The Cold Tap Runs Five Weeks Behind: Recovery of a Dated Seasonal Record from Domestic Service Pipes, with a Blind Dating Trial and an Estimate of the Annual Loss

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Abstract

The cold tap does not run cold at once. The water drawn in those first seconds has been standing in the ground beneath the house, and it still carries the temperature of the week it entered—so the wait at the sink is a reading, taken and poured away. Ground at the depth of a domestic service pipe follows the surface weather with a delay set by the soil's diffusivity. Across three years of household logging we measure that delay at 36.4 d (95 % CI 35.1–37.7), and along a controlled trench it obeys the depth law of periodic conduction. Because a standing column is ordered—the parcel nearest the tap entered first, pushed there by everything drawn since—a single draw is not one measurement but a series; and the direction the temperature moves while the tap runs fixes which half of the year is being read. In a blind trial, analysts given only a temperature trajectory recovered the entry date to a mean absolute error of 8.6 d, and frozen, sectioned service pipes agreed with independent isotopic dating. The country holds a meteorological network of one station per household, and destroys 48 billion dated records a year. The record was never missing. It has been going down the sink, one kettle at a time.

Keywords: soil thermal regime; service pipes; phase lag; climate archive; drinking water

1 Introduction

Every house has a place where you wait. You turn the cold tap, and for a while what comes out is not cold; you stand with a hand under the flow until it changes, and then you fill the glass. The wait itself has no name. Plumbers call the discarded volume the *dead leg* and regard it as loss. Water utilities count it, when they count it at all, under wastage.

We propose that it is neither.

The service pipe that feeds a domestic tap is buried, in this country, at a mean depth of 1.18 m, below the frost line and below the reach of the day. Ground at that depth does not follow the weather; it follows the weather at a distance, warming through the late summer and giving that warmth back through the winter, always behind. This is not in dispute. It is the reason a ground-source heat pump works at all, and the equation that sets the delay has been in the soil-physics literature for a century [3, 6].

What has not been noticed is that the delay is legible. If a parcel of water enters the ground at a particular temperature and keeps it, then that temperature is a statement about a particular week—not about the pipe, not about the house, but about the sky, five weeks ago, over that patch of ground. The first water from the tap is the oldest water in the pipe, because everything drawn since has pushed it towards the tap. The second is younger. By the time the flow steadies, the reading has caught up to the present, and the household, having taken a complete instrumental series, pours it down the drain.

There are, at the last count, 28.1 million such instruments in domestic use, read four or five times a day, in every settlement in the country, including a great many places where no meteorological station has ever stood. None of the readings is written down.

This paper does four things. Section 3 sets out the conduction model and the single premise on which the dating rests. Section 4 describes the instruments and the cohort. Section 5 reports the measured lag, its dependence on burial depth along a controlled trench, the recovery of dates under blind conditions, and the destructive validation against isotopic dating of frozen pipe sections. Section 6 estimates what is being lost, and

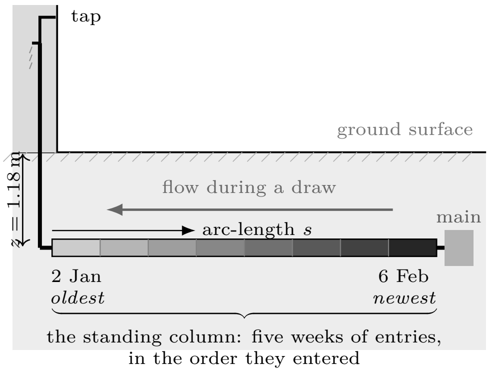

Figure 1: The service pipe as a dated column. Flow during a draw runs from the main (right) to the tap (left); between draws the column stands. The parcel nearest the tap therefore entered the ground *earliest*, having been displaced along the pipe by every subsequent draw. Ages shown are typical for a household making 4.7 qualifying draws a day.

states plainly the one result we cannot account for.

