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AN EVALUATION OF THE COST EFFECTIVENESS OF RAINWATER HARVESTING IN EAST-CENTRAL FLORIDA

Water Supply Solutions, Inc.

Technical Memorandum

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From: Ronald L. Wycoff, P.E., D.WRE

Date: July 18, 2008

Re: An Evaluation of the Cost Effectiveness of Rainwater Harvesting in East-Central Florida

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Purpose

As part of its overall water supply planning and management mission, the St. Johns River Water Management District (SJRWMD) investigates alternative water supply options for potential applicability and relative cost effectiveness. The purpose of this technical memorandum (TM) is to investigate the major factors that influence the performance of a small-scale rainwater harvesting system in east-central Florida and to estimate the life cycle cost, including unit production cost, of a number of potential applications. In this manner, the most appropriate conditions for application are identified.

Rainwater Harvesting Application

Rainwater harvesting is the collection and storage of runoff from small impervious catchments, usually home or building roofs, for later use. It has many potential applications but landscape irrigation is the most common. The application addressed in this TM is the capture of roof runoff from either individual homes or commercial buildings for the purpose of meeting all, or a portion of, landscape irrigation needs, in east-central Florida.

In most cases, residential or small-scale commercial landscape irrigation application involves installation of a buried storage tank and an irrigation pump. Inflow is provided by a consolidated roof gutter system, commonly found installed on homes or buildings. Other appurtences could include a first flush diverter or other device to direct initial runoff away from the storage tank in order to minimize the capture of unwanted roof debris.

Figure 1 illustrates the major components of a small-scale rainwater harvesting system. The availability of potential inflow is governed by local rainfall patterns and by the roof catchment area. Losses can include spills from the gutter system as well as intentional first flush diversions. Total storage is then limited by tank volume. The timing and magnitude of outflow is controlled by the irrigation schedule, the size of the irrigated area and of course the availability of harvested rainwater when needed.

