This Manual is the result of a research project undertaken by Fundación Biodiversidad with the collaboration of the Hydrographic Confederation of the Jucar River and the Hydrographic Confederation of the Guadalquivir River within the programme of work of the Centro Español de Humedales (Spanish Centre for Wetlands). The aim of project was to contribute knowledge related to the techniques to determine the hydrological requirements of wetlands. This is an issue directly related with the application of the Birds Directive, the Habitats Directive and the Water Framework Directive of the European Union in wetlands of the EU member countries, as well as with the application of the Ramsar Convention in the countries which are Parties to the treaty. In this way, the tools proposed in this book are intended to facilitate the management and wise use of an important resource for the survival of wetlands and human beings: water.
MANUAL FOR DETERMINING THE HYDROLOGICAL REQUIREMENTS OF WETLANDS
THE SPANISH CONTEXT

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Madrid, 2012
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This book is the result of a research project carried out by the Fundación Biodiversidad in collaboration with the Hydrographical Confederation of the Júcar. To this project must be added additional works carried out by the Hydrographical Confederation of the Guadalquivir which complement this first research phase and whose progress is outlined in this document.

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Acknowledgements:
Catalonian Water Agency, Spanish Wetlands Center, Consejo Superior de Investigaciones Científicas (CSIC), Hydrographical Confederation of the Guadalquivir, Hydrographical Confederation of the Júcar, Spanish Geological and Mining Institute, Ministry of Agriculture, Food and the Environment, Secretariat of the Convention on Wetlands (Ramsar), Tragsa, INTECMARFASA, Polytechnic University of Catalonia, Polytechnic University of Valencia, University of Sevilla, University of Valencia-Estudi General and WWF-Spain.

To Eugenio Barrios, Delmar Blasco, Reyes del Rio, Arantxa Fidalgo, Rafael Hidalgo, Juan Martinez Rubio, Pablo Sánchez-Gonzalez.

Declaration of responsibility
The authors are responsible for the statements and the data presented in this publication, as well as for the opinions expressed therein, which are not necessarily those of the Fundación Biodiversidad.


This book is available in electronic format in Spanish and in English at the site: http://www.fundacion-biodiversidad.es/images/stories/recursos/proyectos/2012/necesidades_hidricas_humedales.pdf

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The paper used for the printing of this book was manufactured from wood sourced from forests and plantations managed with the highest environmental standards, guaranteeing that the exploitation of resources is environmentally sustainable and socially beneficial. For this reason, Greenpeace affirms that this book meets the requirements of the “Friends of the trees” project, promoted by Greenpeace and the Forest Stewardship Council (FSC). The “Friends of the trees” project promotes the conservation and the sustainable use of the forests, especially of primary forests, the last virgin forests of the planet.
Presentation

This is a work that was needed, both in Spain as well as at the international level.

Fortunately, we have overcome that perception rooted in the collective conscience that wetlands are useless, even dangerous spaces, and that it was better to supplant the spaces they occupy with more useful uses. Little by little, this notion has been replaced by large social acceptance of the importance and value of wetland ecosystems. And, as our scientists and experts contribute more data on the functions and ecological services that they provide, almost no one dares question the need for their conservation and sustainable use. To the contrary, in many cases many are genuinely concerned with trying to restore degraded wetlands and even with recovering, to the extent possible, historical wetlands that disappeared due to human intervention.

This process of positive change has greatly helped the Convention on Wetlands of International Importance (Ramsar Convention). The treaty was signed back in 1971 and little by little it has influenced the policies of the member States (currently 160), policies that have been translated into, among others, education and awareness building campaigns on the value and importance of these ecosystems. And, within the European Union, we have taken a decisive step with the adoption of the Water Framework Directive. The transposition of this Directive, though sometimes slow and not always linear, to the national legislations is ensuring, at last, that water is no longer considered a good that is solely at the service of the human species but that it is also, an essential element for ensuring the correct functioning of the natural processes upon which life depends, not only ours, within our space of existence.

However, it is one thing to recognize the value of wetlands and the need to conserve them. The other is how to do this, especially with regards to the essential and intrinsic element of these ecosystems: water. Because although the perception regarding the limitlessness of the resource and the practical and ethical need to distribute it equitably and efficiently between all the legitimate uses (need and basic human right, productive uses, ecological uses) has changed, we have not yet developed sufficient technical capacities and legal, administrative and consensus building processes, to assign to each use the quantity of water it merits based on right and need.

Accordingly, this Manual which is dedicated specifically to determining the water requirements of wetlands represents an excellent contribution to this topic. I am sure that it will be very useful in Spain as we move forward in the application of the Water Framework Directive. It will also be helpful at the international level as an additional contribution to the work of the Scientific and Technical Review Panel of the Ramsar Convention that continues to work on this issue to provide guidance and technical assistance and for the policies of the 160 nations signatories to the treaty.

Thus, we must be thankful to the authors and collaborators who participated in the preparation of this Manual because its contribution will be of great use to those on the ground who must make the difficult decisions on the rational, equitable and efficient use of this valued and scarce resource: water.

Delmar Blasco
Consultant
Former Secretary General
of the Ramsar Convention on Wetlands
The logic is incontestable: water is not a limitless source of exploitation and demand, but also of conditioning that their use must be compatible with their efficiency, sustainability and rationality, understanding these as water reserved for natural systems so that the systems may conserve their natural values, providing at the same time other functions and services useful to society.

In the field of water management, the principle of "wise use" is based on the concepts of "environmental flows" in the case of rivers and "water requirements" when we talk of wetlands, understanding these as water reserved for natural systems so that the systems may conserve their natural values, providing at the same time other functions and services useful to society.

Wetlands are aquatic ecosystems that host an enormous, varied and unique natural and cultural heritage. They are irreplaceable habitats for a large number of species of high interest for conservation. The origin of these pressures is found in both direct (land use changes, water pollution, accumulation of solid waste –rubbish, rubble, sewage, etc.) and indirect actions (intensive groundwater use, etc.). All this causes alteration of the hydrological system that supplies wet areas, modifying in these cases the regime flows to the wetland, and with this its structure, values and functions.

The spatial and temporal variation of water depth, the circulation regime, the quality of the hydrological resources, as well as the frequency and duration of floods, are often very important environmental factors that determine the "ecological character" of a wetland, of its structure and of its functioning. Thus, to be able to conserve the ecological character it is necessary to guarantee the water contributions and a hydrological regime which resembles its natural dynamic, in so far as one wishes to approximate the natural ecological character of the wetland.

The matter of determining the water needs of wetlands is on the agenda of the organizations and institutions dedicated to the protection of nature and water management across the world. The Ramsar Convention on Wetlands of International Importance considers that the adequate assignation of water resources to wetlands is an indispensable requirement for the conservation and wise use of these.

For the reasons outlined, the definition of the relevant ecological character one wishes to maintain is considered a key element of any wetlands conservation strategy.
In addition, we must highlight that addressing issues of the water requirements of wetlands also has a series of positive consequences. The ascertainment of water requirements can contribute to avoid the degradation of wetlands in the medium or long term, further the efforts for their restoration, avoid beforehand the over allocation of water among users in cases of underestimated water requirements, help regulate an excessive competition between users, contribute to avoiding the loss of economic opportunities in cases of overestimated water requirements, and the escalation of conflict in situations of prolonged drought.

In any case, we must point out that the ascertainment of the water requirements of a wetland is not a simple task, since it includes a varied ensemble of technical and scientific studies that require the collaboration of specialists from diverse disciplines (botany, hydrology, hydraulics, zoology, etc.) working for a common objective. Putting into practice the water requirements also implies multiple decisions in a setting where many interested actors converge and where different competencies coincide, etc. It is therefore a complex process where the lack of transparency can easily result in lack of agreement and consensus between the parties. This manual intends to convey the concept of water requirements of wetlands and the scope of the ascertainment of these requirements, providing clarity on the actions necessary to ensure that the studies to do this are integrated with all other aspects of water management.

2. LEGAL CONSIDERATIONS OF THE WATER REQUIREMENTS OF WETLANDS

2.1. THE RAMSAR CONVENTION AND WATER REQUIREMENTS

The Convention on Wetlands of International Importance or Ramsar Convention has addressed, directly or indirectly, issues related to water since its beginning in 1971, but more clearly and specifically since the Conference of the Parties which took place in Australia in 1996. Initially, its recommendation centred on problems of lack of water in particular wetlands, but, in subsequent meetings of the Conference of the Parties (COP), problems resulting from the excessive use of water that directly impacted some of the wetlands included in the List of Wetlands of International Importance started to be emphasised. A number of resolutions and recommendations thus highlighted the importance of the adequate management of hydrological resources for the conservation of wetlands. Notwithstanding, it was in the 6th Meeting of the COP that, for the first time, it was explicitly recognized that wetlands require a certain volume of water to maintain their ecological character (Resolution VI.23).

Subsequently, Resolution VII.18 makes a specific reference to the water requirements of wetlands in the context of river basin management, stressing the importance of evaluating the ecological water demands as an essential component of river basin management. In addition, this Resolution endorses a series of guidelines for the Contracting Parties to the Convention relating to the maintenance of natural water regimes to maintain wetlands.
Lastly, in 2008 the “Changwon Declaration on human well-being and wetlands” (Resolution X.3) made a call for action, presenting priority action steps for delivering some of the world’s most critical environmental sustainability goals. This Declaration recognizes that the increasing demand for, and over-use of, water jeopardizes human well-being and the environment and that there is often not enough water to meet our direct human needs and to maintain the wetlands we need.

In addition, the issue of determining water requirements for wetlands is also found in the Ramsar Strategic Plan 2009–2015. For example, the effective management of wetlands (Strategy 2.5 and 2.7), calls for an understanding the amount of water (in quantitative terms), required by wetlands as well as their sources. In this manner, it fosters an explicit recognition of wetlands in integrated water resources management (Strategy 1.7). The inventory and assessment of wetlands (Strategies 1.1, 2.4 and 2.6) includes the wetlands’ hydrological regime, management objectives and limits of acceptable change. It is clear that, when wetland degradation is caused by intensive water use, restoration will depend on assigning water volumes sufficient to recovering wetland functions and ecological character (Strategy 1.8).

From a conceptual viewpoint, it was in Valencia (Spain) during the 8th Meeting of the COP in 2002 that the entire process of allocation and management of water for maintaining the ecological functions of wetlands was addressed (Resolution VIII.5). Although the methods for determining the water requirements of wetlands were not addressed in detail, complementary issues such as policy and legislation and decision-making frameworks were undertaken. Two other resolutions directly related to hydrological resources management were also adopted at this meeting: on the one hand, Resolution VIII.40 enabled the adoption of the first guidelines for rendering the use of groundwater compatible with the conservation of wetlands, and on the other hand Resolution VIII.34 focused on the interdependencies between agricultural activities and the wise use of wetlands.

Resolution IX.1 and its Annexes C, C I and C II adopted in 2005, provided scientific and technical direction, additional to the Ramsar guidelines, regarding water, the phases of river basin management and groundwater management.

