Rooftop Rainwater Harvesting for Water Supply and Flood Mitigation in Urban Areas

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1. INTRODUCTION

Global population has more than doubled since 1950 and reached 6 billion in 1999. The most recent population forecasts from the UN indicate that, under a medium-fertility scenario, global population is likely to peak at about 8.9 billion in 2050. In parallel with these changes, there have been profound demographic shifts as people continue to migrate from rural to urban areas in search of work and new opportunities. Since 1950, the number of people living in urban areas has jumped from 750 million to more than 2.5 billion people. Currently, some 61 million people are added to cities each year through rural to urban migration, natural increase within cities, and the transformation of villages into urban areas. By 2050, the total urban population is projected to double to more than five billion, and 90 per cent of this increase is expected to occur in developing countries.

In urban areas, supplying adequate water to meet ever-increasing population water demand and to ensure equity access to water is the most urgent and significant challenges faced by most decision-makers. There are two solutions to satisfy sustainable freshwater management: (1) finding alternative or additional water resources using conventional centralized approaches, and (2) better utilizing the limited amount of water resources available in a more efficient way. Among the various alternative technologies to augment freshwater resources, rainwater harvesting and utilization is a decentralized environmentally sound solution, which can avoid many environmental problems, often created by using centralized, conventional, large-scale project approaches.

Urbanization has also proven to gradually alter urban watershed hydrology by both increasing the quantity and peak of storm water runoff to receiving waters. The results are direct and cumulative adverse impacts on the physical, chemical, and biological integrated of aquatic ecosystems. Development impacts are typically prevented and mitigated by structural and non-structural methods, such as: rainwater harvesting, wetland, detention a/o retention ponds, and infiltration facilities etc. Rainwater harvesting system is managed in small, cost-effective features located at each lot rather than being conveyed and managed in large, costly pond facilities located at the bottom of drainage areas. The source control concept is quite different from conventional end-of-pipe treatment.

Rainwater harvesting systems decrease the demand in the urban areas. They also reduce the amount of runoff that floods and pollutes our oceans, rivers and lakes. By lessening the amount of runoff after a storm, we are actually recharging our groundwater by giving the earth an opportunity to absorb the water that has fallen. This study investigates the extent to which storage volume of rainwater harvesting systems increases water supply and reduces the amount of on-site rainwater volume and peak at developed site in urban areas.

2. FEASIBILITY OF RAINWATER HARVESTING IN URBAN ENVIRONMENTS

Rainwater harvesting has traditionally been viewed as a potential water supply source in remote rural settlements where the provision of water through piped networks is uneconomic or other technically feasible. However, rainwater harvesting in urban settlements has gained momentum due to the recognition that usage of water where it falls has both economic and ecological advantages.

The use of rainwater harvesting system in Germany and Japan, is increasing widespread, with several firms now offering compact off-the-shelf rainwater use systems. One million people in Australia also rely on rainwater as one source of their water supply. The government of South Australia encourages rainwater collection by providing information on cistern sizing, materials and maintenance to the general public and interested parties. After small experiment in various other cities in the Netherlands, Ede, in the east of the country, is the first municipality which will construct a new area of 3500 houses with a dual water system. In the next ten years, the houses will get one pipe for their drinking water, while a separate pipe filled with rainwater will be constructed for flushing the toilet, doing the laundry and watering the gardens. The local energy company will construct the dual net, which is expected to reduce the use of expensive drinking water by 50%. In the higher part of the municipal area, rainwater will be collected per house or block of houses through water containers, sand reservoirs and underground reservoirs. In low-lying areas, rainwater will be collected in ponds.

Scientists and city planners worldwide are beginning to realize how vulnerable the central infrastructure of modern cities to earthquakes and nature hazards. At the top of their list, and one of the most vulnerable, is municipal water supply. For this reason, permanent rainwater reserves are essential in helping a city survive in earthquake and nature hazards.

3. ASSESSMENT OF RAINWATER AS A POTENTIAL WATER SUPPLY SOURCE

Rainwater supply systems in the urban areas need not only target individual households but also can have more resounding success if employed in:

1. Blocks of flats;
2. Offices and commercial complexes;
3. Hotels;
4. Prisons;
5. Industrial complexes and power plants;
6. Large Institutions like school campus, parks for example.

Three main parameters in the design of rain water tank are the contribution area, the rain water consumption rate and the volume of the tank. The most important criterion for the evaluation of the evaluation of the design is the supply reliability.

4. DEVELOPMENT OF A REFERENCE MAP OR COMPUTER TOOLS FOR SIZING OF STORAGE VOLUME FOR RAINWATER HVESTING SYSTEMS

For Rainwater harvesting systems, it is sometimes impossible or impractical when rainfall data or a computation model is not available. A reference map or computer tools is required to overcome this issue.