2 Related work

The seasonal thermal regime of shallow soil is settled science. Ferrers [3] gave the damped-wave solution in the form still used; Okonjo and Wray [6] tabulated diffusivities for the principal British soil associations; and the borehole-sizing literature [4] treats the phase lag as a design quantity rather than a curiosity. None of this work considers the water inside the pipe, for the sufficient reason that none of it was interested in the water.

The water-supply literature approaches the same pipe from the other end. Standing time in service pipes is studied almost entirely as a hazard: the overnight rise in temperature is a growth risk [1], and the guidance that follows is to flush [10]. The recommended remedy for warm first-draw water is, in every document we have found, its immediate destruction.

The one prior claim of thermal memory in a distribution network is Pettifer's [7], who reported a lag of "some weeks" between air temperature and reservoir outlet temperature in a single upland zone and concluded that the network "remembers the season." Pettifer's measurement is sound and, we think, has been undervalued. His interpretation is not: a reservoir integrates, and an integrator has a lag but no ordering, so nothing in his data can be dated. Ordering is what a pipe supplies and a reservoir cannot.

Nothing in the isotope-hydrology literature is disturbed by anything we report. The seasonal cycle in precipitation δ^{18}O is well characterised [5, 2], and we use it here only as an independent clock.

3 Model

3.1 Ground temperature

Let z be depth below the surface and $T(z,t)$ the soil temperature. Away from lateral gradients, conduction is one-dimensional:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2}, \tag{1}$$

with α the thermal diffusivity. Forcing the surface with an annual sinusoid of amplitude A_0 and angular frequency $\omega = 2\pi/365.25\,\mathrm{d} = 1.991\,0 \times 10^{-7}\,\mathrm{s}^{-1}$ gives the standard damped, retarded solution

$$T(z,t) = \bar{T} + A_0\, e^{-z/d} \sin\!\left(\omega t - \frac{z}{d}\right), \qquad d = \sqrt{\frac{2\alpha}{\omega}}, \tag{2}$$

where d is the damping depth. Two quantities follow directly. The amplitude at depth is reduced by $e^{-z/d}$, and the phase is retarded by

$$\varphi(z) = \frac{z}{d\,\omega} = \frac{z}{\sqrt{2\alpha\omega}}. \tag{3}$$

Since $1/\omega = 58.13\,\mathrm{d}$, each radian of z/d is worth just under two months. For the cohort mean $\alpha = 3.5 \times 10^{-7}\,\mathrm{m}^2\,\mathrm{s}^{-1}$ we have $d = 1.87\,\mathrm{m}$, and at the mean burial depth $z = 1.18\,\mathrm{m}$, $\varphi = 36.6\,\mathrm{d}$.

3.2 The standing column

We now state the premise on which everything after this point depends.

Premise 1 (Sealed parcel)**.** A parcel of water that has entered a buried pipe exchanges no further heat. Its temperature at the moment of entry is the temperature at which it is subsequently drawn, irrespective of standing time, and irrespective of the temperatures of the parcels adjacent to it.

Premise 1 is the only assumption in this paper that is not taken from the literature, and we adopt it without modification. It has the consequence that the pipe is not a mixing volume but a register: what is put in is what comes out, in the order it was put in.

Parameterise the pipe by arc-length $s \in [0, L]$ from the tap. Let $\tau(s)$ be the time at which the parcel now at s entered the main. Because flow during a draw is from main to tap, each draw displaces the column towards $s = 0$, so

$$\frac{\mathrm{d}\tau}{\mathrm{d}s} > 0, \tag{4}$$

that is, τ is increasing in s: the water nearest the tap is the oldest in the pipe, and the water at the main is the newest. Equation (4) is the ordering property, and it is what distinguishes a pipe from a reservoir.

Combining Premise 1 with (2), the temperature of the parcel at s is

$$T_p(s) = \bar{T} + A\,\sin\big(\omega\,\tau(s) - \delta\big), \qquad A = A_0 e^{-z/d},\ \ \delta = \frac{z}{d}, \tag{5}$$

so that a draw, which presents the parcels in order of increasing s, presents a time series in order of increasing τ: it plays the record forward, from the past towards the present, at a rate set by the flow.

