URBAN WATER HARVESTING SYSTEM, TUCSON, ARIZONA*

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Paper Presented at the Second International Conference on Rainwater Cistern Systems, St. Thomas, Virgin Islands, June 25-27, 1984

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ABSTRACT

A urban water harvesting system in Tucson, Arizona is described. The system consists of a 100,000 gallon reservoir fed through a 6-inch pipe by a 4-acre urban watershed. In addition a 3-acre watershed is connected to the pond with both a earth lined and fibreglass reinforced asphalt channel.

The 3-acre watershed includes the acre lot on which the reservor is located. A gutter collects the runoff from the house on this lot and directs it into the pond. The front driveway is paved and directly connected to the pond so that a high percentage of its rainfall is harvested.

The reservoir is multipurpose providing irrigation for a large (4000 sq. ft.) garden and orchard area in addition to landscape irrigation. Also in the future the reservoir will provide sufficient water to take care of the flushing of toilets for a family of 8.

The reservoir also is used for the raising of fish thus providing both food and recreation. Trout is raised in the winter and tilapia in the summer. The pond also provides swimming, rafting and aesthetic enjoyment in an arid environment.

The cost effectiveness of the reservoir is high primarily because of the high watershed area to capacity ratio. With a relatively high demand the reservoir refills several times each year. Only a small percentage of the rainfall on the watershed is utilized because of the relatively small storage capacity of the reservoir. This percentage of utilization is estimated to be about 15 percent.

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INTRODUCTION

Urban Water Harvesting of rainwater can be improved through the addition of storage systems. With storage it is possible to collect 90 to 95 percent of all runoff from an urban area. Because an urbanized area contains a large amount of impervious surfaces 40-60 percent or more, large amounts of runoff can be generated even in relatively small rainfall events.

Tucson receives 40 to 50 different rainfall events per year. Most of these events will produce runoff if it falls on a impervious surface. On a natural surface only the longer duration higher intensity rainfall will cause runoff. Thus the use of an impervious watershed increases not only the amount of water but also the frequency of runoff.

The greater the frequency the smaller the storage needed to supply a given amount of water. The greater the frequency the more times a given storage is filled and used in a given year. The frequency of refilling is also dependant upon the size of watershed versus the size of storage and of the demand.

There is 300,000 gallons of rainfall on an acre of land in an average year in the Tucson area. The value of domestic water is approximately $2.50/1000 gallons. Thus the value of rainfall in an urban area would be $750/acre/year if all of the water could be harvested.

With modern methods and techniques effective urban storages can be built to harvest water that now is presently being largely wasted. It appears that cost effective systems can be built in most situations if a proper sizing relation is used between the watershed, the amount of storage and the demand.

In the Tucson area the cost of water has continued to increase. With the advent of importation of Colorado River Water using the Central Arizona Project the cost will escalate at an even faster rate. Because of this the cost of watering a small orchard or garden (2000 sq ft) was becoming excessive, $70/month in the peak months, $500 to $600 per year over all. Furthermore newspaper articles were continually discouraging heavy use of our underground water supply. The last several rate increases penalized the heavy users of water. As a result continued outside gardening in Tucson appears to be headed for extinction.

But I enjoy gardening. I find it an enjoyable and very beneficial from a nutrional, educational and social point of view for my family of eight. For these reasons I decided to use more than 20 years experience in research in water harvesting at the University of Arizona to build my family a urban water harvesting system to irrigate an expanded garden.

DESCRIPTION OF PROJECT

The system that was built on our one-acre lot consists of a 100,000 gallon reservoir fed with a 7-acre urban watershed.

The pond is lined with plastic that is gunite coated with earth-tone mortar. The pond separates into two compartments when the water level drops 2-feet below the top. This compartmented approach gives a pot-hole effect of a elevated pond above a lower one. This adds interest and improves the acceptability or aesthetics of the pond during the dry season when the water level drops. It also can be used to reduce evaporation by concentrating all the water in one compartment whenever possible.

