3. Assessing Volume

3.1 Overview of the Method

Assessing volume is the process of measuring or approximating the space occupied by FLW. To meet the requirements of the *FLW Standard*, the volume of FLW must then be converted to a weight. The method is ideal for liquid FLW, but can also be applied to solid and semi-solid material, including solid FLW suspended in liquid.

An entity may use devices such as calibrated containers to measure the volume precisely, or may use other techniques including water displacement or visual assessment. The international standard measurement unit[6] of volume is cubic meter (m^3) but gallons or liters are also commonly used in relation to FLW.

ADVANTAGES AND DISADVANTAGES

If FLW is in a container, it is easier and cheaper to assess its volume than to weigh it. It can be impractical to carry out the sampling and physical moving that is required for weighing if the FLW needs to be removed from the container.

The principal disadvantage of assessing volume is that it requires the application of density factors to convert the volume to weight, which may introduce inaccuracies into the data.

LEVEL OF EXPERTISE REQUIRED

The level of expertise required will depend on the approach chosen for assessing the volume of FLW. A laboratory-based water displacement method will require basic laboratory skills and equipment, whereas a measurement-based approach in which an entity reads pre-calibrated containers will require no special skills.

COSTS

Because assessing volume requires physical access to the FLW, costs will be related to ease of access. If multiple sites are included in the scope, then visiting them will add to costs, as will purchasing or renting relevant measuring devices.

3.2 Guidance on Implementing the Method

An entity that assesses volume to estimate FLW will need to undertake a series of steps.

1. SCOPE THE STUDY

As Chapter 6 of the *FLW Standard* explains, a well-defined scope, aligned with the five accounting principles and an entity's goals, is important for ensuring a FLW inventory meets an entity's needs. The scope of an entity's inventory, defined by the timeframe, material type, destination, and boundary, will influence the approach taken to assess volume. Chapter 6 also describes how the scope chosen by an entity for its FLW inventory should be aligned with its underlying goals for addressing FLW.

2. DEVELOP A SAMPLING STRATEGY AND TAKE THE SAMPLE

In some instances it will be impractical to assess the volume of all the FLW, in which case a sample of FLW should be taken and the volume of the sample assessed. Guidance on sampling is provided in Appendix A of the *FLW Standard*.

3. TAKE MEASUREMENTS OR MAKE APPROXIMATIONS

There are five basic approaches to assessing the volume of FLW:

- Reading from pre-calibrated containers (e.g., a measuring jug)
- Measuring dimensions (e.g., using a measuring tape)
- Using a water displacement technique
- Using a visual assessment
- Using a flow meter (e.g., where liquid is disposed of through a pipe)

Box 3.1 | Examples of Pre-Calibrated Containers

Example 1.
A study in the United Kingdom supplied a sample of households with three different sizes of measuring jugs. The participants used them to record the amounts and types of liquids thrown away during a one-week period. This allowed for a relatively accurate measurement of volume to be obtained for certain commonly wasted items that could be measured using jugs.

Example 2.
In the United States, the "Take the Challenge Initiative" instructed households to tape a printed "measurement" label on bags of a specified size with the one-eighth-volume measure at a uniform distance from the bottom of the bags. At the end of each week, households measured and recorded the volume of FLW (excluding liquids) in the bag, using the fractions on the printed label. Households were encouraged, if they had a kitchen scale at home, to weigh the FLW as well for a more accurate measurement.

Sources:
WRAP (2013a).
West Coast Climate Forum. 2015. "Take the Measurement Challenge Instructions."
Accessible at: <http://westcoastclimateforum.com/food/wasteless>

Reading from pre-calibrated containers

An entity typically uses pre-calibrated containers to quantify liquids, semi-solid material, and some granular solids. However, a variation of this approach can also be applied to quantifying solid FLW (see Box 3.1).

Measurements from pre-calibrated containers will be most accurate if the containers come from a reputable source and have been calibrated in a way that links back to weights and measures standards. In order for the reading to be made to an acceptable degree of precision, it is important that the container is an appropriate size for the amount of FLW being measured. For example, measuring less than 1 liter of liquid in a jug that has 1 liter as its first marked increment will result in the amount having to be approximated.

