REAL STORIES FROM REAL BUILDINGS

Rainwater Harvesting

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Abstract
This case study examines a rainwater collection and storage system in a newly built Eugene, Oregon residence. Six different water quality tests are performed on samples taken at various points in the system: from roof runoff to an underground concrete cistern. Test results indicate the presence of organic material and bacterial growth in the cistern water. A prototype sand filtration system (designed to improve water quality) is built and tested. The result is complete removal of suspended solids in water samples poured through the filter. A follow-up visit performed one year after the original study shows that water quality in the cistern has improved as a result of design changes implemented by the owners.

Introduction
The environmental design curriculum at University of Oregon uses the case study method as a tool to understand how classroom lessons apply to buildings in the real world. These case studies are modeled on the Vital Signs Project administered by UC Berkeley's College of Environmental Design. The goal of the Vital Signs project is to build an understanding of links between architectural expression and building performance. A specific protocol for investigation and reporting conclusions is prescribed so that results from different students at different schools can be more easily compared. Many of these case studies focus on issues related to energy efficiency (lighting / heating) and occupant comfort (thermal / acoustic). While a great deal of attention is paid to these issues, we chose to investigate rainwater, a resource that is almost universally ignored by the building industry in the United States. It also seemed like a timely choice in Spring 2000, as the Pacific Northwest was headed into a drought. Our research led to the discovery of an unusual and inspiring residence (Fig.1) that illustrates a different attitude about water usage.

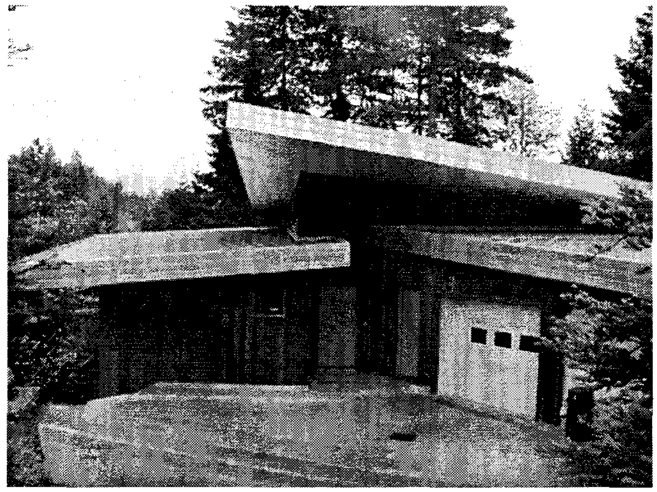

Fig.1.

Anita Van Asperdt and Eimar Boesjes treat rainwater as a valuable resource rather than a problem. Their new house (completed in Winter 2000) is perched on a steep slope surrounded by Douglas Fir woodlands in the South hills of Eugene, Oregon. Rainwater from two of the four roof planes (1,024 sq. ft. of collection area) is directed into an 8,000 gallon concrete cistern. The other two roof planes funnel rainwater through a backyard stream bed and

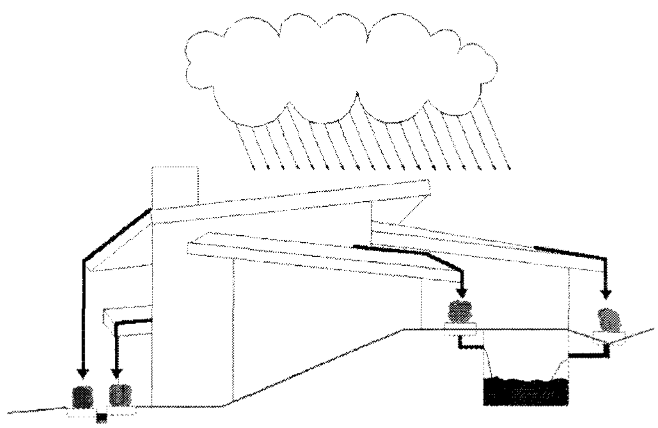

Fig.2.

ultimately into abutting wetlands. According to rooftop collection estimates, 26,800 gallons of rainwater would be diverted to the cistern in a typical year. This is enough to augment landscape irrigation in summer months, and perhaps reduce dependence on municipal water used indoors.

The rainwater catchment system begins with steel roof surfaces. Water is artfully channeled from the rooftop into truncated downspouts that spill onto granite boulders at ground level (Fig. 2). These boulders sit atop concrete footings that house pipes leading to the cistern.

