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**Title:**

**Unexplored channels of the Green Sudoku approach.**

**Where and when Nature-based Solutions come into play in integrated accounting frameworks**

**Author:**

Alessandra La Notte <sup>1</sup>

<sup>1</sup> Senior consultant on Natural Capital Accounting, Ispra (Italy)

\*Corresponding author: [alelanotte.work@gmail.com](mailto:alelanotte.work@gmail.com)

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**For the London Group discussion:**

Some reflections:

- In some cases, we **don't need new accounts, but rather clear connections**
- Statisticians cannot **measure real-world effect**, but ecological modelers can estimate them
- The sudoku logic works not only at the **accounts** level, but also at **classifications** and **statistics** levels
- An effective connection may need to be worked on **over different time periods**

Questions:

- What do you think about the proposed connections and suggested connectors?
  - Which is the main weakness that you see?
  - Do you agree with the above reflections?
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## **Abstract**

This paper presents a conceptual exercise that explores the application of the Green Sudoku approach to connect investments in Nature-based Solutions with reducing hazards to people and the economy, focusing on the 'flood control' service. The approach integrates the System of Environmental-Economic Accounting (SEEA) and the Global Disaster-Related Statistics Framework (G-DRSF) to establish a causal link between Nature-based Solutions and the resulting reduction in risks. The paper discusses the role of ecosystem services accounting, disaster risk assessment, and expenditure accounting in establishing this connection, and highlights the potential of the Green Sudoku approach to provide a comprehensive accounting system for Nature-based Solutions.

## **Key words:**

Ecosystem Services, Nature-based Solutions, Disaster Risk Assessment, Prevention investments, Mitigation investments, Green Sudoku, Flood control, Natural Capital Accounting

## 1. Introduction

There is an increasing interest in nature-based solutions, particularly in relation to a transformative and nature-positive economy. Indeed, they function as ecological assets, capable of supporting a range of human activities across diverse ecosystems. These include urban systems, where continuous and robust support is required by people, and regenerative agriculture, which aims to ensure long-term food production and resilience<sup>1</sup>.

Although it is recognised that nature-based solutions enhance the condition of ecosystems and their capacity to generate services, the existing accounting framework can currently only facilitate the identification and quantification of these services<sup>2</sup>, rather than creating a causal link between investment in Nature-based Solutions and the resulting reduction in risks to people and the economy.

According to the Green Sudoku approach to integrated accounting, the application of specific rules and numeric relationships to the System of Environmental and Economic Accounts (SEEA)<sup>3</sup> and the System of National Accounts (SNA)<sup>4</sup> can create a comprehensive accounting system that neither system alone can adequately represent. The recent availability of the (draft version of the) Global Disaster-Related Statistics Framework (G-DRSF)<sup>5</sup> provides the missing piece of information needed to implement the Green Sudoku logic to Nature-based Solutions.

This paper presents a conceptual exercise designed to explore ways of applying the Green Sudoku logic to connect investments in Nature-based Solutions with reducing hazards to people and the economy. The pivotal concept underlying the narrative is that of ecosystem services. Here, the case study focuses on the 'flood control' service, which is frequently mentioned in disaster risk assessment and climate change adaptation contexts.

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<sup>1</sup> Ref. the Resolution adopted by the United Nations Environment Assembly on 2 March 2022 “Nature-based solutions for supporting sustainable development” available at <https://wedocs.unep.org/bitstream/handle/20.500.11822/39864/NATURE-BASED%20SOLUTIONS%20FOR%20SUPPORTING%20SUSTAINABLE%20DEVELOPMENT.%20English.pdf?sequence=1&isAllowed=y>

<sup>2</sup> Ref. “How to account for nature-based solutions as the ecological assets that support economy and society” available at <https://www.sciencedirect.com/science/article/pii/S2772411524000557>

<sup>3</sup> Ref. <https://seea.un.org/content/homepage>

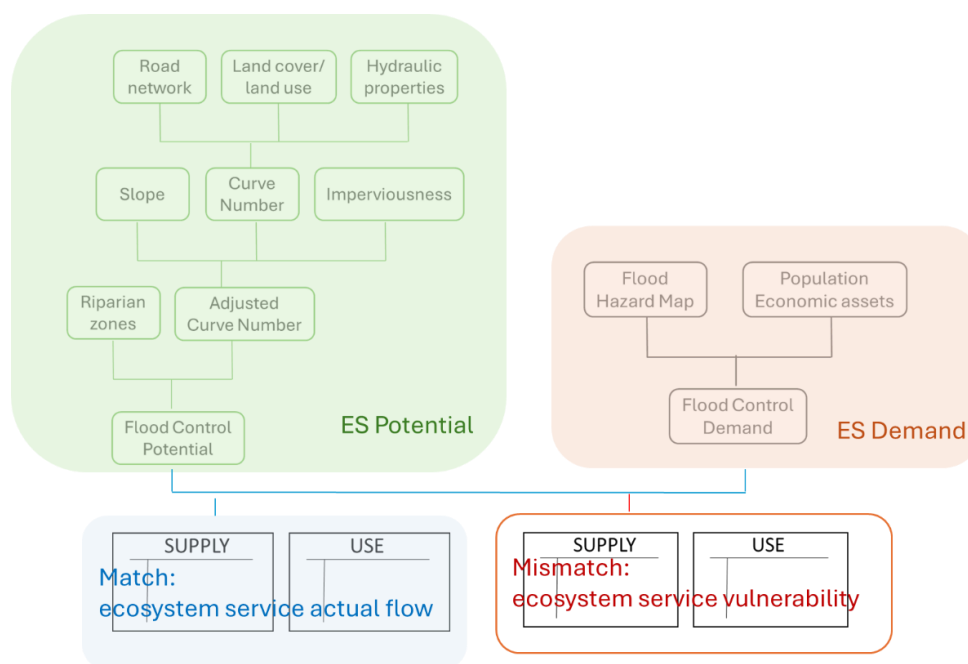
<sup>4</sup> Ref. <https://unstats.un.org/unsd/nationalaccount/sna2025.asp>