Most of the runoff from the watershed comes from a townhouse development, 12 houses/acre on 3-acres of the watershed plus about one-acre of asphalt streets. The runoff from the townhouse subdivision reaches the pond through a 6-inch pipe. Therefore a large percentage of a storm with only moderate intensity will be lost. However, in the past year sufficient runoff has been received to keep the pond filled and overflowing during the summer and winter rainy seasons. An additional pipe will be added in the future if the garden area is expanded and a larger demand is created.

The pond is multipurpose. Its primary purpose is to store rainwater for irrigating landscaping, an orchard and garden. The pond is also used as a year around fishery and in the summer it is used for swimming.

DESIGN PROCEDURES

Beginning in 1976, a computer program was developed which will properly design a water harvesting system. A optimum sized reservoir can be obtained to match a given type of watershed in a specific climatic region with a known demand. The operation model uses historical data, daily rainfall and pan evaporation. It has an agricultural option that will operate specific crop areas in conjunction with the surface storage. It will keep track of the available soil moisture under each of 5 crops, calling for irrigation when needed by the crop. It determines the need for irrigation by keeping track of evapotranspiration losses from the crop. It also determines evaporation losses from the reservoir.

The model has been fully documented in Cluff (1977). The model operates several separated individual reservoirs or a compartmented reservoir in which water is kept concentrated to reduce evaporation. With the model,the optimum number and size of compartments that will minimize costs and maximize benefits, can be determined.

There is an on-going project, with funds from the United States Agency for International Development, that is adopting this model for use on small personnel computers. Much effort is being expended to make the model "user friendly", so that it can be used by anyone with a minimum amount of instructions.

EVAPORATION CONTROL

The pond presently has 3 stucco-coated foam platforms. Two of the platforms are 10 x 10 feet in size the other is 10 x 20 feet. These platforms prevent essentially 100% of the evaporation that would have occurred on the area covered. Since the platforms are constructed of foam little or no heat is added to the surrounding water due to reduction of evaporation. The floating rafts also contribute to the pond essentially 100 percent of the rainfall that falls on their surface area.

The covering of this 400 square foot of water in Tucson would prevent the evaporation of approximately 20,000 gallons of water per year plus conserve another 3,000 gallons of rainfall. This is a $57/year benefit if the water saved is valued at $2.50/1000 gallons. The cost of a 3-inch platform 400 square feet in extent is approximately $300.00 and should last for ten years or more. Thus the covers appear to be cost effective.

The three-inch thick platforms are used for recreation, rafting, sun bathing, etc. My family at first objected to the placement of the rafts on the pond, but now they have proven to be quite popular with my children who enjoy jumping from raft to raft. The pond would not be as popular without them. If the rafts were not used to support foot traffic, they could be made 1 1/2 inches thick which would reduce their cost by 30%.

Other methods of evaporation control that are being tested at the University of Arizona are the use of 3-inch black plastic balls and 16 oz. glass soft drink bottles with re-usable caps. If recycled glass bottles are used, costs as low as 10 to 20 cents per square foot are possible. The glass has an unlimited life provided they are not broken and the aluminum lids are replaced from time to time.

The black plastic balls are UV stabilized with an expected life of 20 years. The black plastic balls when fully covering the surface of the water have a uniform aesthetically pleasing appearance. They always look good, and do not accumulate much dust. The balls let oxygen and carbon dioxide transfer freely between the water and the atmosphere so there should be no aeration or odor problems. The balls should reduce significantly the algae growth particularly the bottom weed growth. They are more expensive than the glass bottles. In Arizona they will cost approximately $1.60 per square foot.

Other methods of evaporation control are discussed in greater detail in Cluff and Frobel (1978) and they will not be reviewed here.

SEEPAGE CONTROL

Seepage control is discussed in some detail in Cluff and Frobel (1978) and will not be covered fully here. Of all the methods available at the present time the use of a wire mesh reinforced gunite coated plastic appears to be the leading method to use for multipurpose urban waterharvesting systems.

