EVALUATING TWO RAINWATER HARVESTING SYSTEMS IN AN URBAN SETTING IN OREGON'S WILLAMETTE VALLEY

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INTRODUCTION

The recent trend toward more extreme periods of drought has been a shock to the residents of the Pacific Northwest – many of whom have relied upon heavy water-use in the summer months in order to make a living (i.e. producers of grass seed and sod, berries, or nursery crops), or to maintain their landscapes at high levels (i.e. certain homeowners, recreational facilities, or commercial properties). Furthermore, population growth has reached the point where even an average year of precipitation has proven insufficient for urbanities that had not previously experienced issues with water scarcity (McDonald et al., 2011). This modern climate scenario has forced people of the Pacific Northwest, and people from all around the world, to rethink their water-use strategies, as the global trend has shifted toward greater sustainability (Tilman, 2001; McDonald et al., 2011). One potential mitigation strategy for cool-humid regions, such as Oregon's Willamette Valley, is to utilize rainwater-harvesting systems to alleviate freshwater demand (Kinkade-Levario, 2007). Rainwater harvesting is a logical choice for this climate zone because the average annual precipitation (42.7-in for Corvallis, OR) is sufficient for the majority of its crop production, however, this precipitation occurs almost exclusively in a nine-month period spanning from fall to spring (US Climate Data, 1981-2010). Although annual precipitation is adequate, irrigation is still required for at least three months of every year. This study considered rainwater harvesting to be ideally suited for the cool-humid Willamette Valley; the excess rainfall in the wet season that could be stored for use in the summer months, thus decreasing demand for municipal water by an equivalent amount.

It should be stated that rainwater harvesting is not a novel idea; there have been studies dating back to the 1980's and earlier that have shown significant water-savings when retrofitting homes with new features like rainwater-harvesting systems (Boers et al., 1982, Karpisack et al., 1990). Even before that, golf courses, sporting complexes, and industrial sites alike were making use of this strategy. However, their methods typically consisted of catching rainwater via surface runoff and storing it in retention ponds (Ferguson, 1998), which is a strategy that is less applicable to the small-acreage homeowner who wants to irrigate their property without having to turn half of their backyard into a pond. Fortunately, there are alternative

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methods of rainwater harvesting that make a lot more sense in a residential setting, where irrigated land is small in relation to the roof-area for which rain can be easily harvested. This study documents the construction of two distinct rainwater-harvesting systems (an aboveground cistern and a belowground AQUABLOX™ matrix storage system), and gives insight into their advantages and disadvantages.

KEYWORDS
rainwater-harvesting system; subsurface matrix storage; cistern; pedal-powered pump

SITE DESCRIPTION

In 2015, two rainwater-harvesting systems were installed at Oregon State University's Oak Creek Center for Urban Horticulture (OCCUH) in Corvallis, OR. Two sections of 6-in seamless K-style aluminum gutters were installed along either side of the building adjacent to the two harvesting systems. This building has a symmetrical roof sloping in two directions from the peak, with a footprint of 57-ft by 16-ft, or 912-ft^2. Therefore, the rainwater-harvesting potential for this roof is a 3,240 ft^3 (912-ft^2 roof footprint multiplied by 3.55-ft of annual precipitation; US Climate Data, 1981-2010), or 24,200-gal. Each gutter runs the length of the roof (57-ft) and collects water from half of the area (456-ft^2), so each rainwater-harvesting system receives roughly 12,100-gal of rainwater in an average year. Each gutter has a downspout leading to a first-flush diverter – a downspout attachment designed to catch debris and divert water to the tank, while preventing particulate (and associated bacteria) from entering the rainwater-harvesting system by bypassing the first flush of water (roughly 10-gal per 1,000-ft^2 of roof) to the storm drain following an extended dry period. From the first-flush diverters, Schedule-40 PVC pipes are angled to drain into the respective rainwater-harvesting system. The two rainwater-harvesting systems in this study are an aboveground 5,000-gal polyethylene cistern (Norwesco, St. Bonifacius, MN) and an underground pond-less waterfall system utilizing a matrix of AQUABLOX™ (Aquascape Inc., St. Charles, IL) that holds roughly 4,000-gal.