When first studied, the system was devoid of any filtration system to help purify stored water. The homeowner's intent was to install sand filters into slots underneath the granite boulder. At first inspection, the cistern was only partially full. The owners wished to fill and drain the system once to leach excessive lime out of the concrete before using the cistern water to irrigate the landscape. Two sets of indoor plumbing allow for cistern and municipal water to flow into the house separately. This feature has not been used, but is built into the house to allow some flexibility for water usage in the future.

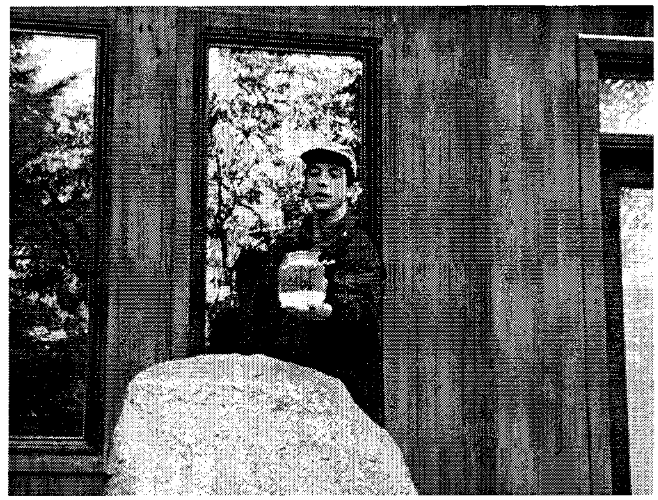

Fig.3.

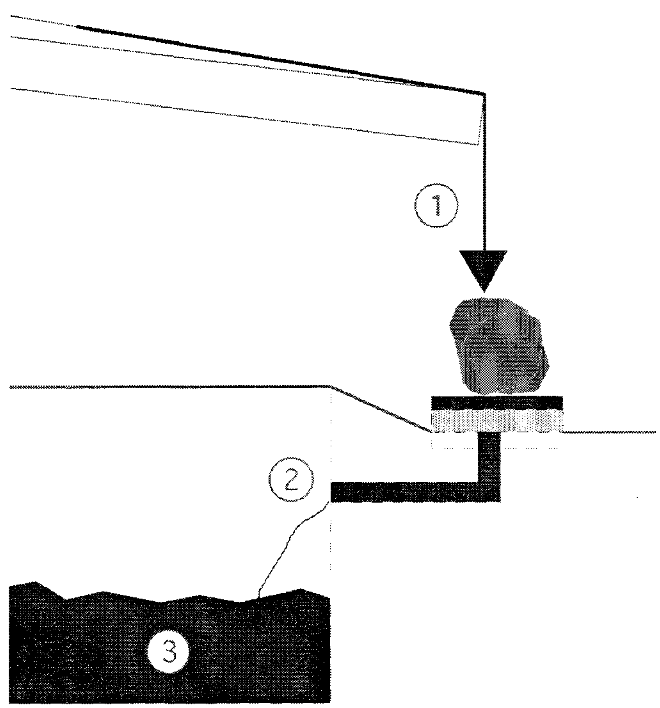

Fig.4.

Hypothesis

Our initial tour of the Van Asperdt - Boesjes residence generated numerous questions about water quality. Was the water stored in the cistern safe to drink? Probably not, since it had a thin layer of translucent scum floating on the surface. But what about water quality at other stages in the process? The water flowing into the cistern looked very pure. Was there a test that could tell us if the rainwater was potable?

Water quality issues

We quickly discovered that there is no single test for safe drinking water. The Environmental Protection Agency (EPA) publishes standards for over a hundred different water quality tests, all of which must be performed by certified laboratories. Faced with a learning curve, we decided to split our investigation into two phases, with the first being research oriented. The Eugene Water and Electric

Board (EWEB) monitors municipal water quality at the Hayden Bridge Water Treatment Facility. With the help of their friendly laboratory staff, we were able to perform simple tests on a variety of water samples. Learning from the test results helped us formulate a plan for improving water quality in the cistern.

Sand filters

During our visit to EWEB, we observed the huge sand beds that filter millions of gallons of McKenzie River water every day. We decided to test this system on a smaller scale as a way to screen out the organic material that contributes to bacterial growth in the cistern. The experiment was conducted using the following hypothesis: *A slow sand filter will remove all suspended solids in rainwater collected from the rooftop at the Van Asperdt - Boesjes residence.*

pH
The measure of the water's relative acidity or alkalinity. A pH of 7 is neutral while higher numbers indicate acidity and lower alkalinity.

Conductivity
A measure of how well the water conducts electricity. This gives an indication of ion concentration in the water sample.

