Remote Sensing applications for Mediterranean Wetlands monitoring

ETC-SIA contribution to the RhoMeo program

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General Introduction

Chapter 1: Introduction

1.1. The RhoMeo program

1.1.1. Presentation and aims

The Water Framework Directive[1] is a European Union directive which commits its member states to achieve good qualitative and quantitative status of all water bodies in 2015. The evaluation of this condition involves knowing the evolution of the status of wetlands as an important part of water bodies especially in terms of biodiversity conservation.

In the share of the Mediterranean Rhone watershed and Corsica in France, the wetland inventories have been performed already, and the evaluation of the status of their habitats is being implemented.

The RhoMeo program, led by the Rhone Basin Water Authority, joins the efforts of managers and researchers to develop methodologies for the construction of an observatory to monitor the changing conditions of wetlands in the Mediterranean basin of the Rhône River. Originally developed in the Rhone-Alpes, this program is implemented throughout the basin with the ultimate goal of developing, in close collaboration with actors in other regions, consistent working methodologies tools for the treatment of compatible information.

Work in the Rhône-Alpes is organized around five themes:

1. Methodological work to identify indicators of the biological conditions of wetlands.
2. Test these methods in test sites (wetlands) scattered throughout the territory.
3. The development and testing of methods for the analysis of wetlands by the interpretation of satellite images within the entire territory.
4. The development of tools for information management and analysis of data.

The outcomes of this work and the return of experiences will contribute to a proposal for a permanent observatory of the wetlands in the broad Rhone-Mediterranean basin.

1.1.2. Remote sensing application within RhOMeo

The Ramsar convention defines the “wise use” concept of wetlands as the outcome of correct and efficient wetland management stressing the conservation of wetlands and the sustainable use of their resources. In order to achieve this concept, the convention recognizes the need to fill gaps in baseline inventory and stresses the need of developing techniques that can fill these gaps by using new technologies namely remote sensing (SRS) and GIS applications (Finlayson et al., 1999; Davidson and Finlayson, 2007).

In the context of freshwater management, resource mapping and inventories provide an indication on the location, biological productivity, potential multiple uses, and biodiversity profiles of wetland ecosystems (Taylor et al., 1995). Traditional methods for mapping and inventorying resources, mainly through fieldwork, are expensive and time-consuming (Rebelo et al., 2009). Furthermore, wetland inventories, especially at regional and national scales,

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:NOT

suffer spatial incompleteness, scalar inconsistencies and temporal uncertainties (Finlayson et al., 1999; Lehner and Doll, 2004).

With regular passages of remote sensing vehicles (aircrafts and/or satellites) over a locality, land information in the form of multi-temporal, multi-spectral space-borne digital imageries can be obtained within a constant period of time. Over large spatial and temporal scales, these techniques are considered to be powerful and cost effective tools of mapping and monitoring wetland systems improving knowledge on wetlands types and conditions (Davidson et al. 2007, Ramsey 1998). Additionally, they are essential tools for standardized wetland monitoring mechanisms, and for managing extensive wetlands in the context of the Ramsar Convention (MacKay et al. 2009).

On one hand, potential and systematic use of spatial information and satellite imagery proved to assess efficiently natural and anthropogenic wetlands (Xie et al., 2010). On the other hand, temporal imagery proved to be effective in analyzing wetland dynamics in space and time (Toyra et al. 2005), making satellite imagery and SRS techniques valid tools to be used by extensive managers and scientific researchers for monitoring and analyzing changes in wetlands.

Relevant spatial studies on wetlands started back in the 1970’s; through aerial photography. Bendjoudi et al. 2002 studied riparian wetlands in France using thermographic aerial survey and electromagnetic prospecting. At a later stage, SRS techniques to create wetland maps using color infrared aerial photography at different scales started to gain importance as a complimentary tool to field studies, and soil information to produce new knowledge through the integration of existing information (Ernst and Hoffer, 1981).

Afterwards, geospatial technology and GIS techniques opened new vistas for wetland inventory at multiple scales. The application of remotely-sensed data for wetland mapping, classification and characterization gained momentum in the past two decades (Ozesmi and Bauer, 2002). Support tools of geospatial analysis, namely Global Positioning Systems (GPS), meta-database and developing query tools and internet GIS, added further dimension to the overall approach of wetland inventory and management. Further development of optical and microwave sensing systems and algorithm modeling brought measurable advancements in the understanding of wetlands.

Though SRS techniques are very useful, they have some limitations as well. For some purposes, such as mapping and inventorying, SRS can serve as a foundation or core technology, but in others, such as monitoring, hydrological modeling or generation of historical time series information, its use is limited to a support technology to complement ground-based programs (MacKay et al., 2009). Furthermore, the results offered by different SRS techniques, despite being very accurate, are only an approximation of reality, and need to be supported and validated by ground-truth (Ozesmi and Bauer, 2002). And therefore, they are a very efficient complementary tool in the context of wetlands management, monitoring and environmental policy-making.

1.2. TdV/ETC-SIA contribution to the RhoMeo program

As agreed with Tour du Valat (TdV), the goal of the work of the European Topic Centre on Spatial Information and Analysis (ETC-SIA) is to assess the relevance of using new generation high-resolution (HR) satellite images as tools and to develop methods that can support detecting changes in wetlands at basin scale.

The contribution of ETC-SIA to RhoMeo is to improve the results that can currently be obtained through Corine Land Cover (CLC). Improvements are expected along 2 lines:

- ✓ higher resolution than the current 25 ha (5 ha for changes) that CLC permits;
- ✓ separating wet meadows (that are wetlands) from dry meadows (that are not), both being currently merged in CLC as “2.3.1 Meadows”. This is currently the main limitation to using CLC for assessing the area of wetlands in general.

1.3. Objetives: Creation of Indicators

ETC-SIA developed 3 indicators based on remote sensing (SRS) and GIS to be used for wetland monitoring in the PACA region. Each indicator covers a particular aspect of these natural areas since the complexity of their operation requires different tools to assess their state at a given moment.

The target and use of each indicator developed by ETC-SIA is presented in more detail below:

1. **Indicator 1:** the target of Indicator 1 is to identify the total surface of wetlands at a given date. In Corine Land Cover terms, it includes all classes under: “4. Wetlands”, “5. Water bodies” (except “523. Sea and oceans”), “213. Rice fields” and the wet part of “231. Meadows”.

2. **Indicator 2:** the aim of developing Indicator 2 is to detect through the use of Earth Observation techniques land use changes in time. Specifically, the use of indicator 2 is to detect the changes between specific land uses to others, namely the **conversion of natural and semi-natural wetlands** surface, between two dates, into either **agriculture** or **urban areas**. In this context, wetlands are understood as the surface detected during the analysis of the Indicator 1.

3. **Indicator 3:** the objective of Indicator 3 is to detect, through Earth Observation techniques, the degree of flooding of wetlands over a year cycle. In this context, wetlands are defined as the surfaces included in the wetland inventories available for the Provenza-Alpes-Costa Azul (PACA) region and the Land-Use/Land-Cover layers of the Camargue Natural Regional Park (PNRC).

1.4. Structure of the report

This document is divided into a total of six parts organized as follows:

- **Part I** – General Introduction

This part focuses on describing the context and the objectives of the work of ETC-SIA, as well as to define the wetland indicators and the dates and locations studied.

- **Part II** – General Methodology

Part II contains a methodological description of the process developed for the analysis of the indicators, including the data used in each case. There is a chapter for each indicator.

- **Part III** – General Results

This part presents the results of the different analyses performed for all three indicators. There is a chapter devoted to each one.

- **Part IV** – General Discussion

Part IV deals with the findings and interpretations from the results obtained for the study of the indicators. There is a chapter on each indicator.

- **Part V** – Final Conclusions

Part V makes a final review of all the work done, dealing with the most relevant ideas and aspects arising from the study of the three wetland indicators, as well as a summary of their strengths and limitations. There is also a chapter on recommendations for improvements and future analyses.

- **Part VI** – References

List of references consulted throughout the study.

- **Annexes**

Finally different annexes are included containing more detailed information and images related to some of the analyses performed in the chapters of the report.

Parts are organized into chapters and sections which treat in more detail the most relevant information related to the analyses performed by ETC-SIA throughout its contribution.

Chapter 2: Study Area

2.1. The PACA region

The spatial framework for these tasks is the region Provence-Alpes-Côte d'Azur (PACA region), in southeastern France, including its six departments (figure 1): Dep. 04 (*Alpes-de-Haute-Provence)*, 05 (*Hautes-Alpes*), 06 (*Alpes-Maritimes*), 13 (*Bouches-du-Rhône*), 83 (*Var*) and 84 (*Vaucluse*). The Camargue Natural Regional Park (PNRC), which was designated a Ramsar site as a "Wetland of International Importance", is included in the area of Department 13.

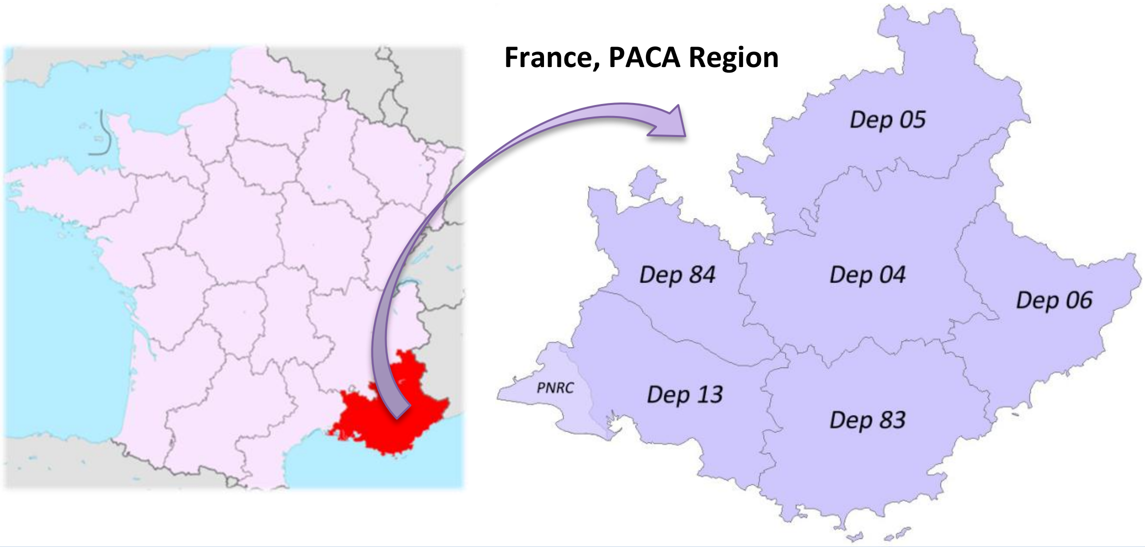
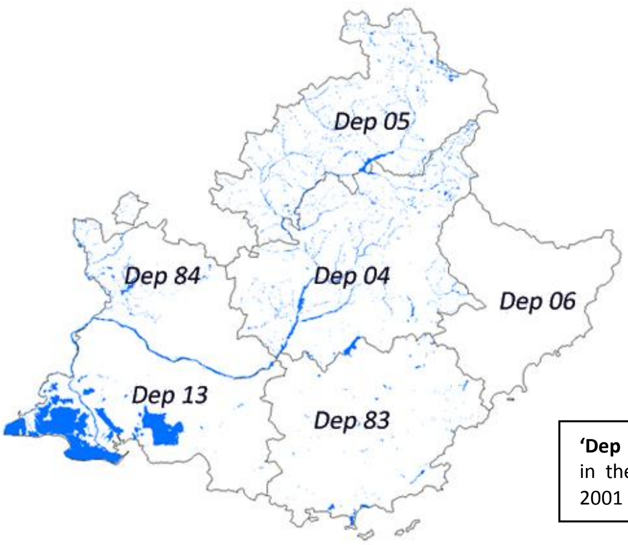


Figure 1. Map of the PACA region: situation and departments.

The PACA region has a total surface of 3,140,000 ha, of which around 140,000 ha are inventoried as wetlands. The PNRC covers 82,000 ha of which 52,000 ha are wetlands. The wetlands within the PNRC are considered one of the most protected in Europe with at least 10 protection statuses applying.



Wetlands information

Department	*Inventoried area*
Dep 05	16,943 ha
Dep 04	20,745 ha
Dep 84	8,247 ha
Dep 13	89,234 ha
Dep 13 + PNRC	104,717 ha
Dep 83	6,166 ha
Dep 06	*Not inventoried*
Total PACA	140,918 ha

'Dep 13 + PNRC' refer to replacing the wetlands inventoried in the PNRC (under-estimated) by those derived from its 2001 Land Use map (data for rest of department unchanged).

Figure 2. Map of the PACA region departments and their relative wetland surfaces (blue colour).

Figure 2 shows the wetland inventories of the PACA region and their surface in ha. being the total 140,918 ha. Around 64% of this surface is located in the south part of the region (Dep. 13), where wetlands are fairly large and highly concentrated with a mean surface of 10 ha. However the size of wetlands and water bodies is highly variable in this part of the region being the minimum size of tenths of ha (around 0.05) and the maximum of 12,500 ha according to the inventories. The diversity of wetlands is also quite remarkable, especially in the PNRC area where there is a mixture of natural and semi-natural wetlands (marshes, ponds, salines, rushes, reeds, salt meadows, rice fields,…).
Due to their topography, being mountainous, the wetlands of the departments of the northern side of the study area are composed mostly of rivers, streams and lakes or dams, accounting for a big percentage of the wetland surface in departments 04 and 05 (about 27% of total).

The PACA region presents topographical and climatic complications affecting the availability of satellite images free of cloud, snow and excessive shadows, especially because of the alpine influence in the North.

Another aspect is the distribution and visual appearance of wetlands throughout the region. While in the southern areas the wetlands are large and well defined (departments 13 and 83), the alpine areas show a very homogeneous appearance, with wetlands mostly poorly defined or with small size and linear features, that hinders their detection (figure 3).

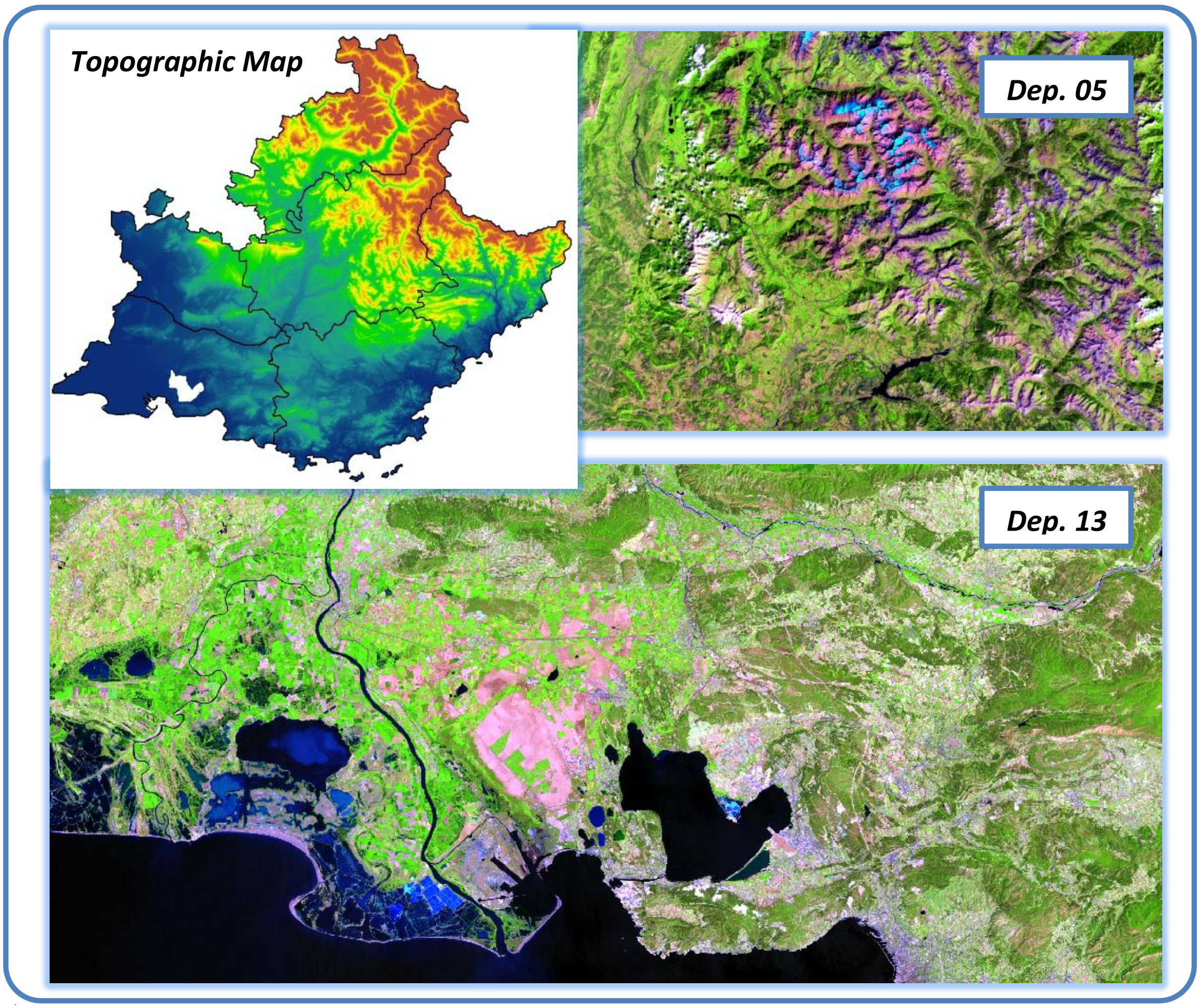


Figure 3. Topographic map of the PACA region showing the complex nature of its northern side, and samples of satellite images in false color of Dep. 13 (littoral) and 05 (mountainous).

2.2. Analysis of Indicators: study area and dates

The calculation of each indicator is performed for the six departments of the PACA region including the area of the PNRC. However, during the implementation of this research, and based on discussions with TdV, some further research has been performed in specific departments leading to detailed analyses focused in certain dates and areas within the PACA region according to different criteria (time constraints, data availability, etc.).
The three indicators are calculated for several dates as well as their changes over time in different periods (according to the indicator). The study includes analyses between 1970 and 2012 focusing more on the period 2001-2012 due to increased availability of information.

2.2.1. Study of Indicator 1

ETC-SIA applied Indicator 1 to the entire PACA region for the year 2001. Based on the results of ETC-SIA for the year 2001, further application of this indicator was done for the years 1975 and 1984 for the whole region. However, due to time restrictions, ETC-SIA focused on doing a detailed analysis of Dep. 13 and the PNRC as:

- ✓ Dep. 13 is the most representative in terms of quantity and diversity of wetlands.
- ✓ There was no availability of an inventory or ground truth layer for the other departments in these dates to make appropriate comparisons between the study period (1975 – 1984 – 2001).
- ✓ The quality of the images available for the 70s and 80s is low, especially for the 70s having a 60 m resolution (compared with 30 m resolution for years 2001 and 1984).

2.2.2. Study of Indicator 2

ETC-SIA applied Indicator 2 to the entire PACA region. As agreed with TdV and following a similar approach as for Indicator 1, the years chosen for the analysis are 1984 and 2001. Tests of Indicator 2 were carried out between these dates using the information already available for the study area: 1) the Indicator 1 layer, 2) the PACA wetlands inventory and 3) the LULC layer of the PNRC.

ETC-SIA's efforts at this stage focused on providing a detailed analysis for the entire region. However, due to lack in data (no ground reference for PACA), the results analysis covered in more detail the PNRC as it is the only area that has a reference layer of land uses that is used to support the validation of ETC-SIA´s results.

2.2.3. Study of Indicator 3

As agreed with TdV, the approach for this analysis was based on the availability of valid satellite imagery for the study period, being comprised between the years 2000 and 2012. The departments fulfilling these criteria for the analysis of Indicator 3 were departments 13 and 83 as they have enough quality images to represent the seasonality of some hydrological cycles, particularly 2001, 2007 and 2012. These years were selected as 1) they had "valid images", 2) their dates are comparable to the reference dates of the LULC layers of the PNRC (2001, 2006, 2011), and the time period between the selected years is valid to detect significant changes in flooding over time.

ETC-SIA also analyzed one of the Alpine departments within PACA region, particularly department 04. In this case, Indicator 3 analysis was carried out only for the year 2001 since the test results obtained were not very satisfactory as the quality of the images was low (many clouds) and the classification process included many errors (due to shading).

- Part II -

General Methodology

Chapter 3: Datasets and spatial information

This chapter is devoted to explain the datasets and spatial information that was used by ETC-SIA throughout the development of the indicators within RhoMeo and the further analysis performed. In general terms, datasets have different nature and have been classified in three categories:

- **Satellite imagery:** Imagery used for all the remote sensing processes: land use analysis, classifications, etc. ETC-SIA chooses Landsat series due to its wide uses and image availably, and its reasonable spatial (30 m) and spectral resolution (7 spectral bands) of the latest satellites (Landsat 5 TM and 7 ETM+).
- **Ground reference data:** field information for ground truthing and other analysis consisting by land use layers and wetland inventories, in addition to other complementary information such as Corine Land Cover.
- **Ancillary data:** useful information for complementary analysis, being mainly a numerical model of the territory with a resolution of 50 m.

Annex 1 provides a detailed overview of the type and specification of the datasets used such as the technical details, dates, sources and references, etc.

3.1. Satellite Imagery – Landsat Series imagery

The Earth Observation system chosen by ETC-SIA for the remote sensing tasks is the Landsat satellite series (NASA, USGS). The Landsat series represents the longest temporal record of space-based earth observations (Ju & Roy 2008, Williams et al., 2006) and their historical data archives are freely available for scientific purposes. The current Landsat systems, carrying the Landsat Thematic Mapper (TM) (Landsat 5), operational from 1984, and the Enhanced Thematic Mapper Plus (ETM+) (Landsat 7), from 1999, capture high spatial resolution scenes over a 183 km×170 km extent with a 16- day revisit capability to provide a balance between requirements for localized high spatial resolution studies and large area monitoring (Goward et al., 2001). The TM and ETM+ sensors are particularly appropriate for providing the imagery used for temporal assessment and monitoring natural resources and ecological characterization over time (Wulder et al., 2008).

During the last decades, the Landsat series with Multispectral Scanner (MSS) were successfully used for assessing relatively large wetlands (Klemas et al, 1975, Work and Gilmer, 1976, Gilmer et al, 1980, Jensen et al, 1986). Basic constraints of using Landsat-MSS data (60 m resolution) for wetland mapping inventory in early studies are the geometric inaccuracy and the coarse spatial, spectral, and radiometric resolutions of data (Carter, 1982). At a later stage, the availability of the 30 meters spatial resolution Landsat-TM data solved this constraint to some extent (Wakelyn, 1990; Al-Khudhairy et al., 2002).

3.1.1. Spectral bands

Landsat imagery, as well as other EO systems can be operated with different spectral bands to highlight certain aspects of the territory or enhance the contrast of some elements to facilitate their differentiation. In the case of water, Landsat TM and ETM+ band 5 can detect the greatest amount of their surface, so it is useful for most of wetlands (Frazier and Page, 2000).

The combination of different bands using ratios and RGB compositions (Red, Green, Blue) can highlight elements of the surface. Namely, ratio 4/5 and 5/4 distinguish water and vegetation, or combination 5, 4, 3 that is one of the most used compositions used in classifying wetlands (Maedel et al., 1996). This combination is represented in figure 4, and the colors represented shown the following:

- **Blue and black regions** are water or wet areas including associated vegetation.
- **Green areas** are vegetation. Croplands are light green while the natural vegetation is shown in darker. Wetlands are easily distinguished due to the dark color caused by the presence of water.
- **Orange tonalities** are related to bare and dry soils with low vegetation or fallow lands.
- **Purple** is associated with urban areas and geological outcrops or deposits (as seen in the coastal sands). Darker tones are related to regions with high moisture.

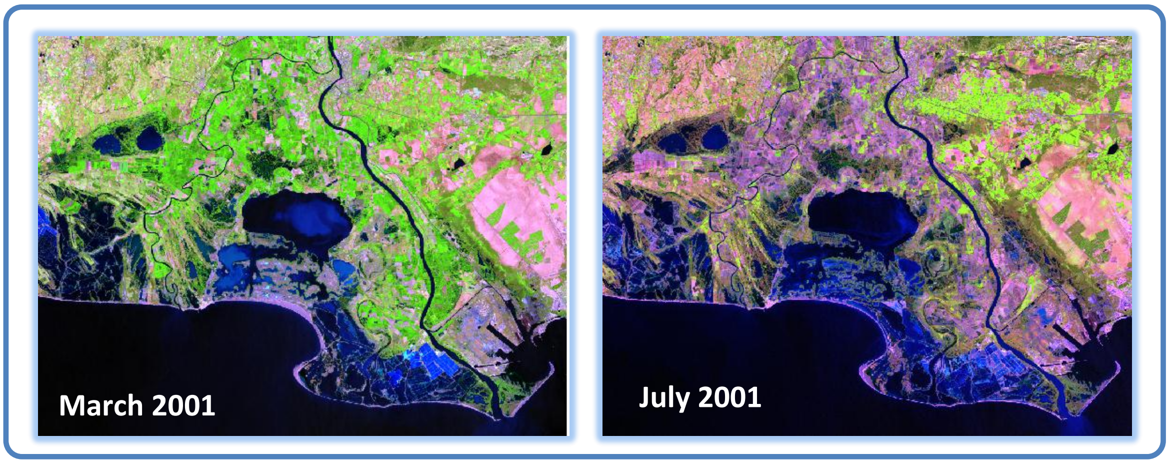


Figure 4. Landsat 7 ETM+ images of the PNRC for year 2001 (July and October). The band combination used is 5-4-3.

3.1.2. Tasseled Cap transformation

Landsat imagery also allows the use of its spectral bands for the calculation of indices or other indirect information. For example, the Normalized Difference Vegetation Index (NDVI), widely used for analyzing vegetation cover properties such as quantity, quality and development, or the Normalized Difference Moisture Index (NDMI), used for water studies. In the case of RhoMeo, ETC-SIA applied the Tasseled Cap (TC) transformation to the satellite imagery which results are similar to the indicated indices.

TC transformation was inspired by the method of principal component analysis combined with a generalization from empirical observations (the actual details had a more analytical basis). Basically, the TC transforms the Landsat bands in six principal components: the first three represent important information of the image while the others provide residual information. Although the calculation process is complex, this technique can be applied automatically by most GIS software.

The TC present three main variables, ranging from 1 to -1 (high values correspond to 1, and low values to -1):

- <u>**Brightness:**</u> associated with reflectance changes of the surface.
- <u>**Greenness:**</u> correlated with the vegetation vigor. Vegetated areas are greater than zero.
- <u>**Wetness:**</u> related to vegetation and soil moisture. Wet areas are greater than zero.

The information provided by Greenness and Wetness is similar to the outcomes of NDVI and NDMI. The advantage is that they are not affected by the noise of the Landsat image (figure 5), and they reduce the effects of an imprecise atmospheric correction.

Note: *The TC variables derived from the Landsat MSS imagery are not the same as the Landsat TM and ETM+. Only Brightness and Greenness are identical. Wetness cannot be calculated for the MSS imagery due to its lower spectral resolution. So this variable could not be used when analyzing images of the 1970s.*

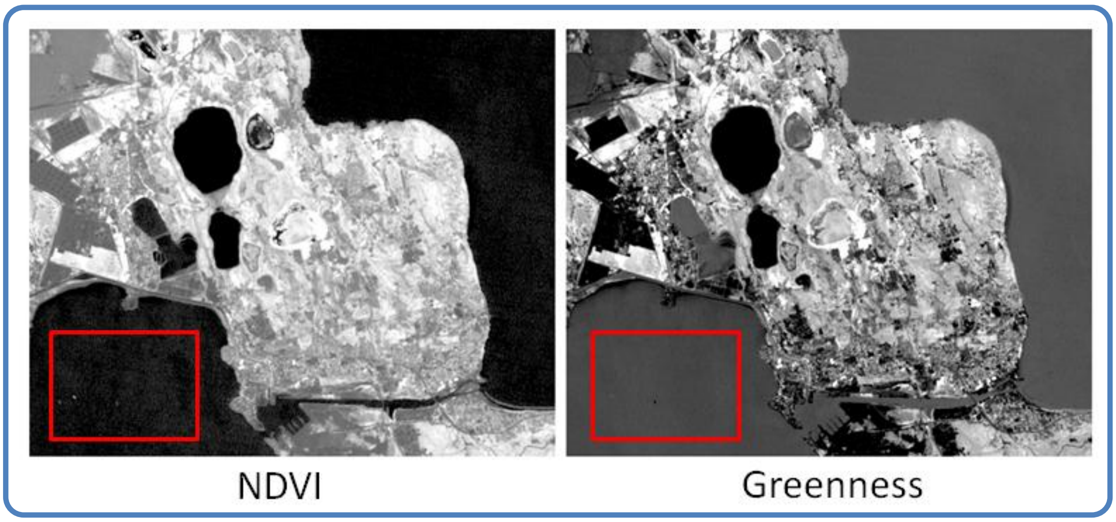


Figure 5. Comparison between NDVI and Greenness of a Landsat 7 ETM+ image of July, 2001. The noise effect of the NDVI can be appreciated inside the highlighted area in red color.

3.1.3. Landsat 7 EMT+ SCL-off imagery

Negative aspect of using recent Landsat imagery in the failure of the SLC system of the ETM+ sensor (used for motion compensation), meaning that there are gaps of data in all the images taken by the satellite from May 31, 2003. Since then, several methodologies have been developed to fill these gaps by pixel interpolation or image combination allowing their use in scientific studies (figure 6). Until now, some of these methods provide good results (Scaramuzza et al., 2004), and there are already applications and plug-ins for different software that streamline the work process when it comes to the gap filling process (Vega, 2012).

