Aqualone — Irrigation control with a weighed atmometer

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Methodology booklet: physical principle, algorithms and proposed validation protocol. No experimental results are reported here.

Summary

Aqualone controls irrigation from a direct measurement of evaporative demand: the water lost by a porous ceramic cup that is weighed continuously in the field. Three mechanisms build on this measurement. Climatic triggering irrigates when the cup has emptied through evaporation. The rain condition cancels a scheduled cycle while rain has filled the cup, then allows it again as soon as evaporation has brought the level back below the threshold. ETR modulation adjusts the duration of a scheduled cycle according to the air temperature and humidity of the previous 12 hours.

To our knowledge, no commercial system combines these three functions on a single field sensor linked wirelessly to a stand-alone controller. This booklet describes the physics, the algorithms and the default settings, then proposes a protocol to measure water savings and the effect on crops.

Background

A crop's water need follows the evaporative demand of the atmosphere, not the clock. The FAO-56 reference method computes a reference evapotranspiration ET0 (Penman-Monteith) from radiation, temperature, humidity and wind, then adjusts it with a crop coefficient Kc (FAO-56).

This demand varies widely. In Nouméa, New Caledonia, the 2001-2020 normal potential evapotranspiration (Penman) goes from 89 mm in June (about 3.0 mm/day) to 185 mm in December (about 6.0 mm/day) (Météo-France, climate sheet 98818001). A fixed schedule set for the hot season therefore applies about twice too much water in the cool season, and the reverse.

Two families of tools already address this problem:

- **Atmometers** (ETgage type): a porous ceramic plate fed by a graduated reservoir, read by hand, that estimates ET0 (University of Nebraska-Lincoln, G1579).
- **Weather-based controllers**: they adjust irrigation from an on-site station or online weather data (US Bureau of Reclamation, 2018 technical review).

Aqualone automates the first principle (a physical, on-site measurement of evaporation) and uses it directly as a trigger, as an effective-rain detector and, combined with an air sensor, as a duration modulator.

The Aqualone sensor: a weighed porous-ceramic atmometer

The Aqualone node measures the water height in a porous ceramic cup by weighing, with no manual reading. The ceramic loses water through evaporation at its surface, like a leaf, and gains water when it rains.

Component	Role
Porous ceramic cup	Evaporating surface exposed to the same conditions as the crop
Load cell	Continuous weighing of cup + water
Filling valve	Refills the cup at each triggered cycle
Air sensor (temperature, humidity)	Feeds ETR modulation
LoRaWAN radio	Sends measurements to the site gateway, within a radius of about 2 km

Water height is derived from weight:

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h [mm] = (P − P0) / r
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P is the measured weight (g), P0 the empty weight recorded at tare (g), r the conversion ratio (g/mm). The ratio r equals the water surface in cm² divided by 10: 1 mm of water over 1 cm² weighs 0.1 g. On the demonstration site, a 42.50 g reference weight gave 7.31 mm, so r = 5.81 g/mm, which corresponds to a surface of about 58 cm².

The measurement is thus expressed directly in millimetres of water, the unit of ET0 and rainfall. The sensor also transmits air temperature and humidity, encoded to a hundredth of a degree and of a percentage point.

Three control mechanisms

All three mechanisms use the same measurement, the water height in the cup, and apply per irrigation region.

1. Climatic triggering

Irrigation starts when the cup has emptied through evaporation, whatever the time of day.

1. The controller monitors the water height h.
2. When h falls below 1 mm, the valve refills the cup for a set duration and the region's zones start.
3. The next cycle waits until the cup has emptied again.

The filling duration sets the volume put back into the cup, and therefore the cumulative evaporation between two irrigations. In hot, dry weather the cup empties quickly and irrigations come closer together; in overcast weather they space out.

2. Schedule + rain condition

A cycle scheduled at a fixed time is cancelled if the cup still holds enough water, then automatically allowed again once it has emptied.

1. At the start time, the controller reads h.
2. If h is greater than or equal to the set cancellation threshold, the cycle does not run: recent rain has already covered the demand.
3. Otherwise the cycle runs normally.

No manual reset is needed. After rain, evaporation brings h down; as soon as it falls below the threshold, the next scheduled start is allowed. Unlike a threshold rain gauge, the cup integrates both rain and evaporation: a shower followed by a hot day does not block irrigation as long as a shower followed by overcast weather.

3. ETR modulation

On scheduled climatic programs, the duration of each cycle is multiplied by a coefficient computed from the mean air temperature and humidity over the 12 hours before the start.

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c = 1 + kT × (T − Tref) − kH × (H − Href), with 0.70 ≤ c ≤ 1.40
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The 12-hour window suits evening irrigation: it covers the day that has just ended. It is adjustable. The coefficient is computed only if at least a third of the window (minimum 3 hours) contains measurements; otherwise the reference duration applies.