A one-inch screen size poultry netting is generally all the reinforcement needed. Gunite is used in a thickness sufficient only to cover the wire. This is normally 3/4 inch. The gunite in this thickness will develop a few hairline cracks but since its function is primarily to protect the underlying plastic the presence of cracks is not that important. The plastic povides the seepage control, not the gunite.

If a heavy 20 mil vinyl plastic or equivalent is used and reasonable care is taken, success is assured. The cement mortar can be added using hand labor if gunite equipment is not available. The use of gunite equipment assures proper compaction of the coating and generally provides a better appearance of the final product than is obtainable using hand techniques.

Gunite coated plastic can be applied to near vertical walls if necessary. However, the closer the walls are to vertical the more difficult the coating becomes. Also the material use goes up dramatically. It is safer not to go any steeper than 4 vertical to 1 horizontal (4:1). In loose sand, the slopes should not be any steeper than the natural angle of repose of the material in which the pond is excavated. However, in well-compacted soil the slopes can be cut steeper.

The wire mesh reinforced gunite-coating, because it requires less than an inch of gunite, is relatively inexpensive, costing less than $0.20 per square foot or $8,000/acre. The 20 mil plastic and wire mesh will add another 30 to 40 cents per square foot. The entire job, including labor for placement of the plastic, should be done for $0.60 to $0.70 per square foot. It would be less if thinner plastic sheeting were used. The thinner plastic would be more than adequate for use in catchments and drainage channels.

FILTER/WATERFALL

For the multipurpose water harvesting system, it is essential that some type of filtration or aeration system is included.

For the system in Tucson a 400 gallon asbestos cement tank was used. It was filled in the bottom with a six-inch layer of gravel. A plastic-wire window screen was then installed and covered with a 2-foot layer of washed concrete sand.

A 1/3 horse power, 40 gpm low-head submersible pump is used to lift water up to the filter. After passing through the filter the water runs by gravity back into the reservoir. The outside of the filter was covered with wire mesh and gunited. The front face of the filter was altered through use of the gunite to form a waterfall. When the filter plugs up or its capacity is exceeded the filter becomes a waterfall adding interest to the multipurpose reservoir.

The slow sand filter reduces some of the biological contaminates, but a water quality analysis indicated the non-coliform bacteria test was to numerous to count (TNTC) See the section on Water Quality.

CONSTRUCTION DETAILS

The construction steps are quite important to assure a successful water harvesting system for the lowest possible price. They are as follows:

1. Excavation can be done using a small dozer, a backhoe or if available a grade-all. The dozer was used in this excavation. Its use is convenient because the excavated soil can generally be moved to an appropriate nearby position within a backyard, thus avoiding the necessity for using more than one type of equipment.

2. A 12" x 12" trench is dug around the top of the pond about 4 inches away from the top edge.

3. After the pond is excavated and the top trench is dug, the surface must be hand raked and all slump rocks, roots, etc. removed.

4. The plastic is then installed taking care that it is not stretched too tightly. This is especially important if the laying of the plastic is done on a cool day. Plastic, particularly polyethylene, does expand and contract due to temperature changes. The plastic is secured with bricks, rocks, sandbags, etc. in the top trench.

5. Following installation of the plastic, poultry netting, with a 1-inch or less mesh opening is laid over the plastic. It is important that the edges of the wire mesh are over-lapped 3 to 4 inches with the next adjacent width of wire and then tied together with galvanized wire. The wire mesh is temporarily secured under the bricks in the top trench.

6. Cement mortar with a 1:4 cement ratio is mixed and used to fill the top trench. The bricks are generally removed as this filling takes place. They can be reused on another project. In small jobs this cement is generally mixed by hand or using cement mixer. On larger jobs redi-mix trucks could be used.

7. Following the curing of the cement in the top trench, the bottom of the pond is coated with cement. This is

generally mixed by hand or using small cement mixers in smaller ponds or ordered in a redi-mix truck. This coating could also be done using the gunite machine in larger jobs. A one or two day curing time should be allowed for this bottom layer before the walls of the pond are gunited. This method of construction secures the wire and provides a base for the men to stand on while they are coating the sides.

