INTEGRATED COASTAL AREA AND RIVER BASIN MANAGEMENT PLAN

Rhone Delta, France

Prepared for:

The Regional Council of the Provence-Alpes-Cote d'Azur (PACA)

ELITE AQUA
CONSULTANCY COMPANY

August, 2020

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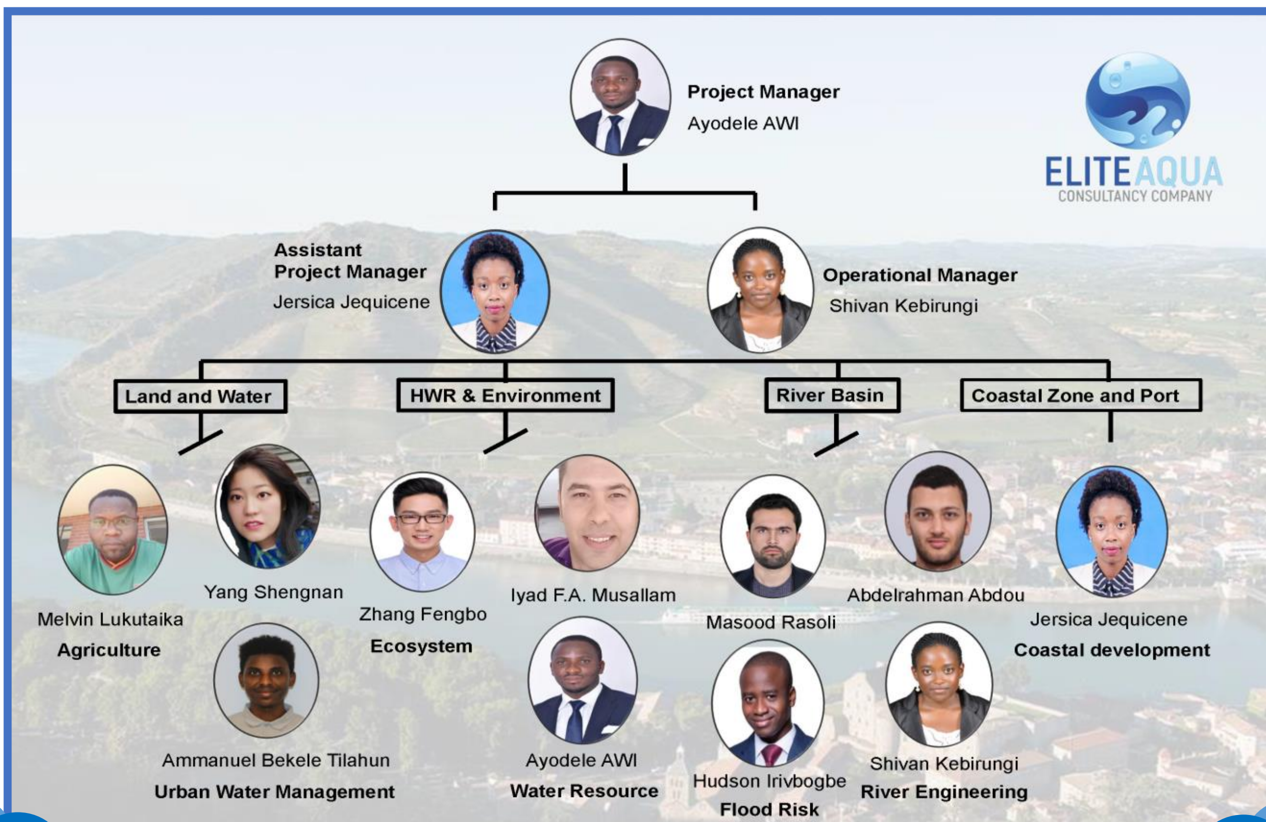

Organisation Management

ABOUT US

Elite Aqua Consultancy Company (EACC) is a professional consultancy firm specialized in providing expert services in integrated and sustainable water resources management to the diverse water related challenges in today's evolving and dynamic environment. Our operations cover four broad specialized areas which represent the departmental structure of our firm, they are; Land and Water Development, Hydrology, Water Resources & Environment, River Basin Development, and Coastal & Port Management.

Our team of experts have several years of international experience in planning, managing, reviewing and implementing both small scale and complex projects with target for sustainability and climate resilience. We take pride in our shared value of excellence, trust, innovation and commitment to delivering a better and cleaner world.

