European Commission

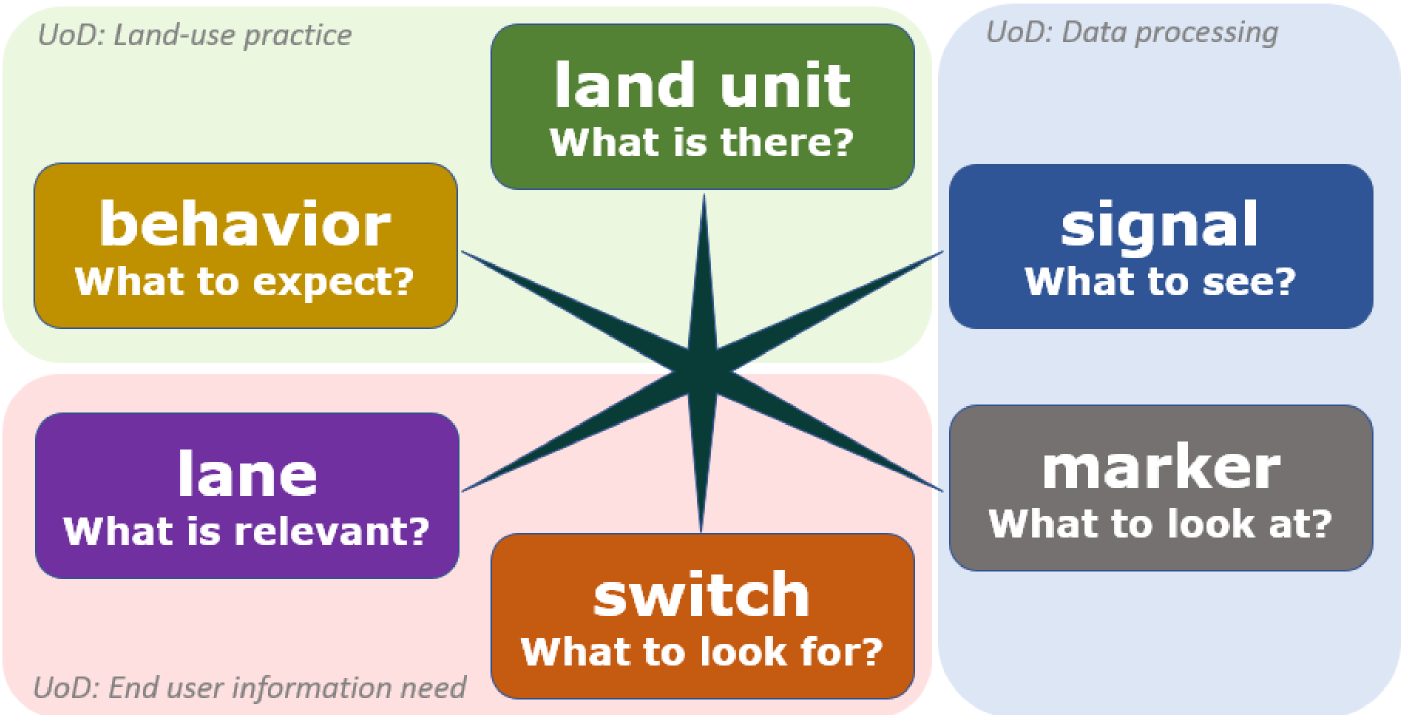
JRC TECHNICAL REPORT

Conceptual basis of checks by monitoring

Guide to the checks by monitoring tool-set

DEVOS Wim, SIMA Aleksandra & MILENOV Pavel

2021



Joint Research Centre

This publication is a Technical report by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information
Name: Wim DEVOS
Email: wim.devos@ec.europa.eu
Tel.: +39 0332 78 58 95

EU Science Hub
https://ec.europa.eu/jrc

JRC127678

Ispra, European Commission, 2021

How to cite this report: Devos W., Sima A. and Milenov P., Conceptual basis of checks by monitoring, 2021, JRC127678.

Contents

Acknowledgements

The authors wish to thank:

- the experts from the Paying Agencies of BE-FL, DK, ES, MT and IT for sharing their implementation experiences over the last two years;
- for an early review of this document, the experts from:
    - the ES coordination body, the Paying Agencies of ES-Cat, ES-CyL;
    - the Paying Agency of HR;
- the auditors of DGAgri H3 and policy officers of DGAgri D3 who were involved;
- the staff of GTCAP not explicitly mentioned below.

Contributors ccc

The CbM team within GTCAP who operates the many internal CbM processes and so contributed to the insights and illustrations of this concept document:

- Acquafresca Laura
- Borio Daniele
- Lemoine Guido
- Loudjani Philippe
- Luketic Natasa
- Puerta-Pinero Carolina
- Sedano Fernando
- Urbano Ferdinando
- Wirnhardt Csaba
- Zielinski Rafal.

Abstract

By 2018, five Common Agriculture Policy (CAP) Paying Agencies had adopted Checks by Monitoring (CbM) as a substitute for their on-the-spot-checks of direct payments. The sole JRC documentation available to prepare and guide these systems were two discussion documents (Devos et al., 2017; Devos et al., 2018a) and a technical guidance (Devos et al., 2018b).

By end 2021, the experience of working with these early adopters had generated enough feedback to revise the concepts laid down in the framework whilst the underlying principles of CbM have proven successful and are thus maintained. Furthermore, the European Court of Auditors had recommended a catalogue of best practices (ECA Special Report 04/2020).

This document aims to be the entry point for that catalogue and so elaborates a revised conceptual framework that should offer the basis for all stakeholders to be appropriately involved.

The farmer's practice, i.e., the field operation what all is about, is disambiguated in a temporal component –**scenario**– and a spatial component -feature of interest or –**FOI**–.

Key to CbM detection selectivity and sensitivity is the reduction of the vast Sentinel data stacks into a simple temporal function –**signal**– and the observed behaviour of the FOI thereon –**marker**–.

Relevance for a given information need comes from analysing the markers and ancillary data into a processing method –**switch**– and combining switches in an appropriate pathway –**lane**–.

This document defines, describes, illustrates and provides best practice considerations for each of these concepts.

The document further details on how reduction and targeting can be achieved through the logical interactions that exist between the six concepts. As monitoring is a year round process, it also duly elaborates the temporal properties. Several processing examples illustrate how these elements can be combined.

This entry document offers neither instructions nor ready solutions. Each CbM designer will have to match the provided theory with his/her local conditions. To help with this challenge, the other documents of the catalogue are briefly presented.

1 Introduction

1.1 Background

The arrival of the free, territory-wide and high frequency Sentinel data allowed a paradigm shift in the checks for CAP subsidies. In 2017, Paying Agencies informally requested the Commission to 'shift as far as possible from Integrated Administration and Control to Integrated Preventing monitoring control system' (Council document 12621/17). By 2018, the applicable Regulation 809/2014 was amended to allow for these 'checks by monitoring as a substitute for the On The Spot Checks' (OTSC).

JRC approached this development in a way similar to the earlier technology introductions in the CAP, i.e., via a progressive, inclusive and collaborative approach. The Commission services and volunteering Member States joined forces to incrementally gain understanding of the challenges and commonly resolve doubtful situations. The resulting experience is subsequently shared within the wider community.

In 2020, the European Court of Auditors published its finding on the ongoing activities and recommended the promotion of these checks by monitoring as the control system of choice for the future CAP (ECA Special Report 04/2020). This document frames into that recommendation, in particular the call to maintain a catalogue of best practices.

1.2 The main characteristics of the proposed approach

In November 2017, the initial outline of the approach for this development defined monitoring as a '*procedure based on regular and systematic observation, tracking and assessment of the fulfilment of eligibility conditions and agricultural activities over a period of time, which involves, where and when necessary, appropriate follow-up action*'.

The assumptions were that:

1. eligible area aspects would be quantified and managed using the Land Parcel Identification System (LPIS);
2. the object was a 'unit of land management' (≈agricultural parcel) with 'pixel based' processing for intra 'parcel' diagnosis;
3. individual but consistent processing was possible per <u>support scheme;</u>
4. (pre-filled) farmer's annual aid declaration acted as processing model <u>input.</u>

Several elements of the definition were further clarified.

- Regularity would be provided through a simultaneous evolution of the legislative framework.
- The systematic nature could be assured by the use of free, EU-wide sources offered by the Copernicus program and state-of-the-art digital services.
- Observations would investigate the bio-physical behavior of the land indicative of agricultural activities.
- The tracking methodology would be developed so that any assessment would be:
    - tiered, via a controlled breakdown of requirements, feasibility and timing;
    - reductive, by eliminating any unnecessary processing;
    - targeted, by prioritizing queries into known expectations.

These three methodology drivers: tiered, reductive and targeted, remain the very basis of the CbM approach and they are understood to be necessary to provide a higher overall reliability, effectiveness and efficiency, than the traditional remote sensing based approaches.

1.3 Earlier developments

By the end of 2021, 4 years of operations have contributed to the content of this document that could be summed up in the following main activity lines.

- Close collaboration with five early adopters helped to deal with conceptual confusion and to identify potential weakness through studying the individual implementation designs.

- The learning process was then accelerated through collaboration on the development of a common quality assessment (QA) methodology, which establishes a common benchmark that ensures a coherent assessment irrespective of the CbM design choice. The aim of the QA is to assess the proper functioning of the CbM using it as an assurance tool that ensures an efficient management and control system. This QA methodology development is the subject of a separate recommendation of the European Court of Auditors' Special Report 04/2020 and documented in a separate report.
- Technical support to DGAgri H3 auditors covering both back-office Sentinels' data processing during audits of OTSC operating systems as well as in-situ missions to CbM implementations.
- The processing technology and architecture, based on cloud technology, was developed through the Data and Information Access Services (DIAS) on-boarding activity of the early adopters and offering a DIAS-based platform for the so-called outreach initiative. The funds for the underlying DIAS services were provided by DGAgri. Portability with local cloud developments was duly considered.
- This outreach initiative aimed to lower the threshold for CbM adoption by de-mystifying the CbM operations and relevant architecture through offering an environment in which Paying Agencies could experiment with the various parameters to find local optima. The output of outreach provides the initial seeds for a catalogue of routines and tools.
- Finally, input from other projects, Sen4CAP, NIVA and standardisation development were also taken into account.

1.4 How to position this guide?

This document partly replaces the first (Devos et al., 2017) and second discussion document on the checks by monitoring as a substitute for OTSC (Devos et al., 2018a).

The replacements or changes reflect two major insights gained over the last years.

1. Where the discussion documents proposed a common processing path and used the six concepts to elaborate that path, in reality, each CbM adopter had implemented an individual processing schema. This document no longer targets a common minimum CbM process but aims to provide common conceptual model for Member States to document their individual implementation design.
2. The development of the QA methodology required a refinement of the original 'lane rules' concept. In fact, it became clear that not the rules themselves, but the enactment of these rules was the relevant item of inspection. This led to the introduction of the term 'switch' as enabler of the rule.

2 Generic CbM Concepts and terminology

A set of concepts has been defined in (Devos et al., 2018a), dealing separately with a particular piece or level of information so that the whole combination allows the transposition of raw Sentinel image data into well targeted and informed decisions. It turns out that processing any regular image supply could benefit from these concepts. While the 'CbM as a substitute for OTSC' context focuses on the decisions regarding CAP eligibility, the basic concepts are believed to be applicable for any land management or land practice monitoring. The understanding of this concepts is key to a correct use of JRC's CbM toolset.

Each CbM key concept points to one of the following three 'universes of discourse' (UoD). Each universe of discourse holds a set of concepts and terms that are understood and used by a particular community of practice.

- Universe of discourse of **land-use practices**

  The first relates to the *land-use practices* in a context of *the natural environment*. It deals with aspects of activity on a unit of land and the way this land use influences and changes the bio-physical characteristics of its land cover. Typical terms would relate to activity on land, land management practice, land management unit, land phenomenon, bio-physical characteristics, related behaviour, anthropogenic/natural event. The farmers, foresters and nature conservationists are communities that operate this type of UoD.