8. Any drainage ditches leading to the pond, filters, waterfalls, foam rafts, can be gunited at the time the pond is being gunited.

9. The pond should be either kept moist with a sprinkler system for 48 hours or a curing compound should be used to retard drying. This is very important to the success of the lining.

WATER QUALITY

An analysis of the water quality in the pond after one year of operation is given in Table 1.

The detailed analysis shows that the water is well within the maximum contaminant levels established under the Safe Drinking Water Act. The only contamination outside of the Safe Drinking Act is the non-coliforms which were TNTC (too numerous to count). This high reading is expected in unclorinated pond water. The important thing the analysis shows is that other difficult-to-remove contaminats is well within drinking water standard. The water is of excellent quality to use for garden and landscape irrigation, fisheries, etc. With filtration or chlorination, it could safely be used for swimming and/or drinking.

IRRIGATION SYSTEM

A 2-inch delivery line was installed to feed water to the garden and orchard areas. High volume flood irrigation is used for the gardens with bubblers used for individual trees.

Irrigation, using this system, can be completed in a very few minutes. Because of the high volume and short length of time required for irrigation the process can be continously monitored. This assures that the water will

TABLE 1

Primary Inorganic Chemicals Parameter	Allowable mg/l *	Test Results	Secondary Inorganic Chemicals Parameter	Allowable mg/l*	Test Results
Arsenic	0.050	0.010	Chloride	250.0	6.5
Barium	1.00	0.10	Iron	0.300	0.035
Cadmium	0.010	0.005	Manganese	0.050	0.016
Chromium	0.050	0.010	Sodium	20-250	14.
Lead	0.050	0.010	Hardness		52.7
Mercury	0.002	0.001	Aluminum		0.169
Nitrate	10.00	0.10			
Selenium	0.010	0.005	pH	6.5-8.5	8.4
Silver	0.050	0.010			
Fluoride	2.40	0.10			
Organic Halides (as Chloride in mg/l)			Total Bacteria Count, per 100 ml		
Purgeable		0.002	Coliforms	1.	1.
Nonpurgeable		0.049	Non-Coliforms		**TNTC
Total		0.051			

Note: * = Maximum Contaminant Levels
** To Numerous To Count

not be wasted. The total time required is much less than using a garden hose, which because of its low volume, is left unattended for long periods of time.

For many vegetables water use is reduced by planting in the bottom of the furrow to minimize the wetted area. Plastic is sometimes used to reduce water use, to enhance germination and reduce surface crusting . These practices save considerable amount of water over conventional flood irrigation.

It would be possible to use the filtered water in a trickle irrigation system if greater irrigation efficiency was required. Because of the modified flood irrigation system that is utilized, the additional savings may not be cost effective.

RECREATIONAL ASPECTS

The pond is used for fishing and rafting all year with swimming in the summer. Last fall it was stocked with 125 catchable rainbow and german brown trout 12 to 15 inches long.

These rainbow and german brown trout did very well through the winter and early spring requiring a minimum amount of supplemental food. The filter was used occasionally. About April 1 the water got too warm for trout and the last 3 or 4 fish that had not been caught died.

There has been ten large mouth bass presently about 12 inches long that have done well since last summer. This summer we are planning to also stock the pond with tilapia, a fast growing warm water fish that are also very tasty. The tilapia will be removed in the fall in preparation for the restocking of the pond with trout for winter fishing.

The fishery has been used by several Cub Scout groups. Most of the boys had never previously caught a fish. One of these after catching the a fish exclaimed "Just wait until I show Dad, just wait until I show Dad".

The cost of the total system including the pump and delivery system for irrigation, evaporation control, the slow sand filter, etc. was approximately $4,000. This included salary for my two sons who did most of the hand labor required. It didn't include supervisory labor, overhead or a profit.

