Figure 1. The schematic of the Potable Rain Maker prototype (Laos)

Potable Rain

Drinking Harvested Rainwater

Overview

Clean rainwater is drinkable, cheap, socially acceptable, and has been harvested for centuries. Inappropriate rain collection and storage may contaminate the water and make it unsafe to drink. The *Potable Rain Maker* is a simple method being developed in an attempt to limit such contamination.

The rainwater contamination is most likely to occur during the initial period of the rainfall event, colloquially called the 'first flush'. Since the rain is usually collected from the roofs, the first flush carries the debris, dust, and microorganisms accumulated on the roof surfaces[1]. Before the rain hits the roof, the fist flush can also scavenge the particles, microorganisms and soluble gases from the air.

It is likely that with the first flush discarded, the rainwater collected afterwards will be much cleaner, physically, chemically, and microbiologically, and may become potable again.

The *Potable Rain Maker* uses simple, locally-made device which, if properly designed and used, will automatically separate sufficient amount of the first flush and allow cleaner rainwater to be collected. If coupled with the proper water storage and handling, the system *may* provide a viable source of potable water for the households, especially in places where other sources of drinking water are hard to come by.

Design

Figure 1 shows the main design features of the *Potable Rain Maker* prototype. The prototype of the *Potable Rain Maker* consists of a stand-pipe cleaner made of bamboo, which intercepts the first flush, allows the clean(er) water to overflow to the locally-made concrete collection/storage tank, and drains the wastewater automatically before the next rain event. The system has no moving parts. Properly designed for the roof footprint and the local rainfall characteristics, it will discard sufficient volume of the first flush. It will also bypass the rain events with intensities insufficient for washing the roof and producing clean water.

The main system features are:

- a locally-made stand pipe cleaner (e.g. made of bamboo, PVC) designed to discard sufficient first-flush volume. The stand-pipe also allows for some fine sediment settling while the rain is being collected. It is fitted with a self-cleaning inlet screen to skim larger debris washed off the roof. The stand-pipe has a properly sized, self-cleaning drain hole which allows for the system's automation.

- a locally-made rainwater storage tank (e.g. concrete jar, cistern, used drum) with the cover/filter, raised outlet and a cleaning drain. The cover, made for the prototype of an old umbrella fitted with triple-folded old mosquito net, prevents the debris to enter the tank, limits evaporative loses, diffuses the momentum of incoming water (thus reducing the potential for the re-suspension of the settled sediment), restricts light penetration to limits algal growth, and prevents mosquito breeding. The collection tank promotes sediment settling and water aging/microorganism die-off, possibly improving the water quality further.

[1] In rare cases, collected rain water can also be contaminated with chemicals such as salts of heavy metals, (e.g. zinc or lead), leached from the roof materials. This is more likely to occur with rainwater of low pH (i.e. in the industrial areas with high concentration of sulfur and nitrogen oxides in the air) and is unlikely an issue in Laos.

Numerical Model

A numerical model of the rainwater collection/purification system has been developed to evaluate the viability of the system and to compute its design parameters. The model has been 'sanity-checked', and preliminarily validated and calibrated in a pilot field study in rural Laos. The model appears to work as intended, though more thorough field verification is needed. The water quality sub-model can be easily incorporated in the main hydraulic model, but there is insufficient data do so as yet.

The model uses an unsteady-state mass-balance that can account for the rainfall input rate, self-cleaning waste-water drain rate, the clean(er) water output rate and the standpipe storage at any time. It calculates the water height as a function of time and the consequent wastewater and clean water output rates and accumulated volumes. It uses the stand-pipe diameter, stand-pipe height, drain-hole diameter, draining discharge coefficient, rainfall event intensity and duration function, the roof footprint area, and the rain collection efficiency, as inputs.

Conclusions to date

Thanks to the model and the preliminary field tests of the prototype the following can be said:

- *Potable Rain Maker* can be constructed easily, cheaply and locally;

- The model, verified in the field, allows for designing and evaluating the *Potable Rain Maker*;

- *Potable Rain Maker* can be hydraulically adapted to the variety of design/roof/storage/rainfall combinations;

- *Potable Rain Maker*, if developed further, stands a chance of producing and storing potable rainwater;

- In the pilot study location (Laos), the *Potable Rain Maker* prototype was met with interest and understanding, giving hopes for its wider acceptability in the future and in other locations.

Future Work

There are several components of the system that need to be evaluated before considering it for a wider use.

