8. Mass Balance

8.1 Overview of the Method

An entity can use a mass-balance method to infer FLW by measuring inputs (e.g., ingredients at a factory site, grain stored in a silo) and outputs (e.g., products made, grain removed from a silo) alongside changes in levels of stock and changes to the weight of food during processing (e.g., evaporation of water during cooking). This method can be applied at various stages in the food supply chain. Using mass balance is one of three methods described in this standard that are based on "inference by calculation." The other two are using a model and using proxy data (see Chapters 9 and 10 of this document).

Mass-balance calculations can be used to quantify FLW where reliable measurement or approximation is not possible. Mass-balance analysis may also be referred to as "Material Flow Analysis" or "Substance Flow Analysis."

Table 8.1 provides several examples of possible inputs, outputs, and stock in a range of circumstances. Changes in stocks may be positive (i.e., an increase in material stored) or negative (e.g., material withdrawn). A negative change in a stock will include FLW but may also include other changes, such as stolen items, which increases the uncertainty associated with this method.

Different categories of inputs, outputs, and stocks may be important. For example, an entity might wish to separately itemize food by type, or record sold outputs separately from donated outputs. At whatever level of detail the mass balance is carried out, it is essential that all parts of the equation are measured in the same units (e.g., kilograms).

Table 8.1 | Examples of Inputs, Outputs, and Stock

SUPPLY CHAIN STAGE/SECTOR	INPUTS	OUTPUTS	STOCK
Processing site/ factory	Ingredients	Final product	Levels of ingredients or final product held on site
Retail store	Food products delivered to the store	Food bought by customers	Food on shelves and in storage
Household	Food purchases entering the home	Food consumed	Food held in the home
Whole economy	Food production and imports	Food consumption and exports	Food held within the country

ADVANTAGES AND DISADVANTAGES

Mass balance is quite flexible and can be applied at either a product or substance (e.g., ingredient) level. It can allow for changes over time and changes in stocks of material held at various points in the process.

One important advantage of the mass-balance method is that there are established procedures for using it.[16] In addition, free software is available to allow calculation of a mass balance for a system or process.[17]

A further advantage is that the information required is likely to be available (e.g., national statistics, company invoices, billing information) because it has often been gathered for other purposes. This makes the data relatively inexpensive and applicable at a range of levels from a nation to a specific site.

There are several disadvantages in using the mass-balance method, however, relating to issues of data availability, unit conversions, and levels of uncertainty.

In many situations, data from a range of sources are required and some data may require conversion, increasing the cost to perform the analysis and reducing the accuracy of the results. For example, in meat supply chains, data may be recorded as live animals, live weight, and carcass weight at different points in the lifecycle, and consistent identification and conversion is required. As another example, the input in drink production (i.e., ingredients) may enter a process measured in weight (e.g., metric tons of oranges) yet leave the process as an output measured in volume (e.g., liters of orange juice concentrate). At some stages, the available data (e.g., financial data) may have little direct relation to a volume or mass and specific conversions may be required to allow recording in a consistent unit. This adds further complexity and uncertainty about the reliability of the results.

An entity should also consider changes in the weight of the food and/or associated inedible parts that are not related to FLW, in particular the loss of moisture (e.g., natural evaporation, cooking, drying) or addition of water. Similarly, there may be uncertainties about the precise materials to which the results of the mass balance apply. The end result will include FLW but it may also include other “flows” of material that are not FLW but still represent material not being used for its intended purpose. For example, it may include theft, which could be a sensitive issue for an entity to investigate.

The uncertainties in the underlying data used in the mass-balance method will affect the uncertainties in the results obtained. The uncertainties in the underlying data will propagate through the calculations (Box 8.1) but these uncertainties can be addressed by assessing the data quality and using information from more reliable data sources (e.g., where larger sample sizes were used and/or where the measurement tool was more accurate). Quantifying the degree of uncertainty in the results of the analysis is an important step for all methods. Guidance can be found in Chapter 9 of the *FLW Standard*.

> *Mass-balance calculations can be used to quantify FLW where reliable measurement or approximation is not possible.*

Box 8.1 | Subtraction and Uncertainty in the Mass-Balance Method

Subtraction is at the core of the mass-balance method and can increase the uncertainties associated with the resulting estimate of FLW, specifically when the FLW is expressed as a percentage.

The following example provides an illustration. In a mass-balance calculation, an estimate of 90 metric tons (t) (±10 t) for the outputs is subtracted from 100 t (±10 t) for the inputs. In this simple example, there is no change in level of stock or in the weight of food during processing. The resulting estimate of FLW would be 10 t (±14 t), assuming the only uncertainty emanates from that associated with the inputs and outputs. The uncertainty, expressed as a percentage in the final result, would be (±140%)[a], which is much greater than in the two original quantities (±11% and ±10%). This is often the case when one quantity is subtracted from another.

