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PROVISIONS IN DESIGN AND MAINTENANCE TO PROTECT WATER QUALITY FROM ROOF CATCHMENTS

GEORGHIOS MICHAELIDES and ROBERT YOUNG†
University of Dundee, Dundee, Scotland

Rainwater may be collected from the roofs of buildings, courtyards or large ground catchments. Rooftop catchments are usually best for satisfying the domestic water requirements of family. Rainwater may be utilised for drinking and cooking, for which high water quality is required, or for other domestic purposes such as washing and bathing.

At present, rainwater catchment systems are not generally built in highly industrialised areas where pollution is extreme. Rainwater has virtually no bacterial content. With few exceptions, the quality of rainwater prior to interception is more consistent than that of other water sources. However, in using rainwater for drinking water supplies, it is not so much the quality of the rainwater itself that is important, but rather the quality of the water as drawn from the storage tank in which the water is collected and stored for later consumption.

Optimising water quality requires attention to each of the processes which transmit water from the atmosphere to the user: contact with the catchment surface (roof or ground), transport in a channel (gutters and downpipes in a roof catchment) to the tank, residence in the storage tank and extraction from the tank. The contaminants in a supply that can be traced back to the characteristics of the system should be identified.

Pollution does not necessarily mean contamination of the water or rendering it unfit for human consumption. Pathogenic (disease-producing) organisms or toxic substances must be introduced into the water before it is unsafe to drink. For most precipitation harvesting schemes the control over the entry to toxic substances into the water should not be difficult. Chances of contaminating a well operated scheme with pathogenic organisms should also be remote, since "water to act as a vehicle for the spread of a specific disease, must be contaminated with the disease organisms, from infected persons"[1] and an elevated roof or fenced ground catchment are unlikely to become contaminated. There is little likelihood that fecal organisms will contaminate roof catchment rain water. Other foreign material that could enter the collected rain water have a negligible effect in comparison to fecal contamination.[2] The scope of the roof catchment will, hence, include the provision of water free from fecal contamination, which is the main cause of death in developing countries.

Although water quality aspects related to health are more important than aesthetic aspects, the latter are not to be disregarded as they could affect the acceptance of a water supply by users. Achieving the goal of health does not only depend on water quality; another significant factor is satisfying the water quantity requirements.

Reduction or elimination of the effects of sources of pollution can be attained by various measures. Part of the measures are preventive. and included in the construction of the system. Water quality can be positively influenced by the sensible design of a precipitation harvesting scheme.

Where water quality problems have been encountered, they are related to defects in systems or failure to adequately maintain them. When properly collected and stored and ordinary precautions taken, the quality of rainwater may compare very favourably with that of the water obtained from other sources. Several research programmes, conclude that rainwater harvesting catchments, are acceptable as a means of water supply, provided that they are adequately maintained.

The basic means of achieving and preserving good water quality after interception are:

1) Technical considerations and provisions in design and construction;

2) maintenance and cleaning of the whole system;

3) water treatment.

An indication of the design, construction and maintenance requirements follows. (Figures 1 and 2 show the most important features.)

DESIGN CONSIDERATIONS IN ROOF COLLECTION

Roofing Materials

The use of construction techniques, materials and coatings in collection (and storage systems) that physically trap polluting matter or ones that cause water quality and health hazards should be avoided. Specifically, the desired water quality related characteristics of artificial catchments are:

a) Run-off from the structure must be non-toxic to the human being and thus lead roofs are unsuitable because of health hazards.

b) The surface should be smooth dense (hard inorganic) since this is less likely to catch and hold wind-blown dust and ebris, which is later collected by the rainwater, as does a rougher type of roof. Rough types of roof include thatched (straw, reed) and wooden ones. Even if thatched roofs are improved by a surface of plastic sheeting, this sheeting would soon be covered by algal growth.

Other unsuitable materials for a roof are asbestos cement, shingle stains, pitch, tarred, roofing felt, cement pans. Bituminous surfaces, such as roofing felt, are likely to make the water unpleasant to taste, rather than dangerous to drink. It is preferable for a roof to be galvanised metal (corrugated plates of aluminium or galvanised iron), free from rust and corrosion. However, many rural houses are roofed with other materials; thatched roofs are common.

