# A Prototype Analysis for Determining the Stormwater Retention and Water Supply Benefits of Cisterns


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## Background:

This study considers the viability of cisterns to provide water supply for landscapes as well as water retention for flood control. Rather than consider average annual conditions, the analysis considers conditions on a daily basis using historical data. It uses 105 years of observed daily rainfall, and the expected daily water use of a typical landscape to determine whether the stormwater and water supply benefits of cisterns will be available when they are needed.

The objectives of this study were as follows:

1. *to assess the effectiveness of cisterns as a flood control measure.* From a flood control standpoint, the flood control benefits with a cistern must be compared with baseline (natural) pre-development conditions, as well as with post-development conditions without a cistern.
2. *to assess the effectiveness of cisterns for landscape water supply*. To ensure some capacity in the cistern for flood control, water must be used rather than retained. This analysis considered the water needs of two medium sized citrus trees, which are trees that cannot be grown in Tucson without supplemental water.

## Methods:

### *Lot Characteristics:*

The analysis considers a 1500 square foot home on a 1/8 acre lot, which is typical of the homes now being built in many of the new developments around Tucson, Arizona. Lot development dramatically changes on-site runoff characteristics. One of the more widely-used hydrologic assessment tools, *Urban Hydrology for Small Watersheds TR-55* (USDA-NRCS, 1986), suggests 65% impervious area for 1/8 acre residential lots.

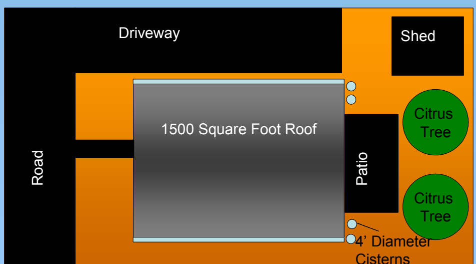


*Figure 1 – A prototype layout of a 1/8 acre lot with a home with a 1500 square foot roof. The layout is approximately to scale. Water is harvested from the1500 square feet of roof. About 2000 square feet of the lot has impermeable cover that is not harvested, and about 1900 square feet remain in desert landscaping. The cisterns have a total capacity of 350 cubic feet. The two trees are mature trees with a diameter of 14 feet each.*

### *Landscape Water Use:*

Daily ETo data for past eight years from the Campbell Avenue AZMET station in Tucson was used to estimate ETo. The mean ETo for a given date is shown in Figure 2.

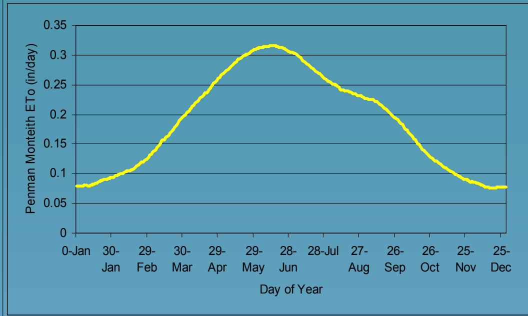


*Figure 2 – Reference Evapotranspiration (ETo) at Campbell Avenue Farm in Tucson based on eight years of published estimates for daily ETo. ETo for a year is about 5.7 feet of water.*

### *Runoff Volume Estimates:*

The runoff volume was estimated using the SCS Curve Number method allows for the estimate of runoff depth given daily rainfall depths. This means that rainfall intensity data are not necessary to determine infiltration losses. The Curve Number equations are as follows:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{\{Equation 1a\}}$$

Where:

Q is the total depth of runoff (inches);
P is the daily rainfall depth of precipitation (inches);
0.8 is empirically derived, and is based on the assumption that initial abstractions are equal to 0.2 S;
S is the potential abstraction, numerically defined as:

$$S = \frac{1000}{CN} - 10 \qquad \text{\{Equation 1b\}}$$

Where:

CN is the Curve Number.

Curve Numbers were estimated based on TR-55 *Urban Hydrology for Small Watersheds* (USDA, 1986). Curve Numbers used were as follows:

*Table 1 – Curve Number Values Used in this Simulation*

| Condition | CN |
|---|---|
| Natural Desert B- Soils with moderately low runoff potential (e.g. loam soil) | 82 |
| Natural Desert C-Soils with moderately high runoff potential (e.g. sandy clay loam) | 85 |
| Natural Desert D- Soils with high runoff potential (e.g. clay loam soil) | 88 |
| Rooftops | 99 |
| Other Impervious Areas | 98 |

### *Schematics of Runoff Scenarios*

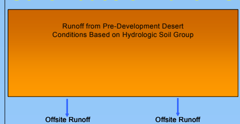


*Figure 3a – Schematic of runoff conditions before development. Native soils limit runoff.*


*Figure 3b – Schematic of runoff conditions following development. Runoff increases because of impermeable rooftops driveways and other surfaces*