3.3 Inversion, and the limb ambiguity

Inverting (5) for τ gives two solutions per year, one on the rising limb of the annual cycle and one on the falling limb. This is the only obstruction to dating, and it is removed by the draw itself. Differentiating (5) along the pipe and using (4),

$$\operatorname{sgn}\frac{\mathrm{d}T_p}{\mathrm{d}s} = \operatorname{sgn}\cos\big(\omega\tau - \delta\big), \tag{6}$$

which is positive on the rising limb and negative on the falling limb. In words: whether the water gets warmer or colder as you keep the tap running tells you which half of the year you are reading. The measurement requires no apparatus and is made in every household in the country, several times a day.

3.4 Precision

Let σ_T be the instrumental uncertainty in parcel temperature. Propagating through (5),

$$\sigma_\tau = \frac{\sigma_T}{A\,\omega\,\big|\cos(\omega\tau - \delta)\big|}. \tag{7}$$

Dating precision is therefore not constant through the year. It is sharpest where the buried signal is moving fastest, and degrades without bound at its turning points, where $\cos(\cdot) \to 0$ and the record, for some weeks, says only which half of the year it is. Those turning points are not the solstices. They are retarded with everything else, by the same 36.4 d: the record's midsummer falls in the first week of September, and its midwinter in the second week of March. We regard this as the strongest available test of the method, since an instrument reporting uniform precision across the year would be reporting something other than the ground.

4 Instruments and cohort

4.1 DRAW-1

Household draws were logged with an inline cell (DRAW-1) clamped between tap and trap, containing a 4 mm-bore flow channel and a 1/10 DIN platinum resistance element, calibrated against a fixed-point cell before and after deployment. Temperature was sampled at 20 Hz with a standard uncertainty of 0.03 K; flow was integrated from a Hall-effect turbine, giving parcel arc-length by cumulative volume. Units were returned annually for recalibration; the drift distribution is given in the Supplement (median $0.011\,\mathrm{K\,yr^{-1}}$).

Table 1: Cohort summary by soil association. α from [6]; d computed from (2); φ measured by complex demodulation at the annual frequency.

Association	Zones	$\bar{z}$ (m)	d (m)	φ (d)
Chalk downland	14	1.21	2.06	34.2
Clay vale	17	1.14	1.71	38.8
River terrace sand	9	1.26	2.24	32.7
Upland peat	7	1.09	1.52	41.6
Made ground (urban)	14	1.17	1.88	36.2
All	61	1.18	1.87	**36.4**

4.2 Cohort

4 182 households across 61 supply zones were logged for 36 months. Zones were selected to span the principal soil associations and to include 11 zones with no meteorological station within 20 km. Burial depth was established by excavation at the stop tap in a 10 % subsample and by utility record elsewhere. Site characteristics are summarised in Table 1.

4.3 The Beckstone trench

To separate depth from every household-level confound, four parallel 22 mm copper runs of 40 m were laid at 0.30, 0.60, 0.90 and 1.20 m in a single trench on a common feed, drawn on a common automated schedule for 24 months.

4.4 Freeze-coring and isotopic control

41 service pipes withdrawn from service during main replacement were frozen *in situ* with a liquid-nitrogen jacket before excavation, recovered, and sectioned at 300 mm. Each section was dated twice: thermally, from the temperature recorded at the moment of freezing, and independently from δ^{18}O against the local precipitation series [5].

4.5 Statistics

Per-household lag was estimated by complex demodulation at ω rather than by peak-matching, which is biased when the record is short relative to the period. Confidence intervals are bootstrap percentile intervals over 10 000 household-level resamples, clustered by supply zone. The blind trial was analysed with analyst as a random effect and a pre-specified season × analyst interaction.