ACKNOWLEDGEMENTS

Elite Aqua Consultancy Company (EACC) will like to appreciate the joint efforts of all partners who have contributed to the intensive collaboration work on the development of the Integrated Coastal Area and River Basin Management Plan (ICARM), a project which aims to provide guidelines for the development and improvement of the coastal area and river basin management in the Provence-Alpes-Cote d'Azur region.

Special thanks to our client, Provence-Alpes-Cote d'Azur (PACA) and their Representative, William Veerbeek for the trust they have in us to develop the ICARM and for their commitment in terms of funding and time for intense dialogue that proved to be pivotal in learning together on how to implement the project to achieve total stakeholders' satisfaction.

We also like to commend the effort of our Coach, Ahmed Eighandour for his relentless support in guiding the team to stay on track throughout the period of the project and also the Panel of Experts whose wealth of experience were very useful in providing clarity on certain grey areas.

Finally, we acknowledge the contribution of every member of EACC whose readiness and doggedness helped us to work together as a team to critical analysis data, discuss findings and jointly review ideas in order to enable us produce an integrated plan in the end.

EXECUTIVE SUMMARY

River basins play a critical role as sources of water to support livelihood and natural ecosystems. Similarly, coastal areas provide home to a variety of natural habitats, resources and support economies of major cities. However, there are important functional inter-relationships between rivers and coastal systems and they often influence each other. In recent years, humans have exerted major influence on this interlinked system through intensive usage. Hence, a new multi-disciplinary approach to effectively manage the socio-economic developments with due considerations for the integration of natural systems over the upstream – downstream sections have become necessary through the Integrated Coastal Area and River Basin Management (ICARM).

The Rhone Delta in the Provence-Alps-Cote d'Azur (PACA) drains an approximate area of 98,000km$^{2.}$ The basin plays a critical role in the support of livelihood and natural ecosystems within the region. The Integrated Coastal Area and River Basin Management (ICARM) gives a new multi-disciplinary approach to elaborate a thorough and integrated diagnosis of the opportunities and threats for the region. Elite Aqua Consultancy Company was invited by the Regional Council of PACA to elaborate a thorough and integrated diagnosis of the opportunities and threats for the Rhone Delta in the region with recommendations on programme of measures supported by specialized additional studies.

The Rhone Delta faces climatic, environmental and socio-economic challenges. The problems ranging from flooding, coastal erosion, unmet demands for navigability of the river. These problems are however interlinked and the interdependency needs to be clearly understood for well-integrated measures. Also, increasing population and climate variability may aggravate some challenges in the future, hence we have proposed a strategy to address future challenges due to climate change.

This report consists of integrated approach with a set of actions and processes that led to the formulation of the ICARM which was carried out in three different phases. Phase one focuses of diagnosis and development of a set of objectives and prioritization while Phase two provides discussion on the approach and strategy with clear programme of measures to achieve the stated objectives. Our overall approach is to develop a climate resilient delta through implementation of proactive measures. Phase 3 elaborates on specialized additional studies required to assess the proposed measures. Overall, the ICARM is a well-integrated approach with due consideration to institutional aspects and stakeholders participation.

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1. INTRODUCTION

River basins play a critical role as sources of water to support livelihood and natural ecosystems. Similarly, coastal areas provide home to a variety of natural habitats, resources and support economies of major cities. However, there are important functional inter-relationships between rivers and coastal systems and they often influence each other. In recent years, humans have exerted major influence on this interlinked system through intensive usage. Hence, a new multi-disciplinary approach to effectively manage the socio-economic developments with due considerations for the integration of natural systems over the upstream – downstream sections have become necessary through the Integrated Coastal Area and River Basin Management (ICARM).

Elite Aqua Consultancy Company was invited by the Regional Council of PACA in August 2020 to develop a proposal for an ICARM that will address challenges faced in the area. This will be carried out through an integrated diagnosis of the problems, opportunities and threats as well as development of recommendations that will encourage sustainable development.