Paint

Painting roofs is to be discouraged. If used, local authorities should develop a list of appropriate paints that may be used.

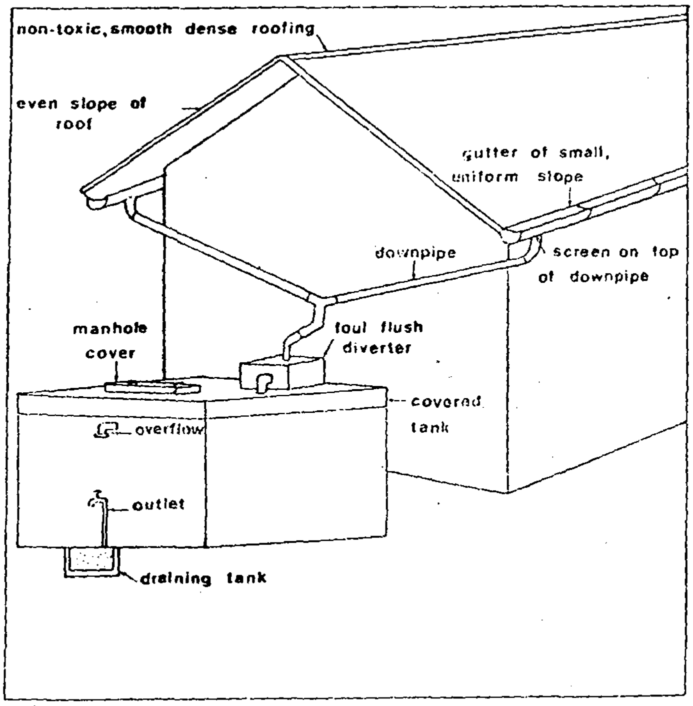

FIGURE 1 Typical roof catchment system.

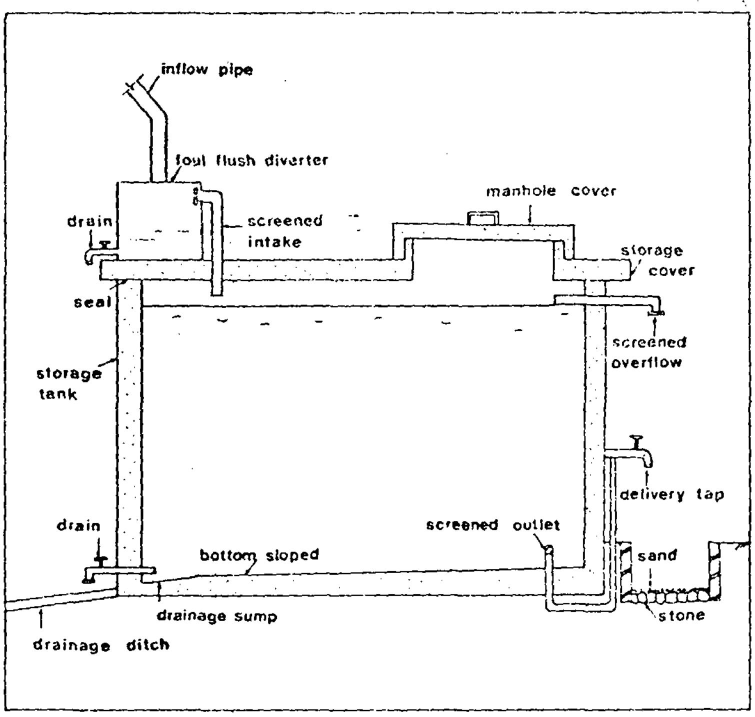

FIGURE 2 Side view of typical rainwater reservoir.

Paint used for rooftop collection systems should have as low a level as possible of heavy metals, such as mercury and lead. White latex, if controlled to assure it is free from metals and aluminium paint may be used.

Newly painted roofs should be allowed to dry and harden completely before the first rainfall. Tar based paints impair taste and at least the first three runoffs[3] from acrylic painted roofs should be discarded.