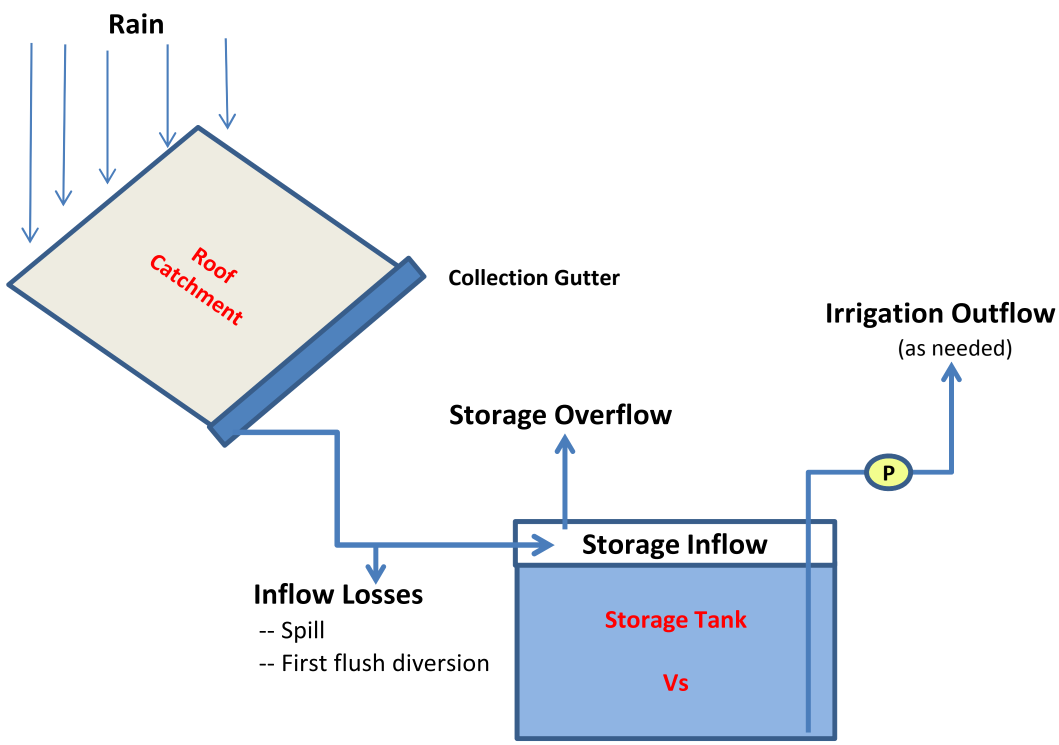

Figure 1. Rainwater Harvesting System Major Components

The performance of the system is defined as the ability to meet landscape irrigation needs over the long term. Performance is influenced by a number of factors including; rainfall patterns, roof area, storage tank volume, irrigation schedule, and irrigated area. It is measured as the total average annual quantity of irrigation water produced and the percentage of the total irrigation need met by rainwater harvesting.

Cost effectiveness is then a function of the total annual cost of the rainwater harvesting system and the volume of irrigation water produced. The final metric for relative cost effectiveness is unit production cost expressed in dollars per 1,000 gallons ($/Kgal) of irrigation water delivered. This parameter can then be easily compared to the unit production cost of other irrigation water supply alternatives.

Rainwater Harvesting System Simulation Model

To aid in this investigation, a continuous systems simulation model was developed. The simulation model is spreadsheet based and considers all the major components and processes shown in Figure 1, including:

- Rainfall
- Potential inflow
- Irrigation demands
- Storage routing

Rainfall

Like any stormwater management system, the primary driver is rainfall. Rainfall is site specific and highly variable. In order to develop reasonable estimates of long-term performance, the selected simulation rainfall period, or test sequence, must be representative of the long-term rainfall in the region of interest. In this application, the region of interest is east-central Florida and a representative 5-year daily rainfall sequence was identified from the National Oceanic and Atmospheric Administration (NOAA) rainfall monitoring station records for Orlando Florida (Orlando WB Airport and Orlando WSO McCoy).

The period of record for this monitoring station begins in 1891. A representative 5-year daily rainfall sequence was identified first by comparing the 5-year annual average rainfall to the normal average annual rainfall. In this case, normal rainfall is defined as the 30-year average rainfall for the period ending in the year 2000 (48.91 inches per year).

Several candidate 5-year sequences were identified with annual average rainfall near the target normal value. These candidate test periods were then compared, based on monthly rainfall distribution, in order to adequately represent expected seasonality. The period 1981 through 1985 (49.17 inches per year) was chosen. Figure 2 compares the average monthly total rainfall for the chosen simulation period to the average monthly rainfall for the 30-year normal period.

Potential Inflow

Potential inflow is calculated for each day of the simulation period by first multiplying the daily rainfall depth by the roof area, expressed in cubic feet per day. This product is then multiplied by a user supplied capture efficiency factor to account for unintended spillage and/or intentional first flush diversion. For this investigation, the capture efficiency factor was assumed to be equal to 95% for all runs.