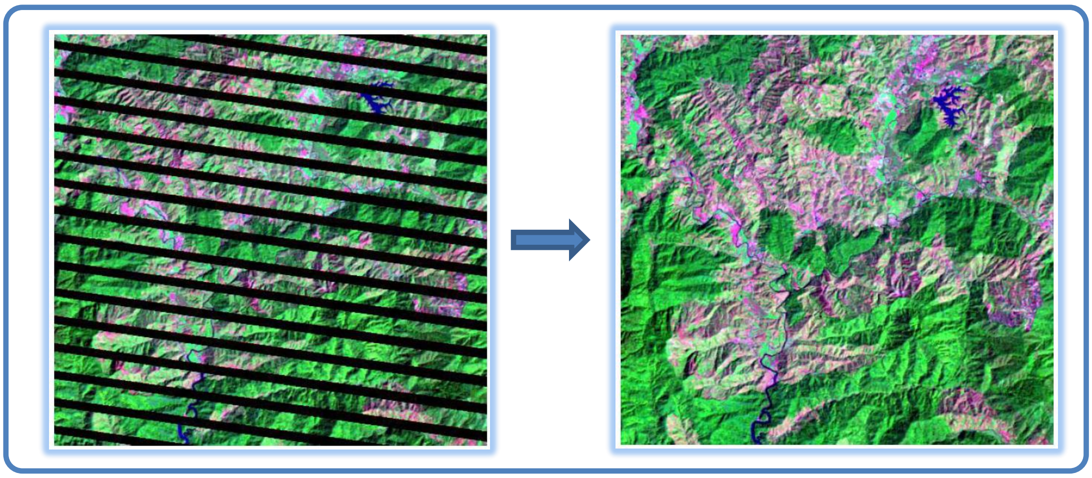


Figure 6. Example of the SCL-off effect in a Landsat 7 ETM+ image. Gaps were filled using a gap-filling technique. Image source: *The Yale Center for Earth Observation.*

3.1.4. Topographic and environmental effects

Highlands in the northern departments of the PACA region introduce a number of difficulties affecting the SRS capacity of image analysis (wetland detection in the context of RhoMeo). Mountainous regions with complex topographic characteristics in addition to the presence of snow and rocks, together with the shadows, complicate the remote sensing analysis as they produce multiple errors and inaccuracy problems (figure 7). These areas require a specific treatment in order to avoid the effects of topographic and environmental elements.

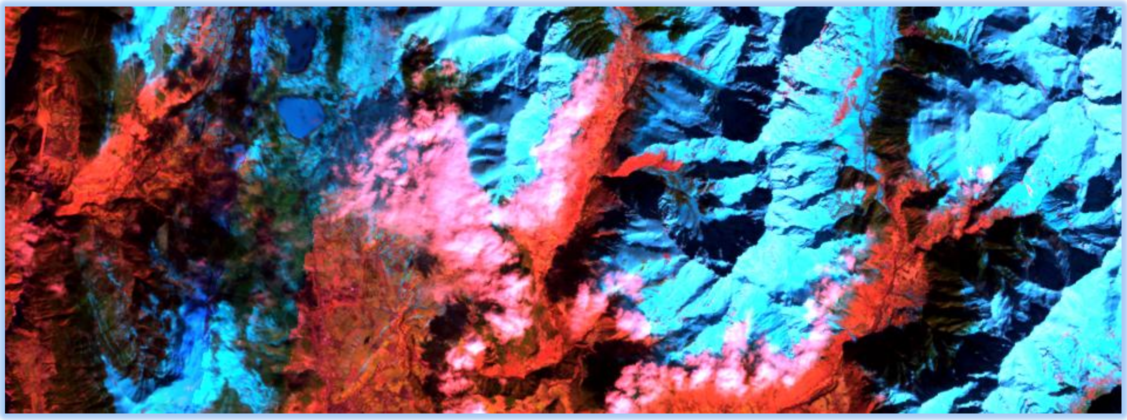


Figure 7. Snapshot of the effects of highland in Dep. 05. It is possible to appreciate the shadows (black), often confused with water in the classifications, the snow (light blue) and the clouds (light red and pink). The image corresponds to a composition with bands 5, 4 and 3 of Landsat 7 ETM+ in March, 2001.

3.2. Ground reference data

Remote sensing mapping tasks need the support of reference information related to the ground surface in order to contrast the results derived from the analysis of the satellite imagery. These are the greatest value datasets in validating the delineation and classification of the different areas of the territory since they are the most accurate reflection of the reality available. However, they are not completely perfect, so errors and discrepancies can be found.

3.2.1. Land cover/Land use layers and wetlands inventories

In the context of the RhoMeO program, field information was provided by TdV as GIS files concerning the PNRC and the departments of the PACA region:

- **Land use/land cover (LULC) layer of the PNRC:** it contains accurate and detailed information about the land use classes in the PNRC (types of agriculture and water bodies, forests, urban areas, etc.). These data are available for years 2001, 2006 and 2011.
- **Water inventories of the PACA region:** this set of GIS layers displays the information regarding the water bodies and wetlands registered (inventoried) in the different departments of the PACA region. Currently there are only 5 inventories available (Dep. 06 is missing) and two of them are not fully complete (Dep. 05 and 84).

Note that the field realities used are acknowledged as imperfect, especially at department level, and therefore there are discrepancies (not errors) between these layers and what is seen in the satellite images or detected by the analysis performed.

3.2.2. Corine Land Cover

Due to the lack of an accurate LULC layer that covers the whole PACA region, ETC-SIA used the information provided by Corine Land Cover (CLC) whenever a deeper analysis of land uses was required when studying areas outside the PNRC. In addition, it is used for dates prior to the LULC layers and the water inventories (before 2001).
CLC data was modified to extract only the classes under Agricultural and Urban areas, Wetlands and Water Bodies (without Sea and ocean), since that is the only information related to ETC-SIA's analysis.

Though data from CLC are not very accurate at the level of detail of an analysis, it has a consolidated and comparable methodology between the different versions that works pretty well.

3.3. Ancillary data

- Numerical Model of the Territory:

In order to reduce the negative effects of the mountain areas in the PACA region (shadows, clouds and snow), ETC-SIA uses the numerical model of the territory (MNT) from the National Geographic Institute of France (data provided by TdV). This model has a resolution of 50 m and allows the calculation of multiple topographic variables such as the slope aspect and flux accumulation areas (further details in the different indicators chapters).

Chapter 4: Methodology of Indicator 1

4.1. Sources of data

- Landsat imagery (see table 1).
- Tasseled Cap (TC) transformation derived from Landsat imagery.
- 50m Numerical Model of the Territory (MNT) of the PACA region.

Period	Satellite	Number of Bands	Bands used	Resolution	Image Date
1970s	Landsat 2 MSS	4 Bands	1 to 4	60 m	Jul 1975 Oct 1975
1980s	Landsat 5 TM	7 Bands	1 to 5, and 7	30 m	Jul - Aug 1984 Sep - Oct 1984 Nov - Dec 1984 Mar 1985
2000s	Landsat 7 ETM+	7 Bands + 1 Panchromatic	1 to 5, and 7	30 m	Feb - Mar 2001 Apr - May 2001 Jul - Aug 2001 Oct 2001

Table 1. Satellite imagery used (dates and properties).

4.2. Calculation of Indicator 1

The target of Indicator 1 is to identify the total surface of wetlands at a given date. It includes the differentiation and calculation of areas of different types of land uses based on the CLC classes considered: "4. Wetlands", "5. Water bodies" (except "523. Sea and oceans"), "213. Rice fields" and the wet part of "231. Meadows". The detection of some types is relatively straight forward, while for other land uses their detection can be hindered due to several reasons (their nature, size, resolution of images…).

ETC/SIA followed a process of spatial division in order to simplify the process and to reduce the margin of errors during the process. The working area was divided into three main categories that have a good representation of all components included for the indicator, being: water bodies, land and vegetation associated to them, and rice fields. In order to identify the most relevant method to use for each land cover, different remote sensing techniques and tools were tested for them around the PACA region, and the results were contrasted.
During this analysis, it was observed that while some of the three classes were well represented (water bodies in most cases), the detection of others was less accurate including some classification errors. Based on these results, we decided to use a separate classification technique for each land cover in order to optimize our results reducing though this methodology the error margins.

In addition, the topography of the region showed to affect the SRS capacity of wetland detection. The complex topography of the alpine departments (Dep. 04, 05 and 84), together with the shadows, snow and rocky areas limited the classification process.
In order to improve these results, we used the digital terrain model (MNT) of the region that was facilitated by TdV. Based on this MNT, we calculated the following parameters: slope, flux direction and flux accumulation.

- **Flux direction:** simulates the direction of a water flow in function of the values of the pixels of a digital terrain model.

- **Flux accumulation:** calculates the points of conversions of the water of these streams (where they accumulate).

The classification results (wetland surface detected) are validated using the available wetlands reference (inventories and LULC layer) by calculating two possible types of errors:

- **Error A:** percentage of land that is wrongly considered as wetland, understood as the surface detected by the satellite that is outside the reference layers (not wetland).

- **Error B:** percentage of real wetlands that are not detected by the analysis of the satellite image. In other words, this would be the surface of the references that is not classified as wetland.

It should be noted that these error rates are not always precise, as the references currently available are not an exact division of the study areas. There may be true wetlands that are not inventoried or some of the areas included as wetland could be wrongly inventoried presenting some discrepancies in our 'reference layer'. Therefore, the so-called 'errors' should be viewed only as discrepancies between the methods to build these layers and the classifications performed.

The steps followed by ETC-SIA to develop and calculate the Indicator 1 are defined in the coming paragraphs. In summary, the methodology developed is a collection of classification techniques that focuses on maximizing the detection accuracy of the components of this indicator (figure 14), and does not represent the remaining thematic aspects of the territory:

1. <u>MNT: Slope mask</u>

Based on the MNT data we created the slopes layer (in percentage). The slope is defined as the amount of inclination of a surface to the horizontal. A larger number indicates higher or steeper degree of tilt.
For the study, we considered low to medium slopes only by extracting the slopes lower or equal to 15% from the slope layer created. This was decided by assuming that wetlands are mainly present in areas presenting low slopes (Rodhe and Seiber, 1999). This step within the process helps reducing errors in mountainous regions within the PACA. The information obtained in this step is transformed into a binary mask that is used for the classification process as areas outside the mask are omitted.

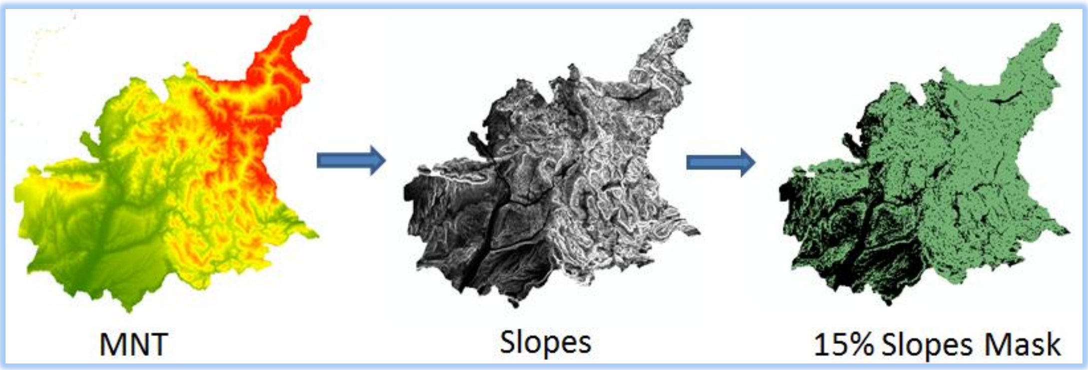


Figure 8. Slope mask calculation process for Department 4. Slopes lower than 15% are in black color.

2. Water bodies – Decision Tree

The variables used as parameters in the decision tree from the TC transformation are the Greenness (G) and Wetness (W) (figure 9). These parameters help us to distinguish between "water" ($G < 0$; $W > 0$) and "no water" areas ($G > 0$; $W < 0$). The slope mask reduces the confusions with shadows and snow reducing by this the range of error.
Water bodies identified in this step are transferred into a second layer that is used as an intermediate 'water bodies' mask.

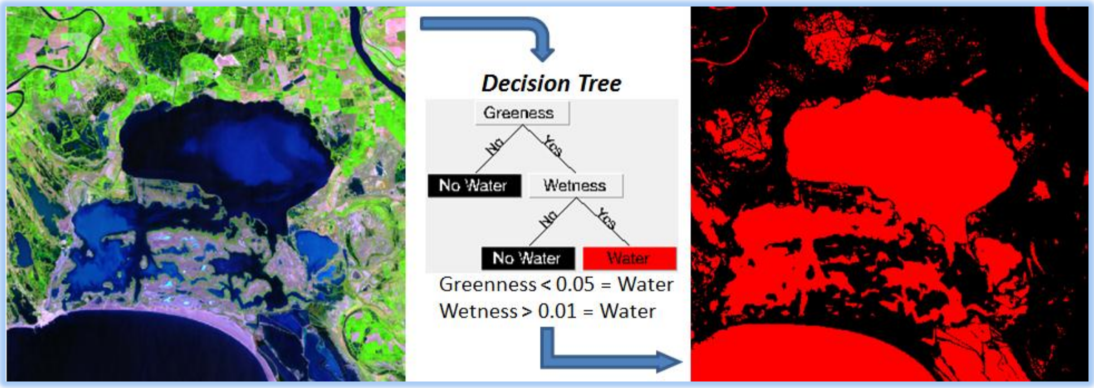


Figure 9. Decision tree classification process for a Landasat 7 ETM+ image of the PNRC from July, 2001. Red surfaces correspond to water bodies. This surface is used as an intermediate 'water bodies' mask in the process.

3. MNT: water courses

We used the MNT to calculate the parameters of flow direction and flow accumulation lines. The accumulation parameter provides a cumulative count of the number of pixels that naturally drain into an outlet (pixel). So this data can be used to find the drainage pattern of a terrain. Once compared with the satellite images, this parameter proves to be a valid tool in identifying narrow linear features (channels and streams) that are not always detected by satellite images.

Flow accumulation lines are reclassified to reduce the amount of information as there are a substantial number of small streams and rivers that may be omitted due to their low contribution in order to reduce error rates. An appropriate threshold was set for each department, based on visual comparisons with inventories and satellite images. In general, only the values higher than 200 - 700 mm/year are extracted and masked with slopes. In this way, the information only relates to certain flow magnitude in areas that allow the development of wetlands. The results are included in the final water bodies layer.

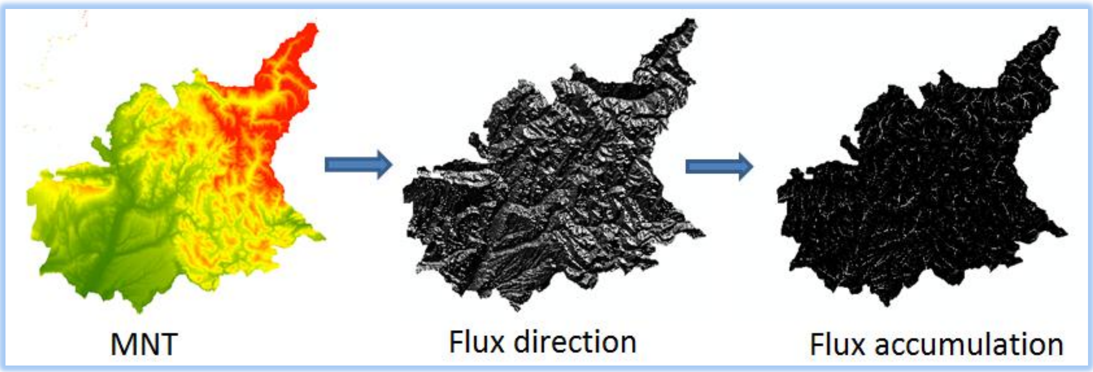


Figure 10. Calculation process of flux accumulation lines for Department 4.

4. Land and vegetation – Supervised classification (Maximun Likelihood)

The Supervised classification process helps to distinguish soils and vegetation related to water bodies or wetlands (i.e. floodplain deposits or riparian forest). We used the maximum likelihood parameter. The classes are set during the training process to allow a clear distinction of Indicator 1 components according to the properties of the image. Basically, we want to separate these elements from others that look like them and could cause confusions in the classification.

As land coverage diversity is not very high, 5 to 7 land use classes have been defined. Classes can be one of the following: soils and materials associated with water bodies, wetland vegetation, croplands, fallows/bare soils, natural vegetation (not considered wetlands), rocky areas, snow or urban areas. For example, fluvial deposits require training areas of soil/bare rock and urban areas to avoid errors. Confusions between vegetation types are also frequent, especially in the natural vegetation, so the training areas process requires special attention. Based on the identified classes, multiple thresholds are required to disinguish all coverages correctly.

The 2 masks generated for slope and water bodies are used in the classification of the satellite images. The first mask is used to reduce confusion with the mountains, as this process covers a larger number of classes and is quite sensitive to the effects of the hillsides (i.e. shadows, bare rocks). The second one is used to reduce the classification area and to simplify the process.

Through this process we extract different wetland classes such as riparian forest, floodplains and river beds. All these classes are joined together in a new layer and a new mask: 'Wet vegetation' or 'Other wetlands' mask.

Figure 11. Supervised classification process for a Landsat 7 ETM+ image of the Dep.05 (August, 2001). It is possible to appreciate confusions between some classes. For example, the riverbed (red) and bare rocks (pink). The software also overestimates riparian forest class (green) or does not detect all the crops in the image (blue).

5. Rice fields – Image change

An image change analysis is performed (masked with the above information). Greenness values are compared between summer and autumn/winter dates. According to rice crops annual cycle, rice plants have their maximum height (growth) between July and August, while the harvest begins in late September. Therefore, the highest differences in this variable are observed during summer and early autumn.

A change threshold is applied to remove other types of vegetation. Sometimes it is necessary to use the wetland classes mask to avoid undesired confusions. The resulting layer represents the surface occupied by rice fields.

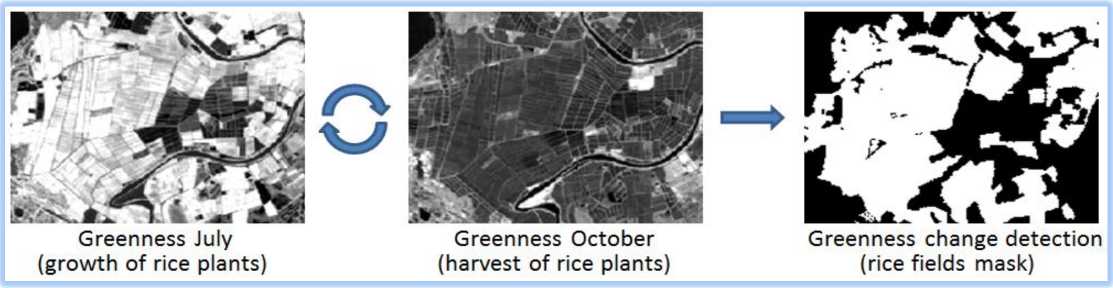


Figure 12. Image change process for rice fields detection in the PNRC between July and October, 2001. White areas correspond to a high change on greenness values representing rice fields.

6. Layer union and ground truth comparisons

The resulting three layers (water bodies, vegetation and rice fields) are joined in the process, leading to the indicator 1. The information obtained is compared with the inventory to verify the results.

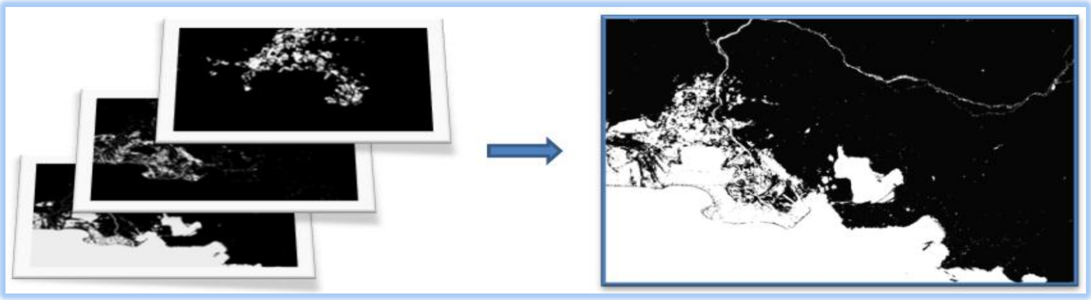


Figure 13. Layer union process example for Dep. 13. Water bodies, wetland vegetation and rice fields are combined to obtain the Indicator 1 layer.

7. Accuracy

Some departments required a special treatment due to their characteristics and the complementary information available:

- Department 13:
  - PNRC and surrounding areas are classified separately from the rest of the department. This region has a greater presence of wetlands, so it is possible to use a lower threshold in the supervised classification, in addition to a smaller number of classes, to maximize results. If these conditions are used to the entire department, the errors obtained in the other departments are high.
  - Flow accumulation is not used in this department. Due to the topographical homogeneity of this department being flat to low slope, the use of the flow accumulation parameter does not provide additional value to the results.
  - Since there are two inventories, one for the departments and one more focused on the PNRC, comparisons are made taking into account both of them.
- Rest of departments:
  - No rice fields classifications were elaborated, since the presence of rice is reduced to the Camargue region according to TdV reports.
  - Flow accumulation was not used in departments 83 and 84. There are more mistakes than improvements since the lines do not match too closely with inventories, and they have many ramifications that add important error areas.

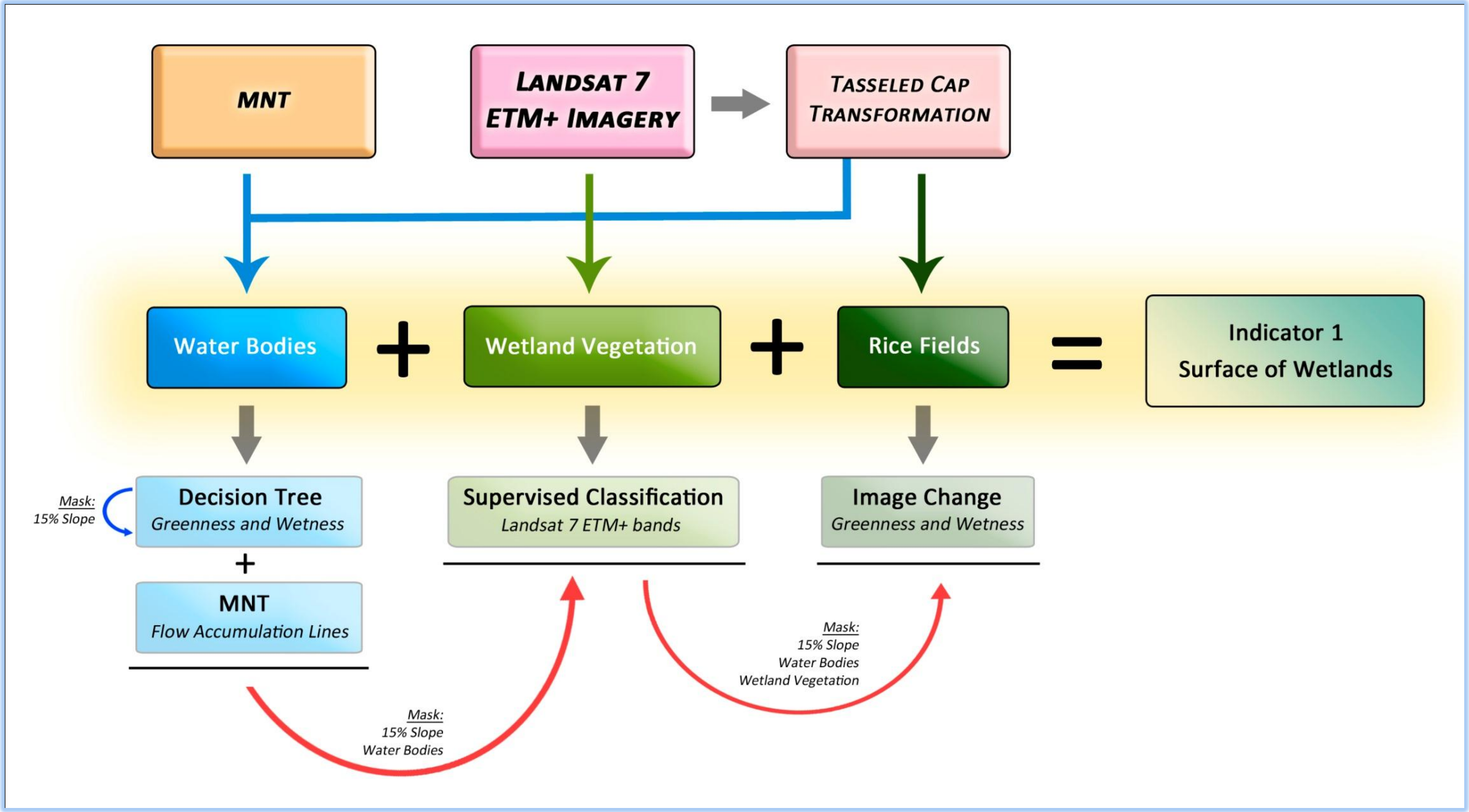


Figure 14. Diagram of the process of the Indicator 1 calculation.

Chapter 5: Methodology of Indicator 2

5.1. Sources of data

- Landsat imagery (table 2).
- Indicator 1 layer of the PACA region for 1984 and 2001 (obtained by applying Ind. 1).
- Corine Land Cover 1990 and 2000.

Period	Satellite	Number of Bands	Bands used	Resolution	Image Date
1980s	Landsat 5 TM	7 Bands	1 to 5, and 7	30 m	Jul - Aug 1984 Sep - Oct 1984 Nov - Dec 1984 Mar 1985
2000s	Landsat 7 ETM+	7 Bands + 1 Panchromatic	1 to 5, and 7	30 m	Feb - Mar 2001 Apr - May 2001 Jul - Aug 2001 Oct 2001

Table 2. Satellite imagery used (dates and properties).

5.2. Calculation of Indicator 2

The aim of Indicator 2 is to detect the conversion of natural and semi-natural wetlands surface, between two dates, into either agriculture or urban areas. In this context, wetlands are understood as the surface detected during the analysis of the Indicator 1. In order to develop this indicator reference layers for agricultural and urban uses were needed to be used as references for the detection of change in land uses. ETC/SIA decided to use Corine Land Cover as a reference as it:

- ✓ provides historical information for the years 1990, 2000, 2006 and 2012; and it will provide a 5 years periodicity (2017, 2023, …),
- ✓ has a consolidated and comparable methodology between the different versions.

The methodology developed for Indicator 2 consists of two supervised classifications of the Landsat imagery, one for agricultural areas and another for urban, where the CLC information for agriculture and urban areas are used as a mask to cover the Landsat images. The two resulting layers are contrasted with Indicator 1 to detect wetlands conversions to either agriculture or urban between the defined years. Figure 19 provides a schematic view of the methodology developed.

The mask used is intended to 1) identify regions of interest to locate changes, and 2) reduce errors coming from the classification process of the satellite images used. This methodology enables the periodic calculation of the Indicator 2 for selected dates and it is not necessary restricted to the dates of the reference information allowing further uses for future periods. Namely, the urban mask of CLC 2006 could be used for 2004 or 2007 since the surface would be quite comparable. The satellite images used by ETC/SIA correspond to the closest available dates for CLC reference years, so that the masked surface is representative of the reality.

Masked classifications also allow the detection of areas that correspond closely to these two land uses, so the regions that CLC (or other reference) may overestimate, either by error or as a consequence of its higher spatial resolution, are not included. For example, in the case of the PNRC, according to the reports of TdV, CLC overestimates rice fields including areas that do not conform to agriculture.

1. <u>Corine Land Cover: Agriculture and Urban masks</u>

The level 1 information related to '1.Artificial Surfaces' and '2.Agricultural Areas' from CLC 2000 is extracted and reclassified to create two masks:

1) one for agriculture, and
2) one for urban areas.

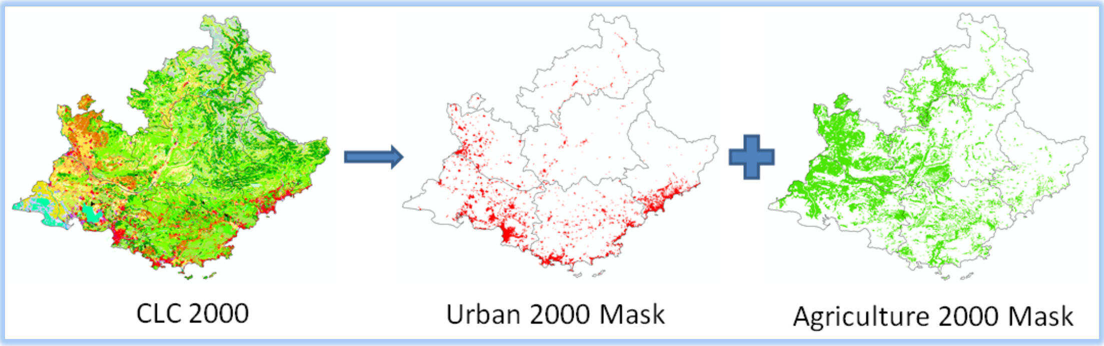


Figure 15. Corine Land Cover agriculture and urban masks construction.

2. <u>Supervised Classification</u>

The 2 masks previously generated are used to perform two supervised classification on the satellite image with the Maximum Likelihood algorithm to obtain the agriculture and urban surfaces for the year 2001.

The class training process is not as critical as in the case of Indicator 1 because the diversity of land coverages is much lower and the possible confusion between classes is significantly reduced by the masks. In the case of agriculture, the aim was to distinguish farm lands (cultivated and fallow) from natural areas (vegetated or bare soils) included in CLC as agriculture. For urban regions, some inconsistencies were detected in the case of some small water bodies and bare soil areas (< 2 ha) included in CLC, so we tried to separate them from the urban use by correctly choosing the training areas.