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Wetlands are among the most threatened ecosystems in the European Union, with more than 56% classified as having a “unfavourable-bad” conservation status and another 30% classified as “unfavourable-inadequate” (ETC/BD, 2009). For example, it is calculated that Spain currently has a surface of 114,100 ha of wetlands, which represents, according to various estimates, less than 40% of the surface which existed 50 years ago (MMA, 2000).

The Birds Directive (BD), the Habitats Directive (HD) and the Water Framework Directive (WFD) are legal instruments of great relevance and pertinence for conservation, protection and wise use of European wetlands at this time.

The application of these Directives must be coordinated and complementary (an obligation established in the respective texts), with the goal of achieving greater coherence both for the conservation of European biodiversity and for the wise use of water.

The Birds Directive (BD) exhorts Member states to pay special attention to the conservation of wild birds through the preservation of their habitats, the creation of Special Conservation Areas (SCAs) and the restoration of altered habitats. Although the text of the Directive does not specifically mention the requirement of creating management plans for the SCAs, it makes reference to the creation of the necessary legal framework for the preservation, maintenance or restoration of a sufficient diversity and area of habitats essential to the conservation of all species of birds, many of which are aquatic.

The Habitats Directive protects a number of habitats and animal and plant species of conservation interest for Europe, with the goal of maintaining or re-establishing a “favourable conservation status”, with a focus on the presence and distribution of these. Many of these habitats and these flora and fauna species are only found in wetlands. This Directive fosters the declaration of a sufficient number of Sites of Community Importance (SCI), which are subsequently designated Special Area of Conservation (SAC), and which together with the SCAs of the Birds Directive constitute the Natura 2000 network. This network is the primary instrument for the protection of species and habitats in Europe. All this is complemented by a system of “strict protection” which the Directive assigns to the taxa included in Annex IV, even when these species are found outside the Natura 2000 Network. This Directive calls for the implementation of management plans.

2.2. WATER REQUIREMENTS IN THE EUROPEAN DIRECTIVES

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3 For special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans (Art. 6.1 of the Habitats Directive).
Although the Directive does not utilize the exact term “hydrological requirement”, the concept is implicit in the planning process since it establishes the need to develop river basin management plans for achieving environmental objectives. It takes into account, of course, the conservation objectives of the Natura 2000 sites that depend on water, which must be explicitly defined in the basin plans. The link established between water management and achieving environmental objectives allows the concept of water requirements to be more flexible, and, depending on the established conservation objective (for a protected area or a heavily modified water body), the necessary volume of water will be different.

The Water Framework Directive establishes a context of conservation and restoration of aquatic ecosystems based on the principle of sustainable use. In hydrological planning, this principle of sustainable use and conservation of aquatic ecosystems is built, to a large extent, on the concept of environmental flows (known as water requirements or needs in the case of wetlands).

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The transposition of the Water Framework Directive to the internal legal framework has been more complicated (there is a multitude of regulations of different ranks). In the area that interests us, we must highlight above all the Hydrographical Planning Regulation (Royal Decree 907/2007), which best captures the Directive’s contents related to planning. This Regulation makes explicit reference to the obligation of determining the water requirements for wetlands with the fundamental objective of contributing to achieving their good status or ecological potential. This is achieved by sustainably maintaining the functions and structure of wetlands, providing the habitat conditions adequate for satisfying the requirements of the different biological communities belonging to these aquatic ecosystems and the associated terrestrial ecosystems, through the preservation of the ecological processes necessary for completing their biological cycles. In addition, in developing this Royal Decree, Order ARM/2656/2008, known as the Hydrological Planning Instruction, was approved. The latter elaborates upon the concepts and details of the methods necessary to determine the hydrological requirement of different water bodies. This Order clearly established the need to link wetland hydrology with the “environmental objectives” sought (the conservation and recovery of the general ecological functions of wetlands, the conservation of species and habitats and the conservation of landscapes).
Environmental objectives in the water requirements study

A. Conservation and recovery of general ecological functions
- Guarantee the maintenance of the structure and functionality of lake ecosystems and their associated elements.
- Maintain a inundation regime in the wetland that maintains conditions compatible with the established environmental objectives.
- Maximize the potential contribution of the site to the migration and wintering processes of birds as an enclave of trophic support and refuge.

B. Conservation of species and habitats
- Serve as a base for the conservation of species in general, serving, amongst others, functions of genetic reserve.
- Provide adequate protection to the plant and fauna elements (communities of species) of greatest value due to their level of threat, richness, diversity, abundance, fragility and scientific value.
- Maintain, in a favourable conservation status the Natural Habitats of Community Interest.
- Maintain, in a favourable conservation status the bird species of Annex I of the Birds Directive and of Directives 91/414/CEE belonging to the site.
- Contribute to the conservation of classified species present in the area and their habitats. The latter must have the area adequate to maintain viable populations of these species.
- Contribute to the development and application of the plans for the recovery and conservation of the threatened species present in the area, as well as ensure the compatibility of the dispositions, directives and actions contained in these plans, both those already approved as well as those that could be approved in the future.

C. Conservation of landscapes
- Maintain the landscapes of the wetland and its surroundings in an adequate condition, addressing its particular uniqueness.

Currently in Spain, the River Basin Hydrological Plans are instruments that must include the environmental objectives of protection, improvement and regeneration of surface water and groundwater bodies. The Basin Organization is the administration body responsible for the application of the Hydrological Planning Regulation (in the case of basins shared by two or more regions these organizations are at the state level, but in the case of intra-region basins they belong to the corresponding Autonomous Community).

As was mentioned earlier, when determining the water requirements of wetlands it is very important to take into account the desired or mandated environmental objectives. For this reason, in the case of Spanish wetlands, the following elements are considered:

1. For water bodies defined by the Basin Organizations, the environmental objective sought is the “good ecological status”, which will be evaluated using indicators of the quality of the ecological status of the water.

2. In wetlands declared Natural Protected Areas and Natura 2000 sites, the conservation objectives which must be achieved are defined in the designation of these sites. Concretely, for Spanish Natura 2000 sites, a “favourable conservation status” should be achieved for the Habitats of Community Interest included in these sites, as well as the conservation objectives of the species included in the different annexes of the Habitats and Birds Directives present in these sites.

3. Other water bodies that do not have a specific protection designation, but are included in other catalogues of interest such as the Spanish Inventory of Wetlands (Royal Decree 435/2004, 12th of March).

In the case of lakes and wetlands dependent on groundwater, the Hydrological Planning Instruction specifies that a hydrological regime based on piezometric levels must be maintained such that “the alternations due to human activity not impede the achievement of the environmental objectives specified for the associated surface waters, or cause any significant harm to the associated terrestrial ecosystems that directly depend on the groundwater body”.

We see thus how the determination of the water requirements of wetlands portends to be a key aspect for the conservation of these ecosystems. The issue becomes especially relevant for the large implications it entails for water management.

We must keep in mind however, that the confluence of several environmental objectives in the same space can result in confusion. It is therefore necessary to, systematically and for every case, identify the conservation objectives for each habitat and species of community interest that depend on water, and to verify whether these are more rigorous than other objectives of the WFD applicable to each water body. Furthermore, the quantity of water reserved for environmental conservation will vary depending on whether one is dealing with protected areas, natural water bodies or heavily modified water bodies. These inputs should contribute to achieving the environmental objectives of the corresponding water bodies. The ultimate goal is not to simply provide a set volume, but rather to achieve the environmental objective of the wetland in question.
The water requirements of wetlands in the legal framework

Which is the applicable legal framework?
The applicable legal framework for the water requirements of wetlands is primarily found in the water sector legislation (Water Framework Directive, successive texts of the Water Law, other mandates such as the Hydrological Planning Regulation and Instruction). In addition, the environmental legislation has bearing on some aspects of the water requirements, as in the case of protected areas or the recovery of endangered species.

Where and when are they established?
According to Article 18 of the Royal Decree 907/2007 of the Hydrological Planning Regulation, the water requirements of aquatic ecosystems are determined in the Basin Hydrological Plan.

How is a water requirements regime defined?
This is the regime that permits the sustainable maintenance of the function and structure of aquatic ecosystems and associated terrestrial ecosystems, contributing to achieve the good status or ecological potential of the corresponding water bodies.

What is the position of the other uses?
Article 57 (7) of Law 46/1999 clearly defines some limits in the use of hydrological resources for environmental reasons, establishing for the first time that “ecosystem flows or environmental demands will not be characterized as use (…), they should be considered as a general restriction on all systems of exploitation”, the exception to the rule being the supremacy of use for the supply of human populations.

For which water bodies should they be calculated?
The water requirements must be determined for all the water bodies in each category, such as transition waters, lakes, wetlands and groundwater bodies.

How is this put into practise?
The establishment of the water requirements regime will be carried out through a process that takes place in three phases: technical studies for the determination of water requirements; a consensus building process; and a process of application of the exploitation systems.

3. BASIC COMPONENTS OF THE HYDROLOGICAL REQUIREMENTS STUDY

The key elements of the study of the hydrological requirements of a wetland are the hydrology, the biological communities and the conservation objectives.

The phases of the analysis that should steer the hydrological requirements study are:

1. As we have seen, the legal analysis provides an understanding of the conservation objectives of wetlands and the particular conditions imposed by the various legislations. The general conservation objectives of wetlands are complemented in turn by the specific objectives of protected areas, which can be especially demanding in the case of some protection designations or when particular endangered species are present. A careful review of the legal framework makes explicit the conservation objectives for which a coherent hydrological requirements proposal must be formulated.

2. The analysis of the physical environment centres primarily on the characterisation of the hydrology and hydrogeology of the wetland. This undertaking includes the study of the natural inundation regime and of the effect of human activities on this regime (water use, impacts, etc.), among others.

3. The analysis of the bio-ecological environment is based on an understanding of the biological communities present in the wetland. These are an important component of the conservation values of wetlands, to the point that in a number of cases management activities are directly or indirectly oriented to the conservation and improvement of the biological communities. In addition, we must keep in mind that habitats and species provide information on the hydrological dynamic, including the distribution and abundance of different organisms. The hydrology-ecology relationship is key for understanding the dynamic of these ecosystems.
3.1. THE HYDROLOGY OF WETLANDS

An understanding of the inundation regime of wetlands in both natural and modified conditions is fundamental for the hydrological study necessary to determine the hydrological requirements of a wetland. The inundation regime is a factor that, to a large extent, determines the organization and dynamic of the ecosystem (presence and distribution of biological communities).

The inundation regime is defined as the variation in water volumes or depth of water over time. The study of the inundation regime is carried out at a monthly scale and lengthy time series are necessary in order to understand the inter-annual variation.

Determining the inundation regime of a wetland is no easy task. To accomplish this, one must calculate the hydrological balance of the wetland and map the bathymetry of its basin.

The hydrological balance study consist of quantifying, for a certain time period, the flows of water in and out of a system, taking into account both surface water and groundwater (precipitation, surface and groundwater flows, infiltration, runoff, water extraction, etc.). For this, one must compile all the climatic and hydrological data available over a sufficient time frame, usually of 20 years. The data must be analysed in monthly intervals.