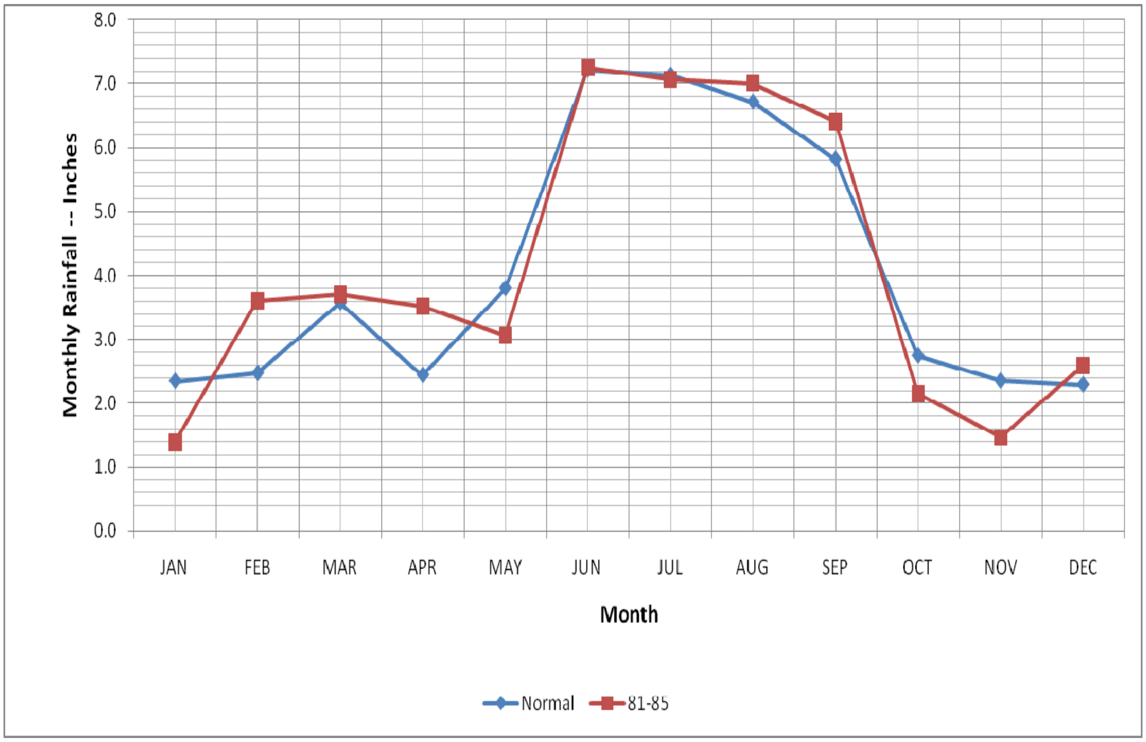

Figure 2. Comparison of Monthly Rainfall for the Selected Simulation Period (1981- 1985) to 30-Year Normal Rainfall

Irrigation Demands

Two landscape irrigation demand schedules are defined for this investigation. The first, termed gross irrigation demands, is based on the currently proposed SJRWMD lawn and landscape irrigation rule. The second, termed net demands, includes a modification of the gross irrigation demands schedule for antecedent rainfall.

Gross Irrigation Demands

The gross irrigation demands are the maximum allowed by the proposed lawn and landscape irrigation rule. Under this rule two seasons are defined. The first is the Day Light Savings Time season, which allows two irrigation days per week, with a limit of ½ inch per irrigation day, resulting in a total allowance of 1 inch per week. The second season is the Eastern Standard Time season, which allows one irrigation day per week and a maximum of ¾ inch per irrigation day (or week).

Application of this schedule results in a total allowable irrigation demand of 47.5 inches per year.

For the purpose of the simulation, Day Light Savings Time season irrigation days were defined as Wednesdays and Saturdays and the Eastern Standard Time season irrigation day was defined as Wednesday.

Net Irrigation Demands

Net irrigation demands begin with the gross irrigation demand schedule and apply an adjustment for recent antecedent rainfall. When rainfall totals for the two days prior to a scheduled irrigation day exceed a certain value, that irrigation day is eliminated from the schedule. The simulation allows the user to specify the two-day rainfall cut off value. However, for the purpose of this investigation, the cut off value was set at ½ inch. That is, when the total rainfall depth for the two-day period prior to a scheduled irrigation day, equaled or exceeded ½ inch, that irrigation day is skipped. This adjustment, to the gross irrigation demands schedule, reduces the total annual irrigation needs to an average of 38.5 inches per year.

Rainwater Harvesting System Estimated Costs

Resource Recovery, Inc., provided SJRWMD with installed cost information for selected Hydrostow ™ rainwater harvesting systems. The system storage capacities and associated base system costs are summarized in Table 1.

Table 1. Base Cost (installed) of Hydrostow ™ Rainwater Harvesting Systems.

Hydrostow System	Storage Tank Volume, gallons	Installed Cost
HS-25	2,500	$11,000
HS-50	5,000	$15,000
HS-75	7,500	$20,000
HS-100	10,000	$26,000

These costs are base costs and include buried storage tank(s), site preparation, pump station with controls, excavation and installation for typical residential conditions.