4.1 Development of Storage Sizing Reference Map

Rainfall stations that have been recording rainfall data for over 50 years throughout the country were selected to calculate the storage capacity under specific roof areas and water supply reliability. Rational water demand is selected. Therefore, a series of storage sizing reference maps are generated for different roof areas and water supply reliability. The map reveals that for a given set of design criteria, storage capacity can be estimated. These sizing maps are a quick reference for designing rainwater harvesting systems.

4.2 Rainfall Zones and Regional Storage Sizing Computer Model

There are several computer-based programs for calculating tank size quite accurately. But when the rainfall shows large fluctuations spacious then a design based on any single statistical indicator can be misleading. Therefore, computer model takes account the spacious fluctuations in the rainfall should be developed. This model is determined in the following manner. Rainfall stations are located on the map of the region to which rainfall normals are assigned. Subsequently, areas of similar rainfall amounts and distribution patterns are identified and boundaries delineated through the use of iso-lines. Each zone is given a numeric designation to refer to a specific storage sizing formula.

Rainfall records are available on a monthly and a daily basis, although considerably more effort is required to process daily data for the purpose of analyzing collection system performance. A second device to compensate for an apparent loss of efficiency due to spillage when storage before spillage occurs, the Yield Before Spillage (YBS) model. This modifies the Yield After Spillage (YAS) model.

Having selected the model, system performance can be evaluated for each time interval of the record by water supply reliability. To facilitate presentation of performance characteristics as a function of demand and storage it is convenient to express demand and storage in non-dimensional form. Demand and storage divided by the supply of rainfall is a non-dimensional demand parameter which lies in the range from zero to 100%.

4.3 Types of Water Storage Structure and Their Selection

Rainwater storage reservoirs can be subdivided into three distinct categories:

1. surface(above-ground tanks) which are common in the case of roof catchment systems, where the catchment surface is elevated e.g. for roof catchments.
2. sub-surface or underground tanks which are normally associated with purpose-built ground catchment systems.
3. dams with reservoirs for larger catchment systems using natural catchment, eg.

Rock catchment, earth dams and sub-surface or sand dams in sand rivers.

5. RAINWATER HARVESTING FOR URBAN FLOOD CONTROL

Normally most of the rainwater from impervious areas in the urban areas is passed through sewer systems. Therefore, the use of rainwater in households can be a good option to tackle this problem. The rapidly drained rainwater leads to problems in the sewer systems and watercourses which cannot cope with too high peak discharges. If the storage in the rainwater tanks can be used to flatten the rainwater runoff, rainwater tanks can have additional benefit. However, much more storage in rainwater tanks must be provided to obtain the same overflow frequency than when downstream storage is used, because the storage in rainwater tanks is less frequency available. When all the economical, social and environmental aspects are considered, rainwater tanks can certainly be promoted as a good solution.

6. STORAGE VOLUME DESIGN

In order to design to maximum water savings and rainwater management benefits, the required capacity will depend on water use, rainfall and roof area. Design of rainwater tank should make provision for:

1. A minimum availability volume (to ensure that water supply is always available or emergency water use).
2. A rainwater storage volume (to regular water supply).
3. A space for additional rainwater management.

7. HYDROLOGICAL IMPACT OF RAINWATER HARVESTING SYSTEMS

Rainwater storage allows for a reduction in rainwater volume and the peak runoff rate. The fundamental affects for implementing rainwater harvesting systems on site hydrology focus on:

1. Change curve number (CN): a factor that accounts for the effects of soils and land cover on the amount runoff generated.
2. Change time of concentration: the time it takes runoff to travel through the watershed.

3. Change design storm: the outflow of the rainwater tank can be converted to equivalent rainfall. The original design storm is corrected with this reduction correction.

8. HYDROLOGIC ANALYSIS OF DISTRIBUTED RAINWATER HARVESTING SYSTEMS

8.1 Theory and Computational Procedures

The hydrologic analysis of distributed small-scale rainwater harvesting systems is a sequential decision making process that can be illustrated by the flow chart in Fig. 1. The procedures for each step are given in the following sections. Determination of rainwater storage volume to maintain the existing volume and peak runoff rates to satisfy rainwater management requirements will be investigated and discussed in the following sections.