2. CHARACTERISATION OF THE STUDY AREA

The characterisation of the study area is given as follows;

2.1 Topography and Climate

The study area (Rhone delta and surrounding areas) is located at the southern part of the Provence-Alps -Cote d`Azur Region (PACA Region) in the south of France. It consists of the Rhone River and its tributaries. The Rhone River runs from the Rhone glacier (a location characterised by ice and snow melt) in Switzerland at an ellipsoidal height above mean sea level of about 1700m, connects with Saone in France and empties into the Mediterranean Sea. Around the mouth of the Mediterranean Sea, the Rhone River branches into the Little (Petit) Rhone and the Great (Grand) Rhone, producing a delta that consists of the Camargue region. The Rhone river basin drains an approximate area of 98000km^2. The Rhone Delta has a relatively flat terrain with an average elevation of 5m above mean sea level (msl), with some areas below the mean sea level. The delta consists of a vibrant coastal area, lagoons and marshy lands that are surrounded by large cultivation areas.

The area has a semi-arid climate with hot temperatures, sunny and dry weather during summer. Low rainfall of less than 750 mm/year is observed during winter. Snowmelt from higher altitudes occurs during spring, releasing a great amount of water into the delta region. ***Figure 1*** indicate the location of the study areas and average evapotranspiration and rainfall over the year in the PACA region (data collected from the nearest weather station in Montpellier).

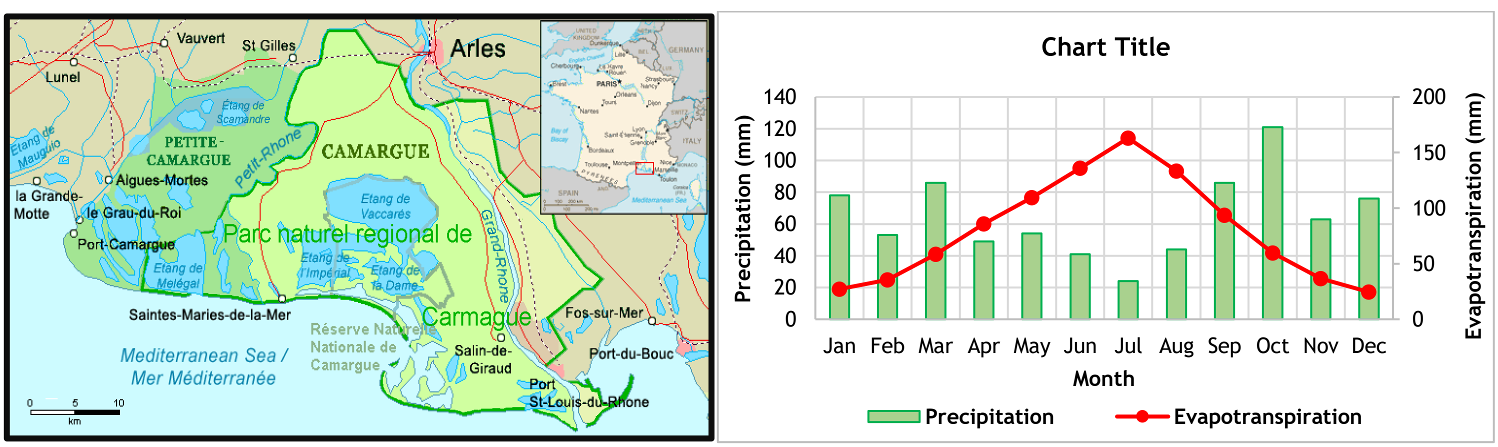

Figure 1. The Rhone Delta (a), Average Rainfall (P) and Evapotranspiration (ETo) in a year (b)

Source of Study area map: https://feal-future.org/eatlas/en/node/61

2.2 Hydrogeology, Water Resources and River morphology

Rhone Delta is located between two arms of the River Rhone and Mediterranean Sea. The eastern arm of the Rhone River is called Grand Rhone, which carries 85-90% of the whole discharge, and the Petit Rhone carries the remaining discharge. For the Rhone Delta the main source of freshwater is from the precipitation. Near Beaucaire, the Rhone River has an average discharge of 2,300 m^3/s. In total, on the Rhone River there are 19 control structures (1 dam and 18 barrages). The slope of the Rhone River is high which makes it feasible for power production, but a poor river for navigation. The delta has shallow and deep aquifers and aquitards as shown in ***Figure 2*** and ***Figure 3*** below. Due to low precipitation, the groundwater recharge is low in the delta. Drilled wells are used for irrigation, domestic and industrial purposes and the river is used mainly for water supply.