Other Precautions

- There should be *no overhanging trees* adjacent to the roof. The aim is to decrease the probability of accumulation of vegetation and bird droppings.
- The configuration of the roof in conjunction with the wind can keep roofs clear of leaves and debris.
- A roof which *birds* regularly use for *shelter* is not suitable for rainwater catchment. A scare-crow may be employed.
- *Aerial spraying* of chemicals in the area is to be discouraged.
- The catchment should be given an even *slope* to prevent the formation of pools.
- Problems are created by *defective plumbing* when drains installed over roof surfaces leak onto roofs.

Inflow System

Conveyance to storage consists of gutters and downpipes. The downpipe is the pipe leading from gutter to the reservoir.

Gutters, of a small but uniform slope to the downpipe without sagging and downspouts should be installed so as to encourage gravity (free) flow of water into storage to avoid formation of puddles that would be a breeding place for vectors of disease. The required slope is 8–10 cm per metre of gutter.[4]

To prevent leaves and other debris from entering the downpipe and possible clogging, a galvanised coarse mesh screen having $1\ cm^2$ openings[2] should be placed over the entrance to the downpipe. The downpipe should be raised about 1 cm above the bottom of the gutter.[2] Gutter and downpipes should be free of rust.

Separation

Roofs accumulate pollutants during dry periods between rains and the longer the dry spell the greater the problem. When rain starts, the first runoff from a collecting surface should be diverted and not allowed to enter storage for a period, since it carries with it maximum concentration of the accumulated dirt from roof and gutter. It has been variously reported that the amount to be discarded should be the first 5–20 minutes of rainfall.

There are several techniques, either manual or automatic, that have been used for separation.

Simple approaches include (1) a movable downpipe so that it can be propped in the "waste" position, then propped in the tank inlet; (2) moving the tank into position in the case of small containers; and (3) in the case of tanks with a small cover, uncovering it after the roof is clean.

Less simple methods are the diversion valve, the foul flush box, the tipping twin funnel.

A diversion valve inside the downpipe may normally be left in the waste position until rain has fallen to wash the roof. The valve is then changed by hand and the water diverted to storage.

A foul flush box or a sediment trap work on the same principle. After the container for foul flush fills up, water automatically overflows and enters the storage tank. A drain is provided at the bottom. A modification is a baffle tank which, by incorporating a baffle crossways and/or a vertical screen, inhibits the stirring action in the case of a torrential rainstorm.

The swing or tipping funnels arrangement is a hinged, twin funnel. The first flush of rain water falls into the first compartment causing an increase in weight and as this funnel fills, the second compartment is tilted into place above the downpipe and the remainder of the rainwater is directed into storage. While both this device and the baffle tank reduce undesirable flows of suspended sediments, this one also enables rejection of an initial flush of soluble pollutants.

Other techniques include trough pivoting and the use of a filter box.

It is expected that this small investment will provide a marked improvement in the quality of water stored in the tank. According to some sources,[5–7] there is in general more to be gained by devising an effective "foul flush" method than by investing in filters, which clog and contaminate quickly and their maintenance requirements are high.

DESIGN CONSIDERATIONS IN STORAGE

The bacteriological and chemical quality of the water stored in the tank will depend initially on the quality of the water put into the tank. The water in the tank must of course be protected from any further possibility of contamination.

Quality control of the water is easier if using small-capacity (roof catchment) reservoirs and above ground tanks. Construction of above ground reservoirs prevents inflow of groundwater and surface water. There is greater risk of contamination in underground tanks. They should be watertight, with no cracks developing, to eliminate possible entry of groundwater. They should extend about 200–300 mm above the ground's surface[8] since most cracks occur near the top. A watertight top (and manhole) prevents surface water entering the cistern.

Locating Storage Tanks

Storage systems should be located in such a manner as to prevent any possibility of pollution of their contents by sewage or surface water, a problem usually for underground storage.

Tanks should be on higher ground than the surrounding area for good drainage and than excreta disposal installations. The construction should be kept watertight, but it would be foolhardy if an underground cistern is located downhill from sewage-disposal installations.

Reservoirs should be separated from any point of sewage-disposal system by at least 15 m according to most sources.[8–10] Various figures are quoted for various installations: at least 6 m for cesspits,[11] 8 m for sewers or drains of any kind,[12] 10 m to 15 m for latrines,[13] 15 m and preferably 30 m for privy vaults and septic tanks and 23 m for cesspools and seepage fields.[12]

Storage should also not be located indoors in basements.