As described above, a detailed study of the historical data series should enable us to identify the seasonal and inter-annual variations of the wetland. Quantitative data for some of the parameters of the water balance equation is typically lacking, especially for monthly balances or historical series of the latter. To make up for these deficiencies, we use hydrological models and programmes for the tracking and control of wetlands which, over the last decade, have provided basic data that in some cases enable us to develop a fairly accurate hydrological balance, at least for some of the more significant elements of the system such as surface runoff.

In addition, it is useful to understand the hydrological regime of the wetland not only under natural conditions but also when its elements have been modified, since the inundation regime will obviously vary.
In order to understand the inundation regime, it is necessary to understand the bathymetry of the basin since the latter provides information on the water storage capacity of the wetland and on the surface area flooded (and with this the direct precipitation on the water surface and the evaporation and infiltration).

Models for determining the inundation regime of a wetland

In most cases, the historical monthly hydrological balance of a wetland can only be calculated using models. In general, hydrological models (for surface water and groundwater) and hydraulic and hydrodynamic models have a direct application for the study of the inundation regime.

Over the last few years, a number of hydrological models have been utilized in Spain to generate data series on the natural runoff in basins. These models replicate the process of runoff generation using meteorological and hydrological information and the characteristics of the basins. They have played an important role in the development of hydrological plans in the 1990s; the SIMPA model (Integrated System for Rainfall-Runoff, Precipitation Aportacion) which was developed by the Center for Hydrographical Studies and Research (CEDEX) during the development of the White Book of Water in Spain; the PATRICAL model (Precipitation Runoff in Network Sections Integrated with Water Quality, Precipitacion Aportacion en Tramos de Red Integrados con Calidad del Agua) which can be applied in a natural regime or a regime modified by human activity; the GIS-BALAN Model which assesses the water balance in the soil, the unsaturated zone and the aquifer, calculating the components in a sequential manner; and the MODFLOW groundwater model developed by the United States Geological Services which provides a three-dimensional model of groundwater flows in saturated porous material.

The hydraulic models are based on the relationships between the morphology of wetlands (morphometric parameters of the basin such as bathymetry, area, depth, etc.) and their limnology. They provide information on the relationships between the slope of the landscape, corresponding water volume and inundated surface. These features are known as the wetland storage capacity curve. Hydrodynamic models simulate and model a number of processes related to the flow of water in the wetland. One of the most frequently used is the SOBEK model, which calculates water level, flow velocity, sediment transport, channel depth, salinity and many other water quality parameters. It is based on a one-dimensional simulation of the river or wetland system. The MIKE-11 model is used for one-dimensional modeling of steady and unsteady flow. Lastly, the HEC-RAS model functions along the same lines as the MIKE 11 model.

When utilizing models to understand the inundation regime of wetlands, it is important to keep in mind that:

- The surface runoff into the wetland is relatively easily obtained by modelling, but difficult to verify in many cases due to the lack of flow measurement stations and series of water levels. This publication offers a rigorous methodology for approaching the data collection on water levels in Spanish wetlands, keeping in mind that this information is fundamental for the understanding and tracking of the hydrological evolution of wetlands (Annex I).

- In the case of wetlands with groundwater flows, the modelling is more complex because water discharges to a wetland are very difficult to quantify on a monthly scale. In the absence of this information, the groundwater flow is usually estimated based on the water balance, which can introduce a great deal of error.

- Evaporation is a key variable of the balance which is rarely known with any degree of precision.

- Calibration is an indispensable step. Many hydrological variables are subject to some degree of uncertainty. In addition, the errors in the data series of wetland water volumes are cumulative, which can result in absurd figures. Sometimes the only available option to adequately calibrate the hydrological models is the use of satellite imagery, although remote sensing also has certain limitations.

Lastly, we must point out that the characterization of the inundation regime has great potential to contribute to the hydrological requirements study. For example, it can be used to:

- Develop models of habitat distribution that include the location of plant communities. The presence-absence analysis of species along with the inundation time series allow us to understand the preference of certain plant communities regarding inundation cycles and their tolerance range. Using this information, we can develop models for the ideal habitat for certain communities or species.

- Develop proposals of the water requirements using hydrological approximations based on certain reference hydroperiods. The natural inundation patterns play a fundamental role for the conservation of the functional and structural character of a wetland. The determination of water requirements based on a hydrological approximation is based on the identifying these inundation patterns. Once these have been identified, we can determine the volume of water necessary to achieve an inundation coverage that enables us to achieve the conservation objectives (conservation and production) for a particular wetland.

- Understand the seasonal variations in the water level and the associated hydraulic properties. The water level is a key parameter that plays a defining role in the nesting area for birds. The development stages of numerous aquatic species (fish, amphibians, invertebrates, etc.) depend on the inundation cycles. It is necessary to develop empirical models that relate the physical variables with the biological variables in order to fully understand the inundation regime of the wetland.
Remote Sensing Techniques for the Determination of the Inundation Regime of Wetlands

Remote sensing technology is excellent for monitoring dynamic natural phenomena and has applications for the study and monitoring of wetlands. In particular, it provides a great deal of information on the evolution over long periods of time (since the 1970s) of the superficial hydrological characteristics of a wetland (changes in the inundation surface, periods of drying and salinization, tracking of water pollution, etc.).

The remote sensing data is analysed to obtain information on the extension of the inundated area over a certain time frame (selecting historical and recent dates). This information is obtained by overlaying satellite images of Earth (Landsat satellite) with calculations of depth and water volume of the wetlands for the same dates. In this manner one can calculate retrospective time series of wetland inundations and use these to calibrate the hydrological models, determine inundation regimes, and other uses.

The methodology consists of analysing the spectral signature of each image for each date and generating a layer of water surface for each image. To do this, a Water Index is used, which is extracted using the green and infrared bands of the Landsat TM sensor.

When a precise digital landscape model (DLM) is available, the depth for each date is calculated based on the water surface and bathymetry extracted from the DLM.

If a precise DLM is not available, the depth is obtained by a calibration methodology that relates the area of the water surface measured with remote sensing and the depth measurements taken in the field by calculating the linear regression that correlates them.

The Demarcation of the Guadalquivir Wetlands Case Study

Although hydrological information is key for understanding the ecological functioning of wetlands, this information usually does not exist or the time series available is too short to statistically characterize a wetland. On the other hand, remote sensing offers a lengthy data series of historical images that provide a large amount of information of the planet’s surface, including some of the hydrological characteristics of wetlands such as the inundated area. A historical analysis using remote sensing enables us to construct a retrospective time series of wetlands inundations, thus contributing to a better understanding of their functioning.

The study carried out in selected wetlands in the Demarcation of The Guadalquivir sought to develop a simple and practical methodology to calculate and monitor the water area over time, using remote sensing techniques and data obtainable at a low cost.

The first step was the creation of a database of Landsat images for the two periods selected (1995-2007 and 2008-2010) containing those images most appropriate for the study objectives (Figure 1). To homogenize the images, these were orthorectified (using a Spot 5 image of the National Remote Sensing Plan and the digital landscape model from the SIGPAC) and radiometrically corrected, converting the digital level values (8-bit, 256 shades of grey) to reflectivity values, that is, the per cent of incident radiation reflected by the surface.

Different indices, such as the Modified Normalized Difference Water Index (MNDWI), the Normalized Difference Water Index (NDWI) and the CEDEX Water Index were tested for the identification of the surface water. The indices were evaluated for different image dates and for different inundation levels. The IAL25 was selected since it was most appropriate for the inundation levels observed in the images. In some particular cases, additional application of the NDVI in combination with the IRM allowed for an improved discernment of the inundated vegetation.

Using the wetland bathymetry obtained from a digital landscape model (DLM) and the water surface obtained from the application of the IAL25 index, the study was able to determine both the water volume and depth for each of the dates of the satellite imagery.

Figure 1. Methodology utilised. Source: TRAGSATEC for CHG, 2011

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By comparing measurements of real water depth obtained in the field with the results obtained with the remote sensing techniques, the study was able to observe that, on average, the differences were less than 20 cm. In most cases these differences could be justified by the uncertainty in the match between the date of the field measurements and the date of the images utilized, as well as by the error resulting from the spatial resolution of the images and the DLM.

From the results obtained from this study we can conclude that remote sensing techniques can be a simple and affordable means for generating a historical series of inundations in wetlands. Data series on water levels and volumes can also be calculated if an adequate bathymetry is available.

Despite these good results, the study noted some caveats that could limit the use of remote sensing technique in other wetlands. For example, the minimum area of the wetlands is proportional to the spatial resolution of the images (this study considered the minimum area to be 0.1 ha, approximately 10 pixels of a Landsat image). In addition, the spectral resolution of the images also limits their application. This fact makes advisable that at least the green, red and near infrared bandwidths be available, although the mid infrared bandwidth is also desirable (as is the case for Landsat images). The type of wetland inundation regime could also limit the application of remote sensing.

3.2. THE BIOLOGICAL COMPONENTS OF WETLANDS

The values that led to the protection of many wetlands have been their vegetation and their fauna. For this reason, the conservation status of these is a fundamental factor that depends largely on water and on the processes that occur in the ecosystem. In many instances, the biological components (habitats and species) are a result of the hydrological behaviour of the wetland and can be considered true “indicators” when determining the water requirements.

The selection of the species that will guide the water requirements study should take into account the susceptibility of these species to changes in the inundation regime of the wetland, and especially, their sensitivity to the types of hydrological alterations taking place in the water body. The species of flora and fauna or the natural habitats can be considered individually or by biological communities or groups of habitats.

It appears that plants are the best indicator due to their high diversity and the fundamental role of vegetation for the refuge, breeding and feeding of the fauna (birds, amphibians, fish, etc.). When we undertake a detailed analysis of the water requirements of plant communities, we observe that there is a dependency gradient that ranges from the strictly aquatic plants that carry out their entire life cycle in the water, to plants that have an affinity for water or exhibit a competitive advantage in wet conditions (for example, phreatophytic vegetation).

The spatial layout of the plant species in a wetland responds fundamentally to environmental gradients, where the inundation regime and salinity conditions are the primary factors responsible for this layout. The resulting landscape is characterized by a zonation of the vegetation in concentric bands distributed around the centre of the lagoon (Keddy, 2002; Wisheu y Keddy, 1992; Wasserberg et al., 2006).

Among the Habitats of Community Interest listed in Annex I of the Habitats Directive that depend on water, we can find: standing water habitats (Group 31), Atlantic and continental salt marshes and salt meadows (Group 13), Mediterranean and thermo-Atlantic salt marshes and salt meadows (Group 14),...
Salt and gypsum inland steppes (Group 15), Sphagnum acid bogs (Group 7), etc. In Spain, the Ministry for Environment, and Marine and Rural Affairs carried out an exhaustive study to characterize the habitats included in Group 31 (VV.AA., 2009) due to the interest of the Ministry to be involved in the synergistic application of the European Habitats and Water Frameworks Directives.