These initial installed cost data are used to develop an estimated initial capital cost curve for residential rainwater harvesting systems (Figure 3)

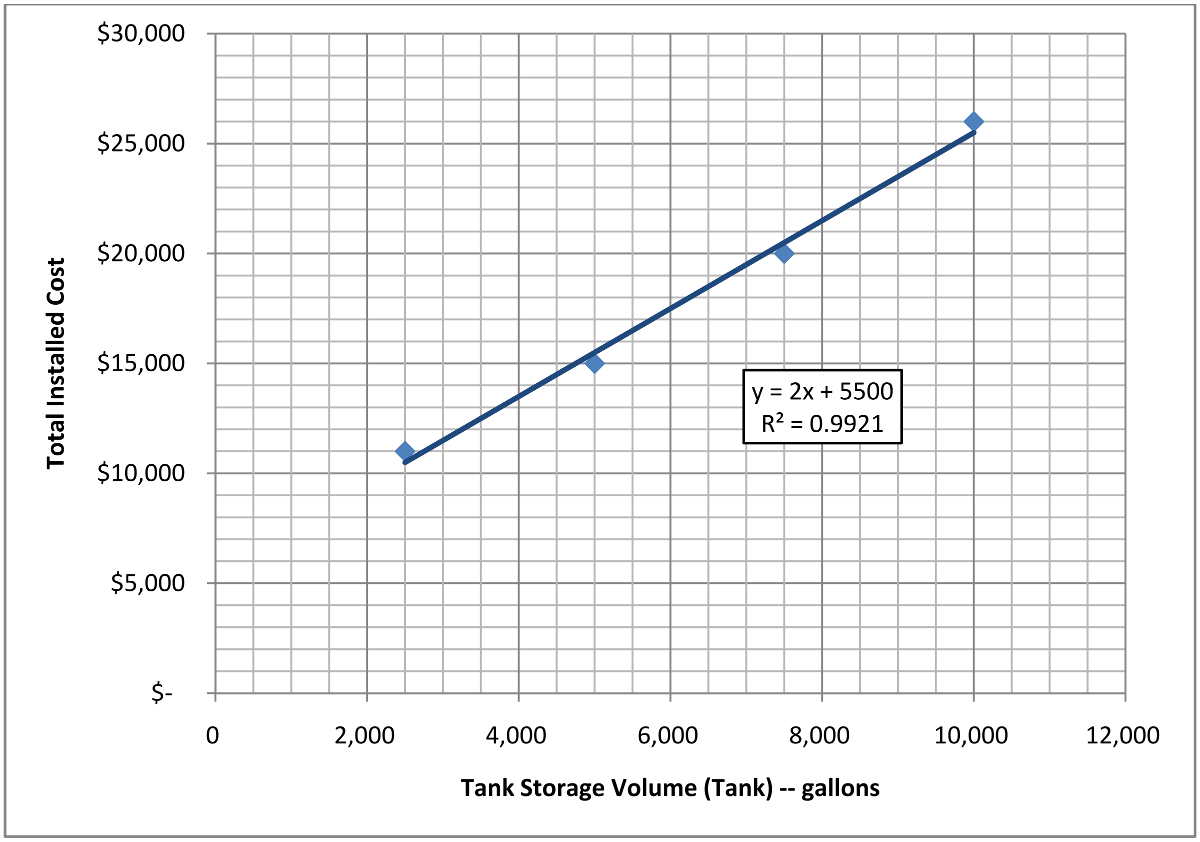

Figure 3. Rainwater Harvesting System Initial Installed Curve (from Hydrostow provided data).

The linear regression equation derived from these data is:

Initial Cost = 5,500 + 2*(Tank) (1)

where;

Initial Cost = expected base cost for complete rainwater harvesting system

Tank = total system storage volume, in gallons

Life cycle cost, expressed as equivalent annual cost, is equal to the amortized initial cost plus operation and maintenance (O&M) cost. For this analysis, O&M cost for a buried tank rainwater harvesting system is considered negligible. Assuming a 40-year economic life for the installed facilities, and a discount rate equal to the current (FY2008) Federal water resources planning discount rate (4.875%), the equivalent annual cost may be expressed as follows:

Annual Cost = 315 + 0.1146*(Tank) (2)

where;

Annual Cost = estimated equivalent annual cost of rainwater harvesting system, in dollars per year.