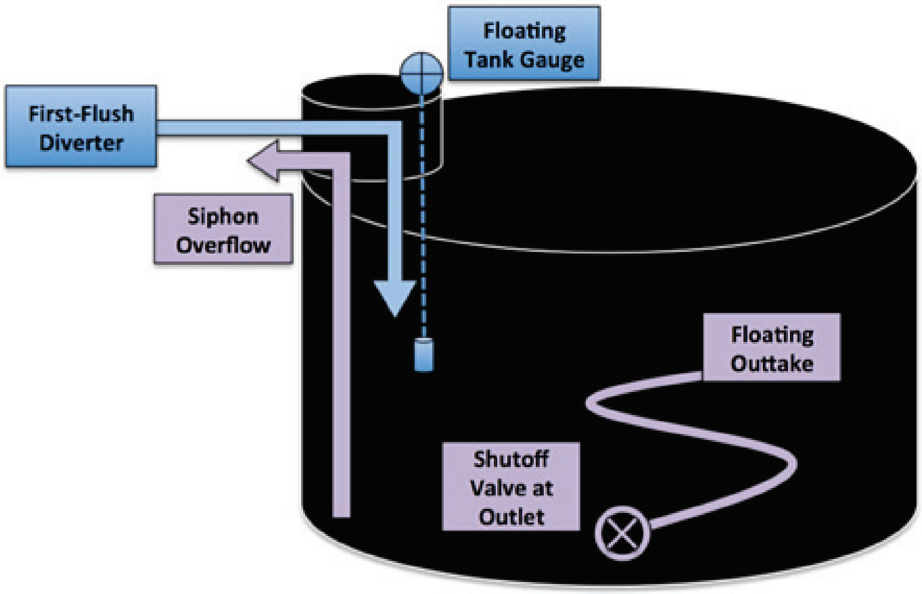
TWO FIELD STUDIES

Aboveground Rainwater-Harvesting System (Cistern)

One of the two gutter downspouts was diverted into a polyethylene tank that sat on the ground surface. This system included the following components: 5000-gal cistern, tank gauge, floating outtake, and siphon-style overflow piping (Figure 1).

The floating outtake consisted of a 5/8-in commercial-grade garden hose threaded onto the internal side of the outlet. The other end of the hose was left open and fixed to the underside of a boat dock buoy to keep it near the surface of the water. The floating outtake was designed to withdraw the cleanest water in the tank, as settling processes result in increased particulate content at the bottom of the tank (i.e. near the standard outlet). The cistern also

FIGURE 1. Diagram of the updated rainwater-harvesting cistern with all the necessary and recommended components.



had an Atlantic Rain Harvesting Tank Gauge (Hydro-Scape, Ontario, Canada) to track water use and recharge over time. To prevent algal and bacterial growth, the tank was painted black to minimize sunlight and prevent photosynthetic activity within the cistern. Overflow piping (3-in Schedule 40 PVC) was installed to allow excess water to drain from the tank before the water level reached the elevation of the inlet. This design prevents backflow into the inlet, which would have been problematic for the entire gutter system. Instead, excess flow was sent away from the tank and into a rock-filled infiltration basin landscaped as a rock garden. Overflow piping was also outfitted with a siphon tube (optional), through which the excess water was drawn from the base of the tank where the water is the dirtiest, in order to remove the dirtiest water possible and maximize tank capacity and function.

FIGURE 2. Picture of the aboveground system with pedal-powered water pump.

In an attempt to keep the aboveground system as simple and carbon-neutral as possible, the pumping method used in this study was pedal-power. A vintage stationary exercise bicycle (Schwinn (Dorel), Montreal, Quebec) was fixed to a custom steel frame, along with a HYPRO 4-roller cast-iron pump (Pentair Hypro, Minneapolis, MN). With a 5/8-in pulley attached to the axle of the pump, a simple lawn mower belt (95-in) was able to transfer power and operate the pump providing five gallons per minute (GPM) at a comfortable pedaling pace. The bicycle-pump assembly was placed on a flattened patch of ground near the cistern, and connected to the outlet via 5/8-in commercial-grade garden hose. Shelter was provided in the form of corrugated plastic sheets screwed onto a PVC frame, which was then fixed to the top of four steel fence posts cemented underground (Figure 2).