The resulting surfaces are very similar to those of CLC, but they are better suited to urban and agriculture areas as they omit some error of regions that do not belong to these land uses and were classified as such by CLC (see figure 16).

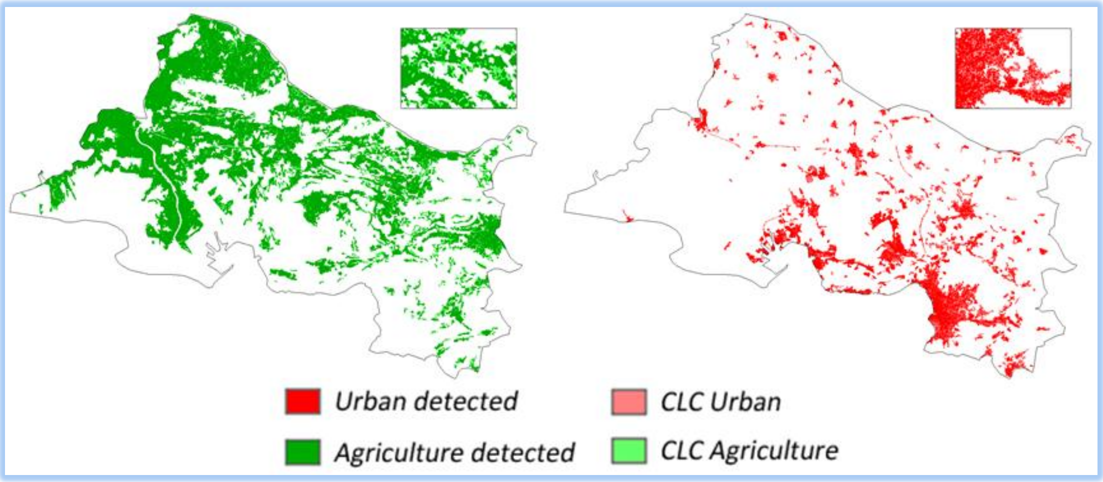


Figure 16. Supervised classification results. Maps and details of CLC versus the surface detected. Light green and red correspond to the original CLC surface. Green and red represent the area detected.

3. <u>Modification of layers</u>

Before contrasting the layers obtained with the surface of wetlands, we excluded the rice fields areas from Indicator 1 layer of 1984, as they are considered as agriculture in Indicator 2. This is only needed for Department 13 as rice is limited to this department within our study region. The removed rice fields were added to the agriculture layer resulting from the last step to complete the information presented in this layers and improve the representation of rice in the classified image.

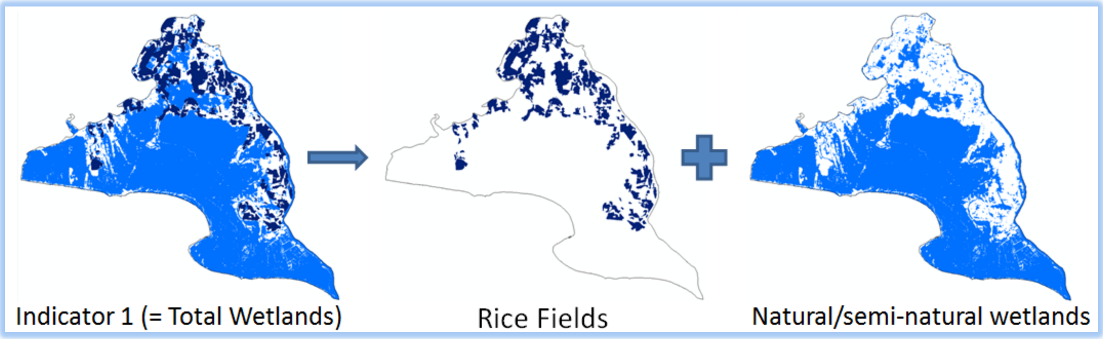


Figure 17. Example of rice fields extraction in the PNRC.

4. <u>Thematic change analysis</u>

For the years 1984 and 2001, Indicator 1 (excluding rice fields) and the agriculture areas (including rice) and urban layers are overlapped to assess the thematic changes between the two dates studied. Five new classes are obtained according to the changes detection:

- Urban *
- Agriculture *
- Wetland *
- Wetland converted to Urban
- Wetland converted to Agriculture

**No change*

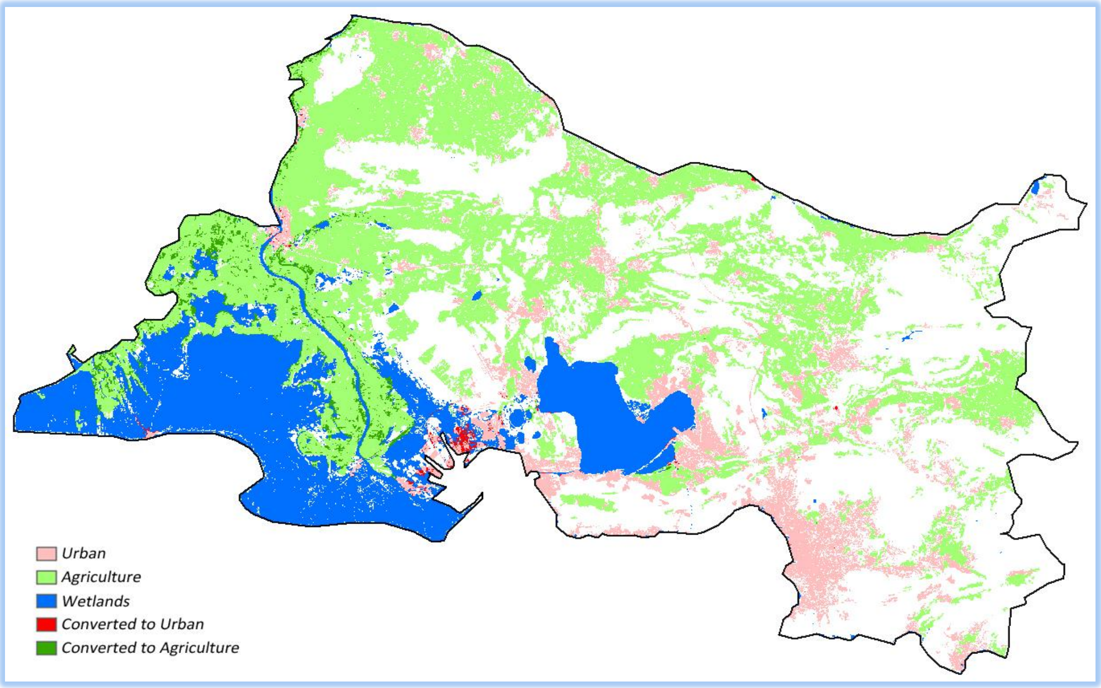


Figure 18. Thematic change map for Department 13

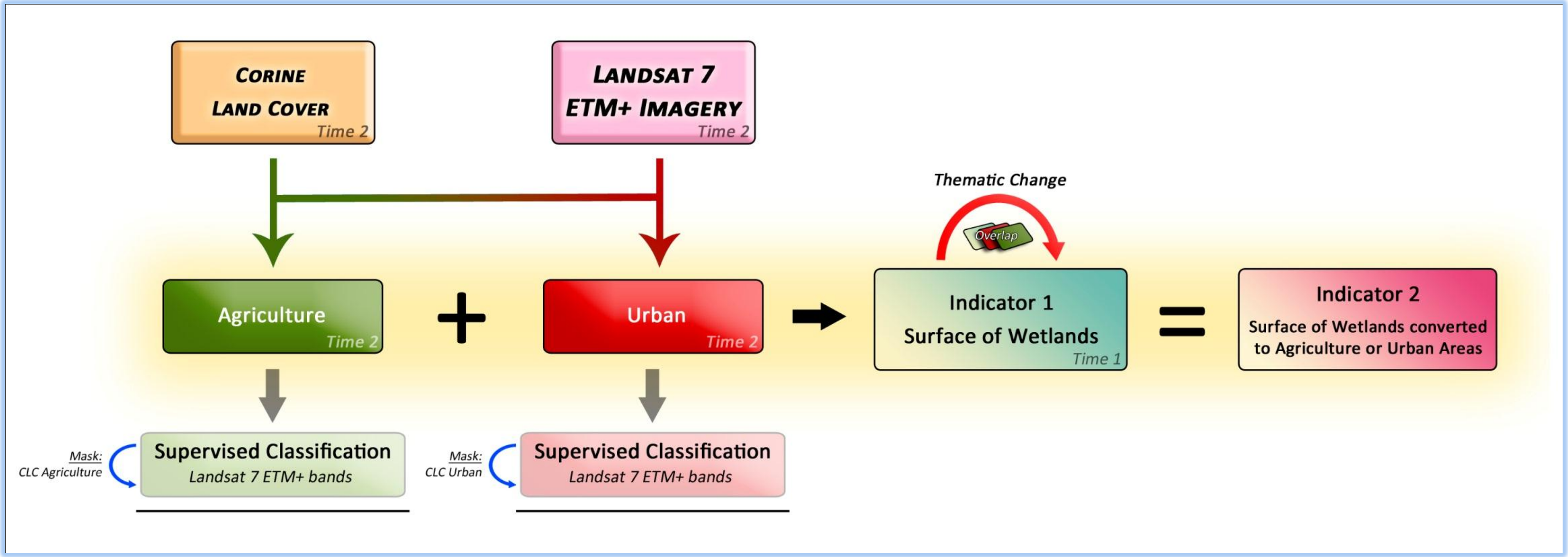


Figure 19. Diagram of the process of the Indicator 2 calculation.

Chapter 6: Methodology of Indicator 3

6.1. Sources of data

- Landsat imagery (technical details present in table 3).
- Wetlands inventories of Departments 13, 84 and 04 provided by TdV.
- LULC layers of the PNRC (Dep. 13). Year 2001, 2006 and 2011.

Satellite	Number of Bands	Bands used	Resolution
Landsat 7 ETM+	7 Bands + 1 Panchromatic	1 to 5, and 7	30 m

Year	Department	Image Month
2001	Dep. 13	Jan, Mar, May, Jul, Oct
	Dep. 83	Jan, Mar, May, Jul, Oct
	Dep. 04	Mar, Apr, Jul, Oct
2007	Dep. 13	Jan, Mar, Apr, Sep, Dec
	Dep. 83	Feb, Mar, Jul, Nov
2012	Dep. 13	Jan, Mar, Jun, Jul, Sep
	Dep. 83	Jan, Mar, Jun, Jul, Sep

Table 3. The properties and dates of the satellite imagery used for the analysis of indicator 3.

6.2. Calculation of Indicator 3

As specified by TdV, Indicator 3 aims at analyzing the flooding level, defined as the degree of water contained within the inventoried wetlands using remote sensing techniques.

For this purpose, the methodology developed follows the same classification process that was previously established for water bodies for Indicator 1. A decision tree, based on TC transformation, was used for each satellite image in order to detect water bodies in different periods of each studied year (fig. 37). The areas detected by the methodology as water bodies constitute the flooded areas of Indicator 3. Figure 23 provide a diagram about the method.

The surface detected in each studied date is contrasted with the reference wetlands layers (the wetlands inventories and the LULC layer) in order to calculate the degree of flooding of wetlands for the studied departments as area flooded (ha) and percentage flooded.

The degree of flooding of wetlands is calculated in three different ways in order to enhance the information obtained:

- **Mean:** the average value of flooded area for the months analyzed during one year.
- **Maximum:** the maximum value of wetland surface flooded during one year.
- **Year Total:** the total surface of flooding during one year (figure 21) which is the spatial union (count) of all Indicator 3 layers (areas that are flooded at least once a year).

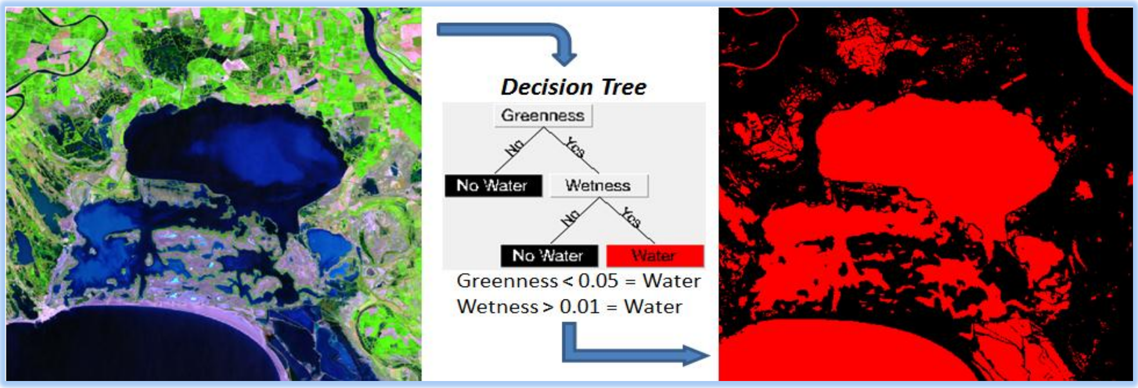


Figure 20. Decision tree classification process used to calculate Indicator 3. This image represents a Landasat 7 ETM+ image of the PNRC from July, 2001. Red surfaces correspond to flooded areas.

In order to study the seasonal variability of flooding within a year, the monthly water surfaces detected for each studied year are overlaid and summed to the rest of the layers We assign the value of 1 for each water layer studied, such that the sum of all layers ranges between a minimum value of 0 (corresponding to areas that are never flooded within a year) and a maximum value equal to the number of months analyzed (for example, the number equals 5 in the case of department 13), being in that case areas that are flooded throughout the year according to this approach (figure 21).

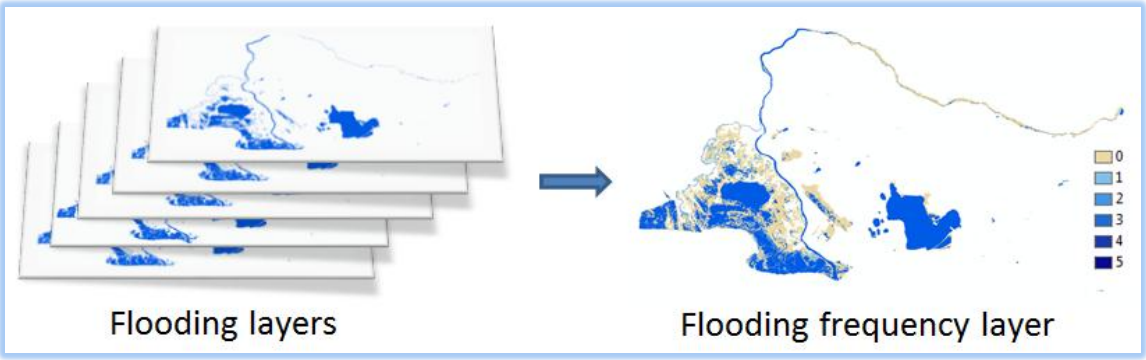


Figure 21. The process of overlaying and summing the different flooding layers calculated within a year.

➢ <u>The influence of rice fields:</u>

In the case of Department 13, ETC/SIA and TdV agreed to provide different types of analyses of Indicator 3 being a department that includes a high amount of rice fields of the PNRC (considered wetlands). Several approaches were tested in this case (specified further in section 3.2.). The 3 methodologies tested are:

- **Wetlands detected by satellite (Ind. 3S):** Water bodies and flooded areas detected by the satellite image classifications in a specific date (no specific criteria applied to rice fields).
- **Wetlands detected by satellite + rice fields included (Ind. 3R):** the whole surface of rice is considered as flooded for images between April and August (as from June to August water is not well detected due to vegetation).
- **Wetlands detected by satellite + rice fields excluded (Ind. 3NR):** rice field areas detected by the satellite are masked for all dates and not included in the classification process.

For each studied year (2001, 2007, 2012), the area covered by rice fields was analyzed following the same classification approach used for Indicator 1: detecting vegetation changes between the period of maximum growth and the period of vegetation harvest (figure 22). The masks generated are used in subsequent classifications, by considering all these areas as "Rice fields".

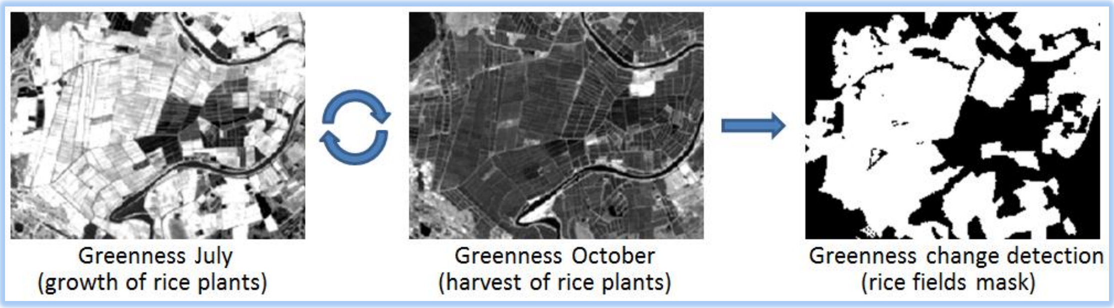


Figure 22. Image change process for rice fields detection in the PNRC between July and October, 2001. White areas correspond to a high change on Greenness values, assuming to represent rice fields.

- Flooding per wetland type:

ETC-SIA also performed a statistical analysis to assess the relationship between the degree of flooding of wetlands and their nature (wetland type/land use type). This test is based on the information obtained for Indicator 3 during the studied years (2001, 2007 and 2012) and the LULC layer covering the PNRC for year 2001, 2006 and 2011 respectively. Therefore, flooding data correspond to Department 13. Five images were used to this study for each year.

The univariate analysis of variance (ANOVA) was used to establish the relationship between the maximum frequency of flooding for the different polygons within the LULC layer and their corresponding type of wetland. All polygons in the layer corresponding to a wetland habitat were selected for the analysis.

ANOVA is a collection of statistical models in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, it provides a statistical test to identify whether there are any significant differences between the means (flooding level) of several independent groups (being wetland types in our study).

This approach is used to analyze the potential relationship between wetland type and the level of flooding, and whether these changes in flooding are significantly different between wetland types. Through this analysis, we emphasize on answering the following questions:

- Does the level of flooding depend on the type of wetland within the PNRC?
- Is the flooding level significantly different between wetland types?

In order to do the analysis, we needed to standardize the nomenclature of wetland categories of the LULC layers between the different years as different terminologies were used in the three reference years (2001, 2006 and 2011). This step was done with close collaboration with TdV in order to identify the most convenient nomenclatures for the LULC layers.

Data on the flooding level were weighted by the polygon size in order to obtain comparable results, since there are important size differences between the wetland polygons (from around 0.01 ha to 12,500 ha).

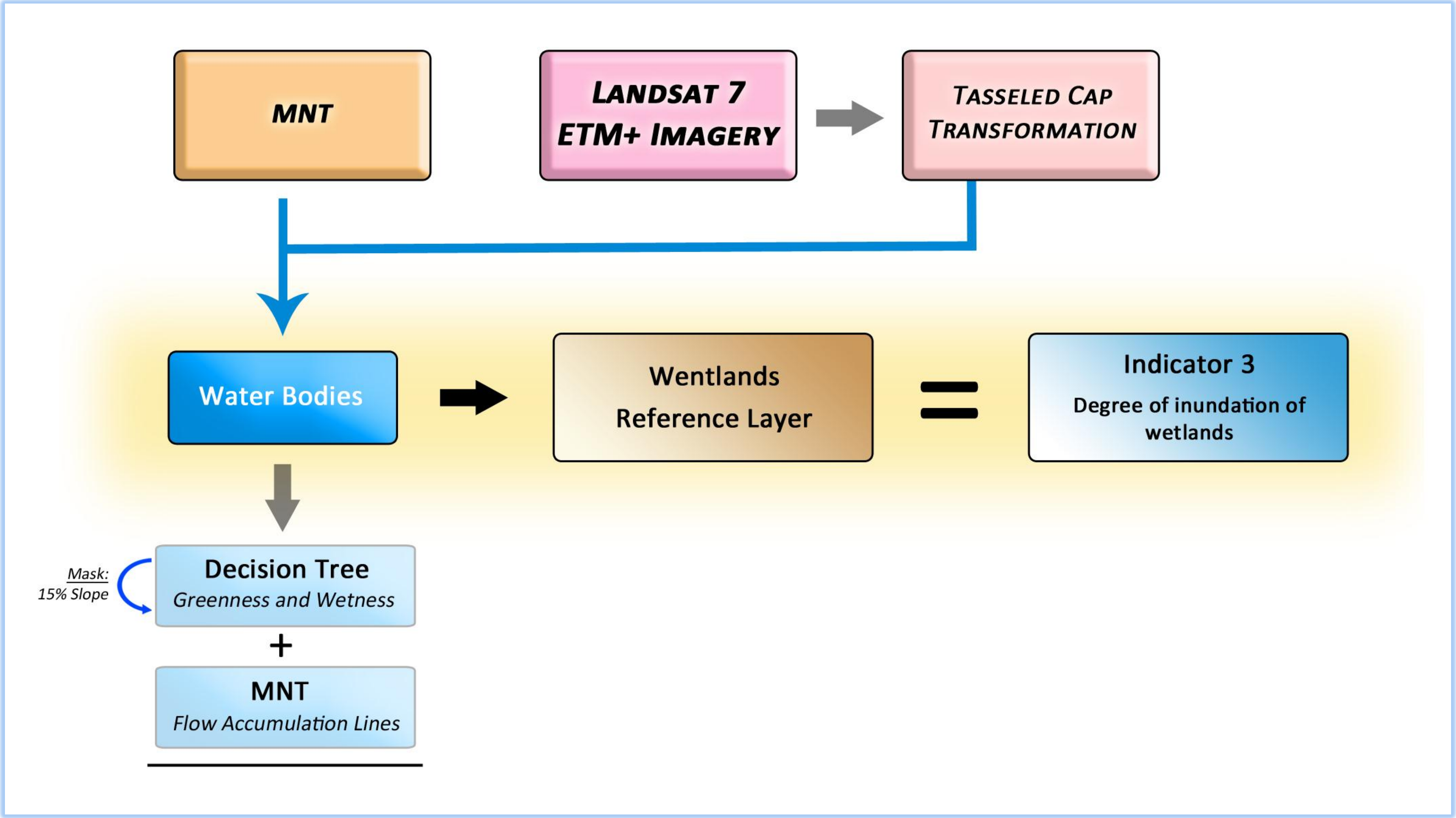


Figure 23. Diagram of the process of the Indicator 3 calculation

- Part III -

General Results

Chapter 7: Results of Indicator 1

7.1. Results of Indicator 1

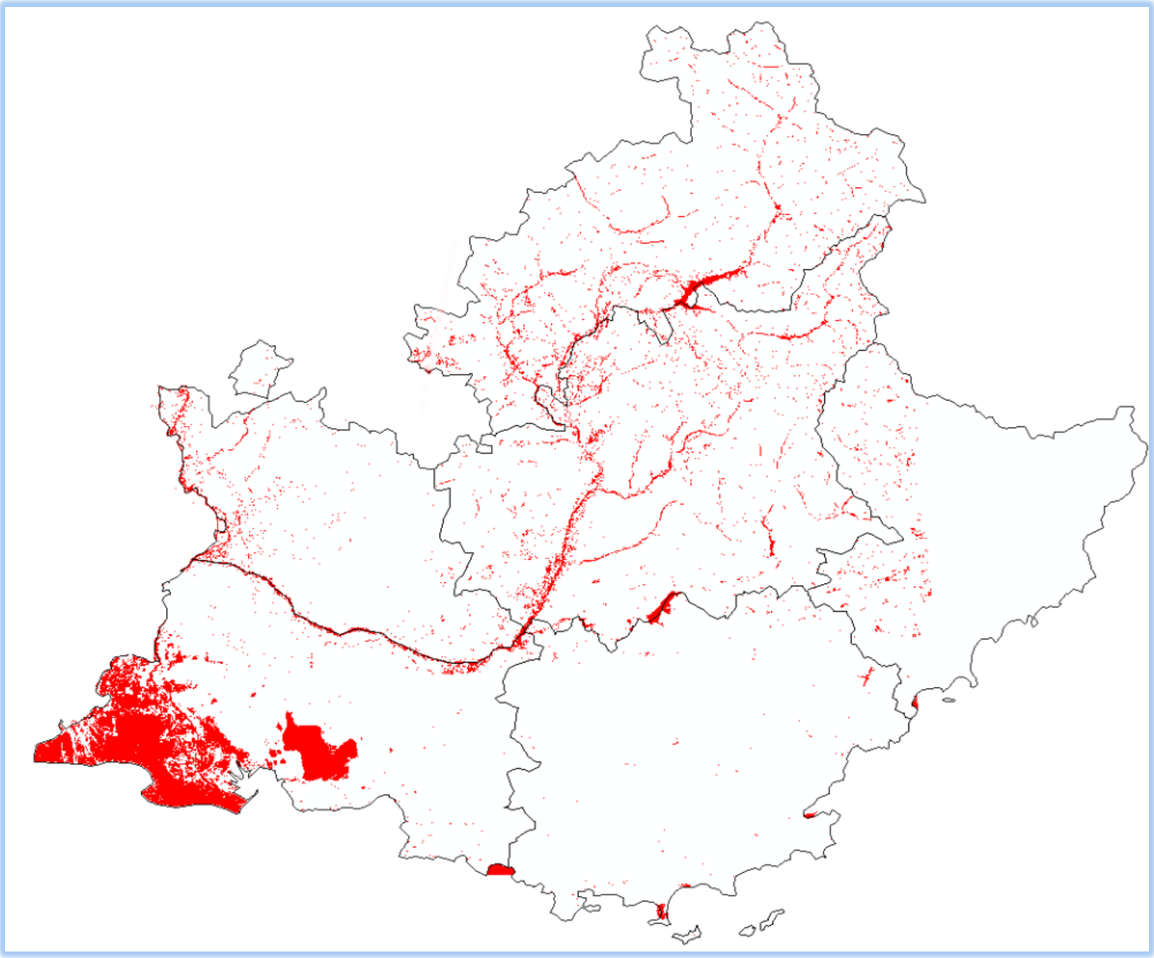


Figure 24. Indicator 1 layer for the PACA region in 2001 (red color). The image correspond to the union of all months analyzed.

- ETC-SIA results:

Department	Inventoried wetlands (ha)	Wetlands detected by satelite (ha)	Wetlands detected inside inventory (ha)	Wetlands detected outisde inventory (ha)	Error A %	Inventoried wetlands not detected (ha)	Error B %
Dep 05	16,943	19,695	6,204	13,491	68.50	10,739	63.38
Dep 04	20,745	23,412	11,200	12,212	52.16	9,545	46.01
Dep 84	8,247	10,553	3,541	7,012	66.45	4,706	57.06
Dep 13	89,234	101,449	78,887	22,562	22.24	10,347	11.60
Dep 13 + LULC	104,717	101,449	91,307	10,142	10.00	13,410	12.81
Dep 83	6,166	2,791	2,293	498	17.83	3,873	62.81
Dep 06	Not inventoried	3,463	-	-	-	-	-
PACA	**141,335**	**161,363**	**102,126**	**55,774**	**34.56**	**39,209**	**27.74**
PACA + LULC	**156,818**	**161,363**	**114,546**	**43,354**	**26.87**	**42,272**	**26.96**
Dep. Mean	***41,009***	***37,545***	***32,239***	***10,986***	***39.53***	***8,770***	***42.28***

Table 4. Results for the Indicator 1 obtained by ETC-SIA. Values correspond to the sum of all images analyzed for 2001.

➢ <u>Tour du Valat (TdV) results:</u>

Department	Inventoried wetlands (ha)	Wetlands detected by satelite (ha)	Wetlands detected inside inventory (ha)	Wetlands detected outisde inventory (ha)	Error A %	Inventoried wetlands not detected (ha)	Error B %
Dep 05	16,943	11,975	2,509	6,831	73.14	14,452	85.30
Dep 04	20,745	22,893	6,807	13,330	66.20	13,901	67.01
Dep 84	8,247	6,591	1,481	5,037	77.28	6,685	81.06
Dep 13	89,234	84,767	65,713	19,054	22.48	23,228	26.03
Dep 13 + LULC	-	-	-	-	-	-	-
Dep 83	6,166	6,127	2,077	4,051	66.12	3,817	61.90
Dep 06	Not inventoried	3,767	-	-	-	-	-
PACA	**141,335**	**136,120**	**78,587**	**48,303**	**35.49**	**62,083**	**43.93**
PACA + LULC	-	-	-	-	-	-	-
Dep. Mean	***28,267***	***22,687***	***15,717***	***9,661***	***61.04***	***12,417***	***64.26***

Table 5. Results for the Indicator 1 obtained by TdV.

Table 4 and 5 shows the Indicator 1 results of ETC-SIA and TdV respectively. Focusing on the results of applying the methodology developed by ETC-SIA (table 4), we show that, in general, the success rate for the departments is hovering around 50%, so much of the information is overestimated (error A) or omitted (error B), with the exception of Department 13 where error percentages achieved are quite small (around 10%).
Results of this Dep.13 contrast with those obtained for the alpine areas (Dep. 05, 04 and 84) which error rates are much higher (ranging around 45-70%) mainly due to problems arising from the mountains in the satellite images.

Regarding total surfaces, the satellite detects more wetlands than are included in the inventories (overestimation). Although as mentioned, much of this surface does not match this information. Error rates (A and B) for the PACA region are close to 27%.