Turbidity
Measures the impedance of light through water. The particles which cause turbidity can interfere with disinfection by sheltering microbes.

Hardness
Inhibits the cleaning action of soaps and detergents. It can also cause deposits of scale on the inside of hot water pipes and cooking utensils. Calcium and high levels of magnesium salts cause hardness

Colony Count
Coliform is a common class of bacteria that is easily cultured. A high count may indicate the presence of harmful organisms such as E. coli, or fecal coliform.

Total Suspended Solids
Undissolved particles ranging in size from a pine needle to a single cell bacterial organism.

EWEB follows the Standard Methods for Analysis of Supply and Waste Water. For exact testing procedures, consult the EPA publication of the same name.

Methodology

Collection of water samples

On a rainy day in April, we arrived at the Van Asperdt - Boesjes residence with a variety of glass jars and plastic tubs. Three locations in the catchment system were selected for sampling (see Fig. 3 & 4). Rainwater spilling from the *metal roof (1)* was the easiest to obtain. Wading through the partially filled cistern was necessary to obtain the other two samples. One was taken from the *plumbing (2)* system flowing into the cistern, a second from the standing water in the *cistern (3)*. Two other samples were collected for comparison. One was taken from the *tap water (4)* stream in the kitchen. The other was collected from the downspout of a different house with a more conventional asphalt *shingle roof (5)*.

All five samples were tested for pH, conductivity, turbidity, hardness, coliform count, and total suspended solids. These tests were selected because they are simple, fast, and give a general indication of

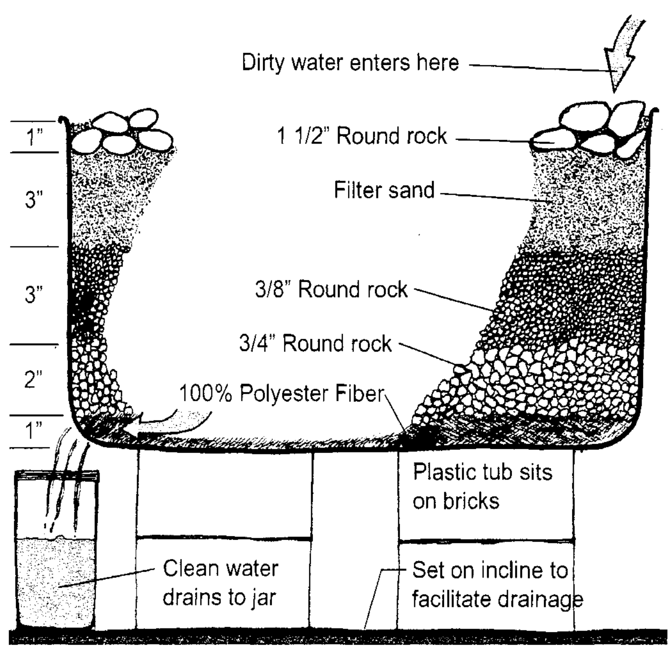

Fig.6.

Fig.7.

After assembling the filter components, it was necessary to flush the filter (Fig. 7) to remove impurities and encourage development of the *schmutzdecke*, a layer of biological slime that aids in trapping small particles. It is important to use unchlorinated water for the flushing, so the filter was set up on the banks of the Millrace, a side channel of the Willamette River. After approximately two hours of flushing, the effluent clarity was indistinguishable from incoming river water being poured into the filter.

We wanted to test a worst case scenario such as water which washes away dirt and debris accumulated on a rooftop after an extended dry spell. This "first flush" scenario was simulated with the addition of organic matter to the rainwater sample. The sample size was about two quarts, half of which was poured through the sand filter. Both samples (pre- and post-filter) were returned to EWEB and tested for suspended solids.

Data & Analysis

Baseline Analysis of Rainwater Samples

Six common water quality tests were performed on the five water samples to provide background on water quality issues relevant for rainwater harvesting (Fig. 8 & 9). The data and analysis of the water water quality. A brief explanation of each test is given in Figure 5.

Construction of a sand filter

Our prototype filter was constructed in an afternoon, using locally available materials. The design (Fig. 6) was based on recommendations from EWEB employees, as well as published examples used for science experiments and fish ponds. The filter sand obtained from EWEB was of uniform grain size and included some activated charcoal. The plastic tub and various sizes of aggregate were obtained from landscape suppliers. Polyester fiber was purchased at a local fabric shop. Material costs were about $10.