In addition to vegetation, birds provide a good indicator for understanding wetland water requirements. Birds have developed numerous strategies, behaviours and morphological adaptations to maximize the diversity of ecological niches available to them in wetlands. As Green and Figuerola (2003) point out, there are a number of limitations and precautions that must be taken into account when utilizing water birds as indicators. However, the conservation status of some species is a reflection of the hydrological changes in wetlands, and, by extension, of the potential benefits for restoring them. Furthermore, in Spain, some species that are highly dependent on water have disappeared or are highly endangered, as in the case of the Eurasian Bittern (Botaurus stellaris).

The current population of the Eurasian Bittern or Great Bittern (Botaurus stellaris) is at most 25 territorial males in Spain and a total Mediterranean population of 200 males in Spain, France and Italy. In the past, this species was a permanent presence in certain Spanish wetlands, but a major decline in populations took place beginning in the mid-20th century. The species was at the brink of extinction in the 1980s. In the following decade, an estimated population of 8 territorial males were found in the Guadalquivir Marshes. These disappeared in the drought of 1992 and have not been seen reproducing in this site since.

The species’s decline is primarily attributed to the degradation and loss of its natural habitat, in particular, the lack of extensive reed beds (and absence of different development stages) and the impact of water management (manipulation of water levels, sewage, extraction, etc.). Another factor in the decline of the bird appears to be the control of the hydrological regime applied in most wetlands, which tends to result in very dense reed bed formations which are inappropriate for the species.

Once the key elements of the wetland have been analysed (hydrology, biological communities and conservation objectives), the next step is to study the methodologies and techniques for determining and applying the water requirements.

The basic principles guiding the studies of water requirements are related to the water that the wetland needs to achieve the established conservation objectives. The environmental objectives associated to the water requirements are oriented, as mentioned earlier, to the conservation and recovery of the general ecological functions of wetlands, their role in the conservation of species and habitats, and the conservation of landscapes.

These principles are reflected in various legal instruments. Article 45 of the Natural Heritage and Biodiversity Law calls for establishing the instruments or management plans for the Natura 2000 sites in order to achieve the “good ecological status” of the ecosystems (“establish the conservation measures necessary, that respond to the ecological demands of the types of natural habitats and of the species present in said areas”). In some wetlands, it may be the case that there are other objectives in addition to this conservation objective, as in the case of protected areas (national park, SCA site, etc.) or Ramsar wetlands. The Birds Directive includes in its objectives the protection of bird species and their habitats and calls for special conservation measures for certain species. Another example is the Ramsar Convention which also applies ornithological criteria for the designation of wetlands. Yet another is the case of wetlands that host species listed in Annex IV of the Habitats Directive, which benefit from strict protection both within Natura 2000 sites and outside these sites. For the latter case, the water requirements established should be sufficient to safeguard the ecological functions of the breeding and layover areas used by the birds in order to effectively contribute to the system of strict protection of these species.
The WFD takes into account all these situations and establishes in Article 4.2 that, where more than one of the objectives relates to a given body of water, the most stringent shall apply. This means that for each case, it is necessary to systematically identify the conservation objectives for the habitats and species of community interest that depend on water and to verify whether these are more stringent that the objectives of the WFD for the water body in question.

The Hydrological Planning Instruction states that “the fundamental objective of characterizing the environmental water requirements of the bodies of water classified as lakes or lagoonal transition zones is to contribute to achieving a “good ecological status or potential” . This conservation objective will be attained “by the sustainable maintenance of the functionality and structure of said ecosystems, providing the habitat conditions adequate for satisfying the requirements of the different biological communities belonging to these aquatic ecosystems and the associated terrestrial ecosystems, through the preservation of the ecological processes necessary to complete their biological cycles”. In the case of lakes and wetlands dependent on groundwater, the Instruction specifies that a hydrological regime based on piezometric levels must be maintained such that “the alternations due to human activity not impede the achievement of the environmental objectives specified for the associated surface waters, or cause any significant harm to the associated terrestrial ecosystems that directly depend on the groundwater body”.

From all these situations we conclude that the best conservation status is achieved with water flows that approximate natural flows and that the water requirements of a wetland should be defined such that significant changes in the biological communities are avoided.

The tools and techniques developed in scientific circles for determining the water quantities required by ecosystems are generally called “calculation methods”.

These methods determine the type of hydrological regime necessary for the wetland to maintain its ecological characteristics. As mentioned in the beginning of this manual, one must first identify the most relevant ecological characteristics that should be conserved in the wetland.

The starting point is the notion that a wetland is compose of a physical environment and a biological environment composed of plant, animal and microorganism communities that interact as a functional unit. As mentioned earlier, the hydrological regime plays a key role in the physical environment. The particular dynamics of the hydrological regime (resulting from groundwater discharges, surface runoff, evaporation losses, etc.), result in a certain inundation regime which varies depending on the characteristics of the basin. The hydrological dynamic is the foundation of the ecological processes and determines the habitat conditions under which the animal and plant species and the microorganisms interact, organise, change, fluctuate and evolve.
Over 200 methods have been described in different parts of the world for determining environmental flows and/or water requirements. These can be categorized as: hydrological methods, hydraulic methods, hydro-biological or habitat modelling methods, ecosystem valuation methods and holistic approaches.

Despite the important progress of these methods in the last years, scientists and managers have not reached consensus on a method that is entirely satisfactory. Hydrological approximations are the most commonly used because of the ease of calculation, whereas habitat modelling is widely employed in the northern hemisphere. Methods that employ an "ecosystem approach" are increasingly recommended. These methods focus particular attention on the natural processes of ecosystems and incorporate, to a greater or lesser extent, components of the natural hydrological regime. Overall, holistic approaches are the best reviewed in the specialized literature (Carreño et al., 2008).

Hydrological methods are based on the natural hydrological regime (and by extension the hydroperiod and inundation regime) since this is a key variable in the dynamics and functioning of wetlands. The advantages of hydrological methods include their analysis capacity and temporal resolution (all the components of the hydrological regime can be characterised at the required time intervals). We must also highlight that this is an analytical approximation that utilizes the other methods as reference variables.

Hydrological methods are adequate for establishing a first approximation of the water requirements of wetlands or when rapid evaluations are necessary. These methods are also useful in wetlands where hydrological significance was applied as a criterion for the designation of a wetland of international importance.

There are numerous variations of the hydrological method, which is based on the analysis of the natural hydrological regime to develop proposals of water for wetlands. The best methods are based on a characterisation of the "natural perturbation regime" and the "natural variability range" (based on analysis by percentiles). In this manner, when applied to a hydrological time series at monthly time scale, these methods can adequately reflect the hydroperiods of wetlands. Because many wetlands are also characterized by high interannual variability, it is also recommended to at least separate wet cycles from dry cycles in order to encompass a greater range of environmental conditions.

The characterization of the natural perturbation regime is based on an analysis of events. The episodes of maximum and minimum water volumes are events of great ecological significance for wetlands.

Some of the limitations for the application of hydrological methods include the lack of hydrological data series that cover a sufficient period of time (at least 20 years) and that reflect natural conditions. However, these limitations are being overcome with the development of hydrological simulation models and retrospective analyses using satellite images.
Hydro-biological, also known and habitat modelling methods analyse the response of certain species to hydrological conditions. These models are based on the preferences of the species for certain habitat conditions. To apply this method, one must identify the species or biological groups of sufficient relevance in terms of interest or indicator value. For this reason, this method is especially appropriate when the biological elements were the justification for the designation of wetlands of international importance. Additionally, one must analyse for each species the limits of their habitat preferences based on detailed studies of the species.

The habitat of a species is understood as “the description of a site, at a determined scale of space and time, in which the organism lives or can live”. The geographical, climate and biological characteristics important for the distribution of the organisms are typically used to describe a habitat. Although it is practically impossible to define all the variables, the habitat of a species can be adequately represented by selecting some of these variables. Undoubtedly, the physical variables related to water (depth, inundation duration and timing, etc.) are especially relevant for aquatic species. This model based on habitats provides information on the potential area that species or communities could occupy as a function of the inundation regime.

One of the advantages of this method is its predictive capacity, which offers an enormous potential when formulating different scenarios of water requirements for wetlands. Furthermore, it can be used in combination with other methods to predict the biological consequences of a particular management scenario and the implications each scenario for other water users or for the economy. For this reason, hydro-biological methods are especially indicated for cases where there are conflicts over water use.

The limitations of the hydro-biological methods include the elevated costs in terms of time and resources of carrying out the necessary biological and physical studies. In many cases, the proposals developed with hydro-biological methods have been based on a single species without taking into account the complex processes governing wetlands or the rich diversity of other species. In wetlands with high biodiversity it is difficult to identify a species that represents the entire ecosystem.

The determination of water requirements based on holistic approximations consider the wetland as a whole as their point of departure. This method seeks to understand the response of the entire system based on the analysis of different components or processes essential to the ecosystem, including its species.

These holistic approximations are not based on a particular methodology but rather on an approach or vision in which different fields of knowledge (including hydrology, hydraulics, hydrogeology, geomorphology, ecology, botany, ichthyology, entomology, water quality, etc.) are organized under a work plan to adopt, in a comprehensive and explicit manner, proposals for water requirements aimed at achieving the environmental objectives of the wetland and its long term conservation. The hydrological and hydro-biological methods described previously are not excluded from this holistic approximation. Rather, they form part of a broader conceptual framework and work plan that takes into account the entire ecosystem at different scales of time and space.

Undoubtedly, the most noteworthy advantage of the holistic approaches is the fact that they encompass the wetland as a whole, focusing on the conservation of the entire system in the medium and long term. The participation of experts from different fields of knowledge, including in many cases local experts, is very important since it gives these methods scientific credibility. For this reason they are also useful approaches in situations where there are conflicts with other water users. In situations with limited data, it can also be useful to draw on the knowledge of experts. The biggest disadvantage of holistic methods is their high cost when compared to hydrological methods.

As we have seen, the final selection of one method over other depends on the concrete characteristics of the wetland (ecological, economic and social) and the context of the decision to be taken (overall resource planning, monitoring, reducing conflict between users, wetland restoration plan, etc.). In all cases it is important to remember that the methods presented are neither exclusionary nor would their necessarily present differing results. Rather, we should keep in mind that the types of analysis and the information utilised by each method is different (some are based on few variables while other employ diverse variable and sophisticated models).
When undertaking a systematic study of the water requirements of a wetland, one must first characterise the wetland, including for this: identification of the wetland type, characterisation of the climate, hydromorphological characterisation, hydrogeological characterisation, hydrological function and water balance, physical-chemical balance, ecological characterisation, identification of the pressures on the wetland.

The information used for these studies is usually dispersed among different organisations and thus far not been compiled or integrated.

## PHASES OF THE ANALYSIS FOR DETERMINING WATER REQUIREMENTS

### Identification of the type of wetland

Wetlands should be identified with their corresponding codes (SIC, SPA, Ramsar, etc.). In addition, they should be classified according to the categories established by the Hydrological Planning Instruction, following the procedures established in the Instruction. Where relevant, and in cases where the information is available and the corresponding body of water typology should also be assigned.

### Characterisation of the climate

The data for the basic variables for the water balance calculation should be obtained: precipitation, mean temperatures, maximum and minimum temperatures, real and potential evaporation and evapotranspiration. The data obtained should be of good quality and be representatives of the climatic conditions of the wetland and drainage basin.