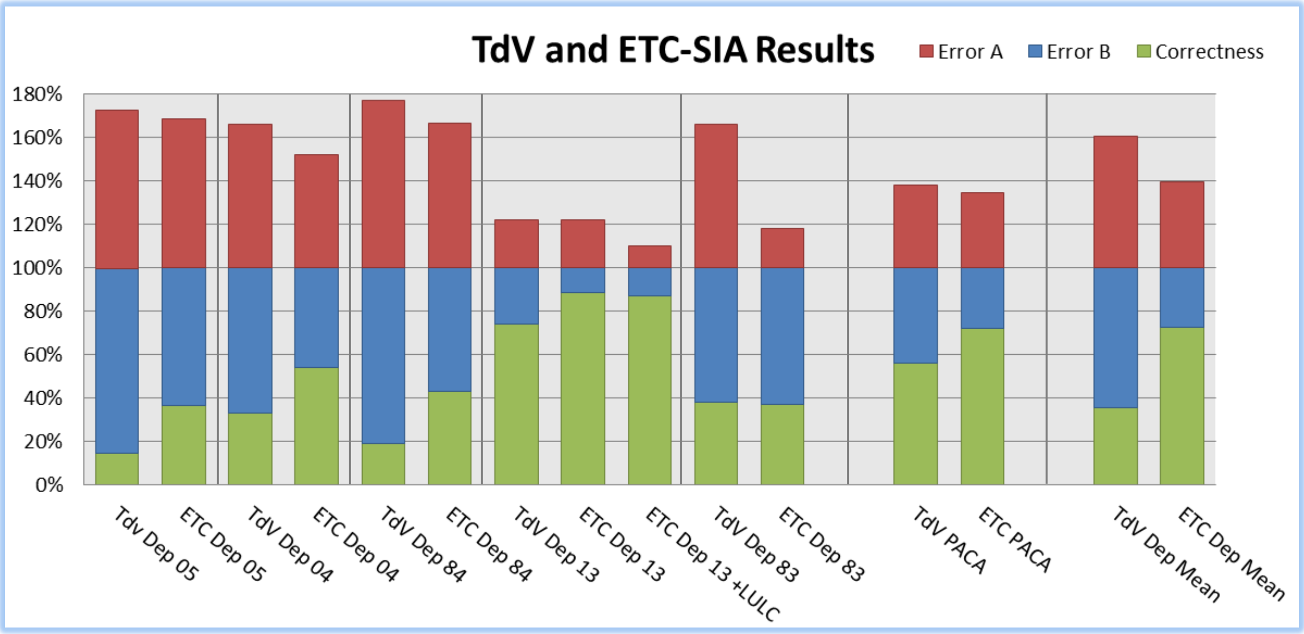


Figure 25. Comparison between TdV and ETC-SIA error rates for Indicator 1.

Comparing the results obtained between TdV and ETC-SIA (figure 25 and table 6), in general, there was a significant improvement by ETC-SIA in some cases such as Dep. 05, Dep. 04 and Dep. 84, but there are other cases where this improvement is not very significant such as the case of Dep. 13. The improvement that Indicator 1 did to Error B is generally more significant than that of Error A, which does not vary too much except in Dep. 83.
In the cases of Error A in Dep. 13 and Error B in Dep. 83 the method developed for Indicator 1 was not able to improve the results of TdV. So in these cases there is some evidence that both methods may be limited by the available information.

In relation to the total results for the entire PACA region, there is a remarkable improvement of Error B by the ETC-SIA, but Error A does not show a major improvement.

Department	Error A (% improvement)	Error B (% improvement)
Dep 05	4.5	21.6
Dep 04	13.8	21.0
Dep 84	10.6	23.9
Dep 13	-0.2	14.4
Dep 13 + LULC	12.0	13.2
Dep 83	48.2	-0.8
Dep 06	-	-
PACA	**3.4**	**16.3**

Table 6. Percentage of improvement made by ETC-SIA for Errors A y B comparing TdV results. Green numbers are improvements in the results, and the red show the cases where results are worse.

In terms of total surface, both methods approximate quite well to the wetland inventories (figure 26). TdV method tends to underestimate the total inventoried area being the surface detected lower in all cases except for Dep.04. On the other hand, the methodology developed by ETC-SIA overestimates the inventories in all cases except Dep. 83.

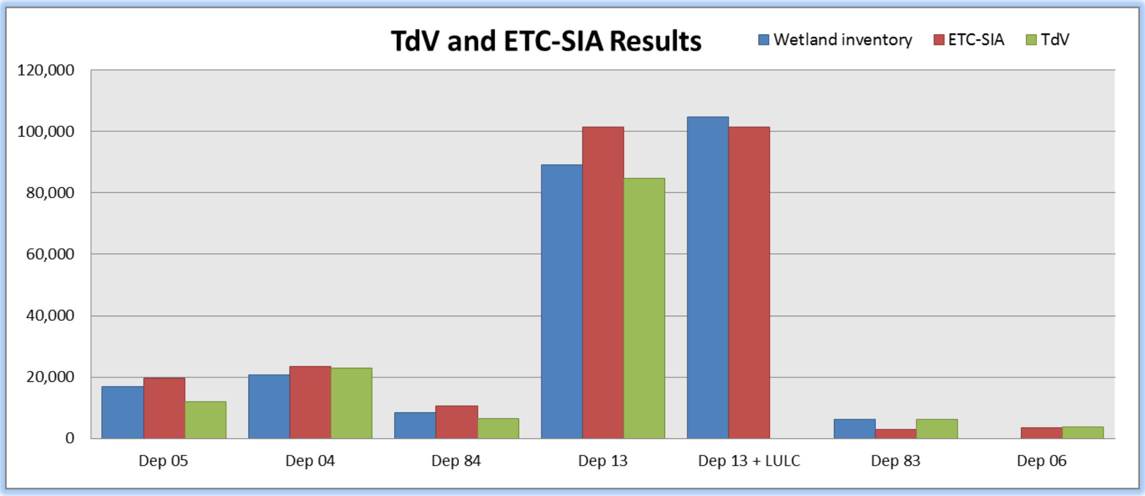


Figure 26. Comparison of wetland surfaces detected by TdV and ETC-SIA for Indicator 1.

In general, the Indicator 1 provides reasonably good results for the entire PACA region, largely due to the Dep. 13 is represented with great accuracy. Although individual results for the alpine areas (error rates range around 45-70%), the wetland surface detected and its distribution largely corresponds with the reference layers from a spatial and visual point of view. Therefore, the Indicator 1 results are acceptable from the perspective of wetland monitoring, especially in Department 13 where error percentages are quite low.

7.2. Wetlands evolution between 1970s, 1980s and 2000s

Ultimately, the purpose of the indicator 1 is not so much the situation of wetlands in a given date, but reliable trends identifying changes in time. Therefore, classifications between 1970s and 2000s were performed to study the evolution of wetlands during this period. Results obtained were compared with the current wetlands inventories as there is no other reference data available at present.

The total surface of wetlands detected by the satellite imagery for the PACA region experiences a slight decline between 1984 and 2001 (around 1.5%). At department level, surface detected within Dep. 05, 04, 84 and 06 increases, while that in Dep. 13 and 83 decreases. For Dep. 83 this decline is quite significant (about 30%).

In Department 13 (table 7) error B is quite low for the three cases studied (1975, 1984 and 2001), being the correctness around 85%. Error A is higher in 1975 and 1984, but this might be mainly due to wetland areas identified do not exist in 2001, so they are not included in the current inventories. In addition, in the case of 1975 many urban areas are wrongly detected as wetlands as the satellite images used have a resolution and quality much worse (Landsat 2 MSS) from those of 1984 and 2001 (Landsat 5 TM and 7 ETM+), so a high percentage of error A is caused by this.

Department	Date	Wetlands detected by satelite (ha)	Wetlands detected inside inventory (ha)	Wetlands detected outisde inventory (ha)	Error A %	Inventoried wetlands not detected (ha)	Error B %
Dep 05	1984	18,823	6,174	12,649	67.2	10,769	63.6
	2001	19,695	6,204	13,491	68.5	10,739	63.4
Dep 04	1984	18,672	7,487	11,186	59.9	13,258	63.9
	2001	23,412	11,200	12,212	52.2	9,545	46.0
Dep 84	1984	9,973	2,341	7,632	76.5	5,906	71.6
	2001	10,553	3,541	7,012	66.4	4,706	57.1
Dep 13 + LULC	1975	118,511	87,820	30,690	25.9	16,897	16.1
	1984	114,538	87,670	26,868	23.5	17,047	16.3
	2001	101,449	91,307	10,142	10.0	13,410	12.8
Dep 83	1984	4,014	2,578	1,435	35.8	3,588	58.2
	2001	2,791	2,293	498	17.8	3,873	62.8
Dep 06	1984	1,644	-	-	-	-	-
	2001	3,463	-	-	-	-	-
PACA	**1984**	**167,664**	**96,294**	**69,726**	**41.6**	**45,041**	**31.9**
	2001	**164,895**	**102,226**	**59,811**	**36.3**	**39,109**	**27.7**
Dep Mean	***1984***	***40,315***	***30,661***	***16,099***	***49.17***	***10,348***	***47.74***
	2001	***38,241***	***32,259***	***11,879***	***42.34***	***8,750***	***42.08***

Table 7. Indicator 1 results of the PACA region for the period 1970s – 2000s. Values correspond to the sum of all monthly images analyzed.

There is a decrease in the surface of wetlands detected within Dep. 13 during the study period (figure 27). Between 1975 and 1984 the total wetland surface experience a decrease of 3,4%, being much less important than that observed from 1984 to 2001, with a loss of 14.4% of the surface. For the entire period the difference in wetland surface is of 17.8%.

Figure 28 shows the loss of wetlands during the studied years. The decrease seems to be higher in the central part of the department and the PNRC. Most of this lost surface is related to rice fields areas detected during the years 1975 and 1984.

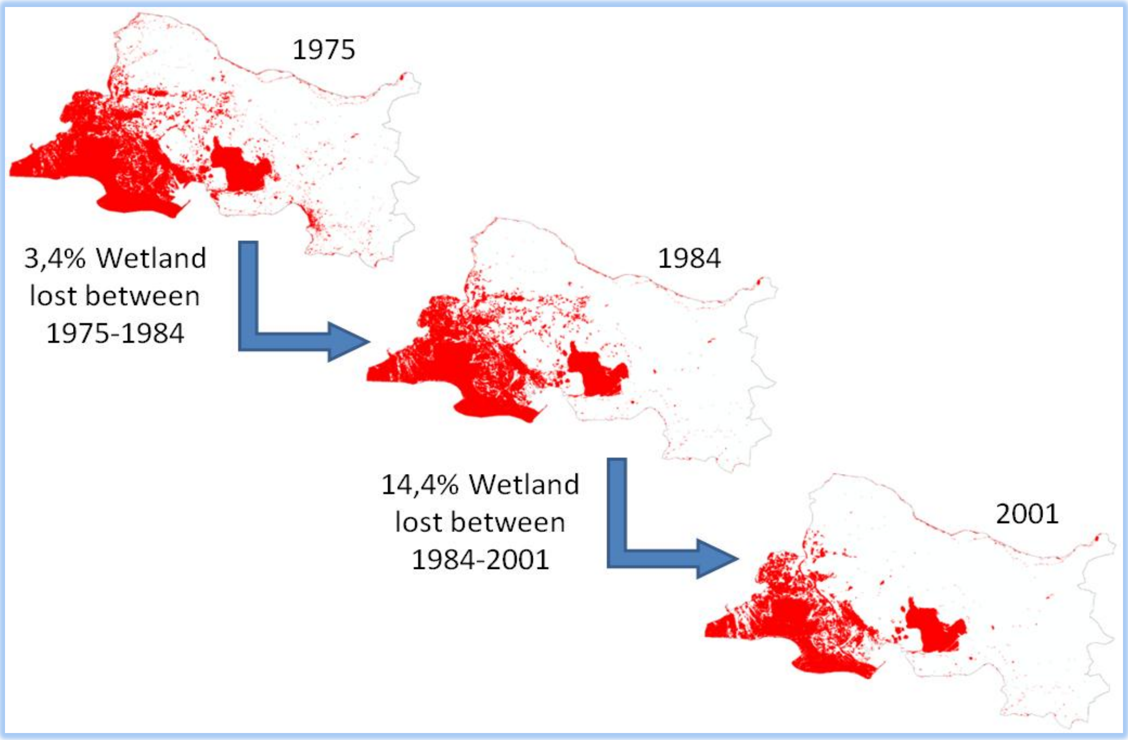


Figure 27. Indicator 1 applied to Dep. 13: surface evolution from 1975 to 1984, and 1984 to 2001. Percentage of surface loss is based on the surface of the year 1975.

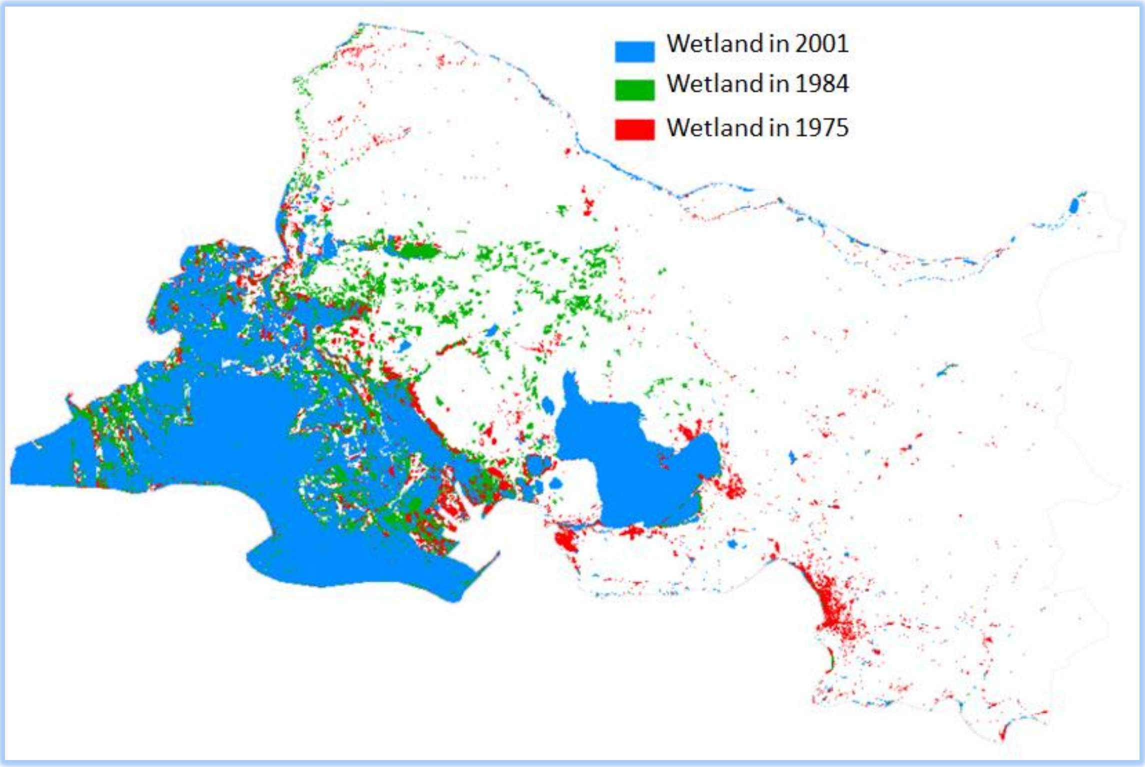


Figure 28. Changes detected by Indicator 1 for Dep. 13 between the years 1975, 1984 and 2001.

Regarding the methodology of this indicator, an important aspect is that for subsequent or previous years there could not be wetland inventories available, only those used for the initial analysis during the 2000s period. This should not be a big problem as the method can identify wetland areas outside the current inventory (with more or less errors) and its availability only affects the validation of the results. Therefore:

- ✓ If there are wetlands not included in the inventory, they should be detected by the satellite image as long as these areas have typical elements of a wetland that can be analyzed (presence of water, vegetation changes, etc.).
- ✓ If any area of the current inventory were no longer a wetland, it would not be detected in the new classifications (another class would be detected).

Further tests of Indicator 1 were performed and tested for the PACA region based on some improvements in the methodology. The detailed analysis and results obtained are presented in **Annex 5 – Indicator 1 Improvements**.

The new results are substantially better so improvements of Indicator 1 could have remarkable effects in the results of the analysis of the evolution of wetlands between 1975, 1984 and 2001. Therefore, new analysis would be recommended to assess the improvement in this context.

Chapter 8: Results of Indicator 2

8.1. Results of Indicator 2

Changes in wetland areas detected in the PACA region between the years 1984 and 2001 are shown in table 8. Indicator 2 estimates the transformed surface to be around 23.000 ha between the studied years, being 13.56% of the total wetlands surface calculated by Indicator 1 of the PACA region. Results show that the conversion from wetlands to urban is low in the region (2.89%), while the total area transformed to agriculture is significant higher (10.66%).

Among the six departments studied, Dep. 13 and 83 show the lowest overall variation in terms of percentage. However, in terms of total surface Dep.13 is the department with the most wetlands conversions. Changes to urban areas highlight in this case (Dep. 13) as they are very low (0.90%). The highest wetlands losses in percentage occur in Dep. 84, where around 45% of detected wetlands are transformed to agriculture.
Departments 04 and 05 experience significant changes in their land use, the main shift is towards agriculture (25.85% and 11.59% respectively). However, the conversion to urban is quite low, almost to the level of Dep. 83. In Dep. 06 wetlands conversion to agriculture is not detected, but the maximum changes to urban areas in percentage occurs in this region.

Region	Wetland surface in 1984 (ha)	Wetlands converted to Urban		Wetlands converted to Agriculture		Total Change	
		Surface (ha)	Percentage %	Surface (ha)	Percentage %	Surface (ha)	Percentage %
Dep 05	18,823	1,129	6.00	2,182	11.59	3,311	17.59
Dep 04	18,672	472	2.53	4,826	25.85	5,298	28.37
Dep 84	9,973	1,471	14.75	4,482	44.94	5,953	59.69
Dep 13	114,538	1,029	0.90	6,249	5.46	7,278	6.35
Dep 83	4,014	184	4.58	139	3.45	322	8.03
Dep 06	1,644	567	34.48	0	0.00	567	34.48
PACA	**167,664**	**4,851**	**2.89**	**17,878**	**10.66**	**22,729**	**13.56**

Table 8. Indicator 2 results (surface and percentage) of the PACA region for years 1984 and 2001. Rice fields are counted as agriculture for this indicator.

8.2. Wetland conversions in Department 13 and the PNRC

Table 9 contains the data related to wetlands conversions between 1984 and 2001 in the Department 13 and the PNRC. As expected, the changes in land uses between wetlands and agriculture or urban were not high considering that the time period analyzed is of 17 years. The identified total losses in agriculture and urban areas are around 6% in both Dep.13 and the PNRC, being the agriculture the most important component of change (around 5.5%).
The conversion to urban areas showed to be much higher in the Department 13 (0.9% vs. 0.08%). Within the PNRC, the surface of wetlands transformed to agriculture represents more than 50% of the entire department area.

Region	Wetland surface in 1984 (ha)	Wetlands converted to Urban		Wetlands converted to Agriculture		Total Change	
		Surface (ha)	Percentage %	Surface (ha)	Percentage %	Surface (ha)	Percentage %
Dep. 13	114,538	1,029	0.90	6,249	5.46	7,278	6.35
PNRC	68,520	57	0.08	3,720	5.43	3,776	5.51

Table 9. Indicator 2 results (surface and percentage) of Department 13 and PNRC region for years 1984 and 2001. Dep. 13 includes the PNRC surface. Ricefields are counted as agriculture for this indicator.

The change between the years 1984 and 2001 in Dep. 13 seems to be influenced by the territory where the major areas that were changed to urban are located around the port area. An interpretation is an increase in the port infrastructure (figure 29). On the other hand, the loss to agriculture seems to affect areas that are within the PNRC region (figure 30).

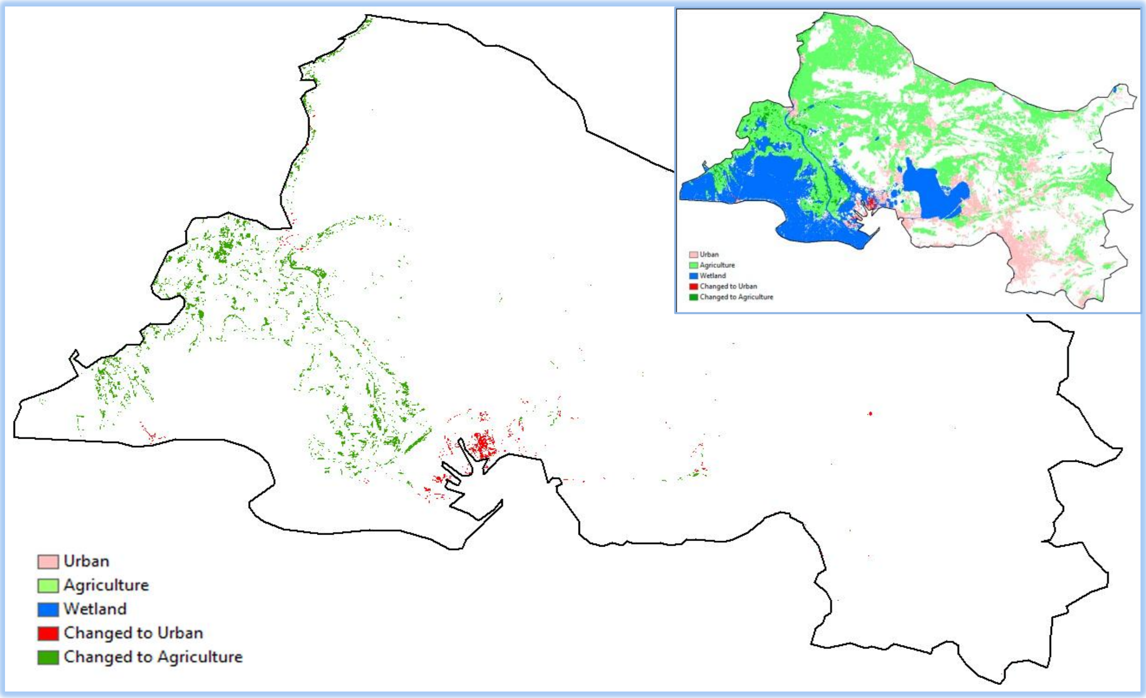


Figure 29. Conversion of wetlands to urban and agricultural areas (Indicator 2) in Department 13 between 1984 and 2001.

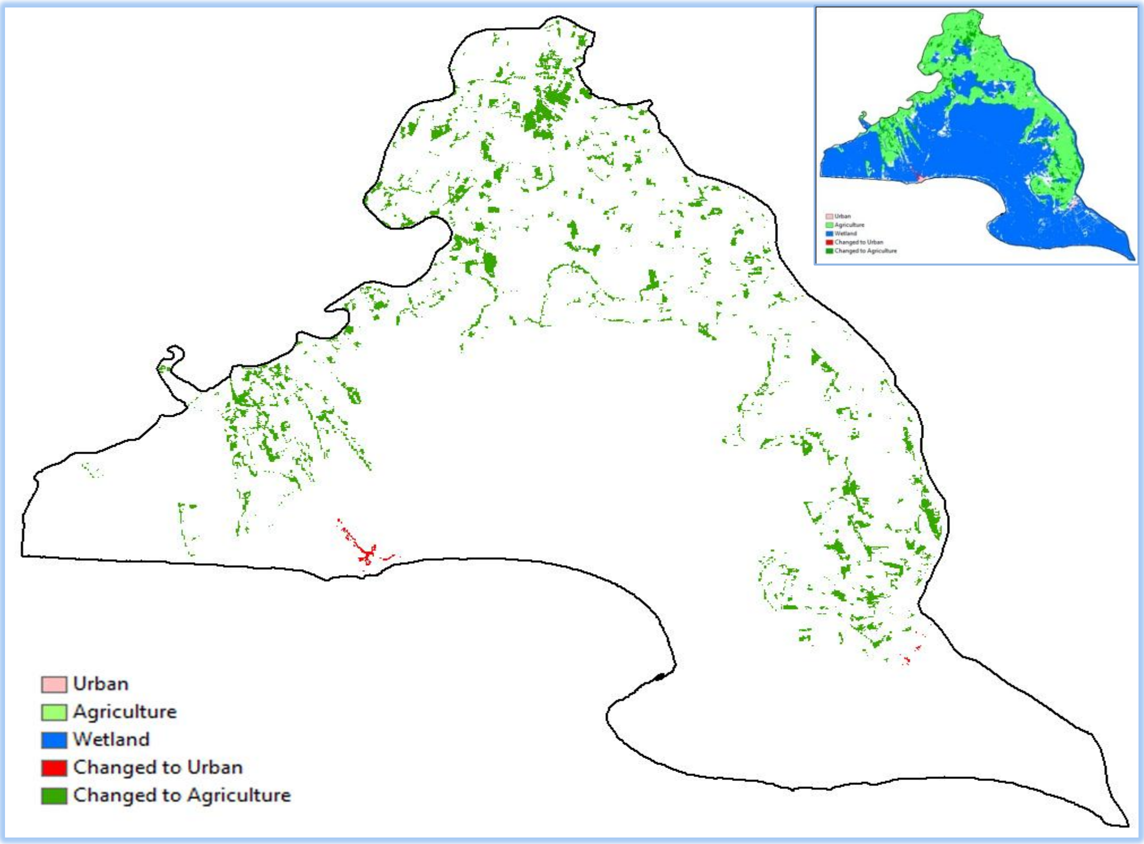


Figure 30. Conversion of wetlands to urban and agricultural areas (Indicator 2) in the PNRC 13 between 1984 and 2001.

8.3. Assessing the quality of results for Indicator 2

The values of wetlands transformation in the case of departments 05, 04, 84 and 06 are very high, especially the figures related to agricultural changes. In response to this, ETC/SIA performed an analysis to:

- ✓ Check the quality/accuracy of the classifications carried out to detect urban and agriculture areas in order to evaluate the quality of the Indicator 2 calculation process.
- ✓ Contrast the wetlands changes detected with reality to validate the results.
- ✓ Test the capacity of CLC for change detection to check the degree of improvement achieved by the ETC/SIA and compare errors.

This analysis showed that the results of Indicator 2 for these departments were not precise as the results are influenced by the detected surface for the Indicator 1. As this layer presents numerous confusions with urban areas, bare soil and agricultural uses among others, the Indicator 2 detects a large number of wrong wetlands conversions in these areas.

Figure 31 shows an example of a wrong wetland conversion to agriculture in Dep. 05 (green color) caused by the limitations of Indicator 1. There are no visible changes in land use between 1984 and 2001, being croplands in these two dates. It is possible to see rectangular plots for both the vegetation (in green color) and the bare soils (in purple). As a result of an error in the wetlands surface detected for the Indicator 1 in 1984, now this area is considered a change to agriculture (more examples are shown in Annex 2).

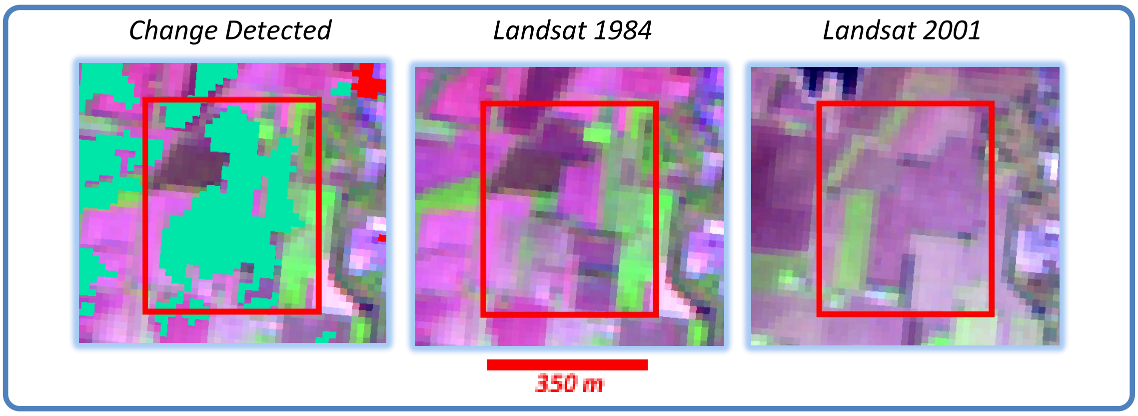


Figure 31. Wrong wetland conversion to agriculture in Dep. 05 (green color) vs. Landsat images for 1984 and 2001. In reality, there is no change in land uses.

In urban areas, classification errors showed to be related to water bodies (figure 32) and some areas that can be detected visually in the satellite image but are not considered as urban in the LULC layer. Therefore they are considered as errors when comparing with the reference.
There are many large urban areas, mainly in the northern departments, which are wrongly classified as wetlands in the Indicator 1 layer. Therefore, a high percentage of the indicator 2 is conditioned by this mistake. Although these areas are pretty well defined (figure 33), so that the visual interpretation of the changes is not extremely difficult (it is appreciated that they are errors).

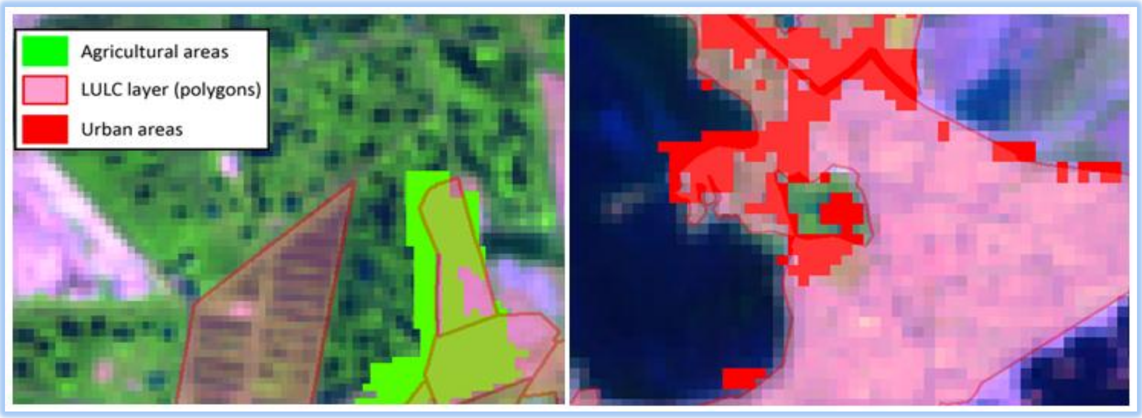


Figure 32. Example of classification errors. **To the left**, supposed agricultural areas (green) outside the LULC layer (light red) which correspond to wetlands. **To the right**, urban area (dark red) wrongly detected on water bodies.