In some cases, the level of uncertainty due to the underlying data used and the propagation of uncertainties within the mass-balance calculations will render the results from a mass-balance method insufficiently accurate for the needs of the FLW quantification study. In such cases, other methods should be considered.

[a] When adding or subtracting two quantities, if the uncertainties associated with those quantities are independent of one another, one can take the square root of the sum of the values (i.e., Sqrt (10^2 + 10^2) = c. 14 metric tons (or 140% of 10 metric tons).

LEVEL OF EXPERTISE REQUIRED

Using a mass-balance method to infer the amount of FLW generated within a process requires access to data on the inputs to and outputs from the process, and on changes in levels of stock.

In a simple process where all data are available in consistent units, little experience is required beyond the ability to work with numbers, which could include using a spreadsheet and processing data.

Where data are presented in different units, contain gaps, and require additional interpretation, a higher level of numeracy and familiarity with calculation methods may be required. This is because all processes (e.g., combining of ingredients) and movement of food between processes (e.g., food product sent to animal feed) must be identified to ensure that FLW is correctly described. It is easy for someone unfamiliar with each of the processes involved to overlook flows.

COSTS

The cost of a mass-balance exercise is principally associated with the time spent by the analyst in sourcing the data and carrying out the mass-balance analysis. Where data are available and already in a standard unit of measurement, the process can be very quick and inexpensive. The time requirements and cost increase if data must be converted from one set of units to another. If any new measurement is required (e.g., of inputs, of outputs), then costs can increase dramatically.

8.2 Guidance on Implementing the Method

An entity that plans to use a mass-balance method 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 that an FLW inventory meets an entity's needs. The scope of an entity's inventory—defined by the timeframe, material type, destination, and boundary—will dictate to a large extent the scope of the mass-balance study. 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. IDENTIFY DATA SOURCES AND OBTAIN DATA

The next step is to identify data sources for the inputs, outputs, stocks, and changes. These should conform to the boundary, time period, and other components identified in the scope.

Information may come from a wide range of sources including invoices, bills, transport/distribution documentation, storage and warehouse records, and data on company management systems (e.g., quality management or inventory systems). See Chapter 5 of this document for more information about how to obtain records. If data are not available, it may be possible to initiate a measurement exercise (e.g., asking production staff to record weights of ingredients and/or products). For national or global estimates, national statistics (e.g., trade data, FLW statistics, food production, and import/export data) may also be a relevant source of data.

Box 8.2 provides an example in which the data source for inputs is sales data on household purchases and the source of data for the outputs is a national survey.

Box 8.2 | USDA's Use of a Mass-Balance Approach to Estimate Amounts of Food Available for Consumption and Food Loss

The U.S. Department of Agriculture (USDA) uses a mass-balance approach in its Loss-Adjusted Food Availability data series to estimate the amounts of 215 foods or commodities (e.g., fresh apples, canned tomatoes, beef, eggs) available for consumption in the United States. The USDA also uses the series to estimate food loss at the retail and consumer levels. USDA defines "food loss" as the amount of food after removing the inedible parts (postharvest) that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (e.g., moisture loss); loss from mold, pests, or inadequate climate control; and food waste. To obtain the underlying consumer-level loss estimates, USDA compared purchasing data from a sales-data provider (Nielsen Homescan data) and subtracted information on consumption from a survey (National Health and Nutrition Examination Survey).

Source: USDA (2014). *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States.* Washington, D.C.: USDA. http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib121.aspx

Box 8.3 | Methodology of FAO's Global FLW Study

The Food and Agriculture Organization of the United Nations (2011) quantified FLW on a global scale using FAOSTAT's Food Balance Sheets, presenting mass-balanced volumes of supply elements (i.e., production, imports, stock variations, exports) and utilization elements (e.g., feed, seed, processing waste, food) for different countries/regions of the world. Data from the national/regional Food Balance Sheets, together with the weight percentages of FLW, were used to quantify the amount of FLW for seven regions and seven commodity groups (cereals; roots and tubers; oilseeds and pulses; fruits and vegetables; meat; fish and seafood; and dairy products).

Data were analyzed along the food supply chain from harvest to consumption for each of the seven commodity groups. Mass flows of each commodity group were considered. Detailed descriptions of these calculations as well as detailed descriptions on how FLW was quantified for each step of the food supply chain are described in Gustavsson et al. (2013).

The study also used (for certain crops) allocation factors to determine the part of the product oriented to human consumption (and not for animal feed) and conversion factors to determine the "edible mass." Because quantifying aggregated commodity groups and regions of the world presents great challenges (e.g., finding representative data on FLW percentages, especially in some developing countries) a number of assumptions and estimates had to be made.

Sources: FAO (Food and Agriculture Organization of the United Nations). 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention.* Rome, Italy: FAO; Gustavsson, J., C. Cederberg, U. Sonesson, and A. Emanuelsson. 2013. *The Methodology of the FAO study: Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome, Italy: FAO.