- **design and construction materials**: to build the prototype, the pilot study used the easiest *ad hoc* materials locally available: bamboo, used door screen, used mosquito net, an old umbrella fabric, a rope, and a set of drill bits. Other options (e.g. PVC pipe, rattan-woven filters and cover, sand filter, different storage containers) have not been evaluated, but may be preferable. Cost analysis is also required.

- **rainfall distribution**: the *Potable Rain Maker* will only work when and where there is sufficient rain to be collected. Hydrologic data, with sufficient spatial and temporal resolution that describe the local conditions, are required to design the system. In many locales such data are unlikely to be available, but simple methods exist to extrapolate low-resolution records or records from other locations with sufficient accuracy. These methods and the base data, once reviewed, will be part of the design manual (please see below).

- **model**: although already calibrated and validated, the model needs to be verified and tested in more diverse field conditions, especially during the rainy season (May to September in Laos). The model should be extended to include parameters such as roof incline and roof building materials to evaluate minimum rain volumes and intensities that effectively result in cleaner water being collected. Water quality sub-model may also be added to the existing hydraulic model, given sufficient filed evaluation data.

- **washing requirements**: to date there is little data that establish the reasonable volumes and rainfall intensities that are sufficient to clean the collecting roof surface. These parameters are essential to establish the *Potable Rain Maker* design parameters. Suspended solids/turbidity may be a good and simple indicator of the washing efficiency. Field experiments to establish it need to be conducted.

- **system's reliability and maintenance**: rigorous field tests are required to establish if the system works in the long term in the field conditions and to make possible improvements to the prototype if it fails to do so. e.g. the preliminary pilot study has already revealed that the small diameter drain holes plugs too easily; young bamboos will crack within days when exposed to the sun, the older ones will not; sediment collection rate in the stand pipe has not been evaluated in the field, but is required establish the maintenance schedule etc.

- **system's efficacy**: the microbial quality of collected water in field conditions has not been tested, and it is required to find out if the water produced by the system is suitable for drinking without other interventions. At the minimum, the presence of E. Coli/faecal coliforms indicators in the treated water needs to be evaluated. The bacteriological quality of the produced water may also be correlated and screened with simpler parameters (such as H_2S test) that can be easily and cheaply measured in the field.

- **epidemiology**: if the system appears to be viable and seems to produce potable water, its main reason for being needs to be rigorously tested in the field: i.e. does it really make things better or worse? A typical endpoint may be the decrease in prevalence of diarrheal diseases as measured by a pilot participatory survey of test users.

- **social acceptability**: while rain water collection is already widely accepted and practiced, its perception of potability is not. If the *Potable Rain Maker* system is proven viable, its desirability and acceptability must be tested and, if the response is positive, the social marketing methods must be established. Such work can only be done when and if all the other requirements of the system are proven in the field.

- **design manual**: based on field studies (scientific, epidemiological and social) and the model results, a design manual, that would simplify the design calculations, will be developed. Such manual would allow for local construction of properly sized and designed *Potable Rain Maker* water collection systems.

Example Model Run

This example scenario run uses the following inputs:

- Standpipe diameter=9.75cm (field-measured; Figure 1)
- Standpipe height=1.62m (field-measured; Figure 1)
- Drainhole dameter=3mm (field-measured; one of the tried values)
- Drain discharge coefficient=0.77 (field-calibrated; Figure 3)
- Rainfall intensity (constant here)=10mm/h (simulated value; doesn't have to be constant)
- Rainfall duration=15min (simulated value)
- Roof footprint area=50m^2 (field-measured; existing roof and gutter condition)
- Rain collection efficiency=0.75 (assumed; includes splashing, gutter leaks etc.)

The model can be run with any combination of these parameters and will describe the system state and outputs as the function of time. Using the model, the limiting values of the rain characteristics and design parameters can be calculated and the system viability and efficiency estimated.