### Hydrogeological characterisation

Where possible, the information should be obtained from a historical data series that is sufficiently representative of unaltered hydrological conditions or minimally altered conditions. In wetlands with groundwater discharges, the functioning of the aquifer associated to the wetland and the piezometric levels that define the hydrogeological behaviour of the aquifer (transmissivity, storage coefficient, piezometric head and extracted volumes) should be described.

### Hydromorphological characterisation

The hydromorphological variables that most influence the structure and functioning of the aquatic ecosystem should be characterised. For this, one requires the bathymetry of the wetland as well as data on the flooded area, water depth and the seasonal and inter-annual variations.

### Hydrological function and water balance

One must identify and quantify the water that enters the system, especially ground water contributions, and discharges or losses. A conceptual model of the functions of the wetland should be created. The model should identify all the components and their seasonal and inter-annual variations. The model will provide information on the origin of the water entering the wetland (surface, groundwater or mixed), the relationship of the wetland with the flows (influent or effluent), as well as the volumes of water contributions, recharge and circulation of the system.

### Physical-chemical balance

Where possible, the chemical composition of the water and the seasonal and inter-annual variations in the chemistry should be characterised. Special attention should be paid to the composition and concentration of dissolved minerals, as well as to the primary sources and sinks of chemical compounds and the conditions of the physical parameters. A wetland with different sources of water will have a chemical dynamic that depends on these different flows. To avoid changes to the chemical-physical conditions of the wetland and a consequent loss of its characteristics, in addition to the flows, it is important to understand their sources and characteristics. This also applies to the groundwater bodies associated with the wetland functions.

### Ecological characterisation

The composition and structure of the biological communities found in the wetland (habitats and species) should be characterised as well as their seasonal and inter-annual variations. Endangered species, protected species and indicator species should be identified.

### Identification of the pressures

The water extractions from the wetlands and their historical evolution should be identified. The direct uses of the wetlands and artificial water discharges such as agriculture runoff should also be identified. Other pressures such as land use changes, water quality problems, etc. should also be noted.

### Aspects considered in the characterisation of wetlands

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Detailed Contents of a Study for the Determination of Water Requirements

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5. CASE STUDIES

5.1. THE DOÑANA MARSHES

5.1.1. Characteristics of the wetland

Doñana National Park is located in in the provinces of Huelva, Seville and Cádiz in the Community of Andalucia, in southern Spain. The wetland is characterised by a great diversity of environments, including forest ecosystems, Mediterranean scrub, sand dune complexes (dynamic and fixed dunes), beaches, lagoon systems and, especially, marshes. The marsh is a clay plain of fluvial depositions subject to marine forces that currently covers 30,000 ha. It was produced by the depositions of the historical estuary system at the mouth of the Guadalquivir and Guadimar Rivers. This area represents an extraordinary site for the wintering, migration and breeding of numerous birds, especially water birds. Doñana is also noteworthy for the presence of several emblematic endangered species such as the Iberian lynx or the imperial eagle, which find here one of the last refuges. The site is globally recognized for its important and unique values.

The most significant pressures that impact the wetland are:

- Land use changes that began with the implementation of agricultural development plans in the second half of the 20th Century that implied the drying-up and transformation of 76% of the original surface (150,000 ha) of the Guadalquivir marsh system (Casas y Urdiales, 1995; MMA, 2001; García Novo y Marín, 2005) as well as part of the native forest cover which was substituted with eucalyptus plantations.
- The extraction of groundwater for irrigation has resulted in the continuous decline of piezometric levels in some locations.

6 This case study is based on the report produced by Rafael Sánchez for WWF Spain in 2009 titled “Caudales ecológicos de la marisma del Parque Nacional de Doñana y su área de influencia”. (Environmental flows in the marsh of the National Park of Doñana and its area of influence).
Indiscriminate hunting was very common in earlier decades and had a large impact on some species which are currently endangered.

- The excess of livestock density has caused damage to the vegetation in Doñana.
- The introduction of non-native species has resulted in damage and significant transformation of the Doñana ecosystems, especially with the introduction of the American freshwater crayfish Procambarus clarkii.

The hydrological functioning of the Doñana wetlands includes a diverse network of rivers, streams and lakes, as well as water from other sources (water transition from the estuary and discharges from aquifers).

The human interventions mentioned above caused profound changes in the hydrological regime of the marshes and a drastic reduction of their area. One of the primary consequences of the recent interventions in Doñana has been the drastic reduction in water inputs to the marsh. Figure 2 presents a rough chronology of the most important interventions and a rough quantification of these.

The drastic reduction of inputs to the marsh have been partially compensated by two factors. Notwithstanding the environmental problems caused (loss of biological connectivity, elevation of the maximum flood levels, transformation into a standing marsh system), the closing of the sluice gates at the Montaña del Río (of Dos Rompidos, of the Figuerola, of Bñenes, etc.) has prolonged the inundation periods in the marsh. In addition, the area of the marsh was reduced in parallel with the reduction of water inputs. This reduction in area can partially compensate for the inundation levels in the remaining marsh.

5.1.2. The Water Requirements Study

An approach based on the Ecological Limits of Hydrological Alteration (ELOHA) conceptual framework was employed to develop the proposal of the water requirements for Doñana. This framework was selected for its scientific robustness and flexibility for assessing and managing environmental flows. In this framework, knowledge is systematically organized around the relations between hydrology and ecology within a broader context of decision making (Arthinghton et al, 2006, Poff et al, 2009).

Using this conceptual framework, the formulation of the proposal for the water requirements of the marshes (steps 1 to 7 in figure 3) requires three fundamental analyses:

1. The hydrological analysis. Based on the available information, the natural and modified hydrological functioning of the marsh and of the main contributing rivers are analysed (steps 1 and 2). The hydrological characterization includes an analysis of natural droughts, the seasonal pattern of base flows and the flood regime of each system. The surface inputs are complemented with the Almonte-Marismas aquifer system balances. Using a comparison of the data series of historical natural conditions with the series of observed conditions (registers of the gauging stations, inundation area, water levels, etc.), the observed hydrological changes are evaluated and the chronology of these changes since 1850 to the present is completed.

2. Hydro-ecological analysis. The natural hydrological regime is a key control factor that, to a large extent, dictates the changes to the ecosystems. The associated habitats and species responses to the natural hydrological dynamism include the distribution and abundance of the different organisms. The hydrology-ecology relationship is a key for understanding the dynamic between ecosystems, habitats and species. The vegetation is noteworthy because of its intrinsic importance; because of the role it plays for the different animal groups; and because of its capacity to indicate changes. There is also a zonification response of the vegetation as a function of the inundation regime.

3. Legal analysis. The conditions imposed by the legal framework impose a number of restrictions to the possible environmental flow options in the Doñana context. The general con-
To simplify the multiple factors involved in the study of environmental flows in Doñana, it is necessary to identify specific indicators. The conceptual models offer an easy and effective alternative to communicate and synthesise extremely complex processes. Figure 4 shows the relationships between the environmental flows, the hydroperiod of the marsh and different biotic components of the ecosystem.

The hydraulic regime of the marsh is fundamentally conditioned by the inputs from the two rivers that drain into it (1). The water balance of the marsh (taking into consideration the inputs and outputs of the system) and the topographic features of the terrain determine the inundation levels of the marshes at each time of year. This inundation regime (number of days inundated, maximum and minimum standing water levels, seasonal distribution, etc.) defines the hydroperiod of the marsh (2). The inundation regime is translated into certain hydraulic parameters (measured depth the standing water, duration, etc.) that have a big impact on the presence and distribution of plant species (3). The different inundation levels link different parts of the marsh, favouring connectivity for different fish species (4).

The natural mouth of the marsh toward the estuary through the Montaña del Río is a clear example of the connectivity that permitted the migration of euryhaline aquatic species, which in turn were preyed upon by birds (4-6). The vegetation of the marsh has a determining role on all the phases of the biological life cycle of fish (4), amphibians (5), birds (6) and mammals (7). The different species of birds are desagregated according to habitat structure and the type of resource they exploit (2-3-6). In the reproductive colonies, the availability of shallow water among the vegetation (2-6) or the presence of branches and shrubs at the edge of the marsh (3-6) condition the reproductive success of a number of species. At the end of spring, the marshes begin the process of drying, drastically reducing the surface of standing water. When the water levels fall too fast and the nests are left dry (2-6), the reproductive success of the species decreases.
An approximation based on the hydrological regime is adequate for determining the water requirements of the wetland since this constitutes the primary organisation factor of the aquatic ecosystem. If we consider that the habitats and species are to a large extent conditioned by the hydrological dynamic of a wetland, then the management proposals that reflect the natural regime will produce the processes and conditions adequate for their conservation.

The recovery of a more natural hydrological dynamic of rivers, streams and the marsh is an indispensable condition for achieving the conservation objectives of Doñana. It is especially relevant to understand the trends of the changes in the vegetation (drastic reduction in the more hydrophilic plants) and decline of some bird species that serve as indicators of the impacts of the hydrological alternation (Eurasian Bittern, Marbled Duck, Crested Coot, Glossy Ibis, etc.).

Taking into account the importance of the hydrological regime of the rivers that discharge into the marsh and the particular legal conditions for this site, a hydrological approach is adopted for determining the water requirements of the marsh. The following criteria are used:

1. The environmental flows proposal is composed of the assemblage of the values of the natural hydrological regime for each of the rivers and streams that flow into the marsh.
2. The water requirements proposal for the marsh is composed of the assemblage of water volumes that discharged into the marsh, in consistency with the proposals developed for rivers and streams.

To formulate this water requirements proposal it is necessary to identify the relevant rivers and streams that flow into the marsh (Figure 5).

There are six stretches of river considered relevant in the assemblage of basins that flow into the marshes (four are in the Guadalquivir River basin).

Three of these stretches contribute inputs that are characteristic of the marsh, and can be added in this case to the inputs of their tributaries.

The availability of hydrological information and the representativeness of the primary elements of the hydrographical system must be considered in the identification of the relevant stretches for the determination of water requirements. Their importance from the environmental perspective and their strategic relevance for the system of water resources exploitation must also be considered.

Figure 6 show the proposal for water requirements of the marsh, taking into account the assemblage of natural inputs carried by the more relevant rivers and streams. The Figure shows the natural hydrological regime of the marsh, while the water requirements proposal for dry and median years have been defined from the 25th and 50th percentiles respectively.
5.2. FUENTE DE PIEDRA LAGOON

5.2.1. Characteristics of the wetland

The Fuente de Piedra Lagoon is located to the northwest of the province of Málaga, at an altitude of 410 meters above sea level in the region known as Hoya del Navazo. It constitutes one of the most important reproduction areas for the Common Flamingo (Phoenicopterus ruber roseus) in the Iberian Peninsula. Between 1983 and 2007, Fuente de Piedra was the site of, on average, 37.7% of the successfully reproducing birds and 40.4% of the chicks born in the western Mediterranean. In 1998, under optimal water conditions, 19,500 reproducing couples of flamingos. The large inter-annual variations in the breeding cycle, predation by mammals, intra-species competition between large flamingo colonies are isolated islands. A proliferation of increasingly deep wells for the extraction of water from the aquifer. The levels registered by the limnograph of the Lagoon provide an estimation of actual water depth of the Lagoon, and the hydrological alternations resulting from the extraction of groundwater.