In another example, the FAO study that quantified FLW at a global level applied elements of a mass-balance method, drawing from a range of data sources (e.g., national statistics); see Box 8.3.

3. IDENTIFY DATA GAPS AND FILL THEM

For a mass-balance study to be successful, all flows must be considered and quantified. For example, in a household analysis, inputs should include donated and grown food as well as purchased food. If these are omitted, then the level of FLW may be underestimated. If data are missing on some inputs or outputs, then efforts should be made to obtain the data, even through measurement if necessary.

In addition, a mass-balance study needs to take into account changes in the food that occur during processing. For instance, dried pasta absorbs water during cooking. If this additional water content is not taken into account in the mass-balance calculations, then the calculated level of FLW could be very inaccurate (a large underestimate). The impact of drying must also be taken into account in mass balances (e.g., unwrapped food left for some time may lose a significant amount of weight).

4. ENSURE THAT UNITS ARE STANDARDIZED

It is essential that all data use the same units of measure. It may be that data can be converted to a standard unit. For example, invoices and bills may not include weight data, but may include other useful information (e.g., number of units sold, financial value of units) that can be converted to a consistent unit via an appropriate conversion factor. Some common conversion factors that may be needed in a mass-balance study are described in Table 8.2.

Table 8.2 | Examples of Conversion Options for a Mass-Balance Study

RECORDED UNIT	DESIRED UNIT	CONVERSION OPTIONS	COMMENTS
Financial value/ number of units	Mass	Weigh a sample of product of a known value, and divide sample weight by value or number to derive a conversion factor Or Use trade data (e.g., Comext)[a] which record some product flows by weight, number, and value	Take particular care with co-products, which can vary in value
Liters of final product and mass of ingredients used	All in mass	Density	

[a] Comext is a statistical database including data on the trade of goods. It is managed by Eurostat. http://epp.eurostat.ec.europa.eu/newxtweb/mainxtnet.do

5. PERFORM MASS-BALANCE ANALYSIS

Once the data have been collected, gaps identified and filled, and the units standardized, the data can be used to infer the magnitude of the unknown flows. The unknown flows will include FLW. The calculation is based on the following equation:

FLW = Inputs – Outputs – Change in Stock + Adjustments

One example of an adjustment is to account for the change in weight during processing. The weight will increase where water content increases (e.g., a product such as rice or pasta absorbs water during cooking) and decreases where the water content decreases (e.g., products lose moisture content both through natural evaporation and drying processes).

In simple situations, calculating mass balance can be a straightforward calculation. For example, a very simple version of mass-balance is to collect or estimate total harvest data for a particular crop and subtract the amount sold. The difference is the estimated FLW.

However, where the flows are more complex, software can be used to assist in the analysis of a system or process. As shown in Box 8.4, some mass-balance studies require that a range of scenarios and data sources be considered.

Box 8.4 | Hypothetical Example: Data Considerations for a Mass-Balance Analysis of Households

It is possible to undertake a mass balance study of food (and drink) entering households within a particular geographic area. This is usually most easily performed for a country, because relevant statistics may already exist. In such a case, the equation would be:

FLW = Input (food brought into homes) – Output (food ingested) – Non-FLW outputs (e.g., donations out) + Adjustment for weight change within household (e.g., adding water) + Adjustment for changes in stock levels (e.g., change in the amount of food in the home over the relevant time period).

Sources of inputs could include food from the following sources: retailers, including grocery stores, farmer's markets, and convenience stores; home-grown (e.g., from a garden or allotment); donations (e.g., from charities or food banks); and/or gifts (e.g., from family and friends). The approach to quantifying each of these sources may be different. For some sources, it may be possible to use existing data (e.g., food purchases in a country). Others may require new measurement (e.g., using diaries or surveys for the amount of food gifted). It is also necessary to define what (if any) are the non-FLW outputs. These may include food donated out of the home (e.g., food donated to other households, collections, or charities).

It is also important to determine which types of food changed weight when in the household. Likely examples include foods that absorb water when cooking (e.g., pasta and rice) and foods that lose water to the atmosphere through evaporation during cooking (e.g., ready-to-eat meals). Many foods will lose weight during storage (e.g., fresh fruit and vegetables) unless effectively wrapped. For some of these changes, data exist on the extent of the change (e.g., some nutrition data-bases[a] include factors for weight change during cooking). Alternatively, measurement of weight change or mathematical models could be used to determine the relevant information.

[a] Public Health England. 2015. *McCance and Widdowson's The Composition of Foods: Seventh Summary Edition.* Cambridge, UK: Royal Society of Chemistry and London: The Food Standards Agency.

Endnotes

16. See Brunner and Rechberger (2004); Morris et al. (2011); UNEP (n.d.).

17. One such site where free software is available is www.stan-2web.net. See also Cencic and Rechberger (2008). http://enviroinfo.eu/sites/default/files/pdfs/vol119/0440.pdf.