<sup>5</sup> Ref. “The need for the Global Disaster-Related Statistics Framework” available at <https://www.undrr.org/media/109255/download?startDownload=20250928> open for global consultation

## 2. SEEA EA: the role of Ecosystem Services accounting

Ecosystem services (ES) are the ecological processes that contribute directly or indirectly to human activities. ES can be estimated by selecting proxies that best represent this contribution. The assessment of such proxies can be undertaken by using (and in case adapting data) that already existing data (inventories, statistics, surveys), or by creating new data through biophysical models<sup>6</sup>.

The case study employed in this paper for the conceptual exercise is that of "flood control". For the assessment of flood control, the JRC-INCA model<sup>7</sup> requires assessing the ES Potential (i.e. the capacity of ecosystems to supply the flood control service (independently whether it is used or not) and ES Demand (i.e. the effective human need for this service). The ES actual flow reported in the official Supply and Use tables, as required by the SEEA EA (Ecosystem Accounting)<sup>8</sup>, accounts for the flood control service that is delivered to economic units. The JRC-INCA model can also assess where the ES is needed but not provided, thereby creating a vulnerability (Figure 1). This ES Potential-ES Demand mismatch component can be reported in complementary supply and use tables, which could be useful in supporting the assessment of Nature-related risks<sup>9</sup>.



**Figure 1** – The accounting structure underpinning the assessment of the flood control service

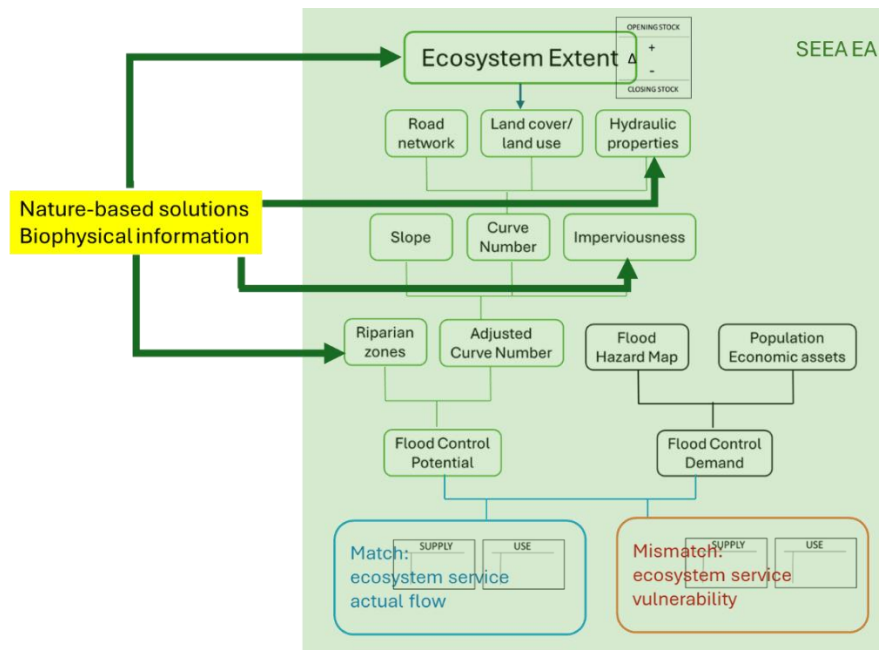
<sup>6</sup> Ref. the Handbook "Guidelines on Biophysical Modelling" available at <https://seea.un.org/ecosystem-accounting/biophysical-modelling>

<sup>7</sup> Ref. Chapter 6 in "Ecosystem services accounting - Part II Pilot accounts for crop and timber provision, global climate regulation and flood control" available at <https://publications.jrc.ec.europa.eu/repository/handle/JRC116334>, and ref. the article "Accounting for changes in flood control delivered by ecosystems at the EU level" available at <https://www.sciencedirect.com/science/article/pii/S221204162030084X>

<sup>8</sup> Ref. Chapter 7 in "System of Environmental-Economic Accounting - Ecosystem Accounting" available at [https://seea.un.org/sites/seea.un.org/files/documents/EA/seea\\_ea\\_f124\\_web\\_12dec24.pdf](https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_f124_web_12dec24.pdf)

<sup>9</sup> Ref. the article "The assessment of nature-related risks: From ecosystem services vulnerability to economic exposure and financial disclosures" available at <https://www.sciencedirect.com/science/article/pii/S0921800925001193>

Nature-based solutions, such as revegetation activities in flood-prone areas, can influence the variables used in ecological models to assess ES potential, including the extent of vegetated areas and soil hydrological properties. Revegetated areas also reduce imperviousness and support the function of riparian zones (Figure 2).