The primary pressures on the lagoon are:
- Morphological changes to the lagoon basin which took place towards the end of the 19th Century to enable salt exploitation (Calderón, 1888). The exploitation of salt continued until 1951 when ceased to be profitable.
- Overexploitation of the aquifer due to water extraction for irrigation and urban supply. This resulted in a reduction of the water resources available for the lagoon and caused a drop in piezometric levels in the areas with concentrations of wells. The overexploitation of certain areas of the Fuente de Piedra basin is currently observed.
- Pollution from untreated effluent from nearby urban centres that impacts the natural hydrological functioning.
- Intensive use by local inhabitants for recreation and leisure, particularly in years with high water levels. This was especially the case prior to the protection of the lagoon. Access to the interior of the lagoon is currently restricted to management and research.
- Loss of habitat for bird communities due to water extraction of agricultural uses and the channelling of many streams. This has caused a reduction in the reproductive success of some species, as well as an increase in intra and inter species competition for nesting sites.

The hydrological functioning of the Fuente de Piedra Lagoon is complex. It includes groundwater contributions, direct precipitation into the basin and the runoff of a number of streams that flow into the Lagoon. The circulation of water in the Lagoon basin occurs through three interconnected storage and regulation systems (the soil, the aquifer and the lagoon itself).

There are numerous exploitations of groundwater in the area surrounding the lagoon. In the mid-1980s, in response to a major drought, there was a proliferation of increasingly deep wells for the extraction of water from the aquifer. The levels registered by the limnograph of the Lagoon provide an estimation of actual water depth of the Lagoon, and the hydrological alternations resulting from the extraction of groundwater.

The extractions result in a reduction of the volume of water stored in the aquifers. This decreases the groundwater contributions to the Lagoon, which in turn means the lagoon does not reach the surface water levels it would hold under a natural regime. Between 1974 and 1983, the decrease in aquifer levels due to groundwater pumping was measured at over six meters in the areas surrounding Fuente de Piedra.

5.2.2. The Water Requirements Study

The study of the biological cycle of the flamingo in Fuente the Piedra uncovered a number of factors that negatively impact the reproductive success of the colony. The most relevant factors include the drying of the Lagoon, the lack of food in the Lagoon towards the end of the breeding cycle, predation by mammals, intra-species competition between large reproductive groups of flamingos and disturbances from photographers and low-flying aircraft. Thus, the water requirements proposals have a direct impact on the reproductive success of the species.

In a general conceptual manner, the factors mentioned above that influence the reproductive success of the flamingos are related to each other as show in Figure 7:
- The hydraulic regime of the lagoon is fundamentally conditioned by the river flow and inputs from the aquifer system (1).
- The inputs and outputs of the system (water balance), together with the topographic characteristics of the terrain, determine the inundation levels of the lagoon basin at every point of the year. The inundation regime (number of days of inundation, maximum and minimum levels of standing water, seasonal distribution, etc.) define the hydroperiod of the lagoon and its levels throughout the cycle (2).
- The emergence of isolated topographical land features (islands) is related to the water levels (3).
- The isolation of these islands is a function of the duration of the inundation (6). The flamingo colonies generally occupy the ruins of dykes from the former salt works, but in the wettest years these dykes are flooded and the colonies are established on natural islands.
- The best sites for the establishment of flamingo breeding colonies are isolated islands. A greater surface of isolated islands reduces intra-species competition by avoiding overcrowding in the area of dykes. Overcrowding causes disturbances in the reproductive colony (5).

One of the aspects of utmost interest for the conservation of Fuente de Piedra is its role in hosting flamingos. The large inter-annual variations in the reproductive success of these birds is tied to rainfall, which determines, for each hydrological cycle, the water level in the seasonal wetlands. This ultimately governs the establishment or absence of the reproductive colony in the wetland.

The flamingo can therefore be identified as a biological indicator for determining the water requirements of the lagoon.

The study of the biological cycle of the flamingo in Fuente de Piedra uncovered a number of factors that negatively impact the reproductive success of the colony. The most relevant factors include the drying of the Lagoon, the lack of food in the Lagoon towards the end of the breeding cycle, predation by mammals, intra-species competition between large reproductive groups of flamingos and disturbances from photographers and low-flying aircraft. Thus, the water requirements proposals have a direct impact on the reproductive success of the species.
establish themselves among the nesting birds, disturbing the flamingos that are incubating or that are caring for recently hatched chicks. The newcomers may even displace the reproducing pairs and take over their nests or may lay their eggs randomly on the dyke and abandon them within a few days. This is the cause of the high laying rate of the Fuente de Piedra colony that has been reported by a number of authors, and of the reproductive success rate of this colony.

- High water levels in spring time maintain the islets isolated. This reduces the predation (7) by foxes (*Vulpes vulpes*), badgers (*Meles meles*) and dogs (*Canis familiaris*).

- The biomass production of the lagoon system increases with an increase in the inundated surface area (8). In the long term, this results in a greater availability of trophic resources for the flamingo (9), which in turn reduces the time the breeding pairs are away from the nest.

In the Fuente de Piedra Lagoon, the estimation of the reproductive parameters has been developed as part of the Flamingo Banding Programme of the Environmental Council of the Junta de Andalucía (Figure 8). This monitoring programme provides key information for empirically correlating the reproductive success of the flamingos with water levels in the Lagoon.

- Different hydrological indicators have been utilized to correlate the reproductive success of different species with water levels. The indicator that showed the best relationship with reproductive success was the mean water levels in the Lagoon for the months of March, April and May (Figure 9).

Based on the graph in Figure 9, we can make the following statements regarding the reproductive success of the flamingos:

- When the mean water depth during the three spring months (March, April and May) is below 20cm, the reproductive success is "null."
- If the mean water surface level during these three months is between 20 and 40 cm, the reproductive success is "low".
- When the water surface level is between 40 cm and 60 cm, the reproductive success “medium”, whereas if the mean water level is greater than 60 cm, the reproductive success is “high”.

Groundwater contributes on average 47.8% of the water input to the Lagoon, while surface flows contribute 11.5% of the total. Direct precipitation on the lagoon surface contributes 39.8% of the total input. Groundwater flows thus become a key variable in the management of the Lagoon. The most significant anthropogenic pressure on the Lagoon in terms of water extraction is currently on the groundwater resource.

To model the impacts of reduced groundwater discharges to the Lagoon, a modelling of water balance of the Lagoon using the SIMPA model was carried out. Different hydrological scenarios were considered, from a progressive reduction of 10% of groundwater discharge relative to natural conditions (100% of the discharge), to an extreme scenario where there is no groundwater discharge. The model scenarios and their impact on the water balance are shown in Figure 10.

Here, we can appreciate the impact of gradual reductions in the inputs of water on the water balance of the Lagoon. The maximum volumes decrease drastically (from 88 hm³ under natural conditions to 18 hm³ without groundwater discharges), and the number of months that the Lagoon remains dry increases from 2.5% of the time under natural conditions to 17% of the time in a scenario without groundwater.

The impacts of reduced groundwater discharges on the potential reproductive success of the flamingos in the Lagoon were evaluated based on the hydrological scenarios described above. This quantification was made possible thanks to the conceptual framework which was developed to quantify the reproductive success of the flamingos based on the inundation levels in March, April and May. The results showing the years with flamingo chicks (expresses as a percent) are shown in Figure 11.

Based on these results, we can conclude that:
- Under natural conditions, the flamingo will reproduce in the Fuente de Piedra Lagoon 70% of the years.
- The reduction in groundwater discharges results in a decrease in the number of years in which chicks are hatched in the Lagoon. In this case, the relationship is directly proportional.
- When the model is adjusted to the conditions observed in the field (water levels measured in the Lagoon), it indicates that the groundwater discharges have been reduced by approximately 70%. This means that the number of years that the flamingo reproduces in the lagoon has been almost halved.
- If the extractions of water from the aquifer result in no discharges to the Lagoon, the percent of years with flamingo reproduction would decrease to 20%.

In a decision-making context, these hydro-biological relationships enable policy makers to determine the maximum extraction levels from the aquifer, for example.
5.3. L’ALBUFERA OF VALENCIA

5.3.1. Characteristics of the wetland

L’Albufera de Valencia Natural Park is located in the Community of Valencia, in the central region of the plain of Valencia. With a current surface area of 21,000 ha, this significant wetland runs along the coast between the new course of the Turia River to the north and the Serra de Les Rabosses in Cullera, to the south. The three primary environments found in the wetland are:

- The coastal shoal is a sandbar 30 km long and approximately 1 km wide formed in the Holocene by sedimentary depositions of the Turia and Xúquer Rivers. Dune ecosystems covered with Mediterranean maquis have evolved here.

- L’Albufera Lagoon which covers approximately 3,000 ha (of which 2,800 ha is open water) is located at the centre. It has large areas of marsh vegetation known locally as “matas” or “mates”. These occupy much of the banks and form some islands (about 290 ha). The Lagoon is communicated with the sea via three drainage canals at which sluice gates have been installed to regulate the water flow. These are crossed by numerous canals and ditches, extend over what was once an extensive bog.

- The rice fields are the environment that cover the largest area (14,000 ha). These, which are vital for the presence of water birds at this time of year or have direct consequences for agriculture and fishing.

According to the Ramsar Information Sheet, the primary factors that contribute to the degradation of L’Albufera are:

- Water pollution in the runoff from domestic, industrial and agricultural (pesticides and fertilisers used in the rice fields and nearby gardens).

- Siltation processes due to the sediments deposited in banks and ditches.

- Alternations and physical occupation of the land by urban developments and buildings from nearby cities.

- Illegal hunting which directly impacts animals.

- Reduction in the contributions of clean water. A reduction of water inputs to the wetland has been observed in the last years. This situation represents a potential problem since it could result in a general decline in the quality of water, in delays in the winter inundation of the rice fields (which is vital for the presence of water birds at this time of year) or have direct consequences for agriculture and fishing.

According to the document “Historical Study of L’Albufera” (MMA, 2004a), the drainage of surface water into the Lagoon was historically very small. Before the expansion of irrigation, the Júcar and Turia Rivers, which were the main forces that shaped the system, only flowed into the lagoon under flood conditions. The only surface runoff feeding into the lagoon came from a handful of nearby springs, and from a few ditches and ravines such as the Barranco Fondo, the Beniparrell (which carried scarce and intermittent flows) but particularly from the Poyo ditch and the ditch of la Catarrina.

The development of irrigation greatly increased the discharges of surface water. The expansion of the irrigation schemes of L’Horta and of the Acequias Mayores de Sueca and Cullera diverted to the Lagoon large quantities of water that had formerly flowed into the sea. This trend has increased in the last centuries.

Currently, surface runoff is carried through the Poyo ditch and a number of ditches that flow into the Lagoon. Groundwater flow occurs through the springs (“ullals”) located both in the floor of L’Albufera Lagoon itself and in the channels that flow into the Lagoon. In the last years, these springs have become less visible or have disappeared due to the decrease of groundwater flows and to the silting of the springs due to natural and anthropogenic causes. In addition to these sources, we must add water discharges from agriculture returns and from sewage, almost all of which is now treated.

