Guidance on Estimation Methods for Inventory Development of Plastic Leakage into the Environment, Including the Marine Environment

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Contents

Executive Summary

Plastic pollution is increasing in scale and complexity across terrestrial and aquatic environments. Many countries face a shared bottleneck: insufficiently harmonized, policy-relevant data and practical, transparent methodologies to estimate plastic leakage and compile an inventory that can be updated over time.

This Guidance, prepared under the Ministry of the Environment, Japan (MOEJ), supports national and subnational teams to develop inventory-grade estimates of plastic leakage into the environment, including pathways to the marine environment. It is a method-selection and implementation guide: it does not propose a new global model, but systematizes existing approaches and provides a stepwise workflow to select fit-for-purpose methods according to policy needs, scale, and data readiness.

Key messages are:

• Estimation of leakage amount and Inventory development should be anchored to policy purpose (upstream measures; solid-waste-system performance; environmental outcomes in land, rivers and the ocean), with explicit definition of units, boundaries and reporting periods. Appropriate quality control (QC) of the data is also necessary.

• Existing estimation approaches can be organized into three complementary families: (i) production and consumption statistics-based methods (M1), (ii) waste management and material-flow methods (M2), and (iii) field survey and monitoring-based methods (F, including coastal/land and aquatic/riverine). Hybrid approaches (e.g., M1+M2, or M1/M2 calibrated with F) are often the most practical for strengthening credibility and comparability.

• Current global practice shows an operational gap for routine, practitioner-facing estimation of leakage to waterways and the ocean using aquatic field evidence (F2). Converting research-grade riverine methods into standardized, inventory-oriented protocols, calculation templates, and reporting formats is a priority for future harmonization.

Structure of the Guidance: Chapter 1 frames the global and policy context; Chapters 2–3 clarify what constitutes a plastic leakage inventory and how to define scope, indicators and terminology; Chapter 4 categorizes existing estimation methods and summarizes their inputs and use cases; Chapter 5 provides a stepwise workflow for selecting and applying methods with QC and reporting.

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1. Background and Objectives

1.1 Current status and challenges of global plastic pollution

Plastic pollution has become one of the most pressing environmental challenges of the 21st century, affecting terrestrial and aquatic ecosystems, biodiversity, and human health. Despite international attention, plastic production and leakage into the environment continue to grow, requiring a coordinated and science-based global response.

Escalating Production and Leakage into the Environment

Global plastic production has grown rapidly over recent decades, reaching approximately 460 million metric tons in 2019. Without substantial policy intervention, this figure is projected to more than double to 1,231 million metric tons by 2060 (OECD, Global Plastics Outlook: Policy Scenarios to 2060, 2022). A key driver of pollution is the mismanagement of plastic waste. The United Nations Environment Programme (UNEP) estimates that between 19 and 23 million metric tons of plastic enter aquatic ecosystems every year, equivalent to about 11% of global plastic waste generated annually (UNEP, From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution, 2021). Projections suggest that without bold action, the annual flow of plastic into aquatic systems could nearly triple by 2040, resulting in over 600 million metric tons of cumulative plastic pollution in the ocean (Pew Charitable Trusts & SYSTEMIQ, Breaking the Plastic Wave, 2020).

Impact on Marine Ecosystems and Biodiversity

According to UNEP, plastics account for at least 85% of total marine litter, posing significant threats to marine biodiversity. Over 800 marine and coastal species are known to be affected by plastic ingestion, entanglement, or habitat disruption (UNEP, 2021). Seabirds, turtles, fish, and marine mammals frequently mistake plastic debris for food. A study of flesh-footed shearwaters on Lord Howe Island found that birds had ingested up to 778 plastic fragments, comprising up to 20% of their body weight (Lavers et al., PLOS ONE, 2014). Microplastics (less than 5 mm in size) and nanoplastics have been detected across a wide range of environments from Arctic snow to deep-sea sediments, raising concerns about bioaccumulation and long-term ecological impacts (Bergmann et al., Science, 2019, Barboza et al., Environmental Science and Technology, 2018).

Economic and Social Implications

Marine plastic pollution also has a significant economic impact. UNEP estimated that it causes annual losses of USD 6 to 19 billion in marine ecosystem services due to its effects on tourism, fisheries, and shipping industries (UNEP, 2021). Plastic pollution can also disproportionately affect developing countries that lack adequate waste management infrastructure, exacerbating environmental injustices.

Challenges in Monitoring and Data Collection

One of the fundamental challenges in addressing plastic pollution is the lack of harmonized, high-quality data. Many countries do not have comprehensive inventories or monitoring systems in place to track plastic production, consumption, trade, and waste flows. This hinders the ability to assess plastic leakage pathways accurately, compare data across regions, and design effective, evidence-based policies. To bridge this gap, several international and nationally supported initiatives have been launched in recent years:

- **The Ministry of the Environment, Japan** is currently implementing a project aimed at developing a “Guidance on Estimation Methods for Inventory Development of Plastic Leakage into the Environment, Including the Marine Environment” (this document). This project seeks to systematize plastic leakage estimation methods, support harmonized data collection, and strengthen science-based policy formulation in collaboration with global partners.
- **The Global Partnership on Marine Litter (GPML)** Community of Practice (CoP) on Plastic Monitoring and Assessment Harmonization, led by UNEP, brings together experts and practitioners worldwide to promote convergence in plastic monitoring methodologies. The initiative is fostering technical dialogue and practical tools to align approaches across countries and sectors. GPML launched the Global Plastic Hub as a platform for data, knowledge, and collaboration to end plastic pollution.
- **The UNEP/European Commission (EC)** project on “Identifying and Quantifying Plastic Contaminant Sources and Leakages into the Aquatic Environment” focuses on the development of harmonized monitoring protocols and pilot studies in various regions. It aims to build the scientific and technical foundation for global plastic leakage monitoring frameworks.
- **The UNEP/UNITAR** Statistical Guideline for Measuring Flows of Plastic throughout the Life Cycle initiative is developing standardized methodologies for national plastic flow accounting. This Guideline will enable countries to track plastic inputs, uses, trade, waste generation, and leakage using consistent statistical approaches aligned with international systems such as SEEA (System of Environmental-Economic Accounting).

These complementary efforts are paving the way for the development of globally recognized methodologies and data-driven governance frameworks. They are essential to building national capacities, improving comparability of plastic pollution data, and supporting future treaty implementation under the Intergovernmental Negotiating Committee (INC) process.

The Imperative for Robust Estimation and Monitoring

Tackling plastic pollution requires estimation and monitoring that are explicitly anchored to policy purpose. This Guidance frames those purposes in three mutually reinforcing areas.

First, upstream production and consumption measures. Estimation should illuminate where and how plastics are put on the market and lost along product systems. So, governments can set and track targets for single-use plastic reduction, eco-design and green procurement, and address losses such as abandoned fishing gear. Clear numbers also strengthen EPR design and corporate disclosure, creating incentives for circular business models and facilitating comparable international reporting.

Second, improvement of waste management performance. Quantifying waste generation and flows what is collected, self-managed, recycled, landfilled, openly dumped or burned, enables authorities to diagnose system gaps, prioritize municipalities and investments, and design effective 3R/EPR measures. Credible estimates guide financing and innovation toward the highest-impact infrastructure and operations, from collection and sorting to WtE and sanitary landfills.

Third, environmental outcomes across land, rivers, and the ocean. Monitoring that identifies hotspots and measures mismanaged plastic waste on land and coasts, together with estimates of riverine fluxes and annual inputs to the sea (including seasonal dynamics), allows targeted countermeasures in river basins and coastal zones and provides an objective basis to evaluate the effectiveness of clean-ups and other interventions.

Taken together, these purposes define ***why* we estimate and *what* we monitor**. The Guidance then recommends a stepwise approach choosing indicators that match policy needs and scaling method complexity to available data, so that countries can start with pragmatic estimates and progressively harmonize and refine them over time.

1.2 INC discussion on plastic inventory, leakage estimation, research, scientific evidence, NAP, and monitoring, etc.

In March 2022, at the Fifth Session of the United Nations Environment Assembly (UNEA 5.2) held in Nairobi, Kenya, a landmark resolution was adopted to commence negotiations on a legally binding international treaty to address plastic pollution, including marine litter. This led to the establishment of the Intergovernmental Negotiating Committee (INC), which began its work with INC-1 in November 2022, and the fifth session was held in two parts: INC-5.1 in Busan, Republic of Korea (25 November - 1 December 2024), and the resumed fifth session, INC-5.2, in Geneva, Switzerland (5 - 15 August 2025). The Geneva meeting adjourned without consensus on a treaty text, with negotiations to resume at a later date. While consensus on the treaty's final text has yet to be reached, discussions have emphasized the importance of data-driven strategies. Key elements of the draft treaty texts and related discussions underscore the necessity of developing robust plastic pollution inventories and estimation methodologies. These include:

- **Upstream production & consumption (prevention at source)**
  Estimation should illuminate where and how plastics are placed on the market and lost along product systems so that Parties can set and track measures on single-use plastic reduction, eco-design and green procurement, and address losses from specific product systems (e.g., abandoned/lost fishing gear, beverage containers, polymer-specific microplastic sources). These estimates strengthen the design of extended producer responsibility or other economic instruments serving the same purpose, support product standards and information disclosure on materials/additives, and enable comparable international reporting.
- **Waste management performance (system improvement)**
  Credible, comparable estimates of waste generation and flows what is collected, self-managed, recycled, landfilled, openly dumped or burned, allow authorities to diagnose gaps, prioritize municipalities and investments, and design effective 3R/EPR packages. They also underpin resource mobilization, infrastructure development (collection, sorting, recycling, WtE, sanitary landfills), and operational improvements, consistent with environmentally sound management and disaster-resilient systems.
- **Environmental outcomes on land, rivers, and the ocean (leakage results)**
  Harmonized monitoring and estimation of releases and leakages including microplastics together with identification of hotspots/accumulation zones and remediation of existing and legacy plastic pollution, enable targeted river-basin and coastal interventions and provide an objective basis for evaluating the effectiveness of measures over time.
- **Cross-cutting: harmonization, comparability, capacity, and social dimensions**
  Across all three purposes above, Parties are expected to prepare national plans, report on implementation and challenges, participate in effectiveness evaluation using production/consumption statistics and comparable environmental monitoring

data, and engage in information exchange and public awareness, education, and research. Delivery depends on adequate and accessible finance, capacity-building, technical assistance, and technology transfer, and is supported by a scientific/technical subsidiary body. A just transition for affected workers and communities is also highlighted. .

Going forward, discussions are expected to focus on the standardization of estimation methodologies, mandatory reporting mechanisms, and integration of scientific research into treaty implementation frameworks.

2. What is Plastic Leakage Inventory

2.1 Current status and challenges of monitoring, estimation and inventory development

Developing accurate inventories and estimation methodologies for plastic leakage into the environment remains a critical global challenge. While many countries have initiated efforts to monitor plastic pollution, the lack of harmonized approaches, data availability, and technical capacity impedes consistent and comparable plastic leakage estimation, particularly in low- and middle-income countries.

One underlying reason is that “monitoring,” “estimation” and “inventory” are often used interchangeably in practice, even though they serve different functions and require different data, protocols, and skill sets. To reduce this confusion and clarify what is being **measured** versus what is being **calculated**, this Guidance distinguishes three related but conceptually different elements: (i) monitoring, (ii) leakage estimation and (iii) leakage inventories.

Monitoring refers to **repeated observation of change** over time and occurs in two distinct forms: **policy monitoring** (tracking implementation and performance of measures such as EPR coverage, collection/treatment capacity, enforcement actions, recycled content, or other policy KPIs) and **environmental field-survey monitoring** (direct measurement in environmental compartments such as land/coasts and waterways using protocols like shoreline transects, net sampling, visual counts, or other field techniques).

Leakage estimation is the analytical step that translates one or more data streams, often combining official statistics and waste-flow data with coefficients or models, and where available using field-survey monitoring as empirical inputs into quantitative leakage indicators (e.g., annual leakage to the environment or to waterways/ocean). In other words, environmental field monitoring can produce leakage-relevant measurements directly, but it also plays a distinct role as evidence used to calibrate, validate, or scale estimation outputs derived from statistical and system-based approaches.

A plastic **leakage inventory** is structured, reportable compilation of indicators or list of leakage sources, and results for a defined boundary and period, typically consolidating upstream statistics (production/consumption), waste-system performance, and (where available) environmental evidence, from monitoring or estimation, into a coherent national or subnational account.

Accordingly, this Guidance treats “methods” as three different families that should not be conflated: **methods for policy monitoring**, **methods for environmental field-survey**

monitoring, and **methods for leakage estimation**. However, because the primary purpose of this Guidance is to support **leakage estimation** and the development of plastic **leakage inventories**, the term "methods" is used in this document primarily to refer to **methods for leakage estimation**, unless explicitly stated otherwise. Clear separation of these functions is essential for harmonization, which prevents mixing governance-performance metrics with environmental measurement protocols, and it makes explicit when "**leakage amount**" refers to a field-derived observation versus a modelled estimate derived through coefficients, equations, or other modelling approaches.

Regional Observations: Southeast Asia

Recent MOEJ stocktakes confirm that only a few Southeast Asian countries maintain formal plastic-leakage inventories or standardized estimation protocols. National monitoring is conducted (e.g., riverine floating litter, macroplastic capture), but harmonized, comparable leakage estimation across the region is still rare. Indonesia's National Coordinating Team for Marine Debris Management (TKN PSL) estimates leakage from land- and sea-based sources using administrative datasets (e.g., SIPSN) and assumptions (e.g., vessel operations), though upstream production/consumption data are not yet integrated. In Viet Nam, multiple institutions conduct monitoring and baseline assessments, but a national guideline or standardized estimation method has not been adopted, and inter-agency coordination remains fragmented. These findings echo common challenges such as data gaps (especially production/consumption and polymer-specific), limited technical capacity and monitoring infrastructure, non-harmonized terminology/classifications, and institutional fragmentation that impedes integrated national platforms.

What the OECD Regional Outlook adds

The OECD's Regional Plastics Outlook for Southeast and East Asia provides some types of inputs that directly strengthen national leakage inventories and policy planning:

- **Country-level leakage benchmarks based on currently available data**
  The Outlook presents comparable leakage rates (share of plastic waste leaking to the environment) for individual countries and regional groupings under Baseline and policy scenarios. For example, in 2022 Indonesia's leakage share is 18.3% (projected 17.1% in 2050 Baseline), while Japan and Korea are at 0.3%, under a High-Stringency policy package, ASEAN Plus Three (APT) countries converge to 0.1 - 0.3% and near-zero leakage volumes by 2050 (ENV-Linkages model). These tabulated rates can be used as provisional benchmarks where national estimates are

not yet available, and as cross-checks where they are.

Table 2-1. Share of plastic waste that leaks to the environment.

	2022	Baseline in 2050	High Stringency in 2050	Reduction in volume
Thailand	6.8%	1.4%	0.2%	0.1 Mt
Rest of ASEAN – HIC & UMIC	12.0%	7.9%	0.1%	0.8 Mt
Indonesia	18.3%	17.1%	0.2%	3.1 Mt
Rest of ASEAN – LMIC	17.4%	10.7%	0.2%	3.0 Mt
Japan	0.3%	0.2%	0.2%	0.01 Mt
Korea	0.3%	0.2%	0.2%	<0.01 Mt
China	6.4%	4.4%	0.3%	6.6 Mt
ASEAN average	**14.2%**	**10.9%**	**0.2%**	**7.0 Mt**
APT average	**7.4%**	**5.8%**	**0.3%**	**13.6 Mt**
OECD average	**1.1%**	**0.5%**	**0.2%**	**0.9 Mt**
Non-OECD average	**9.5%**	**7.6%**	**3.5%**	**23.3 Mt**
Global average	**5.6%**	**5.1%**	**2.3%**	**24.2 Mt**

(Source. Regional Plastics Outlook for Southeast and East Asia, OECD, 2025)

- **A structured view of policies that most affect leakage (design, demand, and downstream controls)**

  The Outlook catalogues upstream/midstream measures (e.g., design for recyclability, recycled content requirements) and shows that promotion of recycled content/recyclability is emerging in the region but with large headroom for circularity improvements, this provides a ready reference when aligning inventory indicators with policy levers (e.g., tracking recycled content, product design attributes).

  It also details four intervention areas critical to closing leakage pathways

  (i) regulation and controls on dumping/littering,

  (ii) household sorting at source,

  (iii) bans/taxes on frequently littered items, and

  (iv) controls on plastic waste/scrap imports

  useful as a checklist to connect inventory results (where/what leaks) to actionable policy responses.

