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Guidance on Good practices for WATER ACCOUNTING

Cement Sustainability Initiative (CSI)

wbcsd

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1 INTRODUCTION

This Guidance is a companion document to the Protocol for Water Reporting for the Cement Industry[1] ('the Protocol') of the Cement Sustainability Initiative (CSI). The Protocol sets out the requirements for disclosure and benchmarking, based on the kind of operations, and specific reporting requirements for cement plant operations, aggregate installations and ready-mix concrete (RMC) operations.

The Guidance offers recommendations, technical direction and methodologies on measurement and making estimates for a reliable accounting of water withdrawals, discharges and consumption, to improve the accuracy of water accounting by companies. The recommendations featured in this document cover cement, aggregates and RMC operations.

Recommendations cover these areas:

- Pre-requisites for water accounting, defining site boundaries and identifying water in-flows and water out-flows from the site;
- Measuring, selecting, installing and maintaining measurement devices;
- Methodologies to calculate by measurement, when continuous or direct readings from meters are not available, and for calculating by estimation as a third option. Alternatives to gauging water consumption in aggregate and RMC operations are included;
- Recording and managing meters and water data; and
- Indicative values for cement operations to help users assess water consumption for accounting purposes.

2 WATER ACCOUNTING REQUIREMENTS

2.1 Operational site boundaries

The first step in water accounting is to set clear operational site boundaries. The boundaries define the limit or extent to which water data and indicators are considered. Site boundaries are defined according to the Protocol and include all activities and operations on-site for the production of goods and related activities,including offices, housekeeping, and landscaping.

Not included in the operational site boundaries:

- On-site captive power plant;
- Water supplied to communities or on-site housing; and
- Storm water run-off and discharges.

2.2 Site water flow

Credible data on water flow relies on a clear understanding of all site water flows. The site water flows are presented in the Protocol (refer to the Protocol, page 5, for a diagram of site perimeter and CSI water-associated indicators). This step must be followed at each facility with the operational managers, as they understand and control the processes.

A site water flow diagram is the equivalent of the process flow diagram for production. It illustrates water flows into all site boundaries and identifies the sources from where the water is withdrawn, as well as the sites where the water is used, consumed, recycled and discharged. It is a visual of all water flows and is easy for someone unfamiliar with the site to understand.

1 The CSI Protocol for Water Reporting, www.wbcsdcement.org/water

To develop a water flow diagram, identify the following items:

- Operational site boundaries
- All water in-flows and out-flows
- Water withdrawals and discharges and receiving bodies, if possible
- Water use distribution, focusing on major water consumers
- Where meters should be installed, and where calculation by measurement or estimation is acceptable

Typical water flow diagrams for cement plant operations, aggregates installations and ready-mix concrete operations are in Annex 1 (page 28).

3 WATER ACCOUNTING

Select the appropriate measurement or calculation methodology to fit the monitoring location. This Guidance include methodologies provided by CSI company members, to help determine the CSI water indicator volumes.

CSI water indicators are the following:

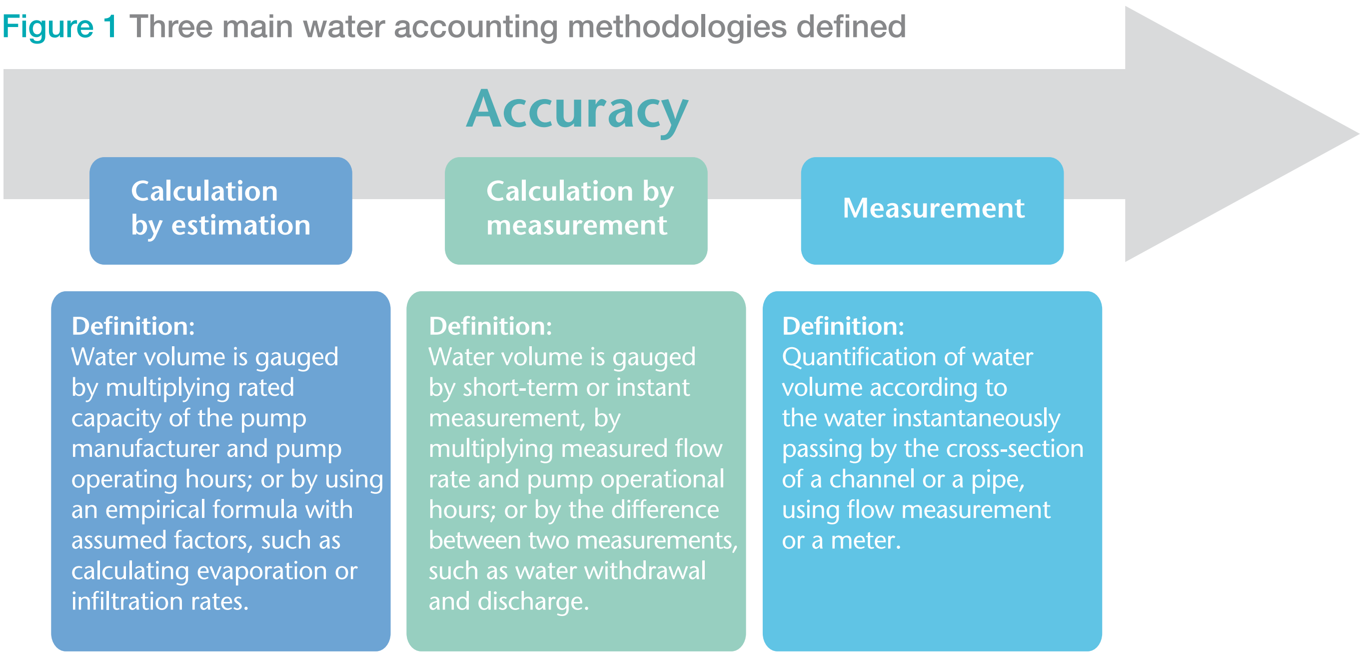
- Total water withdrawal by source (G4 EN8)
- Total water discharge by quality and destination (G4EN22)
- Total water consumption (GWT – CSI)
- Percent of sites with water recycling. For a operations, this is comprised of two indicators: (i) Percent of sites with water process; (ii) Percent of sites with a water recycling system

CSI companies are free to use other methodologies for specific conditions, if they comply with Protocol requirements and conform to the principles in this Guidance.

Broadly speaking there are three categories of water accounting methodologies:

- Measurement
- Calculation by measurement
- Calculation by estimation

Figure 1 Three main water accounting methodologies defined



3.1 Water accounting requirements and principles

Water indicator definitions, discussed in detail in the Protocol, and water accounting requirements, are detailed here.

Total water withdrawal: All water drawn into the boundaries of the reporting organization from all sources, including surface water, groundwater, used quarry water, municipal water, and harvested rainwater, for any use during the reporting period. Table 1 below summarizes water withdrawal sources and the Protocol reporting requirements.

Table 1 Water withdrawal sources and CSI reporting requirements

Water source	Withdrawal source	Freshwater source	Non-fresh water source
Surface water from rivers, lakes, natural ponds[2]	Yes	Yes	Yes[6]
Groundwater from wells, boreholes[2]	Yes	Yes	Yes[6]
Used quarry water, collected in the quarry[3]	Yes	Yes	Yes[6]
Municipal potable water[4]	Yes	Yes	No
External wastewater	Yes	Yes	Yes[6]
Harvested rainwater[5]	Yes	No	No
Sea water, water extracted from the sea or the ocean	Yes	No	Yes[6]

Specific conditions exist for rain and storm water runoff, collected on the site and discharged without being used, and for water collected in the quarry and discharged without being used (refer to the Protocol).

Rain, storm water runoff and water collected in the quarry and discharged without being used are not included in water withdrawal, discharge or consumption.

Total water discharge: Water effluents discharged during the reporting period to ocean, surface, subsurface/well, off-site water treatment, through a defined discharge point (point source discharge), over land in a dispersed or undefined manner (non-point source discharge), or wastewater removed from the reporting organization by truck.

Domestic sewage discharge should be included in total water discharge.

Table 2 Receiving bodies for water discharge and CSI reporting requirements

Receiving water body	Discharge	
	Freshwater	Non-fresh water
Ocean	Yes	Yes
Surface water	Yes	Yes[6]
Subsurface / well	Yes	Yes[6]
Off-site water treatment	Yes	Yes[6]
Beneficial / other use	Yes	Yes[6]

2 Includes sources inside or outside site boundaries
3 Could be from rain, groundwater or surface water
4 Includes water bought from the public grid
5 Includes water collected, stored and used for process and non-process purposes.
6 Includes brackish or saline sources

Total water consumption: Consumption removes water from a system and makes it unavailable for further use. It includes water evaporated for cooling purposes or from water storage facilities, lost via transmission, or incorporated into an organization's products and onsite uses.

It can be calculated as follows:

$$\text{water consumption} = \text{water withdrawal} - \text{water discharge}$$

This Guidance recommend identifying and quantifying major water consumption items as listed in Table 3 below.

Total water consumption includes rainwater harvested on site for any use. It differs from total freshwater consumption, which excludes harvested rainwater.