**Figure 2** – The causality nexus between the building of Nature-based Solutions and an increase in Ecosystem Service Potential for flood control

A causality nexus can therefore be established between the **construction of Nature-based Solutions and the increase in the potential of ecosystems to provide the flood control service and reduce the vulnerability** with respect to the risk of being flooded.

### 3. The G-DRSF: the role of Disaster-Related Statistics

High-quality, comprehensive statistics are needed to capture the immediate impact of individual hazardous events and disasters, and to shed light on the underlying causes. Currently, these statistics are fragmented and inconsistent across sectors and countries in terms of definitions, methods and reporting norms. This makes it difficult to quantify risk trends, compare outcomes and learn from the experience of others.

The Global Disaster-related Statistics Framework (G-DRSF)<sup>10</sup> aims to provide a statistical foundation to help countries compile and use disaster-related statistics more consistently. When data on disaster risk reduction is accurate and consistent, and organized within a common statistical framework, it enables a deeper understanding of risks. This supports evidence-based policymaking and planning. If data and statistics are underpinned by standardized methodologies and made accessible, then a collective understanding can be achieved, as well as enhanced coordination among national authorities, international actors, development partners and communities.

The conceptual framework of G-DRSF is organized across three key measurement areas:

1. disaster risk assessment,
2. impacts from hazardous events and disasters, and
3. disaster risk reduction (DRR) activities.

Our interest is focused on the first measurement area, where disaster risk encompasses the measurement of hazard, exposure, vulnerability and coping capacity, and on the third measurement area, which concerns expenditure data on DRR efforts<sup>11</sup>.

Disaster risk assessment is the process of integrating statistics on social, environmental and economic conditions prior to the occurrence of a hazardous event or disaster. It is hypothesized that, based on the findings of the assessments, it should be possible to predict the expected impact of disasters and intervene by reducing exposure and vulnerability, and increasing coping capacity.

The first component of risk assessment is hazard mapping. Standardized and consistent hazard classifications are essential for effectively compiling disaster-related statistics. Such classifications promote uniformity and consistency in definitions, terminology and data collection standards. Given the interconnected nature of risks and the necessity of multi-hazard approaches in disaster risk reduction, it is fundamental that hazard classifications are used systematically.

Hazard Information Profiles (HIPs)<sup>12</sup> are based on the UN General Assembly's definition of hazards as "processes, phenomena, and human activities that may cause various forms of loss and disruption". HIPs are organized into eight hazard types, 39 clusters and 281 individual hazards. Each hazard meets three criteria: potential to impact the community; measurable spatial and temporal components; and the availability of proactive and reactive measures. In our pilot example, the HIP refers to "Hydrological and meteorological" hazard, and specifically to the cluster "Water-related" and "Flooding" hazard, defined as "...an overflowing by water of the normal confines of a watercourse or other body of water...".

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<sup>10</sup> Ref. Chapter 2 "Conceptual Framework: Scope, Concepts and Definitions" available at <https://www.undrr.org/media/109257/download?startDownload=20250928>

<sup>11</sup> Ref. Chapter 4 "Non-event specific statistics: exposure, vulnerability and coping capacity" available at <https://www.undrr.org/media/109261/download?startDownload=20250928>