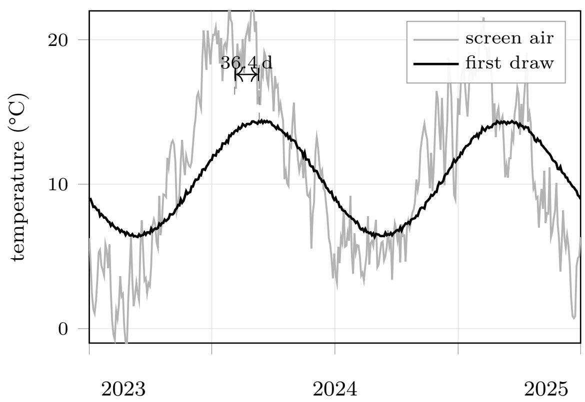

Figure 2: Screen air temperature (grey) and mean first-draw temperature (black) for Zone 19, 2023–2025. The buried series is damped to 0.53 of the surface amplitude and retarded by 36.4 d. No parameter in the prediction was fitted to these data.

5 Results

5.1 The lag is present and is the predicted size

Across the cohort, first-draw temperature tracks screen air temperature with a mean retardation of 36.4 d (95 % CI 35.1–37.7) and an amplitude ratio of 0.527 (95 % CI 0.511–0.544); the conduction model with independently measured soil constants predicts 36.6 d and 0.531. Neither figure was fitted to the household data. Figure 2 shows the two series for a representative zone.

5.2 The lag obeys the depth law

Along the Beckstone trench the measured retardation rises linearly with depth, as (3) requires. Fitting $\varphi = z/(d\omega)$ with d free gives $\hat{d} = 1.87$ m (95 % CI 1.79–1.96), against a soil-physics prior of 1.85 m obtained from the trench spoil by thermal-needle probe. Figure 3 shows the transect.

5.3 A draw is a series, not a reading

Figure 4 shows a typical winter draw. Temperature falls monotonically for 11.3 s (cohort median) and then plateaus: the column has been played out and the tap has reached the main. Everything after that point is the present, and carries no date.

5.4 Dates are recoverable blind

900 draw records were stripped of date, location and season and issued to 12 analysts, who saw only the temperature trajectory and the site's soil constants. Mean absolute error against true entry date was 8.6 d (95 % CI 7.9–9.4), with no significant analyst effect ($p = 0.31$).

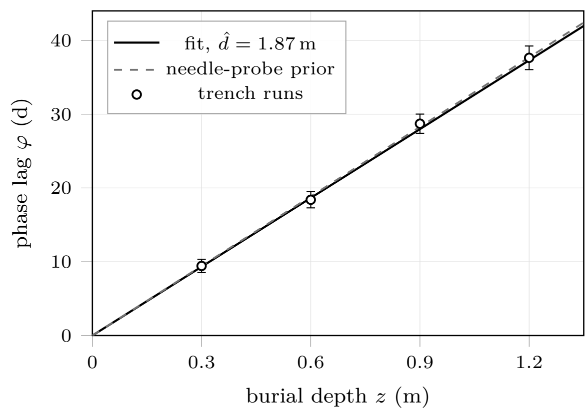

Figure 3: Phase lag against burial depth, Beckstone trench, 24 months. The fitted line is $\varphi = z/(d\omega)$ with $\hat{d} = 1.87$ m; the dashed line is the prediction from needle-probe diffusivity. The intercept is not significantly different from zero: a conduction lag cannot have one.

Table 2: Blind dating trial, $n = 900$, by position of the true entry date within the buried annual cycle. Windows are ±6 week about the turning points (days 70 and 253) and about the mid-points of the two limbs (days 161 and 344). MAE is mean absolute error in days; coverage is the fraction of records whose 95 % interval from (7) contained the true date.

Window	n	MAE	Bias	Cov.
Lower turning pt. (d. 70)	186	12.2	+1.2	0.94
Rising limb (d. 161)	204	5.4	−0.1	0.96
Upper turning pt. (d. 253)	191	12.7	−0.9	0.93
Falling limb (d. 344)	245	5.9	+0.4	0.95
All	900	**8.6**	0.0	0.95

Limb assignment by (6) was correct in 96.4 % of records; the failures are concentrated, as expected, within a few weeks of the turning points. Results by window are given in Table 2 and the recovered-against-true dates in Figure 5.