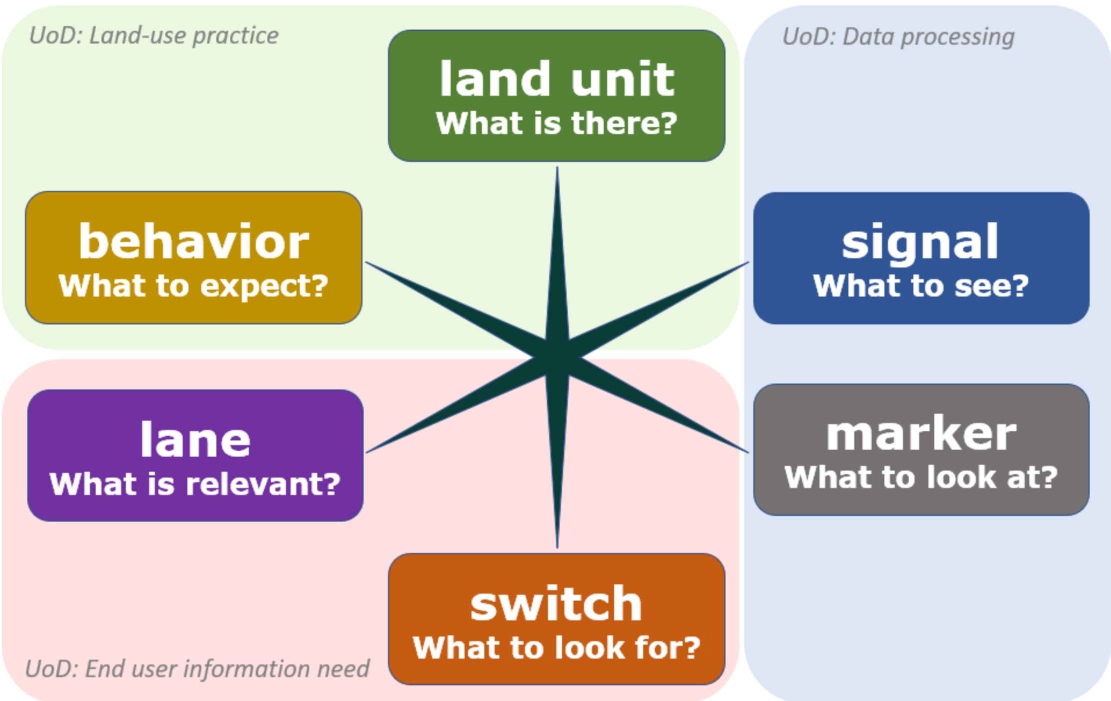
- Universe of discourse of **data processing**

  The second relates to the *processing of observation data* and deals with the way the activities on land are captured and reflected through the observation methods sourced by terrestrial, aerial or spaceborne sensors. The concepts of signal and marker confirming activities on the land, are taken from this community of observers and data analysts.

- Universe of discourse of **end user information need**

  The last relates to the *end user information need*. That need varies over policies and administrations who, despite efforts of data harmonisation and interoperability, often constitute separate administrations. The relevant aspects typically involve: policy measures, support scheme, compliance rules.

Figure 1. The three universes of discourse and the six key concepts.



In (Devos et al., 2017) and (Devos et al., 2018a) the basic concepts related to the CbM system were introduced and briefly discussed. This document provides updated and generic definitions.

- **Signal**: physical quantity that varies with time, space or any independent variable or variables (Proakis et al., 2006).
- **Marker**: observation of a particular physical state or change of state.
- **Unit of land**: observable Earth surface being, or expected to be, subject to specified land management.
- **Behaviour**: anticipated timeline of stages (periods in a process) associated to specified land management.
- **Lane**: processing path, executed by a given resource, which leads to a required conclusion.
- **Switch**: a test mechanism to steer processing paths.

The above generic definitions can apply to any land management challenge. The purpose of this particular document is to elaborate them in the application of checks by monitoring to substitute OTSC. Similar elaborations could be set up for other communities of practice and policy domains, whether inside or outside the EU.

One possible advantage of the six disjoint concepts is that they allow a better targeting of the CbM design. They provide a better understanding of what data aspect should go to what particular concept and also enable a high level expression of the interactions between the respective concepts. For instance, one could easily phrase some trivial conditions:

- scenarios can be expected to represent physical phenomena;
- a unit of land should be appropriate to extract a suitable signal;
- a signal can be trusted on to produce relevant markers;
- markers can be reliably used by decision switches;
- those decisions lead to a meaningful conclusion of the lane.

Such general conditions allow for designing system sub-packages to contain risks or to construct quality bulkheads by modular processing.

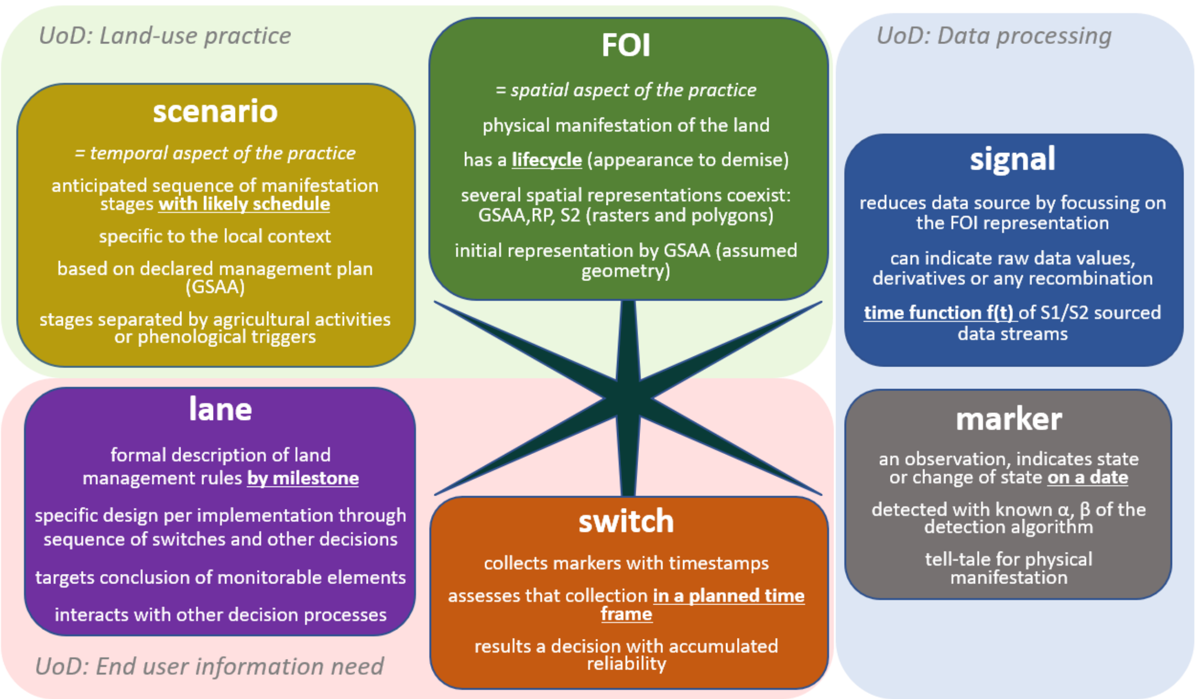
3 Checks by monitoring as a substitute for on the spot checks

Commission Implementing Regulation (EU) No 809/2014 of 17 July 2014, article 40a, introduced checks by monitoring as an alternative for the prevailing on the spot checks. In that particular context, elaboration of this document operates:

- the **UoD of land-use practices** from the viewpoint of the farmer community (allowing smooth communication, early warning), and so ***relies on land management specified by the farmer.*** In this particular CbM context, most practices can be understood as 'agricultural activity' or 'agricultural business' and its two complementing concepts are further specified:
  - the observable unit of land subject to the practice will henceforth be named **feature of interest** (**FOI**);
  - the anticipated behaviour resulting of the practice will be addressed as a **scenario**.
- the **UoD of information need** from the viewpoint of the Paying Agency, responsible for area-related aid schemes or support measures and Good Agriculture and Environmental Conditions (GAEC) cross-compliance, ***reflecting conditions laid down in the CAP regulations***;
- a **UoD of data processing** that ***extracts information from the Copernicus Sentinel data stacks*** for physical input.

Henceforth, the abbreviation CbM will be used when referring to the CbM as a substitute for OTSC.

Figure 2. The three universes of discourse and the six key concepts applied to CbM to substitute CAP OTSC (GSAA: GeoSpatial Aid Application; RP: Reference Parcel; S1: Sentinel 1; S2: Sentinel 2).



3.1 The 6 concepts

3.1.1 Scenario

3.1.1.1 What is a scenario?

The scenario describes the sequence of stages that can be expected from the farmer's choice to use his land over a given timespan. For many practices, the scenario covers a single growing season (for most of arable crops), for some other practices, it can extend to multiple consecutive years (e.g. a full crop rotation cycle).

For Direct Payments, eligible uses are limited to growing crops, raising livestock or performing minimum maintenance. The use is further constraint by the land cover: annual crops require arable land, cattle grazing or hay production requires grassland.

Within the context of CbM, the stage of a scenario has to be understood as a general phase of typical manifestation, i.e. what the farmer recognizes in this land management, resulting from his deliberate activities, from the normal phenology of the crop, or from other anticipated events.

In any given local context, the specified use will allow to anticipate a clear sequence of stages.

- Each major stage has a particular manifestation (e.g. the crop preparation phase could be characterised by absence of vegetation or bare soil presence).
- Specific agricultural activities, natural processes (e.g. vegetation growth, flowering etc) or events such as the start of the rains, can delimit consecutive (sub)stages, e.g. ploughing will leave a rough bare soil, seedbed preparation will smoothen the soil surface.

If an activity, process or event does not induce an observable change in the physical manifestation, it's considered not 'monitorable' and is not expected to trigger a new stage (e.g. pesticide spraying, application of fertilising rate).

Certain manifestations are antithetic to a given scenario and can therefore also be monitored, e.g. one doesn't expect permanent grasslands or permanent crops to be totally cleared of vegetation. One doesn't expect stubble to be burned without permits.

Local natural disturbances that cover the land such as snow or floods, can obstruct the practical observation of the stages in the scenario, so, such disturbances must be appropriately handled.

Identifying an appropriate scenario is a first boundary condition of the CbM. It relies on the aid application for specifying the land management and local context to select the monitorable stages. This ensures the specific targeting that is often not available in other remote sensing approaches.

3.1.1.2 Best practice

- All terminology comes from the universe of the practitioner (farmer), on pair with terms from data processing technology (remote sensing) and legislation (CAP).
- The various stages are merely put in sequence. A scenario is not fixed to the calendar, thus involving neither fixed dates nor deadlines.

3.1.1.3 Examples

The scenario brings the local business logic into the process. That logic integrates results and information from many sources. In the case of agriculture, this can be the available local know-how on crop phenology, crop calendar, traditions of agricultural practices, etc. This predicts the FOI behaviour based on the local land management practices and allows to attribute an observed stage to an expected activity.

For example, any arable crop will invariably trigger a sequence with occurrence of bare soil, growth of vegetation, removal of vegetation and possibly other land cover manifestations. These stages are occurring in a predictable sequence and with a crop dependent timeline, sometimes even linked to last year's use (crop rotation). A permanent grassland under a hay making regime will show vegetation year-round, with drops of biomass after each mowing activity.

Scenarios should also list the possible local natural disturbances (floods, frosts, droughts, fires etc), that are uncertain but potentially block the principal stages of the scenario. For example snow and frost occurring very late in the vegetation season can delay or prevent subsequent stages in the scenario and would require customised data processing workflow or a completely new scenario.

Practical examples of scenarios can be found in sections 4.1 and 4.5.

3.1.2 Feature of interest

3.1.2.1 What is a feature of interest?

The FOI is the surface of the earth where the specified practice will be performed. In a farmer's view, this surface would for example correspond to his/her particular plot, meadow or orchard (or part thereof, when appropriate).

The scenario holds a series of stages, each representing a particular manifestation of that individual FOI. The scenario thus describes a probable lifecycle of the FOI and importantly, this allows to predict how the practice should manifest itself over the course of that cycle.

As previously mentioned, for many practices, the lifecycle lasts a single growing season, for some other practices, it can cover multiple consecutive years. As the FOI is an observable surface with a lifecycle (birth to demise), its physical properties (including spatial boundaries) are neither given nor stable. In fact, the available spatial (digital) representations of the FOI will vary over time:

- with an assumed perimeter at the time when the intended practice is specified (by the farmer through his GeoSpatial Aid Application, GSAA);
- it can be inherited from a reference parcel, registered some years before;
- or a perimeter observed by contemporary high-resolution imagery (i.e. aerial orthophoto, e.g. being part of the LPIS);
- and a perimeter obtained from automatic mapping on Sentinel imagery.