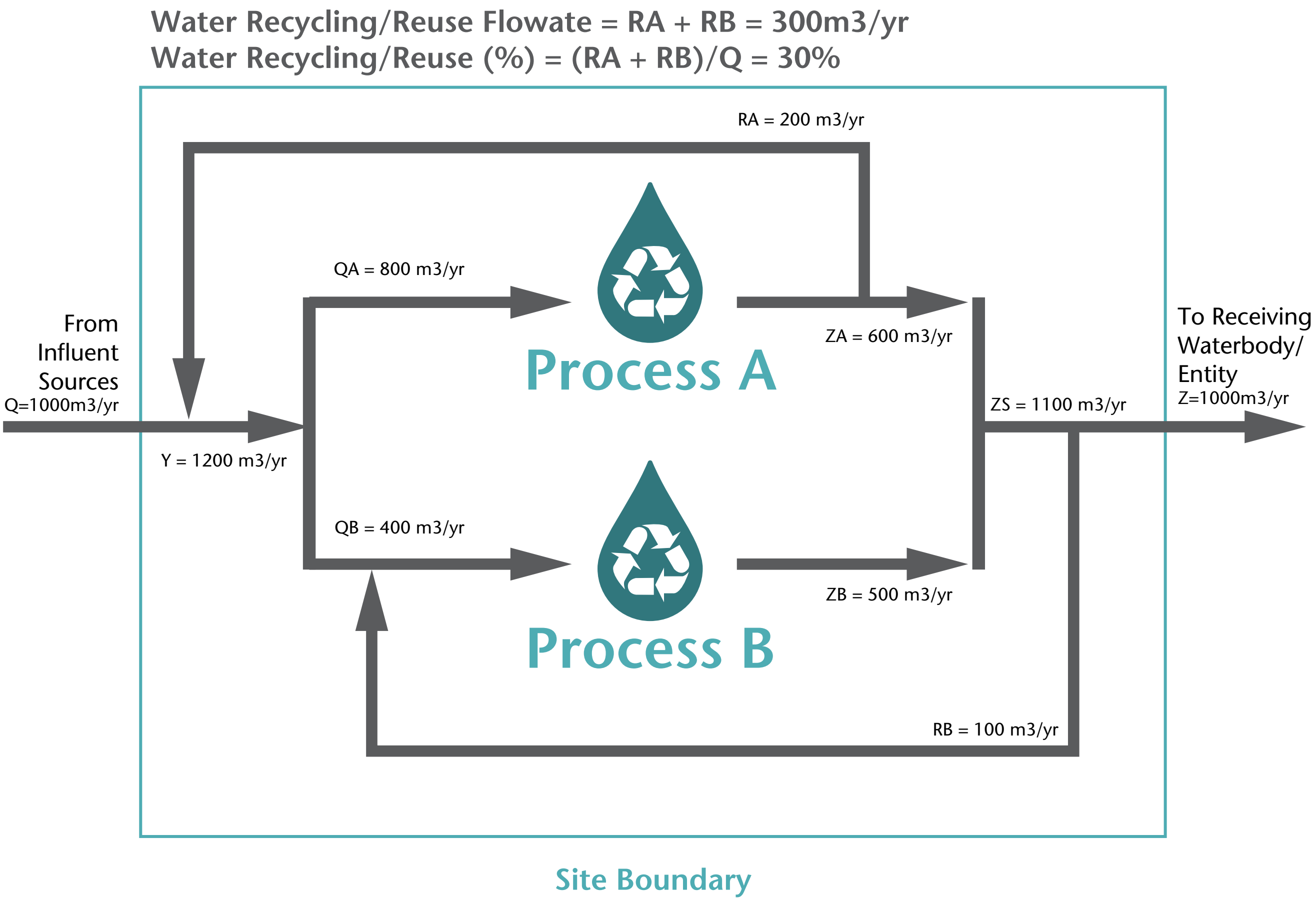
Table 3 Water consumption

*(Excludes reusing or recycling water)

Cement	Aggregate	RMC
Slurry for wet process or granulation for the semi-dry or semi-wet process	Wet screening	Concrete production
Cooling mechanical equipment (such as cement coolers)	Aggregates washing	Mixer & equipment washing
Cooling of materials (e.g. injection into clinker cooler)		Ready-mix truck washing
Exhaust gas conditioning		
Emission controls such as flame cooling, deNOx SNCR, and SO_2 scrubber		
Waste heat recovery systems		
Dust control by watering roads, materials and stockpiles		
Support and ancillary operations such as office buildings, general services, maintenance workshops and garages		
Irrigation for greening and rehabilitation within site boundaries		
Domestic use		
Natural evaporation		
Leakage and loss		

Water recycling and reuse: Water can be recycled and reused within a site boundary. Water can be reused for the same purposes, in a closed cooling loop for cement, or in a washing process for aggregate; or for other purposes, such as cleaning equipment and trucks, and for road maintenance and irrigation.

Figure 2 Example of volumetric flow rate for reusing or recycling water



Note: In this example it is assumed that there are no losses from Process A and Process B

Quarry dewatering: Pumping water from a quarry to lower the water level in the quarry to obtain a dry area. The water collected could be from rain, ground or surface water. The portion of water from quarry dewatering used on site should be reported as 'quarry water used' and is included in water withdrawal in Table 1 (page 4). In areas under water stress or high water stress as defined by the Global Water Tool for the Cement Sector[2] the unused portion of water from quarry dewatering should be publicly reported as 'quarry water not used' because (i) of its potential impact on the local watershed, which must be assessed, and (ii) it is not water withdrawal according to the Protocol. In other areas, public reporting of this Key Performance Indicator (KPI) is a company decision.

For more information on data management see Chapter 7 (page 24). Indicative values for cement water processing are provided in Annex 3 (page 31). Links are given to a source for indicative values for other industries.

2 www.wbcsdcement.org/index.php/key-issues/water

4 MEASUREMENT METHODS

Measurement offers the most accurate and reliable methodology for water accounting. However, it is a company decision to install measurement devices on water withdrawal, water discharge and the major consumption points.

There are different devices for measuring the volume or flow rate of water passing through a pipe or channel. Meters offer the most accurate and reliable way to gauge water flow, and ensure accurate and continuous flow records. It is important to choose a suitable water meter based on:

- **Water quality –** In some cases, such as for turbine meters, trash caught in the meter causes readings to be high, low or non-existent. This problem can be solved by using a strainer or filters ahead of the meter. Others, such as electromagnetic meters require water containing ions, and an electrical insulating pipe surface requires a rubber-lined steel tube.
- **Range of flow –** the lowest to highest pumping rate needed by the operator. In some cases, a meter that measures the lowest rate for a system may not be able to measure the highest rate. A meter should be selected so the lowest anticipated flow is measured at or near 100% accuracy. Also, for highest accuracy, the meter should operate near the midrange of its capability.
- **Consistency of flow or turbulence –** some meters are usually best for measuring medium to high flows but occasionally for low flows as well.
- **Availability of power –** When selecting meters for remote locations, consider if the meter can run accurately on solar power, batteries or even without power.
- **Ease of access –** The meter must be easily accessible for reading and inspection. It must not be blocked by equipment or other obstacles or be located in a site of frequent flooding.
- **Cost –** Generally the more accurate and reliable the meter, the more expensive it is. Other costs than the purchase price to consider are for installation, maintenance, data collection, calibration and longevity.

Meters may be equipped with many options, such as data loggers and telemetry that can relay real time data. In-line meters fall into two categories.

4.1 Forced flow (full pipe) meters

Two main methods of flow measurement are commonly used for water accounting:

- Volume displacement
- Velocity

Displacement meters, such as rotary piston meters or rotating disk meters, are based on the movement of a mobile element in direct relation to the amount of water passing through. They are suitable and are most accurate at low to moderate flow rates of clean water sources, such as boreholes, municipal networks, and springs.

Velocity meters measure the speed of the fluid through an element of a known internal capacity. The speed can be converted into a volume. This includes single- or multi-jet meters, turbine meters, electromagnetic meters and ultrasonic meters.

Table 4 Most common meters

Turbine meters / impeller meters	Electromagnetic meters
• a rotor or turbine is turned by water flowing through it • The rotor is mechanically connected to a register on the outside of the pipe, which records the amount of water that has passed through the meter • No power needed • Special versions allow some weeds or small particles to pass through	• Work by electromagnetic induction • No moving parts, more reliable • Less prone to fouling • Little or no head loss • Power supply or battery required

Each meter has pros and cons. To ensure accurate and robust monitoring, pay attention to selection, installation and maintenance.

4.1.1 Selecting forced flow meters

A meter should match the system configuration, otherwise the readings and recordings will not be accurate.

Table 5 General guidelines for pressurized pipe flow meters

Meters		Advantages	Disadvantages
Displacement meters	Rotary piston meters	• High accuracy and, repeatability • High resistance to wear	• Used with fairly clean liquids only
	Nutating disk meters	• Constructed from a variety of materials. • High accuracy and repeatability	• Accuracy harmed by viscosities below the meter's designated threshold
Velocity meters	Multi-jet meters	• Highly reliable metering technology • Pipe preceding the meter does not need to be straight • Good resistance to suspended solids • Competitive price	• Not suitable for very small diameters • For high flows, registering capacity is small • Starting flow rates not low enough to detect most leaks
	Turbine meters	• High accuracy and repeatability • Handles viscous flow • Cost-effective • Accuracy by changes in viscosity • Requires little maintenance	• Typical construction materials susceptible to corrosion

Meters		Advantages	Disadvantages
Velocity meters	Electromagnetic meters	• Low pressure drop • No moving parts means less wear, no routine maintenance • Insensitive to density, viscosity, pressure, temperature and flow profile • Usable for a variety of otherwise difficult to meter waters • Accurate • Relatively low cost • Measures independently of temperature, pressure, density, viscosity, and electrical conductivity • Measures forward and reverse flow	• Liquids must be conductive • Nearby electromagnetic noise causes interference • Will not work in partially full pipes, even if electrodes are wet • Requires lengths of straight pipe upstream and downstream • Allowing sludge and greasy waters to flow too slowly causes buildup, which affects measurement
	Ultrasonic meters	• Non-invasive, so no drop in pressure • Eliminates local mechanical and electrical noise, allowing use in a variety of locations • Works with a variety of pipe sizes and flow conditions • Measures independently of temperature, pressure, density, viscosity, and electrical conductivity • High resistance to wear and sensor fouling • Easy installation	• Requires relatively clean water • Excess solids or entrained gases may block ultrasonic pulses

Flow meters: Installation, maintenance and calibration

Installation

A poorly installed water meter will give incorrect readings. Follow manufacturer's instructions when installing and operating meters.

Installation includes these instructions:

- Locate meter near as practically possible to the source of abstraction.
- No branch connections between the meter and the source.
- Fit a strainer before fitting the meter.
- Protect meter from frost.
- Avoid high points that trap air.
- Fit turbine meters with lengths of straight rigid pipe of the same diameter as the meter on both sides. Inlet or upstream length should be at least 10 times, and outlet or downstream length should be at least five times the nominal diameter of the meter.
- Meters should be at least 20 times their nominal diameter downstream of a pump.
- Meters must always be full of water when running.
- Meters must be safely accessible for reading, maintaining, and inspecting.
- Register must be clearly readable.
- Handle meter with care.
- For a meter with an electronic output, any wiring between meter and register must be accessible for inspection.
- Protect readings on electronic totalizers from supply interruptions.

Maintenance and calibration

A meter's performance declines with time, leading to inaccurate readings. As a result, a maintenance protocol must be set up according to the manufacturer's instructions. Systematic records must be kept of maintenance and calibration checks.

These steps must be taken so the meter functions optimally:

- Meters must be stored with their ends sealed.
- Examine meters regularly for wear and tear, corrosion and damage, according to how clean the water is and the meter type.
- Keep insides of the meter clean and free from fouling.
- Change batteries regularly.
- Conduct calibration checks to make sure meters are performing at an acceptable standard. The frequency of these checks often depends on water quality, use of meter, and environmental factors concerning the water source. For example, turbine meters in sand and gravel should be checked every three years, electromagnetic meters on a clean water source every seven years. A calibration laboratory should conduct full checks and be certified.