All other terms are as previously defined.

Unit production cost (UPC), for any particular application, is then equal to the estimated equivalent annual cost divided by the average annual volume of irrigation needs met in 1,000-gallon units.

For this investigation, irrigation needs met are estimated for both the gross irrigation demands schedule and for the net irrigation demands schedule. In turn, unit production costs will differ for each irrigation schedule.

Results

Irrigation performance and cost-effectiveness are investigated for several rainwater harvesting example applications. The first set of example applications considers two standard storage tank sizes with varying roof catchment area and target irrigation area. These examples are designed to provide an overview of rainwater harvesting performance and cost-effectiveness over a wide range of potential application conditions.

The second example application considers a hypothetical moderate size commercial application with a given roof catchment area and irrigated area. In this case, various storage tanks sizes are investigated to demonstrate the effect on irrigation performance and cost-effectiveness.

Standard Tank Size Examples

2,500 Gallon Tank

The first standard tank size considered is 2,500 gallons. This size tank is considered typical for a small to moderate size residential application. Expected initial cost would be approximately $10,500 with an estimated equivalent annual cost of about $601.50 per year.

Three roof catchment areas (1,000, 3,000 and 6,000 square feet) are considered. For each roof area, three irrigated areas are also considered, resulting in a total of 9 combinations. In each case, the irrigated area to roof area ratio is held constant. Ratios considered are: 0.5, 1 and 3. Results for each combination, for both gross irrigation demands and net irrigation demands, are reported in Table 2.

Table 2. Estimated Performance and Cost-Effectiveness of 2,500 Gallon Rainwater Harvesting System in East-Central Florida.

Roof Area -- sq. ft.	Storage Volume -- inches	Irrigated Area -- sq. ft.	Irrigation Demand Met - Percentage		Irrigation Demand Met - Kgal/yr.		Unit Production Cost -- $/Kgal.	
			Gross	Net	Gross	Net	Gross	Net
1000	4.01	500	97.6%	98.2%	8.65	7.06	$69.54	$85.20
		1000	80.9%	80.4%	14.34	11.55	$41.95	$52.08
		3000	32.8%	38.1%	17.45	16.45	$34.47	$36.57
3000	1.34	1500	87.0%	85.0%	23.15	18.33	$25.98	$32.82
		3000	66.5%	63.6%	35.38	27.41	$17.00	$21.94
		9000	27.2%	27.6%	43.37	35.72	$13.87	$16.84
6000	0.67	3000	76.4%	72.9%	40.65	31.43	$14.80	$19.14
		6000	53.9%	50.0%	57.4	43.13	$10.48	$13.95
		18000	21.5%	20.0%	68.67	51.77	$8.76	$11.62

Considering the 1,000-square feet roof area, the 2,500 gallon tank provides a relatively large volume of storage equivalent to just over 4 inches. Application of this combination of roof area and storage volume to a small target irrigation area (500 square feet) results in meeting nearly all irrigation needs for either the gross irrigation demand schedule or the net irrigation demand schedule (97.6% and 98.2 % respectively). However, the total annual irrigation volume provided is very small; 8.65 Kgal, for the gross irrigation demand schedule, and 7.05 Kgal for the net irrigation demand schedule. Therefore, unit production costs of the irrigation water are quite high ($69.54/Kgal and $85.20/Kgal, respectively).

Considering the 6,000 square feet roof area, the same 2,500 gallon tank provides a much smaller relative storage volume of 0.67 inches. If this system is applied to an 18,000 square foot irrigation area, the irrigation demand met is reduced to 21.5% and 20.0% of the total gross and net irrigation demands. However, much larger absolute irrigation volumes are provided (68.67 and 51.77 Kgal/yr), and, therefore, the unit production costs are reduced in an amount inversely proportional to the increased irrigation water produced.

7,500 Gallon Tank

The second standard tank size considered is 7,500 gallons. This size tank is considered typical for a large residential application or a small commercial application. Expected initial cost would be approximately $20,500 with an estimated equivalent annual cost of about $1,174.50 per year.