Box 3.1 provides two examples of using pre-calibrated containers as part of a diary exercise to collect information on household FLW. In the first example, households were provided with pre-calibrated measuring jugs, which enabled measurements of liquid FLW to be taken with a high degree of accuracy. In the second example, households created a "pre-calibrated" container using a printed "measurement" label that participants taped to a paper bag with known dimensions (in this case: 5⅛" x 3⅛" x 10⅝"). Since participants affixed the label to a bag themselves, the degree of accuracy may have been compromised; however, this approach to labeling is likely inexpensive to implement.

Measuring dimensions

A simple approach to measuring the volume of a solid object, a reasonably uniform pile of FLW, or a full container of FLW is to measure its dimensions (e.g., with a measuring tape) and use standard formulas to convert them to a volume (see Table 3.1). To help with calculating volumes from dimensions, many online tools allow an entity to enter dimensions and calculate the result automatically.

An entity should ensure that it uses the same units for all the dimensions.

Table 3.1 | Common Formulas for Converting Dimensions to Volumes

ITEM	FORMULA
Cube	Area of side, cubed
Cuboid/block	Width x length x depth
Cylinder	*pi* (3.141592) x radius squared x height
Cone	*pi* (3.141592) x radius squared x (height/3)
Pyramid	(Length x width x height)/3

Using dimensions to measure volume may result in an approximation rather than a measurement if the FLW is an irregular shape, if a pile of FLW is not of uniform height, or if a container is not completely full (see "using visual assessment" below). An entity should declare such sources of uncertainty in its inventory report.

Using water displacement

The technique of water displacement involves submerging FLW in a known quantity of water and measuring the water that is displaced as a result. It may be appropriate for items that cannot easily be measured (e.g., because they are irregular in shape) and which are insoluble, such as items in packaging.

When using this technique an entity must ensure that the container into which the item is submerged is first filled with water, and that the item is submerged slowly to allow the water to seep into any air pockets. The amount of water displaced should be captured and carefully measured using a pre-calibrated container. One way of using water displacement, though focused on "street litter," is described in *Analysis of Birmingham Street Litter and Litter Bin Waste* by M·E·L Research (2002) (unpublished; available on request from info@m-e-l.co.uk).

Using visual assessment

A visual assessment may be used to provide an approximation if more precise measurements cannot be made. For example, if FLW is in a container, the capacity of the container may be known (e.g., from a waste management company) or the dimensions may have been measured. An entity would visually assess the proportion of the known or measured volume that is occupied by the FLW (e.g., half full, three-quarters full) and then derive an estimated volume.

Using a flow meter

If FLW is disposed of through pipes (e.g., to the sewer), a flow meter can be installed to measure the total volume of liquid discharged. An entity can use the volume measured to estimate FLW. In some cases, the liquid flow of FLW will be diluted with another liquid, typically wastewater. One method of dealing with this is to measure the organic compounds within the total liquid waste stream, then derive the FLW liquid waste volume by using a known conversion factor for the organic compounds/FLW product of interest.

Box 3.2 describes how this approach might be used in the case of raw milk, which has a high level of "chemical oxygen demand" (COD).

4. CONVERT VOLUME TO WEIGHT

To complete the inventory and report the weight of FLW quantified, an entity will need to convert the measured or approximated volume to weight. This conversion involves the use of density factors.

If there is no void or empty space in the FLW (e.g., for a liquid measured in a container), an entity can use the standard conversion formula of "volume x density factor = weight."

However, because FLW will normally consist of a number of disparate component parts (e.g., peel, pits, portions of uneaten food), there will often be void space within the measured volume. Because this void space does not weigh anything, including it will overestimate the weight of the FLW. For this reason, if void space is included in the measurement or approximation of the volume (e.g., FLW from a waste collection container), an entity should instead use what is referred to as a "bulk density" factor. The conversion formula is "volume x bulk density factor = weight."

The bulk density of any particular amount of FLW will be determined by the type of FLW, the way in which it is stored, and the degree of compaction. In the case of agricultural crops, it may also vary by variety, by plumpness (e.g., how well grain is filled during growth) and by moisture content. It is therefore difficult to generalize about the appropriate factor to use.