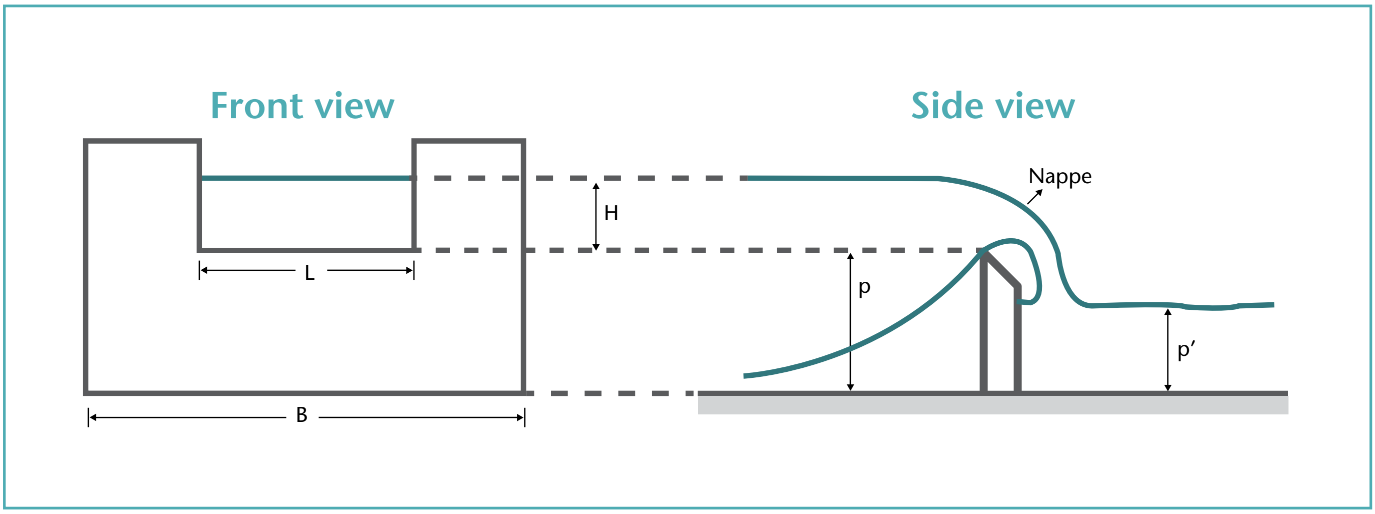
4.2 Open channel / free flow meters

An open channel system refers to any conduit in which liquid flows within a free surface via gravity, and not under pressure. For the permanent and precise measurement of the flow in open channels it is recommended to use structures (known as primary elements). If properly calibrated, a flow equation can be used to calculate the instantaneous flow, depending on the geometry of the structure, hydraulic characteristics of flow, losses and hydraulic heads. The most used structures are sharp-crested weirs and Parshall flumes.

4.2.1 Sharp-crested weirs

Sharp-crested weirs are fixed or removable hydraulic devices that consist of vertical plates with a sharp edge in the upstream face (see Figure 3 below). This type of weir operates on the principle that any blockage in a channel will cause water to back up, creating a high level head behind the barrier. The head, or depth of water flowing over the weir, relates to the flow rate over the weir. The deeper the water flowing over the weir blade, the higher the flow rate.

Figure 3 Front and side views of a sharp-crested weir



Where:

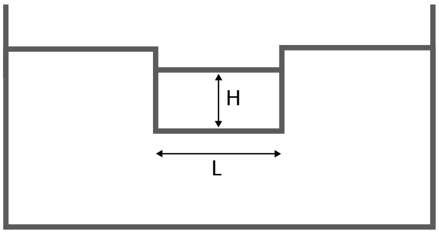
H = Hydraulic head on the crest
L = Length of the crest
B = Width of the access channel

Sharp-crested weirs can be classified according to the following criteria:

- Shape of notch or weir blade: rectangular, triangular (v-notch), and trapezoidal.
- Relative height of crest: full or free weirs (p > p') and incomplete or submerged weirs (p < p').
- Length of crest: weirs without side contractions (L = B) and weirs with contractions (L < B).

When a weir is built and installed properly, measurement accuracy ranges from 85% to 95%.
The experimental equations of the most commonly used weirs for flow measurement in open channels are the following:

Rectangular with contraction:

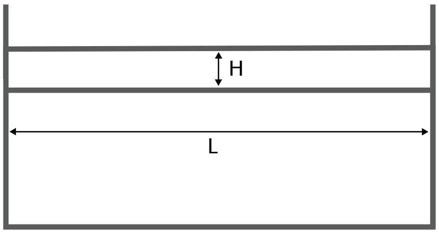


$Q = C * L * H^{3/2}$

Where:

Q = Flow
C = Experimental coefficient

Rectangular without contraction:

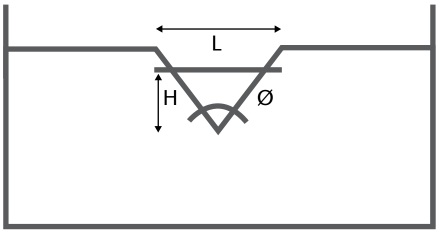


$Q = 3{,}3 * L * H^{3/2}$

Where:

Q = Flow

Triangular (v-notch):



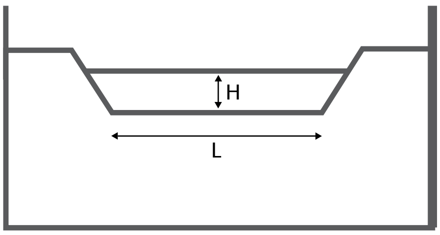
$Q = C * \tan(\varphi/2) * H^{5/2}$

Where:

Q = Flow
C = Experimental coefficient (1.859)

This type of weir is widely used for measuring small flows (< 120 L/s). The most commonly used have a notch angle of 90° and 60°.

Trapezoidal:



$Q = C * L * H^{3/2}$

Where:

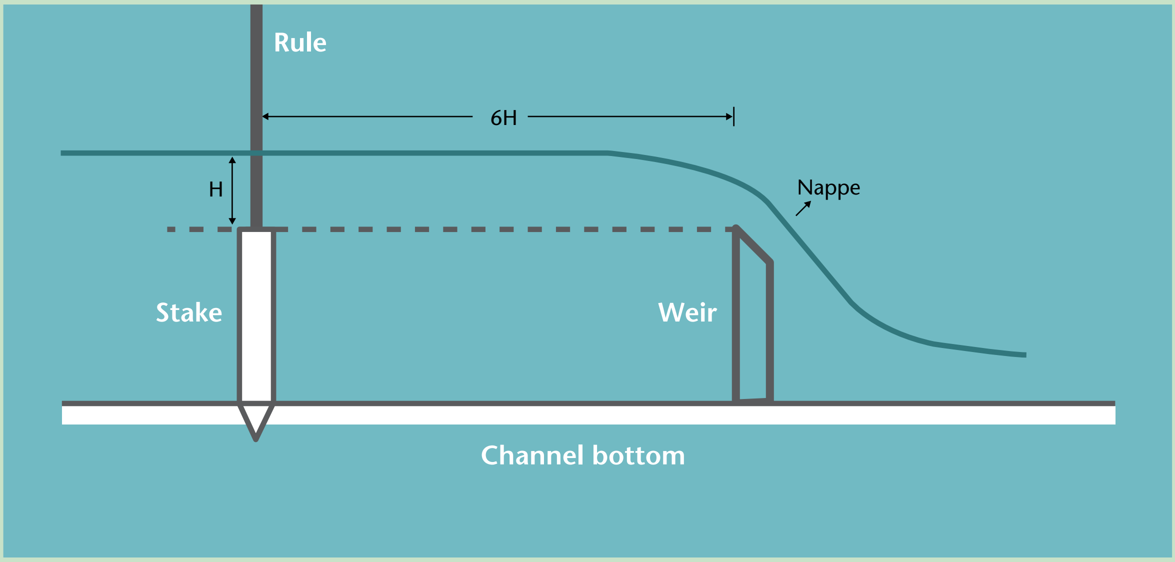
Q = Flow

Measuring open channels

Please take these factors into account when measuring flow in a weir:

- Flow depends on how fast the water arrives in the weir. If it is rapid, flow increases and measurement is affected, so it is important to dam the water by expanding the upstream channel section to get minimum speeds (<0.15 m/s).
- Check for continuous flow in the channel, so water remains at a constant height, and make sure there is no turbulence, so surface waves are avoided.
- Because the nappe is contracted near the weir, head H should be measured upstream at a distance equal to or greater than six times the expected maximum hydraulic head, but never below 2.5H. Use a piezometer to get the measurement of head H, or place a stake level with the crest of the weir; and measure the height of the water above the stake with a rule, as in Figure 4 below.

Figure 4 Measuring water height (H)



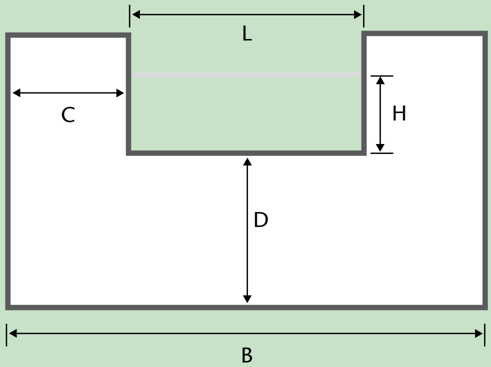
- To calculate flow, a weir must have a calibration equation. An experimental way to get this equation is by assuming the following factors: a hydrostatic pressure distribution exists upstream, implying velocity distribution is uniform; the free surface is horizontal until the plane of the weir and all particles that pass over it are moved horizontally; viscosity and surface tension are negligible; pressure across the nappe is atmospheric. To get the calibration equation, several volumetric gauges must be taken, measuring about 10 in each hydraulic head H. Using a spreadsheet such as Excel, a relationship between variables H and Q can be established and a trend line can be added to get the equation.
- There are two main drawbacks to this method: high head loss; and if the water contains suspended solids, they will be deposited in the pool forming upstream, which gradually modifies the discharge coefficient.

Open channels: Installation, maintenance and calibration

Installation

Figure 5 below shows parts of the weir that must be taken into account during installation:

Figure 5 Diagram of a weir



These instructions should be generally followed:

- Aim to install the weir at the high end of a long channel, long enough or about eight times the width of the weir; and deep enough so the water near the weir is free of eddies and turbulence is at a speed below 0.15 m/s.
- Place the weir perpendicular to the stream on a straight uniform section of the channel, such that upstream the distance is at least 10 times the length of the crest (10xL).
- Build the crest and sides of the weir notch at a maximum thickness of 1/8" (3 mm).
- Design the structure for the maximum head in the watercourse, of no more than one third the length of the crest.
- The weir crest should be edge-shaped, to reduce the effects of viscosity and surface tension and to allow for low heads on the crest, so the nappe does not easily stick.
- Avoid blockages in the upstream side of the weir to prevent immersion of the weir discharge.
- Make sure the crest is straight, level, and well cut.
- The height of the weir crest above the channel bottom (D) must be about three times the water head (H). The distance between sides of the weir notch and the channel walls (C) should be not less than twice the head (H), except in weirs without contraction.
- The width of the channel must be completely covered by the weir so the entire flow passes over the weir.
- H values should be between 0.06 and 0.6 m.
- The v-notch weirs are recommended for small heads.
- For rectangular or trapezoidal weirs, the height must be maximum 1/3 the length of the weir.
- Sharp-crested weirs are usually cut on wood, plastic, fiberglass, metal plates, or other smooth materials, which increases the coefficient in the calibration equation. The notches can be made of beveled metal.
- Sharp-crested weirs are typically used to measure flow rates below 300 L/s.