These different FOI representations can co-exist and the 'most correct' or 'best' one can only be identified for a particular purpose at particular moment of the lifecycle. In fact, only a continuous assessment of these various FOI representations can guarantee the validity of assumptions underpinning the CbM assurance level.

- Whether the scenario is appropriate (if not, start a feedback loop to the farmer)?
- Where relevant, whether corresponding area values can be accepted (if not, obtain a correct perimeter)?
- Where relevant, whether intra-FOI difference can be detected? (Can it be derived from the scenario?)

Handling the different contemporary FOI representations appropriately is a critical success factor in the CbM operations.

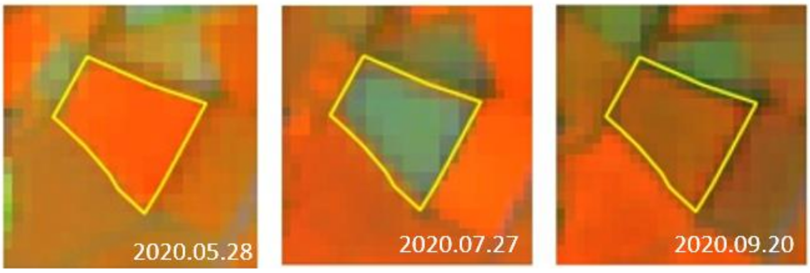
3.1.2.2 Best practice

- Each declared practice has one and only one FOI. Note that a scenario for a single practice may describe many activities.
- CbM starts with an assumed FOI representation early in the scenario, during the CbM process. That assumption should at some point be validated.
- The FOI, or its various representations, should not be confounded with technical criteria such as minimum mapping unit, minimum number of pixels.
- The FOI is still a land-use feature, with several manifestations that influence its bio-physical cover observed over time. It's critical to understand up front whether the manifestation will be homogeneous over this particular FOI or not.
- A FOI under a single practice is non-divisible. A part of the FOI is not necessarily a new FOI in its own right, since the set of bio-physical processes, triggered by the farmer activities, apply to the whole unit of management, and not to part(s) of it.
- Within a given challenge (user information need), one should strive for non-overlapping FOI representations.

3.1.2.3 Examples

The feature of interest refers to a real world feature or set of contiguous features, which in the case of agriculture, corresponds most often to either the 'agricultural field' or the 'crop' (see Figure 3).

Figure 3. A declared GSAA agricultural parcel (in yellow) correctly reflecting the associated land management unit - the feature of interest.



Experiences from the OTSC, as well as LPIS and CbM Quality Assessment processes confirm that such field (or unit of management) is not always on a one-to-one cardinality with either the GSAA agricultural parcel or the LPIS reference parcel, both being a possible spatial representation.

In the CbM system, the FOI has a digital representation, derived from the GSAA in combination with LPIS and uses a polygon as geometric primitive. It acts as candidate FOI and provides the spatial extent of the Sentinel pixels and thus takes only the part of the signal associated with the given FOI. FOIs and their digital representations (candidate FOIs) are critical to improve the effectiveness of a marker to unambiguously reflect the targeted physical property, through the associated signal behaviour. Identification of an individual FOI allows to aggregate smaller adjacent surfaces under a single use (i.e. same farmer or same crop for the year) into a single feature of interest to result in clearer combined signal, in particular where parcel dimension could be an issue. A FOI representation that correctly reflects the associated land unit guarantees that data derived from Sentinel (assuming proper co-registration and noise removal) are exclusively associated with the properties of the phenomenon that occupies that land unit.

The FOI expresses homogeneity, coherence (or lack thereof) of the spatial distribution of the land cover state. This can be tested (Milenov et al., 2021), and failure of such test indicates that either that the candidate FOI is not representing a single unit of management (and a feedback loop can be started) or that there is a desirable land-use practice present (for example, partial grassland mowing).

Box 1: FOI validity

Understanding of the FOI concept is crucial for successful signal processing. This box presents several examples for consideration, each reflecting the cardinality between the initial FOI representation and the land unit observed by Sentinel.

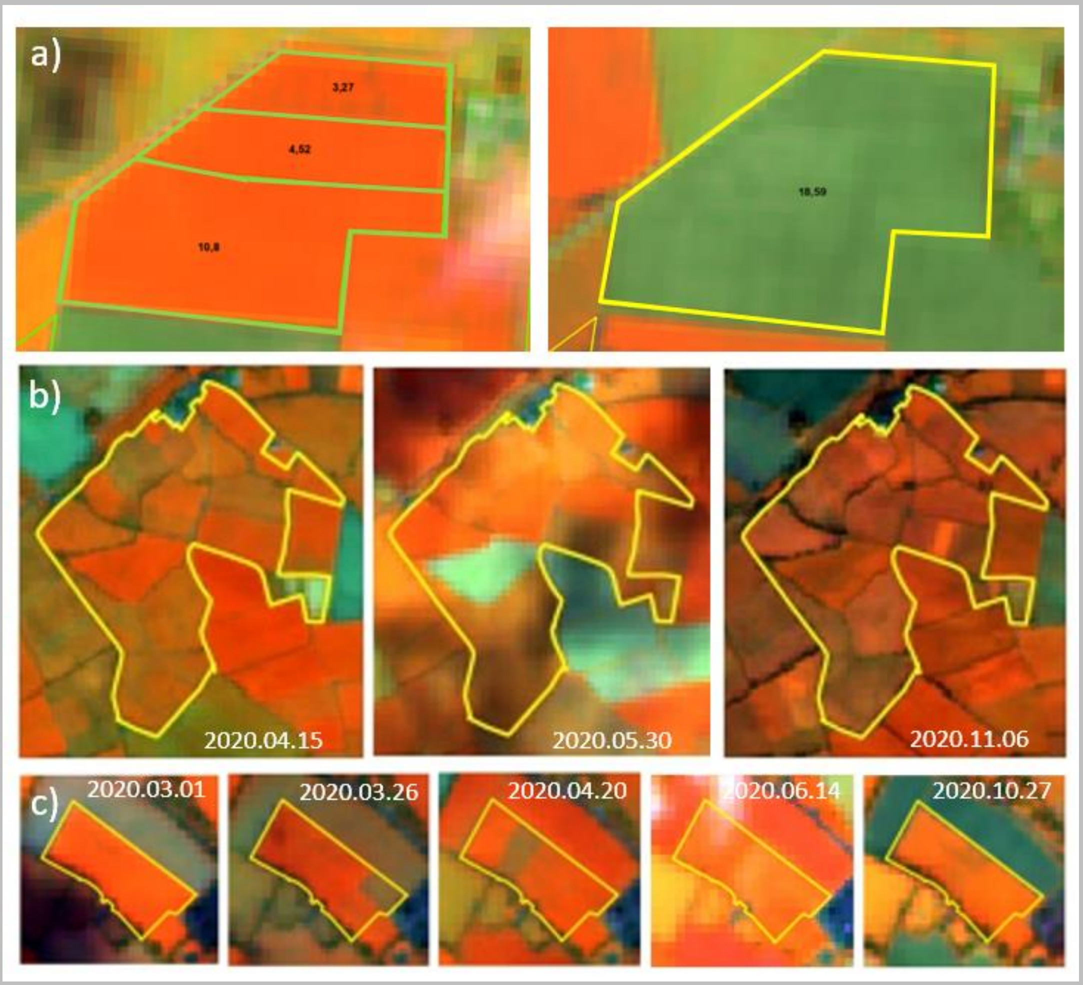
Depending on the LPIS parcel type, the parcel as declared in the GSAA may or may not correspond to the FOI. Furthermore, non-uniform land cover does not necessarily indicate invalid FOI.

a) In Figure 4a the three cadastral parcels declared in GSAA (left, marked in green) correspond to a single feature of interest (right, marked in yellow). Although this subdivision may be relevant (especially when parcels are managed by different users) a merger is beneficial from the signal processing point to increase the signal-to-noise ratio.

b) Figure 4b presents an invalid FOI (>30ha), containing grassland and arable crops (different land cover). In order to ensure correct monitoring results this polygon should be split into the various units covering single management choices. Signal processing from the original polygon results the equivalent of a cacophony.

c) Despite displaying non-uniform use, Figure 4c presents a valid FOI, where intermittent mowing of hay land was performed. Observing that difference inside can be a key criterion for such parcel.

Figure 4. a) Declared GSAA agricultural parcels (left, in green) and corresponding feature of interest (right, in yellow); b) a FOI covering many farmers' management units; c) partial mowing of grassland for hay production.



3.1.3 Signal

3.1.3.1 What is a signal?

The Copernicus program delivers a vast amount of imagery that, even with the progress of artificial intelligence, presents a major challenge to process. The CbM-signal is designed to reduce this 'deluge' to something that is easily, reliably and accountably managed.

A signal only holds information on a specified FOI. When each FOI is part of tessellation, any territory can be considered as a finite set of geolocated signals.

By definition, the signal is a temporal function; it links to the calendars that are implied in the scenario and lane.

The value of that function can be a:

- raw physical measurement (scatter intensity [dB], irradiance [W/m2]);
- derived quantity (reflectance [%], coherence);
- mathematical combination (indexes);
- statistical variable (mean, median, standard deviation); or
- spatial intra-FOI variable (patterns, heterogeneity).

By filtering the vast image archive into FOI relevant time series, the signal is the main reductive instrument for the CbM.

3.1.3.2 Best practices

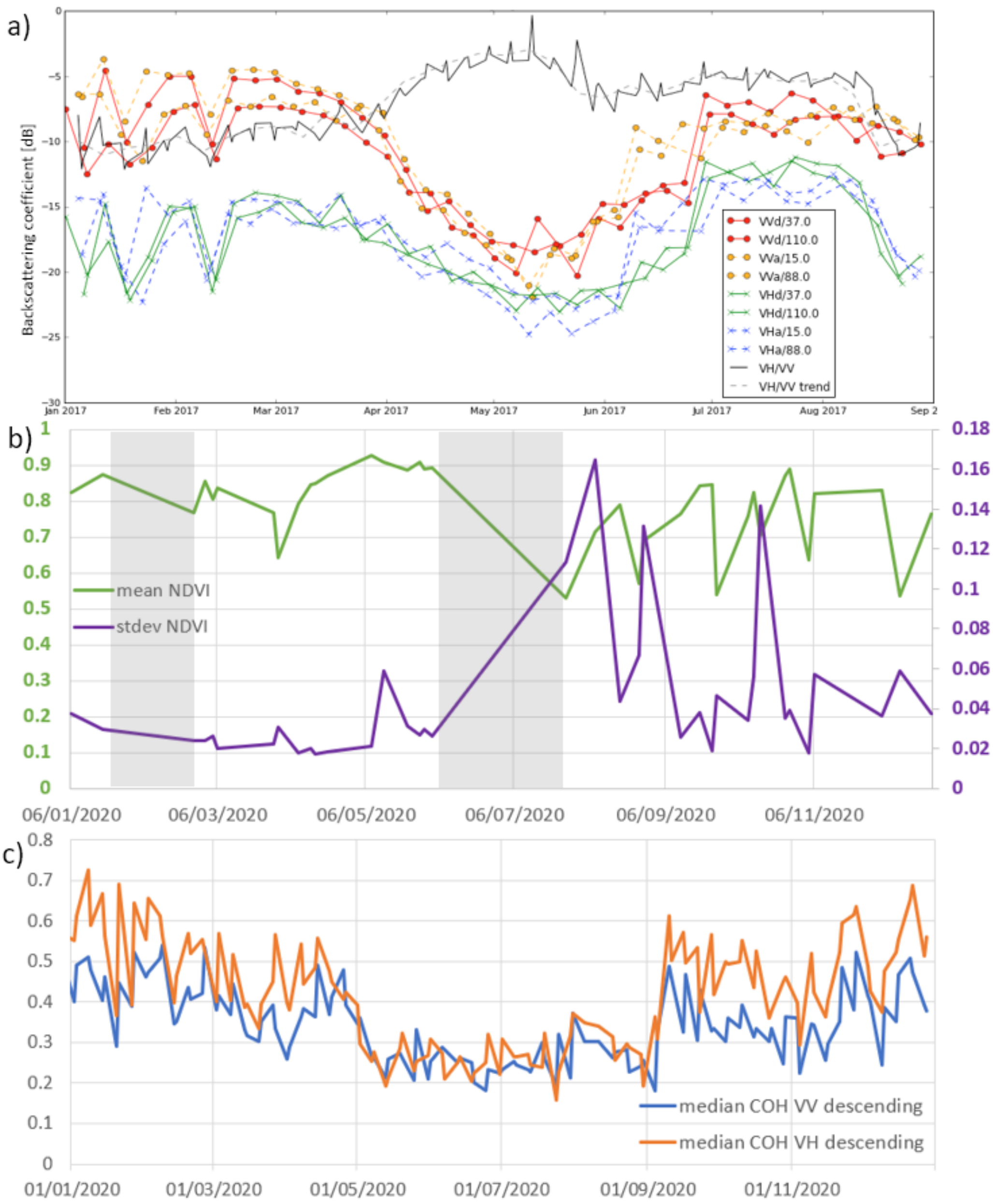
- A particular signal remains relevant for the lifespan of the scenario and FOI, i.e., inherits start and end date from the specified practice.
- In processing terms, the signal can be incrementally processed, e.g. by adding recent information to existing repositories.
- A signal function is the obvious place to apply signal-to-noise enhancement techniques.
- The image data over the FOI could be transformed into values of a signal function for the entire FOI (statistical metric, moment-generating functions) to reduce the complexity of data and to scale it along the temporal axis, critical to analyse the land behaviour.
- The signal extraction process could/should involve quality considerations; these could include techniques to improve the signal/noise ratio or to eliminate an occasional cloud cover or other processing artefact that differs from local natural disturbance.
- Multiannual analysis of the availability of the signal with sufficient quality can predict the feasibility of a particular signal extraction process in the CbM design.