To obtain the most reliable bulk density factor, an entity may take a sample of the FLW, measure the weight and the volume, and then divide the weight by the volume, ensuring that the "volume units" are matched with the "weight units" (e.g., cubic meters with metric tons, liters with kilograms). International standards for this matching are available from ISO.

If an entity does not develop a customized bulk density factor from the FLW it is quantifying, it may use a bulk density factor from another source. The Food and Agriculture Organization of the United Nations (FAO) provides a comprehensive list of densities of specific foods,[7] which are expressed as grams/milliliter (g/ml) and may be used to convert volume to weight. If an entity uses these factors, it would apply the formula "volume x FAO density factor = weight" while ensuring that units match. For example, if the volume of the FLW has been measured in liters it should be converted to milliliters before applying the FAO factor, and the result of the calculation transformed from grams to kilograms—or whichever unit of quantification an entity is using for its FLW inventory report.

An entity should understand how these factors were developed in order to be sure that they are applicable and take into account the standard deviation. The factor used should be relevant to the unit of volume and state the result in the appropriate unit of weight. For example, a factor labeled "t/m^3" will convert cubic meters to metric tons while one labeled "kg/l" will convert liters to kilograms.

Box 3.2 | Illustrative Example: Using Chemical Oxygen Demand to Calculate Raw Milk FLW

Many dairies measure the total Chemical Oxygen Demand (COD) in their liquid waste streams and use it to calculate the corresponding amount of raw milk that is disposed of as part of that waste stream. This allows them to obtain a single, meaningful estimate of FLW from a range of liquid dairy products (e.g., milk, yoghurt, cream).

Description of COD approach

This approach applies an average measure of COD to estimate the quantity of FLW. COD is expressed as milligrams per liter (mg/l); it indicates the mass of oxygen that is needed to fully oxidize the organic compounds in the effluent using a strong chemical oxidant.[a]

Reference values are available for a range of undiluted foods and drinks. The reference values can be compared against measured values in a waste stream to infer the amount of lost product contained in the effluent.[b] This approach is difficult to apply, however, if there is a range of items in the liquid waste stream with different COD conversion factors.

COD should be measured for both water coming into a process and water going out of a process.[c] The difference can be attributed to the effluent from the process. It is important that the monitoring point is prior to any on-site effluent treatment, and does not include effluent discharged from any ancillary sources (e.g., toilets) that could affect the result.

The case of raw milk

A dairy could estimate FLW by dividing the total COD in its wastewater (for example, over the course of a year) by the average COD for milk (a standard value of 180,000 mg COD per liter of milk, or 0.18 metric tons COD per metric ton of milk).

A calculation using this example would involve:

- First, calculating COD in the wastewater. If the COD per liter of a milk-based item is 2,000 mg per liter of wastewater and the dairy produces 100,000 m^3 of wastewater a year, then there are 200 metric tons of COD a year in that wastewater. *The calculation converts the COD of the item (2,000 mg/liter) to metric tons COD/liter by dividing by 1,000,000 (which gives 2×10^{-6} metric tons/liter) and then multiplying this by the amount of wastewater in liters (100,000 m^3 is equivalent to 100,000,000 liters).*
- Second, converting COD to a weight. The 200 metric tons of COD that is calculated in the first step is equivalent to 1,100 metric tons of raw milk going down the sewer each year. *The calculation divides the 200 metric tons COD by the standard value of 0.18 metric ton COD per metric ton of milk.*

[a] COD may also be measured in parts per million (ppm).
[b] For examples, see the BREF for Food Drink and Milk Industries. http://eippcb.jrc.ec.europa.eu/reference/. Reference values are also available for biological oxygen demand (BOD)(e.g., Carawan, R.E. 1979. "Water and Wastewater Management in Food Processing." Raleigh, NC: North Carolina State University.
[c] COD monitoring devices are available for sale around the world, from online automatic monitors to smaller equipment suitable for assessing samples.