Maintenance and calibration

Channels and regular elements of the structure must be reviewed regularly for preventive maintenance as follows:

- Aim to maintain design conditions.

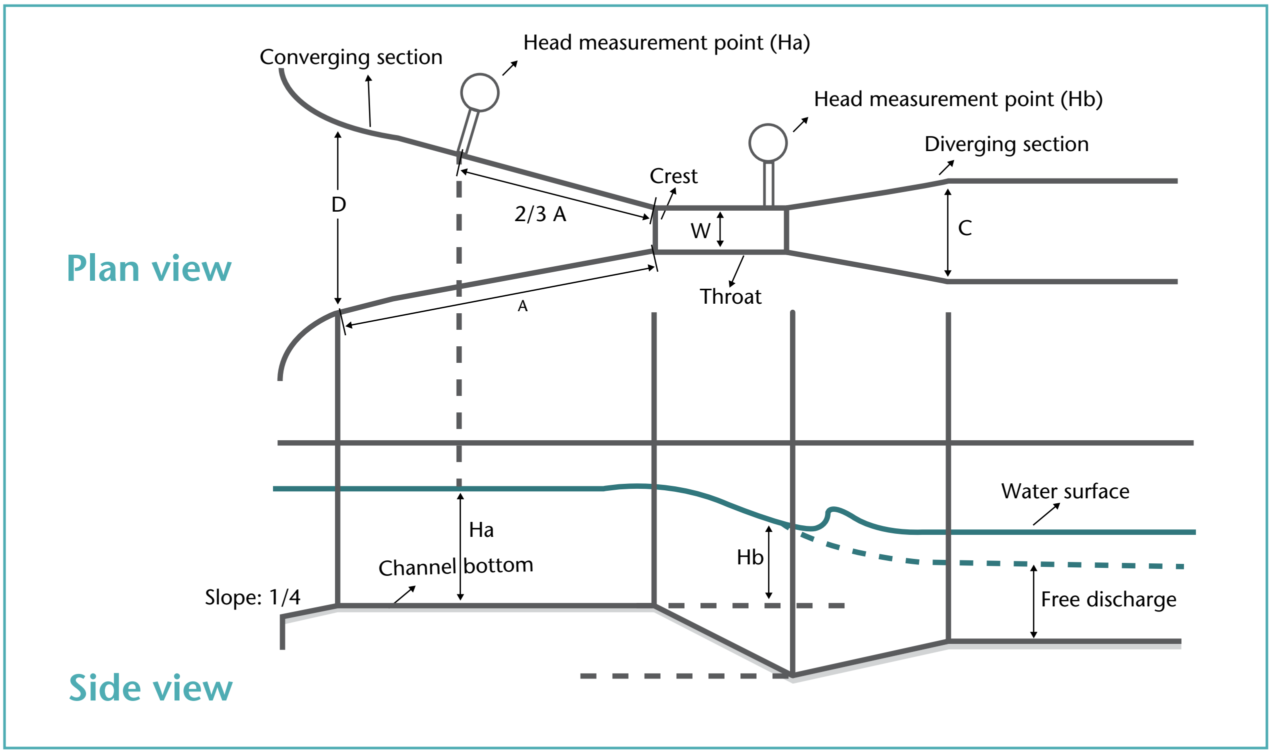
- Regularly review channels and perform periodical removal of sediment and aquatic weeds at the bottom of the channel upstream, Sediments and other obstructions alter the flow direction, resulting in inaccurate readings.
- Revise the condition and position of the rules and other instruments used for head measurement, checking with topography when necessary.
- Verify the position and level (horizontal) of the weir crest, and conduct the proper conservation work.
- Fix leaks in weir wall.
- Check the condition of side and floor walls and conduct conservation.
- Twice a year, update the calibration curve (head vs flow) by performing detailed measurements at different levels. Compare the calibration curve with the theoretical curve (obtained from empirical equation).

4.2.2 Parshall flume

Parshall flume is a sort of open Venturi tube which consists of an input section with converging vertical walls and horizontal bottom, a narrowed throat of parallel walls and descendant bottom and an outlet section with diverging walls and ascendant bottom (see Figure 6 below).

This throat causes an elevation of the water level as a function of flow. The throat width (W) is used to indicate the size of the flume, i.e., a Parshall flume of 9" has a throat width of 9" (0.23 m).

Figure 6 Parshall flume illustration



Where:

W = throat width
A = length of the sidewall of the converging section
2/3 A = distance from the crest to the point of head (Ha) measurement
Ha = head in the converging section
Hb = head in the throat
D = width of the upstream end of the flume at the inlet of the convergent section
C = width of the downstream end of the flume at the exit of the divergent section

These flumes have the following advantages: self-cleaning; operate with a relatively low head loss so they can be used in fairly shallow channels with low slope; increasing speed in the throat prevents particle sedimentation; resistance to chemicals, as they can be built in different materials, and for permanent facilities, they can be built with concrete. A measurement accuracy of nearly 98% can be achieved.

A Parshall flume usually operates under free flow conditions with the critical depth in the contracted section (throat) and a hydraulic jump in the diverging section. However, sometimes the hydraulic jump can be submerged (submerged flow) when the downstream level is high enough to influence and delay the flow through the flume.

In free flow conditions, measuring the head Ha is enough to gauge the flow (at a distance equivalent to two-thirds the length of the sidewall of the converging section, i.e., 2/3A according to Figure 6 above). If the meter is submerged, a second head Hb must be measured at a point close to the final section of the throat (see Figure 6 above). For example, for flumes of 0.15 m to 2.4 m, the position for Hb measurement should be placed 0.05 m upstream of the final part of the throat. For measuring hydraulic heads, install a ruler in the channel wall, or use piezometers. The ratio Hb/Ha is the degree of submergence (S). This relation determines whether the discharge is free flow or submerged flow.

Table 6 Values for Parshall flumes by size and discharge

Flume size (m)	Free discharge	Submerged discharge
$W < 0.30$	$S < 0.6$ (60%)	$0.6 < S < 0.95$ (95%)
$0.30 < W < 2.50$	$S < 0.7$ (70%)	$0.7 < S < 0.95$ (95%)
$2.50 < W < 15$	$S < 0.8$ (80%)	$0.8 < S < 0.95$ (95%)

When the degree of submergence is over 95%, ability to determine flow is uncertain.

The following equations can be used to gauge the discharge in Parshall flumes:

Free flow:

$$Q = K\,Ha^n$$

The constants K and n can be calculated experimentally to get the calibration equation of the flume. Tables of K and n values are available for flumes of different widths (W).

Submerged flow:

Submergence delays the flow, reducing discharge.
In this case, the actual flow rate is lower than flow rate using the free flow equation above. To get the actual flow rate correct, a correction factor (C) must be applied using the following expression:

$$Q = K\,Ha^n - C$$

Where: C = Correction (L/s)

The value of **C** can be measured, where C is related with **Ha**, **S** and **W**.

Parshall flumes: Installation, maintenance and calibration

Installation

For proper installation, follow these guidelines:

- Avoid major turbulence in the initial section, and do not install right after a gate or curve, because turbulence could create waves or eddies that would damage accuracy. Install in a straight section of the channel without obstructions, such as gravel or sandbars to ensure a uniform flow. The distance upstream of the flume should be at least 10 times the channel width.
- Watercourse speed along the upstream channel should be lower than the critical speed.
- Build a ramp with an upward slope of 1:4 right before the converging section, if possible.
- The width of the flume throat must be half to one-third the channel width.
- Install the flume crest to create a free discharge downstream. But if conditions do not allow, maintain the rate of submergence Hb/Ha below 95%.
- Good operation of a fume relies on installing it at the crest, at a suitable height above the channel bottom, to make sure that at the water level upstream the flume is not above the free edge of the channel.

Maintenance and calibration

Conduct these activities to properly manage the structures:

- Review design dimensions periodically.
- Check the level or slope of bottom plates and vertical walls.
- Check hydraulic conditions of operation, such as the type of flow or degree of submergence.
- Because weeds usually grow on the walls and sediment accumulates at the bottom of the entrance to the flume, periodic cleaning of these areas is recommended. For metal flumes, oxides must be removed with a metal brush.
- To prevent corrosion and rust formation, coat the flume with asphalt paint to extend the life of the device.
- At least twice a year do detailed gauging at different levels to get the calibration curve (relation head – flow) and compare with the theoretical curve from equations.

5 CALCULATION BY MEASUREMENT

For the flows that are not metered, calculation by measurement could be used. Such methodologies include:

- Volume measurement
- Speed – area method
- Dust control consumption
- Laboratory measurement of water in product
- Pump instant measured flow rate and pump operating hours (hour meter)
- Invoices from third parties

5.1 Volume measurement

A container of known capacity is filled with water. The total volume is recorded to quantify water use.

This method can be used when the watercourse or discharge has a drop of water in which a bucket can be placed. It can be used to gauge small discharges, by measuring the filling time (t) of a bucket of known volume (V). The flow rate (Q) is determined by dividing the volume of water collected in the container by the elapsed time in collecting it. The longer it takes, the greater the accuracy.

Follow this equation:

$$Q = V / t$$

Where:

Q = Flow rate (L/s)
V = Collected volume (L)
t = Filling time (s)

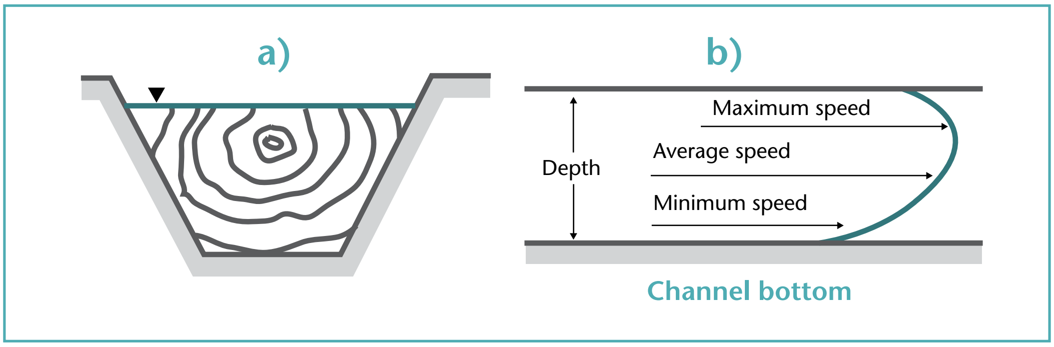
Graduated buckets with marked lines to indicate calibrated volumes are commonly used. In other cases, the measurement is done on larger tanks with exact dimensions. The bucket must get 100% of the flow, with no loss, and the time measurement must be accurate by using a stopwatch, which must be activated simultaneously when the bucket fills and stopped when the bucket is removed. Once the flow rate is taken, it is multiplied with the running hours of this flow to calculate total water flow for a specific period. Because this is done manually, and manipulating the instruments can cause errors, it is not recommended as a permanent measurement system.