Construction Materials and Methods

Cement-based materials The pH value increases further from rain and roof after being kept in the tanks and is higher in new tanks than in old tanks. The increase in alkalinity of rainwater stored in cement tanks is believed to be the results of alkali which is leaked out of cement. The pH value of water stored in old tanks is within desirable levels. New storage containers can be "cured" by washing with a weak acid or vinegar. The high pH value tends to decrease as new rainfall, which is slightly acidic, enters storage.

Metals *Lead* should not be used in contact with rainwater though, in course of time, the risk is reduced.

It is unsafe to use *copper* for the storage of water unless heavily tinned.

Iron and *steel* cisterns should be well covered with pure asphaltum paint, or at greater cost lined with slate, procelain brick or tile. Any possible risk for a galvanised iron tank can readily be avoided by painting the inside of the tank with good asphaltum paint.

Brick or stone Brick or stone, especially for underground storage, must be low in permeability and laid with full Portland cement mortar joints and plaster coats to aid water proofing. However, it is impossible to obtain a permanently water tight structure.

Plastic-lined Plastic-lined rock-filled and butyl lined reservoirs are acceptable for storage of drinking water.

Asphalt or tar Asphalt or tar for water-proofing the interior of storage units is not recommended.

Screening and Covering

The provision of cover and screens aims at preventing the breeding of vectors of disease, intrusion of polluting matter and living organisms and algae production induced by sunlight. One of the important factors in tank maintenance is the quality of the tank cover and screening.

Screens The inlet and outlet openings, the overflow pipe, the drain pipe and any air vent of a tank should be effectively screened. A fine mesh screen strains inflow. The overflow is fitted with a fine wire mesh or a flap-valve; the screen should be non-corrosive having not less than 24 meshes to the inch.[12]

Cover Covering a storage tank is essential. The aim is reduction of seepage and evaporation losses and the principal target is to maintain a high quality of water and reduce the risks of pollution. A cover is likely to bring a greater improvement in the quality of water than a chlorinator on an open tank.

Algae require nutrients and sunlight to survive. An open reservoir provides the latter requirements, but the quality of organic matter (nutrients) in the water from a protected catchment would generally be much less than in a conventional scheme.

The tank should have a tight-fitting well-secured cover and the same applies for a manhole cover. The manhole should be provided with a 5 cm raised concrete lip and its cover should have overhanging edges giving a "shoe box" effect.[12] Manhole covers should be provided with locks.

Floating covers must cover the whole of the water surface and have no holes. Pollution is possible if the rain can flow off the cover into the reservoir.

Preventing Settled Particles

A storage system should be designed to prevent settled particles from being drawn off in normal use. This may be achieved by sloping the floor slightly upwards from the inlet to the outlet which are in opposite sides, the use of a sump in the floor that captures sediment, a downward sloping overflow pipe having a free fall discharge to the ground and the positioning of the outlet pipe at the correct height (5 cm above the bottom of the inside storage flow.[2] The inflows and outflows have to be far apart in order to guarantee renewal of water.

Cool Storage Conditions

In tropical climate the rain water should be kept as cool as possible. Underground tanks because of the insulation provided by the ground, clay containers because of their porosity, tanks shaded by trees and thickened or white painted roofs of storage provide cool storage conditions.

Other Requirements

- No connection should be made between cistern drains and waste, or sewer drains (lines).
- A drainage line is required. Any openings or cracks around the drain should be sealed to keep out sunlight.
- An overflow and/or air vent should be incorporated.
- If the tank is buried, a fence will be needed.
- Structural integrity of the tank and smooth interior surfaces are required.
- Water from other sources, for example water purchased from the private water purveyor, should not be mixed with the rainwater supply.

DESIGN CONSIDERATIONS IN DELIVERY

A drainage box or a soakway under the outlet tap and a drainage channel under the overflow pipe, the drain and the waste pipe of the "foul flush" device, contributes to hygienic disposal. The delivery (drainage) box should remain clean and dry. It is normally provided with a drainage pipe.