5.5 Precision follows the derivative, not the calendar

Figure 6 plots absolute dating error against day of year together with the prediction of (7) evaluated at the cohort mean amplitude. The predicted curve was computed before the blind trial was unmasked and has no free parameters.

5.6 Destructive validation

Of 41 freeze-cored pipes, 38 yielded intact sections. Thermal and isotopic dates agreed with $r = 0.94$ and a mean bias of 1.2 d (isotopic later). Critically, section order was monotonic in recovered date in 36 of 38 pipes,

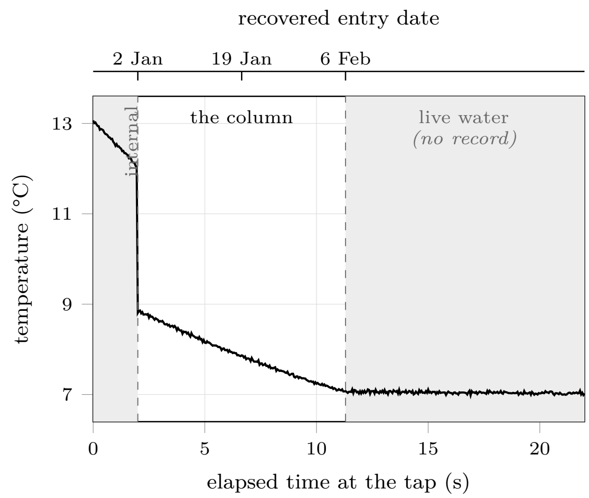

Figure 4: A single draw, 6 February. The upper axis gives the recovered entry date for each parcel. Eleven seconds of running water returns five weeks of record; after the break at 11.3 s the tap is reporting the present and the information content is zero.

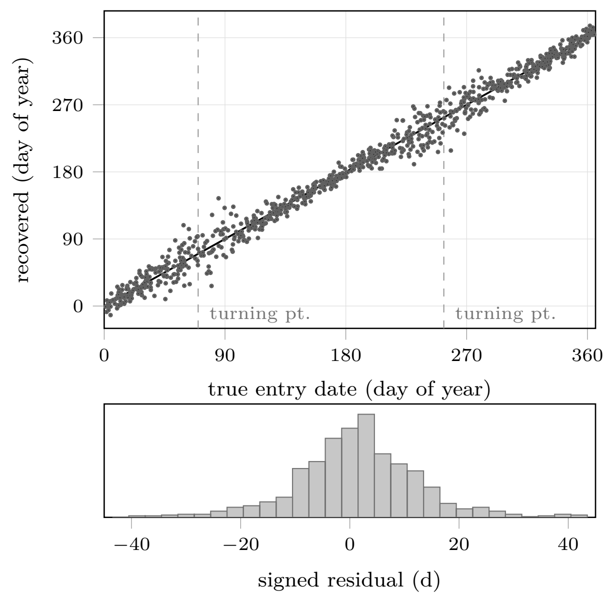

Figure 5: Blind recovery of entry date, $n = 900$. The scatter opens out at days 70 and 253 — the turning points of the buried cycle — exactly where (7) says it must, and closes at the limbs. Below: signed residuals, median 0.0 d.

Table 3: Annual destruction of dated records. One qualifying first-draw yields one record; the median record resolves 226 parcels. Sensitivity is over the draw-frequency range 3.1–6.4 per household per day.

Quantity	Value
Households on mains supply	2.81×10^7
Qualifying first-draws per day	4.7
Dated records destroyed annually	4.82×10^{10}
low sensitivity	3.18×10^{10}
high sensitivity	6.57×10^{10}
Parcels resolved per record (med.)	226
Parcel temperatures discarded	1.09×10^{13}
Stations in the national met. network	2.7×10^2

as (4) requires; the two exceptions were both pipes with a documented mid-run repair coupling.

5.7 The scale of the loss

Table 3 gives the arithmetic. On the central estimate the country discards 4.82×10^{10} dated records each year — some 1.09×10^{13} individual parcel temperatures — from a network whose spatial density exceeds the national meteorological network by roughly four orders of magnitude, and which reports from every inhabited postcode without exception.