For this example (Table 3), the roof area and irrigated area are scaled up (from the 2,500 gallon example) by a factor of three. In this manner the relative storage volume (in inches) and the roof area to irrigated area ratios remain the same.

Table 3. Estimated Performance and Cost-Effectiveness of 7,500 Gallon Rainwater Harvesting System in East-Central Florida

Roof Area -- sq. ft.	Storage Volume -- inches	Irrigated Area -- sq. ft.	Irrigation Demand Met - Percentage		Irrigation Demand Met - Kgal/yr.		Unit Production Cost -- $/Kgal.	
			Gross	Net	Gross	Net	Gross	Net
3000	4.01	1500	97.6%	98.2%	25.96	21.17	$45.24	$55.48
		3000	80.9%	80.4%	43.02	34.66	$27.30	$33.89
		9000	32.8%	38.1%	52.34	49.35	$22.44	$23.80
9000	1.34	4500	87.0%	85.0%	69.45	54.98	$16.91	$21.36
		9000	66.5%	63.6%	106.15	82.22	$11.06	$14.28
		27000	27.2%	27.6%	130.1	107.17	$9.03	$10.96
18000	0.67	9000	76.4%	72.9%	121.96	94.29	$9.63	$12.46
		18000	53.9%	50.0%	172.2	129.39	$6.82	$9.08
		54000	21.5%	20.0%	206	155.31	$5.70	$7.56

The performance of the scaled up system (measured as a percentage of the total irrigation demand met) is the same for both sets of example applications. That is, system performance is a function of the volume of storage, in inches, and the irrigation area/roof area ratio. However, because of economies of scale, the unit production costs for the larger 7,500-gallon system are reduced by about 35%.

Commercial Application Example

The example commercial application considers a 20,000-square feet roof and a target landscape irrigated area of 30,000 square feet. Potential inflow from the roof catchment would average about 579,000 gallons per year, whereas gross irrigation demand for the 30,000-square feet irrigation area will total about 888,000 gallons per year. Therefore, in this case, rainwater harvesting can provide no more than about 65% of the total annual irrigation needs even with unlimited storage. Like many applications, this example rainwater harvesting application would supplement but not completely replace irrigation from another source.

Tank volumes from 5,000 gallons to 25,000 gallons (0.4 inches to 2.0 inches) are considered. The performance and costs of the rainwater harvesting systems are reported in Table 4.

Table 4. Estimated Performance and Cost of Example Rainwater Harvesting System for Commercial Application.

Tank Volume -- gallons	Estimated Initial Cost	Estimated Annual Cost $/yr.	Irrigation Demand Met - Percentage		Irrigation Demand Met - Kgal/yr.		Unit Production Cost - $/Kgal.	
			Gross	Net	Gross	Net	Gross	Net
5,000	$15,500	$888	31.9%	29.3%	170.0	126.3	$5.22	$7.03
10,000	$25,500	$1,461	43.1%	40.4%	229.3	174.1	$6.37	$8.39
15,000	$35,500	$2,034	49.2%	47.2%	262.0	203.5	$7.76	$10.00
20,000	$45,500	$2,607	53.2%	52.4%	283.1	225.8	$9.21	$11.54
25,000	$55,500	$3,180	55.9%	56.2%	297.5	242.3	$10.69	$13.13

As tank volume is increased both costs and performance also increase. However, costs increase at a greater rate than performance, resulting in increasing unit costs with increased tank size.

The storage production function (Figure 4) illustrates the relationship between storage tank volume (level of effort provided) and gross irrigation demands met (output).