Parameter	Default	Rationale
Tref	27 °C	Conditions in which the programmed duration applies unchanged
Href	65 %	Same
kT	2.5 %/°C	Sensitivity of Hargreaves ET0 (FAO-56, eq. 52): about +2.1 to +2.6 %/°C
kH	0.3 %/humidity point	Order of magnitude of Penman-Monteith sensitivity coefficients to humidity
Bounds	70 % – 140 %	Limits the effect of an outlier measurement
Window	12 h	Day before an evening irrigation
Activation	Off	Enabled by the installer, region by region

Examples with the default values:

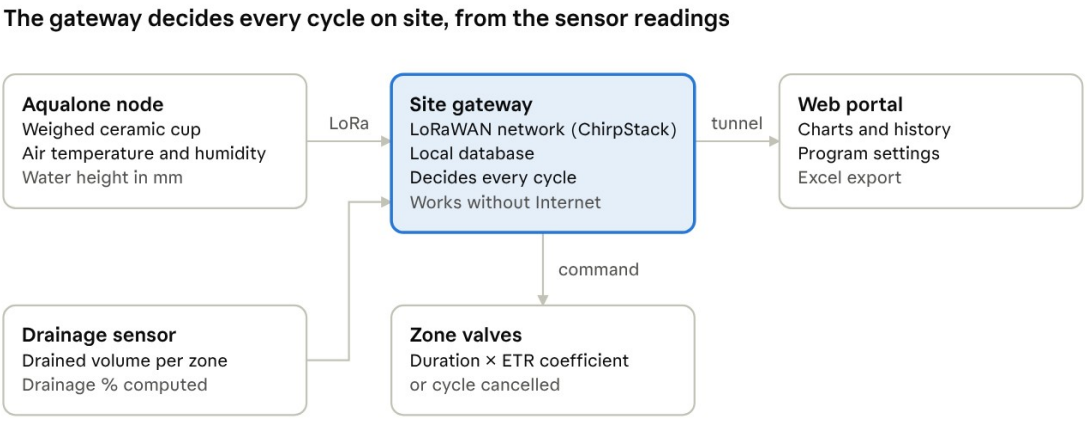
Mean temperature	Mean humidity	Coefficient	10-min cycle
32 °C	50 %	117 %	11 min 42 s
30 °C	65 %	107.5 %	10 min 45 s

Mean temperature	Mean humidity	Coefficient	10-min cycle
27 °C	65 %	100 %	10 min
26.9 °C	81 %	95 %	9 min 30 s
24 °C	65 %	92.5 %	9 min 15 s
22 °C	90 %	80 %	8 min

The 26.9 °C / 81 % row is a calculation actually observed on the demonstration site. The applied coefficient is logged at every cycle, so it can be audited afterwards.

Architecture

All irrigation decisions are taken by the site gateway, without depending on the Internet or a remote service.



architecture · from sensor to portal

The portal is used to view and adjust; losing the link to the portal does not stop irrigation. The drainage sensor closes the loop: it compares drained water with applied water and shows the drainage percentage of each zone, which makes it possible to check that durations are neither too short nor too long.

Limits and assumptions

The cup measures evaporation from a wet free surface, not the transpiration of a given crop. Translating it to the crop relies on the installer setting the filling duration and the irrigation durations, which plays the role of the crop coefficient Kc.

- **ETR modulation coefficients**: kT and kH come from published sensitivity analyses (Hargreaves, Penman-Monteith), not from on-site calibration. The formula ignores radiation and wind, which

weigh in ET0. Hargreaves underestimates Nouméa ET0 by a factor close to 1.4, and FAO warns against its use in island settings.
- **Sensor representativeness**: the cup must be placed in the same sun and wind conditions as the crop. A shaded or sheltered cup underestimates demand.
- **Ceramic maintenance**: fouling (scale, algae, dust) reduces evaporation. A slow drift in the ratio between measured evaporation and reference ET0 may be a sign of it.
- **Weighing metrology**: accuracy depends on the load cell, its thermal drift and the quality of the tare. A fresh tare when empty and a check with a reference weight are recommended at installation.
- **Heavy rain**: beyond the cup's capacity, water overflows and the measured height levels off. This is by design: the cancellation threshold is reached well before, and total rainfall is not needed for control.
- **Instantaneous condition**: cancellation is decided at the start time, on the last measurement received. Rain falling during the cycle does not interrupt it.

Proposed validation protocol

We propose a paired-block comparison over a full season, open to research teams and partner growers.

1. **Design**: at least two identical irrigation regions (same crop, soil, drippers, exposure), replicated in three blocks if possible. Treatment A: fixed schedule set by the grower. Treatment B: Aqualone control (rain condition + ETR modulation, or climatic triggering).
2. **Weather reference**: an on-site or nearby station, to compute daily Penman-Monteith ET0 (FAO-56) and compare it with the evaporation measured by the cup.
3. **Water measurements**: volumes applied per region (flow meter, or duration × number of drippers × flow), drainage measured with a collection tray, soil moisture at two depths.
4. **Agronomic measurements**: marketable yield, fruit size, stress indicators (leaf water potential or a vegetation index), incidence of diseases linked to excess water.
5. **Indicators**: total volume applied, drainage fraction, water use efficiency (yield per m^3), number of cycles cancelled after rain, gap between cup evaporation and ET0.
6. **Analysis**: comparison of treatments with a mixed model (block as random effect), and regression of measured evaporation on ET0 to estimate a site-specific cup coefficient.

The system already logs water height, air temperature and humidity, cycles run or cancelled, the applied ETR coefficient and the drainage percentage. These data can be exported to Excel from the portal.

Outlook

- **Local calibration of kT and kH**: by regressing cup evaporation on T and H, once a few months of data are available on a site.
- **Calibrated Hargreaves**: replace the linear formula with a locally corrected Hargreaves ET0 (factor close to 1.4 in Nouméa), when daily minimum and maximum temperatures are available.
- **Crop coefficients**: add a Kc per crop stage to go from evaporative demand to plant need.
- **Drainage loop**: automatically adjust durations to target a drainage fraction, measured by the drainage sensor already available.

References

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4. US Bureau of Reclamation (2018). *Weather- and Soil Moisture-Based Landscape Irrigation Scheduling Devices*, Technical Review Report, 6th edition.
5. Atmometer, Wikipedia (principle and history).