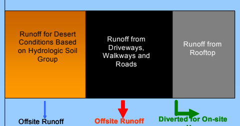


*Figure 3c – Schematic of runoff conditions following development with a cistern. Rooftop water is collected and diverted to the cistern.*

### *Mass-Balance Approach to Cistern Volume Estimate:*

For water diverted from the roof into the cistern, (runoff schematic 3c) the water in the cistern must be estimated on a daily basis to determine storage. For storage > 0 cubic feet and less than 350 cubic feet

For day (i) the storage is:

$$Storage(i) = Storage(i-1) + \Delta Storage \qquad \text{\{Equation 2a\}}$$

$$\Delta Storage = Rain - ET \qquad \text{\{Equation 2b\}}$$

### *Analytical Framework:*

Calculations of both runoff and cistern storage were calculated daily. The analysis looked at overall ability of the cisterns to harvest enough water to irrigate the trees, and to supply it when the plant needed it on average. In contrast, daily runoff values were, because individual events cause floods of concern.

## Results and Discussion:

### *Cisterns as Flood Control Devices*

The results show that cisterns have considerable flood control benefit, but that the benefit depends to some extent on soil type. Figure 4 shows the impact of the cisterns on flood control on Hydrologic Group D soils - soils with the highest runoff potential, while Figure 5 shows the impact of cisterns on Hydrologic Group B soils – soils with the least runoff potential.

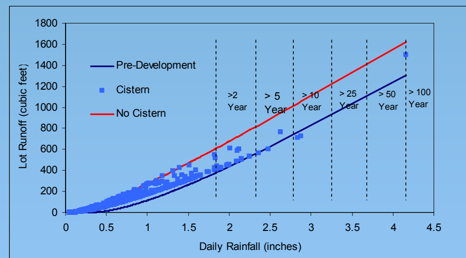


*Figure 4 – Simulated lot runoff based on daily mass-balance for the prototype lot on Hydrologic Soil Group D soils. The figure shows that runoff is held to approximately pre-development rates on days where observed 2 to 10 year rainfall occurred during the last 105 years.*

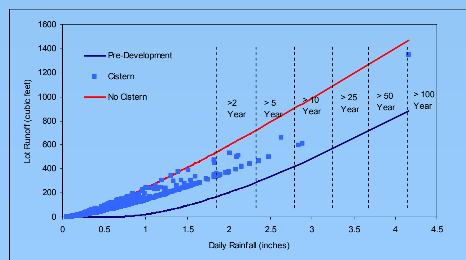


*Figure 5 – Simulated lot runoff based on daily mass-balance for the prototype lot on Hydrologic Soil Group B soils. Runoff is above pre-development rates because the infiltration storage capacity of the B soils is so great. However, the cisterns significantly reduce runoff over the case without cisterns.*

### *Cisterns as a Source of Landscape Water:*

The results showed that cisterns could be a primary source of water for 300 square feet of citrus trees, but on average supplemental water would be required to prevent the trees from becoming drought-stressed.

Figure 6 shows the how much water was harvested. On average, about 1100 cubic feet of water was harvested (8,200 gallons) in a year. On average the 1100 cubic feet harvested fell short of the supplemental water required to grow two citrus trees, which was 1400 cubic feet (10,500 gallons).

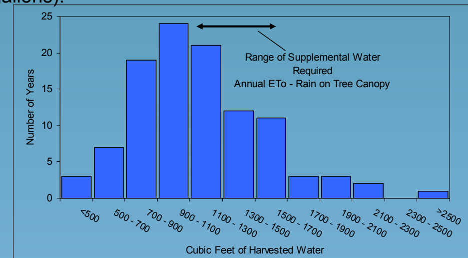


*Figure 6 – Histogram of annual volume of water harvested for the 105 years of simulation. The cistern will supply the majority of water in most years, though some supplemental water may be required during the drier hotter times of the year.*

On average, from July through March harvested water will satisfy the water requirement. The largest deficit between harvested water and water demand occurs in the late spring (Figure 7).

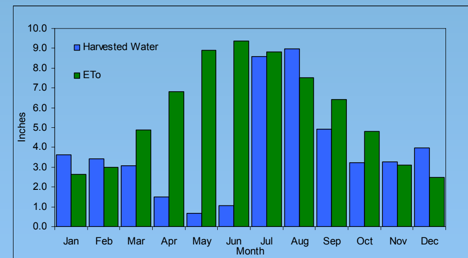


*Figure 7 – Average Monthly Evapotranspiration (ETo) and Harvested Water for the 105 years of mass-balance simulation.*

## Conclusions:

This analysis shows that:

- cisterns can provide significant flood control benefits even under a particularly problematic situations such as impermeable cover over more than half the site, and;
- harvested water could be used to grow citrus trees most of the year in Tucson.

While this scenario used lot characteristics common in new developments around Tucson, the methodology could be used to asses alternative lot layouts that aim to have less of an impact on the runoff characteristics of a watershed than the current practices. It would be helpful to integrate the water harvesting potential of earthworks into the simulation.