3.1.3.3 Examples

An obvious advantage of the signal variation plotted along the temporal dimension (horizontal axis) is that several signals can be represented in a single graph.

Figure 5a holds 10 different mean dB-strength signals (all processed, no raw data) for a FOI representation. Since that spatial feature holds many pixels, the basic statistics (mean, median, standard deviation, maximum, interquartile range etc) of each signal become separate signals. If conditions allow (same weights, symmetry), different signals could be combined in composite functions. Such NDVI mean and standard deviation are represented as two signals in Figure 5b. Longer periods of unusable signals (due to dense cloud cover data, monitored through a dedicated signal function), are indicated in grey, signalling the need for alternative observation methods, preferably weather independent, as well as for constant monitoring of the signal quality indicators. Median coherence in two polarisation modes (descending orbit) over hay land in Ireland is plotted in Figure 5c.

Figure 5. a) Ten different signals (mean scatter coefficient [dB]) produced by a Sentinel 1 time series over a wheat FOI in the Netherlands; b) Two NDVI based signals: mean (in green) and standard deviation (in violet) over hay land in Ireland. Longer periods of unusable data indicated in grey; c) Two coherence based signals over hay land in Ireland.



3.1.4 Marker

3.1.4.1 What is a marker?

A marker records what has been observed on the signal. It holds both the nature of the observation and the time it was manifested on the FOI.

The nature of the observation either reflects a behaviour or a (provisional) status quo in the bio-physical manifestation of the FOI where the signal was calculated.

Markers are detected by algorithms that:

- search the signal values for sequences indicating the occurrence of a known and documented bio-physical manifestations or behaviour;
- are, in most of the cases, based on either the signal's strength/amplitude (S), its behaviour (derivative dS/dt) or its impact (integral $\int_{t1}^{t2} S$).

Among others, two considerations are particularly relevant for the practical extraction of the observations: the temporal resolution (slow changes versus abrupt changes - events) and latency (the possible offset between the time of the observation and the time when the actual change occurred).

For pragmatic reasons a number of marker extraction types has been defined, based on the nature of the manifestation and optimal (pre-)processing resources:

- detecting abrupt land cover type changes (requiring only 2 dates to detect e.g. forest cleaning, urbanization etc);
- detecting gradual land cover transition (requiring more but well spread dates, e.g. for vegetation re-growth, abandonment);
- event detection (requiring high frequency captures, e.g. to detect mowing or ploughing activities);
- crop classification (patterns within a season, based on processing of signal data);
- extraction of intra-FOI spatial aspects;
- analysis of cardinality between FOI-representations.

Every algorithm or method that searches for a marker in the signal, can be evaluated in the local context and its sensitivity and selectivity can be expressed as alpha (α) and beta (β) errors.

The signal quality and sampling rate need to be recorded to monitor fulfilment of the minimal signal requirements for the marker to work as expected (i.e., with its established sensitivity and selectivity).

Markers offer a vehicle to apply the vast remote sensing literature and experience in the specific local conditions with limited needs for additional validation and parametrization.

3.1.4.2 Best practice

Key to a reliable performance of the markers is the validation of the 'tell-tale' aspects of the manifestation and the selection of an optimal signal to observe this. This is where the common 'best practices' of the remote sensing community provide valuable input.

To help identify and select markers for the CbM design, JRC developed a concept of marker cores (Devos et al., 2018a), that documents known signal and manifestation combinations.

The output of a standalone crop classification algorithm that produces crop masks directly from the imagery is NOT a marker. Such algorithms are not using the reductive processing of the signal, but classified pixels are afterwards overlaid with a FOI representation. The CbM setup does allow to use this exogenous crop information but only crop classes that are derived from signal analysis (signal extracts at FOI representation level) are considered markers.

3.1.4.3 Examples

Markers describe at least two aspects: the objective observation on the particular signal and the contextual conditions that provide reliability to reveal the behaviour behind that observation.

The first, central component of the marker, called **marker core**, is a mere observation of the signal value or its evolution in time. The evolution of the signal variation can be simple or complex as the amplitude can be stable, change gradually, drop sharply, rebound etc. What makes a marker core is that these variations can be explained by the evolution of the physical state of the land cover property. Sentinel data respond to the presence/absence of human interaction, maturing of a crop, removal of vegetation, grass regrowth after mowing. Cores reflect basic but well-known phenomena, documented by the given expert community (for example, remote sensing), where the physical state of a given property is explicitly related to a particular signal and amplitude. The knowledge of the physical 'trigger' of the state/change allows to predict at what time the marker is more likely to be observed.

So to make a core applicable, i.e. introduce the sensitivity and selectivity (alpha (α) and beta (β)) needed for the particular local context of the spatial feature, **marker parameters** need to be derived, tested and applied. A phenomenon like 'fast vegetation growth' will appear differently on a signal recorded in the Mediterranean than on one recorded in the Baltics. In mountainous areas, a phenomenon like 'appearance of vegetation' will be delayed for parcels in mountain top positions compared to those located in the valley below. The marker intensity (or amplitude of the signal) of the same crop can vary inside and between regions and can change from one year to another.

To summarize, the core is a selected generally applicable signal function (F(t), dF/dt etc) that explains an observation of a physical event. The parameters allow this to be fine-tuned according to local and seasonal differences and make the markers applicable to each local context.

The simplest example of a marker could be a rapid surge of signal, with signal values increasing above a certain threshold, e.g. as shown in the example in Table 1.

Table 1. Mean coherence derived from Sentinel 1 for a FOI as the signal to detect a surge in SAR coherence, evidencing the decrease of grass height and the reduction of canopy between weeks 34 and 35.

Halfweek	33a	33b	34a	34b	35a	35b	36a	36b
Date	13.08.20	16.08.20	20.08.20	23.08.20	25.08.20	29.08.20	01.09.20	04.09.20
Coherence	0.25	0.24	0.28	0.28	0.35	0.38	0.38	0.37

At the end of week 34, a surge of mean FOI coherence from 0.28 to above 0.35 was observed. The resulting marker 'coherence surge' on this FOI is timestamped 25 August (the date of the first Sentinel 1 image evidencing the conference surge).

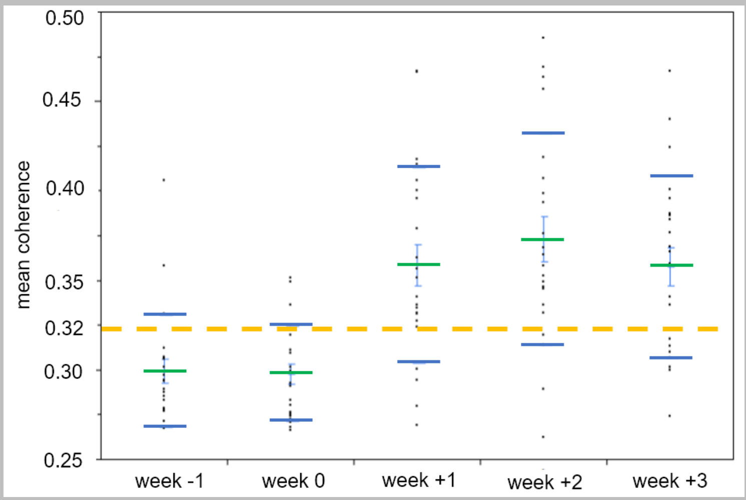
Please note that the example provided here and in Box 2 below is presented for illustration purposes only, to facilitate understanding of the marker concept. A thorough analyses of the signal recorded by the Sentinel sensors and the corresponding bio-physical phenomena on the ground, confirmed by ground observations, are required to choose reliable markers and optimise their parameters or thresholds.

Box 2: the 'coherence surge' marker illustrated above

This box aims to illustrate the marker concept in a very simplified manner. The example implies that one knows the context of the FOI as well as the exact timing to look. Real world implementations will be much more elaborate.

Analysis of ground truth data (weekly field visits) for FOIs distributed in a region, showed that the coherence increased above a threshold, in this case the value of 0.32, within a week after mowing of the grassland had been confirmed on site (week 0 in Figure 6.). So, the marker 'coherence surge' seems appropriate to detect such grassland practices as coherence tends to increase with lower grass height and reduction of canopy. Both phenomena reduce the potential of a SAR scattering signal to variate on consecutive days, what leads to a higher coherence; this is the marker core's logic. A mowing activity is likely candidate for causing both phenomena, hence an instantaneous 'coherence surge' can be indicative of mowing activities in a grassland management scenario. The delay of one week drives the local parameter settings.

Figure 6. Weekly mean coherence for multiple FOIs preceding (week -1) and proceeding (week +1, +2, +3) the mowing observed (week 0) during weekly field visits.



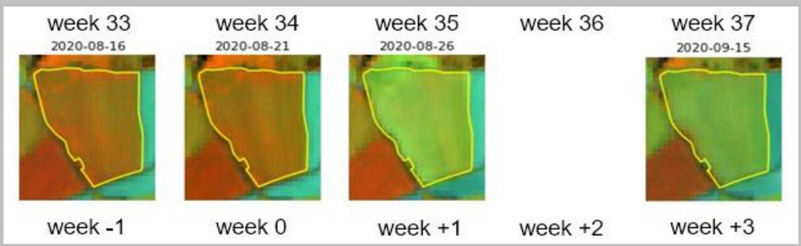
Using a threshold, here set at 0.32, for marker detection also implies that two groups of FOIs, where the above phenomena occurred (decreased height and reduced canopy), will NOT be detected by this particular, threshold based, marker detection process, namely:

1. those FOIs for which in week 0 (the week when the phenomena occurred) the mean coherence value was already above the threshold (0.32),
2. those FOIs for which the occurrence of phenomena does not sufficiently increase the coherence value to raise above the threshold (0.32).

The combination of the two types represents all possible false negatives that can be expected from using this marker detection algorithm in this local context. The graph thus allows to directly estimate the selectiveness or β error of the 'coherence surge' marker detection used.

The fact that an increased coherence corresponds to an actual physical change on the FOI can be independently illustrated by interpreting the Sentinel-2 data before and after the detected marker. The images show that the transition from closed grass canopy cover to open grass canopy cover, with the bare soil visible beneath, is well evident. A coherence marker makes this detection process weather-proof.

Figure 7. Weekly false colour composite Sentinel 2 data for the example FOI from Table 1. Marker of coherence surge observed on 25.08.2021 in Sentinel 1 data (in Table 1).



3.1.5 Switch

3.1.5.1 What is a switch?

A switch is an operational method to apply markers in a meaningful way, in line with the end user information needs. The markers originate from the signal data processing observed over the FOI in question. The relevance of that operation, in end user context, will be embedded in the lane.