Plastic taps fitted into water jars help to prevent waste and are a more hygienic way of dispensing water.

Water should be pumped (manually-operated) from underground storage (if used) and potentially contaminating receptacles should not be introduced into the reservoir. Badly mounted and improperly designed pumps frequently admit contamination. A defect to be corrected is pumping equipment which allows leakage water to drain into the cistern. The pump suction should be located at some height, 20–50 cm (Ref. 14) above the reservoir floor in order to avoid the transport of sediment.

An inter-connection between the water pipes of the cistern supply and any other drinking water source, regardless of valves, should never exist.

As with all water which is transported into the home, however short the distance, there remains a risk to the user from recontamination in the household.

MAINTENANCE FOR WATER QUALITY

In addition to preventive measures in the construction of the system, regular inspection and maintenance is needed. The objectives of maintenance are to maintain water quality and to keep the steam working. Any rainwater harvesting system has catchment, channeling, storage and delivery components which must be given frequent attention.

Household systems, that is roof catchments, require a correspondingly smaller scale of organisation than community systems and a great responsibility for operation and maintenance rests with the individual user.

The whole system (catchments, gutters, tanks, pipes, screens, vents) should be cleaned and kept in good repair especially at the end of the dry season. Gutters and pipes, especially, must be cleaned often to prevent clogging and contamination.

A possibility is to use water from the first rain to clean roofs and flush the piping for the system.

Collection and Inflow Systems

It is an essential, but invariably quite simple operation to maintain and protect a clean catchment. There should be good accessibility for cleaning.

Roof, guttering and downpipe should be cleaned regularly. In Bermuda[11] roofs are commonly repainted every two or three years, following wire brushing and rinsing with a hypochlorite solution.

If a collection box for foul flush is used, it should be cleaned out after each heavy rain to remove any sediment or scum.

Storage Systems

The maintenance requirements of the tank itself will depend to a large extent on the effectiveness of the maintenance of the collection and inflow system.

If water testing is carried out, it should be performed initially at quarterly intervals and eventually at semi-annual to annual intervals.[15] The local health authorities could provide low-cost testing of the sanitary quality of each cistern supply. It would, however, be sensible to concentrate scarce resources on preventive measures.

The design of a storage tank should take into account the need for periodic and thorough cleaning, for example, provision of a drain at the bottom of the tank to empty it easily and a covered manhole.

Most impurities, such as dust are insoluble and if allowed to settle, precipitate to the floor of the tanks which then need periodic cleaning. Cleaning is to be carried out at the latest when the bad taste of water is noticed.[14] The storage tank should be cleaned out, the sediment collected at the bottom disposed of, and (ideally) disinfected, *annually* after a dry period when the reservoir will be empty or nearly empty. Other suggestions for the frequency of sludge removal are once every two years,[3] and for water-storage wells 3–5 years.[16] The Bermuda regulations[11] provide for cleaning at least once every six years or where water in a tank appears to be polluted or in danger of pollution.

The annual maintenance of a ferrocement tank includes removing deposits from bottom and scrubbing the bottom and interior walls with clean water and also disinfection of the tank.

Decreasing the pH economically can be done by washing the storages more frequently.[17]

Pipes and screens should be cleaned. The inlet strainers should be kept clear. The screen of the overflow drain should be removed periodically and both screen and pipe cleaned.

There are recorded cases, where cleaning of storage tanks has proved to be unnecessary.[14] Apparently, micro-biological processes may provide for a self-cleaning effect. The silt layer—which was examined—seemed to perform this.

Various methods of disinfecting a tank have been suggested: Scrubbing concrete cisterns with bleach to disinfect (and the other cleaning operations), once every two or three years.[18] Cleaning solutions for yearly scrubbing of inside of concrete cistern walls are three parts vinegar to one part water; 1 kg baking soda dissolved in 8 l of water.[19] A newly built or repaired cistern should always be disinfected with a 50 parts per million chlorine solution. The cistern walls (and filter) should be thoroughly washed with this strong solution and then rinsed.[20] The Bermuda practice consists of washing with hypochlorite solution, applying a cement wash and waiting for several days before refilling to assure that the pH is not excessively raised by leaching from the cement wash.[11] Before the beginning of cleaning and preparations of chlorine, the CO_2, a by-product of biological processes has to escape.[14] To disinfect a reservoir of ferrocement construction, an amount of 10 g/m^3 of water of free chlorine is added and mixed thoroughly with the water in the reservoir.[21]

If a filter is employed, it requires periodic and thorough cleaning.