While the aboveground rainwater-harvesting system constructed in this study was fitted with a pedal-powered pump, the system could easily be adapted to an electronic pump. The aboveground system also has the benefit of being able to pump out water using gravitational forces. The total budget for this system was $3,083 (Table 1).

TABLE 1. Budget for the aboveground cistern rainwater-harvesting system.

	Product	*Qty.*	*Unit Cost*	*Total*
Gutters and Diversion	6" K-Style Gutter (57')	1	$292.50	$292.50
	Atlantic Clean Rain Downspout Diverter	1	$148.98	$148.98
	3" Sch. 40 PVC Pipe (10')	3	$10.00	$30.00
	3" Sch. 40 PVC Elbow	5	$2.58	$12.90
Cistern Storage System	141" x 96" PPE Rain Tank (dia. x height)	1	$1,899.99	$1,899.99
	Atlantic Rain Harvesting Tank Gauge	1	$39.99	$39.99
	Banjo Tank Valve Assembly (2")	1	$38.00	$38.00
	5/8" Garden Hose (25')	1	$27.99	$27.99
	Boat Dock Buoy	1	$20.00	$20.00
	Plastic Chain (ft)	5	$0.95	$4.75
	Zip Ties	8	$0.10	$0.80
Dispersal via Pedal-Powered Water Pump	Vintage Schwinn Stationary Bicycle	1	$50.00	$50.00
	HYPRO 4-Roller Pump	1	$150.00	$150.00
	5/8" Garden Hose (25')	1	$27.99	$27.99
	95" Lawnmower Belt	1	$10.00	$10.00
	5/8" Pulley	1	$5.00	$5.00
	7' Steel Fence Post	4	$24.97	$99.88
	3' Hardened Steel Bar	1	$13.99	$13.99
	5/8" Bolts	12	$0.75	$9.00
	5/8" Nuts	12	$1.44	$17.28
	5/8" Washers	12	$0.68	$8.16
	8' Steel Poles	4	$13.97	$55.88
	Quikrete Fast-Setting Concrete (50 lb)	2	$5.47	$10.94
	1 1/4" PVC (10')	3	$8.00	$24.00
	1 1/4" PVC Connectors	20	$2.33	$46.60
	3/4" Minus-Aggregate Gravel (yd)	1	$38.00	$38.00
Total				**$3,082.62**

Subsurface Rainwater-Harvesting System (Pond-less Waterfall)

The storage method chosen for the second study was an Aquablox system, which included the following components: subsurface basin with structural-matrix of Aquablox, ethylene propylene diene terpolymer (EPDM) pond liner, protective geotextile underlayment, recirculating waterfall feature fed from a submersible pump, water level gauge, overflow piping, external pressure pump for dispersal, and a sump pump placed outside the tank for flood prevention (Figure 3).

FIGURE 3. Pond-less waterfall system (foreground) built next to the cistern system (background).

In this system, the downspout diverted rainwater into the side of the recirculating waterfall feature (Figure 4).

FIGURE 4. Recirculating waterfall feature built with gutter-diversion piping entering the system between the second and third spillway.

The Aquablox system in this study utilized a matrix of structurally-supportive plastic blocks. Each block was 26.5-in by 17.5-in by 16-in (4.3-ft^3) and had a porosity of 95%. A matrix of these blocks provided structural support for the subsurface basin when empty, but also allowed for significant storage of rainwater below the ground surface. For the installation of the Aquablox storage system, a 9-ft long by 17-ft wide by 6-ft deep hole was dug and lined with protective underlayment. Next, a 20-ft wide by 30-ft long by 0.045-in thick rubber pond liner (Firestone Tire and Rubber Company, Nashville, TN) was placed in the hole to create a watertight basin. The inside of the pond liner was then covered with an additional protective geotextile layer to prevent the Aquablox from puncturing it. Finally, the matrix of Aquablox was installed inside the pond liner. Blocks were placed one layer at a time, with continual backfilling and compacting around the sides of the basin to keep everything in place (Figure 5).