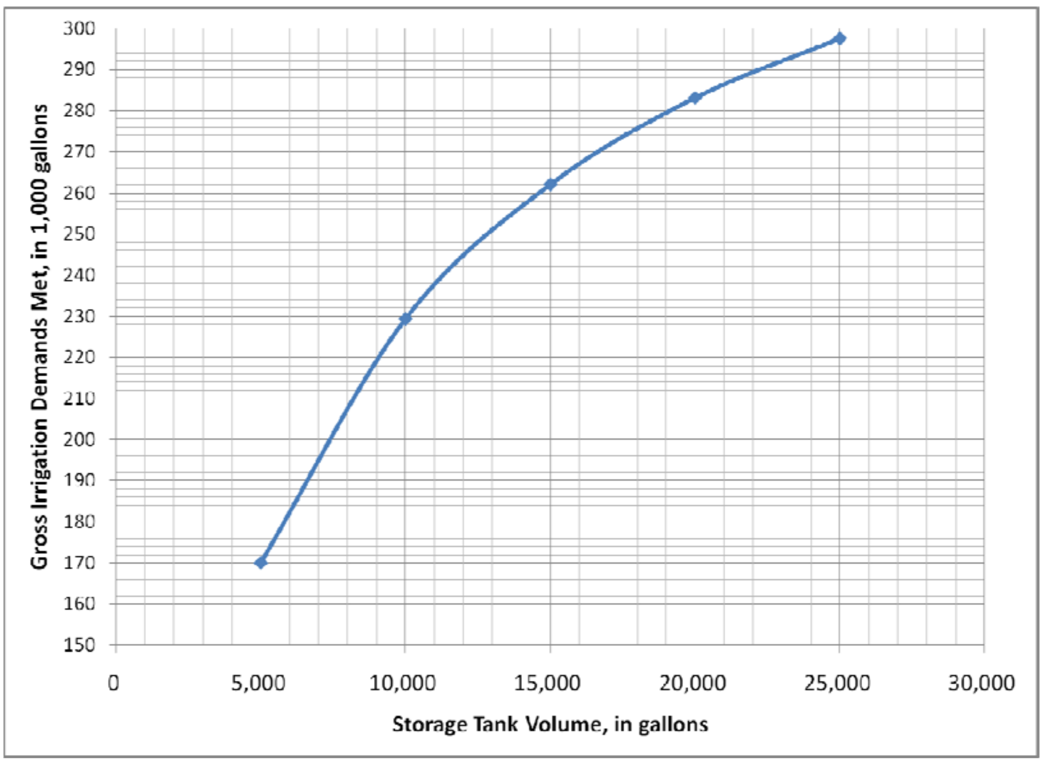

Figure 4. Storage Production Function for Example Rainwater Harvesting Application

As can be seen by inspection, this relationship exhibits diminishing returns. That is increasing storage volume at the lower end of the function is more productive than increasing at the higher end. For example, the initial 5,000 gallon storage increment will produce 170 Kgal of irrigation water; whereas the last 5,000-gallon increment (from 20,000 to 25,000 gallons) will produce only 14.4 Kgal of irrigation water.

Conclusions

Residential and commercial rainwater harvesting is a relatively simple and immediately available technology for supplying a potion of east-central Florida's landscape irrigation needs. Although the concept is straightforward and easy to implement, performance and cost effectiveness are somewhat complex and depend on the interplay of many factors including:

- Roof catchment area
- Storage volume
- Irrigation area
- Irrigation quantities and schedule

Storage volume relative to the roof area, expressed in inches, and the ratio of the irrigated area to the roof area are key characteristics influencing the performance of any individual rainwater harvesting application.

Like all stormwater management systems, capture increases with relative storage volume, but significant diminishing returns are exhibited. Therefore, as the relative storage volume is increased, a larger portion of the total need can be met, but the unit production cost can become excessive.

The irrigation schedules considered in this investigation provide 47.5 inches per year (gross irrigation schedule) and 38.5 inches per year (net irrigation schedule) while the potential roof runoff inflow will average about 46.5 inches per year. Therefore, if the target irrigation area is larger than the roof area then only a portion of the irrigation needs can be met, regardless of the effectiveness of the storage tanks.

Given inherent limitations on potential inflow quantities and the diminishing returns associated with increased relative storage volume, it is likely that the most appropriate application of rainwater harvesting would be as a supplemental source of irrigation water. A primary, relatively drought proof source would also be needed. Even under relatively favorable application conditions the unit production cost of the rainwater harvesting system will likely exceed the unit production cost of the primary source.