5.2 Speed area method

Since the flow rate of a watercourse can be gauged by multiplying the cross sectional area of the channel by the average flow speed, this procedure is based on these variables. In this method flow is laminar and flow lines are normal to the cross section. The speed should be measured at points of the cross section where the average speed has been attained.

In a channel, the maximum speed occurs between 5% and 25% of the depth, and the minimum speed shifts onto the walls of the channel, where the roughness tends to stop the advance of the current. The average speed is located at about 60% of the depth. Figure 7 below shows the typical speed distribution for a channel.

Figure 7 Flow speed distribution in a channel by a) cross-section and b) speed profile

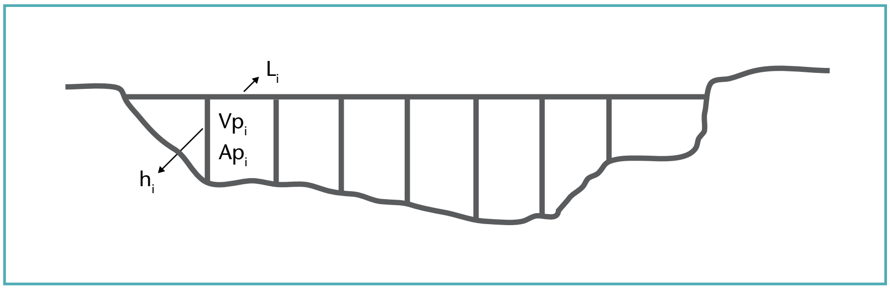


The most reliable way to measure flow speed is using a secondary element (see appendix for more information). For example, the most common instrument is a current meter. When it is immersed in a watercourse, it rotates in proportion to the speed of the watercourse.

To measure the speed of a watercourse with a current meter follow these recommendations:

- The width of the watercourse section (cross-sectional area) must be divided into equal segments, or sections. In narrow channels of less than 3 m, the section must be divided into four equal segments, and in wider channels, the section must be divided into more segments (see Figure 8 below).

Figure 8 Cross-section of a watercourse divided into equal sections



- Measure the depth of each segment. In shallow channels, use a a dipstick; in deeper channels, use a weight suspended from a wire.
- In each section, submerge the current meter to measure the average flow speed in the section. Hold the current meter in the correct position using a dipstick in shallow channels, or suspend the meter with a cable from a bridge or scaffold. To take this measurement there are a few options, depending on how deep the stream is, or how accurate a reading is required:

- **One point method:** immerse the current meter to 60% of the water depth, where the average flow speed can be found.
- **Two point method:** submerge the current meter 20% and 80% of the water depth, since the average of these two values equals the average speed:

$$\text{Average speed} = \frac{\text{(speed at 20\% of water depth + speed at 80\% of water depth)}}{2}$$

- **Three point method:** the current meter is placed to 20%, 60%, and 80% of water depth:

Average speed = 0.25 (speed at 20% of water depth + (2 * speed at 60% of water depth) + speed to 80% of water depth)

- **Five point method:** the current meter is immersed near the surface and at water depths of 20%, 60%, 80%, and near the bottom. The current meter must not rub the surface water at the bottom of the channel.

Average speed = 0.1 (surface speed + (3 * speed to 20% of the depth) + (2 * speed to 60% of the depth) + (3 * speed to 80% of the depth) + bottom speed)

- Measure the total flow rate based on the partial flows, as follows:

$Qpi = Api * Vpi$

Where:

Qpi = Partial flow rate of section i
Api = Partial area of section i
Vpi = Partial average speed of section i

The total flow rate is calculated by adding up the partial flows, as follows:

$Q_T = \Sigma Qpi$

Where:

Q_T = Total flow rate

To calculate total water flows for a specific period, the total flow rate is multiplied with the running hours of the flow. For more information on secondary elements for measuring water flow using the speed-area method, see Annex 2 (page 31).

5.3 Calculating water use of dust control container

In many sites, small water tank wagons are used to reduce dust on roads. Always count this as a withdrawal when water is taken from outside operational boundaries. This formula can be used to estimate water use:

WV = TwV x no. of loads

Where:

wv = Water volume (i.e. discharged)
TwV = Volume of the tank

5.4 Analysis of water content in the end product

This method applies to aggregates and to RMC operations. To calculate the volume of water consumed in the end product, the laboratory analysed water content in the final product can be multiplied by the production volume.

Water consumed for aggregates washing can be gauged by laboratory measurement of the water content, using samples collected from the product stockpile.

The water content in the product should be evaluated periodically for each aggregate specification according to grading. The evaluation should be done once a month. Take the sample from freshly produced material, to eliminate effects of precipitation and natural evaporation.

This procedure is based on a standard quality control test. The water content is calculated by the differential of the mass between a raw aggregate sample (with humidity) and once it has been dried. Use the following guidance to develop a formal procedure that a quality control technician can support.

- Sample the material in freshly-produced aggregates, to avoid humidity loss
- Vary the mass of material sampled by size. Small aggregates require less material
- Weigh the raw material: The volume of aggregates sample is weighed as it is sampled, and humidity is determined. The mass is noted
- Dry the material of the sample in an oven at 110°C until the mass is constant, then cool at room temperature
- 12 hours at 110 °C is usually sufficient. Material will dry easily if sprayed in a pan
- Once the material is at room temperature, weigh the sample and note its dry mass
- Assess the water content, by subtracting the dry mass from the raw mass divided by the dry mass:

$$\% \text{ of water} = \frac{(\text{weight of raw sample}) - (\text{weight of dry sample}) * 100}{\text{weight of dry sample}}$$

In ready-mix operations, weighing systems used in the ready mix concrete mixer can be used to measure the water added in concrete production and for other uses, such as mixer washing. These systems are usually linked to a recording device or software for online data acquisition, such as the batch plant Programmable Logic Controller (PLC) .

WV =
TwV x no. of loads

Where:

WV = Water volume
(i.e. discharged)

Alternatively, measurement of the water in the ready-mix concrete can be determined through measurement on-site of the water content in the freshly-produced concrete. A sample of freshly produced concrete is dried at 80°C to 110°C in a pan or an oven until its mass is constant, and the total water content is determined.

5.5 Pump flow rate and pump operating hours

The volume of water pumped during a period of time is calculated using this equation:

Volume of water

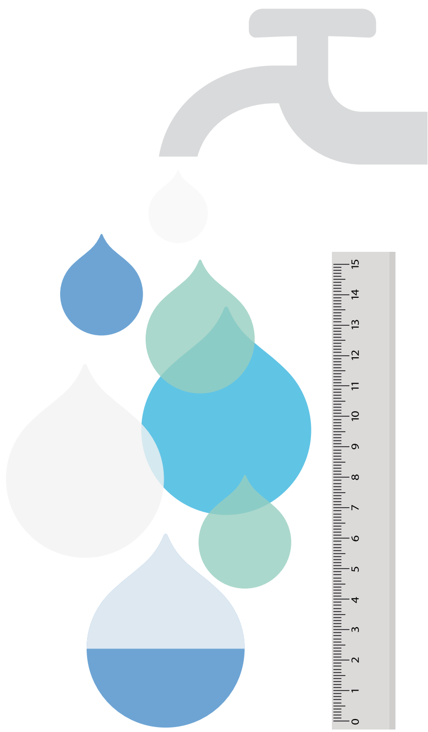
=

time * measured flow rate

To determine the pump flow rate, measure the water flow periodically with a portable flow meter and use measured flow, instead of pump capacity. Hour meters only record the pumping time. The flow rate must be measured at least once a quarter in stable conditions and more often if operating conditions change significantly. For example, if the water level changes in the pump basin that generates a head lift, or if a pump is relocated or replaced. The main drawback with this method is that it does not account for pump fluctuation over time, which could cause less precise readings of flow rates.

5.6 Third-party invoices

Meters belonging to a third party can at times be as reliable as direct readings from meters. Measuring devices belonging to third parties, such as city meters, should be verified, if there is access to read a meter on site. Check invoices to make sure accurate data are reported.



6 CALCULATION BY ESTIMATION METHODS

For unmeasured flows, calculation by estimation techniques can be useful, including:

- Pump capacity and pump operating hours
- Calculating evaporation and storm water flow volumes

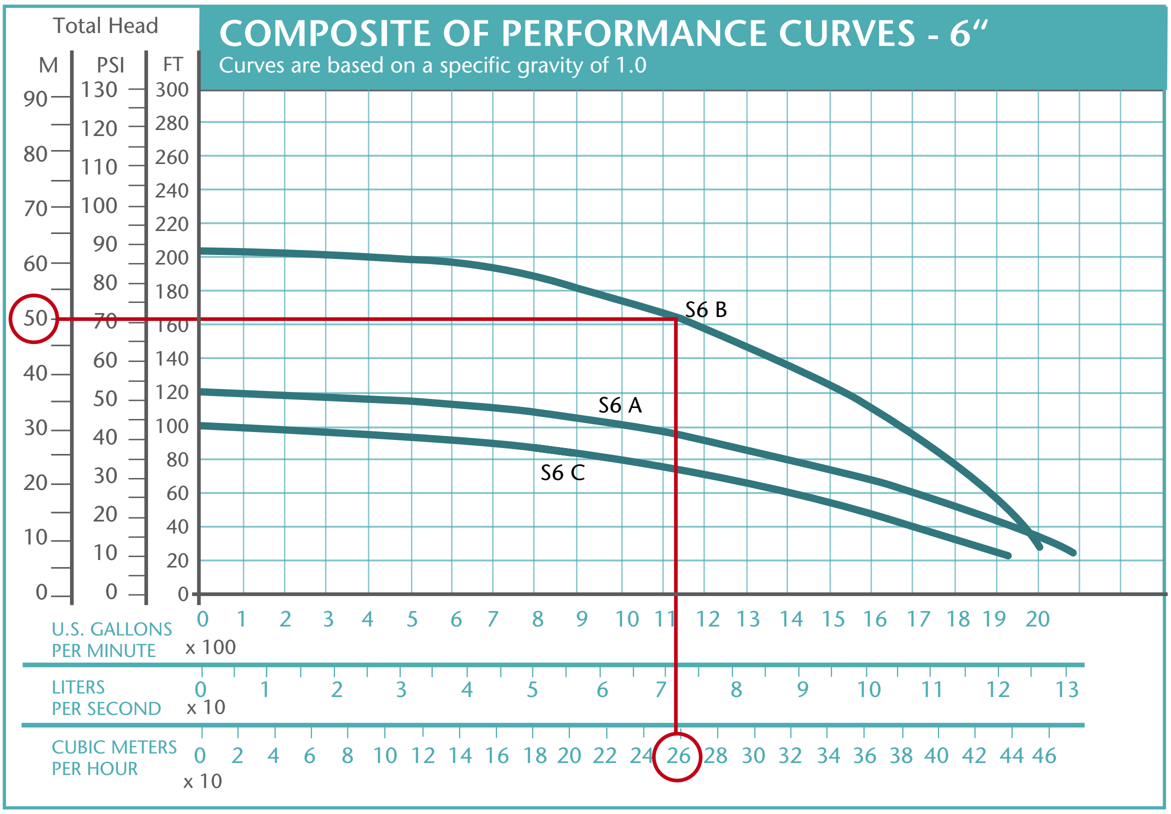
6.1 Pump capacity and pump operating hours

Use of theoretical pump flow rate is not recommended because it may deviate significantly from the actual flow rate. However, in the absence of other information, this method may be used.