Agricultural areas incorrectly classified correspond to wetland vegetation (figure 32) which CLC includes as agriculture by mistake or by its highest resolution. As occurs with urban areas, an important surface of agriculture is included in the Indicator 1, so multiple errors are generated for the Indicator 2. However, in this case it is difficult to distinguish real changes from the erroneous since these are distributed throughout the entire PACA region (figure 33).

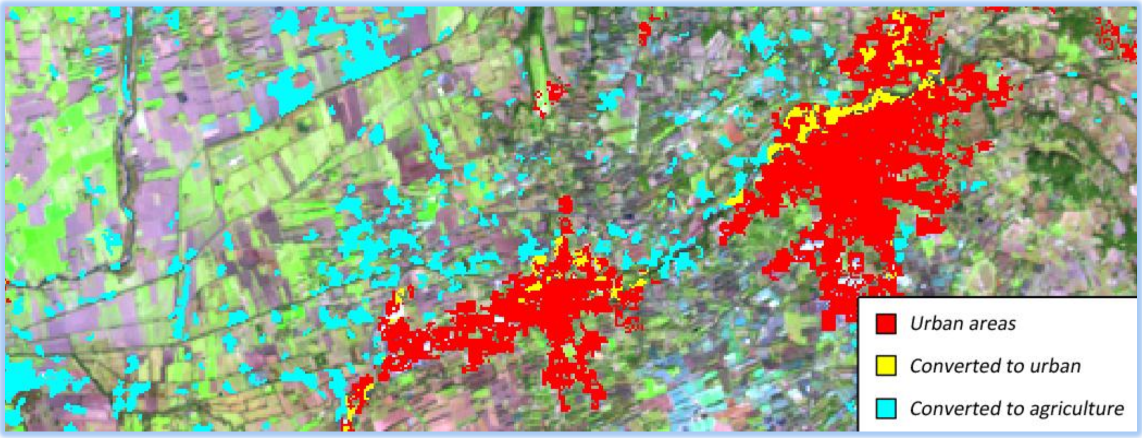


Figure 33. Distribution of classification errors in Dep. 84. False urban changes are located inside or close to exiting urban areas, while agriculture errors are scattered along the territory (from a visual point of view, this makes difficult the interpretation of the results).

8.3.1. Classification accuracy

ETC/SIA contrasted the thematic changes with the LULC layer of the PNRC in order to verify that the transformed areas correspond to real changes in land uses and assess the quality of the classification process. The analysis is limited to this region because there are not more references available with similar quality for other areas of the PACA region. Error A (changes wrongly detected) was calculated to assess the reliability of the CLC masked classification and changes detected. As there is no LULC layer for the year 1984, it was not possible to have a real reference for wetland changes for this period. Therefore, the analysis focuses on the changes detected that match the LULC layer for 2001 because it is unknown whether they are real changes or not. In addition, Error B (undetected changes) was not calculated for the same reason. The results of the comparisons carried out are found in Table 10.

The results in the detection of urban and agricultural areas using Landsat imagery and CLC maks are very satisfactory. The surfaces of urban and agriculture areas detected through Indicator 2 were overestimated when compared to the surfaces indicated in the LULC layer. The methodology elaborated for Indicator 2 was able to detect a high percentage of the urban and agricultural areas of the PNRC. 85% of urban and 87% of agriculture surfaces included in the LULC layer were successfully detected.

The accuracy is lower in regions where wetlands transformation to urban and agriculture was detected, in which the correctness for urban is around 65% and 73% for agriculture. So a high percentage of changes between 1984 and 2001 match with the ground truth reference layer. In the rest of the areas, where there is no change, the surface detected was even higher, around 90% in both cases. Therefore, regarding to Indicator 2 errors, rather than a fault in the methodology, it seems it is a matter arising from the problems observed for Indicator 1.

Land cover	Detected (ha) by Indicator 2	Inside LULC (ha)	Outside LULC layer (ha)	**% correctness**	**% error**
Total Urban	224.55	189.18	35.37	84.25	15.75
Urban areas in both 1984 and 2001	167.94	152.82	15.12	91.00	9.00
Wetlands converted to Urban	56.61	36.36	20.25	**64.23**	35.77
Total Agriculture	26,578.80	23,132.34	3,446.46	87.03	12.97
Agriculture areas in both 1984 and 2001	22,859.01	20,435.13	2,423.88	89.40	10.60
Wetlands converted to Agriculture	3,719.79	2,697.21	1,022.58	**72.51**	27.49

Table 10. Accuracy test results for agriculture and urban areas. Percentage of error corresponds to Error A while correctness is the opposite (100 - % Error A), the surface that match the LULC layer.

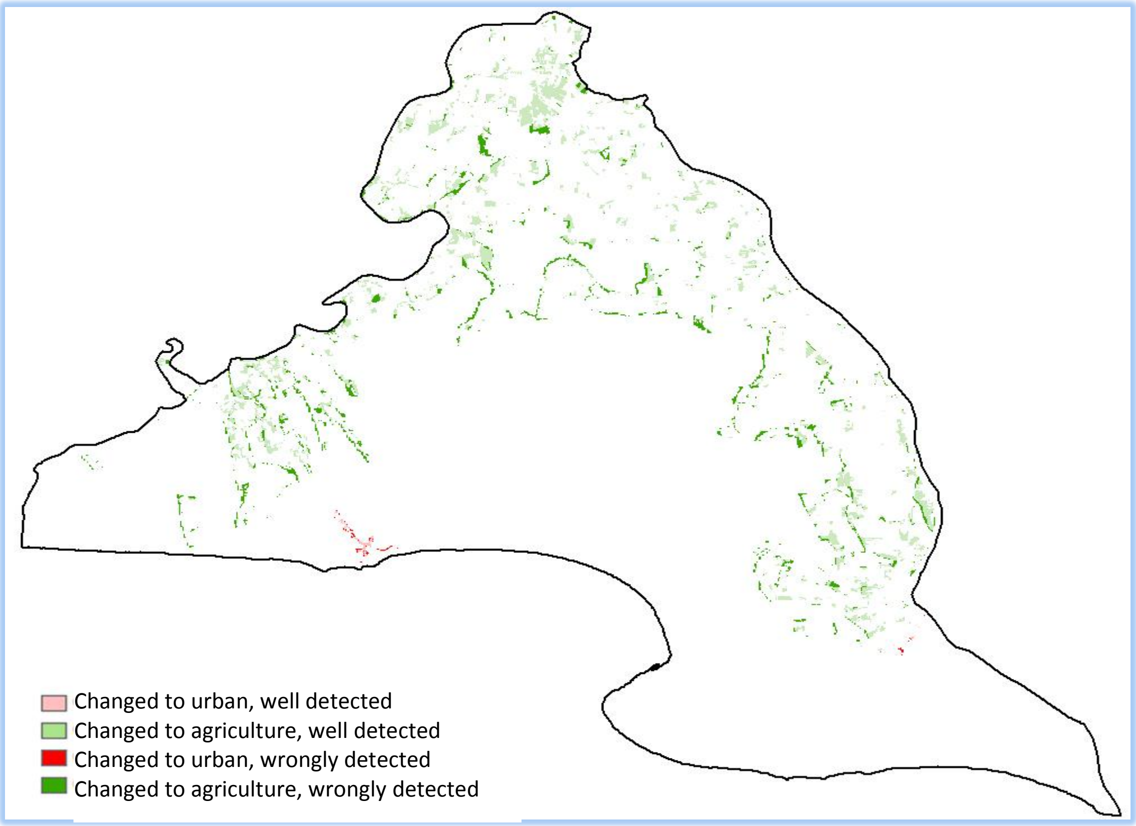


Figure 34. Error A in calculating Indicator 2 for the PNRC. Dark green and red correspond to wetlands transformed into agricultural or urban areas detected by Ind. 2 which are not included in the LULC layer.

8.3.2. Change detection analysis

The absence of a precise reference layer of land uses for the PACA region between the year 1984 and 2001 makes difficult to perform a correct analysis of the results obtained from Indicator 2. Alternatively, we performed a visual comparison between urban and agricultural changes detected trought Indicator 2 layer and satellite images of both years (1984 and 2001).

The limited availability of good quality images (with limited cloud presence) in some departments conditioned this task, especially in mountainous areas. In some cases we relied on images from different seasons, which hampered the visual detection of changes in many areas, particularly the ones related to agriculture due to the seasonality of crops.

The visual analysis process is based on the count of a total of 100 polygons with different shapes and sizes corresponding to wetlands changes to urban and agriculture. Polygons were chosen randomly but looking for an equitable distribution between the two land coverages. Four classes were established according to the polygon size: *Small* (< 2 ha), *Medium* (2-6 ha), *Big* (6-20 ha) and *Very big* (> 20 ha).
Each of the 100 selected areas was compared with satellite images from the year 1984 and 2001 to check the correctness of the change detected (table 11). Depending on the degree of change detection, 3 classes were established:

- **Good:** wetlands conversion to urban or agriculture is clearly visible.
- **Moderate:** partial change (a high percentage of the pixels inside the polygon are transformed from wetland to urban or agriculture).
- **Wrong:** wetlands conversion is wrong (no changes visually detected).

				Detection		
				Good	Moderate	Wrong
ETC Indicator 2	Polygon	Pol. Size (ha)	Samples	Samples	Samples	Samples
Urban	Very big	> 20 ha	5	1	2	2
	Big	6 to 20 ha	12	9	2	1
	Medium	2 to 6 ha	17	9	1	7
	Small	< 2 ha	17	4	7	6
Total Urban			51	23	12	16
Agriculture	Very big	> 20 ha	6	4	2	0
	Big	6 to 20 ha	11	3	6	2
	Medium	2 to 6 ha	16	7	4	5
	Small	< 2 ha	16	3	5	8
Total Agriculture			49	17	17	15
Urb+Agr	Very big	> 20 ha	11	5	4	2
	Big	> 6 ha	23	12	8	3
	Medium	2 to 6 ha	33	16	5	12
	Small	< 2 ha	33	7	12	14
Urb+Agr Total			100	40	29	31

Table 11. Polygon count performed for 100 samples to which the visual change comparison and their detection degree was performed. *Urb+Agr* corresponds to the sum of urban and agriculture polygons.

After counting and checking the polygons ETC/SIA calculated the total surface of each of the classes in order to review their importance and evaluate the change detection quality (table 12). Data reveal that there is relationship between the size of the area of change and the level of detection achieved with the method (see figure 35). Large areas (*Big* and *Very Big*) of wetlands conversion are quite well detected (low *Wrong* percentages). *Medium* and *Small* polygons have more confusions, especially in the second case (*small*) which percentages of success are quite low (*Good* detection class).

In general, urban and agricultural areas present high *Good* and *Moderate* percentages for the different size categories, being 46% and 27% for urban, and 50% and 39% for agriculture respectively (fig 31). Small wetland conversions to urban areas are detected better than areas converted to agriculture. This tendency changes for *Medium* zones where many errors are detected in urban conversions (37% is wrong). *Big* areas are well detected for both agriculture and urban (50% are good conversions). The class *Very Big* has a low number of polygons (around 5) in both cases so it is not too representative for comparisons. In any case, agriculture has better results since the entire surface was classified quite well (no wrong changes).

				Detection					
				Good		Moderate		Wrong	
ETC Indicator 2	Polygon	Pol. Size (ha)	Area (ha)	Area (ha)	%	Area (ha)	%	Area (ha)	%
Urban	Very big	> 20 ha	124.8	20.9	16.7	51.0	40.9	52.9	42.4
	Big	6 to 20 ha	128.7	92.0	71.5	26.1	20.3	10.6	8.2
	Medium	2 to 6 ha	56.8	33.1	58.3	2.4	4.3	21.2	37.4
	Small	< 2 ha	21.1	6.4	30.5	8.7	41.3	6.0	28.2
Total Urban			331.4	152.4	46.0	88.3	26.7	90.7	27.4
Agriculture	Very big	> 20 ha	199.8	139.3	69.7	60.5	30.3	0.0	0.0
	Big	6 to 20 ha	149.7	46.8	31.2	84.6	56.5	18.3	12.2
	Medium	2 to 6 ha	69.4	32.4	46.7	18.4	26.5	18.6	26.8
	Small	< 2 ha	21.0	3.5	16.7	8.2	39.0	9.3	44.3
Total Agriculture			440.0	222.0	50.5	171.7	39.0	46.3	10.5
Urb+Agr	Very big	> 20 ha	324.6	160.2	49.4	111.5	34.4	52.9	16.3
	Big	> 6 ha	278.4	138.7	49.8	110.7	39.8	28.9	10.4
	Medium	2 to 6 ha	126.2	65.5	51.9	20.8	16.5	39.8	31.6
	Small	< 2 ha	42.2	10.0	23.6	16.9	40.2	15.3	36.2
Urb+Agr Total			771.3	374.4	48.5	260.0	33.7	136.9	17.8

Table 12. Visual change comparison results. Surfaces and percentages of each polygon class.

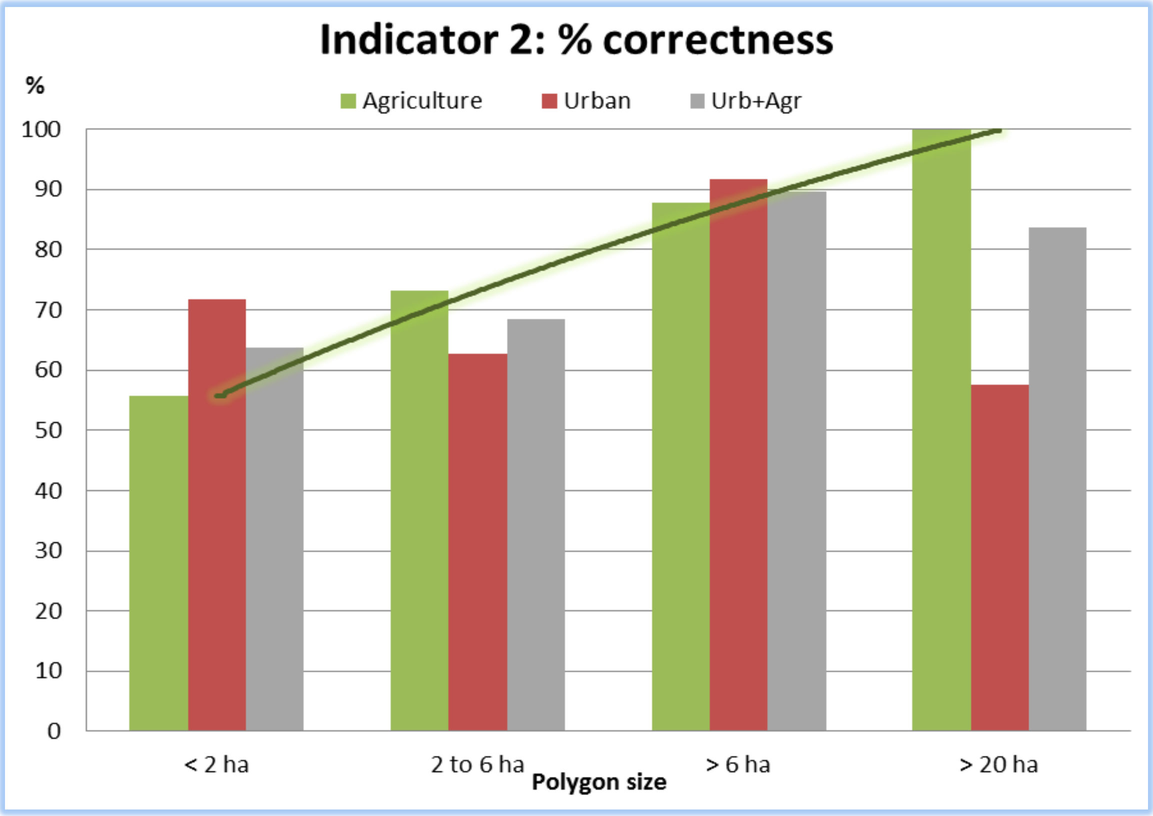


Figure 35. Correctness percentages for Urban, Agriculture and Urb+Agr. Correctness is understood as the sum of *Good* and *Moderate* classes. The trend line corresponds to agriculture.

Out of 100 polygons analyzed by ETC-SIA spread throughout the PACA Region, ranging in size between 0.5 - 47 ha., covering a total area of 771 ha., and that were detected with ETC-SIA's method as having been converted from wetland to either urban or agriculture land between 1984 and 2001, the visual analysis (table 11) concluded that:

- 40% of the polygons had actually been fully converted to either urban or agriculture.
- 29% of the polygons had actually been partly converted to either urban or agriculture.
- 31% of the polygons had actually not been converted.

These percentages are respectively 48%, 34% and 18% of wetland surfaces that were rightly/wrongly assessed as having changed (table 12). Our method provides and acceptable way to assess wetland conversions specially in wetland areas larger than 6 ha. This methodology seems to reach it limitation when the wetland areas are lower than this size.

8.3.3. Corine Land Cover comparisons

ETC/SIA calculated the Indicator 2 surface using CLC 1990 and 2000, and carried out a visual analysis similar to the above. However in this case there is a significant lack of information, as in this case CLC only detect large changes (between 8 and 10 ha) and they are located only in the southern departments (Dept. 13 and 83). The total number of polygons was low (11 in total) so all were analyzed (table 13).

				Detection		
				Good	Moderate	Wrong
CLC Indicator 2	Polygon	Pol. Size (ha)	Samples	Samples	Samples	Samples
Urban	Big	> 6 ha	5	2	2	1
Agriculture	Big	> 6 ha	6	1	1	4
Urb+Agr	Big	> 6 ha	11	3	3	5

Table 13. Polygon count applying the visual change comparison of Indicator 2 using CLC. *Urb+Agr* corresponds to the sum of urban and agriculture polygons.

Total correctness rates (*Good* and *Moderate*) achieved using CLC are much lower than those obtained by the proposed method (table 14). Comparing urban and agriculture, CLC detects better the wetlands conversion to urban areas being around 83% correct to moderate. In the case of polygons analyzed for agriculture is only 35%.

				Detection					
				Good		Moderate		Wrong	
CLC Indicator 2	Polygon	Pol. Size (ha)	Area (ha)	Area (ha)	%	Area (ha)	%	Area (ha)	%
Urban	Big	> 6 ha	47.8	18.8	39.3	20.9	43.7	8.1	17.0
Agriculture	Big	> 6 ha	57.7	9.8	16.9	10.4	18.0	37.5	65.0
Urb+Agr	Big	> 6 ha	105.5	28.5	27.1	31.3	29.7	45.7	43.3

Table 14. Visual change comparison results of Indicator 2 using CLC. Surface and % of each polygon class.

The detection using CLC allows the identification of some changes that ETC/SIA methodology does not. However most of these areas are wrong (figure 36). Only in a few cases real changes are observed, corresponding to wetlands transformation to urban areas. On the other hand, there are areas where changes match in both cases (CLC and ETC/SIA). In these cases, Landsat imagery improves the area detected due to its higher resolution (30 m vs 250 m of CLC).

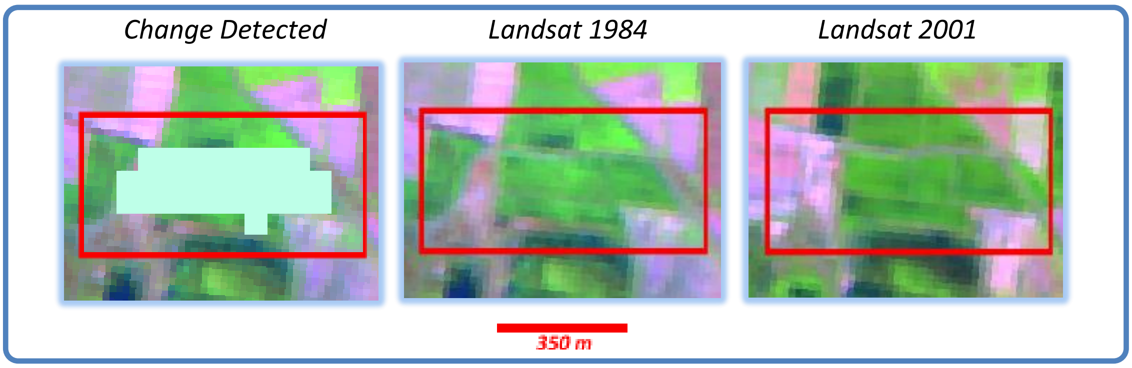


Figure 36. Example of a wetland conversion only detected using CLC, between 1990 and 2000. Green surface correspond to a wrong wetland change to agriculture.

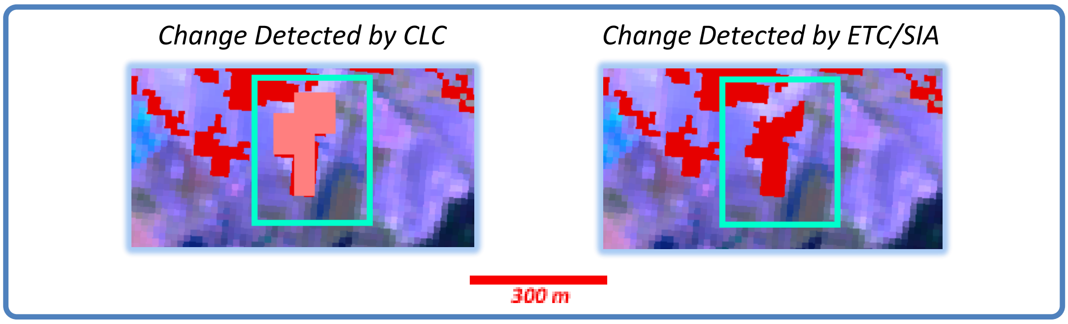


Figure 37. Wetlands to urban conversion detected by both CLC and ETC/SIA. Dark red surfaces correspond to ETC/SIA detection method (Landsat imagery) and light red to CLC. The comparison of both images shows the improvement in surface delimitation though satellite images.

From the 11 polygons analyzes using CLC within the PACA Region, ranging in size between 8 – 10 ha., covering a total area of 105.5 ha., and that were detected with ETC-SIA's method as having been converted from wetland to either urban or agriculture land between 1984 and 2001, the visual analysis (table 11) concluded that:

- 3 polygons had actually been fully converted to either urban or agriculture land.
- 3 polygons had actually been partly converted to either urban or agriculture land.
- 5 polygons had actually not been converted.

This corresponds respectively to 27%, 30% and 43% of the wetland areas assessed (table 14). Therefore, due to these low percentage of detection, CLC does not appear as reliable enough to detect the wetland conversions to agriculture or urban land compared to the satellite image technique.

Chapter 9: Results of Indicator 3

9.1. Results of Indicator 3

In this section, we present a summary of the results of Indicator 3 for departments 04, 13 and 83 which were the only analyzed as the approach for this analysis was based on the availability of valid satellite imagery for the period 2000 - 2012. The detailed datasets and intermediary results corresponding to the analyses performed are presented in Annex 3.
Wetlands in Department 04 are associated with rivers and streams in mountainous areas, so flooding levels are considerably lower than the watersheds for departments 83 and 13 being mainly wetlands in flatter coastal regions.

9.1.1. Department 04

The analysis of Dep. 04 was affected by the complex topography of the mountainous areas. The presence of high mountains increases the appearance of shadows, clouds and snow in the satellite imagery, complicating the analysis and influencing the results, hindering the correct image analysis as these generate multiple confusions in the classification process (Giles, 2001).

This is reflected in the results for Indicator 3 for this department, being presented in table 15. The first table (to the left) shows the flooded surface for each month; the center presents the frequency of inundation, and data to the right corresponds to the Indicator 3 values.
The degree of flooding in January, March and May (around 5,000 ha) is much higher than those in August and October (2,500 ha). This is mainly due to the presence of snow in the first three images causing many classification confusions. The differences are over 2,500 ha (15% of the inventory) so the results are considered not reliable due to this variability. For this reason, we decided to analyze only year 2001 in order to provide some information on the limitations of this methodology in mountainous areas (due to the high quantity of shadows in the images), and the presence of snow (as a limiting factor hindering the detection of wetlands).

Dep 04	
Wetlands inventoried	20,745

2001		
Month	Surf. Flooded (ha)	% Flooded
Jan	5,342	25.75
Mar	5,513	26.58
May	5,252	25.32
Aug	2,536	12.23
Oct	2,440	11.76
All months	5,712	27.53

	2001	
Frequency	Surf. Flooded (ha)	% Flooded
1	134	0.65
2	178	0.86
3	3,073	14.81
4	224	1.08
5	2,103	10.14
Total	5,712	27.53
Not flooded	15,033	72.47

	2001	
Ind 3.	Surf. Flooded (ha)	% Flooded
Mean	4,217	20.33
Maximum	5,513	26.58
Year Total	5,712	27.53

Table 15. Indicator 3 results of Dep. 04 for year 2001. Surfaces are in hectares and percentage.

9.1.2. Department 13 (satellite detected – Ind. 3S)

Wetlands in this department are coastal flat wetlands. They show a high degree of flooding throughout the year. During the period studied (2001, 2007 and 2012), mean water lever covers at least 50% of inventoried surface (table 16). As expected, this percentage seems to be influenced by the seasonality, reaching its maximum during the winter (influenced by rainfall) and spring (rice fields flooding) seasons. Highest flooding percentages are detected in *May 2001, December 2007*, and *January 2012* (being 58%, 51% and 52%). In annual terms (year total), taking into account all the area flooded at least once a year, the degree of flooding of wetlands increases, covering around 56-62% of the area covered by the inventory.

Regarding the frequency of flooding, the results show that most of the surface corresponds to areas that are always flooded (about 40% of inventoried wetlands). The results show that less than 10% of areas are flooded only once a year. When comparing the amount of flooding (surface and %) of the studied wetlands during the studied years, a decreasing tendency is observed (figure 38).

ETC-SIA did not have access to climatic data for the region for this period. In case such information is available, it will be interesting to correlate the temperature and precipitation to the flooding levels.

	2001		2007		2012	
Ind 3S	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	53,278	50.88	52,437	50.08	50,646	48.36
Maximum	60,493	57.77	53,910	51.48	53,939	51.51
Year Total	65,377	62.43	61,449	58.68	58,630	55.99

Table 16. Results of Indicator 3 expressed as surfaces (ha.) and in percentage flooded for department 13 for the years 2001, 2007 and 2012.

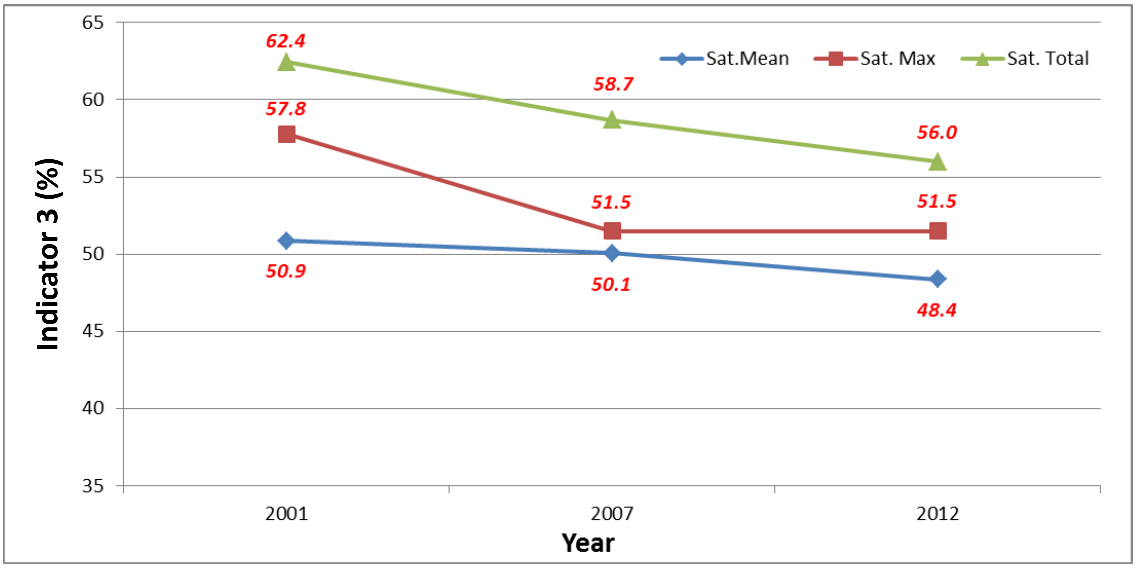


Figure 38. Evolution of mean, maximum and year total values of Indicator 3 (Ind 3S) between 2001 and 2012. Indicator 3S relates to all areas interpreted as flooded from satellite imagery only

9.1.3. Department 83

The results of the level of flooding of wetlands in Dep. 83 prove also to be high where around 37% to 40% of the surface covered by the inventory in this department is flooded throughout the year during the studied period (table 17). As in the case of Department 13, the maximum values are reached in winter (*Feb* 2007, and *Feb* 2012; 41% and 48%) and spring (*May* 2001; 39%). The level of flooding of wetlands shows a slight increase when compared to the mean in 2001 and 2007 (41-43%) that shows to increase more significantly in 2012 (around 52% of the inventory) (figure 39). Regarding the frequency, Department 83 shows a high frequency of flooding with a 35% of the wetlands being flooded almost all year round.

In contrast to Department 13, where flooded area tends to decrease over time (figure 38), the level of flooding of wetlands in Dep. 83 shows an increasing trend (figure 39). Average flooded areas calculated from Indicator 3 show an increase over time (41% in 2001 to 52 % in 2012).

	2001		2007		2012	
Ind 3	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	2,265	36.74	2,423	39.30	2,351	38.13
Maximum	2,375	38.52	2,544	41.26	2,963	48.05
Year Total	2,525	40.95	2,635	42.74	3,208	52.02

Table 17. Indicator 3 results of Dep. 83 for 2001, 2007 and 2012. Surfaces are in hectares and percentage.