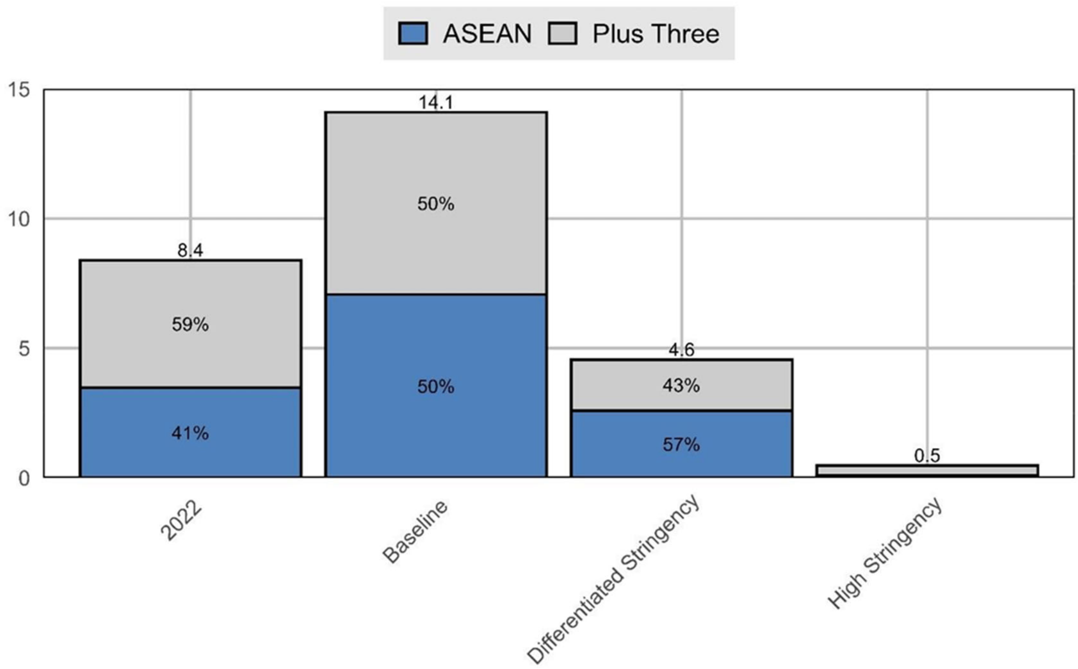
Table 2-2. Examined policy intervention areas critical to closing leakage pathways

Policy	General Aim
Regulation and controls on waste dumping and littering	Reduce littering, burying, burning, dumping, or discharging of waste on land or in waterways via the use of penalties for the offenders, such as fines and imprisonment for citizens, businesses and waste operators.
Measures for household waste sorting at source	Mandate and improve sorting at source of recyclables, mixed (wet/dry), hazardous and other waste stream. Improving sorting at source is critical to move towards higher recycling and material recovery at the end-of-life.
Bans or taxes on frequently littered items	Reduce the circulation and leakage to the environment of frequently littered (plastic) items by targeting their import, production and consumption, e.g. through bans or taxes.
Plastic waste and scrap import regulations	Control the import of plastic waste and scrap, e.g. via bans or via quality requirements to prevent harmful effects locally and to ensure imported waste supports the recycling sector's needs.

(Source. Regional Plastics Outlook for Southeast and East Asia, OECD, 2025)

- **Scenario pathways linking policies to time-bound leakage outcomes**

  The report's policy scenarios quantify how combinations of upstream, collection/sorting, recycling and disposal measures reduce mismanaged waste and leakage through time. A key result is that **plastic leakage is eliminated only in the High-Stringency scenario**, less-ambitious pathways lower leakage relative to Baseline but do not stop accumulation in the environment. These trajectories help countries translate inventory baselines into targets and track whether planned measures are sufficient to reach "near-zero leakage".



(Source. Regional Plastics Outlook for Southeast and East Asia, OECD, 2025)

Figure 2-1. Plastic leakage is eliminated only in the High Stringency scenario

- **Implications for national inventories and monitoring**

Where countries lack complete inventories, the tabulated leakage shares and volumes (by country/region) can seed provisional baselines and inform priority-setting, with later replacement by country-specific estimates as data improve. Inventory and monitoring frameworks should include indicators tied to (i) design for circularity/recycled content, and (ii) the four leakage-closure interventions above, enabling evidence-based evaluation of policy effectiveness over time. Countries can set stepwise targets (e.g., mismanaged waste ↓, recycling ↑, leakage share ↓) consistent with “near-zero leakage” trajectories demonstrated in the High-Stringency case, using the modelled time paths as a reality check on ambition and investment needs.

- **Persistent challenges to address**
  Even with improving policy ambition, the Outlook highlights that **current policies alone are insufficient to end leakage by 2050**, particularly in ASEAN Low- and Middle-Income Countries (LMIC) without accelerated investment and enforcement, convergence to near-zero leakage requires comprehensive measures across the plastic lifecycle and substantial waste-management upgrades. This reinforces the need for harmonized definitions/terminologies, comparable datasets (production, trade, use, waste, environmental stocks/flows), and interoperable methods so that national inventories can both guide domestic action and support regional/international reporting.

Global Challenges and the Need for Harmonization

According to the Global Partnership on Marine Litter (GPML) and its Communities of Practice (CoP), consistent monitoring and estimation of plastic leakage across the plastic life cycle is essential to identify sources, track progress, and inform national actions. However, global assessment efforts face several obstacles:

- Divergent methodologies with little interoperability or validation
- Lack of harmonized terminology and indicators
- Limited data transparency, particularly regarding plastic production and trade data
- Need for pilot national source inventories to guide methodology selection

The GPML CoP has recommended the development of a harmonized glossary, better mapping of linkages between tools, and the identification of key performance indicators (KPIs) to enable integration into global platforms such as the Global Plastic Hub.

Tools and Guidance under Development

To support countries in overcoming these challenges, several international initiatives have been launched, among others:

- The **UNEP/EC Toolkit** on plastic leakage estimation proposes the use of Plastic Leakage Factors (PLFs) to simplify estimation in data-scarce contexts and to guide national and local decision-makers in selecting appropriate methodologies.
- The UNEP/UNITAR Statistical Guideline aim to standardize the production of plastic-related statistics throughout the life cycle, aligned with systems such as SEEA and SNA. These guidelines highlight the lack of unified units, product flow traceability, and classification standards as key barriers.
- The **UNEP-IETC** assessments[1] highlight the absence of standard methods to quantify leakage, noting that while multiple tools exist, none offer full comparability across geographies and sectors.

While efforts are underway globally and regionally to improve plastic leakage monitoring, the field remains fragmented. Robust inventory development demands systematic harmonization of terms, indicators, and methods, supported by strong institutions, financial resources, and international collaboration.

2.2 Science-based policy decisions and interventions

The development of plastic leakage inventories and estimation methodologies is critical for enabling science-based policy decisions aimed at mitigating plastic pollution. In this Guidance, Chapter 4 (*Categorization of Estimation Methods*) provides further detail, comparing the three method families including M1 (Production & Consumption-based), M2 (Waste Management-based), and F (Field Survey/Monitoring-based), and summarizing their data requirements, technical characteristics, strengths and limitations, and policy applications.

Accurate, reliable, and harmonized data serve as the backbone of evidence-based policymaking, allowing stakeholders to prioritize interventions, assess effectiveness, and track progress toward national and international environmental targets.

Several science-policy frameworks underscore the role of plastic leakage estimation in strategic decision-making. For instance, the **UNEP/UNITAR Statistical Guideline for Measuring Flows of Plastic Throughout the Life Cycle** emphasizes the need to align national statistics with international standards to enable systemic tracking of plastic flows from production to end-of-life stages. By incorporating methodologies such as physical supply-use tables and sectoral disaggregation, the Guideline provides a comprehensive statistical architecture that supports the formulation of policies aligned with Sustainable

[1] An Overview to the Plastic Waste Estimation Models, 1st Meeting of the UNEP/EC Working Group to develop a toolkit on plastic pollution sources, Brussel, 3-4 September 2024

Development Goals (SDGs), circular economy objectives, and lifecycle-based waste management principles.

In practice, estimation methodologies have informed impactful policy decisions. For example, the Plastic Drawdown model has been used to project business-as-usual plastic emission scenarios and compare them against the potential effects of various interventions, such as bans, recycling improvements, or extended producer responsibility (EPR) schemes. This model provides governments with a cost-benefit framework to identify the most effective policy levers for reducing leakage.

Furthermore, the **MOEJ leading project** (https://www.env.go.jp/page_00041.html) and **GPML Community of Practice** have advanced efforts in harmonizing monitoring and estimation methodologies, interoperability and comparability across datasets. Their initiatives include categorizing existing methodologies to facilitate their practical application, mapping indicator discrepancies, recommending harmonized glossaries, and creating metadata standards for microplastic monitoring. These efforts have been vital in aligning national inventories with global platforms like the **GPML Global Plastic Hub**, thereby facilitating transboundary collaboration and benchmarking.

At the implementation level, rapid assessment methodologies, including those documented in **UNEP's IETC guidance**, have supported low-resource countries in conducting baseline evaluations. Techniques such as waste characterization audits, stakeholder surveys, and simple leakage factor calculations (e.g., using the formula Plastic Consumption × Mismanaged Plastic Factor) have empowered policymakers to design actionable strategies even in data-scarce environments. The **OECD ENV-Linkages Plastic Leakage Model** further exemplifies how macroeconomic modeling can inform national policies. This computable general equilibrium model incorporates economic drivers, structural changes, and sector-specific plastic use data to simulate long-term scenarios, including the trade-offs among policy objectives such as economic growth, environmental protection, and waste minimization.

In summary, data-driven plastic leakage estimation and inventory methods are indispensable tools for enabling scientifically grounded policy interventions. They offer critical insight into hotspots, forecast the impacts of proposed measures, and support national efforts to meet global obligations under emerging treaties such as the UNEA-mandated legally binding instrument to end plastic pollution.

3. Target, Scope, and Scale

3.1 Target Readers of the Guidance

This Guidance is intended to support a wide range of stakeholders who are engaged in understanding, assessing, and managing plastic leakage into the environment. The target readers include both users of plastic leakage estimation methodologies and developers or evaluators of such methodologies.

Users are those who seek to apply practical tools to quantify plastic leakage, develop inventories, or support evidence-based policy actions. These may include:

- Policymakers and regulators in **national and local governments**
- **Municipal authorities and practitioners** involved in waste and water management
- **Environmental NGOs** and **community-based organizations**
- **Private-sector actors**, such as producers, retailers, or businesses engaging in circular economy initiatives

In addition, methodology developers and evaluators, including academic researchers, technical experts, and statistical offices may use this Guidance to:

- Compare existing estimation methodologies
- Identify gaps in available methods and data
- Contribute to the development or refinement of harmonized assessment frameworks

Given the diversity of data availability and capacity among countries, especially in low- and middle-income settings, the Guidance has been designed to accommodate varying levels of technical and institutional readiness. It aims to:

- Provide **simplified, practical and transparent estimation approaches** for data-scarce environments
- Translate available data into empirical information that can be readily used by decision-makers
- Enable harmonization and comparability of statistics across national, regional, and global levels

Ultimately, this Guidance serves as a **bridge between science and policy**. It empowers stakeholders with different technical backgrounds to make informed decisions about plastic pollution mitigation and resource allocation, and to contribute toward global efforts such as the UNEA-mandated legally binding instrument on plastic pollution.

3.2 Objectives of leakage estimation, estimation scale, dataset for estimation

Effective assessment of plastic leakage into the environment is essential for designing informed, science-based policies and interventions. In this Guidance, the primary objectives of leakage estimation are organized following three policy purposes with a cross-cutting enabler, so estimates are directly usable for decisions and accountability. In line with this applied purpose, this Guidance does not develop new estimation models. Rather, it serves as a method-selection guide that helps readers choose from established approaches in the literature according to their policy objectives, estimation scale, and the maturity of their current data infrastructure.

- **Upstream production & consumption (prevention at source)**
  - Set and track targets for single-use plastic reduction/substitution, eco-design and green procurement.
  - Quantify placed-on-market volumes, in-use stocks, and product-/polymer-specific losses (e.g., abandoned/lost gear, priority microplastic sources) to inform standards, disclosure, and producer responsibility measures.
- **Waste-management performance (system improvement)**
  - Diagnose gaps and prioritize investments across generation, collection, sorting, recycling, energy recovery, and disposal.
  - Quantify waste flows by pathway (collected, self-managed, recycled, landfilled, openly dumped/burned) and mismanaged shares to design effective 3R/EPR packages and compliance/enforcement measures.
- **Environmental outcomes on land, rivers, and the ocean (leakage results)**
  - Identify hotspots/accumulation zones, estimate riverine fluxes and annual inputs to the sea (including seasonal dynamics).
  - Evaluate the effectiveness of interventions and clean-ups, including remediation of existing and legacy pollution.
- **Cross-cutting: harmonization, comparability, capacity, and social dimensions**
  - Establish standardized definitions, metrics, QC, and interoperable methods to support national planning, reporting, and effectiveness evaluation.
  - Mobilize finance, capacity-building, and technology transfer, ensure just transition considerations for affected workers and communities.
- **Note (scope and quality considerations)**
  - **Pathway considerations for leakage to land:** Depending on the selected estimation approach, assessing leakage to land may require explicit consideration of intermediate pathways and compartments such as losses to **soils/terrestrial surfaces**, releases to **wastewater and sewer networks**, and leakage from **waste-management facilities** (e.g., collection points, transfer stations, dumpsites/landfills) before plastics are transported to waterways or coastal environments.

- **Scope boundary for ocean-based sources:** This Guidance primarily addresses **land-based sources and leakage pathways** to rivers and the ocean. Estimation approaches for **direct leakage to the ocean from at-sea activities** (e.g., shipping and fishing operations, or releases from vessels and maritime infrastructure, such as losses of shipborne plastics and operational wastes, as well as paint-related emissions (e.g., flaking and abrasion of marine coatings, including hull/anti-fouling coatings) are not yet fully covered in the current version.
- **QC terminology:** QC may refer to different functions. **Monitoring QC** concerns field measurement and laboratory analysis quality (e.g., survey design, instrument calibration for sampling, or blank test in the analytical process), whereas **estimation/inventory QC** concerns the validity and reproducibility of the estimation method and the fitness-for-purpose of input data (e.g., boundary consistency, unit checks, avoidance of double counting, uncertainty treatment, and documentation of assumptions).

Estimation Scales

Plastic leakage estimation must be flexible and scalable to be meaningful across different contexts. Commonly recognized spatial and jurisdictional scales include:

- **National and sub-national (provincial/municipal)** levels for national action plans and waste management planning.
- **River basin level**, which is crucial for identifying upstream sources and implementing river-based interventions.
- **Coastal and marine zones**, where cumulative leakage impacts become visible and integrated management is necessary.
- **Regional and global levels** for comparative policy benchmarking and international cooperation.

The estimation scale must be chosen according to the policy purpose and availability of disaggregated data. Many initiatives, such as the **GPML Community of Practice**, stress the importance of harmonizing methodologies to ensure comparability across scales.

Datasets for Estimation

Leakage estimation methodologies rely on diverse datasets, often collected and managed by multiple stakeholders. The types of data required may include:

- **Production, import/export, and consumption data**, ideally disaggregated by polymer type and product use category.
- **Municipal solid waste statistics**, including collection, treatment, disposal, and recycling rates.

- **Informal and illegal waste management activities**, such as open burning or dumping.
- **Environmental monitoring data**, including riverine and marine debris surveys, remote sensing data, and microplastic sampling.
- **Socioeconomic and behavioral data**, which are relevant for estimating waste generation, leakage behavior, and policy impact.

Due to varying availability and quality of data, many toolkits, including the **GPML's methodological work** and **UNEP/EC Toolkit** have proposed simplified estimation pathways based on Plastic Leakage Factors or Coefficients, which use proxy data to enable leakage estimation even under constrained conditions.

Need for Standardization and Quality Control(QC)

A key challenge is the heterogeneity of definitions, units, and classifications across datasets. For example, plastic may be measured in kilograms, items, or monetary value, product categories may overlap, and informal sector contributions are often underreported. To overcome these barriers, global initiatives such as the UNEP/UNITAR Statistical Guideline for Measuring Flows of Plastic propose the use of harmonized classifications, units, and supply-use tables.

Standardization needs to be accompanied by clear **quality control** provisions. Importantly, this Guidance distinguishes between **monitoring QC** (quality control for field measurements, sampling and analytical protocols) and **estimation/inventory QC** (quality control for the estimation method and its inputs, such as boundary consistency, unit conversions, avoidance of double counting, uncertainty treatment, and documentation of assumptions). In this section, "quality control" primarily refers to **estimation/inventory QC**, unless monitoring QC is explicitly stated.

QC help ensure that leakage estimates are:

- Scientifically credible
- Comparable across contexts
- Actionable for policy formulation

The estimation of plastic leakage is a foundational element for practical, targeted, and measurable environmental policy. For this reason, quality control should not only verify the reliability of underlying datasets, but also demonstrate that the chosen estimation approach is reproducible and fit-for-purpose for the intended decision context, while keeping it distinct from QC procedures used to generate environmental monitoring data. The selection of estimation scales and datasets should align with national priorities, available capacities, and the intended use of results, whether for local intervention, national policy, or international reporting.