FIGURE 5. Final layer of AQUABLOX installed with pond liner and underlayment folded over the top during backfilling and compaction around the basin.

The basin was designed to hold 126 blocks (7 long by 6 wide by 3 deep), however, a stack of three blocks was removed from one corner of the tank to incorporate a vertical conduit for pumping, known as a pump canyon (Figure 6).

The subsurface basin was topped with a permeable weed-barrier cloth and covered in round river-rock to sit flush with the ground surface. The open top allowed rainwater to enter the system from the surface, thus adding to the rainwater-harvesting potential. At the surface of the Aquablox system, 3-in ABS pipe was installed to send excess rainwater to a separate rock garden downhill from the subsurface system (Figure 7).

FIGURE 6. A vertical conduit extends down into a perforated pump enclosure (pump canyon) in the corner of the basin where a stack of three Aquablox was removed.

FIGURE 7. Overflow pipe fixed to pond liner at the top of the Aquablox to maximize capacity.

The same water level gauge as the cistern system was installed to track water use and recharge in the subsurface basin.

Excess dirt from the excavation was mounded and shaped into the recirculating waterfall feature. The waterfall was powered by an Eco 4950 GPH submersible pump (EcoPlus, Vancouver, WA) that drew water from the bottom of the pump canyon to the top of the waterfall feature, where it then flowed back into the underground Aquablox system to complete the pond-less waterfall. The waterfall feature provided constant circulation of the stored water, thus keeping it oxygenated and clean. The submersible pump was threaded onto a 10-ft length of 2-in Sch. 40 PVC pipe with an inline check valve installed 1-ft from the pump end to prevent backflow into the pump. The pipe was then lowered pump-first into an Elite Pump Canyon and Extension (Pondbuilder Inc, Saginaw, MI) installed at a 6.5-ft depth inside the pond liner. The pump canyon was a perforated-plastic housing with a circular opening (10-in diameter) at the top that extends vertically to just above the ground surface. The pump canyon was held in place by round river-rock backfilled inside the basin and around the conduit. The 10-ft length of 2-in Sch. 40 PVC pipe was cut and fitted with an elbow that allowed the flow to exit just below the ground surface. A short length of pipe was glued into the elbow, which was then coupled to a 2-in Sch. 40 flexible PVC pipe using a compression fitting. This flexible pipe extended from the pump canyon, out over the edge of the pond liner, through the mounded dirt, and was attached to a 22-in Elite Biological Waterfall Box (Pondbuilder Inc, Saginaw, MI) that sat at the top of the mound (Figure 8).

FIGURE 8. Waterfall box carefully leveled to create an even spillway at the start of the falls.

The waterfall box distributed water pumped up from the bottom of the subsurface basin and sent it down a short waterfall path that terminated over the exposed surface of the Aquablox system.

Finally, a 12-in diameter conduit was installed to a 6.5-ft depth adjacent to the Aquablox system outside the pond liner. A 1/4-HP cast iron sump pump (Liberty Pumps, Bergen, NY) was placed at the base of the conduit. The purpose of this sump pump was to ensure the ground water table stayed below the underground water storage system. Ground water collected from the sump pump was sent to the rock garden downhill from the subsurface system using 2-in Sch. 40 flexible PVC pipe. The budget for the second rainwater-harvesting system was $12,775 (Table 2).

TABLE 2. Budget for the subsurface AQUABLOX rainwater-harvesting system.