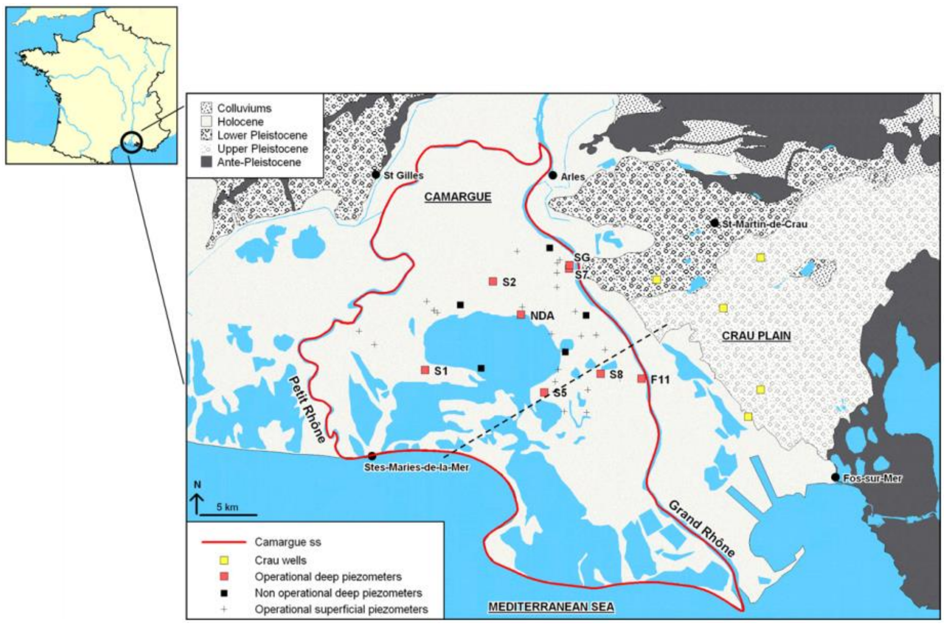

Figure 2: Location and Monitoring network of the hydrogeology of the area

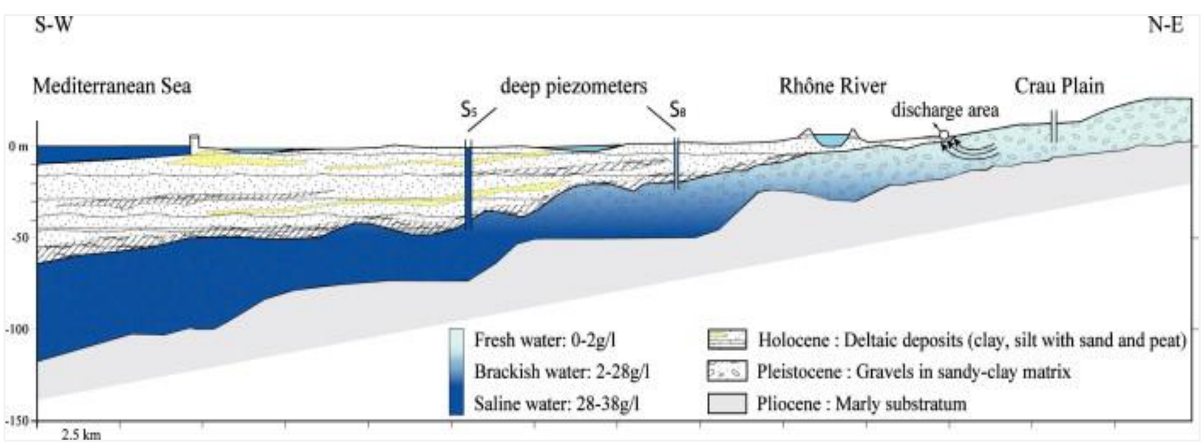

Figure 3: Cross Section of the area along the dotted line in Figure 2 above

The Durance River in the Crau and the Camargue area deposited fluvial sediments of gravels coming from the erosion of the Alps located in the north east of the PACA region. From geomorphological point of view, Camargue region can be divided into two main parts, the Northern Camargue and the Southern Camargue. The

Northern Camargue (from Arles to the north of the main central lagoon) is dominated by fluviatile coastal plain and lacustrine deposit. This area is used for fruit-growing and irrigated culture (rice mainly). The Southern Camargue results both from marine and continental origin. This area contains numerous lagoons of brackish waters and the soils are highly saline.

At the east of the Rhone River, is the Crau plain, is a fresh unconfined aquifer, which continues into the sea. It is greatly exploited for drinking water and industrial purposes. It has two main sources of recharge: 2/3 from drainage water from irrigation supplied by the Durance River and 1/3 from rainfall.(de Montety, Radakovitch et al. 2008).