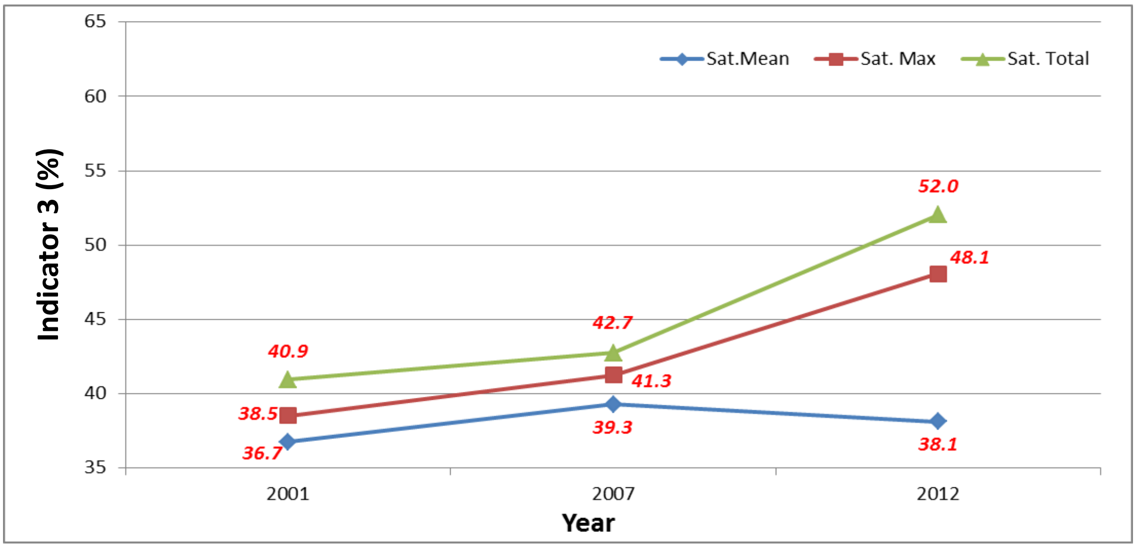


Figure 39. Evolution of mean, maximum and year total values of Ind. 3 in Dep. 83 from 2001 to 2012.

9.2. Influence of rice fields in Department 13

The previous section presented the flooding data obtained for the studied departments through the classification of Landsat imagery. This information only corresponds to water bodies and flooded areas that were detected by the satellite in each image analyzed.

Within Department 13, ETC-SIA performed a deeper analysis to study the effect of rice fields in the results achieved in Indicator 3. As discussed in Section 4.2.2, this analysis was based on including (or not) the cultivated areas (under wetlands) in the analysis of the indicator.
Table 18 presents the specific results obtained for this analysis from Indicator 3 either including or excluding rice field areas of the original satellite imagery classifications. Results are presented in hectares and percentage flooded. For further details, the whole set of data are available in Annex 3.

Results for indicator 3 show a different behaviour whether or not rice field areas are included (Ind. 3R), or when these are included partially (Ind. 3S).

The results during the studied years show that the rice fields contribution to the total area flooded in Dep. 13. This is confirmed by the greater degree of flooding of wetlands when rice fields are fully included in the months of flooding (Ind. 3R) or partially when only using the information detected by Landsat images (Ind. 3S). When the rice fields are excluded (Ind. 3NR), Indicator 3 tends to underestimate the flooded areas showing a significant decrease in total and maximum values (up to 11%), though this difference seems to be less significant when considering the mean values (around 2-3%).

Rice

	2001		2007		2012	
Ind 3R	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	56,476	53.93	53,401	51.00	53,204	50.81
Maximum	65,441	62.49	58,157	55.54	57,028	54.46
Year Total	70,277	67.11	66,086	63.11	66,854	60.57

Satellite

	2001		2007		2012	
Ind 3S	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	53,278	50.88	52,437	50.08	50,646	48.36
Maximum	60,493	57.77	53,910	51.48	53,939	51.51
Year Total	65,377	62.43	61,449	58.68	58,630	55.99

No Rice

	2001		2007		2012	
Ind 3NR	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	51,984	49.64	51,915	49.58	49,953	47.70
Maximum	54,388	51.94	53,715	51.30	53,881	51.45
Year Total	59,473	56.79	59,161	56.50	55,947	53.43

Table 18. Indicator 3 results of Dep. 13 either including or excluding rice fields areas and the original satellite imagery classifications. Surfaces are in hectares and percentage flooded.

Results of Indicator 3 including the rice fields (Indicator 3R) show a decreasing tendency, similar to that seen in the previous section (derived from satellite classifications) although slightly more pronounced. The mean and total values decrease between 2001 and 2012 (figures 40 and 42). The maximum values experience a decreasing tendency (62.5% in 2001 to 55.5% in 2007 after which the inundated area seems to stabilize between the years 2007 and 2012 (figure 41).

On the other hand, when rice fields are excluded (Ind. 3NR) this decreasing trend loses significance. Mean and total values remain similar between the years 2001 and 2007 decreasing in 2012 (figures 40 and 42). Maximum values remain almost constant throughout the period suggesting no significant change in the level of flooding throughout the period.

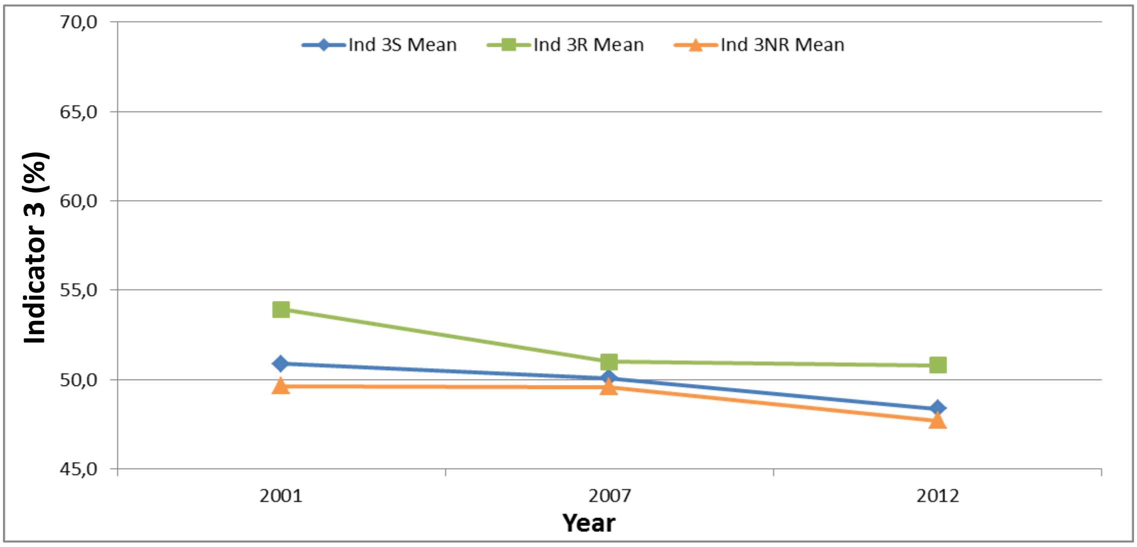


Figure 40. Evolution of mean values of Indicator 3 between 2001 and 2012. Ind. 3S relates to flooded areas detected from the satellite imagery only; Ind. 3NR corresponds to the same but excluding all rice fields; Ind. 3R to the same but considering all rice fields as being flooded between April and August.

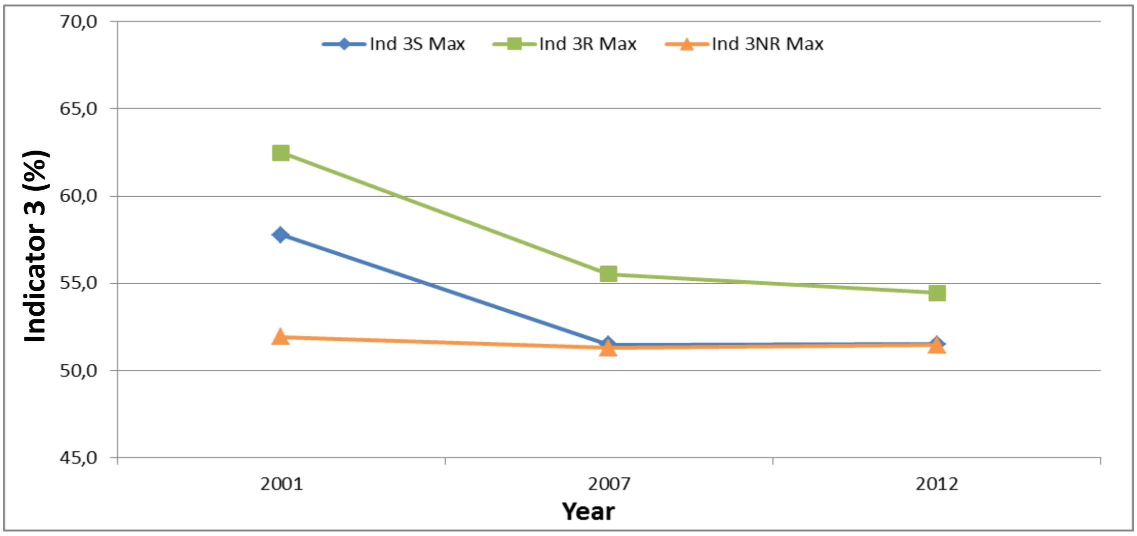


Figure 41. Evolution of maximum values of Indicator 3 between 2001 - 2012. Ind. 3S relates to flooded areas detected from the satellite imagery only; Ind. 3NR corresponds to the same but excluding all rice fields; Ind. 3R to the same but considering all rice fields as being flooded between April and August.

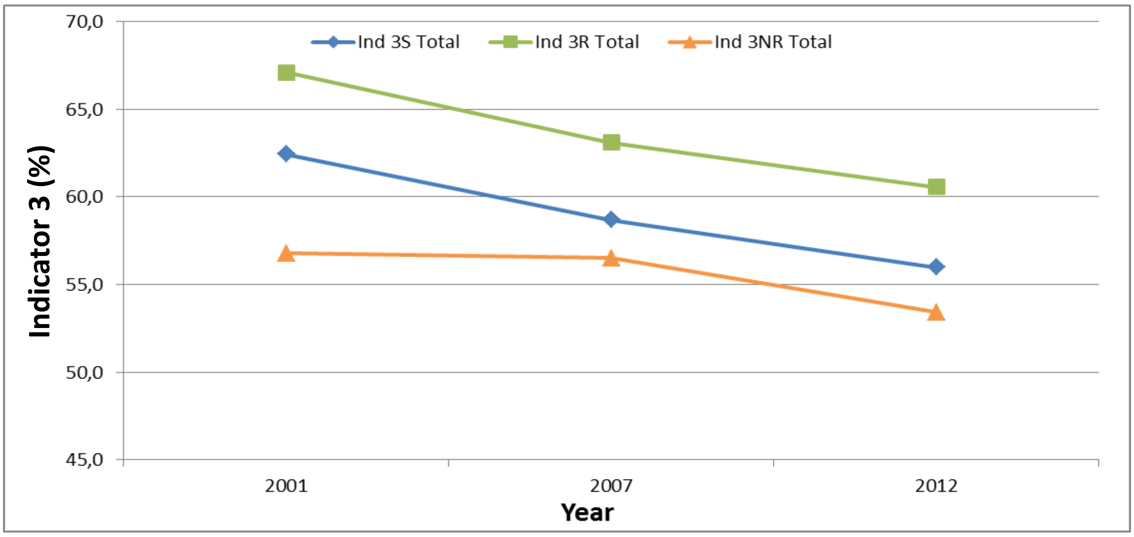


Figure 42. Evolution of total annual values of Indicator 3 between 2001 and 2012. Ind. 3S relates to flooded areas detected from the satellite imagery only; Ind. 3NR corresponds to the same but excluding all rice fields; Ind. 3R to the same but considering rice fields as being flooded between April and August.

Our results suggest that the variability observed between 2001, 2007 and 2012 depends largely on the level of flooding of rice fields and their seasonality. The analysis of data reveal a decline of rice fields between 2001 and 2007 in Dep.13 due to the lower degree of flooding experienced over time. In 2012 Indicator 3 values are quite similar to those of 2007, suggesting a certain stabilisation in the rice fields areas. Table 19 shows the rice field surfaces detected inside the inventoried areas for the years analyzed, which confirm the variation of this agricultural activity. Rice experiences a significant decline between 2001 and 2007 where surface changed from 10.56% to 5.6%, and seems to stabilize in 2012 (7.73%).

Year	Surface (ha)	% Inventory	Annual Variation (%)
2001	11,053	10.56	-
2007	7,073	6.75	-36.01
2012	8,095	7.73	14.45

Table 19. Rice field data for the Dep.13 inventory. Annual variation corresponds to percentages of the initial surface in 2001.

The decreases in mean and total values of indicator 3, when the rice fields are not considered, suggest the potential loss in wetland areas in Department 13. Another hypothesis is related to the effect of precipitation levels over the flooded areas. ETC-SIA did not have precipitation data for the studied years in order to perform a further analysis, and was not able to confirm the relationship between the rainfall and the declines of flooding degrees observed.

9.3. Flooding of wetland types in the PNRC

9.2.1. Analysis of descriptive statistics

Table 20 shows the descriptive statistics for wetland types included in the LULC layer. These data correspond to the average value of the maximum frequency of flooding (*mean* column) for all the polygons of the layer for the three studied years (*samples* column of table 20).

A clear difference in behaviour between wetland types was revealed based on the frequency of flooding. Wetlands were sorted and classified according to their flooding mean values. So the categories *Very low, Low, Medium* and *High* refer to the duration and magnitude of flooding in a particular wetland type.

These results, presented in table 20, are reliable as the wetlands that are often flooded, such as ponds, saline and open marshes, show high mean flooding values (mean > 4). Intermediate flooding is assigned to marsh emergent vegetation and reed that are present in rather transitional zones. Other wetland types, such as grasslands and meadows, are flooded less frequently as they are normally present on more elevated areas within a wetland profile (transitional zones). These wetland types show mean values of less than 1, reflecting the short seasonality of their flooding.

Wetland Type / Land Use	Mean	Samples	Flooding Category
Meadow	0.05	496	Very low
Grassland	0.33	3,296	Very low
Rice field	0.98	6,891	Low
Rushes	1.65	3,623	Low
Salt low meadows	1.99	4,549	Low
Bare soils	2.31	3,189	Medium
Salt high meadows	2.49	5,776	Medium
Other marsh emergent vegetation	3.20	896	Medium
Reed	3.30	2,052	Medium
Open marsh	4.38	3,741	High
Saline	4.80	905	High
Lagoons and ponds	4.96	779	High
Total	3.41	36,193	-

Table 20. Statistics on wetland types included in the LULC layer presenting the mean value of the maximum flooding of all the studied images (ranging from 0 to 5), the number of samples studied, and their flooding categories (ranging from *Very low* to *High*).

The mean values calculated in terms of maximum flooding frequency are in line with the behaviour of a typical wetland area profile (figure 43), where the lowest areas experience higher flooding frequencies than the higher wetland types as they receive more inputs of water due to runoff from rivers and snow melting, in addition to tidal influences in the case of saline and coastal lagoons and ponds (table 20).

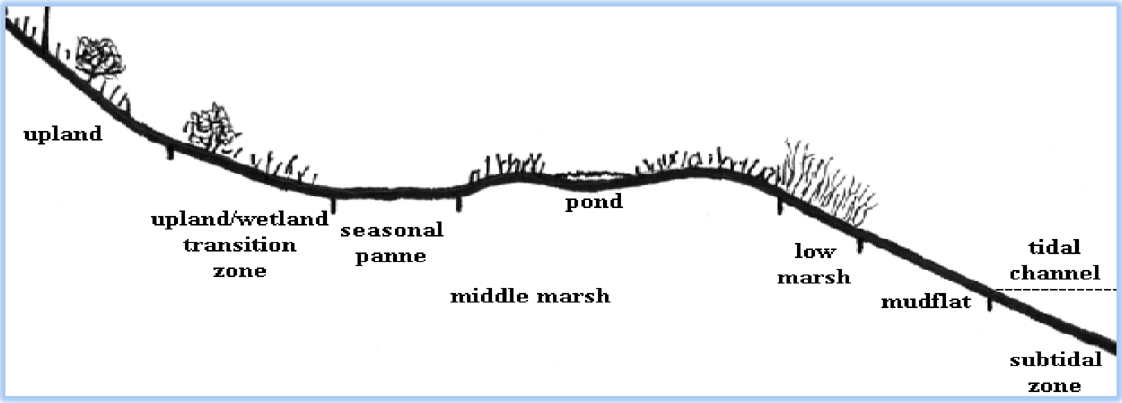


Figure 43. Profile of a wetland. Modification of *Daily, Reish, and Anderson (1993*).

The map of flooding frequency (figure 44) shows the flooding frequency layer of the PNRC in 2007 and the digital terrain model provided by TdV (50 m MNT from the National Institute of Geography of France). It is clearly observed that wetlands are located mainly in the areas of lower elevation where flooding frequencies are much higher (darker blue).

Our results also indicate that the areas closest and mostly connected to the coast line are the most flooded regions due to the water contributions (rives, tidal inputs, etc.). This provides an overview of the clear differences between the degree of flooding of different wetland types, namely, open marshes, meadows, rice fields, etc.

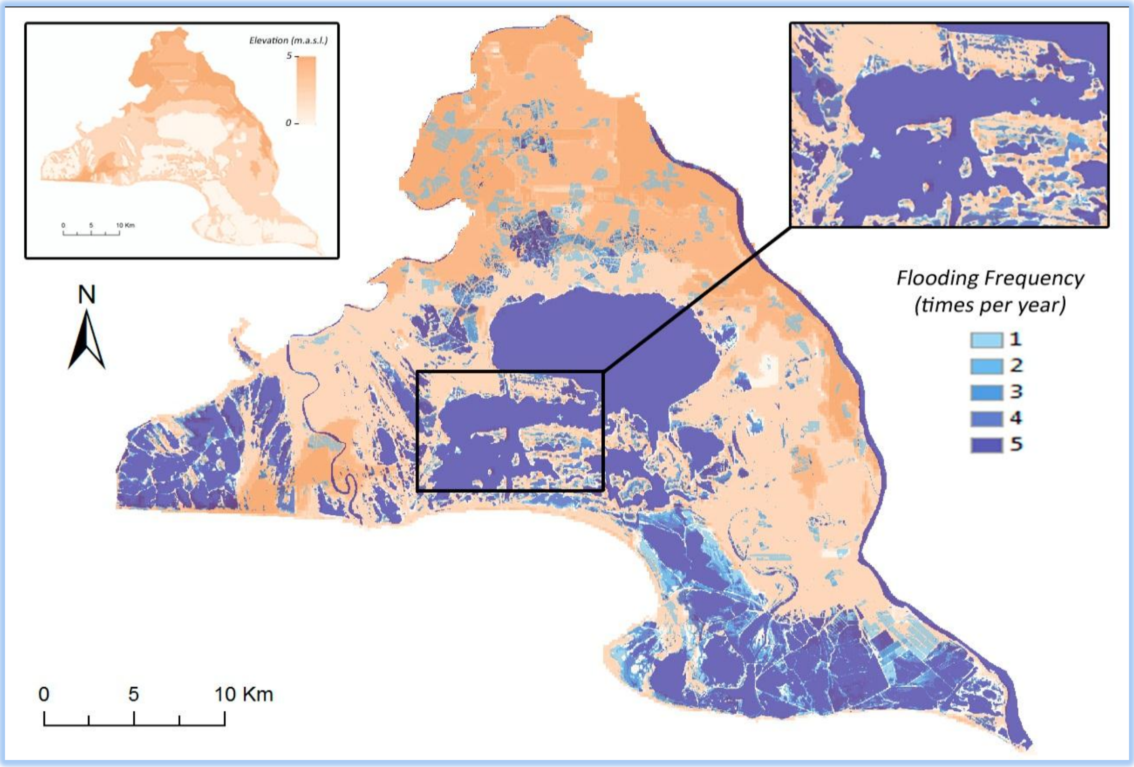


Figure 44. Frequency of flooding map of the PNRC in 2007 (blue tones) and the digital terrain model (brown tones) showing the location of wetlands being mostly situated at low elevations.

Figure 45 provides a detailed overview of the evolution between the years 2001, 2007 and 2012 of the maximum frequency of flooding per wetland type studied. Different flooding categories are easily distinguished based on the wetland type:

❖ <u>Very low:</u>

Meadows and Grassland have low means with slight variations throughout this period. This type of wetland is flooded with low frequency because they are typically located on the uplands where floods are not very frequent (figure 43).

❖ <u>Low:</u>

Wetlands included in the Low category present higher mean values of the flooding frequency. Rice field values have a similar trend that seen for their surface in section 4.3.2: a decrease between 2001 and 2007, and a slight increase in 2012. Crop seasonality explains its low degree of flooding as they are flooded just a few months each year.

Rushes and Salt low meadows have higher flooding levels since they are natural wetlands from lower lands. They are more conditioned by the rainfall and the seawater inputs. Salt meadows have a trend quite similar to the rice. The big decline in 2007 could be related to major changes in precipitations and flooding from external sources (artificial canals, for example). The results show that the flooding levels of rushes seem to be more stable with a slight tendency of increasing flooding over time in the studied year.

❖ <u>Medium:</u>

Wetlands in the Medium category have flooding values significantly higher than the previous ones. Reed, bare soils and other marsh emergent vegetation are related to areas very close to the water bodies located in the deepest parts of the basin, so they are flooded more frequently. Water inputs are also common in the salt meadows since they are linked to the seawater inputs coming from the coast.

Bare soils and other marsh vegetation present a decreasing trend that could be related to human activity and a continued decline in the precipitations. As they are in higher areas than lagoons and ponds the effects of the rainfall are more noticeable since they require significant precipitations in order to be flooded. They are also more vulnerable to be transformed for other activities such as agriculture.

❖ <u>High:</u>

High category corresponds to wetlands that are always flooded. They are the areas where runoff water is collected and the groundwater reaches the surface, and they also receive contributions from the marine tides (figure 46).

The mean values remain very constant during the study period probably because their inputs are more regular. There is a slight decreasing trend probably related with the precipitations (less water inputs) since they are deep areas not so vulnerable to human activity (transformation in other land uses).

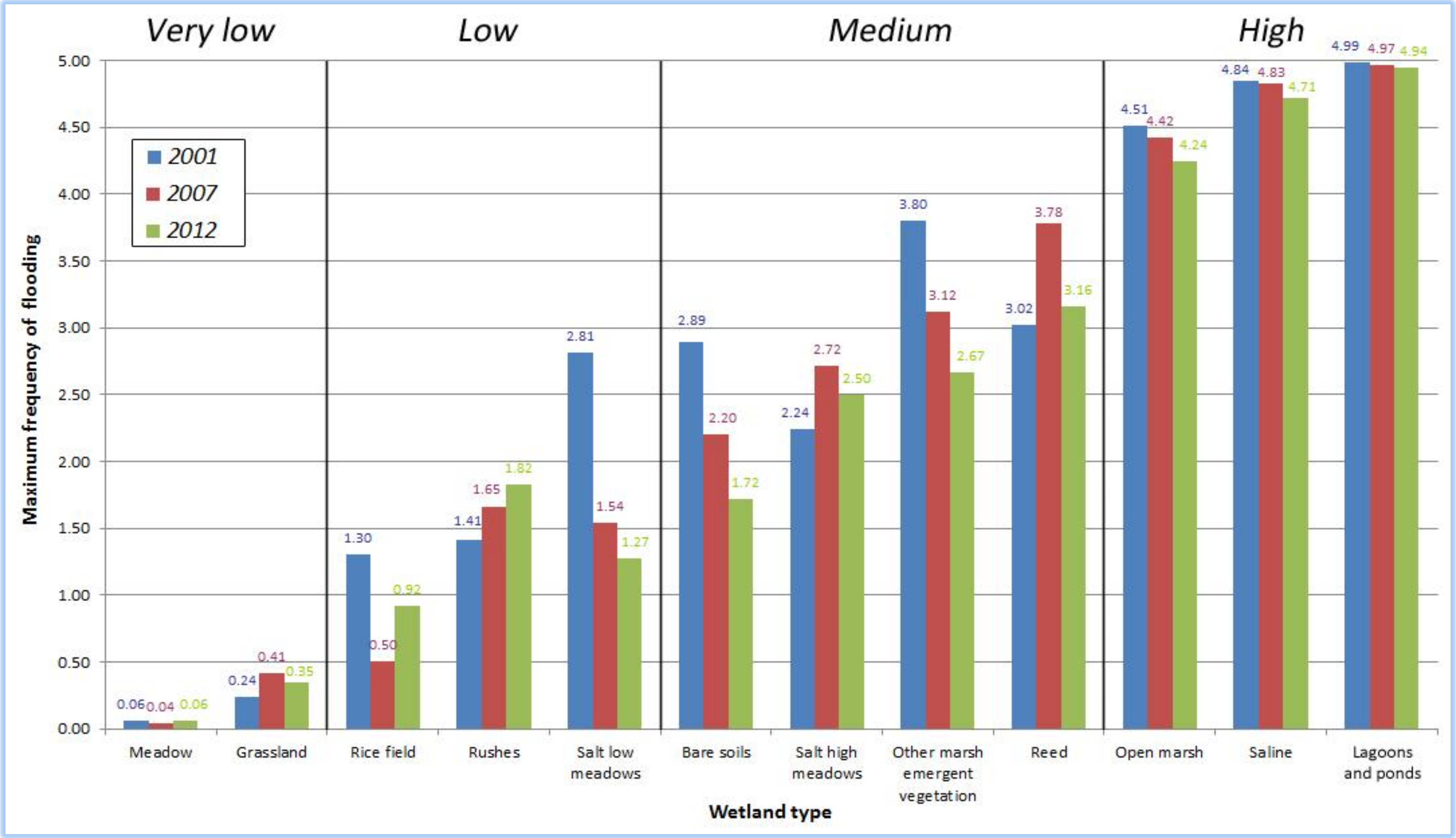


Figure 45. Evolution of the mean values of the maximum flooding frequency between 2001 and 2012 for the wetlands types of each flooding category.

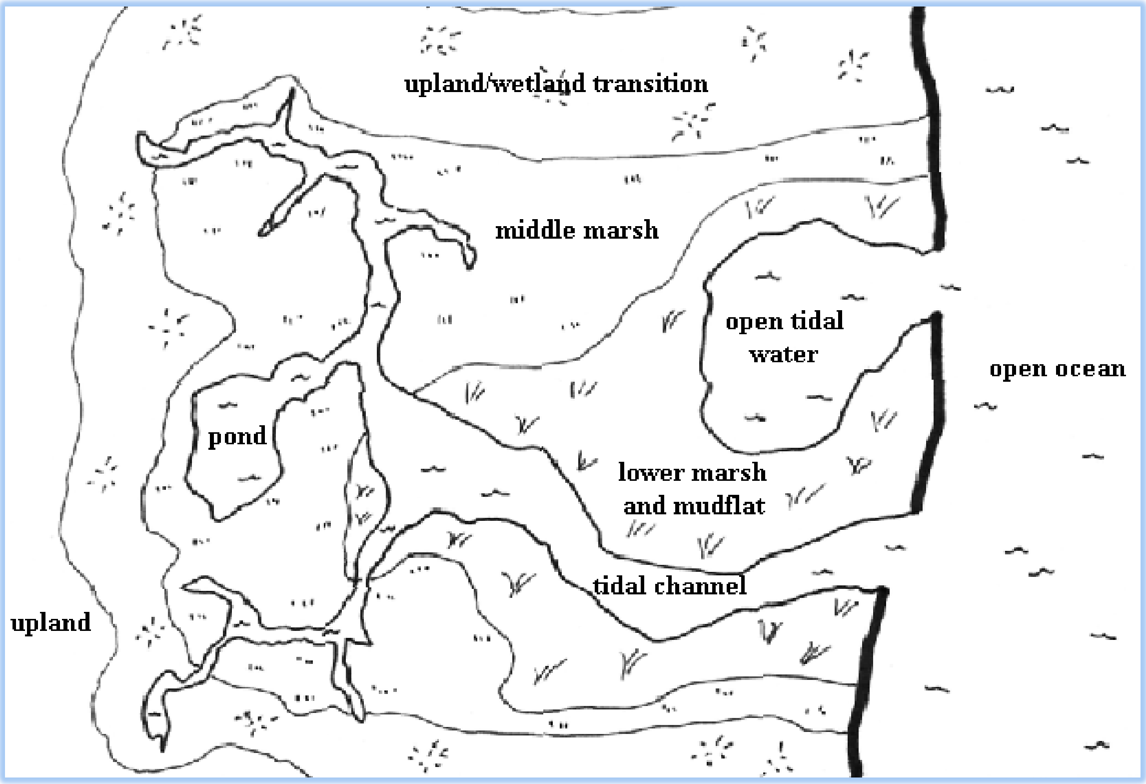


Figure 46. Diagram of a wetland. Modification of *Daily, Reish, and Anderson (1993*).

9.2.2. ANOVA results

We tested the relation between wetland type and the frequency of flooding further though an ANOVA. The results show a statistically significant relation between the flooding level and the wetland type being the P-value close to 0 (table 21). Furthermore, the flooding frequency seems to be influenced by the studied year as well, suggesting that more factors need to be studied in the future such as the climatic variation that differs from one year to the other, especially in the case of the Mediterranean region.

Annex 4 shows more detailed results which highlight the significant difference present between each type of wetland in terms of the flooding frequency, suggesting a link between the type of wetland and its degree of flooding. According to the ANOVA results, mean flooding differences for each wetland type are statistically different from each other for a confidence interval of 95%, being the P-value very close to 0 in most cases. Differences between flooding groups *Very low, Low, Medium* and *High* are also very clear, being wetland types in the same group statistically more similar between them.