	Product	*Qty.*	*Unit Cost*	*Total*
Gutters and Diversion	6" K-Style Gutter (57')	1	$292.50	$292.50
	Atlantic Clean Rain Downspout Diverter	1	$148.98	$148.98
	3" Sch. 40 PVC Pipe (10' sections)	6	$10.00	$60.00
	3" Sch. 40 PVC Coupler	3	$1.37	$4.11
	3" Sch. 40 PVC Elbows	3	$2.58	$7.74
	3" ABS Pipe (10' sections)	7	$15.62	$109.34
	3" ABS Connectors	8	$3.98	$31.84
Pond-less Waterfall Storage System	AQUABLOX Standard Matrix (26.5" x 16" x 17.5")	123	$62.99	$7,747.77
	EPDM Pond Liner (20' width) [ft]	30	$21.80	$654.00
	Protective Geotextile Underlayment [ft^2]	900	$0.30	$270.00
	EcoPlus Eco 4950 GPH Submersible Pump	1	$235.60	$235.60
	2" Sch. 40 PVC (10')	1	$8.50	$8.50
	2" Flex PVC [ft]	20	$3.47	$69.40
	2" Check Valve Assembly	1	$53.79	$53.79
	Small Elite Pump Canyon	1	$233.99	$233.99
	Small Elite Pump Canyon Extension	2	$85.49	$170.98
	22" Elite Biological Waterfall Box	1	$449.99	$449.99
	EPDM Pond Liner for Stream (20' width) [ft]	9	$21.80	$196.20
	Geotextile Weed Barrier (10' width) [ft]	20	$1.00	$20.00
	Atlantic Rain Harvesting Tank Gauge	1	$66.00	$66.00
	Excavator and Operator [days]	1	$825.00	$825.00
	Black Basalt Wall Rock	0.97	$120.00	$116.40
	Round River Rock (1" - 5") [ton]	1	$60.00	$60.00
	Iron Mountain Stepstone (1" - 2") [lb]	120	$0.20	$24.00
	Dump Truck Delivery	1	$60.00	$60.00
Dispersal	External Pressure Pump	1	$839.64	$839.64
	3/4" Poly Pipe (100')	1	$18.98	$18.98
Flood Control	Liberty 1/4-HP Cast Iron Sump Pump	1	$125.00	$125.00
Total				**$12,774.75**

FINDINGS

There's a large range of options available to people interested in rainwater harvesting. The advantages of the aboveground system were in its simplicity and robustness. Installation took very little effort, and cost was kept to a minimum. The cost of product for the entire 5,000-gal aboveground system was only $3,083. Aside from the fact that the system takes up a decent amount of space and doesn't provide any aesthetic benefits, the only major deterrent to the aboveground system was the stagnant nature of the stored water. Even though the tank had been painted black to eliminate light from entering the water column, there was still a significant layer of slime on the inner walls of the cistern and on the floating outtake. While this had no impact on the function of the tank in the first year of operation, it was decidedly a problem that the water quality decreased (via biomass accumulation) during the storage period.

The subsurface storage system was considerably more expensive than the cistern system, at $12,775 for product and excavation services. The majority of the cost was associated with the Aquablox matrix; however, this is a necessary component for maximizing sub-surface storage capacity. The plastic matrix allowed for the storage of roughly 4,000 gallons of rainwater, while a rock-filled basin of the same size would only hold around 1,000 gallons. Along with the construction cost, another deterrent to the pond-less waterfall system is that electricity is required to power the recirculating waterfall; thus, adding to the total cost of the Aquablox system. However, there is no denying the aesthetic benefit of a recirculating waterfall feature, and when considering the fact that the water remains clean throughout the storage period, it may be worth the cost.

CONCLUSION

Aboveground systems are a good choice for retrofits of existing free standing homes, particularly in cases where aesthetics are less of a concern or the cistern's effect on site lines can be mitigated. In addition, the large amount of space taken up by the cistern precludes its use where space is limited or where space is reserved for other uses. In contrast, subsurface storage systems are a good choice for confined spaces or where an aboveground cistern would significantly impact aesthetics. Unfortunately, the cost of these systems is likely prohibitive for many homeowners. Subsurface systems might be more widely appropriate when installed as part of initial construction where they can be integrated into overall building design and construction, which would reduce the per-unit cost.

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