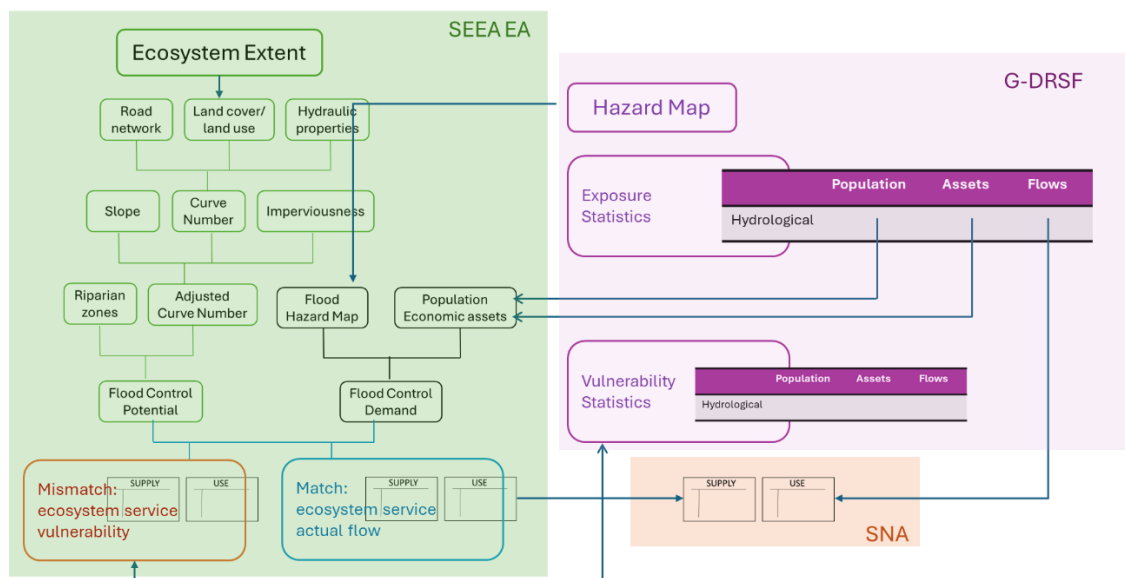
<sup>12</sup> Ref. <https://www.undrr.org/publication/documents-and-publications/hazard-information-profiles-hips-2025-version>

Hazard mapping is a pivotal process in the generation of non-event-specific statistics. The process of mapping potential hazards involves the estimation of two key elements: the probability of their occurrence, and their likely timing or frequency. It is acknowledged that each hazard possesses its own unique nature and degree of predictability. Hazard mapping is a process that is underpinned by a body of scientific knowledge. **Hazard mapping is directly connected to the spatial layer of the biophysical model that determines where the flood control service is required. It is therefore an integral part of ES demand.**

Exposure statistics provide a quantitative assessment of the presence of the population, assets and flows within a probabilistically determined hazard area. Analysing these statistics and combining them with those on vulnerability and coping capacity provides a comprehensive understanding of the potential impacts of a hazardous event or disaster, even before it occurs. Elements included in exposure statistics are: population, assets (such as fields, dwellings, buildings, transport infrastructure, utilities) and flows, which include production, income and employment generated by the presence of economic activities. **The population and asset components of exposure statistics are directly connected to “population” and “economic assets” that, together with the hazard map, form the definition of the ES demand.** On the other hand, the flows relate to the economic flows reported in the supply and use tables of the SNA.

Vulnerability statistics reveal the social, economic and environmental factors that could exacerbate the impact of a hazard on a given area. **The link with the ES vulnerability accounts is straightforward.** This metric indeed provides evidence of areas where ecosystems are either too degraded to provide the necessary services, or where they are completely absent.

Figure 3 provides a simplified illustration of all the connections that establish the common data sources which could potentially inform both the flood control service assessment for the SEEA EA and G-DRSF risk assessment components.

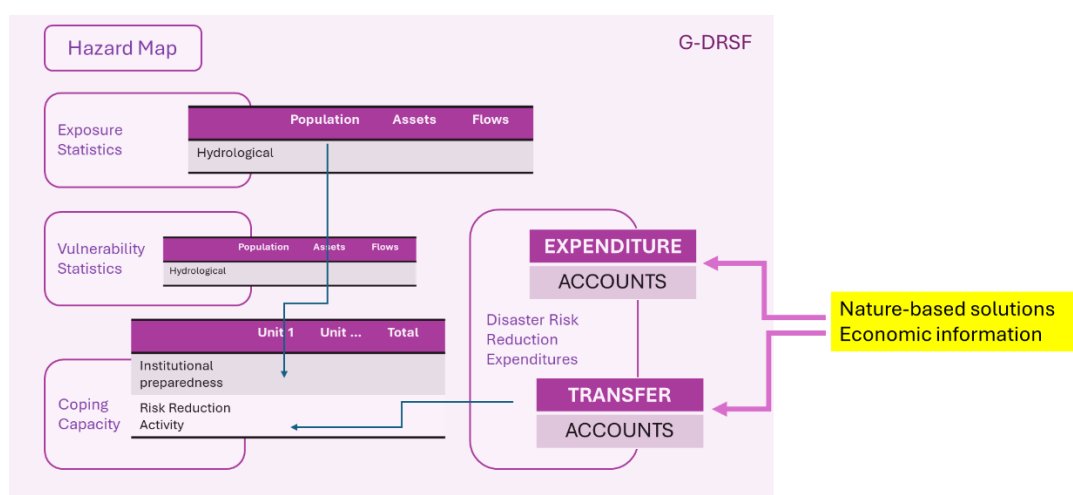


**Figure 3** – The connection between some components of the Disaster-Related Statistics and the Ecosystem Service Demand for flood control service

An important chapter of the G-DRSF are Disaster Risk Reduction (DRR) activities, which aims to reduce the risk posed by hazards and enable communities and societies to cope when such events occur. DRR expenditure accounts<sup>13</sup> comprise both an expenditure account and a transfer account. The first account records expenditure incurred by purchasing units. The second account is used to record transfers made by funding units to support these purchases. Once organised, the scale of DRR expenditure can be meaningfully compared with that of other economic activities and total GDP. Furthermore, analysing transfer sources can inform strategies for the sustainable financing of DRR and international cooperation.