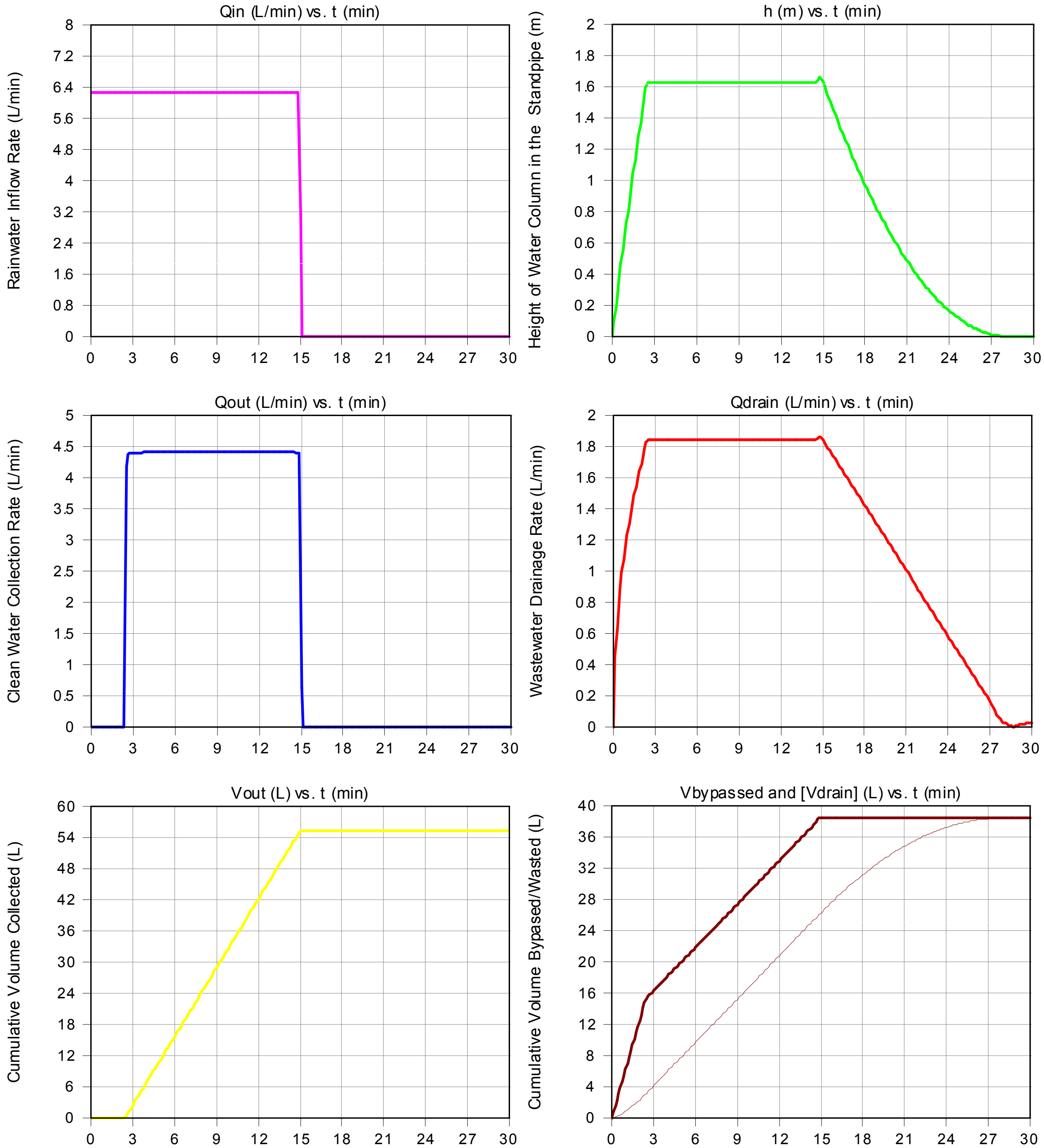

Figure 2. Sample model run outputs for the described scenario.

Output graphs in Figure 2 describe the results of this trial run:

The rainwater from the roof's spout starts flowing at t=0, lasts for 15 minutes and has a constant inflow rate of ~6.25 L/min. The water level in the standpipe is zero at t=0, then in raises to the maximum level of 1.63m in less than 3 minutes, when it start overflowing to the storage tank at a constant rate of ~4.4L/min until the rain ends (at t=15min).

The wastewater draining rate increases quadratically as the standpipe is being filled (i.e. at t~<3min), remains constant at ~1.8L/min during the duration of the rain and decreases gradually to zero for ~13minuts after the rain stops (when the water level in drops back to the level of the drainhole).

The cumulative volume of the water collected in the storage tank during this rain event was ~55 L, while the total volume of the wastewater drained was ~38L.

For this combination of rain characteristics, roof footprint size and the *Potable Rain Maker* design scenario, the model confirms that rain intensity of 10mm/hr is likely sufficient to wash the roof[2].

The first flush water discarded before the clean water collection started was about16 liters (volume of the full pipe plus the wastewater discarded during the pipe filling), which is likely insufficient to capture the first flush fully[3]. Decreasing the roof footprint area or increasing the pipe volume (especially the standpipe's diameter as the volume is a function of its square) could be tried and modeled again. The first flush discarded will also increase if the drain hole diameter is made larger.