At a minimum a switch will have to handle these actions:

- collect markers, at a minimum one marker for the particular FOI under processing, but optionally other markers, and sometimes markers from other FOIs (e.g. for outlier detection, local neighbourhood comparison, etc…);
- monitor whether the set of collected markers allows for a substance test, and if so, trigger that substance test. In other words, the switch checks whether the combined markers collected with respect to certain physical information requirements (about activities, disturbances, or abnormal behaviour) is sufficient to take a decision to: (1) complete the operation; (2) trigger new action within the operation; (3) choose the next operation;
- report and record the outcome of that substance test.

The desired outcome of this series of mostly automated actions is a documented decision whether to alter the process flow or not. Process flow altering could take the form of:

- triggering new actions;
- choosing between processing paths;
- assigning final verdicts.

The ability to collect markers that combine observations allows a switch to manage the reliability of individual algorithms into a better overall reliability of the resulting decision, in line with the end user information needs.

Any particular switch can be used differently in different lanes depending on its basic requirements, e.g. the detection of ploughing can be desired for arable crop scenarios but undesirable for Environmentally Sensitive Permanent Grassland (ESPG) scenarios.

Switches turn markers into information meaningful for the system administrators (UoD: end-user information need).

3.1.5.2 Best Practices

- Switches are standalone methods to analyse the accumulating observations for a single information need. Their design should not be contaminated with decision logic that goes beyond that basic physical information need.
- Switches can be simple (one marker for one FOI) or more complex (e.g. machine learning analysis of many markers covering several FOIs). A general tip is to keep it simple where possible.

3.1.5.3 Examples

Examples of switches used for non-compliance rules (see section 3.1.6.3) could be:

- for arable crops: any detected burning of crop residues leads to a verdict on FOI's non-compliance ('red light') with GAEC rules;
- for permanent grassland: any detected land conversion will lead to a conclusion on non-compliance ('red light') with the Basic Payment Scheme (BPS)/ Single Area Payment Scheme (SAPS) rules; ploughing detected in FOI declared as ESPG will lead to a verdict on the FOI being non-compliant.

Switches operated for compliance rules (see section 3.1.6.3) could e.g. be the confirmation of any agricultural activity such as a single mowing on permanent grassland or ploughing on arable land. These could enable a conclusion ('green light') on fulfilment of minimum requirements for the BPS/SAPS.

Switches implementing the validity rules (see section 3.1.6.3) could e.g. manage markers confirming minimum activities over the entire FOI. If partial practices are detected, the switch triggers a request for input from the farmer ('yellow light'), possibly leading to either a change of scenario or a FOI update.

3.1.6 Lane

3.1.6.1 What is a lane'?

A lane integrates the formal land management rules necessary and sufficient to confirm the scenario for the FOI. The lane is elaborated as a flow diagram where the selected switches are combined to collect the necessary external evidence (markers) for a conclusion on the compliance or non-compliance of all requirements relevant for a specific practice.

In that capacity, a lane will reflect the particular CbM design choices:

- a selection of the scenario stages, where identification or discrimination is deemed essential for the conclusion;
- a selection of operational switches that, via the markers they contain, link directly to the FOI;
- a rationale for the switches applied to conclude on the stages of the scenario (e.g. origin of the rule it implements).

Many land management rules come with hard deadlines, whereas scenarios are not fixed on the calendars (e.g. the exact date of activities such as sowing, mowing or ploughing etc depends on the recent meteorological conditions), lane elements often are (e.g. deadlines implied by compliance rules).

The processing itself may be iterative, as certain switches may direct towards a new start or trigger particular loops.

The lane provides the tiered aspect of CbM, by allowing simultaneous processing of different monitoring schemes.

3.1.6.2 Best Practice

The close inter-connectivity between scenario (UoD: land-use practice) and lane (UoD: user information need) must be duly considered in the design phase. As a farmer can be expected to manage a particular land respecting rules of different origins (e.g. eligibility rules, greening rules or cross-compliance rules), it makes sense to investigate how these requirements can be compiled in a single scenario via a complex lane or whether separate scenarios and simple lanes are more appropriate, whatever makes the communication simpler. This is obviously a balancing exercise, and some iterations may be needed.

Lane design must accommodate for all FOIs under a comparable scenario. A decision based on several detected markers at FOI level can be a valid design choice, either as a complex switch with different markers or a concatenation of simple switches that operate on a single marker.

It might be beneficial for the end-user to document/report the ex-post final reliability estimate of a processing sequence by an individual lane.

3.1.6.3 Examples

The lane offers a boundary ensuring that tasks within one sub-process can operate autonomously from those in other lanes, i.e. the outcome of the lane is independent of other processes. Still, each lane can exchange information (i.e., provide conclusions, markers or parameters) with other lanes which will subsequently take that information into account.

Even if the definition of lanes is subject to a fair amount of discretion of the system designer, the overall objective of a lane remains to ensure a targeted and reductive approach.

For visualisation of the lane's outcome and possible reuse of outputs, a traffic light representation was proposed (Devos et al., 2018a). It holds lights, blinking lights and flags, inspired by the Vienna Convention on road signs and signals.

Pending on the complexity of the lane: it could process several observation based decisions.

Set of switches evidencing compliance of specific FOIs with a given requirement could be called *compliance rules*. For example, in the context of CAP implementation:

- for a voluntary coupled support (VCS), a switch that manages the necessary markers to identify the crop (i.e. discriminate from all other potential crops) would be needed in the rule;
- for a crop diversification decision, a switch triggered after the observation of markers discriminating it from the other crop in the holding;
- for a BPS/SAPS, a switch that looks for single marker that best shows the agricultural activity (e.g. mowing on permanent grassland).

A lane can also hold switches that track markers contradicting the truthfulness of the declared scenario, e.g. the unauthorized ploughing (through appearance of bare soil) within permanent grassland where ploughing is banned. Such a set of switches apply *non-compliance rules*. Note that these markers can come from the declared scenario (as above) but also from a series of incompatible scenarios. Incompatible scenarios would also be those related to non-agricultural land covers and land uses (forest, water, urbanization).

A third type of rules, **critical** to the automatic processing, are called *validity rules*. The validity rules are those that help control and steer the automatic process. If violated, they trigger a change in processing, either automatically or manually depending on their nature and context.

Examples of switches that control a validity rule could be:

- observing variability within a FOI, which contradicts the assumption of a correct candidate FOI;
- assessing the minimum conditions that are required for an algorithm to correctly function (e.g., completeness/sufficient frequency of Sentinel data);
- observing local natural disturbances that override the scenario's expectations.

These validity rules are rather generic, i.e. applicable to many landscapes and land-use practices. They should be part of the automatic processing where possible, because they drive the early warnings and feedback loops that are fundamental for successful monitoring of regulated land-use practices.

The lane processing is terminated when either:

- a conclusion on the intended information need is achieved;
- time runs out (roughly corresponding to the end of the scenario), or;
- switches hand over control to another CbM or non-CbM decision process.

3.2 Interactions

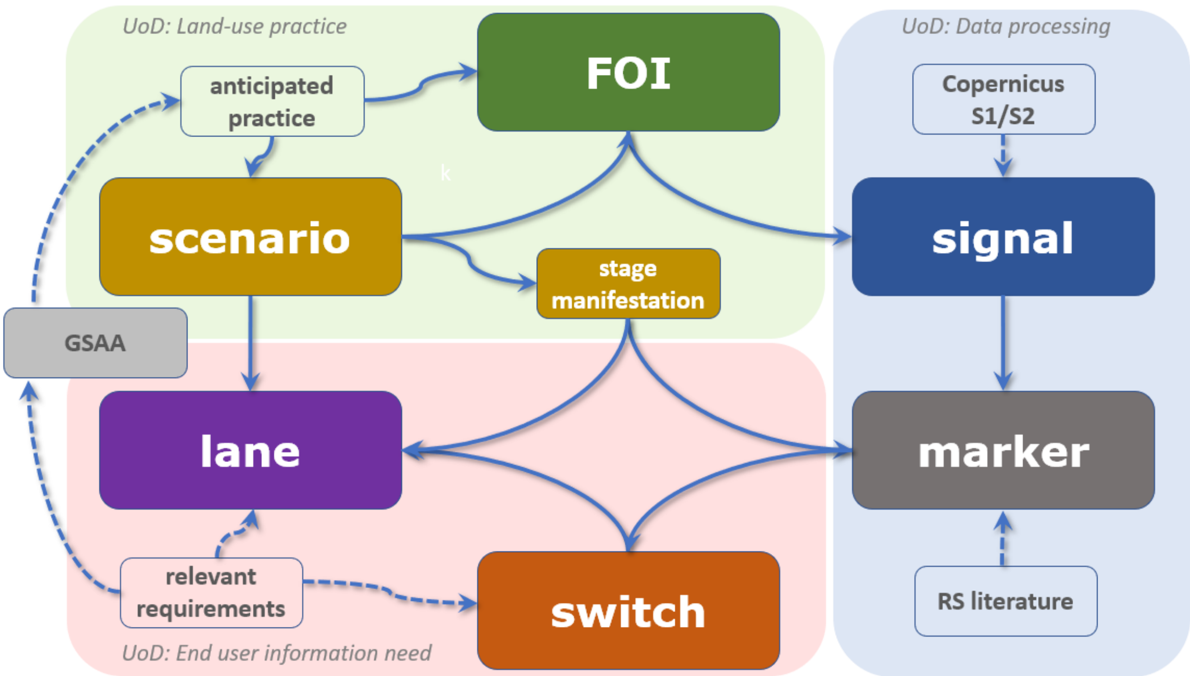
Although the lane determines the data processing and is therefore the foundation for an operational implementation, designing that lane will require interaction with the other 5 concepts to ensure the system targets, tiers and reduces the data sufficiently to enable a reliable conclusion.

This chapter provides a modus operandi or guideline how to evaluate, select and instantiate the concepts in such operational context.

The six basic concepts are supplemented with:

- the rules and GSAA that lead to the declaration of a practice and identification of information needs;
- the land use / land cover semantics that allow to describe the manifestations in the scenario;
- the Copernicus environment that offers data and access services;
- the Remote Sensing literature that allows to identify marker cores.

Figure 8. Interactions between concepts and information sources for CbM as a substitute for OTSC.



A scenario:

- is the external starting point, it describes what should happen on the ground that is observable with available monitoring techniques on available data and relevant for the end user;
- also lists potential local natural disturbances that may impact the scenario;
- relates to a physical surface/entity, reflected digitally by a FOI representation;
- will be used to reduce information extraction, it has at least one lane linked, occasionally more;
- is expressed as a sequence of stages/events/phenomena, time restricted, that have observation potential (if remote sensing is used, that potential can be expressed through markers);
- offers the business terminology that can be used to communicate with the farmer.

A FOI:

- comes with a spatial representation that provides the starting point for the information extraction of the remote sensing data; the starting point can be external (GSAA);

- has an initial representation whose geometry needs to be confronted with image data to ensure correct signal extraction at critical moments;
- prefers a spatial representation that ensures optimal masking of any signal noise for any processing using markers, through an optimal S/N ratio of the corresponding signal;
- is a subject to markers for spatial validity test, controlling the processing loop;
- provides that graphical representation to communicate spatial information to the farmer;
- ensures the correctness of the area component.

A lane and lane rules:

- generate the boundary of the processing for a particular information need (practice, eligibility check, data assessment, general analysis etc);
- contain a sequence and time frame of decision rules in the process that result in a single conclusion on a FOI, given its scenario;
- the lane rules are often implemented as a combination of algorithms (addressing specific information extraction types) that, through the appropriate selection of markers, analyse a variety of signals;
- can communicate with other lanes in the system;
- can communicate with the world outside the system (administration, farmer) through the 'traffic lights'.

A marker:

- implements a targeted and very specific information extraction from the vast amount of remote sensing data (serves as a kind of an optimal data query);
- allows the sharing of best practices using a core documenting the relationship between a physical phenomenon and the observable variation in remote sensing data (temporal variation);
- ensures, through the parameters, that this relationship is optimally tuned for a particular local and seasonal context. Markers addressing the same property change, but using different signals, are different markers;
- often uses a relevant statistical metric or moment-generating function to capture any spatial aspects of the phenomena within the FOI ;
- comes with a known reliability. One phenomenon or land cover manifestation can be observed by multiple markers reinforcing the reliability of the information;
- can be expressed as function of time;
- can be applied on different spatial feature primitives (polygons, image segment, image pixel clusters), as long as they are representative for the FOI in question;
- can be used in combination through simple algebraic operations to capture specific behaviour, in condition that they all relate to the same type of property change and use the same signal (diff marker for winter crops = marker NDVI EOS1 – marker NDVI EOS2; EOS: End of Season);
- should be selected and tuned for each lane. This is THE alpha and omega of the design of a monitoring system;
- offers factual evidence in the discussion of the outputs of the monitoring system.