DRR expenditure and transfer accounts can be connected to investments and current expenditures in Nature-based Solutions (as illustrated in Figure 4). Specifically, Nature-based Solutions can be listed within two main groups:

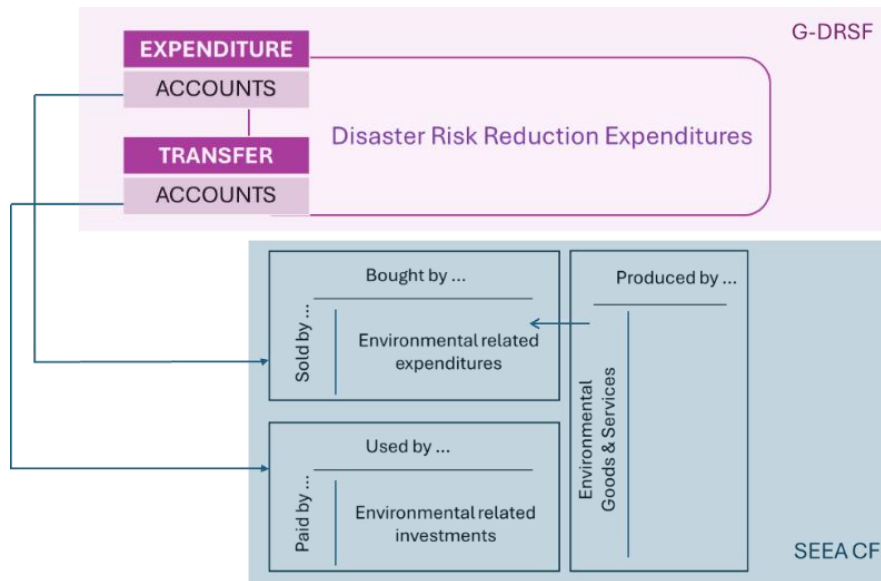
1. Disaster risk prevention, and in particular “Risk prevention before disasters”, and
2. Disaster risk mitigation, and in particular “Structural measures” and “Land use planning”.



**Figure 4** – The causality nexus between the building of Nature-based Solutions and the Expenditure and Transfer accounts in the Disaster-Related Statistics Framework

DRR expenditure and transfer accounts are used to record all types of expenditure and transfers in the economy that are undertaken with DRR as their primary purpose within the reporting period. With regard to expenditure on nature-based solutions, these modules can be linked to the climate change thematic accounts currently under development within the SEEA CF (Central Framework) (Figure 5).

<sup>13</sup> Ref. Chapter 6 “Disaster risk reduction expenditure Accounting” available at <https://www.undrr.org/media/109265/download?startDownload=20250928>

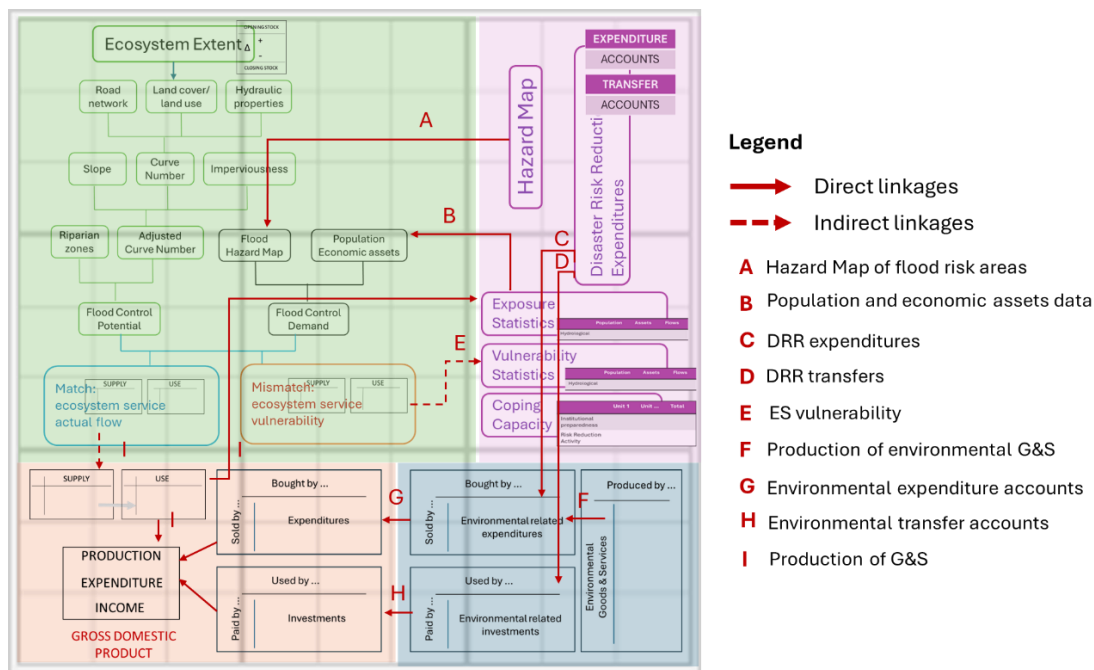


**Figure 5** – The connection between the expenditures accounting of the Disaster-Related Statistics and the expenditures accounting of the SEEA Central Framework