2.3 <u>Land use and Agriculture</u>

Agriculture is an important sector in Province-Alpes-Cote d'Azur (PACA). Its contribution to the French overall agricultural economy is significant, producing mainly cash crops: fruits, oil crops, flowers and vegetables. In the Rhone delta, irrigated rice cultivation covers an area of about 20,000 hectares. Besides the rice production, the area also produces on lesser scale, wheat and grapes (wine). Livestock production, of horses and black bulls is also common. Over the years, there has been an increase in irrigated land at the expense of natural reserve land in the region. Notably, there has been a 28% reduction of natural areas in the Camargue region from 1942 to 1976. On the other hand, arable lands increased by 18,000 hectares (Tamisier, 1990).

The predominant land use in the study area is agriculture, covering over 120,000 hectares. Other uses include wetlands, forest and natural areas, artificial surfaces and waterbodies as given in the figure below. ***Figure 4*** shows the Landover and percentage spread for the location.

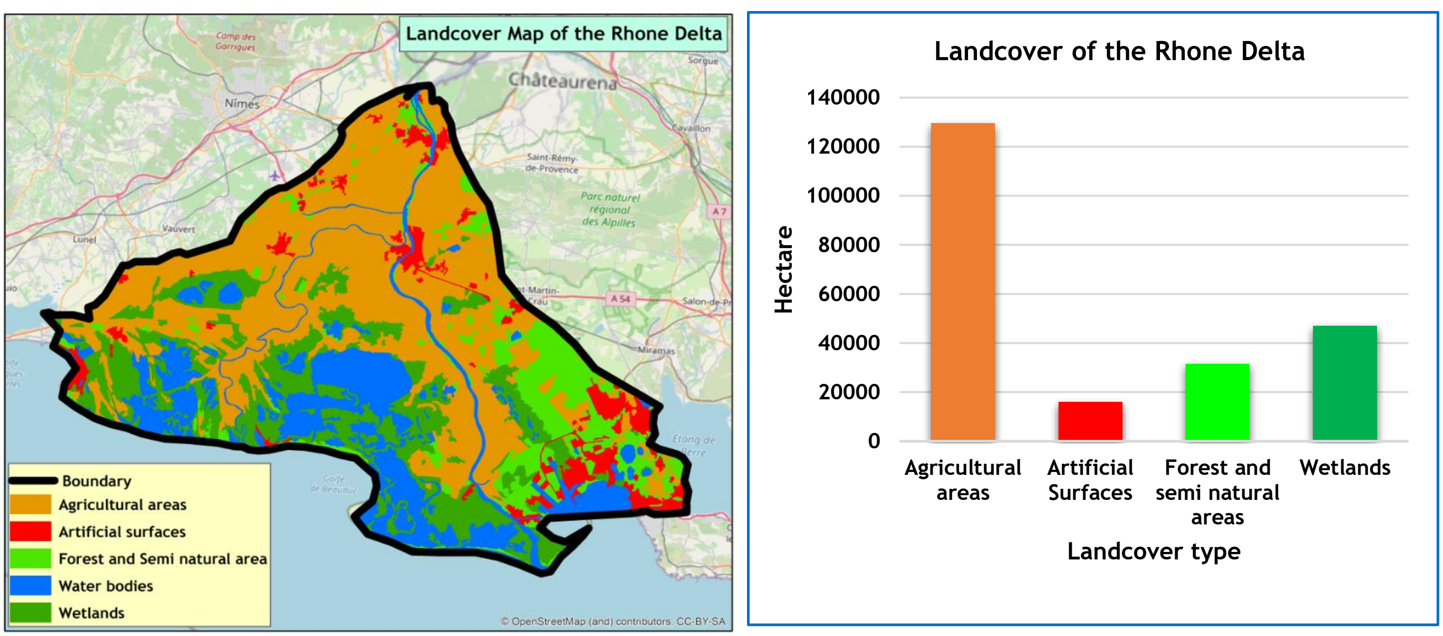

Figure 4. Land cover of the study area

2.4 <u>Coastal Development</u>

The Camargue coastal line is about 90 Km long. Tourism, harbour and industrial activities among others exist at the coastline. About 85 % of the coastal line is protected by coastal protection structures, which consists of groins and breakwaters. The coastline has undergone some changes due to the occurrence of fine sediment accretion and erosion over the years. Furthermore, the shortage of sediment loads that come from the Rhone River, caused by the upstream dams, have exacerbated coastal erosion. The existing coastal protection structures could stop this to some extent. The Gracieuse spit between the grand Rhone and Fos gulf extended towards northeast direction causing sedimentation and threatened the navigation channel but this expansion was controlled by rebuilding the ganivelles network (a fence used for sand trapping) at the dune ridge of the spit and limiting the tip advance. Moreover, the dunes system has suffered significant degradation due to human activity, however, controlling measures have already been implemented so as to restore the dunes. ***Figure 5*** shows the delta coastline.

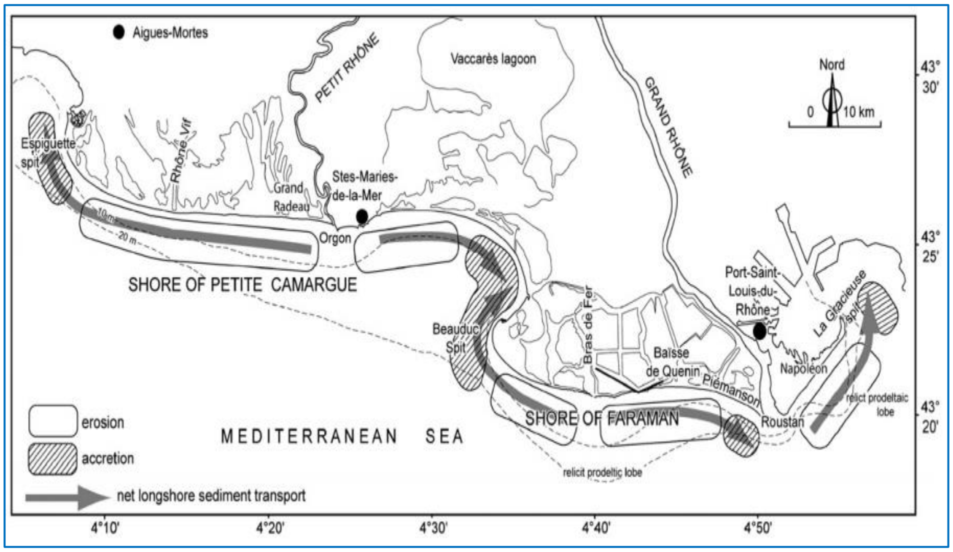

Figure 5. Delta coastal line overview and sediment transport (Sabatier et al, 2006)

2.5 <u>Environment</u>

Currently, to protect the fauna and flora and to keep nature balance, 23% of the PACA consists of national parks, reserves and conservatories. The area supports a biodiverse ecosystem existing in freshwater, brackish water, saline water conditions as well as a large number of breeding and wintering water birds. The existing rice fields, which occupy 16% of the Camargue region, provide natural habitats for the water birds. The European Water Framework and the European Habitats directives at play in the study area help to steer all future development and efforts towards maintaining existing biodiversity to attain good ecological status.

2.6 <u>Economic Activities</u>

The main economic activities in the study area include agricultural, industrial and tourism activities. For the current agricultural economy, rice production dominates the farming and it has gradually increased since 2000. The Camargue occupies for 90-95 % the French rice production. With the advancement of technology and the growing awareness of environmental protection, the organic farming is becoming a new trend, and it involves organic rice, durum wheat, alfalfa, and more recently lentils.

The various industrial activities include those in the port of Fos-sur-Mer and the salt industry. The annual salt production is approximately 1.5 Mt, and the two sites respectively are, the Petite Camargue (10,000 ha) and the Salin de Giraud (12,000 ha). However, it is worth noting that any flooding of the pans with seawater or fresh water would seriously harm salt generation. In addition, the port is an industrial park to store natural gas, fuel and chemicals.

Tourism is an important economic activity in the Camargue area, and it focuses on the seaside resort activities on both side beaches of the mouth of the Grand Rhone and artificial marina of Port Camargue. It is estimated that between 350,000 and 500,000 people visit the beaches of Camargue every year. Nowadays, with the increasing awareness of environmentally protection, the “green” tourism is enhanced, providing opportunities to maintain the Regional Natural Reserve that is a habitat for wildlife, birds and flora.