Theoretical pumping flow

The theoretical flow rate at the final discharge outlet can be calculated by combining the pump capacity and the head losses through the piping system. The manufacturer typically provides a graphical representation of the performance of its pump.

Figure 9 A manufacturer's pump performance curve



The pump curve describes the behaviour of the flow rate as a function of the total head loss. According to the pump setup, the pump manufacturer calculates the total head losses and then the theoretical flow rate, using the pump performance curve.

Once the theoretical pump rate is calculated, it is multiplied with the running/operating time of the pump to get the total water flow for a certain period.

6.2 Calculating natural evaporation

Natural evaporation can have a huge impact on water consumption. In large open areas, wind, temperature, and humidity affect the evaporation rate.

Natural evaporation cannot be measured, but it can be estimated using available empirical equations.

6.3 Calculating precipitation

You can estimate precipitation based on the quantity of precipitation and the size of the catchment area. The volume of precipitation used can be estimated by multiplying the precipitation and the catchment area factor.

Volume of precipitation

A pluviometer installed onsite or consigned data published by a government or meteorological institute can both be used to gauge the volume of precipitation.

Pluviometer - also called a rain gauge, it measures the depth of water from precipitation at a point. It is the most reliable method, because it is site specific.

Principle: A pluviometer collects precipitation in a container open to the sky. The precipitation that falls into the container is measured, by mass or by volume. The measure is recorded by sight or by an automatic weather station.

Precision: Weather conditions affect accuracy. Heavy winds, low precipitation, a mix of liquid and solid precipitation, and freezes may cause a false measurement. For snow, specific gauges are available. To boost precision, install the pluviometer in an open area without objects such as trees or buildings that would interfere with collecting rain water.

Consigned data - meteorological data from a recognized agency, such as a government body or meteorological institute. These organizations uphold high standards of measurement that include all precipitation, including snow. However, since the data are not site-specific, an on-site pluviometer is preferable, but not mandatory.

Catchment area

The catchment area of the surface that collects precipitation runoff must be evaluated. Once done, the data will not change until the site configuration changes.

The amount of precipitation runoff produced in a catchment area is directly related to the geological and topographical characteristics of the drainage area. These catchment area characteristics include:

- Size and shape of the catchment area
- Slope and length of hills and mountains
- Type of vegetation or surface cover
- Type and condition of soils and rock strata
- Presence of streams, ponds, lakes, and other water bodies

7 DATA MANAGEMENT

There are two types of data sources:

- Periodic water monitoring
- Continuous water monitoring systems

Table 7 Advantages and disadvantages of continuous and periodic monitoring

Characteristic	Continuous water monitoring systems	Periodic water monitoring
Sampling period	Monitors all or most of period	Snapshots of profile
Speed of generating results	Nearly real-time output of results	Real-time results with portable instrument analysers, delayed results with laboratory end-method
Stability	Sensors prone to fouling at times	Sample integrity must be maintained before analysis
Availability	For limited number of determinants	Comprehensive range of methods
Applicability	May not meet performance requirements	Methods meet performance of most regulatory requirements
Reporting results	Results continuously averaged, typically over one hour or 24 hours	Results reported as daily average or instantaneously
Capital cost	Tends to be higher than equivalent periodic monitoring	Tends to be lower than equivalent continuous monitoring
Equipment certification	Available	Available, laboratory equipment use covered by ISO 17025 or equivalent
Monitoring accreditation	Not applicable	Available for sampling and analysis

Continuous monitoring systems are recommended. The systems should be selected, installed, maintained and calibrated according to this Guidance.

The type, reference, and maintenance of meters, and their calibration over time should be reported in log sheets and filed.

The process for continuous and periodic monitoring including data management should be put in writing and available at site level to those in charge of monitoring and reporting and include the following:

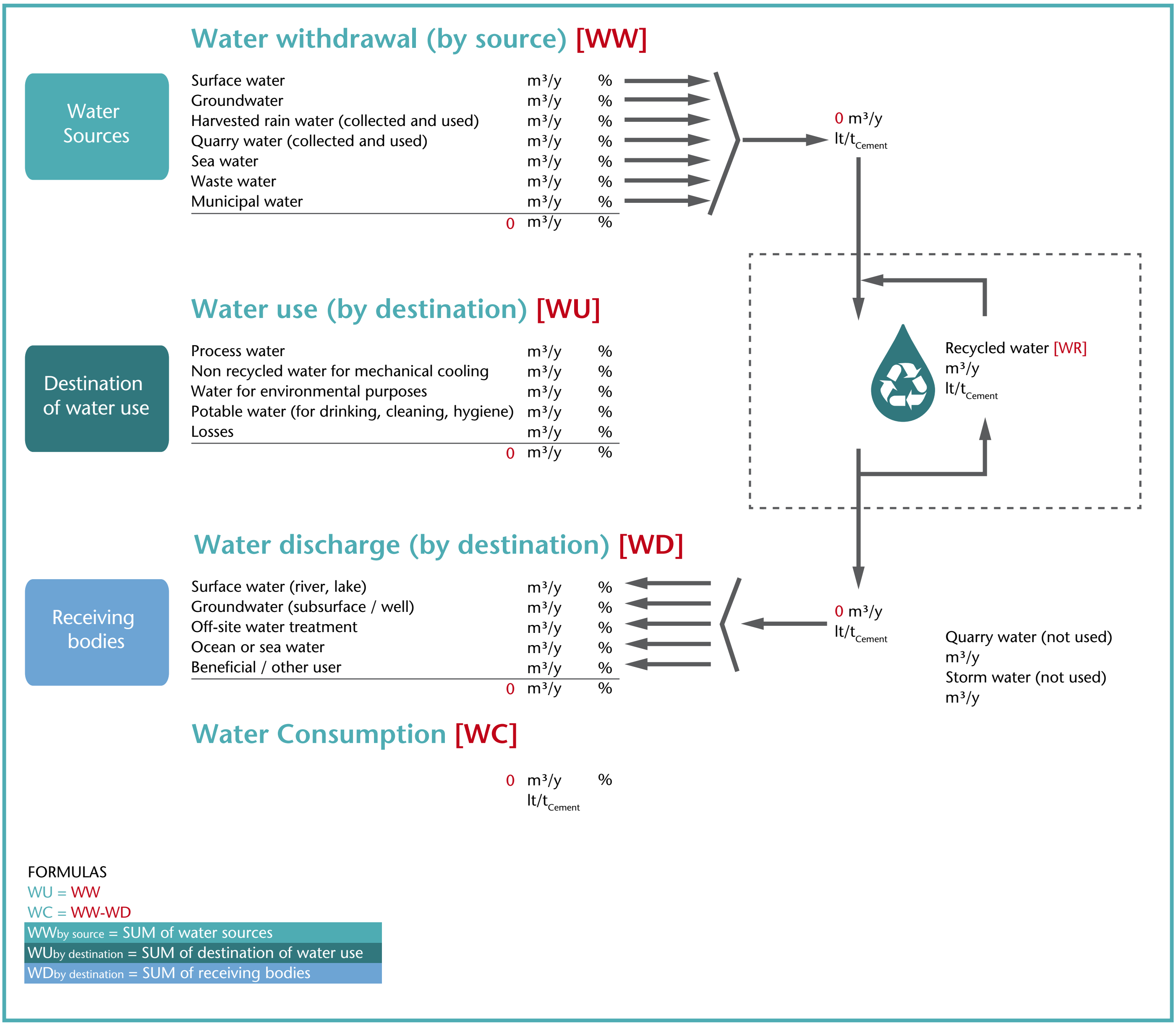
- Identification of measured flows
- Standards, methodology for periodic monitoring
- A monthly frequency is recommended
- Log sheets
- People-in-charge

A process should be issued for each cement plant. But a single process could cover several aggregate installations and ready-mix concrete units according to business, area, or zone. Assign resources and responsibilities for maintenance follow-up and calibration of meters, monitoring, and data logging.

Assess how coherent are the data. Then create and put in place a validation process in which the data are placed. Explain variations of flows over time. Check the coherence of water accounting with simplified water balances between water withdrawals, and check discharge and consumption by identifying main water usage. People who monitor, report and validate should be trained, so they have a basic knowledge of water accounting, and can assess the coherence of figures.

Here is a simplified diagram that shows cement water withdrawal, consumption and discharge and a balance sheet for water accounting, with a rough breakdown by source, usage and discharge destinations:

Figure 10 Water accounting balance sheet



8 GLOSSARY

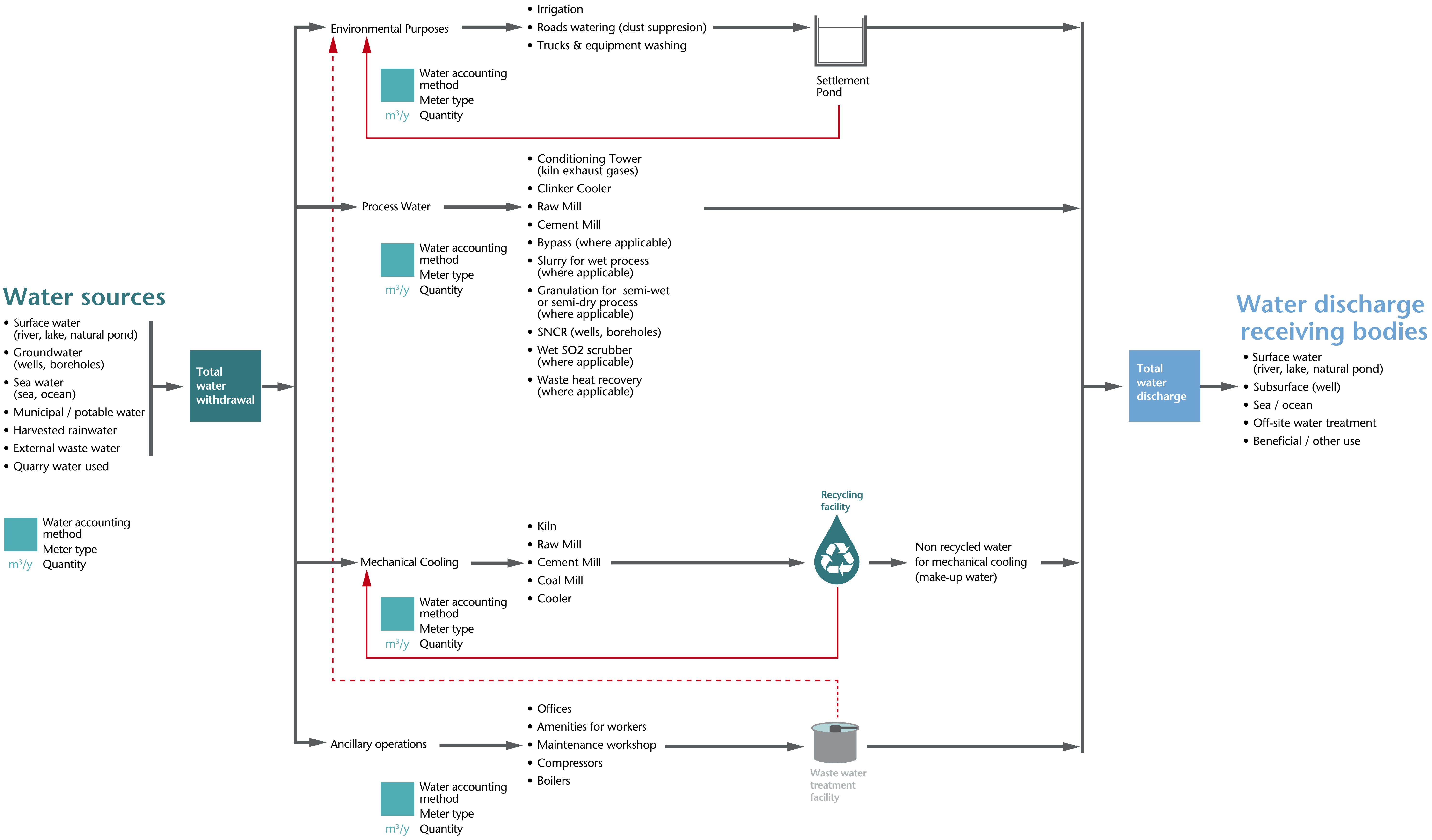
- **Aggregate operations:** Quarrying, handling and processing non-metallic mineral products for classification or size reduction. Mineral products are supplied from quarries or recycled aggregate products. Processing sand and gravel for a specific market may involve different combinations of washers, screens and classifiers to segregate particle sizes; crushers to reduce oversized materials; and storage and load facilities.
- **Beneficial use:** Discharges directly to external organizations for specific use by industry, agriculture, for human use or to construct wetlands.
- **Cement operations:** Quarrying, handling, crushing, milling, burning and cooling materials to produce clinker or cement. If a captive power plant is located on the same premises as a cement plant, water indicators should be reported separately. On the other hand, waste heat recovery systems included in the cement process should be reported together with the cement plant.
- **Freshwater:** The constituent content of freshwater should be defined by local regulations. In the absence of local regulations, a limit of 1000 mg/L of TDS recommended by the World Health Organization is the gauge for categorizing fresh and non-fresh surface water and groundwater.
- **Groundwater:** Water in soil beneath the soil surface, usually when the water pressure is greater than the atmospheric pressure, and the holes in the soil are filled up with water.
- **Harvested rainwater:** Rainwater that is collected and used on site.
- **Operation:** Any kind of business activity.
- **Municipal supply:** Drinking quality water supplied by a public organization.
- **Potable water:** Water suitable for drinking.
- **Product:** A material of commercial value in one of three forms: cement, aggregate or ready-mix concrete.
- **Quarry water:** Water extracted from the cement or aggregates quarry, also called quarry dewatering. It may be any combination of groundwater, surface water, and precipitation.
- **Ready-mix concrete (RMC) operations:** Concrete manufactured in a factory or batching plant, according to a set recipe, and delivered to a work site, by truck mounted in–transit mixers. Process units include mixers, pumps and handling.
- **Receiving body:** Destination of water discharges.
- **Recycled water:** The amount of used water or wastewater used in another cycle that goes back into the same process, or in a higher use in the process cycle, before discharge for final treatment or to the environment.
- **Recycled or reused water (%):** The amount of recycled and reused water as a percent of total water withdrawal.

- **Reporting:** Disclosing data and relevant information to internal and external stakeholders, such as management, employees, governments, regulators, shareholders, the general public, local communities or interest groups.
- **Reused water:** The amount of used water or wastewater deployed for another function in a lower use in the process cycle, before discharge for final treatment or to the environment. Reuse includes for irrigation inside the boundary of a facility.
- **Source:** Origin of water withdrawal.
- **Stormwater:** Rain and stormwater run-off collected and discharged not used on the site.
- **Subsurface discharge:** Injection of effluent water into any underground medium for disposal.
- **Surface water:** All waters on the surface of the earth, including fresh and salt water, ice, and snow, oceans, lakes, rivers, and wetlands, but not including water from the sub-surface, such as groundwater.
- **Value chain:** The chain of activities of a firm operating in a specific industry.
- **Water consumption:** water evaporated for cooling and from water storage facilities, lost via transmission, or used in an organization's products and onsite, calculated as difference between water withdrawals and water discharges. Total water consumption includes rainwater harvested on site for any use. Unlike total freshwater consumption, it excludes harvested rainwater.
- **Water discharge:** The sum of water effluents discharged, over the course of the reporting period, to the ocean, surface, subsurface or well, off-site water treatment, beneficial user or other user through a defined discharge point (point source discharge), over land in a dispersed or undefined manner (non-point source discharge), or wastewater removed from the reporting organization via truck.
- **Water withdrawal (or use):** The sum of all water drawn into the boundaries of the reporting organization from all sources (including surface water, groundwater, used quarry water, municipal water, external waste water, and harvested rainwater) for any use during the reporting period.
- **Watershed:** any area with a common outlet for surface runoff. Synonyms include catchment, drainage area, and river basin.

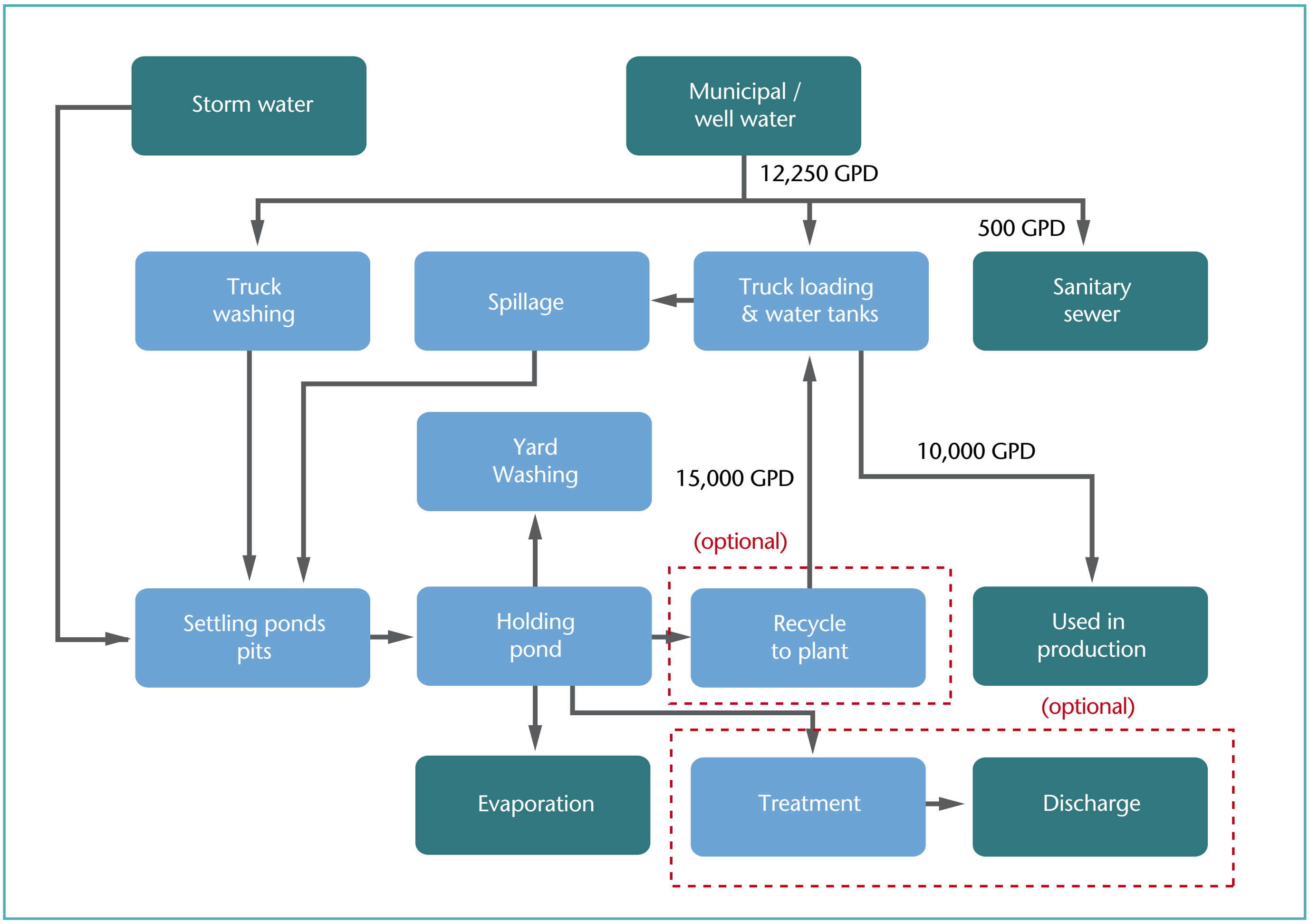
Annex 1 Water flow diagrams

Typical water flow diagrams for (a) cement, (b) aggregate and (c) ready-mix are provided below.