3.3 Definition of terms

Approach taken in this Guidance

To ensure consistency, clarity, and comparability across datasets, estimation methodologies, and stakeholder practices, this Guidance adopts and operationalizes internationally recognized definitions for key terms related to plastic pollution assessment. Rather than creating new standards, it follows terminology currently under discussion in the INC process and reflected in leading references including the GPML Communities of Practice, the UNEP/UNITAR Statistical Guideline, and the GESAMP Guideline for monitoring and assessment of plastic litter in the ocean. These definitions support both data producers and end-users in interpreting and applying leakage estimation results across geographies and contexts, where national usage differs, a mapping to this glossary should be provided.

At the same time, multiple legitimate definitions are used across jurisdictions and literatures. In particular, terms such as "leakage," "mismanaged," "reuse," and "microplastics" can vary in scope and measurement boundaries, which may materially affect estimation results (see the table below). Therefore, this Guidance sets out working descriptions for estimation purposes and requires users, when their national or legal usage differs, to supply a terminology mapping to these working descriptions and to state the measurement boundaries applied (e.g. geographical coverage, reference period, and life-cycle stage).

To safeguard comparability, users should pair terminology with metadata and QC measures (e.g. data sources, estimation rules, assumptions, and uncertainty ranges). Where the INC process or the above international guidelines evolve the underlying terminology, this Guidance will defer to the updated usage and the mapping should be revised accordingly.

Table 3-1. Plastic Waste and Management: terms as organized in this Guidance

Term	Working description used in this Guidance	Notes / edge cases to watch
Plastic waste	Any plastic material discarded, intended to be discarded, or required to be discarded by the holder, includes post-consumer and post-industrial streams.	Aligns with international waste-statistics practice, specify inclusion/exclusion of production scrap if relevant.
Waste	Quantity of plastic waste arising within a	Clarify treatment of on-site

generation	defined boundary (geography/sector/time) **prior to collection**.	pre-sorting or pre-processing residues.
Waste collection	Organized removal from point of generation to authorized facilities, **includes formal and informal systems**.	State whether pre-sorting/temporary storage is counted as "collection" in your data.
Uncollected waste	Plastic waste **not** reached by formal **or** informal collection during the reference period.	Often a driver of leakage, document estimation method (surveys, proxies).
Mismanaged waste	Collected or uncollected plastic waste **inadequately managed** (open dumping/burning, uncontrolled burial, leakage to waterways, or processing in facilities lacking basic environmental safeguards).	If national categories differ, map local classes to "mismanaged" vs "managed."
Managed waste	Waste handled with **minimum environmental controls** (controlled disposal, sanitary landfill, compliant WtE, compliant recycling).	Record control levels to support scenario analysis.
Controlled disposal	Site with some controls but possibly lacking full liner/leachate/gas systems.	Do **not** assume equivalence to sanitary landfill.
Sanitary landfill	Engineered facility with comprehensive controls (liner, leachate collection, cover, gas management, monitoring).	If partial upgrades exist, note compliance status.
Recycling (material recovery)	Reprocessing of plastic waste into products/materials, **excludes** energy recovery.	Track **input, output, yield** for mass balance, avoid double counting with reuse.
Energy recovery (WtE)	Combustion or other processes with energy recovery.	Report separately from recycling.
Reuse /	**Reuse:** product used again for original purpose without significant reprocessing.	Some regimes count certain preparation steps as recycling—state your convention.
Leakage Release / Loss	**Leakage: uncontrolled entry into the environment** (land, riverine, coastal,	In this Guidance, **leakage** is the primary outcome

(Refer to "BOX")	marine) from any life-cycle stage. **Release:** emission/discharge (e.g., tire wear, pellet loss). **Loss:** general reduction from a system (spillage, attrition).	indicator, document how releases/losses translate to leakage.
Open dumping / Open burning / Ocean dumping	Practices prohibited or being phased out, tracked distinctly due to direct leakage and health risks.	If illegal practices are under-reported, note uncertainty treatment.
Informal sector	Individuals/co-ops performing collection/sorting/recycling outside formal contracts/regulation.	Recognize for capture rates and **just transition** metrics.
Facility classes & controls	Facilities tagged by control level (**uncontrolled / controlled / sanitary, compliant / non-compliant**).	Enables harmonized aggregation and consistent scenario modeling.

Table 3-2. Size classes and environmental compartments (per international practice)

Category	**Working description used in this Guidance**	**Notes / edge cases to watch**
Macroplastics	**> 5 mm ***	Visual surveys common, ensure protocol consistency. *GESAMP(2019)[2] defines mesoplastics as 5-25 mm and macroplastics as 25-1,000 mm, as shown in Table 2.2 and Figure 2.5 of that document. However this guidance tentatively defines 'macroplastic' as plastics larger than 5 mm for simplicity.
Microplastics	**< 5 mm**, includes **primary** (manufactured small) and **secondary** (fragmented) particles.	Follow GESAMP-aligned sampling/analysis, report size bins where possible.
Nanoplastics	**< 1 µm**.	Definitions and detection methods are evolving, treat figures as **indicative**.

[2] Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean (https://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean)

Environmental compartments	**Terrestrial**, **riverine/freshwater**, **coastal**, **marine**.	"Leakage to the ocean" aggregates riverine discharges **plus** direct coastal/marine inputs, state aggregation rules.

*Table 2.2 in GESAMP(2019)

Table 2.2 Size categories of plastic marine litter, assuming a near-spherical form, showing common definitions and alternative options that may be appropriate for operational reasons.

Field descriptor	Relative size	Common size divisions	Measurement units	References	Alternative options	Remarks
Mega	Very large	> 1 m	Metres	GESAMP		
Macro	Large	25 – 1000 mm	Metres Centimetres Millimetres	MSFD	25 – 50 mm	
Meso	Medium	5 – 25 mm	Centimetres Millimetres	MSFD	< 25 mm 1 – 25 mm	MARPOL Annex V (pre revision)
Micro	Small	< 5 mm	Millimetres Microns	NOWPAP MSFD	1 – 5 mm < 1 mm > 330 µm*	Eriksen *et al.* (2014)
Nano§	Extremely small	< 1 µm	Nanometres		< 100 nm	Not considered for monitoring

*operationally-defined, referring to the typical mesh size of 330 µm of towed plankton nets; §nano-sized particles can only be identified under carefully controlled laboratory conditions and may form a monolayer on one (plates) or two (fibres) dimensions

*Figure 2.5 in GESAMP(2019)

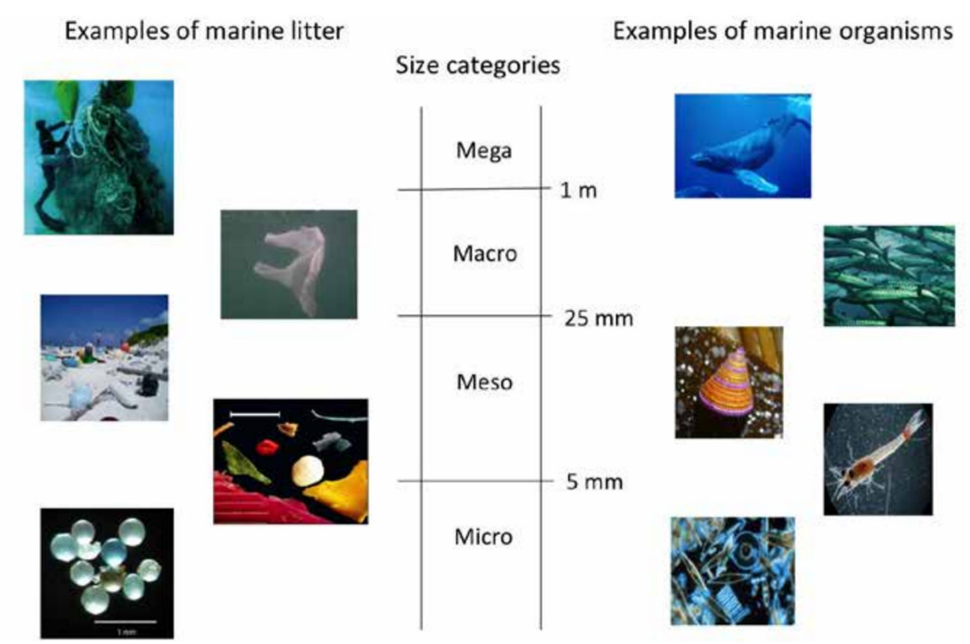


Figure 2.5 Schematic showing field descriptors, typical aquatic organisms in that size category, examples of marine litter and common size divisions.

BOX. Terminology used in this Guidance: leakage, release, loss, and discharge

Terms such as "**leakage**", "**release**", "**loss**" and "**discharge**" are frequently used in the plastic pollution discourse, but not always consistently across reports, monitoring programmes, and modelling studies. This can create confusion in practice, particularly when comparing national baselines, interpreting "**leakage results**" or linking monitoring data to inventory estimates. To support harmonization and transparency, this Guidance adopts a clear editorial convention grounded in **widely used international references** (e.g., OECD and UNEP-related guidance): "**leakage**" is used as the default outcome term for plastics entering environmental compartments (land, waterways, and the ocean), while "**release**", "**loss**" and "**discharge**" are reserved for **specific technical situations** (e.g., source emissions, system-accounting losses, and waterway flux reporting) and are explicitly mapped back to leakage indicators when used.

The table below summarizes these working definitions, how they are used in major guidance, and how each term should be interpreted and applied within a plastic leakage inventory. However this definition is preliminary and for convenience only for this Guidance and will be revised based on future discussions.

Table 3-3. Terminology for plastic pollution accounting

Term	**Evidence-based meaning (how it is used in major guidance)**	**Typical use in practice**	**How it maps to your inventory indicators**	**Key sources (examples)**
Leakage	Plastics that **enter terrestrial or aquatic environments** (outcome concept: "to the environment").	National/ regional **inventory outcome** (e.g., leakage to land, rivers, ocean).	Use as the **default umbrella term** for outcome indicators in this Guidance.	OECD defines "plastic leakage" as plastic entering terrestrial or aquatic environments
Loss	Material **lost from a managed system** (system-accounting concept), which may or may not become environmental entry unless further specified. UNEP–IUCN hotspotting uses *loss rate* as an intermediate step in deriving leakage.	Tracking losses along production, distribution, collection/ transport, or facility handling.	Use as an **intermediate accounting term** only when the environmental compartment is not yet specified; if used, state how it is converted to leakage.	UNEP–IUCN hotspotting guidance (loss-rate / leakage-rate logic)

Release	Plastics **emitted/ released** from a source/ activity (source-emission concept). UNEP/UNITAR uses language around plastics being released (intentional/ unintentional) in life-cycle flow discussions.	Microplastic emissions (e.g., tyre wear), pellet spills, operational releases.	Use when quantifying **source emissions**; add a mapping statement to leakage (e.g., fate/transport and capture factors).	UNEP/ UNITAR Statistical Guideline (terms/concepts for plastic flows and releases)
Discharge	A **flux/ load across a boundary** into a receiving compartment (commonly water), often used in hydrology-style reporting. OECD uses "leakage to aquatic environments"; UN guidance often uses "flows to the environment/ release" rather than standardizing "discharge," but the concept is widely used for riverine loads.	River loads at river mouth, outfall/ pumping station loads, annualized flux reporting.	Use when reporting **measured/ modelled waterway loads at a control point**, then explicitly map to "leakage to waterways/ ocean" in the inventory.	OECD uses leakage-to-aquatic framing; UN guidance focuses on flows/ release terms; "discharge" is best treated as a pathway/flux reporting term

4. Categorization of Estimation Methods

4.1 Introduction of Japan's inventory and methods

Plastic pollution, including microplastics, has become a critical and urgent global issue due to its transboundary nature and adverse effects on ecosystems and biodiversity. In response, Japan has actively led international discussions and initiatives. One notable example is the "**Osaka Blue Ocean Vision**," proposed by Japan, which aims to reduce additional pollution from marine plastic litter to zero by 2050. This commitment was further reinforced by the decision at the fifth session of the United Nations Environment Assembly (UNEA 5.2) in March 2022 to establish an Intergovernmental Negotiating Committee (INC) to develop a legally binding instrument on plastic pollution. In May 2023, the **Hiroshima G7 Summit** also declared an ambition to end additional plastic pollution by 2040. As a result, there is growing demand for Japan to provide scientific knowledge and share effective mitigation measures.

A crucial foundation for national and international plastic pollution policies is the development of plastic leakage inventories, comprehensive databases that estimate the total quantity and breakdown of plastic waste leakage into the environment, including marine ecosystems. Such inventories enable countries to understand their specific situations, formulate targeted measures, and monitor progress. Despite this need, globally harmonized statistical and estimation methods for plastic leakage have not yet been established, making this a shared challenge worldwide.

In response, Japan has continued its work since FY2020 to develop and refine methods for estimating plastic waste leakage into the ocean. The Japanese methodology involves three key approaches:

- ➢ **Source- and item-based estimation methods (mainly for Japan):** Applying emission factors such as leakage and abrasion rates, as developed by a Japanese expert advisory group. (Preliminary estimation has been published since 2024 in English)
- ➢ **Macro-statistical approaches (mainly for Japan):** Using 1. national-level data (e.g. plastic production, consumption, and waste generation) and 2. leakage rate calculated from field survey data, for estimating overall leakage, as discussed by a Japanese expert advisory group. (Estimated by using PET bottle consumption data and leakage rate from field survey in 2024)
- ➢ **Global harmonized methods for developing a discharge/leakage inventory :** Building on the first two approaches, exploring pathways to contribute to **globally applicable estimation methods for inventory development** through the Japanese expert advisory group in collaboration with the **GPML**.

Building on Japan's experience, this Guidance organizes existing leakage estimation approaches into three complementary categories such as **M1** (production/consumption–data-based), **M2** (waste-system/material-flow–data-based), and **F** (field/monitoring–data-based), to help users select fit-for-purpose methods.

4.2 Categorization of existing plastic leakage estimation methods

This Guidance **classifies existing plastic leakage estimation methods into three complementary families** based on their primary evidence stream and analytical logic: **M1** (production & consumption data), **M2** (waste-management and material flows), and **F** (direct field observation and monitoring).

Reader's map

At a glance, Table 4-1 below summarizes each family's typical inputs, analytical approach, strengths/limits, and policy use cases. The detailed descriptions that follow (Sections M1, M2, and F) expand on these features and provide representative references and stakeholders.

Table 4-1. Classification of existing plastic leakage estimation methods

Major Dataset			Existing method	Output, Target Indicator	Data Source, Model, National Statistic, Leakage rate	Stakeholder / Measure: Stakeholder	Stakeholder / Measure: Indicator
M1	**Production & Consumption (total plastic, sector, polymer)**		・Nakatani et al., 2020 (Input-Output Table) ・Toolkit for the product-lifespan method, Basel Convention, 2022 ・CGE model ENV-Linkages, OECD, 2020	Waste Generation	ENVI/CGE, Input-Output Table, Physical Supply and Use Tables	Ministry of Industry, Ministry of Environment (MOE), Statistics Department, etc.	Reduction, Substitution, SUP reduction/phase-out, green procurement, etc.
	Production & Consumption (item)	**MacP**	・MOEJ, 2024 (Macro-statistical approaches (using PET bottle /polymer type consumption data (M1) and leakage rate from field survey (F))	Leakage to Ocean	National Statistic, Discharge rate, etc.		
		MicP	・UNEP, 2018 ・ICF&Eunomia, 2018	Waterway, Soil	National Statistic, Discharge rate, etc.		
			・ECHA, 2020	Waterway, Soil, Air, Waste Treatment			
			・MOEJ, 2024 (Source- and item-based estimation methods)	Water, Soil Ocean			
M2	**Waste Management**	**Waste Flow**	・Waste Flow Diagram (WFD), GIZ, 2020	Leakage to Land & Ocean	National Statistic, etc.	Ministry of Environment (MOE), Ministry of Interior (MOI), Local Government (LGs), etc.	3Rs, improved waste collection, EPR, various recycling schemes, introduction of WtE, improved
			・Toolkit for material flow analysis method, Basel Convention, 2022 ・Plastic Pollution Calculator (PPP), ISWA/UoL, 2019		National Statistic, Discharge rate, etc.		
			・National Analysis and Modelling		Global, National		

			(NAM) Tool, GPAP, 2022 ・SPOT Model, Cottom et al., 2024		Statistic, Statistic model, etc.		landfill sites, etc.
F	**Field survey and Monitoring**	**Coastal and other Land Field Measurements**	・Regional Assessment on Marine Litter in the East Asian Seas, CSIRO and COBSEA, 2024	Leakage to Land	Survey, Statistic model	MOE, LGs	Mitigation measures (Collection, Awareness-raising, etc.), Impact assessment of the mitigation measures
			・MOEJ, Beach litter survey, (latest result: 2025)	Leakage to Land & Ocean	Survey, extrapolation		
		Aquatic (mainly Riverine) Field Measurements	・Schmidt et al., 2017 ・Lebreton et al., 2017 ・Van Emmerik et al., 2019 ・Nihei et al., 2020 ・Meijer et al., 2021 ・Plastic Waste Discharges, World Bank, 2021 ・Mellink et al., 2022 ・MOEJ, Pumping station survey (latest result: 2025)	Leakage to Ocean	Survey, GIS,/Hydrological/ Social Economic related data source, Statistic model	MOE, Water & Marine related departments, LGs	

(Note: The estimation methods used by OECD (ENV-Linkages model + UOL + DTU) and UNEP (National Guidance on Plastic Pollution Hotspotting and Shaping Action) integrate data from both M1 and M2.)

