CISTERN FOR DOMESTIC WATER USE

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Cisterns are often an important source of water in rural areas. Information for their design has not been available. This paper presents preliminary design considerations and information on the variability of rainfall catch for a simple gable roof surface at Arkell, Ontario. About 71% of the rainfall events were associated with winds blowing from a southerly direction and represented 76% of the total runoff. The southeasterly facing roof area recovered 72% of the precipitation as roof drainage, while the northwesterly facing roof only recovered 45%. Runoff coefficients are presented for each month for the total roof area and for each roof surface.

INTRODUCTION

A cistern is an artificial reservoir, often located in a basement or underground, for storing rainwater collected from runoff from roofs or paved catchment areas.

Cisterns have been used to store rainwater from ancient times. For example, the city of Venice used 177 public and 1,900 private cisterns as the principal source of water well into the 16th Century (Anonymous 1860). Yet, for this history of use, an intensive library search has yielded little information on cistern design.

Roof drainage stored in cisterns has been a principal source of water in rural Ontario for many years. A survey of water sources (Farm Economics Branch 1966) carried out a decade ago identified the usage of cisterns on farms (Table I).

Rainwater is a supplementary source of water in areas devoid of satisfactory ground water and surface water supplies. In some communities where the ground water is high in total dissolved solids, roof drainage is used principally for household work and general washing purposes because of its softness. Domestic use exceeds livestock use (Table I) and is probably a function of the volume of useful water in storage. That is, livestock use a greater volume of water and the cistern would not be a dependable source. Some areas depend on cisterns extensively, such as Haldimand County which reported 71% of households using cisterns as a source of water.

The objective of the experiment was to develop a ratio of the yield of precipitation collected in a cistern from a roof area to the total precipitation falling on the roof area on a monthly and seasonal basis and to determine the effect of roof orientation and wind direction on these ratios. Once such ratios are determined it is a simple procedure to combine them with a precipitation probability for a location to determine a safe yield for a specific roof area.

The site and apparatus used for the experiment are described below.

DESIGN CONSIDERATIONS

For individual homes, rainwater running off the roof is led through gutters and downspouts to the cistern situated in the basement or in the ground. The cistern storage converts the intermittent rainfall into a continuous supply.

TABLE I USE OF CISTERNS ON FARMS IN ONTARIO, 1965

Region of Ontario	Percent of farms reporting	
	For livestock use	For domestic use
Northern	2.4	8.5
Eastern	5.0	30.9
Central	9.4	34.4
Western	6.1	25.1
Southern	4.7	24.7
Ontario	5.7	26.3

There are six factors to be considered in the design of a cistern, i.e.

1. Amount of water required for use
2. Amount and distribution of rainfall
3. Characteristics of the collection surface
4. Water treatment for quality
5. Location of the cistern
6. Construction details

This paper will not include a discussion of the construction, location, and water treatment design considerations.

Water Required

The amount of cistern water required will depend upon the number of uses and users for the water. In the home, soft cistern water is generally used for hot and cold water to the bathroom and laundry. Data on average daily water requirements for several uses are available (Hore 1973). When water is in short supply, there is a tendency to be sparing of it. This is particularly true of cistern water.

The total daily water requirement is estimated by adding the water requirements for each during the day.

Amount and Distribution of Rainfall

Precipitation in Ontario is ample for most uses and, on the average, is remarkably evenly distributed throughout the year (Brown et al. 1968). The mean annual rainfall is approximately 720 mm, or 60 mm/per mo. This is adequate if sufficient collection area and storage are provided. Previously, winter precipitation had not been included for the design of cisterns as it was presumed that the snow tended to blow or slide off the roof.