Box 3.3 | Example of Converting Volume of Grain to Weight

This example is based on grain stored in a container with parallel sides. The volume of grain in cubic meters (m^3) is calculated very simply by multiplying container length x width x depth of grain in the container. For example, if the container is 1.8 m long, 1.0 m wide and is filled to a depth of 2.1 m with sorghum grain, then the volume of grain is: 1.8 m x 1.0 m x 2.1 m = 3.78m^3.

The weight of grain is then determined by multiplying this volume by the bulk density of sorghum. Bulk densities of various common cereal grains are shown in the table below. In our example, the weight of sorghum grain would be: 3.78 x 730 = 2,759 kg.

GRAIN	BULK DENSITY (KG/M³)
Barley (bulk)	605–703
Maize (shelled, bagged)	613
Maize shelled (bulk)	718–745
Millet (bagged)	640
Millet (bulk)	853
Paddy rice (bagged)	526
Paddy rice (bulk)	576
Rice (bagged)	690
Rice (bulk)	579–864
Sorghum (bulk)	730
Wheat (bagged)	680
Wheat (bulk)	768–805

Sources: Hodges R., M. Bernard, and F. Rembold. 2014. "APHLIS – Postharvest Cereal Losses in Sub-Saharan Africa, their Estimation, Assessment and Reduction." *Joint Research Centre (JRC) Technical Report* EUR 26897: 99. Brussels, Belgium: European Commission; Golob, P., G. Farrell, and J. Orchard. 2002. Crop Post-harvest: *Science and Technology.* Hoboken, NJ: John Wiley & Sons.

Box 3.3 provides a sample calculation using a bulk density factor to convert the volume of grain in cubic meters to kilograms.

Table 3.2 summarizes several bulk density factors that have been used for quantifying FLW. However, it should be kept in mind that, if an entity does not calculate its own density factors and uses factors from another study, those factors may not precisely reflect the entity's own circumstances. Before using external density factors, an entity should refer to the original source to understand how these factors were derived and the standard deviation.

5. SCALE UP THE DATA

Where data have been produced from a physical sample of FLW or from a sample of FLW-producing units, they will require scaling up. Guidance on scaling is provided in Appendix A of the *FLW Standard*.

Table 3.2 | Selected Bulk Density Factors Used in Previous FLW Studies (kg per liter)

TYPE OF FLW[A]	SECTOR	SMALL CONTAINER (E.G., CADDY, HOUSEHOLD BIN)	LARGE CONTAINER (E.G., SKIP/DUMPSTER)
Animal and vegetable wastes[b]	Commerce and industry	0.29	
Animal waste from food preparation and products[b]	Commerce and industry	0.29	
Vegetation and/or vegetable waste[b]	Commerce and industry	0.34	
Waste food—animal or mixed[c]	Commerce and industry		0.20
Whole and/or part animals[c]	Commerce and industry		0.83
Animal fats, oils, waxes and/or grease[c]	Commerce and industry		0.61
Food waste[d]	Household	0.29	0.50
Mixed food and garden waste[d]	Household	0.16	
Mixed food, cardboard, and garden waste[d]	Household		0.50
Food scraps[e]	Households, commercial establishments, institutional and industrial sources	0.89	

[a] Definitions of food categories listed are taken directly from source material noted in this table and may not conform to definitions used in the *FLW Standard.*
[b] Jacobs Engineering UK Ltd. 2010. *Survey of Commercial and Industrial Waste Arisings 2010.*
[c] Debenham, J.M.P., A.P. Harker. 2002. “Volume to Weight Conversion Factors for Industrial and Commercial Wastes.” *Proceedings of the Waste 2002 Conference:* 250–258. September 24–26, Stratford upon Avon, UK.
[d] WRAP (The Waste and Resources Action Programme). 2010. *Material Bulk Density: Summary Report.* Banbury, UK: WRAP.
[e] USEPA (Environmental Protection Agency). 1997. *Measuring Recycling: A Guide for State and Local Governments.* Washington, D.C.: EPA. Conversion factor of 0.89 is calculated based on the following: 55 gal = 208l; 412 pounds = 186kg; 186/208 = 0.89 kg/l.

Endnotes

6. Based on Système Internationale (SI), the international system of specifying standard units.

7. FAO/INFOODS (2012).