At the other end of the system, the Lagoon drains through the canals (golas) de Pujol, Perellonet and Perelló. The Gola del Perelló, and possibly that of del Perellonet are natural waterways whereas the de Pujol was excavated in 1953. Today, the three canals have sluice gates that artificially control the water level in the Lagoon and impede the entry of marine water. There are also two other canals in L’Albufera National Park: Gola del Marney or Rei and Gola de Sant Llorenç, that drain the southern portion of the Park.
5.3.2. The Water Requirements Study

In the context of hydrological planning, L’Albufera de Valencia has been classified as a highly modified water body given that the water levels and area inundated depend on the anthropogenic actions in the canals connecting the Lagoon with the sea and on agricultural activities. One possible scenario for management objectives is presented in the activities listed in the "Study for the Sustainable Development of L’Albufera de Valencia" prepared by the company Técnica y Proyectos, S.A. (TPSA) for the General Direction of Hydraulic Works and Water Quality (DGOHCA) of the Environment Ministry under the direction of the Hydrographical Confederation of the Júcar.

The debate among experts regarding the environmental objectives for the wetland which took place in 2003 concluded that the waters of the Lagoon should have the following biological and physical-chemical characteristics:

- Clear water and oxygenated surface sediment.
- Presence of phytoplankton, diatom and other algae typical of coastal lagoons but absence of explosive growth of cyanobacteria. Chlorophyll concentrations corresponding to meso-eutrophic aquatic ecosystems (values always below 50 μg/l of Chlorophyll-a).
- Filtering zooplankton composed of large species, seasonally dominated by Cladocera.
- Regeneration of swam and submerged vegetation and associated invertebrates:
  - Recovery of the populations of several invertebrates, for example shrimp populations (Atyaephyra desmaresti, Dugastelia valenti-na and Palaemonetes zariqueyi).
  - Regeneration of swam and submerged vegetation and associated invertebrates:
  - Richness of fish, amphibians, reptiles, birds and mammals.
  - Recovery of the species characteristic of L’Albufera, since some of these are endemic and are included in the list of protected species (some species of crustaceans, molluscs and fish of the cyprinodontidae family).
  - Improvement of the fishery resources of L’Albufera with populations of sea bass (Dicentrarchus labrax) and eels (Anguilla anguilla) in sand banks stabilized by a high biomass of benthivorous and zooplankton species.
- Good status of the riparian formations in the waterways of the drainage basin. Growth of natural riparian vegetation in the surrounding waterways and on the submergible banks of the ravines. Minimal artificial channelling of the waterways.
- Maintenance of rice cultivation using sustainable practices, and of the multiple functions of the irrigation infrastructure (inundation-drainage) as a means to counteract the impact of invasive aquatic species that could be better controlled at times when the swamp is dry.
- Recovery of the species characteristic of L’Albufera, since some of these are endemic and are included in the list of protected species (some species of crustaceans, molluscs and fish of the cyprinodontidae family).
- Improvement of the fishery resources of L’Albufera with populations of sea bass (Dicentrarchus labrax) and eels (Anguilla anguilla) in sand banks stabilized by a high biomass of benthivorous and zooplankton species.

Other hydromorphological and biological characteristics desirable in L’Albufera are:

- Water through flow and recycling adequate for achieving the health of the ecosystem. This implies a guarantee of water flows of sufficient volume and quality, to control not only eutrophication, but also salinization. Entry of important volumes of surface flows in the north and west to balance the dominance of flows from the south.
- Sustainable sedimentation rates in the Lagoon by controlling and reducing pollution, erosion, transport and sedimentation processes.
- Improvement of the fishery resources of L’Albufera with populations of seabass (Dicentrarchus labrax) and eels (Anguilla anguilla) in sand banks stabilized by a high biomass of benthivorous and zooplankton species.

The modelling of the hydrodynamic functioning of the wetland and the nutrient cycling and eutrophication process that impact water quality corroborated two circumstances (MAMA, 2004b):

- The modelling of a scenario based on the ideal upper limit of pollution, and on water volume discharges below the average of the last few years shows a good response of the system with regards to its trophic state. If these variables were applied, some of the fundamental conditions defined in the sustainable development scenario for L’Albufera could be achieved.
- Unless the deficiencies of the wastewater treatment systems in surrounding L’Albufera are addressed and corrected, the addition of flows of clean water would be an ineffective measure. Under this scenario, the previously defined conditions for reaching the environmental objectives would not be reached.

The overwhelming dominance and permanence of cyanobacteria in L’Albufera is primarily related to: eutrophication; the existing oligotrophic conditions; the stabilization and feedback process of the bacteria populations through their re-suspension the water column due to the polymixis of the Lagoon and recruitment from the sediment; and to the lack of predation by the micro-zooplankton species that dominate in the Lagoon. The dominance of filamentous cyanobacteria in the phytoplankton community impedes the advent of phases of clear water due to the reduced capacity of zooplankton to filter these algae. Furthermore, the turbidity is stabilized by a high biomass of benthivorous and zooplanktonvorous fish.

The reduction in the entry of nutrients triggered the decline of the populations of Planktothrix agardhii and the emergence of clear phases with duration of up to five weeks (during the months of February and March 1999 and 2000). During these clear phases the phytoplankton community was dominated by centric diatom algae and Chlorophyceae.

The submerged macrophytes play an important structural and stabilizing role in the ecology of shallow lakes. The role of charophyte water plants in water clarity is especially recognized and their disappearance from shallow lakes results in eutrophication and a dramatic increase in turbidity. Creating the adequate habitat conditions and the availability of resources for these plants increases...
the richness of fish, amphibians, reptiles and birds. This will contribute to the recovery of the species characteristic of L’Albufera.

Keeping in mind the importance of nutrients in the ecological dynamic of L’Albufera, an approach based on the physical-chemical characteristics of the water (especially the concentrations of phosphates) is indicated for determining the volumes of water and the corresponding water quality required by the wetland.

Figure 12. Ecological model of L’Albufera de Valencia which highlights the importance of nutrients in the dynamics of the ecosystem.
6. BIBLIOGRAPHICAL REFERENCES


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7. ANNEX

PROTOCOL FOR MEASURING WATER LEVELS IN WETLANDS

1. APPLICATION

The purpose of this protocol is to obtain the water surface level in water bodies classified as “lakes” (lakes, lagoons and wetlands).

This protocol is meant for application by the Hydrographical Confederations in the implementation and exploitation of the official networks for the evaluation and monitoring of the ecological status/potential established in Directive 2000/60/EC (Water Framework Directive).

The protocol will also be applied in for the inventory of the natural water resources of the river basins in cases where water levels are used to determine the water requirements of lakes, lagoons and wetlands. It will also be used to analyse the coherence of other hydrological variables in these water bodies (precipitation, potential evapotranspiration, real evapotranspiration, aquifer recharge, surface runoff, groundwater flow and total runoff or discharge).

Overall, the water surface level values obtained can be used for:

- Application for establishing the indicators of hydromorphological status “water level fluctuation” and “variation of water depth”.
- Identification of reference water bodies using the evaluation of hydromorphological pressure and their possible deviation with regards to the range of natural variation of the two indicators mentioned above.
- Monitoring of water bodies classified as lakes to the extent that these hydromorphological indicators impact the ecological status of the water bodies. They will be used in particular for determining the degree to which the water requirements of the water bodies classified as lakes are met.
- Designation of highly modified water bodies when the artificial fluctuations in water levels impede the achievement of a good ecological status.
- Designing the program of measures to identify the possible causes of the failure to comply with the environmental objectives due to hydromorphological pressures.
- Determining the water requirements of lakes, lagoons and wetlands when the data series of water levels meet the necessary requirements established in Order ARM/2656/2008 by which the Hydrological Planning Instruction was approved.
- Use in the inventory of natural water resources as a data series that synthesises and can be contrasted with the other hydrological variables.

2. OBJECTIVE

Directive 2000/60/EC establishes that the member States should control and assess the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential.

The Water Framework Directive states that the methods used for the monitoring of type parameters shall conform to the international or national standards which will ensure the provision of data of an equivalent scientific quality and comparability.

Therefore, the objective of this protocol is to establish the conditions for the measurement of water surface levels in water bodies classified as lakes or lagoons, in compliance with the requirements mentioned above.
3. REFERENCE LEGAL FRAMEWORK

The following is the legal framework used for this protocol:

- Legislative Royal Decree 1/2001 which establishes the text of the Water Law
- Legislative Royal Decree 907/2007 which approves the Hydrological Planning Regulation
- Order ARM/2656/2008 which approves the Hydrological Planning Instruction.

The current instruction was drafted taking into account the following standards:

- UNE-EN 13757-4:2006 - Communication systems for meters and remote reading of meters - Part 4: Wireless meter readout (radio meter reading for operation in the 868 MHz To 870 MHz Srd Band).
- ISO 772 – Hydrometric determinations -- Vocabulary and symbols.
- IEC 60529 – Degrees of protection provided by enclosures (IP Code).

4. DEVICES AND EQUIPMENT

The data on water surface levels in the lakes and lagoons will be obtained using measuring devices, and, where relevant, the recording of data in the field.

4.1. Water level measuring devices

4.1.1. Specifications of the instruments

The devices for measuring water levels in wetlands should be classified, at least, for a “class 3 action” as defined in the UNE-EN ISO 4373:2009 standard.

That is, the nominal error in the range of measurements should be less than 1%. The uncertainty of the chronometer devices should be within ±150 seconds at the end of a 30 day period in the case of digital chronometers, or within ±15 minutes at the end of 30 days in the case of analogue chronometers.

4.1.2. Types of devices for measuring water levels

One or more devices for measuring water levels shall be set up in the water body, taking into account the characteristics of the latter (size, number and type of basins, morphology, etc.) and the existing measurement devices.

The following devices for measuring water levels can be used:

- a) Vertical or inclined staff gauges. A staff gauge is a graduated scale, directly or firmly fixed on an appropriate vertical surface (Fig. a1). When the range of water levels exceeds the capacity of a single staff gauge, other complementary gauges can be installed in a section, on an axis perpendicular to the rising/falling direction of the water. The overlap should be no less than 15 cm.

- b) Wire weight gauge. This consists of a weight that is manually lowered until it touches the surface of the water. The wire weight can be wound around drum which is connected to a unreeling device or it can be bobbin connected to a bar. The equipment can be difficult to use in low light conditions or where direct visibility is difficult.

- c) Mechanical float gauge. A float gauge consists of a float (which usually functions within a measuring well), a graduated tape or wire, a counterweight or resort, a pulley and a gauge. The tape or wire runs through a pulley which is designed to avoid slippage. The tape or wire is maintained taut by the action of the counterweight or resort. In this manner the float, that positions the tape in relation to the gauge, detects the variations in water level. Usually, a float is used with a continuous strip-chart or a drum-type recorder to maintain a continuous record of the water level data.

When used alone, a float gauge delivers a direct measurement of water levels, providing a good resolution at low levels. The drawback is that it is a mechanical device (subject to errors resulting from variations in temperature, lag and friction) and it generally requires a measuring well that can be costly to build and maintain.

- d) Electronic pressure transducer. An electronic pressure transducer converts the pressure of a fluid into electronic signals. A typical sensor is composed of a mechanical force collector that responds to variations in pressure by displacement, an electronic component that produces a signal proportional to this displacement and a vented tube to eliminate atmospheric pressure variations or two absolute pressure devices, one of which measures atmospheric pressure. An electronic transducer does not require a measuring well to dampen the fluctuations in water level. It is ideal for adapting to electronic systems for registering and transmitting data.

The levels of uncertainty are generally on the order of ±0.1 to ±0.5% of the scale. The transducer is impacted by variations in the environment such as the density of the water column.

4.1.3. Level of reference in the measurement of water levels

The level of the water surface recorded in a wetland is not an absolute measure. It must always be taken in relation to a reference point. In the same manner, the measuring devices require points of reference from which to record the level of the water surface.

In the context of water surface levels in lakes and wetlands, the points of reference shall be used to:
a) Establish the point of reference in the field.
b) Provide a value that serves as a reference for the levels recorded by the measuring devices.
c) Periodically verify the levels of the measuring devices relative to the point of reference.

Each measuring device will have, at the least, one reference point which is permanently installed in a stable and safe site. The capacity of the reference point to maintain its position relative to the terrain is essential for referencing the levels of the measuring device (Fig. 3).

The level of reference for each measuring station should be checked periodically. If possible, these should be referenced relative to a point in the national geospatial network.

**4.2. Equipment for field work**

The following equipment and complementary material shall be provided for the collection of water surface level measurements in the field:
- Sampling protocol
- Field log books
- Field note books
- Waterproof covers for field records
- Digital camera
- Mobile telephone
- Adequate maps
- GPS device
- Compass
- Thermometer

**5. DETERMINING THE NUMBER OF DEVICES FOR MEASURING WATER SURFACE LEVELS**

The number of devices for measuring the water surface level will depend on the characteristics of the water body. More than one water level measuring device will be utilized under the following circumstances:

a) When the size of the wetland or its morphology result in centimetres of difference in the water surface levels measured at different points.
b) When the water body is at risk of failing its environmental objectives due to significant hydromorphological pressures (operational control design). In these cases, sufficient control points will be available to evaluate the magnitude and impact of the hydromorphological pressures.
c) When the wetland is divided into different sections that present differentiated behaviour in water levels (for example, different hydraulic mechanisms for controlling levels).
d) When there is more than one well-defined basin in the wetland complex.
e) For any other relevant and justifiable reason.

When the installation of additional measuring devices is necessary, their location and number will be determined keeping in mind the specific characteristics of the water body such that the measurements recorded by the devices are as representative as possible of the entire wetland.

**6. LOCATION OF THE MEASURING DEVICES**

A water level measuring device will be well located, designed and built if it meets the following criteria:

a) It is possible to obtain a precise reading of the water level for all levels.
b) It is possible to obtain a precise reading of the water level in all seasons and for all years.
c) The location is accessible and/or visible to the operators that carry out the maintenance and collect the readings.
d) The measuring device is in good structural conditions (level reference point and devices in stable and safe locations).

e) When the wetland is divided into different sections that present differentiated behaviour in water levels (for example, different hydraulic mechanisms for controlling levels).

**7. NUMBER OF READINGS PER MEASUREMENT**

For the devices that provide discrete measurements (staff gauges and wire weight gauges), at least three readings of the water surface level shall be recorded for each of the devices found in the water body.
8. FREQUENCY AND TIMING OF MEASUREMENTS

The periodicity of the measurements of the water surface level in wetlands should provide information that is sufficient for carrying out a confident evaluation of the water level fluctuations and variations of the average water depth in a water body.

For the devices that provide discrete measurements (staff gauges and wire weight gauges), the periodicity of the measurements should take into account the nature of the variations in water levels resulting from natural and anthropogenic conditions. The dates selected for carrying out the readings shall reflect the alterations in the water body due to the changes brought about by anthropogenic pressures. If necessary to meet this objective, other control readings will be recorded in different seasons of the same year.

As a general guideline, the recordings of water level readings in wetlands should take place at intervals no greater than one month, unless the technical knowledge and the judgment of experts justify longer intervals.

The timing of readings for research purposes will vary in function of the specific circumstances of each water body. In cases where the water body is subject to strong pressures due to water extraction or modification of surface flows, an effort shall be made to install devices that continuously measure water levels for the duration of the research.

For the devices that provide discrete measurements, at least three readings shall be recorded for each device.

In the cases where waves complicate the readings of manual devices, readings shall be recorded for the maximum and minimum heights caused by the waves.

In the field visits, the following complementary information shall be recorded:
- Estimated wind speed (at least on the Beaufort scale)
- Wind direction
- Estimated wave height
- Temperature
- Time

The data sheet for field measurements attached to this protocol shall be completed.

9. PROCEDURE FOR RECORDING WATER SURFACE LEVEL DATA

For the devices that provide discrete measurements, at least three readings shall be recorded for each for each device.

In the cases where waves complicate the readings of manual devices, readings shall be recorded for the maximum and minimum heights caused by the waves.

In the field visits, the following complementary information shall be recorded:
- Estimated wind speed (at least on the Beaufort scale)
- Wind direction
- Estimated wave height
- Temperature
- Time

The data sheet for field measurements attached to this protocol shall be completed.

10. DETERMINING THE UNCERTAINTY IN THE MEASUREMENTS

The level of uncertainty in the measurements of water level will depend on the type of device utilized, as described in section 4.1.2 of this annex. According to UNE-EN ISO 4373:2009, for these types of devices the uncertainty will be calculated as follows:

a) Vertical or inclined staff gauges. A triangular distribution is applied to the uncertainty associated with the readings of a wire weight gauge. The equation is the same as the one applied above.

\[ u(x_{\text{max}}) = \frac{1}{\sqrt{6}} \frac{(x_{\text{max}} - x_{\text{min}})}{2} \]

Where \( x_{\text{max}} \) is the maximum discernable limit; \( x_{\text{min}} \) is the lowest discernable limit.

b) Wire weight gauge. A triangular distribution is applied to the uncertainty associated with the readings of a wire weight gauge. The equation is the same as the one applied above.

\[ U(x_{\text{max}}) = \frac{1}{\frac{1}{6}} \frac{(x_{\text{max}} - x_{\text{min}})}{2} \]

Where \( x_{\text{max}} \) is the maximum discernable limit; \( x_{\text{min}} \) is the lowest discernable limit.

c) Mechanical float gauge. Due to the lag in the system of the mechanical float gauge, the distribution of the uncertainty is bimodal such that:

\[ U(x_{\text{max}}) = \frac{(x_{\text{max}} - x_{\text{min}})}{2} \]

Where \( x_{\text{max}} \) is the maximum discernable limit; \( x_{\text{min}} \) is the lowest discernable limit.

d) Electronic pressure transducer. A pressure transducer has a rectangular distribution of uncertainty. The following equation applies:

\[ U(x_{\text{max}}) = \frac{1}{\frac{1}{6}} \frac{(x_{\text{max}} - x_{\text{min}})}{2} \]

Where \( x_{\text{max}} \) is the maximum discernable limit; \( x_{\text{min}} \) is the lowest discernable limit.
### Data Readings of Water Surface Levels in Lakes and Wetlands

#### Measurement Identification Information

- **Name of the water body:**
- **Organisation/company:**
- **Person collecting the sample:**
- **Measurement code:**
- **Date:**
- **Beginning time:** ___ : ___
- **End time:** ___ : ___
- **Control programme**
  - [ ] Surveillance
  - [ ] Operative
  - [ ] Research
  - [ ] Reference
  - [ ] Protected area

#### Data from the Measuring Device

- **Device operated by:**
- **Name of the station:**
- **Station code:**
- **Coordinates:** UTM X________  UTM Y_______  Huso_______
- **Zero volume scale height:**
- **Type of device**
  - [ ] Staff gauge
  - [ ] Wire weight gauge
  - [ ] Mechanical float gauge
  - [ ] Electronic pressure transducer
- **Type of data registration**
  - [ ] Discrete
  - [ ] Continuous
- **Precision of the measurement**
  - [ ] 2 mm or less
  - [ ] 5 mm or less
  - [ ] 1 cm or less
  - [ ] Greater than 1 cm

#### Climate Conditions

- **Estimated wind speed (m/s):**
- **Wind force (according to Beaufort Scale):**
- **Wind direction:**
- **Temperature (°C):**

#### Notes on the Climate Conditions:

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1 Scale available at the end of this Annex.
### ACCESS AND LOCATION

**Description of Access route:**

**Location map:**

### BEAUFORT SCALE OF WIND FORCE

<table>
<thead>
<tr>
<th>Beaufort number</th>
<th>Wind speed (km/h)</th>
<th>Description</th>
<th>Effects on land</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 a 1</td>
<td>Calm</td>
<td>Calm, smoke rises vertically</td>
</tr>
<tr>
<td>1</td>
<td>2 a 5</td>
<td>Very Light</td>
<td>Smoke drift indicates wind direction</td>
</tr>
<tr>
<td>2</td>
<td>6 a 11</td>
<td>Light breeze</td>
<td>Leaves rustle, vanes begin to move</td>
</tr>
<tr>
<td>3</td>
<td>12 a 19</td>
<td>Gentle breeze</td>
<td>Leaves and small twigs constantly moving, light flags extended</td>
</tr>
<tr>
<td>4</td>
<td>20 a 28</td>
<td>Moderate breeze</td>
<td>Dust, leaves, and loose paper lifted, small tree branches move</td>
</tr>
<tr>
<td>5</td>
<td>29 a 38</td>
<td>Fresh breeze</td>
<td>Small trees in leaf begin to sway, whitecaps on lakes</td>
</tr>
<tr>
<td>6</td>
<td>39 a 49</td>
<td>Strong breeze</td>
<td>Larger tree branches moving, difficulty keeping umbrellas open</td>
</tr>
<tr>
<td>7</td>
<td>50 a 61</td>
<td>Near gale</td>
<td>Large trees moving, resistance felt walking against wind</td>
</tr>
<tr>
<td>8</td>
<td>62 a 74</td>
<td>Gale</td>
<td>Treetops breaking, difficulty moving against wind</td>
</tr>
<tr>
<td>9</td>
<td>75 a 88</td>
<td>Strong gale</td>
<td>Trees damaged, impossible to move against wind</td>
</tr>
<tr>
<td>10</td>
<td>89 a 102</td>
<td>Storm</td>
<td>Trees broken or uprooted, considerable structural damage</td>
</tr>
<tr>
<td>11</td>
<td>103 a 117</td>
<td>Violent storm</td>
<td>Widespread damage to buildings, rooftops and trees</td>
</tr>
<tr>
<td>12</td>
<td>118 y más</td>
<td>Hurricane</td>
<td>Great and widespread damage. Many trees uprooted. Total destruction.</td>
</tr>
</tbody>
</table>