The use of the water harvesting system has allowed our family to reduce our water bill from $70 down to $10 per month while at the same time more than doubling our garden size. In addition the vegetable yield from our garden per unit of land has almost doubled. I realize now that because of the high cost of water we were not applying enough to assure good yields. If we were irrigating the amount of garden we now have, our water bill would average at least $125 per month or $1500/year at todays rates.

It appears that the system will pay for itself in 3 or 4-years from water savings alone. Although the recreational aspects, particularly the fishing, has added a lot of interest and excitement to our our family and neighborhood it is hard to put a value on that.

The use of the water harvesting system has improved our peace of mind with regard to water use for our garden. Previously in addition to the high water bills we also had guilt feelings of using more than our share of a groundwater supply that is being depleted. With the water harvesting system we are making use of a resource that was previously wasted.

CONCLUSIONS

The urban water harvesting system using modern techniques can be built to be cost effective in most cities that are arid enough to require sizable amounts of water for gardens and/or landscape irrigation.

These systems can be multi-purpose, improving the quality of life in arid environments in addition to providing recreation, food and water. The system described in this report has been proven to be a very worthwhile investment.

Similar systems can be built on a subdivision scale to improve the economics and improve the overall efficiency. With maximum development they could greatly reduce the amount of additional water that is needed to supply a urban area. If recycling of "greywater" and other water conservation practices, with the utilization of additional impervious areas if necessary it should be possible to develop, in many areas now thought to be arid, "rainfed subdivisions" that would obtain all of their water supply from rainfall.

LITERATURE CITED

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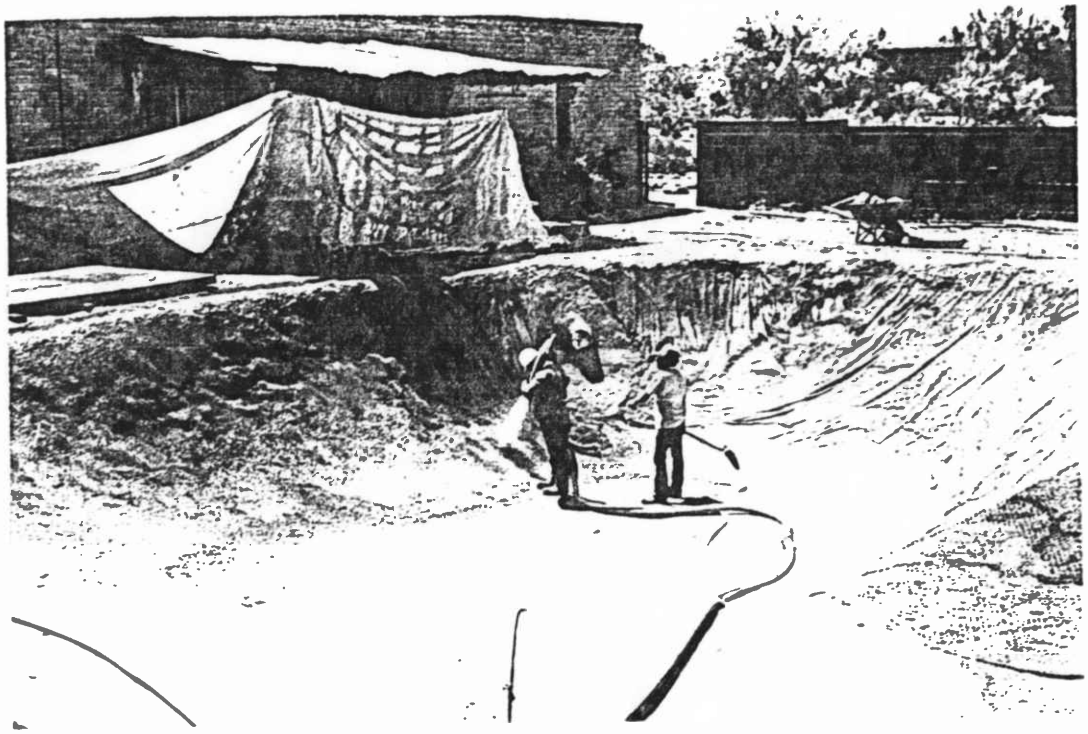
Cluff, C. Brent, Water Harvesting, Catchment and Reservoir Construction Methods, Water Resources Contribution No 2, 1978, Water Resources Research Center, College of Earth Sciences, University of Arizona, Tucson Arizona 85721