From statistical and accounting perspectives, expenditure accounting illustrates the flow of resources, emphasising the purchasing and funding units. This is key to understanding how Nature-based Solutions are financed. On the one hand the flow of expenditures are grouped into two categories: recurrent (intermediate consumption and final consumption) and investment (gross fixed capital formation) expenditures, classified by DRR activity. These are generally compiled and presented on an annual basis at a national level. However, DRR investments, such as the construction of protective infrastructure, may extend across multiple reporting periods. On the other hand, transfer accounts make it possible to identify sources and beneficiaries of Nature-based Solutions (as one of the DRR activity) financing. Both transfers from the general government and those from the rest of the world require particular attention. The former can be sourced from relevant administrative records, while the latter can be identified through balance of payments statistics.

#### 4. The Green Sudoku to connect investments on Nature-based Solutions to the advantages generated by Nature-based Solutions

According to the Green Sudoku logic, the connection between classifications, statistics and accounts generate figures that match across different framework, in this case specifically the SEEA EA, G-DRSF, SEEA CF and SNA (Figure 6). A connection is considered direct when the same figure fits into two different modules or tables. It is considered indirect when a relationship or correlation underpins the two figures in their respective modules or tables.



**Figure 6** – The Green Sudoku framed for the Flood Control Service (SEEA EA), in conjunction with the Disaster-Related Statistics Framework (G-DRSF), Environmental Expenditure (SEEA CF), and Production and Expenditure in National Accounts (SNA))

As described in the previous sections, there can be many direct connections such as:

- the definition of the ES Demand for the flood control service that needs hazard mapping and presence of population and economic assets;
- the expenditure accounting related to Nature-based Solutions, that can be considered as DRR prevention and mitigation activities and are also pivotal for Climate Change related expenditures.

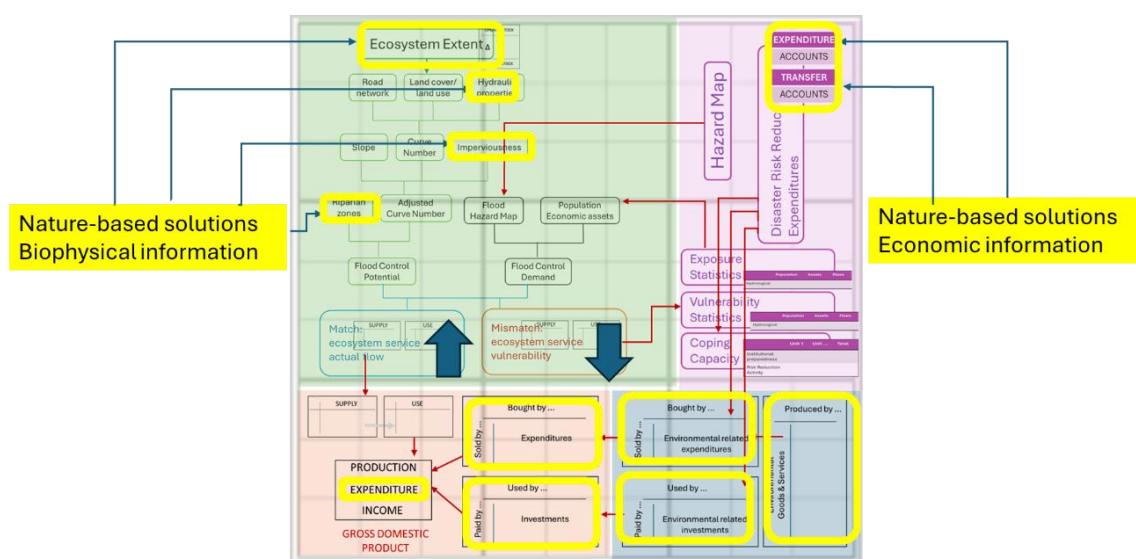
Some other connections are indirect, such as:

- the flood control vulnerability depends on degraded or totally absent ecosystems, where instead they are greatly needed and therefore contribute to one of the characteristics that define the vulnerability accounts of the disaster risk framework. However, this contribution would need to be spelled out. This can happen by reporting explicitly descriptive statistics of the ES vulnerability,

or by creating ad hoc indicators that address specific objectives of the Sustainable Development Goals<sup>14</sup>;

- the flow component that composes the exposure statistics is related to the provision of the flood control service, but the way to measure this dependency is through an ex post correlation analysis.