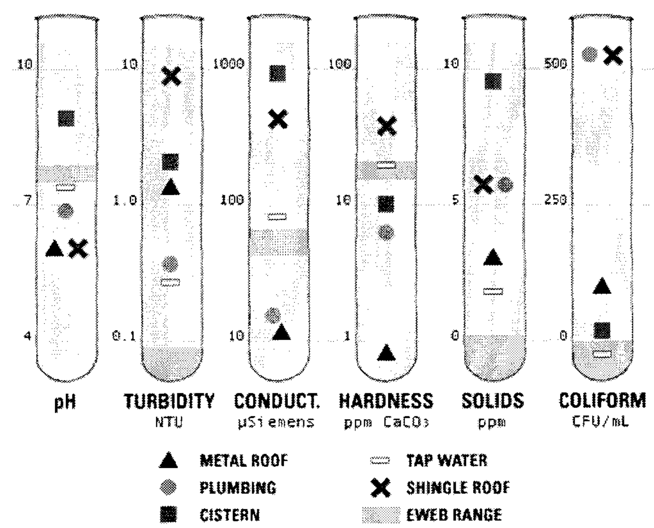

Fig.8.

Sample	pH	Turbitidy (NTU)	Conductivity (µSiemens)	Hardness (ppm CaCO3)	TSS (NTU)	Coliform Count (CFU/mL)
1.Metal Roof	5.97	1.3	12.4	0.5	3	100
2.Plumbing	6.89	0.5	17.1	6	6	>500
3.Cistern	8.91	2.4	735	10	9	3
4.Tap Water	7.32	0.3	77.1	24	2	0
5.Shingle Roof	5.94	8.3	455	41	6	>500
EWEB lo	7.5	0.02	45	18		
Range hi	7.8	0.04	65	25	<0.5	0

*TSS = Total suspended solids
*NTU = nephelometric turbidity unit
*µSiemens = SI unit of electric conductance
*ppm CaCO3 = parts per million of calcium carbonate
*CFU/mL = colony forming units per mL

Fig.9.

samples aided in the decision to build a prototype filter.

pH

pH levels in the cistern water were predictably high due to leaching from the concrete cistern structure. This is a standard chemical reaction with new concrete and will require a full flush to remedy the problem. Both the metal and shingle roof water samples were low, or acidic, in comparison to the EWEB norms.

Turbidity

The asphalt shingled roof water was the most turbid, as was expected given its brownish color (picked up from tannins in decaying pine needles). This roof structure was not designed for rainwater collection but was sampled to display the difference in water quality. Tap water collected at the Van Asperdt-Boesjes residence tested higher than EWEB standards with regard to turbidity. This is reasonable since the water is bound to pick up some sediment during distribution. EWEB standards reflect quality from the source up to one's door. Once water is delivered into a structure, it is out of their control.

Conductivity

Rainwater, in its natural state, is very close to de-ionized but after passing over the zinc based anti-moss compound found on the shingled roof structure, conductivity is much higher. Water collected from the metal roof and from the plumbing inlet to the cistern was less conductive than the tap water and the EWEB range for quality.

Hardness

In its natural state rainwater is very soft and this was true of the samples collected from the metal roof. There is little opportunity for the water to absorb minerals running off a smooth metal surface. After passing over the granite boulder and then into the cistern the water hardness levels begin to rise. Concrete leaching within the cistern structure could also be a factor.

Total Suspended Solids

Given a chance to settle out, one would expect sub-surface cistern

PRE-FILTER
19 ppm

POST-FILTER
0 ppm

Fig.10.

water to have fewer suspended solids than water sampled from the catchment inlet. In this case however, bits of flocculant scum floating in the cistern water suggest bacterial activity, the presence of organic food matter, and thus suspended solids.

Coliform Colony Counts

Results of this test are not scientifically accurate because the collection containers were not sterilized prior to sampling. It is interesting to note, however, that residual chlorine in the tap water prevented any coliform growth in that sample.

Prototype filter sample analysis

Visual inspection of the pre- and post-filter water samples (Fig. 10) provided clear evidence that water quality improved. The test results confirmed our hypothesis. The prototype filter removed 100% of total suspended solids in the water.

In addition to (or perhaps as a result of) suspended particle removal, our prototype filter also removed all traces of color in the post-filtered sample. While we did no further testing with regards to water color, it would be an interesting issue to investigate further.

Conclusion

Based upon our prototype testing results, we conclude that a sand filtration system will effectively eliminate all suspended solids in rainwater collected at the Van Asperdt-Boesjes residence. Because organic particles are removed from rainwater by the sand filter before entering the cistern, the potential for bacterial growth is drastically diminished. Such a filtration system can be easily implemented in the current design and will result in significant water quality improvements.