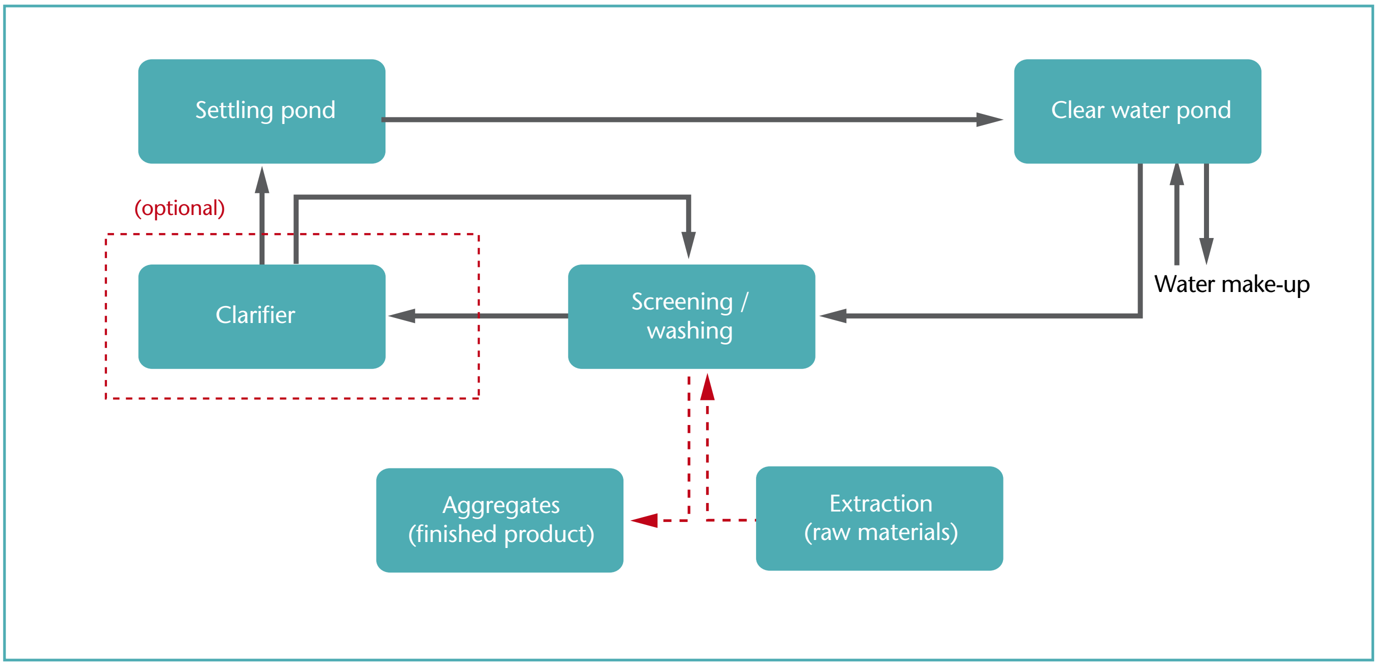
(a) Water flow diagram for cement plants (source: Titan)



(b) Process water flow diagram for a ready mix concrete plant (source: Cementos Argos)



(c) Process water flow diagram for aggregate installations (source: Italcementi)



Annex 2 Secondary elements

A secondary element measures the velocity of flowing water. Velocity is used to calculate the flow of water through the speed-area method.

Here are a few secondary elements:

a. Rotating-element mechanical meters

The operating principle of a mechanical meter, or rotating element current meter, is based on the proportionality between the velocity of water and the angular velocity of the meter rotor. By placing a mechanical current meter at a point in a stream, and counting the number of revolutions of the rotor during a measured interval, the velocity of water can be discovered from the meter rating.

b. Electromagnetic meters

An electromagnetic current meter is based on the principle that a conductor (water) moving through a magnetic field will produce an electrical current directly proportional to the speed. By measuring this current and the distortion in the magnetic field it causes, the instrument can be calibrated to measure point velocities of flowing water.

c. Acoustic meters

The acoustics meter uses the Doppler principle to determine point velocities of flowing water and complete vertical velocity profiles. An example is the ultrasonic meter: installed over the water level, it emits a noise pulse and measures the time response proportional to the flow rate.

d. Optical meters

The optical current meter uses a device calibrated to measure surface velocities of flowing water, but cannot be used to determine sub-surface velocities.

Annex 3 Indicative values for process water consumption (generic ranges)

The following values are only to assess water consumption for accounting purposes, but may need to be adapted to the local context.

a. Cement manufacturing

Water for wet kiln feed preparation:

Basis: 1T of clinker requires 1.55T of raw materials

Water content of natural raw materials applied in wet processes

Minimum: 10%, corresponding to 172 L / T clinker

Maximum: 20%, corresponding to 388 L / T clinker

Water content of slurries

Minimum: 32%, corresponding to 729 L / T clinker

Maximum: 42%, corresponding to 1,122 L / T clinker

Water added for slurry preparation

Low water slurries (10% to 32%) 557 L / T clinker

High water slurries (20% to 42%) 734 L / T clinker

Total water for slurrification: 550 to 750 L / T clinker

Water for semi-wet process:

This technology is between wet and semi dry processes
270 to 550 L / T clinker

Water for semi dry process:

Total water for granulation (12 to 15% moisture)
200 – 270 L / T clinker

Water for cooling kiln exhaust gases to 150°C

4 stages preheater kiln (800 kcal/kg, 340°C):
150 L / T clinker

4 stages precalciner kiln (760 kcal/kg, 370°C):
170 L / T clinker

5 stages precalciner kiln (730 kcal/kg, 320°C):
130 L / T clinker

6 stages precalciner kiln (710 kcal/kg, 300°C):
110 L / T clinker

Conditioning water for kiln exhaust gases
in direct operation mode (20% run time):

110 – 170 L / T clinker

in compound operation mode (80% run time):
Fraction of the above

Water consumption of closed circuit equipment cooling systems

Make-up water approx.: 50 - 60 L / T clinker

Thereof:

To compensate evaporation cooling 20 - 30 L / T clinker

To compensate bleed water 20 - 30 L / T clinker

To compensate drift losses 5 L / T clinker

Water consumption of open circuit equipment cooling systems

Suggested: 1400 – 1500 L/T clinker

Water injection in bypass cooling towers

Suspension preheater kilns 60 L / T cli, 10% bypass rate

Precalciner kilns: 30 L / T cli, 10% bypass rate

Water injection in clinker coolers

Grate coolers: 2 – 5 L / T clinker

Planetary coolers 30-40 L / T clinker

Rotary coolers 40-60 L / T clinker

Water injection in cement mills

Average 10 – 30 L / T cement

Maximum 40 L / T cement

Water consumption for wet SO^2 scrubbers

Rough estimate 100 L / T clinker

b. For RMC and aggregate

In the absence of data for ready-mix and for concrete, the following link may provide a useful basis. However, values vary from country to country.

The values stated should first be used first to give an indicative direction, and to give guidance for calculations at the site level:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/509928/LIT_9909.pdf
For RMX, review the National Ready Mixed Concrete Association (NRMCA) manual www.nrmca.org/sustainability/Certification/SCP Guidelines Version 1.1.pdf. Note average water consumption on page 21 and average batch water usage on page 24.

About the World Business Council for Sustainable Development (WBCSD)

The World Business Council for Sustainable Development (WBCSD), a CEO-led organisation of some 200 forward-thinking global companies, is committed to galvanising the global business community to create a sustainable future for business, society and the environment. Together with its members, the council applies its respected thought leadership and effective advocacy to generate constructive solutions and take shared action. Leveraging its strong relationships with stakeholders as the leading advocate for business, the council helps drive debate and policy change in favour of sustainable development solutions.

The WBCSD provides a forum for its member companies – who represent all business sectors, all continents and a combined revenue of more than $7 trillion – to share best practices on sustainable development issues and to develop innovative tools that change the status quo. The council also benefits from a network of 65+ national and regional business councils and partners organisations, a majority are based in developing countries.
www.wbcsd.org

About the Cement Sustainability Initiative (CSI)

The CSI is a global effort by 24 leading cement producers, with operations in more than 100 countries. Collectively, these companies account for around 30% of the world's cement production and range in size from very large multinationals to smaller local producers. All CSI members have integrated sustainable development into their business strategies and operations, as they seek strong financial performance with an equally strong commitment to social and environmental responsability. The CSI is an initiative of World Business Council for Sustainable Deveplopment (WBCSD).
www.wbcsdcement.org
www.wbcsdcement.org/water

Disclamer

This report is released in the name of the WBCSD. It is the result of a collaborative effort by members of the Secretariat and executives from member companies participating in the CSI. Drafts were reviewed among CSI members, so ensuring that the document broadly represents the majority view of this group. This does not mean, however, that every member company agrees with every word.

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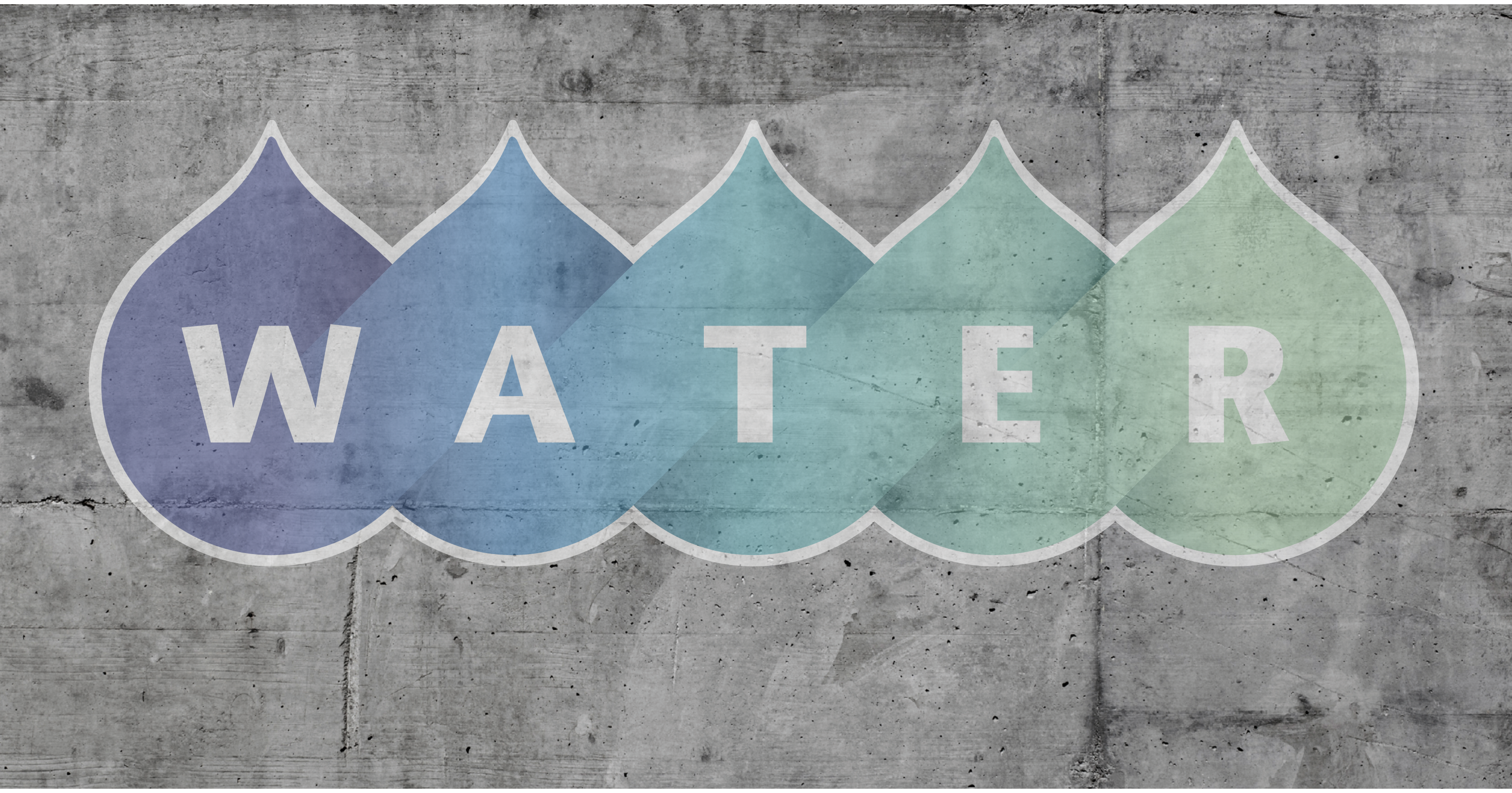

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