Source of variation	df	F	P
Studied year	2	70.26	< 0.0001****
Wetland type	11	6538.47	< 0.0001****
Studied year * Wetland type	22	61.6	< 0.0001****
Residuals	36.132		

****P<0.0001

Table 21. ANOVA results for the relation between the land use type and the studied year on the level of flooding of wetlands.

- Part IV -

General Discussion

Chapter 10: Discussion

10.1. Indicator 1

Indicator 1 proved to be a valid indicator to calculate wetland surfaces in a Mediterranean context. The best results were reached in Department 13 including the PACA region. The indicator proved to be affected by topography and wetland nature. The best results being in flat areas having water bodies (polygons), and the wetland surface detected and its distribution largely corresponds with the reference layers from a spatial perspective (visually are quite similar). Potential wet areas identified outside the inventories, those that do not match with the references, should be verified on the field.
The indicator behaves less accurately in the rest of the departments where the percentage error ranges between 45% and 70%. Due to the complex topography of alpine areas (Dep. 05, 04 and 84) the results are less accurate suggesting that the topography negatively affects the behavior of Indicator 1.

The accuracy of Indicator 1 can be improved using different classification techniques, whenever the visual characteristics of each type of wetland, such as water bodies, associated vegetation and rice fields, were considered. Furthermore, the use of multiple masks to conflictive areas of the territory has improved the final results reducing the errors. The masks are critical in the mountainous areas of the PACA region due to the nature of wetland, as discussed before, consisting of linear features, namely small and narrow rivers.
The use of different classification techniques and masks improves significantly the results, comparing with those obtained by TdV, especially in departments 05, 04 and 84. Error B is reduced by the ETC-SIA, but Error A does not experience great change.

The wetlands in the PACA region showed a different behavior overtime where wetlands between the studied period (1975, 1984 and 2001) decreased in surfaces in the littoral areas of the PACA region (Dep. 13 and 83) and showed a slight increase in the alpine side based on our results (table 7). However as there is no inventory of wetlands or land use layers for these dates, it is quite difficult to validate the accuracy of the results obtained.

Although ETC-SIA improved the developed methodology throughout the research and minimized classification errors, some limitations were reached in the image analysis process being mainly related to data or image resolution used, so improvements, corrections or the use of new information could improve even more the results.
Mountainous areas in the northern departments have a number of difficulties already mentioned previously. The complex topography showed to complicate the process affecting negatively the classification accuracy. Although the use of MNT has significantly improved the results, some limitations still exist being:

- ✓ **Presence of clouds shadows and snow**. The images require a special pretreatment (slower process) and they add accuracy errors.
- ✓ **Homogeneous appearance.** Wetlands are not well defined, not as in the case of Dep. 13. It is difficult to distinguish them from other land covers (e.g. riparian vs hill forest).
- ✓ **Wetlands inventories in these areas seem to be mainly based on water bodies and courses.** Narrow rivers and streams are not well detected by the satellite image. In this case, the image resolution is a limiting factor for the accuracy of the results. Flux accumulation lines add much information that is not inventoried (increases of error A).

During the development and verification phases of Indicator 1, the wetland inventories used as reference layers to test the preciseness of the indicator showed to omit wetlands that we were able to detect visually through the satellite images. Therefore, it is hard to know how far the error A is real indicating that the inventories may have some limitations. In this case, some areas might need some "Ground truthing" in the future to make sure of the accuracy of the results.

Related to the above, there are also areas in the inventories that do not seem as wetlands on the satellite image. These areas are not detected by the satellite image classification because they have no elements, such as water or wet vegetation areas that may allow distinguishing them from other coverages. In addition small plots of land, such little rice fields, water bodies and rivers, are inaccurately classified or not detected.

A limitation of Indicator 1 is related to the classification process, where confusions between wetlands and other classes are frequent, especially in the case of non-vegetated areas such as dry salines, river banks, urban areas or rock and bare soil. It is also difficult to distinguish wetland vegetation from other types of natural vegetation. In fact, this is the main source of errors A and B. In the first case by taking areas outside the inventory, and the second the software do not choose wetland classes by mistake (this results in an increased error B).

All these highlight certain limitations of the Landsat spatial and spectral resolution to detect some of the wetland elements that require a higher level of detail.

Based on the limitations discussed of Indicator 1, some future improvements in the methodology are possible. Namely, errors A and B can be minimized creating a buffer area around the inventories features (or use them directly) and conducting more specific classifications inside their areas using fewer classes and lower thresholds. This will enable the detection of further wetlands. On the other hand, land use reference data, like CLC, could be used to masking some conflictive coverages such as crops and urban areas, and reduce errors rates.

Due to the time restrictions of the research period, further tests of Indicator 1 based on the recommendations stated previously were performed and tested for the PACA region using these new changes. This improved the results significatively where error A experienced a great decrease in the case of alpine departments with an improvement of 45% in the Dep. 84, and around 20% for Dep. 04 and 05, while error B improvements are around 15% in these areas. For Dep. 13 error A and B are of 3% and 6% respectively.

The detailed analysis and results obtained are presented in **Annex 5 – Indicator 1 Improvements**.

10.2. Indicator 2

Indicator 2 shows very variable results depending on the analyzed area, as it is particularly affected by all the shortcomings discussed earlier such as image quality, lack of references, etc. While in the PNRC and the Dep. 13 the detection of changes in wetlands showed good results, in the rest of the PACA region, where remote sensing is more conflictive, the results were less encouraging, presenting frequent errors of considerable size making difficult the data interpretation.

A correlation between the wetland size and change detection were detected (figure 35). Large areas showed a high detection rate (around 80% - 90%). Growing areas, where agriculture or urban use expands over wetlands, are detected better than those that arise sporadically or areas that are isolated having few isolated pixels. Wetland transformation into urban areas is very low in the PNRC, so the changed surfaces are not very representative for an analysis of the classification accuracy mainly because each pixel that is outside the inventory adds a significant error.

It should be noted that the quality and accuracy of the information obtained by calculating this indicator is limited by the surface of wetland detected by the Indicator 1, being this layer used as reference of wetlands during the process. Therefore, a large part of the Indicator 1 errors are dragged to the results of the Indicator 2.

To a lesser extent, some error were introduced by the agricultural and urban areas wrongly classified, despite a pretty good level of detection was achieved using the CLC masks (around 85%).In urban areas, classification errors showed to be related to water bodies (figure 32) and some areas that can be detected visually in the satellite image but are not considered as urban1 in the LULC layer. Therefore they are considered as errors when comparing with the reference. Agricultural areas incorrectly classified correspond to wetland vegetation (figure 32) which CLC includes as agriculture by mistake or by its highest resolution.

Though Indicator 2 shows good results in many cases where major changes occurred over time, the presence of so many errors, especially in the case of small changes, requires a strong visual review as it is not possible to compare the results with a good reference information from the field as it is not available at the moment.

During the analysis of Indicator 2 it was possible to perform a short evaluation of the use of CLC to monitor wetland conversions into agriculture or urban areas. Results show that CLC only detects a few changes that have a significant size (around 8 - 10 ha).
ETC-SIA detects a greater amount of changes using satellite imagery. Conversion size reaches small areas (less than 2 ha) but there is an important percentage of errors. When CLC and ETC-SIA Indicator 2 match, the areas of change detected by ETC-SIA have greater accuracy with reality, mainly due to the better spatial resolution of Landsat imagery (30 m versus 250 m).

The transition areas between land and water detected by Indicator 2 present some classification errors as they are regions where land cover is not well defined. There are color gradients in the image that cause confusions, so the urban and agriculture layer overlaps with the surfaces of wetlands detected by the Indicator 1. This is the case, for example, of land plots with elongated shapes, like the edges of rivers or some farming areas, where wrong wetlands conversions are notable (annex 2).

Analyzing more deeply the errors, ETC-SIA proposes different improvements in the methodology of the Indicator 2. Performing new supervised classifications with different thresholds could avoid some of the errors mentioned for urban and agriculture, improving the change detection accuracy, for example: confusions in water-land transition areas. In addition, other references can be used to masking urban and agriculture areas such as the Soil Sealing layer from the European Environment Agency (EEA). On the other hand, improvements of Indicator 1 results in different ways could avoid some of the troubles discussed.

10.3. Indicator 3

The methodology developed for Indicator 3 provided very accurate and consistent results. In departments 13 and 83, where image quality is pretty good, the analysis of the indicator is very successful. The degree of flooding of wetlands is quite high in these departments. Dep. 13 shows a decreasing trend in the Indicator 3 between 2001 and 2012, while in Dep. 83 the degree of flooding is increasing. In this case it should be noted that flooding is notoriously variable in the Mediterranean climate.
Dep. 04 results are quite variable depending on the quality of the image by the presence of clouds, snow and shadows, showing the limitations of this methodology in mountainous areas.

According to the rice fields analysis, a significant portion of the variability in the flooded areas of the Dep. 13 depends largely on rice fields and their seasonality. Results show notable differences between include or discard them from the analyses. Data reveal a steady decline of rice between 2001 and 2007.

Moreover, the ANOVA results prove a significant relation between the wetland type and the frequency of flooding. Results showed that each type of wetland determines the degree of flooding whose magnitude and evolution can be explained by the different characteristics of these spaces (location, topography, water inputs, etc.).

From the viewpoint of the availability of images, Indicator 3 is the one that bears most constraints comparing to indicators 1 and 2, because 5 to 7 good quality satellite images are needed to analyze a complete year with reliable results. On the other hand, the lack of meteorological data, in particular the precipitation, also has limited the analysis of the spatial data and the interpretation of results.

The topographical and climatic conditions in the PACA region affect the availability of images free of cloud, snow and excessive shadows, which are very conflictive when analyzing the Greenness and Wetness values of the images (many classification confusions). For most departments, there are 2 - 3 good images per year, sometimes 4. The main problem is that the temporal distribution is very irregular, hindering to make comparisons between departments periodically or at the same times. Therefore, Indicator 3 calculation at regular intervals will be less reliable than for others.
Regarding the limitations by using Landsat imagery, they are practically the same as those seen for Indicator 1. However, it is noteworthy that the water in many areas of the alpine departments, such as narrow streams, is virtually undetectable because of its small size (close to the Landsat 7 ETM+ resolution), as this significantly affect the quality of the results and makes impossible analysing some areas of the region. There are still some little classification mistakes between water and other classes, especially in the case of urban areas or rock and bare soils.

Future analyses could be performed including climatic data such the precipitation and temperature. It is possible to find trends related to these climatic variables, the degree of flooding and the wetland type to better understand the results and improve their interpretation.
The application of radar remote sensing for the northern departments could solve some problems experienced with the Landsat imagery. Radar allows the detection of soil moisture, water and snow water content without disturbance of clouds or other meteorological agents. In addition, the soil texture can potentially be estimated from a time series of measurements during a drying period following precipitation (*Inggs and Lord,* 2001).

- Part V -

Final Conclusions

Chapter 11: Conclusions

This research provides an overview of the benefits and limitations of using satellite imagery and remote sensing techniques for monitoring wetlands.
Indicator 1 provides reasonably good results from the perspective of wetland monitoring. The results are affected negatively by topography. In mountainous regions the information is sometimes overestimated, but in general terms the wetland surface detected largely corresponds with the wetland inventories.
Indicator 2 showed some good results for specific changes but presented frequent errors of considerable size making difficult the data interpretation. Therefore, it does not allow tracking reliably wetlands conversions to agriculture or urban for the whole PACA region.
The methodology developed for Indicator 3 provided very accurate and consistent results for most images analysed, and allowing the correct monitoring of wetland flooding seasonality.

This research proved that the use of SRS techniques improves the results reached so far using traditional references layers such as CLC. The environmental conditions of the PACA region such as climates and geomorphology showed to have some limiting effects on the analysis in some cases, mainly in the alpine departments of the region (Dep. 05, 04 and 84).

The climatic and topographic characteristics significantly limit the availability of good quality images due to the presence of clouds and snow. So the periodic analysis of the mountainous departments could be hindered in some cases.
The topography determines the presence of shadows in the mountainous areas of the region, so that the processes of image classification increase the level of errors. In addition, the snow also causes serious problems with the accuracy of the classifications.

The nature of wetlands showed to affect the accuracy of the indicators results. While in southern areas of the PACA region the wetlands are large and well defined (Dept. 13 and 83), the alpine areas show a very homogeneous appearance, with wetlands mostly poorly defined or with small size and elongated shapes, that make difficult to distinguish them from other land coverages, especially of other natural areas such as forests and grasslands.

Moreover, the analysis of the results is hindered by the limited availability of reference or ground data in most areas of the region, and for the errors or discrepancies in the information currently available. Sometimes wetland inventories do not include areas whose appearance seems to correspond to a true wetland. In the same way, there are areas inventoried as wetlands that do not look like them from a visual standpoint. These areas are not detected by the satellite image classification as they do not have visual elements that may allow distinguishing them from other land coverages.
The most detailed ground information belongs to the PNRC. Therefore, most complex analyses are focused exclusively on this area. It is not possible to make a detailed validation of the results throughout the entire PACA region.

Landsat imagery of 30 m resolution and present free of charge proved to support efficiently the monitoring of wetlands within the PACA region. The best uses are for the detection and monitoring of flooding and the identification and calculation of wetlands.
Results for the analysis of the indicators in the alpine departments of the PACA region are not the best because of the problems commented before. However, in Department 13, where we find most of the wetlands in the study area, it has been shown that the indicators provide accurate results since it is possible the correct validation of the data with the existing field references. Therefore, despite these adverse effects, it was possible to develop a methodology for each of the indicators providing reasonably good results facing the telematic monitoring of wetlands, and improving the current use of Corine Land Cover.

Chapter 12: Further research

Following the development and analysis of the indicators, ETC-SIA proposes different solutions and improvements to solve the identified problems as well as some recommendations for future studies and more detailed researches:

Some of these proposals have already been put in place to make improvements in the methodology of the indicator 1 (see Annex 5 – Indicator 1 Improvements).

- Wetlands and water bodies High Resolution layers (HRL) from GIO. Seamless pan-European HRL with specific land covering characteristics of 5 main land cover types for the same reference year 2012 are currently being produced as part of the Land Monitoring service in the framework of the GMES Initial Operations (GIO) phase. The main scope of the high resolution layers is to provide a set of land cover characteristics that can be used as attributes to different kind of map objects, such as NUTS20, CLC polygons, regular grids, designated areas, etc. The 5 HRL layers are on Forest, Agriculture/Grasslands, Wetlands, and Water bodies.

  The 2 layers that are of special interest for this project are the layers on:

  - **Wetlands:** mapping of wetlands for designated areas of international importance (e.g. from the Ramsar Convention and European classifications) at a 20 m resolution.
  - **Water bodies:** mapping of small inland and coastal surface water based on high resolution satellite images at a 20 m resolution.

- Obtain higher resolution satellite imagery (both special and spectral):
  - Higher level of detail. Better spatial resolutions could resolve some of the difficulties, as the case of narrow water courses or small land plots.
  - A greater number of spectral bands, especially in the infrared, would reduce confusions between classes besides allowing separate various types of vegetation and soils.
  - Other image index and detection techniques could be applied.

- The application of radar remote sensing for the northern departments could solve some of the problems experienced with the Landsat imagery. Radar allows the detection of soil moisture, water and snow water content without disturbance of clouds or other meteorological agents.

- Other references can be used to build better classification masks. In addition, the existing information could be improved using the new data from the analysis of the three indicators.

- Climatic data such the precipitation could be included for future analyses of the Indicator 3. It would be possible to search trends related to these variables, the degree of flooding and the wetland type to improve the results and their interpretation.

- Part VI -

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Chapter 13: References

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- Annexes -

Annex 1:

Datasets and Spatial Information– Part II, Chapter 3

Data Type	Layer	Resolution	Years	Format	Details
Satellite Imagery	Landsat 2 MSS Imagery	60 m	1970s	Raster	Landsat 2 Multispectral Scanner System imagery: 4 multispectral bands. - General info: http://landsat.gsfc.nasa.gov/about/landsat2.html - Technical info: http://landsat.gsfc.nasa.gov/about/mss.html - Imagery source: http://earthexplorer.usgs.gov/ http://glovis.usgs.gov/
	Landsat 5 TM Imagery	30 m	1980s	Raster	Landsat 5 Thematic Mapper imagery: 7 multispectral bands. - General info: http://landsat.gsfc.nasa.gov/about/landsat5.html - Technical info: http://landsat.gsfc.nasa.gov/about/tm.html - Imagery source: http://earthexplorer.usgs.gov/ http://glovis.usgs.gov/
	Landsat 7 ETM+ Imagery	30 m	2001 - 2012	Raster	Landsat 7 Enhanced Thematic Mapper (ETM+) imagery: 7 multispectral bands and pancromatic data. - General info: http://landsat.gsfc.nasa.gov/about/landsat7.html - Technical info: http://landsat.gsfc.nasa.gov/about/etm+.html - Imagery source: http://earthexplorer.usgs.gov/ http://glovis.usgs.gov/
Ground Reference Data	Aministrative Limits layers	-	-	Shapefile	Administrative boundaries of the Provence-Alps-Blue Coast Region (PACA Region) and the Carmague Regional Nature Park (PNRC), and also the limits of the Rhone mediterranean watershed. Provided by Tour du Valat.
	Wetland Inventory layers	-	2001 - 2012	Shapefile	Water bodies inventory of the Provence-Alps-Blue Coast Region. This set of shapefiles contains the main water bodies in the PACA Region (marshes, rivers, etc.) and data on its surface in hectares. Provided by Tour du Valat.
	Land Use/Land Cover layers	-	2000, 2006, 2011	Shapefile	Information on the types of land use of the PNRC for the years 2000, 2006 and 2011, and the surface of the different areas in square meters. Provided by Tour du Valat.
	Corine Land Cover	250 m	1990, 2000, 2006	Raster	Land use coverage through interpretation of Landsat and SPOT imagery. The database has been modified to extract only the classes concerning to Agricultural and Urban areas, Wetlands, and Water Bodies (without Sea and ocean). - More info: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2 http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-raster-2
Ancillary Data	Numerical Model of the Territory (MNT)	50 m	2001	Raster	Elevation data for the PACA region (National Geographic Institute of France). Provided by Tour du Valat.
	Aerial photography	-	2000 - 2011	Raster	Aerial photography available through Google Earth service. - Software source: http://www.google.com/intl/en/earth/index.html

Table 1. Datasets and spatial information used by ETC-SIA throughout its contribution to the RhoMeo program.

Annex 2:

Indicator 2: Wetlands conversions – Part III, Section 8.3

Below are shown some examples of the changes detected in Indicator 2 in order to illustrate some of the effects and errors discussed.

➢ Wetlands conversions:

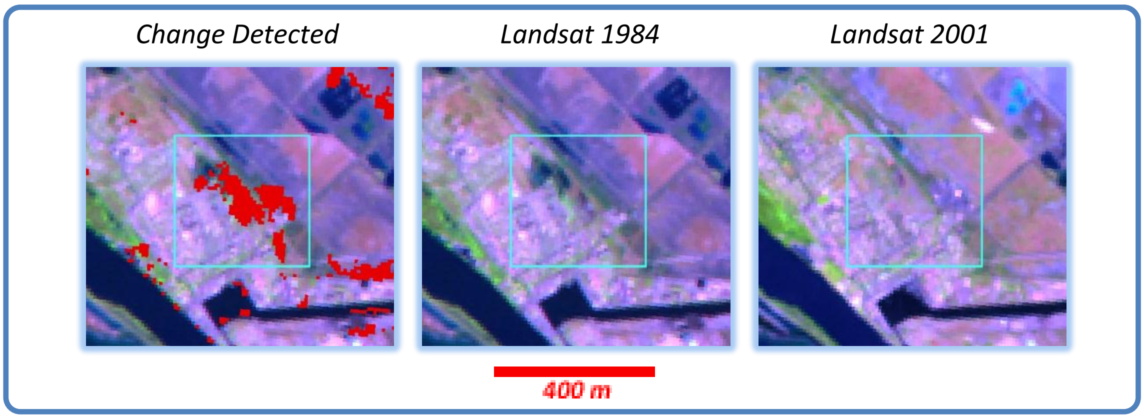

Figure 1. Wetland conversion to Urban in Dep. 13 (red color) vs. Landsat images for 1984 and 2001. The change is well detected.

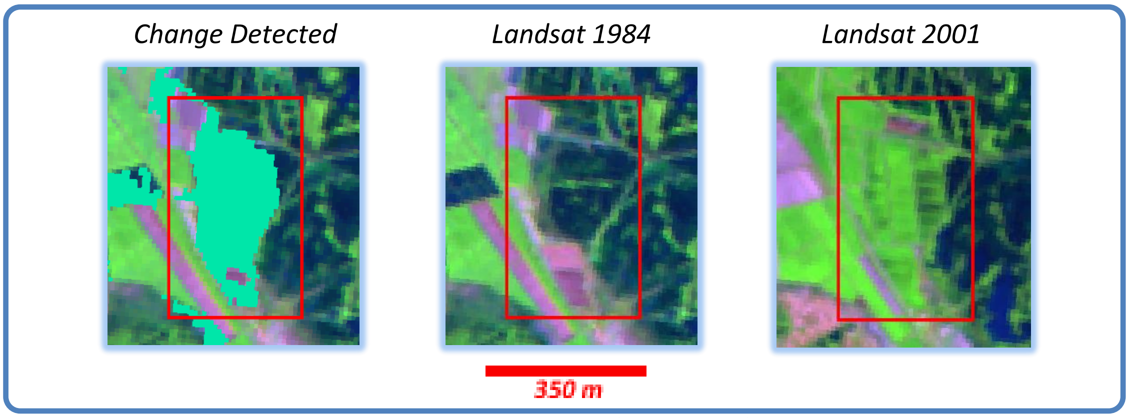

Figure 2. Wetland conversion to Agriculture in Dep. 13 (green color). Change is real.

- <u>Errors of change detection:</u>

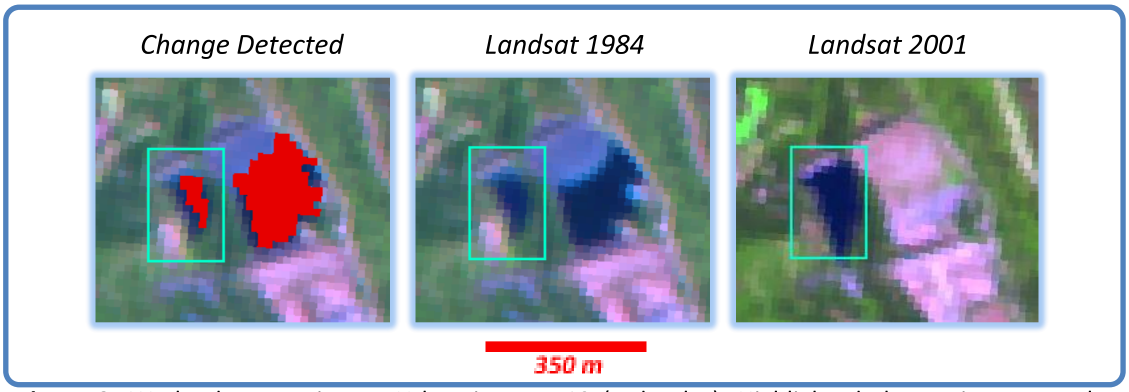

Figure 3. Wetland conversion to Urban in Dep. 13 (red color). Highlighted change is wrong. The largest red surface is correctly detected.

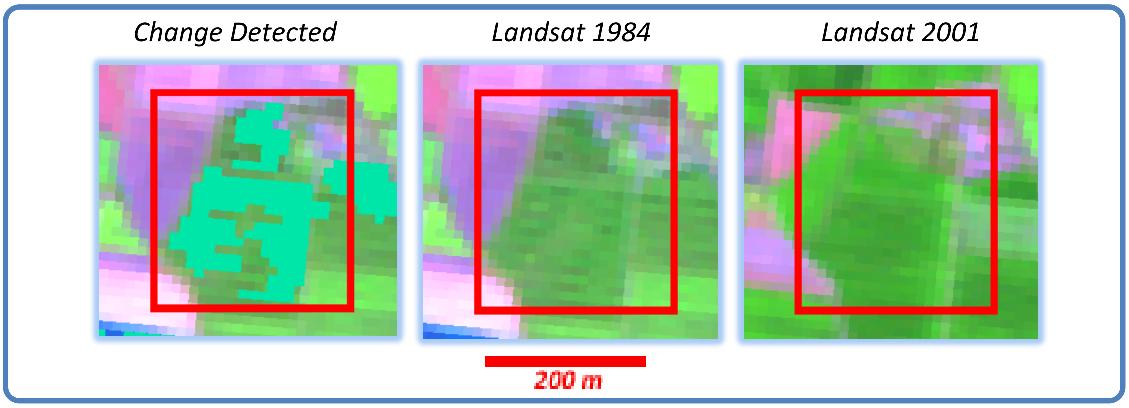

Figure 4. Wrong wetland conversion to Agriculture in Dep. 13 (green color). It was agriculture in 1984, and remains so in 2001.

- <u>Elongated shapes:</u>

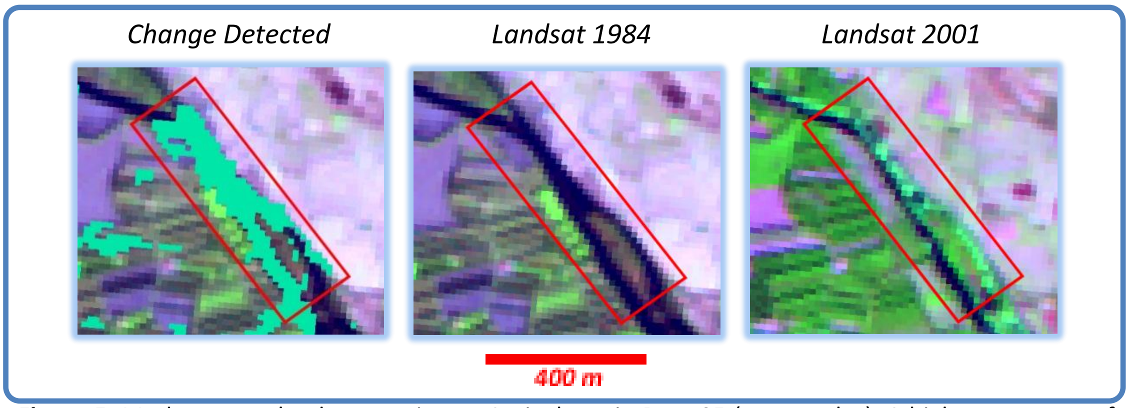

Figure 5. Moderate wetland conversion to Agriculture in Dep. 05 (green color). A high percentage of land pixels change but there are confusions with the water of the river.

Annex 3:

Indicator 3: results – Part III, Section 9.1 and 9.2

Below it is detailed the whole data concerning the Indicator 3 results for the departments 13, 83 and 04. Data for Dep. 13 include the results for the different approaches used for rice fields areas.

There are three different approaches for rice fields:

- **Satellite detected wetlands (Satellite - Ind. 3S):** Water bodies and flooded areas detected by the satellite image classifications in a specific date (no specific criteria applied to rice fields).
- **Rice fields included (Rice - Ind. 3R):** the whole surface of rice is considered as flooded for images between April and August (as from June to August water is not well detected due to vegetation).
- **Rice fields excluded (No Rice - Ind. 3NR):** rice field areas detected by the satellite are masked (left out) for all dates (not included in the classification process).

❖ Department 13:

Dep 13	
Wetlands inventoried	104,717

Rice

2001			2007			2012		
Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded
Jan	52,022	49.68	*Jan*	53,789	51.37	*Jan*	53,939	51.51
Mar	52,059	49.71	*Mar*	52,002	49.66	*Mar*	50,104	47.85
May	65,441	62.49	*Apr*	58,157	55.54	*Jun*	57,028	54.46
Jul	62,356	59.55	*Sep*	49,147	46.93	*Jul*	56,820	54.26
Oct	50,504	48.23	*Dec*	53,910	51.48	*Sep*	48,130	45.96
All months	70,277	67.11	***All months***	66,086	63.11	***All months***	66,854	60.57

Satellite

2001			2007			2012		
Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded
Jan	52,022	49.68	*Jan*	53,789	51.37	*Jan*	53,939	51.51
Mar	52,059	49.71	*Mar*	52,002	49.66	*Mar*	50,104	47.85
May	60,493	57.77	*Apr*	53,339	50.94	*Jun*	51,870	49.53
Jul	51,314	49.00	*Sep*	49,147	46.93	*Jul*	49,186	46.97
Oct	50,504	48.23	*Dec*	53,910	51.48	*Sep*	48,130	45.96
All months	65,377	62.43	***All months***	61,449	58.68	***All months***	58,630	55.99

No Rice

2001			2007			2012		
Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded	Month	Surf. Flooded (ha)	% Flooded
Jan	51,865	49.53	*Jan*	53,646	51.23	*Jan*	53,881	51.45
Mar	51,968	49.63	*Mar*	51,991	49.65	*Mar*	50,102	47.84
May	54,388	51.94	*Apr*	51,084	48.78	*Jun*	48,933	46.73
Jul	51,303	48.99	*Sep*	49,141	46.93	*Jul*	48,726	46.53
Oct	50,397	48.13	*Dec*	53,715	51.30	*Sep*	48,124	45.96
All months	59,473	56.79	***All months***	59,161	56.50	***All months***	55,947	53.43

Table 1. Flooding data for Department 13 including (rice) and excluding (no rice) rice field areas.