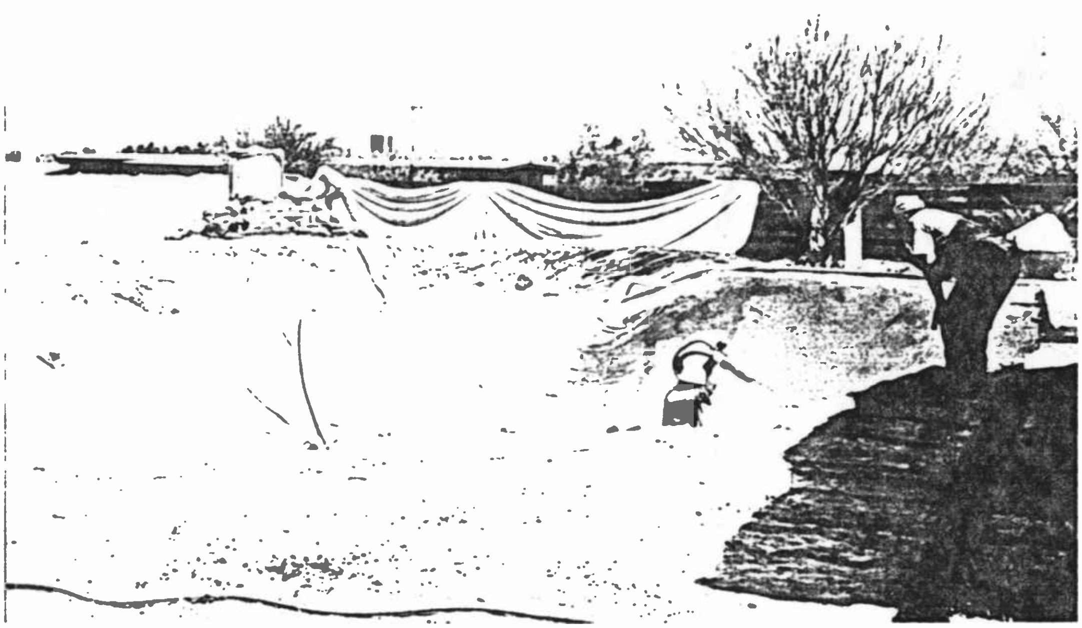


FIGURE 1: Construction of Two Compartmented Pond

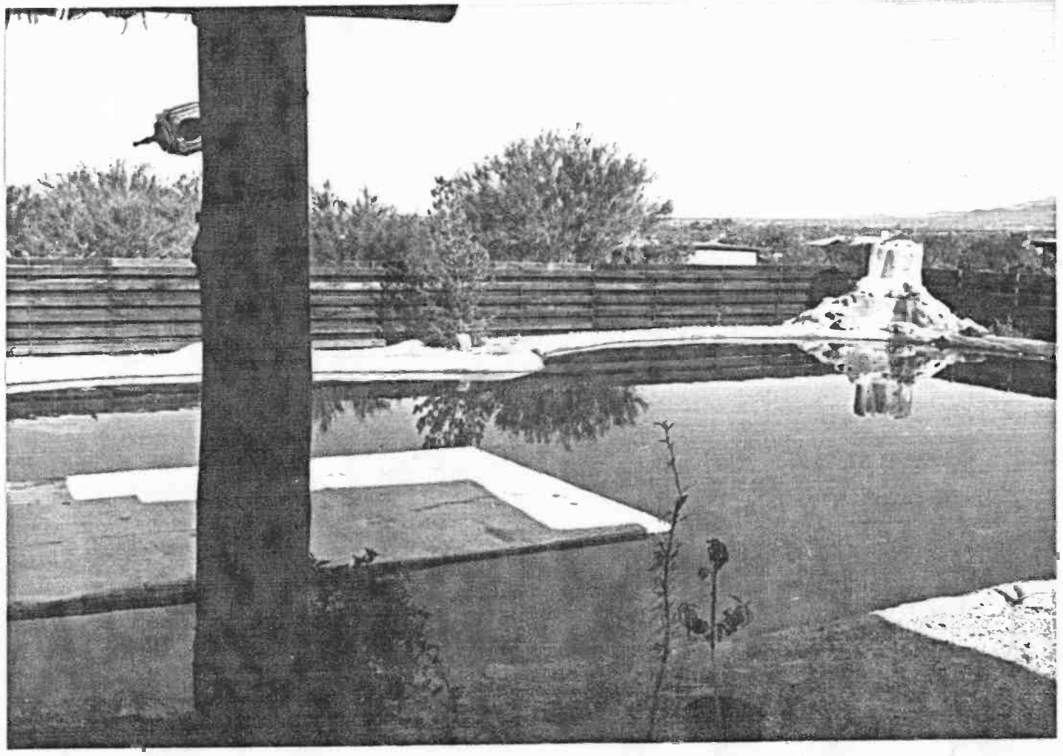