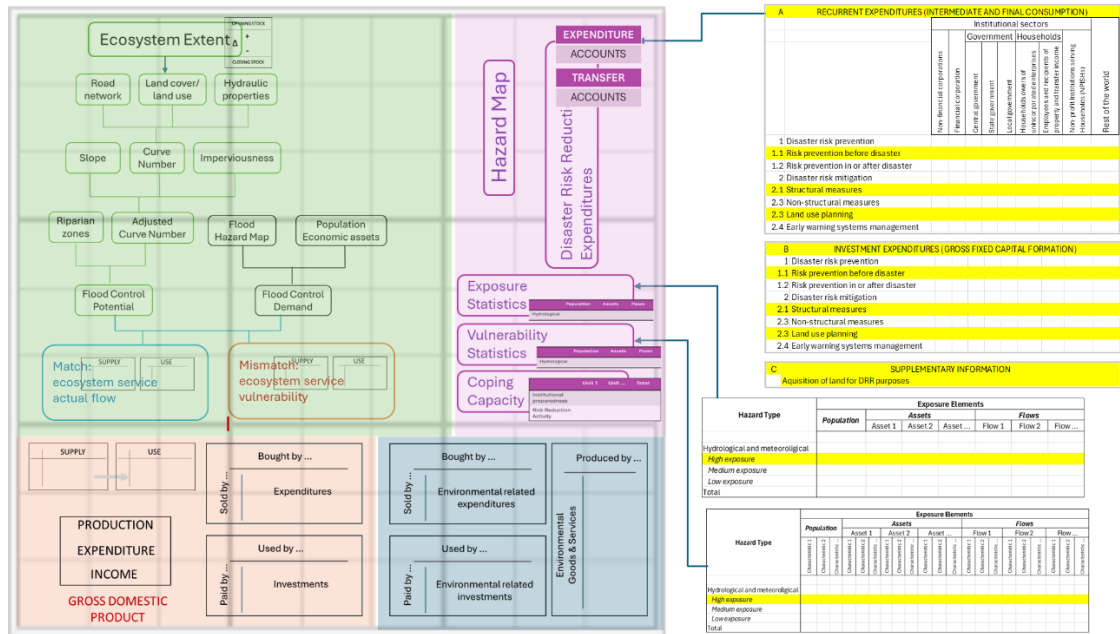
The next step is to add the role of Nature-based Solutions to this picture. Biophysical information on Nature-based Solutions can support the assessment of the flood control ES because (depending on the Nature-based Solution employed) they affect ecosystem extent, hydrological properties, imperviousness and riparian areas. Economic information on Nature-based Solutions can be explicitly reported on the Expenditure and Transfer accounts, specifically as prevention and mitigation activities. This is in turn reflected in Environmentally related expenditures and eventually affect the sequence of accounts that generate the Gross Domestic Product (Figure 7).



**Figure 7** – The role of biophysical and economic information related to nature-based Solutions with respect to the Green Sudoku at Time 0

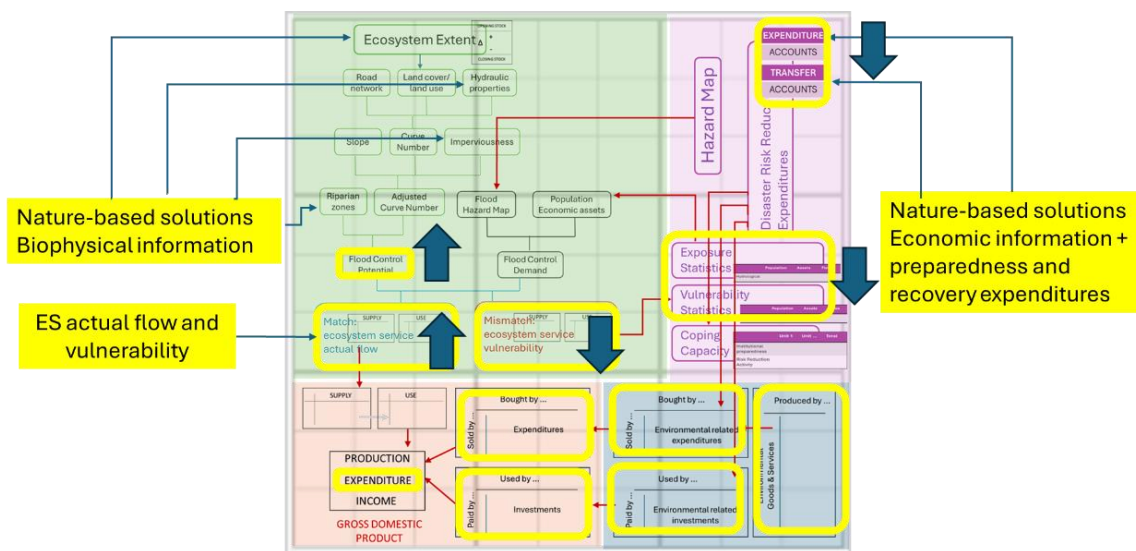
Initial high expenditures and investments in Nature-based Solutions are reported in the dedicated accounts, that in this case refer explicitly to the area that have high exposure and vulnerability in terms of “hydrological and meteorological hazards” (Figure 8).