Rice

	2001		2007		2012	
Frequency	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
1	3,728	3.56	11,069	10.57	4,493	4.29
2	14,216	13.58	3,067	2.93	11,108	10.61
3	3,654	3.49	2,831	2.70	2,542	2.43
4	4,131	3.95	4,287	4.09	3,548	3.39
5	44,547	42.54	44,833	42.81	41,737	39.86
Total	70,277	67.11	66,086	63.11	66,854	60.57
Not flooded	34,440	32.89	38,631	36.89	37,863	39.43

Satellite

	2001		2007		2012	
Frequency	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
1	9,632	9.20	6,549	6.25	7,182	6.86
2	3,639	3.47	3,011	2.88	3,622	3.46
3	3,481	3.32	2,770	2.65	2,541	2.43
4	4,086	3.90	4,286	4.09	3,547	3.39
5	44,539	42.53	44,832	42.81	41,737	39.86
Total	65,377	62.43	61,449	58.68	58,630	55.99
Not flooded	39,340	37.57	39,340	41.32	39,340	44.01

No Rice

	2001		2007		2012	
Frequency	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
1	3,919	3.74	4,388	4.19	4,923	4.70
2	3,501	3.34	2,905	2.77	3,199	3.06
3	3,437	3.28	2,751	2.63	2,541	2.43
4	4,078	3.89	4,286	4.09	3,547	3.39
5	44,539	42.53	44,831	42.81	41,737	39.86
Total	59,473	56.79	59,161	56.50	55,947	53.43
Not flooded	45,244	43.21	45,556	43.50	48,770	46.57

Table 2. Flooding frequency data for Department 13 including (rice) and excluding (no rice) rice field areas.

Rice

	2001		2007		2012	
Ind 3R	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	56,476	53.93	53,401	51.00	53,204	50.81
Maximum	65,441	62.49	58,157	55.54	57,028	54.46
Year Total	70,277	67.11	66,086	63.11	66,854	60.57

Satellite

	2001		2007		2012	
Ind 3S	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	53,278	50.88	52,437	50.08	50,646	48.36
Maximum	60,493	57.77	53,910	51.48	53,939	51.51
Year Total	65,377	62.43	61,449	58.68	58,630	55.99

No Rice

	2001		2007		2012	
Ind 3NR	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
Mean	51,984	49.64	51,915	49.58	49,953	47.70
Maximum	54,388	51.94	53,715	51.30	53,881	51.45
Year Total	59,473	56.79	59,161	56.50	55,947	53.43

Table 3. Indicator 3 results of Dep. 13 either including or excluding rice fields areas and the original satellite imagery

❖ Department 83:

Dep 83	
Wetlands inventoried	6,166

2001		
Month	Surf. Flooded (ha)	% Flooded
Jan	2,189	35.50
Mar	2,305	37.39
May	2,375	38.52
Jul	2,290	37.13
Oct	2,169	35.17
-	-	-
All months	2,525	40.95

2007		
Month	Surf. Flooded (ha)	% Flooded
Feb	2,544	41.26
Mar	2,465	39.98
Jul	2,356	38.21
Nov	2,327	37.74
-	-	-
-	-	-
All months	2,635	42.74

2012		
Month	Surf. Flooded (ha)	% Flooded
Jan	2,594	42.07
Feb	2,963	48.05
Mar	1,563	25.36
Jun	2,336	37.88
Jul	2,300	37.31
Sep	2,279	36.96
All months	3,208	52.02

	2001		2007		2012	
Frequency	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded	Surf. Flooded (ha)	% Flooded
1	112	1.81	120	1.95	639	10.36
2	100	1.62	116	1.88	137	2.23
3	133	2.15	256	4.15	111	1.80
4	178	2.88	2,143	34.76	128	2.08
5	2,003	32.49	-	-	876	14.21
6	-	-	-	-	1,316	21.34
Total	2,525	40.95	2,635	42.74	3,208	52.02
Not flooded	3,641	59.05	3,531	57.26	2,958	47.98

Table 4. Indicator 3 results of Dep. 83 for 2001, 2007 and 2012. Surfaces are in hectares and percentage.

❖ Department 04:

Dep 04	
Wetlands inventoried	20,745

2001		
Month	Surf. Flooded (ha)	% Flooded
Jan	5,342	25.75
Mar	5,513	26.58
May	5,252	25.32
Aug	2,536	12.23
Oct	2,440	11.76
All months	5,712	27.53

	2001	
Frequency	Surf. Flooded (ha)	% Flooded
1	134	0.65
2	178	0.86
3	3,073	14.81
4	224	1.08
5	2,103	10.14
Total	5,712	27.53
Not flooded	15,033	72.47

	2001	
Ind 3.	Surf. Flooded (ha)	% Flooded
Mean	4,217	20.33
Maximum	5,513	26.58
Year Total	5,712	27.53

Table 5. Indicator 3 results of Dep. 04 for year 2001. Surfaces are in hectares and percentage.

Annex 4:

Indicator 3: ANOVA results – Part III, Section 9.3

Below it is detailed all the data related to the univariate analysis of variance (ANOVA) performed in section 8.3 to study the flooding frequency in the Camargue Natural Regional Park (PNRC):

- Descriptive Statistics:

LAND_USE	Year	Mean	N
Bare soils	2001	2,89	1092
	2007	2,20	1436
	2012	1,72	661
	Total	2,31	3189
Grassland	2001	,24	925
	2007	,41	1186
	2012	,35	1185
	Total	,33	3296
Meadow	2001	,06	73
	2007	,04	187
	2012	,06	236
	Total	,05	496
Open marsh	2001	4,51	1026
	2007	4,42	1320
	2012	4,24	1395
	Total	4,38	3741
Other marsh emergent vegetation	2001	3,80	229
	2007	3,12	402
	2012	2,67	265
	Total	3,20	896
Pond	2001	4,99	293
	2007	4,97	311
	2012	4,94	175
	Total	4,96	779
Reed	2001	3,02	556
	2007	3,78	829
	2012	3,16	667
	Total	3,30	2052
Rice field	2001	1,30	697
	2007	,50	3019
	2012	,92	3175
	Total	,98	6891

Rushes	2001	1,41	993
	2007	1,65	1531
	2012	1,82	1099
	Total	1,65	3623
Saline	2001	4,84	298
	2007	4,83	298
	2012	4,71	309
	Total	4,80	905
Salt high meadows	2001	2,24	1888
	2007	2,72	2257
	2012	2,50	1631
	Total	2,49	5776
Salt low meadows	2001	2,81	1527
	2007	1,54	1637
	2012	1,27	1385
	Total	1,99	4549
Total	2001	3,41	9597
	2007	3,53	14413
	2012	3,31	12183
	Total	3,41	36193

Table 1. Descriptive statistics derived from the ANOVA performed in section 4.3.3. LAND_USE corresponds to the types of wetlands, and N to the number of samples. Flooding values are between 0 and 5.

- Tests of Between-Subjects Effects:

Source	Type III Sum of Squares	df	Std. Deviation	F	Sig.
Corrected Model	4,896,551,365.711	35	153.018	2,093.217	0.000
Intercept	3,542,970,518.974	1	105.222	53,010.217	0.000
Year	9,392,312.359	2	43.333	70.264	0.000
LAND_USE	4,807,029,825.856	11	216.200	6,538.471	0.000
Year * LAND_USE	90,574,766.743	22	319.062	61.599	0.000
Error	2,416,575,375.776	36,157	126.776		
Total	28,555,803,000.000	36,193	455		
Corrected Total	7,313,126,741.487	36,192	322		

R Squared = .670 (Adjusted R Squared = .669)

Table 2. Correlation test results derived from the ANOVA.

➤ <u>Post Hoc Tests - Multiple Comparisons:</u>

(I) LAND_USE	(J) LAND_USE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Bare soils	Grassland	1,98*	,062	,000	1,86	2,10
	Meadow	2,26*	,098	,000	2,07	2,45
	Open marsh	-2,07*	,057	,000	-2,18	-1,96
	Other marsh emergent vegetation	-,89*	,069	,000	-1,02	-,75
	Pond	-2,65*	,053	,000	-2,76	-2,55
	Reed	-,99*	,058	,000	-1,10	-,87
	Rice field	1,33*	,054	,000	1,22	1,44
	Rushes	,66*	,059	,000	,54	,77
	Saline	-2,48*	,053	,000	-2,59	-2,38
	Salt high meadows	-,18*	,055	,001	-,29	-,07
	Salt low meadows	,32*	,060	,000	,21	,44
Grassland	Bare soils	-1,98*	,062	,000	-2,10	-1,86
	Meadow	,28*	,090	,002	,10	,45
	Open marsh	-4,05*	,043	,000	-4,13	-3,97
	Other marsh emergent vegetation	-2,87*	,058	,000	-2,98	-2,76
	Pond	-4,63*	,037	,000	-4,71	-4,56
	Reed	-2,97*	,043	,000	-3,05	-2,88
	Rice field	-,65*	,038	,000	-,73	-,58
	Rushes	-1,32*	,046	,000	-1,41	-1,23
	Saline	-4,47*	,037	,000	-4,54	-4,39
	Salt high meadows	-2,16*	,039	,000	-2,24	-2,09
	Salt low meadows	-1,66*	,047	,000	-1,75	-1,57
Meadow	Bare soils	-2,26*	,098	,000	-2,45	-2,07
	Grassland	-,28*	,090	,002	-,45	-,10
	Open marsh	-4,33*	,086	,000	-4,50	-4,16
	Other marsh emergent vegetation	-3,15*	,095	,000	-3,33	-2,96
	Pond	-4,91*	,084	,000	-5,08	-4,75
	Reed	-3,25*	,087	,000	-3,42	-3,08
	Rice field	-,93*	,084	,000	-1,10	-,77
	Rushes	-1,60*	,088	,000	-1,77	-1,43
	Saline	-4,74*	,084	,000	-4,91	-4,58
	Salt high meadows	-2,44*	,085	,000	-2,61	-2,28
	Salt low meadows	-1,94*	,088	,000	-2,11	-1,76
Open marsh	Bare soils	2,07*	,057	,000	1,96	2,18
	Grassland	4,05*	,043	,000	3,97	4,13
	Meadow	4,33*	,086	,000	4,16	4,50
	Other marsh emergent vegetation	1,18*	,052	,000	1,08	1,28
	Pond	-,58*	,028	,000	-,64	-,53
	Reed	1,08*	,036	,000	1,01	1,15
	Rice field	3,40*	,029	,000	3,34	3,45
	Rushes	2,73*	,038	,000	2,65	2,80
	Saline	-,42*	,028	,000	-,47	-,36
	Salt high meadows	1,89*	,031	,000	1,83	1,95
	Salt low meadows	2,39*	,040	,000	2,31	2,47

Other marsh emergent vegetation	Bare soils	,89*	,069	,000	,75	1,02
	Grassland	2,87*	,058	,000	2,76	2,98
	Meadow	3,15*	,095	,000	2,96	3,33
	Open marsh	-1,18*	,052	,000	-1,28	-1,08
	Pond	-1,77*	,048	,000	-1,86	-1,67
	Reed	-,10	,053	,058	-,20	,00
	Rice field	2,22*	,049	,000	2,12	2,31
	Rushes	1,54*	,054	,000	1,44	1,65
	Saline	-1,60*	,048	,000	-1,69	-1,50
	Salt high meadows	,70*	,049	,000	,61	,80
	Salt low meadows	1,21*	,055	,000	1,10	1,32
Pond	Bare soils	2,65*	,053	,000	2,55	2,76
	Grassland	4,63*	,037	,000	4,56	4,71
	Meadow	4,91*	,084	,000	4,75	5,08
	Open marsh	,58*	,028	,000	,53	,64
	Other marsh emergent vegetation	1,77*	,048	,000	1,67	1,86
	Reed	1,67*	,029	,000	1,61	1,72
	Rice field	3,98*	,020	,000	3,94	4,02
	Rushes	3,31*	,032	,000	3,25	3,37
	Saline	,17*	,018	,000	,13	,20
	Salt high meadows	2,47*	,022	,000	2,43	2,51
	Salt low meadows	2,98*	,033	,000	2,91	3,04
Reed	Bare soils	,99*	,058	,000	,87	1,10
	Grassland	2,97*	,043	,000	2,88	3,05
	Meadow	3,25*	,087	,000	3,08	3,42
	Open marsh	-1,08*	,036	,000	-1,15	-1,01
	Other marsh emergent vegetation	,10	,053	,058	,00	,20
	Pond	-1,67*	,029	,000	-1,72	-1,61
	Rice field	2,31*	,030	,000	2,26	2,37
	Rushes	1,64*	,039	,000	1,57	1,72
	Saline	-1,50*	,029	,000	-1,55	-1,44
	Salt high meadows	,80*	,031	,000	,74	,87
	Salt low meadows	1,31*	,040	,000	1,23	1,39
Rice field	Bare soils	-1,33*	,054	,000	-1,44	-1,22
	Grassland	,65*	,038	,000	,58	,73
	Meadow	,93*	,084	,000	,77	1,10
	Open marsh	-3,40*	,029	,000	-3,45	-3,34
	Other marsh emergent vegetation	-2,22*	,049	,000	-2,31	-2,12
	Pond	-3,98*	,020	,000	-4,02	-3,94
	Reed	-2,31*	,030	,000	-2,37	-2,26
	Rushes	-,67*	,033	,000	-,74	-,61
	Saline	-3,81*	,020	,000	-3,85	-3,77
	Salt high meadows	-1,51*	,024	,000	-1,56	-1,46
	Salt low meadows	-1,01*	,035	,000	-1,07	-,94
Rushes	Bare soils	-,66*	,059	,000	-,77	-,54
	Grassland	1,32*	,046	,000	1,23	1,41
	Meadow	1,60*	,088	,000	1,43	1,77
	Open marsh	-2,73*	,038	,000	-2,80	-2,65
	Other marsh emergent vegetation	-1,54*	,054	,000	-1,65	-1,44
	Pond	-3,31*	,032	,000	-3,37	-3,25
	Reed	-1,64*	,039	,000	-1,72	-1,57
	Rice field	,67*	,033	,000	,61	,74
	Saline	-3,14*	,032	,000	-3,20	-3,08
	Salt high meadows	-,84*	,034	,000	-,91	-,77
	Salt low meadows	-,34*	,042	,000	-,42	-,25

Saline	Bare soils	2,48*	,053	,000	2,38	2,59
	Grassland	4,47*	,037	,000	4,39	4,54
	Meadow	4,74*	,084	,000	4,58	4,91
	Open marsh	,42*	,028	,000	,36	,47
	Other marsh emergent vegetation	1,60*	,048	,000	1,50	1,69
	Pond	-,17*	,018	,000	-,20	-,13
	Reed	1,50*	,029	,000	1,44	1,55
	Rice field	3,81*	,020	,000	3,77	3,85
	Rushes	3,14*	,032	,000	3,08	3,20
	Salt high meadows	2,30*	,022	,000	2,26	2,34
	Salt low meadows	2,81*	,033	,000	2,74	2,87
Salt high meadows	Bare soils	,18*	,055	,001	,07	,29
	Grassland	2,16*	,039	,000	2,09	2,24
	Meadow	2,44*	,085	,000	2,28	2,61
	Open marsh	-1,89*	,031	,000	-1,95	-1,83
	Other marsh emergent vegetation	-,70*	,049	,000	-,80	-,61
	Pond	-2,47*	,022	,000	-2,51	-2,43
	Reed	-,80*	,031	,000	-,87	-,74
	Rice field	1,51*	,024	,000	1,46	1,56
	Rushes	,84*	,034	,000	,77	,91
	Saline	-2,30*	,022	,000	-2,34	-2,26
	Salt low meadows	,50*	,036	,000	,43	,57
Salt low meadows	Bare soils	-,32*	,060	,000	-,44	-,21
	Grassland	1,66*	,047	,000	1,57	1,75
	Meadow	1,94*	,088	,000	1,76	2,11
	Open marsh	-2,39*	,040	,000	-2,47	-2,31
	Other marsh emergent vegetation	-1,21*	,055	,000	-1,32	-1,10
	Pond	-2,98*	,033	,000	-3,04	-2,91
	Reed	-1,31*	,040	,000	-1,39	-1,23
	Rice field	1,01*	,035	,000	,94	1,07
	Rushes	,34*	,042	,000	,25	,42
	Saline	-2,81*	,033	,000	-2,87	-2,74
	Salt high meadows	-,50*	,036	,000	-,57	-,43

*. The mean difference is significant at the ,05 level.a. Weighted Least Squares Regression - Weighted byAREA

Table 3. Results of the multiple comparisons test derived from the ANOVA.

Annex 5:

Indicator 1 improvements – Part V, Chapter 14

A5.1. Purpose of the new tests

Following the results obtained for the analysis of the Indicator 1, which were not bad but not too promising for some departments, ETC-SIA propose the implementation the improvements suggested after assessing the problems and errors identified for this indicator. In particular, the proposals tested are:

- ✓ Minimizing errors A and B by conducting more specific classifications on areas included in the wetland inventories using fewer classes and lower thresholds. This way, well known areas could be better represented.
- ✓ Masking conflictive land coverages (especially urban areas) with some reference data such as Corine Land Cover.

For these new tests ETC-SIA has worked in the PACA region for year 2001 using the same Landsat images and reference layers used previously for the indicator, with the inclusion of the CLC mask for urban and agricultural areas (year 2000) used for the Indicator 2 analysis.

❖ Summary of data and spatial information:

- Landsat imagery (see table 1).
- Tasseled Cap (TC) transformation derived from Landsat imagery.
- 50m Numerical Model of the Territory (MNT) of the PACA region.
- Corine Land Cover 2000 (agriculture and urban data at level 1).

Period	Satellite	Number of Bands	Bands used	Resolution	Image Date
2000s	Landsat 7 ETM+	7 Bands + 1 Panchromatic	1 to 5, and 7	30 m	Feb - Mar 2001 Apr - May 2001 Jul - Aug 2001 Oct 2001

Table 1. Satellite imagery used (dates and properties).

A5.2. Methodological description

A5.2.1. New changes in methodology

Basically, the only thing that has changed of the previous method is the supervised classification performed for land and vegetation areas related to wetlands and water bodies (section 2.2.2.4. of the Indicator 1 chapter). This process is quite sensitive and it generates most of the classification errors observed for the Indicator 1. Therefore, a modification of this step is critical to enhance the final results.

To implement the improvements proposed, two new masks are generated (figure 2):

1. **Inventory mask:** this mask is created for each department using the spatial information of the wetland inventories of the PACA region and the LULC layer of the PNRC (only wetlands classes).

2. **Combined mask:** it is based on the information of three sources:

   - Slopes lower than 15% (the previous mask used in the process)
   - Inventory mask: inventoried wetlands and LULC layer
   - CLC agriculture and urban areas (used for the Indicator 2)

   These layers are joined in a new mask which replaces the slope mask throughout the analysis of the Indicator 1.

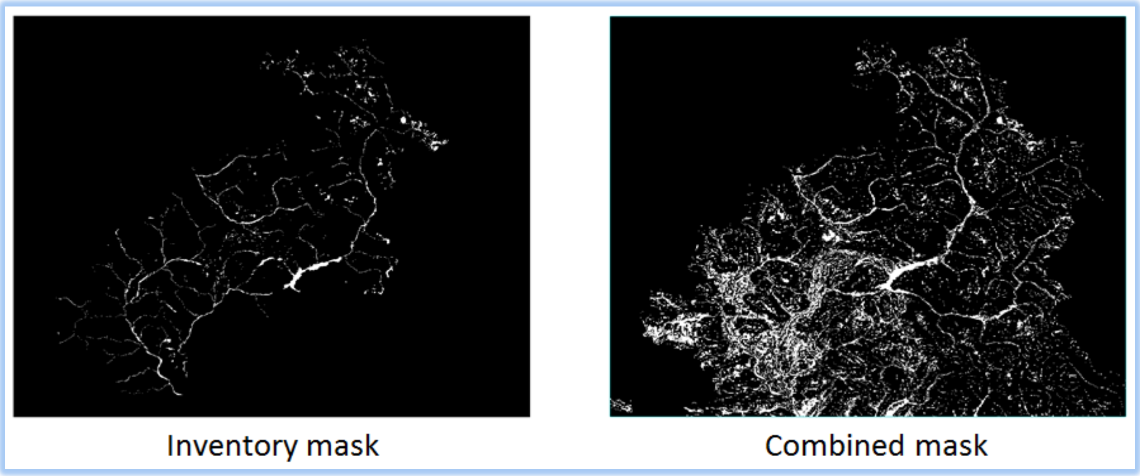

Figure 2. Inventory and combined mask of the Department 05. Black color corresponds to omitted areas.

The old supervised classification is now split in two processes with different approaches according to the analyzed area (figure 3):

1. **Areas inside the inventories:** using the inventory mask a supervised classification is performed only for those areas of the image that are included in the wetlands inventories or in the PNRC LULC layers. That way, it is possible to focus the process to better represent those areas that are known as true wetlands.
   Lower thresholds can be used for the different classes making the classification more sensitive for wetland detection. So error B can be minimized without increasing error A.

2. **Areas outside the inventories:** the second classification process use the combined mask (slope, CLC and inventory) focusing this time on representing the areas outside the inventories (not inventoried as wetlands).
   To avoid introducing too many errors (error A in this case), the thresholds used for the classes must be lower than the previous ones (less sensitive classification). As a result of using the new mask with the CLC data, less classification confusions are generated.

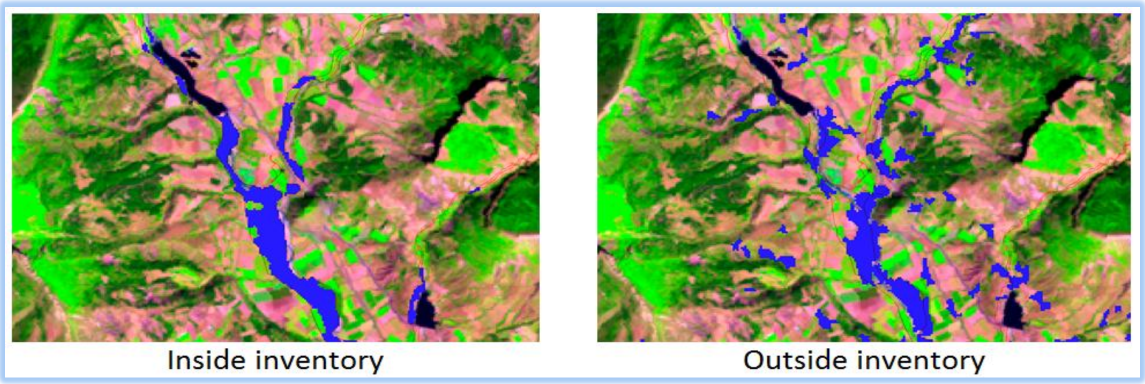

Figure 3. Example of the two supervised classification approaches for wetland vegetation (blue areas).

A5.2.2. Summary of the calculation process

Below is a short summary of the steps taken for the recalculation of the Indicator 1 with the new improvements, so that the whole process is properly understood:

A. Produce masks - First step is the creation of all masks to use them when needed:

1. Use low-slope areas (<15%) from MNT to create the "slope mask".
2. Create an "in-house" mask from CLC data, to exclude Urban/ built-up + Agriculture areas (except rice fields).
3. The mask based on the wetlands inventories.

With these three basic layers, two final masks are generated (to simplify their use):

4. Inventory mask
5. Combined mask (slope + CLC + inventory).

Then wetlands are identified in 3 steps: first water bodies, then water courses, finally wetland vegetation (= all vegetated wetlands) – the latter can be split if needed between Ricefields/ Others.

B. Water Bodies - Analyse tasselled cap variables from Landsat imagery by a decision tree:

Work with the combined mask (*in most cases this step doesn't require to use a mask, but in mountain areas it is recommended to reducing possible errors*).

1. Identify Water bodies using Greenness and Wetness values.
2. Calculate the flow accumulation lines derived from the MNT and add them to the water bodies layer.

C. Wetland vegetation - Analyse Landsat 7 images by a supervised classification (maximum likelihood); two separate supervised classifications are performed (inside/ outside inventoried wetland limits):

- Using the inventory mask: *to work on area inside the inventoried wetlands.*
  1. Identify vegetation and wetland classes.

2. Low thresholds can be used for the classification.

- Using the combined mask: *to work on area outside the inventoried wetlands.*
  1. Identify vegetation and wetland classes.
  2. Higher thresholds must be used to avoid errors

D. Rice fields - Only in areas where rice fields occur and if separation of rice fields from other wetlands is later needed:

- Analyse greenness differences between two dates (recommended: July and October). Mask are not used for this step.

E. Total Wetlands (Indicator 1 layer) – Produce a final wetland layer by adding the information of water bodies, wetland vegetation and rice fields.

A5.3. Results

Results obtained for the analysis of Indicator 1 using the new methodology (table 2) are very satisfactory at the level of the whole PACA being total error rates quite low: around 18% for both, error A and B.

Department 13 still present the best results being the correctness very close to 95% when comparing the detected surface with its wetland inventory and the LULC layer of the PNRC. As before, the other departments show less promising results, although quite good in the context of wetland monitoring. Error rates range between 50% and 20% being worse in departments located more to the north (more mountainous).

Department	Inventoried wetlands (ha)	Wetlands detected by satelite (ha)	Wetlands detected inside inventory (ha)	Wetlands detected outisde inventory (ha)	Error A %	Inventoried wetlands not detected (ha)	Error B %
Dep 05	16,943	15,658	8,625	7,033	44.92	8,318	49.09
Dep 04	20,745	21,863	14,153	7,710	35.26	6,592	31.78
Dep 84	8,247	6,286	4,970	1,316	20.93	3,277	39.74
Dep 13	89,234	104,970	83,867	21,103	20.10	5,367	6.01
Dep 13 + LULC	104,717	104,970	97,925	7,045	6.71	6,792	6.49
Dep 83	6,166	5,501	2,470	3,031	55.10	3,696	59.94
Dep 06	Not inventoried	3,463	-	-	-	-	-
PACA	**141,335**	**157,741**	**114,086**	**40,193**	**25.48**	**27,249**	**19.28**
PACA + LULC	**156,818**	**157,741**	**128,144**	**26,135**	**16.57**	**28,674**	**18.29**
Dep. Mean	***41,009***	***37,530***	***35,335***	***7,873***	***30.50***	***5,673***	***32.17***

Table 2. Results of the new analysis of the Indicator 1. Values correspond to the sum of all images analyzed for 2001.

Regarding the previous results, the percentage of improvement achieved (table 3) is quite remarkable, especially for the alpine departments whose results were not the best. For the whole PACA region and departments mean the errors improvement is about 10%, so that the overall results are significantly better.

Error A has been greatly reduced by using the CLC mask for agriculture and urban areas. These declines are very important in departments 84, 05 and 04, being the degree of improvement

45.5%, 23.6% and 16.9% respectively. Similarly, the classifications made in the inventoried areas allowed a better representation of the previously known wetlands. This means lower percentages of error B, especially in these conflictive departments: about 17% for Dep.84 and 14% for Dep. 05 and 04. Considering that improvements have been developed in order to improve the detection of wetlands in these areas of the PACA region, we can conclude that it has been achieved.

Results for Department 13 do not experience much improvement. However, error percentages were already very low, so the improvement is quite remarkable, approaching 95% of correctness in both cases.

Dep. 83 shows a slight improvement in the error B (around 3%), but it is still very high (59.9%). By contrast, error A presents a significant aggravation for the department, but this is produced by including the wetland vegetation layer (from the supervised classification) as part of the new tests of the Indicator 1 methodology. Recall that previously (for the first calculations) this layer was not included because it introduces many errors, as it is still happening. Therefore, this department obtains lower error percentages using only the information corresponding to water bodies.
A field contrast of the detected areas outside the inventory would be necessary to assess the veracity of the classification errors (error A in this case).

Department	Error A			Error B		
	Old	New	% Improv	Old	New	% Improv
Dep 05	68.5	44.9	23.6	63.4	49.1	14.3
Dep 04	52.2	35.3	16.9	46.0	31.8	14.2
Dep 84	66.4	20.9	45.5	57.1	39.7	17.3
Dep 13	22.2	20.1	2.1	11.6	6.0	5.6
Dep 13 + LULC	10.0	6.7	3.3	12.8	6.5	6.3
Dep 83	17.8	55.1	-37.3	62.8	59.9	2.9
Dep 06	-	-	-	-	-	-
PACA	**34.6**	**25.5**	**9.1**	**27.7**	**19.3**	**8.5**
PACA + LULC	**26.9**	**16.6**	**10.3**	**27.0**	**18.3**	**8.7**
Mean	*39.5*	*30.5*	9.0	*42.3*	*32.2*	10.1

Table 3. Comparison between the error rates obtained for the Indicator 1 (old and new method), and the percentage of improvement achieved.

A5.4. Conclusions

Changes in the methodology of the Indicator 1 have supposed a very significant improvement in the final results, both overall for the PACA region and for each department. This improvement is particularly remarkable in reducing the error A, which was previously very high in most cases, especially for departments located in the northern region. Error does not present changes as substantial but they are equally very remarkable, certainly achieving a better representation of the inventoried wetlands.

The use of multiple masks to avoid conflictive land coverages such urban areas has worked very well in terms of reducing errors. Performing two supervised classifications, one focusing on the inventories and other on the areas outside, has allowed to better represent the wetlands of these departments without introducing too many errors, in addition to identifying potential wet areas which should be verified on the field.

There are still some classification confusions between wetlands and other land uses, especially in the case of natural vegetation since it is difficult to distinguish between dry and wet areas, and sometimes even with crops (for example riparian and hill forest). Other errors seen, but to a lesser extent, are non-vegetated areas such as salines, river banks, urban areas or rock and bare soils.

Another important aspect is that for subsequent years (or previous) there could not be new wetland inventories available, only those used for the initial analysis. This should not be a big problem as the method can identify wetland areas outside the current inventory (with more or less errors). Therefore, in the future:

- ✓ If new wetlands appear, they should be detected by the satellite image as long as these new areas have typical elements of a wetland that can be analyzed (presence of water, vegetation changes, etc.).
- ✓ If any area of the current inventory were no longer a wetland, it would not be detected in the new classifications (another class would be detected).

Improvements of the Indicator 1 could have remarkable effects in the results of the Indicator 2 and the analysis of the evolution of wetlands based on the Indicator 1 between 1975, 1984 and 2001. Therefore, new analysis would be recommended to assess the improvement in this context.