FIGURE 2: Completed Pond Filled with Urban Runoff

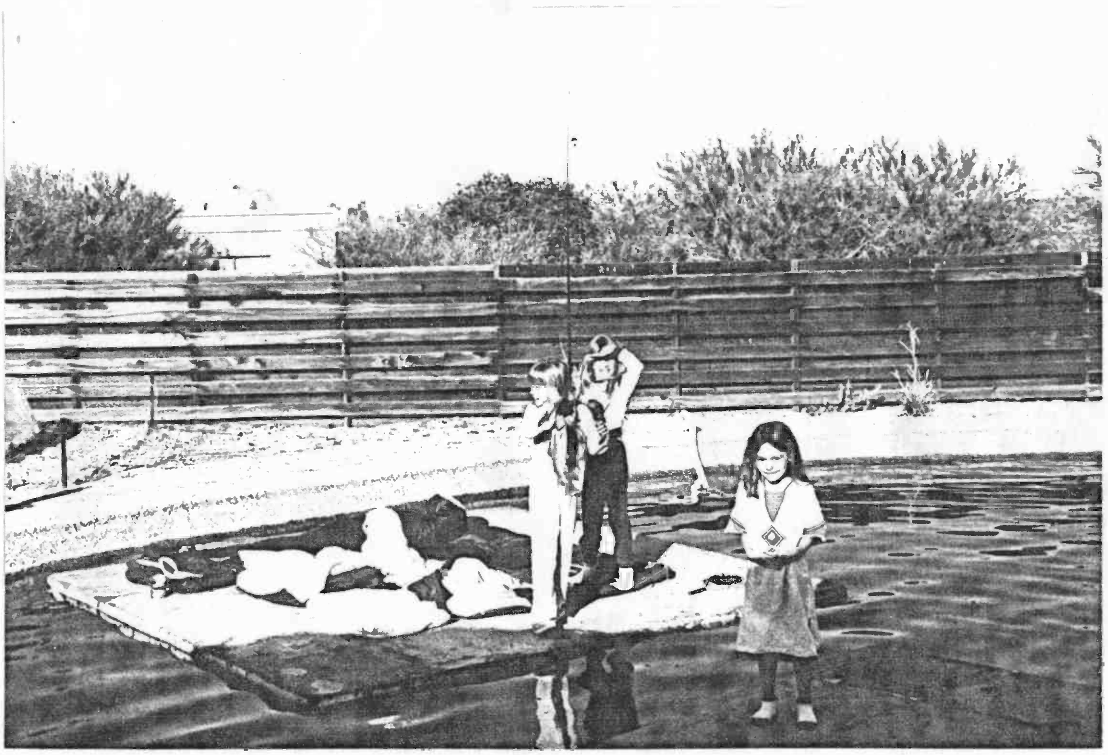


FIGURE 3: Recreational Aspects of Urban Water Harvesting Pond