A signal:

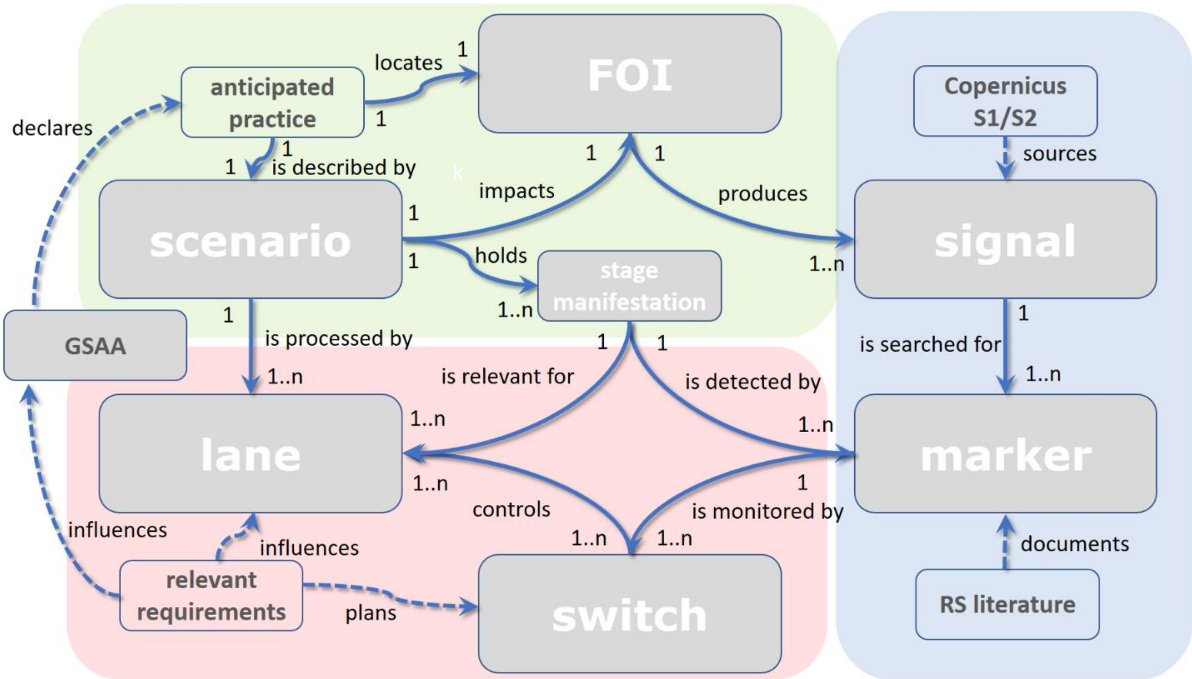
- is the result of the reduction of the image data stack targeting a single surface (the FOI) and represented as a function of time;
- ultimately originates from some raw sensor data, but the concept allows to recombine and process (integrate, differentiate, calculate, filter) that original and other functions to generate a new signal with optimal S/N ratio for the marker to read;
- always has some rationale/cause for an observed signal variation and underlying physical phenomena, i.e., a relation beyond a mere statistical correlation. The marker core should document this rationale;

- is best chosen in combination with a documented (or validated) marker core;
- if new, signal could and should be researched, tested and, if found suitable, shared;
- has a quality that depends on correctness of the FOI.

A switch:

- monitors markers, collects and evaluates them (timed process);
- turns markers into information meaningful for the system administrators (UoD: end-user information need);
- is designed to answer user information need based on relevant requirements;
- controls the lane and is active in timeframes imposed by scenario and requirements.

Figure 9. Cardinalities between the concepts and the linked vocabulary.



4 How to connect all the elements to design a lane?

4.1 Describe a scenario

4.1.1 The practice

The design process starts with the collection of detailed knowledge of practices applied by the beneficiaries/farmers. The local practices and/or crop calendar should be arranged to obtain a sequence of probable activities on the FOI and their likely dates. In principle, these activities and subsequent processes should result in a change of the FOI's land cover manifestation.

It is to some extend a discretionary choice which elements are placed under a single scenario, but given the scenario is in the UoD of the farmer, the farmer's perception of the practice, NOT the information need or rule should determine what could fit in a single scenario.

The example in Table 2 presents a scenario of hay production on permanent grassland, including periods when listed activities/practices are likely to happen for this declared land management choice. The table also lists the resulting land cover manifestations occurring on the entire FOI surface (1-1 cardinality), or possibly on a part of it (1-1..n).

Table 2. Scenario: hay land (permanent grassland), based on local practices.

Likely period	Trigger activity	Stages	LC manifestation	FOI cardinality
Jan-March		[re-] growth of vegetation	grass present and natural vegetation growth	1-1
March-April	topping	topping and regrowth of vegetation	grass shorten and natural vegetation growth (uniform)	1-1..n
April-end October	mowing (up to 3 times)	mowing and regrowth	grass is cut and natural vegetation growth (uniform)	1-1..n
Oct-Nov	topping	topping and regrowth	grass shorten and natural vegetation growth (uniform)	1-1..n
Nov - Dec		growth of vegetation	grass present natural vegetation growth	1-1

4.1.2 Local natural disturbances

Although, strictly speaking, it is not a part of a FOI or scenario setup, a list of the possible local natural disturbances such as: floods, snow, drought stress, with their likely occurrence period should be compiled. Such disturbances may influence the practices, timing of phenological stages or observation capabilities of thereof. Likely, these disturbances will simultaneously affect other lands in the direct vicinity and hence represent an element of common processing. Taking that into account should be considered as a best practice in the monitoring system design.

4.2 Translate requirements into rules

Next, the requirements driven by the data user information need should be translated into time-related rules, that will be, in turn, used to construct switches for the lane (see section 4.4).

In the particular example of hay production on permanent grassland the following activities are required:

- a single mowing, as minimum activity in BPS/SAPS for permanent grassland (PG); and
- two extra mowings to comply with Rural Development (RD) requirements.

This information can be translated into the following set of lane rules:

- non-compliance rules: no land conversion over the whole period (PG should remain PG in order that mowing is exerted);
- validity rules: e.g. confirmation that activities/phenomena are valid of the entire FOI at one point of the campaign;
- compliance rules:

    1. single mowing required (April-October);

    2. two additional mowing activities required for RD (April-October).

The absence of land conversion can possibly be confirmed in the next LPIS update cycle, which could avoid the need to rely on Sentinel processing. Alternatively, there might be a rationale for a provisional Sentinel driven update in cases where checks of FOI validity indicate persistent problems and therefore hint towards a possible land conversion.

For the validity and compliance rules, appropriate markers and signals should be selected to enable reliable conclusion on the lane, based on markers that target the land cover manifestations listed in the scenario.

4.3 Select most suitable markers

For every lane rule identified in the previous step, knowledge of remote sensing and image processing allows to select a set of signals and markers that should offer sufficient evidence to conclude.

Table 3. Example of signal and markers relevant for the scenario of hay land on permanent grassland specified in previous sections. NDVI = (NIR − RED)/(NIR + RED); NDWI = (GREEN − NIR)/(GREEN + NIR); CI red-edge = (NIR-Red Edge)/Red Edge; NDSI = (GREEN − SWIR)/(GREEN + SWIR).

Land cover manifestation	State of land cover		Signal 1 (S_1)	Signal 1 behaviour	Marker 1 (M1)	Signal 2 (S_2)	Signal 2 behaviour	Marker 2 (M2)
	Pre-condition:	Post-condition:						
grass is cut	fresh and dense grass	short and sparse grass	NDVI	drop↓↓	dS_1/dt	SAR Coherence	high	S_2
natural growth (uniform)	short and sparse grass	fresh grass	NDVI	increase↑↑	dS_1/dt	SAR Coherence	low	S_2
flood	absence of surface water	presence of surface water	NDWI	increase↑	dS_1/dt	SAR Backscatter	low	S_2
drought stress	dense grass/higher chlorophyll content	open grass/ lower chlorophyll content	NDVI	drop↓	dS_1/dt	CI red edge	drop↓	dS_2/dt
snow	absence of snow	presence of snow	NDSI	increase↑↑	dS_1/dt	S2 Blue /Red	increase↑↑	dS_2/dt

A prior knowledge of the markers' local sensitivity and selectivity (expressed as alpha (α) and beta (β) errors of the detection algorithm) is essential at this stage. This knowledge allows one to select the most suitable markers for confirming absence or presence of land cover state/change.

It is important to understand and consider what is the marker algorithm's ability to detect a phenomenon, and whether that ability will be applied either to evidence manifestation or to demonstrate absence. Individual markers may be good at one (i.e. sensitive) but poor at the other (i.e. not selective).

4.4 Build lanes with switches

Markers are 'monitored' by switches which make sense of these observations. In case the performance of a single marker may not be deemed sufficient to reach a conclusion, a switch can track consecutive markers, covering different stages. This may bring a reliable conclusion within reach by combining their respective sensitivity and selectivity.

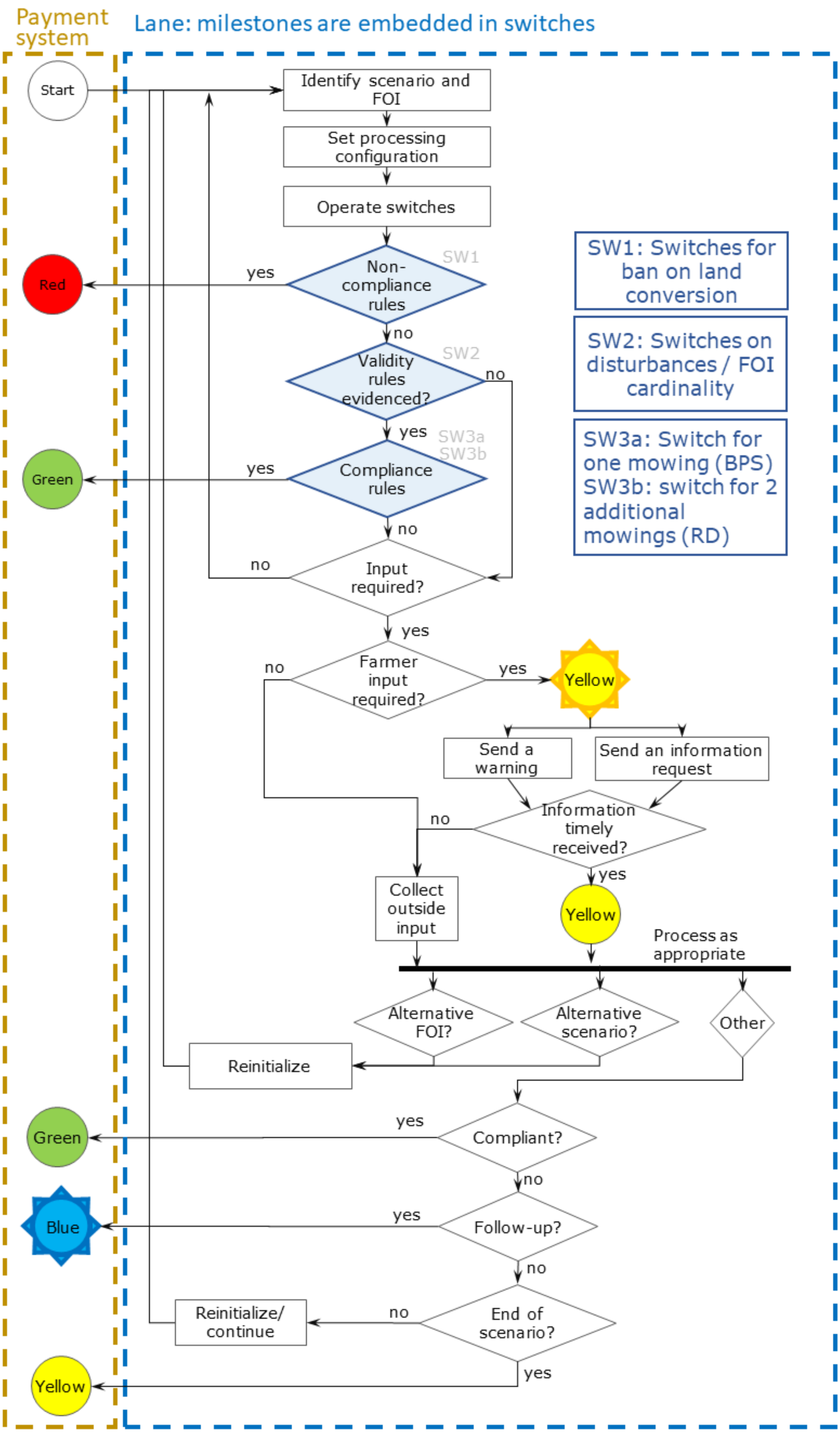
When designing the processing lanes, the deadlines and milestones involved should be specified based on a temporal analysis of the user information needs. A set of markers, their parameters and signals need to be configured to operate on the FOI in the pre-defined operation windows, along with appropriate signal quality monitoring routines (action 'Set processing configuration' in Figure 10).