(MOEJ, 2025)

M1: Production & Consumption-Based Estimation Methods

A **top-down, screening-oriented** approach that maps **placed-on-market and in-use stocks** to **source/sector/application–specific activity data** and multiplies them by **leakage factors (coefficients)** defined per source. It organizes flows along **life-cycle stages (production - manufacturing - use - end-of-life)** and cross-cuts with **managed systems** (wastewater, solid waste) and **diffuse sources** (e.g., tyre abrasion, paints, urban dust, open burning). Outputs are **order-of-magnitude leakage estimates** suitable for early policy design and prioritization, not for pinpointing exact locations of leakage.

Table 4-2. M1 Overview (please also see Table 4-5)

Feature	**Description**
Key references	UNEP/UNITAR Statistical Guideline (2026), UNITAR Product-Lifespan/Market-Flow worksheets (2023), OECD ENV-Linkages CGE plastics extensions (2020), Nakatani et al. intersectoral PSUT/IO-MFA (2020), MOEJ item/source-based coefficients (e.g., PET bottles 2024), UNEP (2018), ECHA (2020) for micro sources.
Main inputs	Placed-on-market and in-use stocks by sector/application/polymer, product lifespans & retirement rates, proxy activity data per source (e.g., agricultural area, fishing days, traffic intensity), leakage factors by source/application, national IO/SUT, trade/customs, industrial surveys, optional micro-source activity (textiles, tyres, pellets, PCPs).
Analytical approach	Life-cycle mapping (production – use - EoL) using PSUT/IO-MFA, coefficient-based leakage per source/application, optional statistical reconciliation across datasets, scenario exploration via macro/CGE or stock-and-flow where relevant. Managed pathways (wastewater/solid waste) are represented as modules, diffuse sources are treated with activity × factor equations.
Target estimates	Placed-on-market (POM) and in-use stocks by sector/application/polymer (t, items where relevant), Retirements to waste (end-of-life outflows) and managed shares (collected/sorted/recycled/energy-recovered/landfilled) where available or inferable, Mismanaged waste by product/sector (t/yr), Leakage to land / to freshwater / direct coastal discharge via source- or item-specific coefficients (t/yr), (Optional via coupling with M2/F) Riverine load to the ocean and contribution analysis by product/sector,

	Indicators for priority sources/actors (e.g., polymer × application leakage rates).
Scale	**Spatial:** Primarily national with sub-national resolution by sector/application (e.g., province/municipality via activity allocation). Can be aggregated to river basins/coastal zones for reporting, but M1 alone is not designed to pinpoint exact leakage locations. **Temporal:** Typically annual baselines, supports historical back-casting (time series where data exist) and forward scenarios (5–40 years) via macro/CGE or stock-and-flow extensions. Seasonal profiling is possible for specific items/sources if seasonal coefficients or activity data are available.
Uncertainty & QC	Tiered confidence bands (e.g., ±5/±20/±50%), sensitivity/Monte Carlo where feasible, explicit data lineage and assumption logs, encourage triangulation with M2/F (waste-system balances, field monitoring).
Strengths	Rapid, harmonized and comparable across countries, highlights who/what drives leakage (sectors, applications, polymers), supports EPR design, eco-design, green procurement, and early target-setting.
Limitations	Coarse spatial resolution, coefficients drive results and may under-represent informal/unregistered flows, not designed to model fate/transport or precise locations, some flows (e.g., detailed transit trade, logistics losses) may be excluded when data are insufficient.
Policy use cases	Single-use reduction/phase-outs, polymer/application prioritization, EPR obligations and fee modulation, government disclosure standards, upstream KPIs and monitoring frames, screening inputs for national action plans and treaty reporting.
Example stakeholders	Ministries of Industry/Trade/Environment, national statistical offices, customs, sector regulators (fisheries, transport, agriculture), city/state planning units, producer responsibility organizations, NGOs/academia supporting inventories.
Toolkit Availability	➢ Toolkit for the Product-Lifespan Method (UNITAR, 2023) ➢ UNEP/UNITAR Guideline includes harmonized terms, flow diagrams, and statistical frameworks (under development). ➢ **Toolkit for identifying & quantifying plastic contaminant sources and leakages into aquatic environments**, UNEP/EC Project, 2025, under development

M2: Waste Management and Material Flow-Based Estimation Methods

A **system-level accounting** of municipal solid waste (MSW) from **generation - collection - sorting/recycling - treatment/disposal**, using **Material Flow Analysis (MFA)** to quantify **managed vs mismanaged shares** and to locate **leakage pathways** (on-land dispersion, drains/stormwater, open dumping, open burning, uncontrolled disposal, residuals from low-efficiency facilities). Results are directly actionable for policy and infrastructure planning

Table 4-3. M2 Overview (please also see Table 4-6)

Feature	Description
Key references	GIZ Waste Flow Diagram (WFD, 2020), Toolkit for material flow analysis method, Basel Convention, 2022, University of Leeds / ISWA Plastic Pollution Calculator, GPAP/UNDP NAM (national scenario suite), SPOT (probabilistic MFA with sub-national layers)
Main inputs	MSW generation rates (per-capita × population), composition (plastic fractions by rigid/flex, film, etc.), service coverage & capture (collection efficiency, informal recovery), facility performance (sorting yields, reject rates, landfill controls, WtE performance), disposal technologies, littering/illegal dumping prevalence, and context modifiers (tourism seasonality, rainfall/storm events). Optional layers for hydrology/GIS when routing land leakage to rivers/coasts
Analytical approach	Core is MFA with node- and pathway-specific leakage factors, decision-tree logic (e.g., WFD) to allocate flows, probabilistic variants (Monte Carlo / ranges) for uncertainty, scenario modules to test interventions (e.g., expand collection, MRF upgrades, landfill upgrades, EPR capture). Some suites include GIS visualization and benchmarking (WAB 2.0)
Target estimates	Waste generation, managed flows (collected/ sorted/ recycled/ energy-recovered/ landfilled), mismanaged waste, leakage to land/ freshwater/ coastal environments by pathway/ stage, optionally riverine load to the ocean when coupled with hydrology, SDG-linked indicators (e.g., 11.6.1).
Scale	**Spatial:** City/municipal - sub-national - national (extensible to river basins with GIS). **Temporal:** Typically annual baselines with multi-year scenarios, seasonal modules where tourism/monsoon effects are material.

Uncertainty & QC	Tiered data quality (e.g., default - surveyed - measured), traffic-light reliability scoring (common in Leeds/GIZ tools), data lineage and versioning, sensitivity analysis on key coefficients (collection efficiency, sorting yields, leakage rates). Encourage triangulation with F-family monitoring (litter/flux) and with M1 top-down totals.
Strengths	Direct line of sight to policy & infrastructure levers, fits government workflows, compatible with EPR planning (capture targets, fee modulation), supports hotspot mapping and costed scenarios, can function with progressive data improvement (defaults → primary audits).
Limitations	Sensitive to coverage and performance data, informal/illegal activities can be under-captured, leakage factors may be context-dependent (urban morphology, rainfall), hydrological exports require additional coupling to avoid double counting.
Policy use cases	Expansion of collection services, MRF design and recovery targets, landfill control & compliance, open burning elimination, storm-drain/CSO mitigation, EPR system design and performance tracking, WtE planning with reject management, city benchmarking and SDG reporting.
Example stakeholders	Ministries of Environment/Interior, municipal governments and utilities, waste authorities/regulators, EPR organizations/PROs, planning and finance ministries, development partners, NGOs/academia supporting audits and QC.
Toolkit Availability	➢ GIZ WFD, ISWA PPP and Toolkit for Material Flow Analysis Method (Basel Convention, 2022) offer user-friendly toolkits with step-by-step implementation guidance. ➢ P2O is academically sophisticated but may require expert facilitation for national adaptation. ➢ SPOT is under piloting in several countries and may require technical customization.

F: Field Survey and Monitoring-Based Estimation Methods

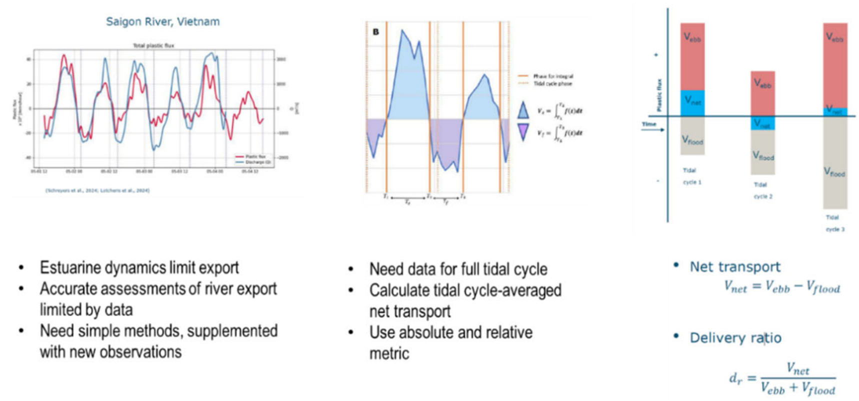
Bottom-up quantification from **environmental observations** (rivers, coasts, urban hotspots), then **standardized extrapolation** to spatial/temporal coverage. Field data are organized by monitoring domain such as **F1: coastal & land** and **F2: aquatic (riverine/lacustrine)**, and can be fused with GIS/hydrology/socio-economic layers to scale up and contextualize results.

Table 4-4. F Overview (please also see Table 4-7)

Feature	Description
Key references	CSIRO & COBSEA (2024) regional shoreline protocols, MOEJ national beach & pumping-station surveys (2024), Schmidt et al. (2017), van Emmerik et al. (2019), Meijer et al. (2021), Nihei et al. (2020, Japan grid-scaling from field–basin correlations)
Main inputs	Standardized surveys (shoreline transects, river booms/nets, bridge visual counts, UAV imagery), composition & size classes, plus GIS (land use, access), hydrological metrics (discharge, runoff, flood regime), and socio-economic covariates (population density, urban share) for scaling.
Analytical approach	(i) Direct metrics: items/m², kg/km, items/s (flux) (ii) Extrapolation: length- or area-based raising factors, discharge-normalized flux curves, seasonal/event factors (iii) Model integration: regressions linking densities/flux to basin traits, hydrology-coupled upscaling to grids, image detection (AI/ML) for counts.
Target estimates	Litter density/flux, item- or mass-based accumulation, leakage to waterways (river flux), leakage to coast, and on-land hotspot loads, trend and intervention effect sizes.
Scale	Site - reach - basin/coastline (with stratified sampling frames), snapshot, seasonal, or annualized (using event/season multipliers or hydrological normalization).
Uncertainty & QC	Use a clear sampling plan (stratified sites, revisit schedule), repeat counts and compare surveyors, note errors in item-to-mass conversion and river flow measurements, for imagery report detection accuracy (precision/recall), explain how short surveys are scaled to seasons/years and give confidence ranges using simple resampling, check upscaling with cross-checks and ground truth, compare methods run side-by-side (nets, visual, cameras) and prevent double counting, grade data quality (default / surveyed / measured) and record data sources, validate against clean-up/interceptor records and municipal statistics, publish uncertainty bands for each metric (e.g., items per metre, kilograms per kilometre, tonnes per year).
Strengths	Ground-truths leakage, pinpoints hotspots, sensitive to change - well suited to before/after and effectiveness evaluations.
Limitations	Cost- and labor-intensive, spatial/temporal gaps, difficult national scaling without harmonized designs, flood events can dominate annual loads but

<table>
<tr><td></td><td>are hard to sample.</td></tr>
<tr><td>Policy use cases</td><td>Rapid hotspot abatement, siting traps/interceptors, beach/river clean-up targeting, tourism-site management, validation/calibration for M1/M2 models, SDG 14.1.1b reporting.</td></tr>
<tr><td>Example stakeholders</td><td>Environment & water agencies, research institutes, local governments, port/river basin authorities, community & NGO networks.</td></tr>
<tr><td>Toolkit Availability</td><td>

➢ No widely available estimation toolkits for **Aquatic Field Measurements** currently exist. However, the Ministry of the Environment, Japan (MOEJ) is preparing a Japanese-language "**Seto Inland Sea Inflow Estimation Manual**" and as illustrated below, van Emmerik et al. have provided practical training on estimation methods using monitoring data collected at river mouths ("Plastic Export from Rivers").



(Source. van Emmerik et al., Workshop material, 2024)

➢ On the other hand, there are some monitoring protocols and manuals available as below.

- CSIRO/COBSEA Protocol Manual
- MOEJ Beach Monitoring Guide
- Marine Debris Program Shoreline Survey Field Guide (National Oceanic and Atmospheric Administration: NOAA, 2013)

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</table>

Integration and Hybrid Methods

Hybrid approaches combine evidence families (e.g., **M1+M2**, **M2+F**, **M1/M2+F**). For transparency and comparability, tag each method with all applicable families (e.g., "M1+F") using the selection criteria in **Chapter 3.2** (policy purpose, estimation scale, datasets, capacity tier) and current data/resource availability. Hybrids are not a fourth category; they are **purpose-built combinations** of the three families.

- **OECD integration (ENV-Linkages + consumption data)**
  Useful as a **research-grade** example of M1+M2 thinking, but the modelling suite is **complex and not released as a ready-to-use toolkit** for external users.
- **UNEP's National Hotspotting Guidance**
  A **publicly available toolkit** (https://plastichotspotting.lifecycleinitiative.org/) that reconciles national statistics with waste-flow balances and GIS hotspotting, an operational **M1+M2** implementation for countries.
- **MOEJ project pilot (M1/M2+F)**
  A practical calibration pathway currently **being refined**.
  - ✓ **Field (F):** Measure annual plastic leakage at a river mouth and convert short campaigns to **t/year**.
  - ✓ **Scaling:** Normalize by catchment population to obtain **per-capita leakage**, then upscale to **national leakage**.
  - ✓ **Macro (M1/M2):** Align the national discharge with a national "generating/handling" denominator for a target item (e.g., PET bottles), either (i) **placed-on-market/consumption (M1)** and/or (ii) **waste management quantities (M2)** such as plastic waste generation to compute an empirical leakage rate.
  - ✓ **Use:** Apply the calibrated rate within M1 to estimate **source/item-level leakage** to land/freshwater/ocean and to test policy scenarios.
  - ✓ **Tagging & QC:** Report as **M1/M2+F**, documenting assumptions, campaign-to-annual scaling, and uncertainty bands per Chapter 3.2.

This integrated design shows how measured river flux can anchor top-down inventories, strengthening credibility while maintaining national coverage using **either M1 (placed-on-market/consumption) and/or M2 (waste management quantities such as plastic waste generation)** as the national denominator, especially where comprehensive M2 system data are limited, but targeted monitoring (F) and **basic M1 and M2 dat**a exist, recognizing that **M1 (production/consumption / placed-on-market) statistics** may be difficult to access or incomplete, while **M2 plastic waste generation data** are often more readily available.

4.3 Overview of existing plastic leakage estimation methods

This chapter complements the category map in Chapter 4.2 by profiling **representative methods within each family** such as **M1** (production & consumption–based), **M2** (waste-system & flow–based), and **F** (field/monitoring–based), using a **common**

template (Official report / method name, Author / Year, Scale (spatial / temporal), Input Data (key variables), Estimation Approach (type) and Output (examples)). The tables provide an at-a-glance comparison, each table is followed by a **generalized method description** that distills how the family is typically used, what it estimates, and what it needs.

M1: Production & Consumption-Based Estimation Methods

Production and consumption-based estimation methods (M1) focus on upstream data regarding the quantities of plastics produced, imported, exported, and consumed, often disaggregated by sector, item, or polymer type. These methods provide a material flow-oriented perspective and are particularly relevant for identifying source-level interventions and quantifying systemic plastic flows throughout the lifecycle. The table below presents **representative M1 methods** that start from **market and statistical evidence** (placed-on-market, trade, supply–use accounts, product lifespans) and convert it into **source- or product-level leakage estimates**. The entries illustrate the **spectrum of M1 designs**:

- **Accounting frameworks** (PSUT/IO-MFA) that reconcile production, use and end-of-life flows and can attach **leakage coefficients** by source/item.
- **Cohort/stock-flow worksheets** that turn product sales and lifespans into retirements, mismanaged shares and leakage.
- **Economy-wide scenario models** (e.g., CGE) that link sectoral plastics use and waste outcomes to policy shocks, providing **leakage proxies** over long horizons.
- **Item/source-based coefficient approaches** for priority products (e.g., PET bottles, ALDFG) that deliver **fine-grained contributions** and seasonality.
- **Quick-assessment toolkits** that apply **activity × leakage-factor equations** across source categories to produce **inventories of flows to aquatic environments**.

Read the columns as follows:

- **Scale** indicates the typical spatial/temporal resolution.
- **Input Data** lists the key variables you must assemble.
- **Estimation Approach** clarifies whether the method is accounting, coefficient-based, statistical reconciliation, or simulation.
- **Output** shows the **decision-ready metrics** you can expect (e.g., placed-on-market, in-use stocks, retirements, mismanaged shares, and **leakage by source/product** in t/yr).