It should be mentioned that the elimination of suspended solids does not equate to water potability. To meet EPA standards for safe drinking, a certified laboratory should test water samples. Many owners of rainwater harvesting systems use chlorine, ozone, or ultra-violet purification systems to ensure that their drinking water is free of pathogens.

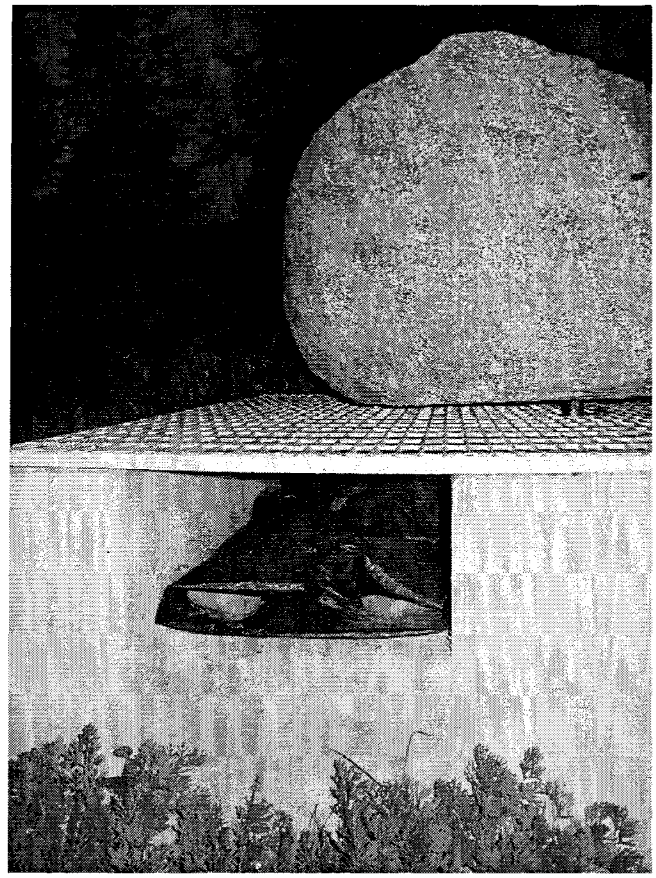

Fig.11.

This case study allowed us to learn about water supply on two very different scales. At the community scale, EWEB's Hayden Bridge facility embraces water quality in a technical manner with a huge supply flume that runs directly through the building's second floor landing. On a residential scale, the Van Asperdt-Boesjes residence celebrates water in an artistic manner with streams of rainwater falling over granite boulders.

After hours of research and study of rainwater collection, storage and re-use systems, it is our belief that this is a viable and economically sound method for water collection and use. With inevitable upcoming scarcities in this seemingly abundant resource, it is also a sustainable and sensible solution for the future.

Follow-Up Visit

The case study of the Van Asperdt-Boesjes residence was completed in June 2001. One year later we conducted a follow-up visit to the site. We learned that the homeowners had drained and cleaned the cistern prior to the start of the rainy season. They also installed a black fabric filter over the cistern inlet as a temporary filtration system (Fig. 11). While this is a different solution than the proposed sand filter, it seems to have worked well. By December 2001, the eight thousand-gallon cistern was full of cool, clear water. Visual inspection found the water to be relatively clean and devoid of solid matter.

Credits

The authors wish to thank the following people for their generosity and contributions to this study: Anita Van Asperdt & Eimar Boesjes, homeowners, Melissa Wisely, Steve Blair, Mitch Postle, and Doug Wise from the EWEB Hayden Bridge Facility, Tom Kimball at UC Davis, Gail Andrews at Oregon State University, and the following faculty and staff at the University of Oregon: Professors Alison Kwok, Virginia Cartwright, and Paul Engelking and Graduate Teaching Fellows Matt Larson, Laura Wade Jensen, Christina Bollo, and Chad Weltzin.

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2 Reynolds, John S. and Benjamin Stein (2000). *Mechanical and Electrical Equipment for Buildings*, 9th ed., Wiley, New York.

3 Texas Water Development Board in Cooperation with the Center for Maximum Potential Building Systems (1997). *Texas Guide to Rainwater Harvesting*, 2nd ed., Austin Texas.

4 Safe Drinking Water Act (SDWA), Public Law No.93-523, effective Dec. 16, 1974.

This entire case study including a more in-depth analysis, additional images, and links to other rainwater harvesting resources can be found at http://www.uoregon.edu/~hof/Spring2001.html.