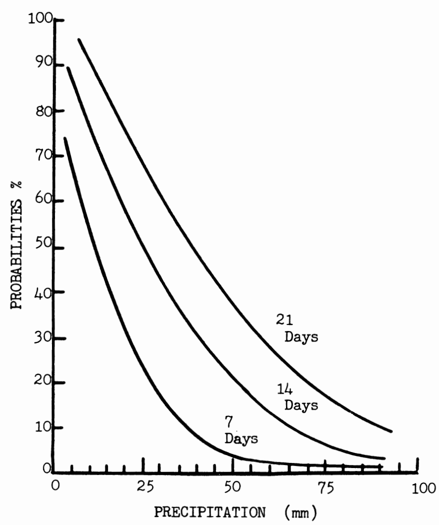

Figure 1. Precipitation probabilities for June to October (based on 30-yr record for Guelph, Ontario).

In Ontario, the prevailing winds are westerly, that is blowing from the west, northwest or southwest over 50% of the time, southwest predominating. Wind direction and wind speed have a great effect on the depth of precipitation falling on a particular roof surface.

The probability was calculated (Fig. 1) of receiving selected amounts of rainfall at Guelph for periods of 1 wk, 2 wk and 3 wk,

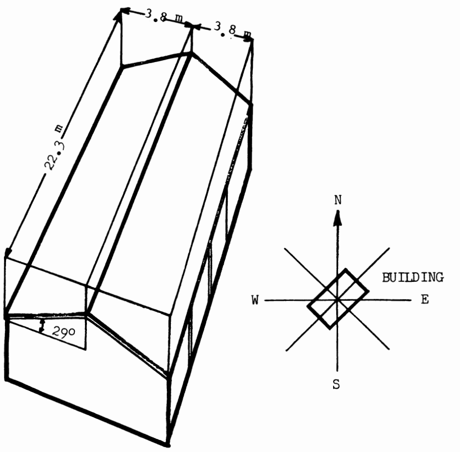

Figure 2. Sketch of roof area and building orientation.

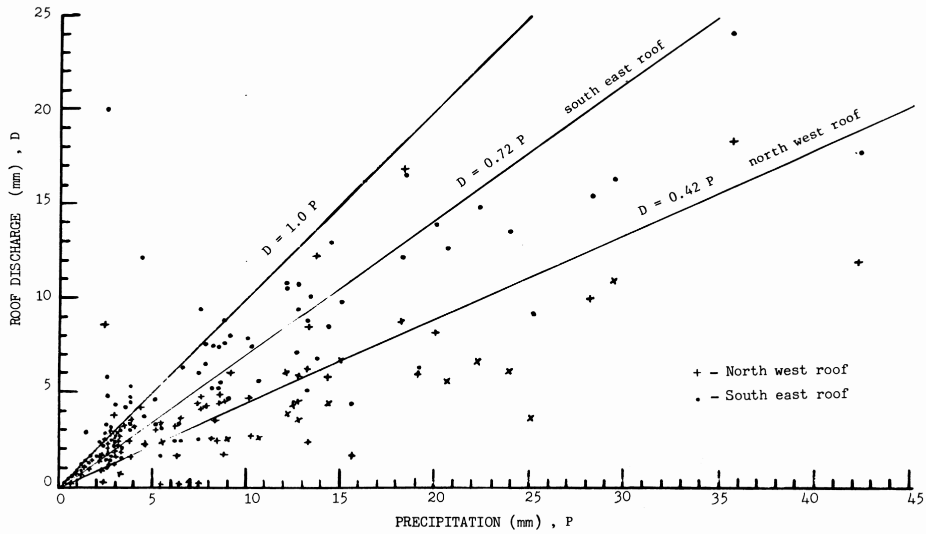

Figure 3. Relationship of roof discharge to precipitation for each roof surface.

for the months June to September, based on 30 yr of daily precipitation records. For example, the probability of receiving 25 mm of precipitation in 1 wk is 24%, it is 50% for 2 wk and 70% for 3 wk. These probabilities, when combined with the daily water use, can be used to calculate the required storage volume of a cistern.