Variety of other scenarios and design parameters can be quickly and efficiently modelled in a similar fashion.

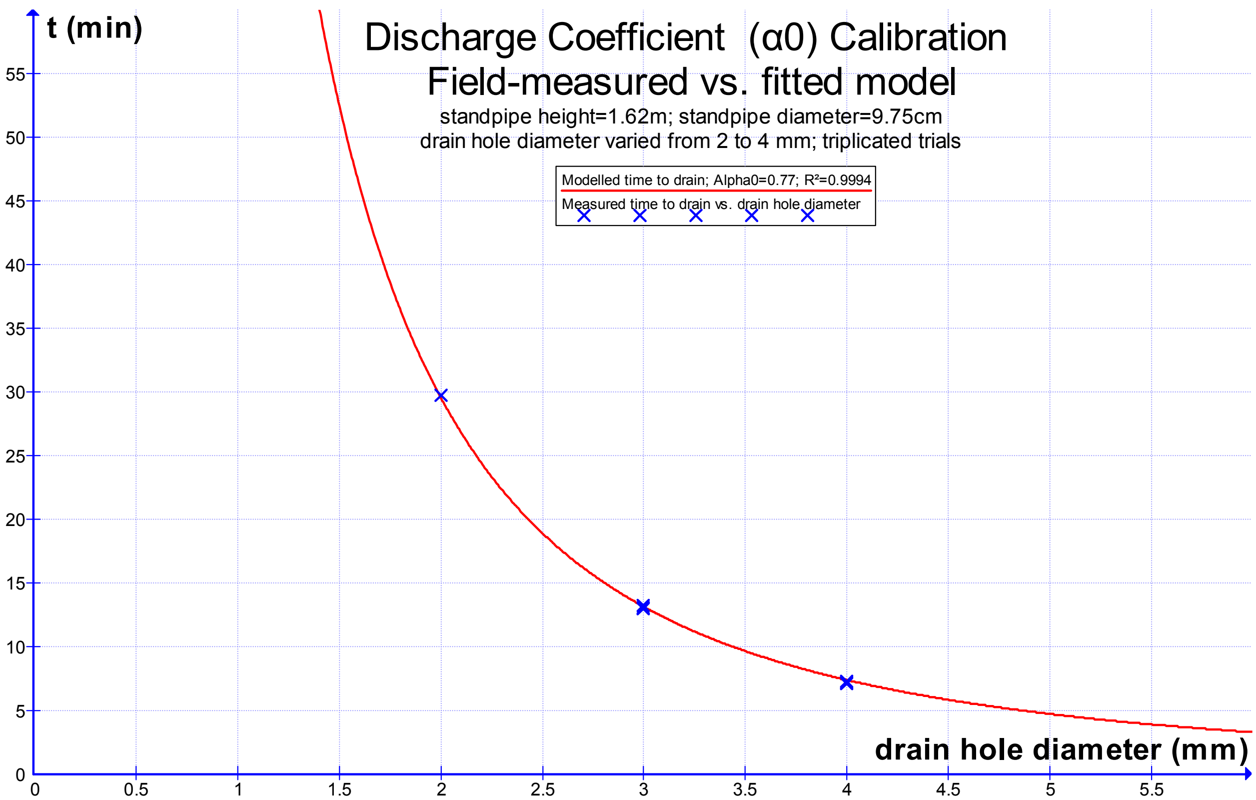

Figure 3. Field calibration of the model (discharge coefficient)

The model has been calibrated in the field by measuring the drainage time at different drainhole diameters, as shown in Figure 3. The discharge coefficient (alpha0) has been calculated as 0.77 (which is typical and expected for such system) and used in the model run described above[4].

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[2] Preliminary estimates suggest that the minimum rain intensity between 2 and 5 mm/hr is required to wash the roof surface. This requirement is different from the first flush volume to be discarded as low intensity drizzles are thought not to have enough energy to dislodge the dirt, even if duration is long.

[3] The estimated volume of the first flush to be discarded is possibly in a range of 0.5L per square meter of actual roof surface from which the rainwater is collected. The actual design value needs to be established in field trials.

[4] Please note that the function fitted to the field data is a closed-form algebraic solution to the differential equation describing the drainage of the system while there is no rainfall input. It has one empirical degree of freedom, the discharge coefficient. The three pairs of drain hole diameter/discharge time scenarios, triplicated except for d=2mm due to clogging, are sufficient to estimate it.