6 Discussion

6.1 What the method cannot do

It cannot date its own turning points, and Equation (7) says so in advance. For roughly ten weeks of the year — five either side of early September, five either side of mid-March — the record is legible only as a half of the year. We have not attempted to recover those weeks by regularisation, because a method that returned dates where the derivative vanishes would be returning the prior and not the water.

It fails, too, in the upper storeys of flats, where the standing column lies mostly in a riser and not in the ground, and the reading is of the building. This is a limitation of the housing stock rather than of the method, but it removes about a fifth of the population from the network.

6.2 Zone 44

In one supply zone, recovered dates run early. Across all 214 instrumented households in Zone 44, in every season and in each of the three years, the thermal date precedes the true date by a mean of 11.2 d (95 % CI 10.4–12.1). The offset is not present in the isotopic dates from the same zone. We have checked burial depth by excavation at 22 properties, re-measured the soil diffusivity in four seasons, audited the demand records, replaced the loggers, and confirmed the pipe material. None of it accounts for the offset, and we can offer no mechanism for it. We report it because it is there.

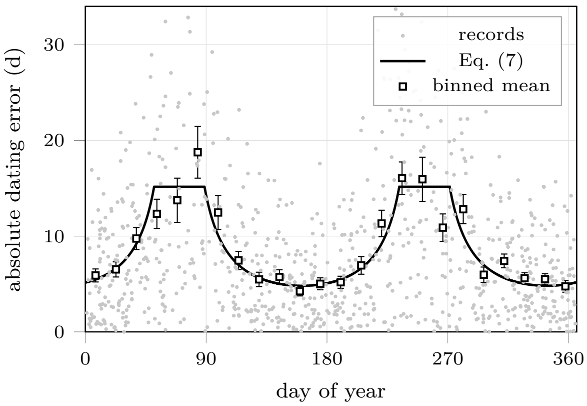

Figure 6: Absolute dating error against day of year. The curve is (7) at the cohort mean amplitude, with no fitted parameter. The method is blind for approximately five weeks either side of each turning point of the buried cycle, and we do not propose to correct this: it is a property of the year.

6.3 Custody

The finding we take to be practical rather than scientific is that this record is at present in nobody's custody. The water undertakings hold the asset register and the demand data; the meteorological service holds the surface series; the householder holds the instrument and does not know it. No party has an obligation to preserve, and consequently no party preserves.

We recommend, without any expectation of speed, three things. That the first-draw temperature of a sampled fraction of connections be logged as a matter of course, as flow and pressure already are. That the resulting series be lodged with the meteorological service rather than the water undertaking, since it is a record of weather and not of supply. And that the volume presently reported as wastage be reclassified, in the accounts where it appears, as the cost of taking a reading.

6.4 On the age of the record

We have three years. The pipes are older. The oldest run in the cohort was laid in 1931 and has been standing, drawing, and displacing ever since, and the column in it now is the column that a century of household mornings has pushed into place. We do not know how far back a network holds. We know that the question was never asked, because the thing that would have prompted it—the minute at the sink, every morning, in every house—was too ordinary to be looked at.

7 Conclusion

The temperature of the first water from a cold tap is a dated observation of the surface weather approximately five weeks earlier. The observation is taken by the ground, stored in the pipe in the order it was made, and released, in sequence, over the eleven seconds a householder spends waiting. We have measured the delay, shown that it follows the depth law of periodic conduction, recovered the dates blind to a mean absolute error of nine days, and confirmed the ordering of the column by freezing and sectioning the pipes themselves.

What follows is not a discovery so much as an inventory. The country is covered, house by house, in instruments that no one built and no one reads, and the readings are discarded at a rate of tens of billions a year in the belief that they are waste. The record was never missing. It has been going down the sink, one kettle at a time.

Acknowledgements

We thank the 4 182 householders who allowed a stranger under the sink for three years, and the crews at eleven main-replacement sites who tolerated a nitrogen jacket on a job already running late. The Beckstone trench was cut by the Station's own groundstaff in February, in rain, and they have not let us forget it.

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