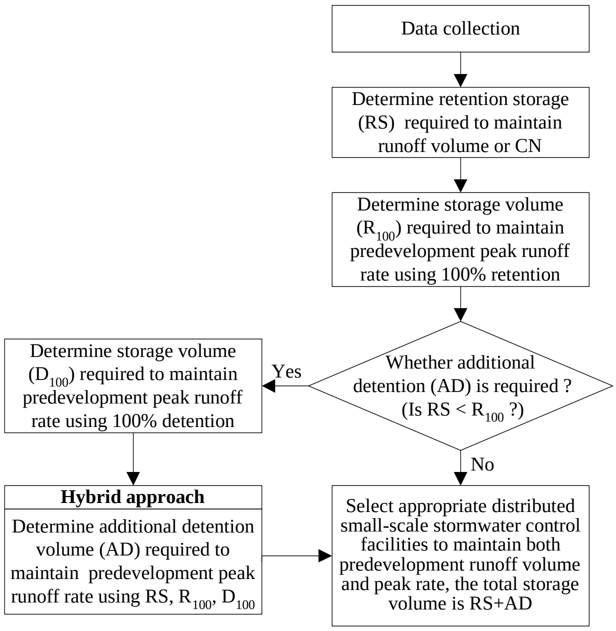

Fig. 1 Planning procedure of small-scale distributed rainwater harvesting control systems

The basic information used to develop the distributed small-scale rainwater harvesting systems management plan and used to determine the runoff curve number and time of concentration for the pre- and post-development condition is the same as that described in the TR-55.

8.2 Determine Storage Volume Required to Maintain Runoff Volume

Rainwater storage volume is required to control the increase in runoff volume if runoff volume reduction cannot reach the acceptable level. The post-development runoff volume generated as a result of the post-development custom-made CN is compared to the pre-development runoff volume to determine the volume required.

8.3 Determine Storage Volume Required to Maintain Peak Runoff Rate

Rainwater harvesting systems retains a permanent pool. The storage volume provided is used to control the runoff peaks caused by the specified designed storm events. The designed capacity of rainwater storage volume generally accumulates until inflow equals to pre-development peak at recession of inflow hydrograph. Before inflow reaches the pre-development peak flow, no outflow passes through the storage tank. Hence, the volume required to maintain the peak runoff rate using rainwater harvesting systems is greater than the requirement for detention ponds.

If storage volume required maintaining pre-development peak runoff rate using rainwater harvesting systems is less than that in the last step, no additional detention storage is needed; otherwise, additional detention storage is required.

8.4 Determine Storage Volume Required to Maintain Peak Runoff Rate Using 100% Detention

During a given design storm, to suppress peak flow to a given degree requires a certain definite amount of storage. Derivation of the required detention volume is based on the basic storage equation. Storage is accumulates as long as inflow is greater than outflow. It stops accumulating when inflow falls below outflow. The maximum storage is the required storage volume of the detention basin. This is represented in the hydrograph by the area between the high inflow and low outflow curves. By this method, inflow, outflow, and detention storage volume can be computed for selected increments of time and accumulated over the duration of the storm event.

8.5 Use Hybrid Facility Design (Required for Additional Detention Storage)

When the percentage of site area for peak control exceeds that for volume control as determined in step 3, a hybrid approach that is defined as the combination of retention and detention practices must be used.

9. ILLUSTRATED EXAMPLES

To demonstrate the application, a user-friendly computer-based model for estimating storage volume based on design criteria and a series of design charts are developed in this research and be used in the illustrated examples which include three cases:

1. water supply only;
2. storm water runoff control only;
3. both water supply and storm water runoff control.

10. ECONOMIC BENEFITS INCURRED BY INTEGRATED SYSTEMS

When such relative cheap rainwater harvesting systems are established and integrated with existing water supply and flood mitigation systems, it will have a considerable impact on both the rising demands and savings in deferred capital costs for both water supply and flood control. They can replace the proposed new conventional projects. Consequently, these projects can be postponed which means capital invested can be delayed leading considerable savings for the water authorities.

In general, rainwater harvesting systems can affect facilities by:

1. Eliminating the need for facilities.
2. Delaying the year in which it is constructed.
3. Reducing the size of the facilities.

11. DISCUSSIONS AND CONCLUSIONS

With urban development relentlessly expanding and the emergency of megacities, particularly in developing countries, it is strongly recommended that smaller rainwater harvesting systems be implemented in all possible sites and these schemes should be designed multi-objectively and integrated with existing conventional schemes and operated optimally. Rainwater harvesting systems that is an alternative method for rainwater control employs small scale and distributed management practices to achieve desired peak runoff rate and runoff volume. Also, a wide variety of upstream and downstream controls for managing urban flood are available. The economic performance of this control can be evaluated by estimating the benefits of the outputs and the costs of the inputs. While it is possible to find optimal solutions for complex blends of on-site and off-site controls, it is essential to recognize that the transaction costs of deciding how to pay for such complex systems may offset the gain in economic efficiency.

12. REFERENCES

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13. Presentation of Author

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