Use this table to **match a method to purpose and data reality**: select accounting tools when you need **consistent national balances**, cohort sheets for **product-specific retirements**, CGE for **policy scenarios**, item-based coefficients for **priority sources**, and quick-assessment toolkits for a **first-pass inventory** that can later be calibrated with M2/F evidence.

Table 4-5. Representative M1 methods

Official report / method name	Author, Year	Scale (spatial / temporal)	Input Data (key variables)	Estimation Approach (type)	Output (examples)
Revealing the intersectoral material flow of plastic containers and packaging in Japan	Nakatani et al., 2020	National, annual (historical series 2000–2015)	Physical supply-use tables, resin/forms, sectoral uses, trade/production stats	Statistical model: IO-MFA/PSUT, Default: accounting balance, Leakage rate: optional coefficients	Inter-sector flows, inflows to use & waste stages, recycling rates, leakage by source where coefficients applied (t/yr)
Statistical Guideline for Measuring Flows of Plastic Throughout the Life Cycle	UNEP/ UNITAR, 2026	National / sub-national, annual (can be extended to multi-year)	Production, import/export, consumption by sector/item, product lifespans, harmonized classifications (SEEA CF, CPC/ISIC)	Default: PSUT/physical supply-use mapping, Leakage rate: coefficients by source/ item, Statistical model: reconciliation/ triangulation	Placed-on-market, in-use stocks, waste flows, estimated leakage by source/sector (t/yr)
Product-Lifespan / Market-Flow Worksheets	Basel Toolkit, 2023	National / sub-national, annual	Placed-on-market by product/polymer, lifespans, retirement rates, trade	Default: cohort/ stock-flow accounting, Leakage rate: end-of-life coefficients, Statistical model: simple consistency checks	In-use stock trajectories, retirement to waste, estimated mismanaged shares & leakage by product/polymer (t/yr)
ENV-Linkages Modelling Framework	OECD, 2020	Global / regional / national, long-	SAM/IO tables, trade, sectoral plastics use, policy shocks, literature	Simulation: CGE, Statistical model: calibration to historical	Plastics use & waste by sector, system outcomes (recycle/landfill/incineratio

		term scenarios (e.g., 2019–2060)	coefficients	series, Leakage rate: via linked coefficients	n/mismanaged), scenario-based leakage proxies (t/yr)
UNEP/EC Project “Guiding Document V.2” (Toolkit for identifying & quantifying plastic contaminant sources and leakages into aquatic environments, under development)	UNEP-IETC with EC DG ENV; project team (Alvaro Z., Felipe D.), 2025-06-24.	User-defined territory (e.g., national, basin, city) and “determined time”; focus on inventories of flows to aquatic environments.	Activity data by source category + leakage/ transfer coefficients (production & handling, SWM, wastewater, sectoral uses (agriculture, fisheries), diffuse sources (tyres, paints), with suggested data sources.)	Quick-assessment, leakage-factor toolkit: life-cycle/source perspective; equations per category; user enters data via a platform; produces inventories of plastics leaving the managed system to the environment.	Numerical estimates of plastic pollution flows to aquatic environments and sectoral contributions; example visualisations of inventory outputs referenced in the document.
Source- and item-based estimation methods	MOEJ, 2024 (the latest report) (https://www.env.go.jp/content/000320691.pdf) pp. 6-46	National / mainly leakage into the marine environment, annual	Item counts/market data, product use profiles, loss/abrasion rates, return rates	Leakage rate: source/item-specific coefficients, Default: bottom-up aggregation, Statistical model: parameter calibration	Leakage by item/source, annual inputs, contribution analysis to total leakage (t/yr)
Macro-statistical approaches (using	MOEJ (the latest report:	National / mainly leakage	Production, consumption of PET	Simple calculation: PET bottle / polymer	Total leakage amount of plastic products (t/yr)

PET bottle / polymer consumption data (M1) and leakage rate from field survey (F))	2024) (https://www.env.go.jp/content/000320691.pdf) pp. 47-52	into the marine environment, annual	and overall polymer types	consumption data (M1) × leakage rate from field survey (F))	(This is a case in Japan. For the pilot projects in Vietnam and Indonesia, see Table 4-8)

M2: Waste Management and Flow-Based Estimation Methods

Waste management–based estimation approaches (M2) focus on identifying plastic leakage points throughout the waste lifecycle from generation to disposal, by utilizing national and subnational data on waste collection, treatment, and infrastructure. These methods are often based on material flow analysis (MFA) and are widely used to inform policy in developing and implementing waste management systems. The table below gathers **representative M2 tools** that start from **municipal solid-waste system data** (generation, collection, sorting, treatment, disposal) and use **Material Flow Analysis (MFA)** to quantify **managed vs. mismanaged** streams and **where leakage occurs** in the system. The entries span:

- **Rapid, city-scale diagnostics** (e.g., **WFD**) that standardize flow mapping, apply **predefined leakage factors**, and flag **priority leakage nodes** with a simple QA "traffic-light" score.
- **Calculator-style MFAs** (ISWA) that allocate flows to **on-land dispersion, open burning, drains → water**, and support **what-if scenarios** and **benchmarking** across cities or countries.
- **System simulations** (**P2O**) that couple stock-and-flow equations with **policy levers** and **uncertainty analysis** to generate **global to regional** pathway leakages and **long-term** intervention effects.
- **Probabilistic, sub-national models** (**SPOT**) that fuse municipal data and defaults (WaCT/WABI/WaW2.0) with **machine-learning** to produce **pathway-resolved emissions** and **hotspot maps** at municipal scale.

Read the columns as follows:

- **Scale** shows the spatial/temporal resolution you can expect.
- **Input Data** lists the minimum variables to collect (and typical default sources).
- **Estimation Approach** clarifies whether the method is **MFA decision-tree**, **calculator**, or **dynamic simulation**, and how uncertainty/QA are handled.
- **Output** summarizes the **decision metrics** (e.g., mismanaged waste, leakage by pathway in t/yr, hotspots, SDG-aligned indicators, scenario effects).

Choose **WFD** for a **fast baseline** and clear leakage nodes; the **ISWA Calculator** when you need **simple scenarios** and comparable **pathway splits**; **P2O** for **long-horizon policy portfolios** under uncertainty; and **SPOT** for **municipal-level hotspotting** with probabilistic results. Where river/coastal reporting is required, couple M2 outputs with **hydrological routing** or **field monitoring (F)** to derive **riverine load** and to validate city/national leak estimates.

Table 4-6. Representative M2 methods

Official report / method name	Author, Year	Scale (spatial / temporal)	Input Data (key variables)	Estimation Approach (type)	Output (examples)
Waste Flow Diagram (WFD)	GIZ, 2020	Spatial: Municipal/City Temporal: Annual (rapid assessment)	Population, MSW generation & composition, collection efficiency, facility data, SDG 11.6.1 links	MFA + decision tree: standardized flow mapping, Leakage rate: predefined factors, QC: traffic-light reliability	Managed vs mismanaged flows, leakage amounts by stage (t/yr), priority leakage nodes, SDG-aligned indicators
Plastic Pollution Calculator	ISWA, 2019	Spatial: City → national (scalable to regional/global comparisons) Temporal: Annual, scenario capable	Waste generation, composition, collection coverage, socio-economic conditions, littering prevalence	MFA: pathway allocation using default/ locally-calibrated leakage factors, simple scenarios	System leakage by pathway (open burning/ on-land/drains -> water) (t/yr), ranked interventions, benchmarking
Plastics-to-Ocean (P2O) model	Systemiq, 2020	Spatial: Global (8 archetypes) Temporal: Annual projections to 2040	Population, per-capita MSW (macro), microplastic use, loss & collection rates, informal sector, policy levers	Simulation: coupled ODE stock-and-flow, Uncertainty: Monte Carlo, Leakage rate: pathway coefficients	Global/system plastic leakage by pathway (t/yr), cumulative leakage to 2040, scenario effects of interventions
Toolkit for material flow analysis method	Basel Convention, 2022	Spatial: National, built by archetypes (Mega/ Medium/ Small Cities)	Population, MSW generation rate, % plastic in MSW, plastic	Stepwise Excel MFA with 4 steps: (1) Baseline data,	Archetype estimates: Plastic waste collected, recycled, incinerated,

		Temporal: Daily and annual estimates	disposed to landfill, plastic to incineration, plastic to recycling, imports/ exports	(2) Leakage factors, (3) Flow calculations, (4) National summary	disposed, uncollected at source, and leakage by stage (collection/ sorting/ transport/ disposal), MPW, Stage-specific leakage
National Analysis and Modelling (NAM) Tool[3]	GPAP, 2022	Spatial: primarily national / country level, with archetype-based differentiation within countries Temporal: baseline assessment plus forward-looking scenario modelling to 2040.	Demographics and waste generation data, plastic flow data, waste system flow parameters, and user-adjustable baseline / intervention variables (mainly cover municipal solid waste plastics, including five application categories: bottles, other rigid mono-materials, flexible mono-materials, multilayer / multi-material plastics,	A scenario-based systems modelling tool based on the Breaking the Plastic Wave methodology and compatible with UNEP hotspotting analysis (baseline plastic waste flows, simulates intervention pathways, and compares scenarios)	Examples include baseline plastic waste flows, plastic pollution / leakage metrics, future scenario results, and decision-support metrics (cost to government, GHG emissions, circularity score, and source of plastics)

[3] The NAM Tool (and the Breaking the Plastic Wave methodology) are conceptually grounded in the Plastics-to-Ocean (P2O) modelling framework. While P2O provides the core flow-based estimation logic, the Breaking the Plastic Wave methodology extends this into a comprehensive scenario-based assessment framework, and the NAM Tool further adapts it into a country-level operational tool with simplified and customizable data structures.

			and other household goods)		
SPOT: Spatio-Temporal Quantification of Plastic Pollution	Cottom et al., 2024	Spatial: Global → sub-national (municipal level) Temporal: Annual (base 2020)	Municipal waste generation & composition, collection coverage, socioeconomic indicators, defaults from WaCT/ WABI/ WaW2.0/ UNSD	Probabilistic MFA + ML: bottom-up municipal modeling, Uncertainty: Monte Carlo	Macroplastic emissions by municipality/pathway (t/yr), hotspot maps, intervention impact comparisons

F: Field Survey and Monitoring-Based Estimation Methods

Field-based methods (F) rely on direct observation, measurement, and sampling to estimate plastic leakage. These methods are particularly valuable for generating empirical evidence on the presence, movement, and accumulation of plastics in the environment. The table below gathers **representative F methods** that start from **direct environmental observations** including shoreline transects, river flux measurements, and image/GIS analyses, and convert them into **densities, fluxes, and annual loads**. The entries span: (i) **standardized beach surveys** for accumulation trends and indicators; (ii) **riverine flux studies** that build **rating curves (flux vs. discharge)** to annualize loads; and (iii) **statistical/transport models** that **scale** local observations with **basin traits, hydrology, and land use** to produce **hotspot maps** and **nationwide grids**.

Read the columns as follows:

- **Scale** shows the monitoring domain and time resolution.
- **Input Data** lists field variables plus covariates (hydrology, land use, socio-economics, GIS).
- **Estimation Approach** clarifies whether the method is **empirical field model**, **statistical regression**, or **numerical transport**; **Output** summarizes **decision metrics** (e.g., items/m, kg/km, river export t/yr, hotspot maps).

Use **beach monitoring** for **trend tracking** and indicator reporting, **river flux measurements** for **load estimation** at mouths and intervention evaluation, **statistical/transport upscaling** when you need **basin/national coverage** from limited field points. For national inventories, pair F outputs with **M1** (to calibrate source/item coefficients) and with **M2** (to reconcile pathway totals), and always report **uncertainty bands** and QC notes consistent with your chapter standards.

Table 4-7. Representative F methods

Official report / method name	Author, Year	Scale (spatial / temporal)	Input Data (key variables)	Estimation Approach (type)	Output (examples)
CSIRO Global Plastic Leakage Baseline Project (Cambodia)	CSIRO, 2024	Spatial: Local (coast, inland, river sites) Temporal: Short-term (two campaigns, 2022–2023)	Site accessibility/ cleanliness, population density, infrastructure, distance to roads/rivers/coast, on-site counts, GIS, socio-economic datasets	Statistical model: Generalized Additive Model (GA), relates debris density to socio-economic/geographic predictors	Debris density maps (items/km, items/m²), hotspots, estimated total items on coastline (e.g. >80M items)
MOEJ Beach Litter Monitoring (Japan)	MOEJ, (latest result: 2025[4]	Spatial: National coastlines Temporal: Seasonal -> annual	Standardized shoreline transects, item/type tallies, mass/volume, GPS, weather/season notes	Default: standardized survey + Statistical aggregation, optional coefficients for source attribution	Beach accumulation rates (items/m/day, t/km/yr), trends by item/type, policy indicator tracking.
High-Resolution Mapping of Japanese Microplastic and Macroplastic Emissions from the Land into the Sea	Nihei et al., 2020	Spatial: Nationwide Japan, 1-km grid (aggregable by basin/admin unit) · Temporal: Annual (water-balance normals ~2011-2015), river	River MicP concentrations (number & mass, 70 rivers/90 sites), basin characteristics (population density, urban-area ratio), land-	Hybrid (Statistical + Hydrological scaling): regress MicP vs population density/urban ratio (linear/ piecewise/ log-quadratic), compute grid outflow via simple	Total input (MicP+MacP): 210-4,776 t/yr (Japan), MicP: 65-503 t/yr and 0.55-2.54 trillion items/yr (median 1.40 trillion), 1-km hotspot maps

[4] Methodology: https://www.env.go.jp/content/000331279.pdf

		sampling 2015-2019 mainly under low-flow	use classes, precipitation & simple water-balance components (ET, surface runoff, infiltration), MacP/MicP mass ratio (from literature)	water balance, MicP emissions = MicP concentration × outflow, infer MacP from MicP using MacP/MicP ratio, sum to total. Validation: Qcal–Qobs slope 0.963, R^2 0.925 (n=109 rivers), MicP number–mass slope = 0.201 mg/particle	highlighting highly urbanized regions (Tokyo, Nagoya, Osaka)
Export of Plastic Debris by Rivers into the Sea	Schmidt et al., 2017	Spatial: Global/Regional (large rivers) Temporal: Annual (seasonal signal considered)	Population density, waste generation, mismanaged plastic waste (MPW), river discharge	Statistical model: power-law/linear regression using MPW & discharge as predictors	Estimated riverine plastic input to the ocean by river/basin (t/yr), ranking of high-load rivers
River Plastic Emissions to the World's Oceans	Lebreton et al., 2017	Spatial: Global (river basins) Temporal: Annual (with seasonal variability)	MPW, runoff/discharge, catchment characteristics, observed river concentrations	Statistical model: empirical regression calibrated to observed rivers, Default: coefficient-based emissions	Global riverine input to oceans (t/yr), contribution shares by basin/region, seasonal emission profiles

Seasonality of Riverine Macroplastic Transport	van Emmerik et al., 2019	Spatial: Local (Saigon River) Temporal: Monthly/seasonal/annual	Item counts, mass, rainfall & discharge, polymer-specific obs. (e.g., PS-E, POsoft)	Empirical field observation model (seasonal flux + spatial distribution)	Plastic outflow 1.1×10^3–1.6×10^3 t/yr, seasonal variation & cross-section profiles
More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean	Meijer et al., 2021	Spatial: Global (100,000 outlets) Temporal: Annual	Population density, land use, discharge, rainfall, wind, distance to river/ocean	Distributed probabilistic model (MPW – river - ocean)	Global riverine input to oceans: 0.8-2.7 Mt/yr, 1,656 rivers = 80% of emissions
Plastic Waste Discharges from Rivers and Coastlines in Indonesia / Baseline estimation of plastic discharges from land-based sources via rivers and coastlines	World Bank, 2021	Spatial: national baseline for Indonesia, with subnational resolution by province, kabupaten/kota, river catchment, and coastline Temporal: annual estimates with seasonal variation represented through hydrological modelling.	Plastic waste generation, household waste handling practices, collection and recycling losses, disposal site type and containment conditions, urban/rural split, plastic fractions available for wash-off, and hydrological variables such as rainfall, runoff, river discharge, elevation,	Source-to-sea baseline estimation model combining a MPW assessment with distributed hydrological and fate-and-transport modelling (including WFLOW and DELWAQ)	Annual plastic waste discharges to the marine environment, catchment-level and provincial hotspot identification, seasonal discharge patterns, and breakdowns by source pathway such as uncollected waste, open dumping, and leakages from disposal sites.

			land use, and soil type		
The Plastic Pathfinder: A Macroplastic Transport and Fate Model for Terrestrial Environments	Mellink et al., 2022	Spatial: Regional/Local (terrestrial → river basins) Temporal: Daily → annual aggregation	Wind speed, surface runoff, land use/land cover, terrain slope, MPW generation	Simulation: numerical spatio-temporal transport (threshold-friction), Statistical model: parameter calibration	Overland routing maps, accumulation hotspots, entry points into rivers, time-evolving MPW distribution
MOEJ, Pumping station survey	MOEJ, (latest result: 2025)	Spatial: survey sites at drainage pump stations within and outside urban areas, with extrapolation to catchment, regional, and national levels;, Temporal: seasonal field observations converted to annual estimates	River plastic litters concentrations (number & mass), basin characteristics (population density, urban-area ratio), land-use classes, precipitation & simple water-balance components (annual runoff volume, rainfall and runoff data)	Field-based empirical estimation with hydrological scaling and national extrapolation (Estimated at survey sites from observed plastic waste and runoff conditions, then annualized using runoff volume. (Scaling approaches: runoff/land-use based, per-capita based, and catchment-area based)	Annual macroplastic leakage from land to sea (t/year), Site-level annual plastic discharge, Comparative estimates by three extrapolation methods, National-level leakage estimate for Japan

Reference. Integration and Hybrid Methods (M1+M2 and M1/M2+F)

Hybrid approaches deliberately combine evidence families (e.g., M1+M2, M1+F) so that upstream "market signals" (placed-on-market, consumption) can be reconciled with either waste-system performance or measured environmental fluxes. They are not a fourth category; they are purpose-built combinations chosen using Chapter 3.2 criteria (policy purpose, estimation scale, datasets, capacity tier). Sound hybrids document assumptions, avoid double counting, and, where feasible, calibrate against field evidence with uncertainty ranges.