In the example of hay production on permanent grassland (Figure 10) four switches are used. The naming of the switches is discretionary, here they are just numbered.

- SW1: switch representing the non-compliance rules, i.e. any detected land conversion will lead to red light, indicating the FOI is no longer compliant with the assumptions or requirements.
- SW2: switch representing the validity rules, i.e. confirming minimum activities over the entire FOI. If that is not the case, input may be requested from the farmer, possibly triggering either a change of scenario or a FOI update.
- SW3a, SW3b: switches representing the compliance rules, i.e. confirmation of one mowing will enable conclusion (green light) on fulfilment of minimum requirements for the BPS/SAPS (SW3a), confirmation of two more mowing activities indicates compliance with the RD requirements (SW3b).

The conclusion of each switch is transferred to the payment processing system as a particular traffic light setting.

Figure 10. Example of processing lane design for hay production on permanent grassland.



An example of lane with switches for arable crops, i.e. durum wheat followed by a cover crop implies the following required activities:

- active agricultural use of land, i.e. ploughing as minimum activity in the BPS/SAPS season;
- growing the specific crop, i.e. durum wheat, as main crop in VCS;
- growing any cover crop following the main crop required to comply with GAEC.

This information supplemented with the GAEC requirements can be translated into the following set of lane rules:

- non-compliance rules: no residue burning after harvesting;
- validity rules: confirmation that activities are valid on the entire FOI somewhere in the season;
- compliance rules:
    1. agricultural activity (at least one in the season);
    2. durum wheat confirmed as main crop (until shortly after the harvest, i.e. end of August);
    3. cover crop present as subsequent crop (between harvest and sowing of next main crop).

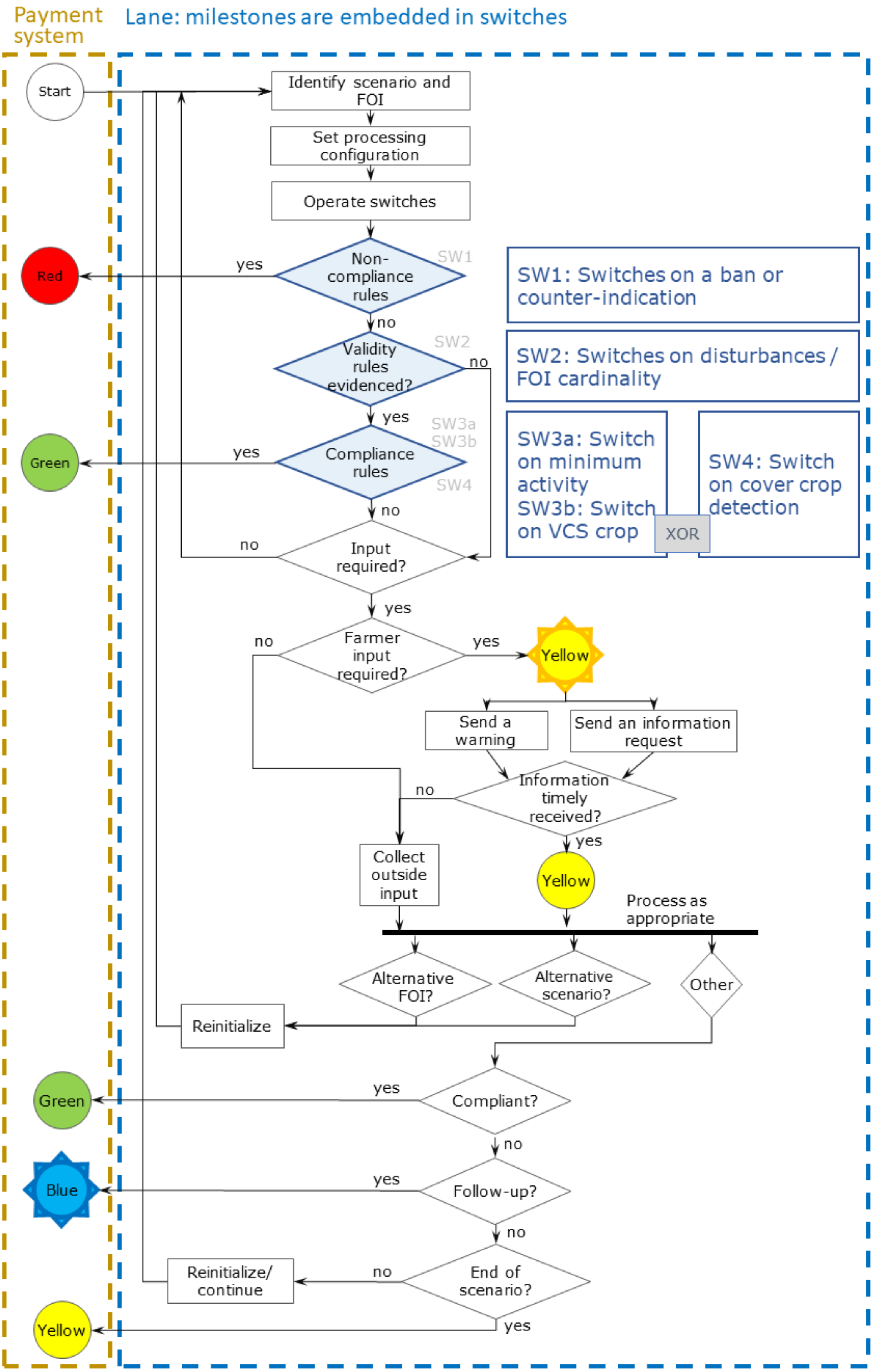
With a set of such end user requirements the following switches can be used (Figure 11):

- SW1: switch representing the non-compliance rules, i.e. detected burning of residues will lead to red light, indicating FOI being non-compliant with the requirements;
- SW2: switch representing the validity rules, i.e. confirming minimum activities on the entire FOI. If that is not the case, input may be requested from the farmer, possibly triggering a change of scenario or a FOI update;
- SW3a, SW3b, SW4: switches representing the compliance rules, i.e. confirmation of any agricultural activity will enable conclusion (green light) on fulfilment of minimum requirements for the BPS/SAPS (SW3a), confirmation of the crop (durum wheat) indicates compliance with the VCS requirements (SW3b), detection of cover crop in the required period enables conclusion on respected GAEC rules.

In the case of the mowing regime, it is a fairly simple single practice, with a series of activities. A single loop with farmer interaction allows for a warning system (Figure 10).

In the case of the arable crop (Figure 11) followed by cover crop, we are dealing with two distinct but consecutive practices (the main crop and subsequent crop and thus the XOR operator between switches SW3a, SW3b and SW4). The lane holds the feedback loop with the farmer, including the warnings. Whereas a warning system on the BPS activity and VCS crop identification makes a lot of sense. for the cover crop detection, warning the farmer may not be practical, as by the time the lack of cover crop is confirmed, it will be too late to sow it. Still the information request could be needed when Sentinel based detection fails.

Figure 11. Example lane design for durum wheat crop followed by a cover crop.



4.5 Managing time when designing a lane

As illustrated in the previous section, each of the six main concepts comes with distinct temporal characteristics.

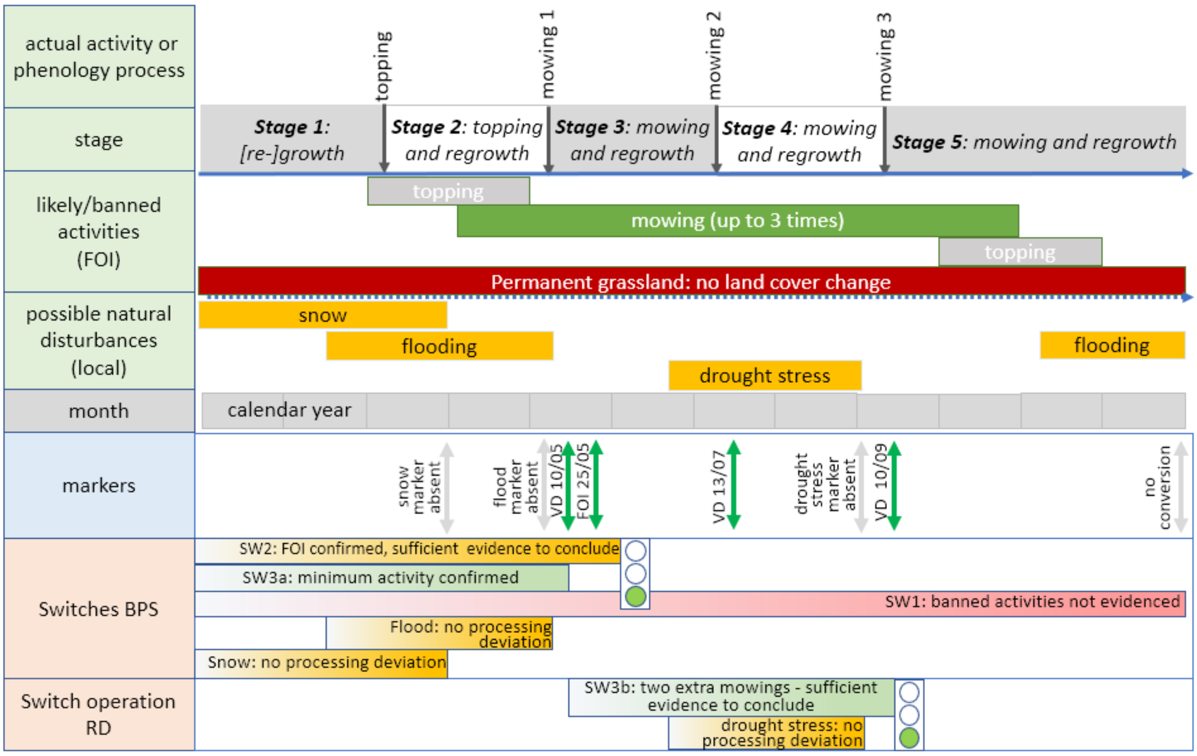
- The scenario provides a likelihood of occurrence for each stage. There is no fixed date as the occurrence of an activity depends on a farmer's decision and meteorological conditions triggering most phenological changes.
- The corresponding FOI has to be considered in the frame of a lifecycle: changes will only occur after a first activity on the land is performed and the FOI ceases to exist when the next practice starts. The lifecycle of a practice thus holds not only the main declared use, but also all preparations before and activities after that main use. A FOI will not always appear as homogenous during its lifespan. This understanding is crucial to guide the validity tests.
- The signal is by definition a function of values over time.
- Each marker comes with an observation date, recorded through the observation algorithm. That date is obviously inside the likelihood range provided by the scenario, but by definition always after the expected activity or trigger occurred.
- The lane provides all relevant deadlines or milestones, either in terms of absolute dates, date intervals or time differences.
- The switch is the method where these different time aspects are meaningfully processed, based on business rules such as:
    - markers should only be observed in the likely interval;
    - marker observation dates should be interpreted in the context of the particular activity and stage dynamics;
    - delays between the marker date and lane deadlines are processed.

Figure 12, Figure 13 and Figure 14 illustrate this temporal characteristics for three practices (two grassland mowing regimes and a durum wheat crop followed by a cover crop).