Collection Surface

The gross yield of rainwater is proportional to the receiving area and the depth of precipitation. Some rain is blown off a roof surface by wind, evaporated, or lost through splash and wetting of the collection area and conduits, or goes to fill depressions on improperly pitched roofs. Also, the first flush of water contains most of the dust and other undesirable washings from the collection surface and may have to be wasted.

The Agricultural Engineering Research Division, U.S. Dep. Agric. (1971) infers that the entire rainfall can be collected. The Joint Committee on Rural Sanitation (1962) states that a conservative design should be based on the assumption that about three-quarters of the rainfall could be collected but suggested a design value of two-thirds of the rainfall. It is inferred that losses from sheet metal roofs are usually small but asphalt surfaces may absorb 10% and shingled and tar and gravel surfaces 15% of the rainfall.

The Canadian Plumbing Code (National Research Council of Canada 1970) gives information useful for designing the size of gutters and downspouts but does not include information on the design of cisterns.

EXPERIMENT

During 1974-75, drainage from the metal gable roof of the Arkell Waste Management Research Building was collected and measured. The building is located at 80° 12' longitude and 43° 31' latitude. The ridge line of the bulding is oriented N 47° E.

The dimensions of the collection surface are shown (Fig. 2). The horizontal projection of the roof area is 171.6 m² (22.3 X 7.7 m). The pitch of the roof is 29° and the actual area of one roof surface is 98.1 m². Since it is customary to base cistern recommendations on the horizontal projection of the roof area and because each roof surface was treated independently, the actual area of each collection surface was 85.8 m².

Precipitation

Precipitation was measured at the site. A recording raingauge was operated continuously from 12 June 1974 to 13 August 1975 and a M.S.C. standard raingauge was operated during the non-freezing weather (26 June — 25 Nov. 1974 and 19 Apr. — 13 Aug. 1975). These were located 30 m north of the building.

Precipitation was also measured in a M.S.C. standard raingauge at the adjacent waste management station on a 5-day basis. Precipitation records for Guelph and Elora were also used to check on-site measurements.

Wind records for Elora (25 km from the site) were used to estimate the wind speed and direction at the site during periods of precipitation, on the assumption that the wind would be similar.

TABLE II EFFECTS OF WIND DIRECTION ON PROPORTION OF RAINFALL RECOVERED

Wind direction	No. of events	Precipitation (liters)	Proportion of precipitation	
			Northwest roof	Southeast roof
E	14	18,875	0.71	0.42
SE	20	14,979	0.78	0.46
S	14	15,261	0.82	0.43
SW	21	11,292	0.66	0.49
W	11	2,805	0.65	0.54
NW	5	8,933	0.51	0.28
N	4	8,535	0.78	0.88
NE	8	3,114	0.78	0.47

One half of the horizontal projection of the roof area would yield 2,145 liters of water from 25 mm of precipitation if there were no losses.

Measurement of Yield

Gutters were installed at each eave and were sloped to the southwesterly end of the building where individual downspouts led the water to two measuring barrels.

Each barrel had baffles to reduce turbulence and a V-notch weir with water level recorder to measure flow. The weirs and barrels were calibrated before installation.

The water level recorders were operated with 12-h charts. These charts were analyzed by the horizontal strip method (Holton et al. 1962) to obtain increments of volume which were summed to obtain the total volume of discharge for the storm event. The volume was converted to an equivalent average depth on the horizontal projection of the half-roof area and was compared with the measured depth of rainfall from the raingauges.

RESULTS

The relationship for each event with respect to the resulting roof drainage from

TABLE III PRECIPITATION RECOVERED FROM ROOF AREAS

(1) Month	(2) Precipitation (liters) (P)	(3) Precipitation recovered from roof area — Northwest roof (liters) (Dm)	(4) (Dm/P)	(5) Southeast roof (liters) (Ds)	(6) (Ds/P)	(7) Combined (Dm+Ds)/P
June 1974	10,956	3,997	0.36	8,042	0.73	0.55
Jul.	4,258	1,566	0.37	2,687	0.63	0.50
Aug.	5,055	2,054	0.40	3,301	0.65	0.53
Sept.	6,085	3,547	0.58	4,142	0.68	0.63
Oct.	3,644	2,426	0.67	2,929	0.81	0.74
Nov.	8,579	5,075	0.59	6,882	0.80	0.70
Dec.	3,311	831	0.25	2,914	0.88	0.57
Jan. 1975	5,558	3,180	0.57	4,944	0.89	0.73
Feb.	3,654	2,523	0.69	3,905	1.07	0.88
Mar.	3,605	2,025	0.56	4,548	1.26	0.91
Apr.	4,364	2,165	0.50	2,880	0.66	0.58
May	5,118	2,136	0.42	3,282	0.65	0.54
Jun.	9,792	3,470	0.35	4,852	0.50	0.43
Jul.	5,746	1,286	0.22	2,789	0.49	0.36
Aug.	4,069	1,696	0.44	2,286	0.61	0.53
Total period	83,794	37,978	0.45	60,383	0.72	0.59

TABLE IV FREQUENCY OF DISCHARGE RATES FROM SOUTHEAST ROOF SURFACE

Discharge (liters/m)	Occurrence (%)	Discharge (liters/m)	Occurrence (%)
0 - 0.4	30	15.5 - 20.0	01
0.4 - 1.8	29	20.0 - 25.0	01
1.8 - 4.1	20	25.0 - 30.9	006
4.1 - 5.9	08	30.9 - 38.2	005
5.9 - 8.2	04	38.2 - 45.5	004
8.2 - 11.4	03	45.5 - 53.6	003
11.4 - 15.5	02	53.6 - 61.8	002

each roof surface is shown (Fig. 3). The points above the 1:1, or 100% line are attributed to discharge from snow melt and snow drifting. Also, under certain conditions of rainfall and wind, the roof appears to have collected more water than the raingauges indicated. This problem has not been resolved; however, the points are associated with small volumes of drainage so do not greatly affect the design data.

The proportion of the measured precipitation that was recorded as drainage from rain events from selected directions is shown (Table II). It is noted that 71% of the events were from the SW-S-SE-E directions and produced 76% of the total drainage. The direction of the wind, with reference to the orientation of the collection surface, at the time of the event had an effect on the proportion of the rainfall that was collected.

The proportion of the precipitation collected as roof drainage from each half-roof area by month is shown (Table III). It is noted that the mean annual drainage from the southeasterly facing roof was 0.72 of the precipitation and the northwesterly facing half roof was 0.45 of the precipitation. These proportions are noted (Fig. 3). The effect of snow melt and snow drifting can be seen for February and March. The proportion of precipitation collected tended to increase for October to March, when compared with summer storms, probably due to low-intensity rains. The proportion of the precipitaion collected for the October to March period was 0.57 for the northwesterly facing roof and 0.92 for the southeasterly facing roof.

An analysis of discharge rates was made for the southeasterly roof surface (Table IV). From these data, it is noted that low rates of discharge predominate. This information may be of interest for design of gutters; it is of little significance in the design of cisterns other than for overflow pipes.

Based on this experiment, the following roof discharge coefficients are recommended for the design of cisterns:

Period	Northwest roof surface	Southeast roof surface	Total roof area
Dec. - Mar.	0.55	0.90	0.75
Apr. - Jul.	0.40	0.65	0.66
Aug. - Nov.	0.60	0.75	0.70

CONCLUSIONS

The roof discharge coefficients determined in this experiment vary from the 0.66 recommended by the Joint Committee on Rural Sanitation (1962) depending upon the season. These roof drainage coefficients are recommended for the design of cisterns until additional data are available.

Additional investigations in this area are recommended, particularly for buildings with other orientations, roof slopes and roof heights. It is essential that wind speed and direction be measured at the site during periods of precipitation.

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