- **M1+M2 (UNEP, 2020): National Guidance for Plastic Pollution Hotspotting and Shaping Action**

  A publicly available, country-implementation toolkit from UNEP/IUCN/Life Cycle Initiative with six Technical modules (T1–T6) and three Strategic modules (S1–S3). It ships with input/assessment/output spreadsheets, data libraries, and a GIS hotspotting module.

  How it works (workflow & data model).

  - **T1 (Inputs & Outputs):** Inventory polymer/application/sector flows (production, imports/exports, consumption).
  - **T2 (Waste & Wastewater):** Compile collection, sorting, recycling, disposal, wastewater metrics for leakage calculation.
  - **T3 (Polymer–Application–Sector MFA):** Reconcile T1–T2 via mass balance; compute mismanaged shares and leakage using loss/release rates; rank hotspots in absolute and relative leakage.
  - **T5 (GIS):** Map geographic hotspots using T1–T3 outputs.
  - **T4/T6:** Qualitative waste-system assessment and impact framing that feed hotspot prioritization.
  - **S1–S3:** Convert hotspots into prioritized actions and enabling instruments.

  Target estimates.

  - Leakage by polymer/application/sector, waste-system node, and geography; mismanaged shares; regional hotspot maps; and an actionable short-list of priority hotspots/interventions.

  Scale. National with sub-national archetypes (e.g., urban/rural/coastal) and annual reporting; GIS enables spatial drill-down.

  Key inputs. Production/trade, sector/application data (T1); waste and wastewater performance (T2); default loss/release factors; optional local coefficients; GIS layers for T5.

  Estimation approach. Mass-balance reconciliation (T3) + GIS hotspotting (T5); quantitative hotspot ranking by absolute and relative leakage; strategic modules guide action design.

Outputs (examples). Polymer/application leakage (t/yr), leakage by system stage, hotspot maps by archetype, prioritized actions and instruments with a transparent audit trail of assumptions.

QC & uncertainty. The Guidance prescribes a reproducible workflow, triangulation across modules, and clear documentation of loss/release rates, data gaps, and prioritization criteria to ensure consistency and comparability.

Who uses it. National ministries, statistical offices, and technical teams implementing country assessments with a standardized toolkit.

- **M1/M2+F (MOEJ pilot, 2025: Indonesia & Viet Nam)**

  A product-based calibration that derives an empirical leakage rate by pairing **basic national M1 and/or M2 data** with measured waterway waste fluxes or waste accumulated at a pumping station (F) for the same product (e.g., PET bottles). In practice, **M1 placed-on-market/consumption data may be difficult to access or incomplete**, while **M2 plastic waste generation data are often more readily available** and can be used to cross-check or proxy the denominator when needed. The pilot activities are being refined under the leadership of MOEJ in 2025 in Indonesia and Viet Nam (see Annex).

  Procedure

  1) Extract **national consumption/placed-on-market of the target product (M1, t/yr)**; where unavailable, compile **M2 plastic waste generation** and use it to **cross-check** or **approximate** the product mass with documented assumptions.
  2) In Indonesia, this was done in a river using image-based monitoring to estimate litter flow; in Viet Nam, this was done at a pumping station using a waste composition survey, supplemented by image interpretation for unrecovered waste.
  3) Convert the field measurements to annual discharge (t/yr): in Indonesia, by linking litter flow to river discharge through an L–Q relationship; in Viet Nam, by annualizing observed accumulated waste using assumed minimum and maximum accumulation periods
  4) Compute catchment-level discharge for the monitored catchment.
  5) Upscale to national discharge (e.g., population-based and/or area-based scaling, depending on the monitored catchment and available data).
  6) Leakage rate = national discharge ÷ **national M1 consumption/placed-on-market** (product-specific); **where M1 is constrained**, report an **M2-supported approximation** (e.g., using plastic waste generation with product share

assumptions) and clearly document the basis.

7) (Optionally) apply the calibrated rate to related products/plastics with documented assumptions.

Target estimates

Product-specific leakage rate and national riverine inputs, when looped back into M1 tables, supports scenario testing of upstream policies. **M2 plastic waste generation can also be used to sense-check plausibility and improve internal consistency (e.g., ensuring estimated leakage does not exceed feasible waste generation ranges).**

QC & uncertainty

Explicit tagging as **M1+F** (or **M1/M2+F** when M2 is used materially); document monitoring periods and flow-time upscaling, sampling bias, population scaling, **M2-M1 consistency checks**, any proxy assumptions (e.g., product shares within plastic waste generation), and confidence intervals.

Table 4-8. Hybrid Methods (M1+M2 and M1/M2+F)

Official report	**Author, Year**	**Scale (spatial / temporal)**	**Input Data**	**Estimation Approach**	**Output (examples)**
National Guidance for Plastic Pollution Hotspotting and Shaping Action	UNEP/ IUCN, 2020	National → sub-national archetypes; annual with GIS hotspotting	Production & trade; sector/application; waste & wastewater metrics; loss/release rates; GIS layers	**Hybrid (M1+M2):** mass-balance reconciliation (T3) + GIS hotspotting (T5); strategic modules S1-S3 for actions	Polymer/ application leakage (t/yr), leakage by system stage, hotspot maps, prioritized actions/instruments with documented assumptions.
Product-based national leakage calibration (PET example,	MOEJ, 2025 (pilot project in Vietnam and Indonesi	National (calibrated by monitored catchment); annualized from campaign periods	**Basic national M1 and M2 data**: **(M1)** placed-on-market/ consumption of target item	**Hybrid (M1/M2+F):** derive empirical leakage rate using national discharge vs	**Product-specific leakage rate**; national riverine input (t/yr); when applied in **M1**,

	a) See also Annex1.		where available; **(M2)** plastic waste generation (for cross-checking or proxying when M1 is constrained); plus **river-mouth/ pumping-station flux** (counts/ mass), catchment population; optional camera/AI	**M1** consumption/ placed-on-market; where M1 is limited, use **M2** plastic waste generation with documented product-share assumptions to approximate/ validate the denominator; then extrapolate within M1 tables	source/ item-level leakage estimates and policy scenario testing; **M2** supports plausibility checks and internal consistency (e.g., leakage not exceeding feasible waste generation ranges).

5. Selecting and Applying Existing Estimation Methods

Chapter 5 sets out a practical method-development pathway for estimating plastic leakage into the environment, including the marine environment. Building on the method categories introduced in Chapter 4 (notably macro-statistical approaches (M1), waste-system/flow-based approaches (M2), and field/monitoring-based approaches (F)), this chapter explains how to move from a policy question to a transparent quality-assured estimate that is reproducible and fit for decision-making. Rather than presenting a single "best" method, Chapter 5 emphasizes **fit-for-purpose method selection**, **data readiness**, and **triangulation across complementary approaches** (e.g., reconciling top-down statistics with waste-system evidence and field observations).

Section 5.1 (Stepwise Workflow for Inventory Development and Method Selection) introduces the overall stepwise workflow used throughout this Guidance. It begins with defining the **policy use-case** (e.g., production/consumption measures, municipal solid waste management improvement, terrestrial impacts, and river-basin/ocean impacts), then scopes the **leakage pathway(s)** and sets **indicators/targets** (units, boundaries, time/space), followed by **data inventory and method selection**, and finally applies **QC, verification and validation** before **reporting** minimum tables/figures, uncertainty, and lineage. This stepwise framing clarifies what decisions must be made at each stage and what evidence is required to support them.

Section 5.2 (Linking Policy Use-Cases to Data Families and Estimation Tools (Step 1–3)) then unpacks the early stages (Step 1–3) in more detail by mapping policy/intervention needs to the four core **data families** used in this Guidance: **M1.** Production & Consumption statistics (including sector activity data), **M2.** Solid Waste Management statistics, **F.** Field Survey and Monitoring-Based Estimation Methods (F1 Land/coastal field survey data, and F2 Aquatic (mainly riverine) survey data). This section shows how users can structure a national or subnational "**data inventory**" and connect available datasets to established toolkits, models, and guidance (e.g., statistical Guidances, waste-flow tools, and field survey protocols), while recognizing that some linkages are direct (primary) and others are optional/indirect depending on the purpose and capacity.

Section 5.3 (Quantifying Leakage Along the Plastic Value Chain Using Coefficients and Models) highlights how leakage can be quantified along the value chain from production and consumption through waste management to leakage to land and waterways by applying **leakage factors**, **scaling parameters**, and **statistical/empirical models**. The intent is to make explicit *where* coefficients are used, *why* they are needed (e.g., to bridge gaps between activity data and observed leakage), and *how* modelling choices (including uncertainty treatment) affect results. This section also reinforces the importance of cross-checking estimates against independent evidence (e.g., comparing M1/M2-derived leakage with F1/F2 signals) to improve robustness and interpretability.

Section 5.4 (Methodological Gaps and Operational Usability) interprets the synthesis matrix (Table 5-1) as an **operational diagnostic** of the current estimation-method ecosystem. Rather than repeating the stepwise workflow in Sections 5.1–5.3, it uses the matrix to clarify **which estimation approaches are already practitioner-ready (toolkit/guidance-supported)** and where **operational usability constraints** remain, particularly for field-evidence-based estimation, most notably **F2 aquatic/riverine survey data**. The section highlights that, while a substantial body of research-developed methods exists, their application in routine national/subnational inventories is often limited by the lack of **widely usable, inventory-oriented toolkits and standardized operational guidance** (including protocols, scaling logic, QC procedures, and reporting templates). It then draws practical implications for method choice and identifies priority areas where further **standardization and packaging** would most strengthen consistent governmental use and comparability across reporting cycles and geographies.

5.1 Stepwise Workflow for Inventory Development and Method Selection

This Guidance adopts a **stepwise workflow** to support users in developing fit-for-purpose estimation methods and compiling an inventory of plastic leakage into the environment, including the marine environment (Figure 5-1). The workflow is designed to be **policy-driven**, **transparent**, and **auditable**: it starts from the policy question to be answered, translates that question into well-defined pathways and indicators, identifies the required data and applicable methods, and then applies systematic quality assurance before reporting results with clear uncertainty and data lineage. While presented as sequential steps, the process is **iterative** in practice; gaps identified at later steps (e.g., in QC) may require revisiting earlier scoping decisions or data selections. In practice, the workflow is iterative rather than strictly linear: data availability and quality may require revisiting and refining the policy use-case, pathways, and indicators, and QC findings may also necessitate returning to earlier steps to adjust data and method selection.

Step 1. Define the policy use-case

The first step is to clarify the **policy use-case** and the decision context the estimate is intended to inform. Typical use-cases include:

- **Measures for Production and Consumption (including sectoral measures)** (e.g., placed-on-market or sector activity perspectives);
- **Improvement of Solid Waste Management (municipal)** (e.g., collection, treatment, and service performance);
- **Terrestrial impacts** (e.g., leakage to land and associated risk/impact framing); and
- **River basins and ocean impacts** (e.g., leakage to waterways, riverine transport, and marine exposure).

A clear use-case definition determines the required level of detail (national/subnational; sector/item specificity), the expected outputs (baseline, trend, scenario), and the minimum evidence needed for credibility.

Step 2. Scope pathways and set indicators/targets

Next, users scope the **pathway(s)** and define the indicators/targets that the inventory will quantify. This includes selecting one or more pathways such as:

- **Mismanaged plastic waste (MPW)**,
- **Leakage to Environment**, and/or
- **Leakage to Ocean**.

In parallel, users define indicators with explicit specifications for **unit**, **boundary**, **time and space**, and **targets** (where relevant). This step establishes what is “in scope” (and what is not), prevents inconsistent interpretation across agencies or reporting cycles, and enables comparability over time.

Step 3. Conduct data inventory and select methods

With the scope fixed, users compile a **data inventory** and select estimation methods consistent with the pathway(s), indicators, and available capacity. The Guidance organizes evidence into four complementary data families:

- **M1. Production and Consumption statistics** (placed-on-market, **sector activity data**)
- **M2. Waste statistics (municipal)** (generation, collection, treatment)
- **F1. Land/coastal field surveys** (litter counts, audits, remote sensing where applicable)
- **F2. Aquatic field surveys** (river flux, concentration, shoreline surveys)

Method selection at this stage should be explicitly justified against (i) the policy use-case, (ii) data readiness/coverage, (iii) required spatial/temporal resolution, and (iv) transparency and reproducibility requirements. Where feasible, users should plan for **triangulation** (e.g., combining M-type statistical evidence with F-type field evidence) to strengthen robustness.

Step 4. Apply QC, verification and validation

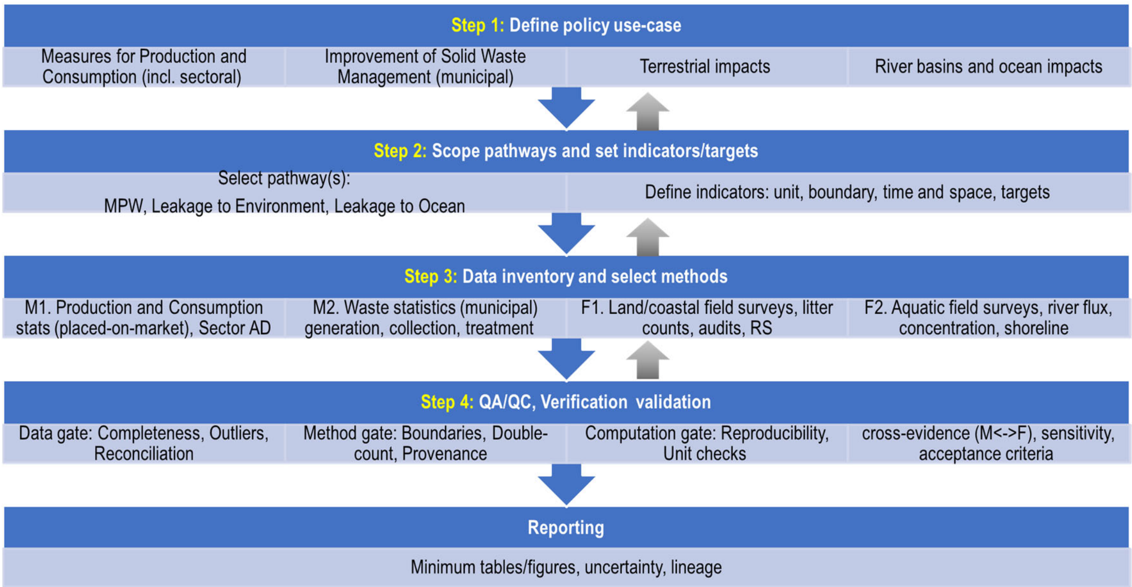
Before results are finalized, the workflow applies structured QA/QC through multiple "gates":

- **Data gate:** completeness checks, outlier screening, and reconciliation across sources
- **Method gate:** boundary checks, double-count prevention, and provenance documentation
- **Computation gate:** reproducibility, unit consistency, and calculation checks; and
- **Cross-evidence gate:** consistency checks between macro-statistical estimates and field evidence (M↔F), sensitivity analysis, and acceptance criteria

This step ensures that results are credible for policy use, comparable across time, and defensible in technical review. In this Guidance, QC at this step primarily refers to estimation/inventory QC (method and input-data quality, reproducibility, and uncertainty handling); for monitoring QC related to field survey protocols and measurement quality, please refer to Chapter 3.

Step 5. Reporting

The final step translates the validated estimate into standard reporting outputs, including **minimum tables/figures**, **uncertainty characterization**, and clear **data/method lineage** (what data were used, how they were processed, and which assumptions were applied). Reporting should make the estimate interpretable for decision-makers while preserving sufficient technical detail for replication and future inventory improvement cycles.



(Note) In practice, this is an iterative workflow: data constraints may require returning to Step 1–2 to refine the policy use-case and indicators.

Figure 5-1. Stepwise Approach to Estimating Plastic Leakage

5.2 Linking Policy Use-Cases to Data Families and Estimation Tools (Step 1–3)

This section elaborates **Step 1–3** of the stepwise workflow by showing how policy and intervention needs can be systematically translated into an operational **data inventory** and a set of **candidate estimation methods** (Figure 5-2). The core idea is to map the policy question to the **four data families** used in this Guidance (**M1**, **M2**, **F1**, and **F2)** and then connect available datasets to established toolkits, models, and guidance. This mapping helps users make transparent choices about (i) which datasets are essential, (ii) where assumptions and coefficients are required, and (iii) how to combine complementary approaches to improve robustness.

5.2.1 Four data families as the common "building blocks"

Figure 5-2 below organizes the information needed for leakage estimation into four core data families:

- **M1. Production & Consumption statistics (including sector activity data):** placed-on-market and sectoral activity information that defines upstream quantities, product categories, and potential sources.
- **M2. Solid Waste Management statistics:** municipal waste generation, collection coverage, treatment/disposal pathways, and performance parameters that define how plastics flow (or fail to flow) through the waste system.

- **F1. Land/coastal field survey data:** litter counts, waste audits, and land/coastal monitoring (including remote sensing where applicable) that provide empirical evidence on leakage to terrestrial and coastal environments.
- **F2. Aquatic (mainly riverine) survey data:** measurements and monitoring of plastics in rivers and other water bodies (e.g., concentration/flux, shoreline surveys) that inform leakage to waterways and the likelihood of reaching the ocean.

These data families are designed to be **modular and combinable**. Countries can start with what is available and strengthen the inventory over time by improving coverage, resolution, and consistency across datasets.

5.2.2 Mapping policy/intervention needs to data requirements (Step 1–2)

The policy use-case determines which data family (or combination) is most critical:

i. **Measures for Production & Consumption** typically rely on **M1** as a backbone (e.g., placed-on-market and sector activity), supported by M2 and field evidence where needed to validate implied leakage pathways.
ii. **Improvement of Solid Waste Management** places **M2** at the center (generation, collection, treatment), using M1 for upstream context and F-data to verify whether system improvements translate into reduced leakage.
iii. **Impact on terrestrial ecosystems** prioritizes **F1** (land/coastal evidence) while linking back to M1/M2 to attribute sources and explain drivers.
iv. **Impact on river basins and ocean** prioritizes **F2** (aquatic/riverine evidence) and may combine M2 (waste and wastewater pathways) and M1 (upstream drivers) to interpret observed flux and support scenario design.

In Step 2, users translate these needs into clearly scoped pathways and indicators (e.g., MPW, leakage to environment, leakage to ocean), with explicit units, boundaries, and spatial/temporal frames. This scoping determines the minimum dataset requirements and the appropriate level of disaggregation (national/subnational; sector/item).

5.2.3 Structuring a national or subnational "data inventory" (Step 3)

Step 3 begins with a structured data inventory aligned to the four families. At minimum, users should document for each dataset: **source/owner, reference year(s), spatial coverage, definitions and classifications, units, QC status, and known limitations**. The inventory should also record how datasets will be harmonized across families (e.g., plastic categories, administrative boundaries, timeframes) to support consistent computation.

Figure 5-2 also distinguishes **primary linkages** from **optional/indirect linkages**. In practice:

- **Primary (direct) linkages** are those required to compute an indicator within the chosen scope (e.g., M2 for system-based leakage estimation; F2 for riverine flux-based estimation).
- **Optional/indirect linkages** may enhance attribution, scaling, or validation (e.g., using M1 to disaggregate a national estimate by sector; using F1/F2 to cross-check implied leakage rates derived from macro statistics).

This distinction supports realistic planning: inventories can be produced even when not all indirect linkages are available, provided assumptions are documented and uncertainty is handled transparently.

5.2.4 Connecting datasets to existing tools, models, and guidance

Once the data inventory is defined, users can link datasets to established resources, as illustrated in Figure 5-2. Examples include:

- **Statistical guidance** to strengthen M1/M2 compilation and comparability (e.g., statistical guideline frameworks);
- **Waste-flow and material flow tools** to translate M2 data into leakage-related parameters and outputs (e.g., waste-flow diagnostics and material-flow-based toolkits);
- **Bottom-up source/item estimation approaches** to quantify specific leakage sources where detailed local evidence exists (e.g., targeted estimation for priority items or sources);
- **Field survey protocols and monitoring frameworks** (F1/F2) to generate empirical leakage evidence and enable trend tracking; and
- **Scaling and modelling approaches** (including statistical/empirical models) to bridge gaps between available data and required indicators, while explicitly quantifying uncertainty.

The figure further emphasizes that different approaches can be combined for stronger inference (e.g., reconciling M-type estimates with F-type observations), and that some methods function primarily as **validation and triangulation** rather than as the main calculation engine.

5.2.5 Practical output of Section 5.2

By the end of Step 1–3, users should have:

i. a defined policy use-case and scoped pathway(s)/indicators;

ii. a structured data inventory across M1/M2/F1/F2, including harmonization needs; and

iii. a documented shortlist of candidate methods/tools, with a clear rationale distinguishing primary vs optional/indirect linkages.

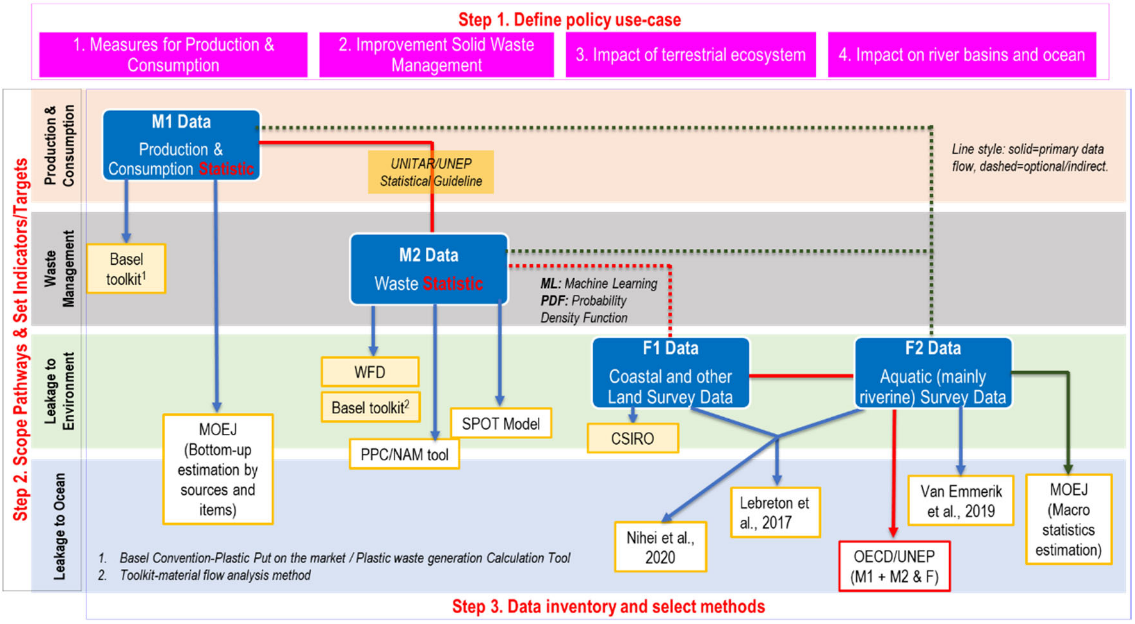


Figure 5-2. Mapping Policy Use-Cases to Data Families and Estimation Tools (Step 1–3)

5.3 Quantifying Leakage Along the Plastic Value Chain Using Coefficients and Models

This section explains how plastic leakage can be **quantified along the plastic value chain** from **production and consumption**, through **solid waste management**, and onward to **leakage to land and waterways** by applying a set of **coefficients, scaling parameters, and statistical/empirical models** (Figure 5-3). The focus is on making explicit **where** such parameters are introduced in the estimation chain, **why** they are required (typically to bridge gaps between what is measured in official statistics and what is observed in the environment), and **how** modelling choices influence results, including uncertainty.

Figure 5-3 also distinguishes **primary data flows** (solid lines) from **optional/indirect linkages** (dashed lines). In practice, countries often start with the strongest available statistical backbone (M1/M2) and progressively enhance robustness by integrating field evidence (F1/F2) and the supporting parameters described below.

5.3.1 Why coefficients and models are necessary

National statistics rarely observe "leakage" directly. Instead, leakage is inferred by combining:

- **Activity data** (what is produced/consumed and what enters the waste system),
- **System performance data** (how waste is collected, treated, and disposed), and
- **Environmental observations** (what is found on land/coasts and in waterways).

Between these elements, there are inevitable **measurement gaps** (e.g., unobserved littering, informal dumping, loss during collection/transport, fate and transport in rivers). The light-blue elements in Figure 5-3 represent the **bridging parameters** that translate available data into leakage-relevant quantities and allow scaling from limited observations to national or basin-wide estimates.

5.3.2 Key parameters and models used across the value chain (light-blue elements)

1) Product lifespan (linking P&C to waste generation timing)

Production/consumption statistics (M1) often describe what is placed on the market, but a portion becomes waste only after a delay. **Product lifespan** parameters support:

- aligning placed-on-market quantities with the year(s) of waste generation, and
- producing consistent time series (baseline vs trend) when durable and semi-durable products are included.

2) Activity Data (AD) (disaggregation and policy relevance)

Activity data (AD) enables sector- or item-specific estimation (e.g., packaging types, tourism-related consumption, fisheries-related plastics). AD is essential when the policy use-case requires:

- sectoral targeting,
- product-level indicators, or
- scenario analysis for upstream interventions.

3) Leakage Factor (LF) (translating waste-system performance into leakage)

Leakage factors are central bridging coefficients that translate M1/M2 flows into leakage outputs. They may represent:

- loss during collection and transport,
- uncollected waste becoming litter/dumped,
- disposal site leakage, and/or
- broader "release rates" to the environment.

LFs can be applied at different points depending on method design (e.g., directly from M1 placed-on-market to leakage, or from M2 waste management stages to leakage). Their selection strongly affects totals and therefore requires transparent documentation and sensitivity checks.

4) Statistical scaling tools: ML and PDF (from sparse data to distributions)

Where direct measurements are limited, **statistical tools** are used to scale or extrapolate:

- **Machine learning (ML)** can help predict unobserved waste-system parameters or spatial patterns using proxy variables (e.g., population density, service coverage, socio-economic factors).
- **Probability Density Functions (PDFs)** represent uncertainty and variability in parameters (e.g., leakage rates, composition, capture efficiency), allowing uncertainty propagation rather than single-point estimates.

These tools are especially relevant for countries with uneven data coverage across provinces/municipalities.

5) Geographic characteristics and land use (contextual modifiers)

Leakage is not only a function of waste quantity but also of **where leakage occurs**. Parameters related to **geographical characteristics and land use** are used to adjust or interpret leakage potential, such as:

- proximity to waterways/coasts,
- urban/rural settlement patterns, and
- topography and drainage characteristics.

These modifiers are often needed when translating national estimates into river-basin or hotspot-relevant outputs.

6) Hydrological data (linking land leakage to riverine transport and flux)

For leakage to waterways and potential ocean delivery, **hydrological data** are essential to connect terrestrial release to aquatic transport. Typical roles include:

- converting observed riverine concentrations to flux,
- scaling river measurements across seasons and sub-basins, and
- estimating transport capacity and retention.

Hydrological data is the main "bridge" between F2 observations and national/basin-scale estimates.

7) Composition ratios and conversion factors (e.g., MacP/MicP)

Some methods require conversion between categories (e.g., macroplastics vs microplastics) or between measurement types. **MacP/MicP ratios** (or similar composition conversion factors) help integrate different monitoring streams and align outputs with the chosen indicators and reporting units.

5.3.3 Practical estimation chain along the value chain

From M1 to waste generation and upstream attribution

M1 statistics, supported by product lifespan and activity data, provide the upstream basis to estimate potential waste generation and to attribute leakage to sectors/products where policy measures are targeted.

From M2 to system leakage and release to the environment

M2 waste statistics describe how waste is managed. Applying leakage factors (and, where needed, statistical scaling such as ML/PDF) translates system performance into an estimate of leakage to land or to the wider environment.

From F1/F2 to validation, calibration, and pathway refinement

F1 (land/coastal) and F2 (aquatic/riverine) data provide empirical signals that can:

- validate whether M1/M2-derived leakage magnitudes are plausible,
- support calibration of leakage factors, and
- refine spatial prioritization (hotspots, river basins, coastal zones).

5.3.4 Cross-checking and uncertainty treatment (Step 4)

Because coefficients and models can substantially influence results, this Guidance emphasizes **cross-evidence checks** and explicit uncertainty treatment.

- Compare M1/M2-derived leakage estimates with F1/F2 signals (magnitude, composition, spatial distribution).
- Use sensitivity analysis to test how results respond to alternative leakage factors, lifespan assumptions, and scaling choices.
- Where distributions are used (PDF), propagate uncertainty and report ranges, not only point estimates.

This strengthens both **robustness** (resilience to uncertain parameters) and **interpretability** (clear explanation of what drives results and how confident users can be).

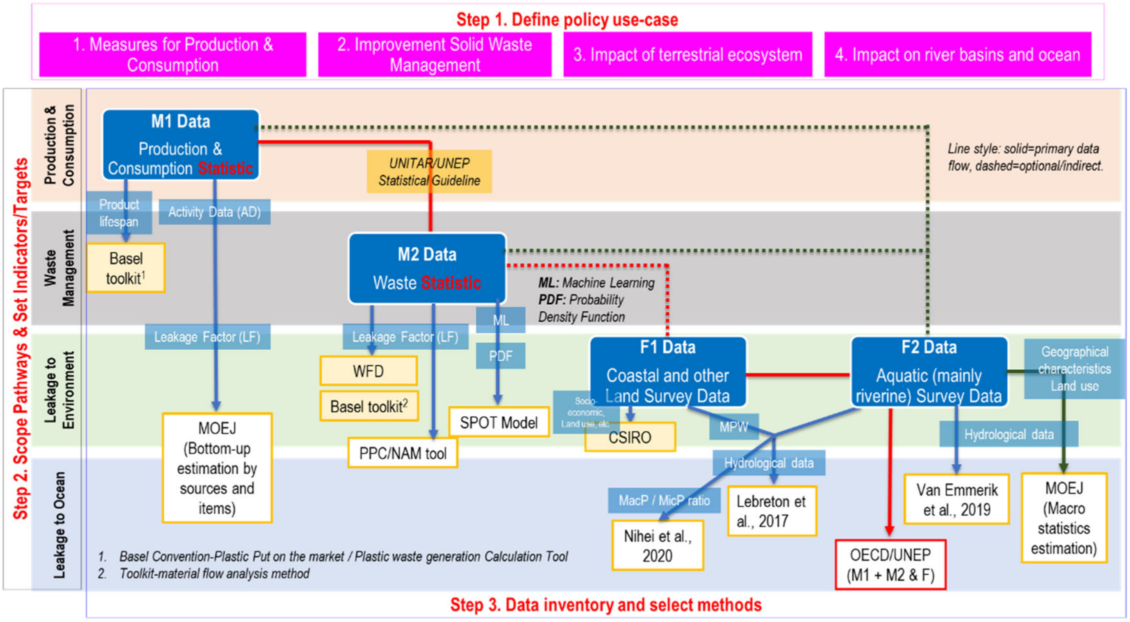


Figure 5-3. Quantifying Plastic Leakage Along the Value Chain Using Coefficients and Models according to the existing methods

5.4 Methodological Gaps and Operational Usability

This section uses the synthesis matrix (Table 5-1) to make explicit where estimation approaches are already operational for routine inventory development and where significant methodological gaps and usability constraints remain. Rather than repeating the stepwise workflow (Sections 5.1–5.3), the purpose here is to interpret the matrix as an "**operational diagnostic**": it clarifies which combinations of target outputs and data families are currently **toolkit-ready**, which remain **literature-led**, and where additional **standardization and packaging are needed** to support consistent governmental use.

5.4.1 Reading the Matrix: Axes and Operational Legend

Table 5-1 below is structured by **Target Output** (rows) and **Data Families** (columns: M1, M2, F1, F2). It should be read as an **operational diagnostic**: it distinguishes where estimation can be implemented routinely with **existing practitioner-facing tools**, where methods exist but remain insufficiently operationalized, and where usability constraints or methodological gaps prevent consistent government inventory use.

The operational legend applied in the matrix is as follows:

- **Blue-highlighted methods = practitioner-ready.** These cells represent estimation approaches that are accompanied by toolkits, calculation templates, or operational guidance that practitioners can apply with reasonable reproducibility and traceability.
- **Black-text methods = documented, but not yet toolkit-ready.** These entries

indicate estimation approaches that have been reported in academic literature, technical studies, or project outputs, but are **not yet packaged** into standardized, widely accessible toolkits or operational guidance for routine inventory development (e.g., limited standardization across contexts, incomplete documentation, or absence of reporting templates).

- **Grey cells = not currently suitable for routine, practitioner-usable inventories**, but for **two distinct reasons**:
  - **Dark grey = non-recommended reverse inference.** These combinations would require inferring upstream production/consumption or system inputs from downstream waste management outcomes or observed was, an inference direction that can conflict with mass-balance logic, create circular reasoning, and weaken interpretability for policy and reporting.
  - **Light grey = conceptually valid but not yet toolkit-ready.** A plausible estimation pathway may exist, but it is not yet consolidated into transferable and standardized operational packages that practitioners can apply consistently (e.g., high technical requirements, fragmented methods, or missing QC and reporting formats).

Accordingly, the matrix is not only a mapping of methods; it functions as a **gap-identification and usability screen**, clarifying what can be implemented today, what is **evidence-backed but not yet operationalized**, and what requires further standardization or methodological development.

Table 5-1. Estimation Methods and Operational Gaps

Major Dataset Target Output		**Data Families**			
		M1. Production & Consumption (including Sector Activity Data)	**M2. Solid Waste Management**	**F1. Coastal and other Land Field Measurements**	**F2. Aquatic (mainly Riverine) Field Measurements**
Output (Target)	**Production & Consumption**	• Toolkit for the product-lifespan method, Basel Convention, 2022 (Plastic Put on the market Calculation Tool) • Input-Output Table	• N.A.	• N.A.	• N.A.
	Solid Waste Generation, Waste Flow	• Toolkit for the product-lifespan method, Basel Convention, 2022 (Plastic waste generation Calculation Tool) • Input-Output Table	• Toolkit for material flow analysis method, Basel Convention, 2022	• N.A.	• N.A.
	Leakage to Land (including MPW)	• MOEJ Bottom-up method by sources and items • UNEP/EU (under development)	• WFD • PPC/NAM tool • SPOT Model	• CSIRO	• N.A.
	Leakage to Sea			• N.A.	• Lebreton et al., 2017 • Van Emmerik et al., 2019 • Nihei et al., 2020

5.4.2 Methodological gaps and usability constraints

1) Practical implications for inventory development today

Given the current ecosystem shown in Table 5-1, a realistic approach for many users is:

- **Use M1/M2 as the practical backbone** for routine baselines (where toolkits and guidance already exist), and
- **Use F1/F2 as evidence-strengthening streams** where feasible, while transparently documenting constraints where practitioner-ready aquatic estimation is not yet available.

This ensures inventories remain implementable and comparable over time, while identifying where evidence strengthening is most needed.

2) Priority area: toolkitization of aquatic/riverine estimation (F2)

The matrix indicates that the **highest-value development opportunity** is to convert strong scientific know-how into **practitioner-ready toolkits** for F2. This includes packaging methods so that they can be applied consistently for inventory purposes.

In particular, the table suggests that toolkitization priorities should include:

- Standardized protocols for aquatic/riverine monitoring that are explicitly inventory-oriented (units, boundaries, minimum sampling requirements);
- Harmonized procedures to convert aquatic observations into inventory outputs (including seasonal scaling and uncertainty treatment);
- QC and reporting packages compatible with routine national/subnational cycles; and
- Clear integration points with M1/M2 baselines to enable cross-evidence checks (triangulation) and improve robustness.

3) Strategic opportunity

Because aquatic pathways (F2) are the most prominent gap area in the matrix, **toolkitization of Japanese expertise and methods in aquatic/riverine leakage estimation** represents a strategically valuable contribution. Converting such know-how into accessible toolkits and guidance would directly address a widely recognized operational bottleneck and improve the practicality of inventory development, especially in countries where riverine and coastal dynamics are central to policy priorities.

5.4.3 Navigating Existing Approaches and Identifying Gaps

While Sections 5.1–5.3 describe the stepwise workflow and the role of data families, users ultimately need to decide which established estimation approach to adopt or align with in practice. **Building on the gap and priority-area insights highlighted in Sections 5.4.1 and 5.4.2,** Figure 5-5 below therefore serves as a navigation map that links the Chapter 5 steps (Define policy use-case → Scope pathways and set indicators/targets → data inventory and select method → QC, verification validation → reporting) to representative method families that are currently operational and widely referenced. In many national applications, the practical choice tends to converge toward one of the following "method families", depending on the policy question, data readiness, and the required output level:

1) MOEJ & UNEP/EU-type approaches

This family is typically selected when the policy use-case requires source- and item-level insights (e.g., priority products, sector-specific measures, targeted interventions) and when M1 production and consumption statistics and sector activity data can support bottom-up attribution. The approach can incorporate leakage factors and supporting parameters to translate placed-on-market or activity data into leakage-relevant outputs. It is particularly useful for identifying what to prioritize (items/sources) and for structuring policy measures in upstream parts of the value chain.

Refer to Table 4-5. Representative M1 methods in Chapter 4.3 (Overview of existing plastic leakage estimation methods), particularly the methods below.

- Macro-statistical approaches (using PET bottle consumption data (M1) and leakage rate from field survey (F)), MOEJ 2024 (and also the pilot project, 2025 in Indonesia & Vietnam in Table 4-8 and Annex-1)
- UNEP/EC Project "Guiding Document V.2" (Toolkit for identifying & quantifying plastic contaminant sources and leakages into aquatic environments, under development)

2) WFD / Basel toolkit / PPC-NAM / SPOT-type approaches

This family becomes a pragmatic choice when the primary objective is to assess or improve municipal solid waste management performance and to estimate leakage by modelling waste flows through the system. It typically relies on M2 waste statistics (generation, collection, treatment/disposal) and applies system-based parameters (including leakage factors) to derive leakage outputs. This approach is often the most feasible for producing national/subnational baselines where waste management data exist, and it provides a direct policy bridge to operational measures (collection coverage, treatment expansion, controlled disposal, etc.).

Refer to Table. Representative M2 methods in Chapter 4.3 (Overview of existing plastic leakage estimation methods), particularly the methods below.

- Waste Flow Diagram (WFD), GIZ, 2020
- Plastic Pollution Calculator, ISWA, 2019
- Plastics-to-Ocean (P2O) model, Systemiq, 2020

- Toolkit for material flow analysis method, Basel Convention, 2022
- SPOT: Spatio-Temporal Quantification of Plastic Pollution, Cottom et al., 2024

3) CSIRO-type monitoring approaches

Monitoring-driven approaches are selected when the policy use-case requires empirical evidence on the ground/in the environment, such as hotspot identification, intervention effectiveness tracking, or confidence-building through observed trends. They rely on F1 land/coastal survey data and/or F2 aquatic (mainly riverine) survey data and are frequently used to:

- Validate or calibrate macro/statistical estimates (M1/M2-derived leakage)
- Refine spatial prioritization
- Strengthen QC through independent cross-evidence

Importantly, monitoring approaches often complement (1) or (2) above rather than replacing them, especially when the inventory needs national completeness and time-series comparability.

Refer to Table. Representative F methods in Chapter 4.3 (Overview of existing plastic leakage estimation methods), particularly the methods below.

- CSIRO Global Plastic Leakage Baseline Project (Cambodia), CSIRO, 2024

4) Leakage to Waterways Pathways

In Table 5-1, many output–data combinations relevant to waterways-related estimation are captured not as empty gaps, but as **black-text methods**, reflecting that a substantive evidence base already exists in the form of academic studies, technical reports, and project applications, even though these approaches are **not yet packaged into standardized, practitioner-facing toolkits**. Accordingly, the key operational constraint for waterways pathways is often **not the absence of methods per se**, but the lack of transferable operational elements, namely standardized protocols, practical calculation templates, QC procedures, and reporting formats that can be applied consistently across jurisdictions and drainage system types.

At the same time, some combinations remain **grey** in the matrix, either because they would rely on **non-recommended reverse inference** (dark grey) or because conceptually valid approaches have **not yet been consolidated** into a broadly usable form (light grey). This pattern underscores a practical priority for future work: converting the existing research-rich base (black-text methods) into repeatable, inventory-grade operational packages, while clearly flagging and avoiding reverse-inference pathways.

Using Chapter 5 steps to select a practical method family

A practical way to apply the Chapter 5 workflow is to treat the method families above as "landing zones":

- If Step 1–2 emphasize **upstream measures and item/source specificity**: users often converge on (1) MOEJ & UNEP/EU-type approaches.
- If the focus is **MSWM performance and system interventions**: users typically converge on (2) WFD/Basel/PPC/SPOT-type approaches.
- If the objective is **empirical trend tracking**, hotspot evidence, or validation: users incorporate (3) CSIRO-type monitoring as a primary evidence stream and/or cross-check.
- If the pathway involves **drainage/pumping-station dynamics and engineered waterway pathways**: users can draw on a substantial body of documented, research-developed approaches, often reflected in Table 5-1 as black-text methods (e.g., Schmidt et al., 2017; Lebreton et al., 2017; van Emmerik et al., 2019; Nihei et al., 2020; Meijer et al., 2021; World Bank, 2021; Mellink et al., 2022; ERDTF S-19; MOEJ, 2024 pumping-station survey) to design a context-specific (tailor-made) estimation approach. The key constraint is not the absence of methods, but the **limited availability of inventory-oriented**, widely usable toolkits and standardized operational guidance that practitioners can apply consistently across geographies, drainage system types, and reporting cycles. Accordingly, a priority opportunity is to translate and package these research-developed methods into **practitioner-ready toolkits**, including clear protocols, scaling logic, QC procedures, and reporting templates.

In all cases, the synthesis matrix supports transparent documentation of why a given method family was selected, what data families underpin it, and where limitations or gaps remain, thereby ensuring that the resulting inventory is both fit-for-purpose and auditable.

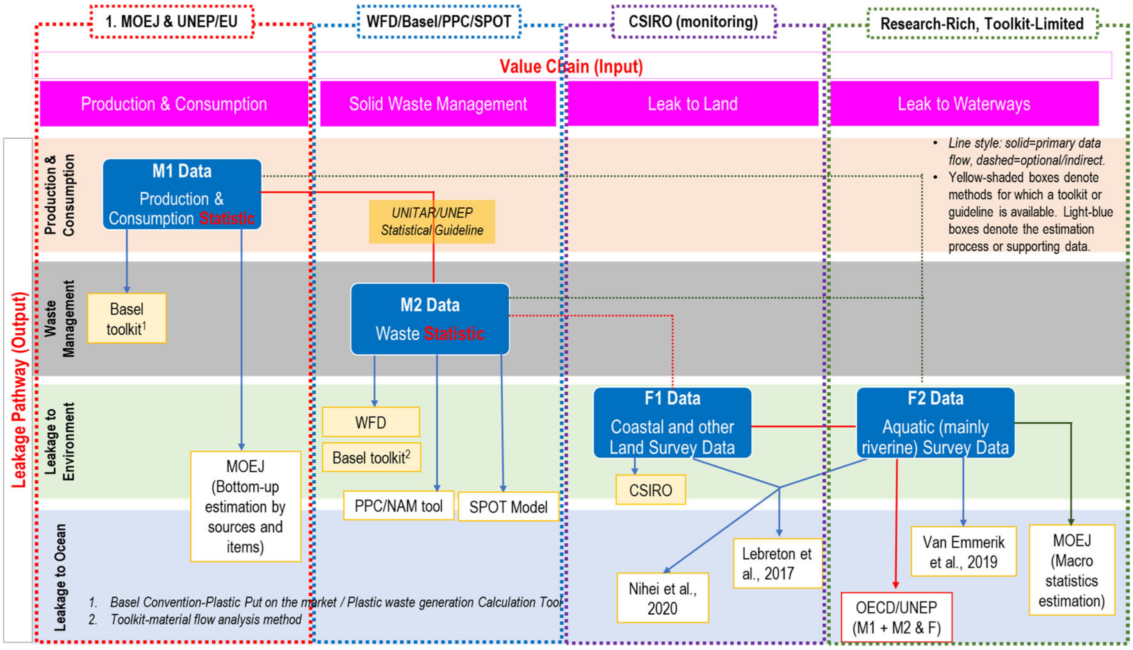


Figure 5-5. Navigating Practical Estimation Approaches: Positioning Representative Methods and Identifying Gaps

Annex 1. MOEJ Case Study (M1/M2 + F): Indonesia / Viet Nam

1. Background

This case study illustrates a practical **hybrid estimation approach (M1/M2 + F)** that combines **macro-statistical data** with **measured field evidence** to estimate plastic leakage. The case study is positioned within the Ministry of the Environment, Japan (MOEJ)'s multi-year work programme launched in **FY2020** to develop and improve a **plastic leakage inventory for Japan**, including the marine environment. As part of this programme, MOEJ has examined how national-level macro statistics such as production/consumption/use and waste-related aggregates can be combined with empirically observed leakage of representative items (e.g., PET bottles and key polymers) to derive **leakage rates** and estimate national leakage in a transparent, reproducible manner. This domestic work also highlighted the need to identify common methodological elements that could support **globally comparable inventories**, and to examine applicability of macro-statistics-based approaches beyond Japan.

Against this background, the **2025 pilot** focused on **Indonesia and Viet Nam** as a feasibility assessment of whether the macro-statistics-based estimation approach developed and tested in Japan can function as a **practical, simplified estimation option** in other countries where data availability and capacity may differ. In line with this objective, the pilot collected missing national statistical inputs and conducted targeted field measurements to derive **empirical leakage rates** for selected calibration items and then upscale to national estimates, while comparing results with literature-based estimates and refining interpretation considering national/regional characteristics such as land use.

The field component differed by country: **Indonesia applied image-based monitoring**, while **Viet Nam conducted direct measurement through waste composition surveys**. In both countries, **plastic bags and PET bottles** were used as calibration items, and the derived leakage rates were applied as an empirical anchor to infer broader plastic leakage under the **M1/M2 + F framework**.

2. Method

The pilot applied a **three-step hybrid workflow (M1/M2 + F)** that combines **macro-statistical data** with **field-based leakage measurements** (Refer to the figure below).

A) Estimate field-based leakage of selected products (F)

Field surveys were first used to quantify the **annual leakage of selected calibration items** in this pilot, **plastic bags and PET bottles**, at a monitoring site.

- For **Indonesia**, the field survey was conducted in a **river (tributary of the**

Ciliwung River) in Jakarta using **image-based monitoring** (Refer to the photos below.). Videos were analysed to derive litter-flow area, converted to litter-flow mass using field-based mass-per-area values, and linked to river discharge through an **L–Q relationship** to estimate annual leakage.


- For **Viet Nam**, the field survey was conducted at a **pumping station connected to the Nhue River in Hanoi** using a **waste composition survey**, supplemented by image interpretation for unrecovered waste (Refer to the photos below). Daily leakage was estimated from the observed waste quantity and then annualized. Because the accumulation period of waste was uncertain, **minimum and maximum accumulation periods** were applied to generate a range of annual estimates.



The site-level results were then scaled up to the national level using **population-based and/or area-based scaling factors** derived from the monitored catchment.

B) Derive product-specific leakage rates (M1/M2 + F)

For each calibration item, an empirical **leakage rate to the environment/ocean** was derived by dividing the estimated national leakage of that product from Step A by the corresponding **macro-statistical denominator** for the same product, such as:

- Production
- Supply

- Use/consumption, or
- Waste generation/discard.

This step links the field-observed leakage of specific items with nationally available macro-statistics and produces a transferable **item-specific leakage factor**.

C) Estimate national leakage of plastics overall (M1/M2 + F)

The leakage rates derived in Step B were then used as proxies to estimate **national plastic leakage overall**. In practice, the product-specific leakage rate was applied to national totals for plastics or plastic products (e.g., plastic production, supply, use, or waste generation) to infer the overall **national leakage to the environment and, where relevant, to the ocean**.

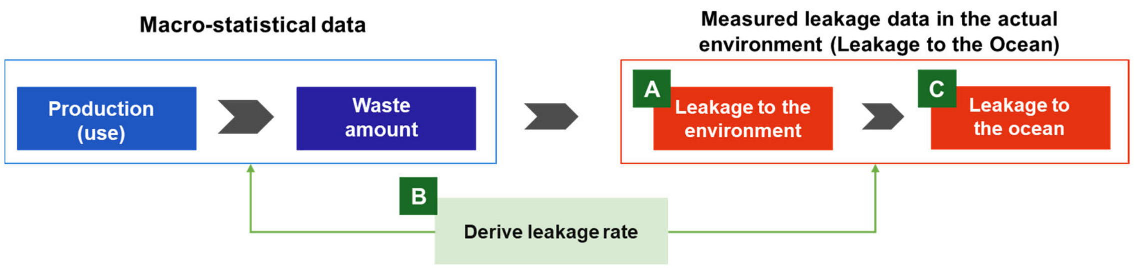


Figure A1-1. Three step hybrid estimation approach (M1/M2 + F)

Implementation notes

- **Indonesia:** annual leakage was estimated from **video-derived litter flow** and an **L–Q (leakage–discharge) relationship**.
- **Viet Nam:** annual leakage was estimated from **recovered waste quantity and unrecovered waste quantity estimated by image interpretation at a pumping station**, with **minimum/maximum accumulation periods** used to reflect uncertainty in deposition time.
- In both countries, **plastic bags and PET bottles** were used as **calibration items** to connect field evidence with macro-statistical data.

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