EFFECTIVENESS AND REALISATION OF MEASURES

The Bermuda Department of Health is satisfied that the quality of water from rain water cistern supplies is adequate, if these systems are properly installed and maintained.[11]

In Belau, W. Caroline Islands, the water quality is quite variable which probably reflects the differences in design and maintenance of the systems.[22] This is important because it reflects the fact that catchment water is only as good as the design, operation and maintenance permit. None of the domestic rainwater catchment systems samples utilised water treatment in the system in Belau.

The measures are not at all sophisticated. A cost-benefit analysis of these design features would indicate to what extent water treatment can be made redundant. Water quality would be protected by the enforcement of legislation for design measures and achievement of proper maintenance by education and motivation.

In sociological terms, the individual owner becomes responsible for the quality of his water and this undoubtedly is a factor in the protection from contamination. According to a study[23] in Belau, W. Caroline Islands, 90 percent of the surveyed households indicated that they took precautions for the safekeeping of their drinking water for either the maintenance of the stored vessels or the water itself while the remaining ten percent stated that no precautions were necessary for rain water.

WATER TREATMENT?

Some treatment may be needed in rain catchments.

Water treatment methods may include sedimentation (in storage), filtration, disinfection, coagulation or the use of indigenous plants and natural products. These methods may be used singly or in combination.

The sedimentation process in storage is inherent to the system. The settling of particles from the stored water, of course, will be more effective as the water is kept longer in the storage tank.

Filtration techniques that may be employed are: household filters; pre-filtration, that is between catchment and storage; a filtering chamber as part of the storage tank which is either pre-filtration or filtration during the withdrawal of water from storage; typical filtration techniques like Venetian, Siphon and German cisterns; a continuous slow sand filter between the storage reservoir and a small clear water reservoir which is used for consumption for one or two days; and for ground catchments (using storage tanks of polythene layers or sand-cement polythene bags) a filter bed may be incorporated before storage and before withdrawal of water.

Disinfection techniques that may be used in rainwater harvesting schemes: pot chlorination; disinfectant tablets; drip feed chlorinators; application of dosage of chlorine or iodine; and boiling which is not a viable alternative due to the scarcity and expense of fuel.

Usually filtration or chemical disinfection or both are used for water treatment in rainwater harvesting schemes. Irrespective of the requirements in each particular case, rainwater harvesting does not require complicated purification processes. Any decision concerning treatment of a water supply should be based on both the water quality expected from the scheme and the consequences of not providing treatment.

According to some references[1,17,24] the need for water treatment may not even arise with relatively simple measures to prevent faecal material for animals or humans from entering the supply. Water harvested through adequate catchment provisions and stored under safe conditions often does not require any treatment to be suitable for domestic water supply, simple disinfection can be used as a safety precaution[16] and exceptionally, when pollution has occurred, filtration and disinfection.[25]

A preferred "appropriate" design approach is (a) to choose a source of water which provides high quality water, and then (b) to collect the water and protect it from pollution so that treatment is not necessary. Treatment should only be considered if it can be afforded and reliably operated. Requirement (a) is satisfied by rainwater. Requirement (b) which is concerned with the prevention of contaminant introduction, is the primary water quality problem in rainwater harvesting.

If by diligent work the engineer can eliminate a pump, an engine, another piece of equipment, or a treatment process, he is thereby removing a possible obstacle to efficient operation. A system requiring no treatment and no pumping is ideal from the point of view of maintenance which is reduced to an absolute minimum.

Thus, the weight falls on proper design and maintenance provisions. We are trying to ensure the elimination of sources of contamination as much as possible.

In rural areas of developing countries rainwater is fairly clean and may be used directly when pollution of the catchment areas can be prevented. In properly designed, constructed and maintained water harvesting systems, there is no reason to expect any poisonous substances or disease-producing organisms to enter the water.

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