<sup>14</sup> Ref. “Linking accounts for ecosystem Services and Benefits to the Economy Through bridging (LIBBETH) Part III” available at <https://publications.jrc.ec.europa.eu/repository/handle/JRC141728> and the article “Natural Capital Accounts as a Source of Information to Support Sustainable Development Goals” available at <https://onlinelibrary.wiley.com/doi/10.1002/sd.70229>



**Figure 8** – DRR assessment and expenditures related to hydrological and meteorological hazards within the Green Sudoku at Time 0

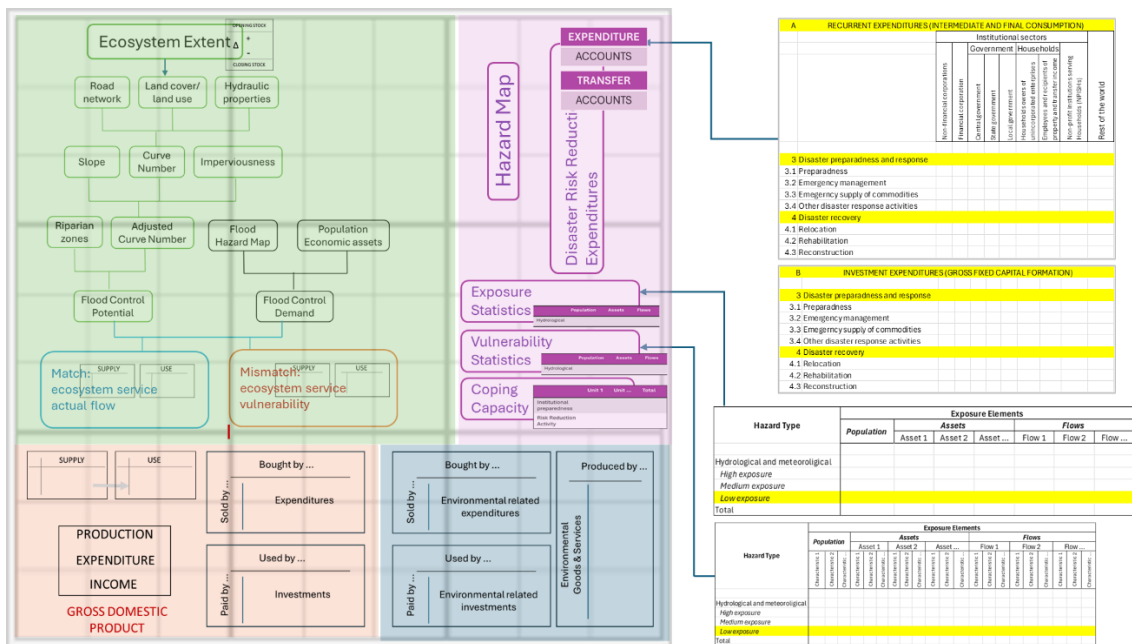
Implementing Nature-Based Solutions enhances the potential of ecosystems to provide the flood control service. Therefore, the flood control actual flow (match) increases and the flood control vulnerability (mismatch) decreases (Figure 9).



**Figure 7** – The role of biophysical and economic information related to nature-based Solutions with respect to the Green Sudoku at Time 1

The concrete measurements that can be collected refer to exposure and vulnerability statistics that move from "high" to "medium" or to "low". In addition, the expenditures and investments related to disaster preparedness and recovery are likely to decrease, given the area's reduced vulnerability. The

caption of Figure 9 and 10 refers to 'Time 1', the length of which depends on the type of nature-based solution implemented. This could be after 2, 5 or 10 years.



**Figure 8** – DRR assessment and expenditures related to hydrological and meteorological hazards within the Green Sudoku at Time 1

The logic chain that connects investments in Nature-based Solutions to the advantages generated by Nature-based Solutions is the decrease in the risks to which people and economic sectors are exposed to. The measurement of such decrease can only take place a few years after the investment has been undertaken. However, to keep the logic chain facilitate to track the nexus between the “cause” (i.e. investments in Nature-base Solutions) and the “effect” (i.e. the decrease in exposure, vulnerability and recovery expenditures).

## 5. Next steps

This conceptual exercise provides a clear indication that measuring ES can be pivotal in justifying the need to invest in nature. In fact:

- when assessing ES, crucial ecological features that are important for risk assessment can be highlighted,
- when accounting for ES, the entry point into the economic accounts can be established, as the users of ES are the same sectors operating within the national accounts framework.

However, it is important to note that there are several definitions and specifications that require further refinement. First, it is necessary to establish an appropriate classification of nature-based solutions and to identify the ES they generate. Such classification should ideally become part of the

Second, in order to establish which disaster risk reduction activities could be implemented, it is necessary to identify the relevant ecosystem services for each hazard information profile, wherever applicable.

Third, the temporal parameters of investments and expenditures on nature-based solutions require further exploration and delineation in short- and long-term scenarios, thereby establishing an appropriate auditing horizon for the measurement of performance indicators.

Even though the consolidation of Nature-based Solutions in a Green Sudoku (composed by SEEA, SNA and G-DRSF) still requires a significant amount of work, the approach appears to be promising.