These examples also give an idea on the nature of local conditions that could be considered when designing the process within a lane. As with any design, simple is often better. A modular design where switches and sub-practices are recombined will often reduce the development and testing cost.

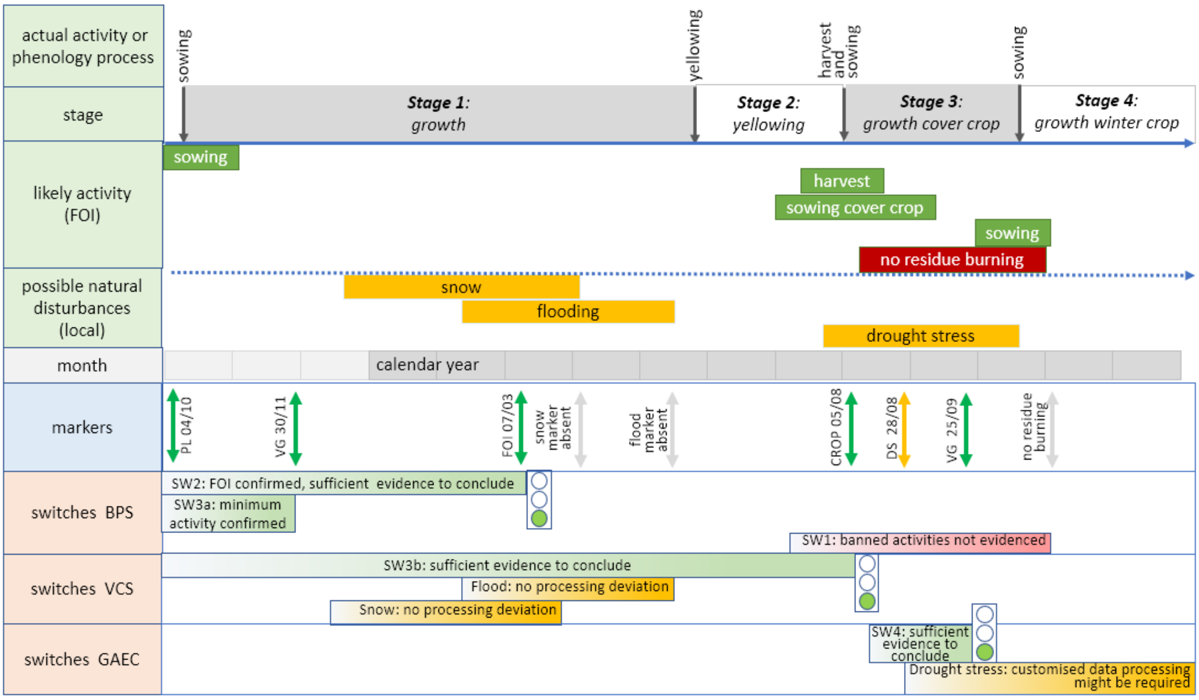
In the example of hay production on permanent grassland (Figure 12) the topping, although being a part of the scenario, was not monitored as it is not required and thus irrelevant from the user information need point of view. Since no local natural disturbances were detected (by the relevant marker algorithms), there was no need to deviate from regular processing plan (there were no delayed or missed phenological phases to deal with). The conclusion on FOI complying with the BPS rules was reached with outputs of switches SW2 and SW3a evidencing that the entire FOI was mowed. Detection of two more mowings provided sufficient evidence to conclude on respecting RD requirements.

Figure 12. Practice: hay land on permanent grassland; scenario (rows marked in green), markers (rows marked in blue) and switches (rows marked in pale rose); Markers: VD: vegetation drop, FOI: FOI validity marker.



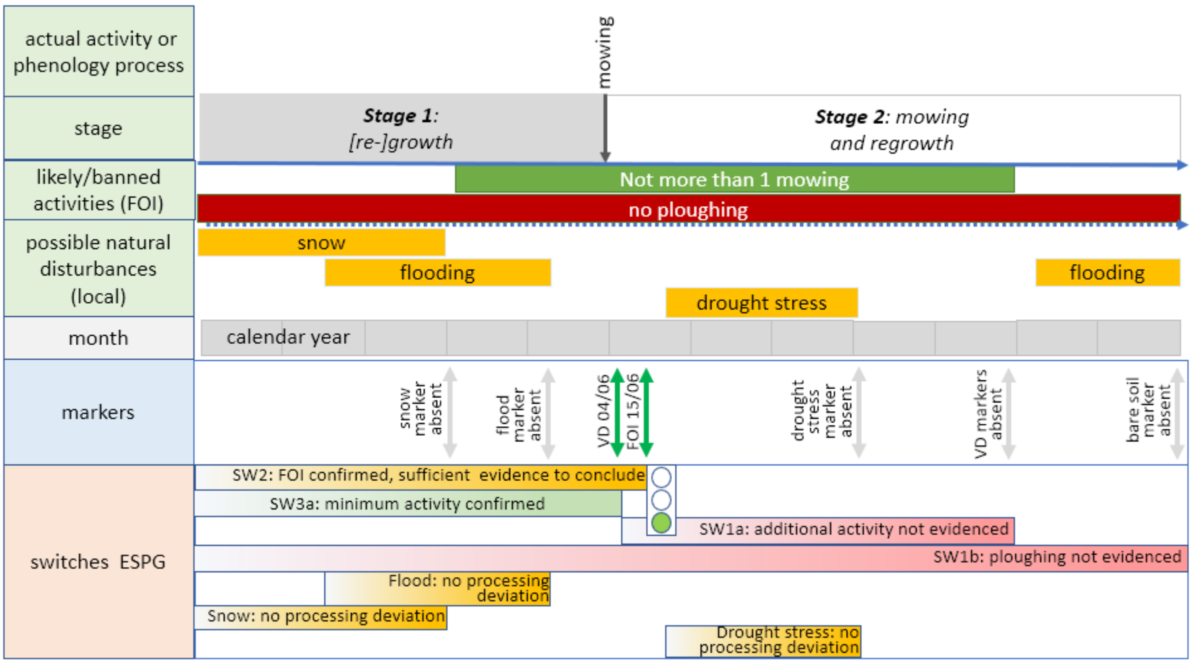
The scenario of durum wheat crop followed by a cover crop (Figure 13) consists of the following activities and observable stages: sowing followed by crop growth and yellowing, harvest and sowing of the cover crop (a cover crop can be also sown before the harvest of durum wheat), removal of the cover crop and sowing of the winter crop. Residue burning is forbidden at all time, but in practices occurs only between August and October, after harvest. Local natural disturbances are also taken into account (corresponding markers are searched for). Drought stress is detected (end of August) indicating possible need for customization/recalibration of processing (parameters). Despite this, a marker confirming vegetation growth of a cover crop was recorded and this enabled conclusion on respecting the GAEC rules.

Figure 13. Practice: durum wheat crop followed by a cover crop; scenario (rows marked in green), marker (rows marked in blue) and switches (rows marked in pale rose); Markers: PL: marker confirming ploughing, FOI: FOI validity marker, CROP: crop type marker, DS: drought stress, VG: vegetation growth.



An example of processing a scenario for environmentally sensitive permanent grasslands is shown in Figure 14. Ploughing is not permitted and exactly one mowing between April and October required, as subsequent mowings would degrade the biodiversity of the grassland. A vegetation drop marker confirmed mowing in early June (SW3a concluded on compliance with minimum activity). The same marker algorithm remains operational until the end of October and its output is monitored by SW1a, the switch representing the non-compliance rules on no additional mowings. A marker confirming ploughing is searched for throughout the year and monitored by SW1b.

Figure 14. Practice: environmentally sensitive permanent grasslands; scenario (rows marked in green), marker (rows marked in blue) and switches (rows marked in pale rose); VD: vegetation drop, FOI: FOI validity marker.



5 Analogy

With a scenario, a well-known term from the film industry, we dare to compare the six basic concepts with concepts from that industry.

- The scenario is, plainly, the scenario, i.e., an outlook of the unfolding story before the shooting starts.
- The switches are the script scenes used by the director to plan the shooting and design the set.
- The signal is the individual combination of camera/film/lens he uses for each scene.
- The FOI is the protagonist, present in all scenes of the movie, either alone or with other actors.
- The marker captures the action, emotion or gestures of the protagonist within each scene.
- The output of a completed lane corresponds to an edit/cut with the selected scenes shown to a selected crowd.

6 What else?

These conceptual elements are elaborated here as a theoretical framework, providing terminology needed to describe the different components and elements of a particular CbM design. That description is necessary to enable technical discussions and correct quality reporting for the CbM users. In fact, the local conditions and increased subsidiarity do not allow for a centrally designed, implementation-ready solution. But, while these concepts remain too abstract to offer a complete a best practice guidebook, their framework has been essential as a basis for JRC's technical elaborations that are or will be published in separate documents or on dedicated platforms:

- the 2021 Outreach project clarifies the aspects of scenario, manifestation stages, markers and signals;
- the 2020-2021 CbM QA development uses the switch as an entry point for inspecting, assessment and reporting method for system reliability (details can be found in: https://marswiki.jrc.ec.europa.eu/wikicap/index.php/CbMQA_TG_v1_2);
- the CbM-toolkit offers all open source components to set up the data processing aspects (in particular markers based on Copernicus S1/S2 derived signals);
- the Land Cover (LC) / Land Use (LU) documentation provides a framework to deal with the semantics of the international land cover and land use domains;
- the best practices to combine markers allowing for optimised switches control will be developed and documented;
- the JRC will collect and document the operational examples of CbM implementations.

This conceptual basis allows for each elaboration to be considered a separate but interacting element of a single 'best practices' catalogue.

7 References

Commission Implementing Regulation (EU) No 809/2014 of 17 July 2014 laying down rules for the application of Regulation (EU) No 1306/2013 of the European Parliament and of the Council with regard to the integrated administration and control system, rural development measures and cross compliance, 2014, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32014R0809

Council of the European Union document 12621/17, 2017. https://data.consilium.europa.eu/doc/document/ST-12621-2017-INIT/en/pdf

Devos W., Lemoine G., Milenov P., Fasbender D., Loudjani P., Wirnhardt C., Sima A., Griffiths P., *Second discussion document on the introduction of monitoring to substitute OTSC: rules for processing applications in 2018-2019*. EUR 29369 EN. Publications Office of the European Union, Ispra, 2018a, doi:10.2760/344612

Devos W., Lemoine G., Milenov P., Fasbender D.: *Technical Guidance on the decision to go for substitution of OTSC with checks by monitoring*. Document. DS/CDP/2018/17, EUR 29370 EN. Publications Office of the European Union, Ispra, 2018b, doi: 10.2760/693101

Devos W., Fasbender D., Lemoine G., Loudjani P., Milenov P., Wirnhardt C.: *Discussion document on the introduction of monitoring to substitute OTSC - Supporting non-paper* DS/CDP/2017/03 revising R2017/809, EUR 28830 EN, Publications Office of the European Union, Ispra, 2017, doi: 10.2760/258531

ECA Special Report 04/2020: Using new imaging technologies to monitor the Common Agricultural Policy: steady progress overall, but slower for climate and environment monitoring, 2020, doi:10.2865/46869

Milenov P., Vajsova B., Voican G., Acquafresca L., Anastasakis K. and Lemoine G, 2021. Assessing the Validity of the Feature of Interest in the context of the CAP Checks by Monitoring, Ispra, 2021, JRC123711 https://marswiki.jrc.ec.europa.eu/wikicap/images/7/75/JRC123711_foi_assessment_final22.pdf

Proakis, J.G., Manolakis, D. K.,: Digital Signal Processing, 4th Edition, Prentice-Hall, Inc., 2006, ISBN:978-0-13-187374-2

8 List of abbreviations

AP	Agricultural Parcel
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CbM	Checks by Monitoring
DIAS	Data and Information Access Services
EOS	End of Season
ESPG	Environmentally Sensitive Permanent Grassland
EU	European Union
FOI	Feature of Interest
GAEC	Good Agriculture and Environmental Conditions
GSAA	GeoSpatial Aid Application
LPIS	Land Parcel Identification System
OTSC	On The Spot Check
QA	Quality Assessment
RD	Rural Development
RP	Reference Parcel
RS	Remote Sensing
S1	Sentinel 1
S2	Sentinel 2
SAPS	Single Area Payment Scheme
UoD	Universe of Discourse
VCS	Voluntary Coupled Support

9 List of figures

10 List of tables

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub