this sizing is a large required infiltration volume in periods of intense and long duration rains. This maximum of cistern overflow added to the daily irrigation demand (or required treated greywater discharge) and maximum site storm water event provides the maximum design case for infiltration sizing. As intense rains often occur in back-to-back sequence, each simulation case experiences the maximum 24 infiltration as the maximum 24 hour storm event in the 10 years over the site and catchment area modeled. Thus, regardless of cistern size, maximum infiltration is directly related to catchment area. However, the average amount of infiltration does show fluctuation based on storage capacity.

6.3 Drought, Catchment Area, and Infiltration

Given the effectiveness threshold of the storage, the operation of system sizing is narrowed to the interrelationship of catchment area and resulting infiltration. The aim is to size a catchment area adequate to establish resiliency without over stressing infiltration demand and creating additional cost. The model shows that given the storage of 125,000 gallon, a catchment area over 43,000 sf would be the optimal scenario.

Table 4. Simulations Performed

Simulation Number	Storage Capacity (gal)	Catchment area (sf)	Max infiltration per 24 hr (gal)	Average days empty per yr (days)	Average infiltration per 24 hr (gal)	Average infiltration per 24 hr wo stormwater (gal)
Simulation 1	80,000	19,000	94,249	132	765	75
Simulation 2	100,000	19,000	94,249	120	756	66
Simulation 3	150,000	19,000	94,249	67	749	59
Simulation 4	500,000	19,000	94,249	67	700	10
Simulation 5	80,000	43,000	152,298	47	1,091	401
Simulation 6	100,000	43,000	152,298	22	1,070	380
Simulation 7	150,000	43,000	152,298	2	1,054	364
Simulation 8	500,000	43,000	152,298	0	835	144

7.0 Conclusion

The study finds that in severe drought prone conditions, storage size is relevant only up to a threshold closely mapped with demand. Net zero water system resiliency is accomplished through the precise interrelation of catchment area and infiltration capacity. Rather than investing in an enormous cistern, catchment area (and corresponding infiltration) is deemed as the most important design variable.

The successful operation of net zero water buildings adds resiliency to regional water systems. In aggregate, this contribution can be significant. The architecture and engineering integrated design team required to produce a net zero water system employs professionals outside large municipal agencies. To accomplish the mandate to create greater resiliency in Southern California water management system, building design and a wide array of professionals will need to be engaged.

As Southern California receives the vast majority of their water from imported sources, the goal of individual building water independence both begins to loosen this dependence and create greater building owner choice in the embodied energy of the water used in their building. Further, by taking individual buildings off of the municipal system, stress is removed from deteriorated and outdated regional water infrastructure. Net zero water buildings have the potential to delay or negate large infrastructural investments needed to address growing populations and oversubscribed infrastructure. The largest obstacles to implementation of net zero water building design are code barriers, public perceptions of water reuse, and system capital costs.

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