2.7 <u>Interrelation</u>

The topography, geology and climate dictate the water resources potential of a given area. The movement of both ground and surface water is directly influenced by the topography and geology of an area. Hence, due to the low altitudes of the Rhone Delta, the areas receives significant surface waters from the Alps. The river is known for having a steep gradient, which affects the geomorphological evolution of the river channel. In addition, due to the low terrain elevations of the delta, the water table is low and this increases the risk of intrusion of salt water from the sea. Since the average rainfall received is low, consequently ground water recharge also and this affect the water quantity to be utilised within location. At the same time, extreme precipitation events at the upstream lead to significant flood risk in the low-lying delta.

The environment and biodiversity ecosystems are affected by human activities such as agriculture, urbanisation, tourism, industrial developments and these activities alter the landuse. Human activities like irrigation vary the supply of water to the lagoons, which in turn varies the salinity of lagoons. These changes in salinity lead to changes in biotic communities of the lagoon. Other practices like dam construction affect the river morphology, which has an impact on the sediment input into the sea that forms part of the Rhone delta coastline areas. The coastal developments especially the ports (Camargue, Saintes-Maries-de-la-Mer, Fos-sur-Mer, Marseille and St. Louis-du-Rhone) additionally diversify the coastal landuse. These have been important contributors to the PACA economy, creating livelihoods for the local population.

3. PROBLEMS AND OPPORTUNITIES

In order to establish the problems and opportunities in the study area, a SWOT analysis was conducted to identify the possible strengths, weaknesses, opportunities and threats of the different aspects in the relevant fields, as shown in ***Table 1***. This gave a background for more in-depth analysis as described in the sections below.

Table 1. The SWOT Analysis

Field	Strengths	Weaknesses	Opportunities	Threats
Flood Risk Management	• Ability to control flood water from Rhone River for the current 1/100 return period	• Relatively High Slope of the Rhone River • Old age Dykes	• Use flood water for environment and ground water	• Urbanization • Climate change
Urban Water Management	• Existing storm water drainage facilities • Resilient community	• Uneven population distribution • Dense building distribution in urban centre	• Good Economy of the area • Progressive technology for treating water-related problem	• Sea level Rise leading to coastal flooding • Increasing population
River engineering	• Existence of Petit Rhone and Grand Rhone for navigation • High gradient river which is good for hydropower generation • Existence of locks along the river which is beneficial to navigation	• Limited sediment input into the Delta region • Formation of bars that could hinder the navigation for big vessels	• Incision of the river which is beneficial to the navigation for big barges • Innovative Technological tools for monitoring the change in river morphology	• Sediment build-up upstream the dams which reduces water storage increasing flood risk downstream • River bank erosion
Coastal Management	• 85% of the coast is equipped with coastal protection • Attractive coast with touristic and economic development	• Illegal camping on dunes causing deterioration • Three important coastal areas (Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud) are prone to erosion	• Expansion of port area along the coast	• Extreme events and climate change that could cause flooding in Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud. • Siltation at the channel entrance to the port of Fos • Reduction of sediment inflow from rivers due to dams existence leading to loss of coastal area (from 0.80 m/year to 0.1 m/year)

Water resources & Ecosystem	• Existence of almost sandy shallow and deep aquifers • Large area of natural environments (less urban sprawl) leading to higher GW recharge • Continued provision of freshwater to the catchment from the rivers (perennial nature of rivers) • Existence of wetlands for reduction of flooding risk • Ecological bio-diversity (birds and flora) to promote tourism	• Data management problem due to poor organization of different water users downstream. • Over-extraction of the groundwater increasing the risk to seawater intrusion • Highly fluctuated salinity of the lagoons which is a problem for the bio-diversity • Exploitation of salt pans threatening ecological status of the Camargue	• High transmissivity of the unconfined aquifers increasing recharge capacity • Flood water that can be utilized for Managed aquifer recharge	• Water pollution from agriculture and industry • Nature conservation intruded by expansion of agriculture, industry and urbanization • Sea water Intrusion • Excessive damage due to illegal buildings and excessive unregulated tourism • Low precipitation ((just 750 mm/a)
Land use and Agriculture	• Availability of fresh water from the Rhone River • Presence of complex system of canals and ditches for irrigation. • Moderate sensitivity of rice and other crops grown to salinity • Presence of local farmers associations to manage agricultural developments	• Relatively low rice yields • Salty soils, due to increasing salinity levels in surface water and groundwater are a concern.	• Good market for organic rice, wheat, alfalfa and lentils. • Potential subsidies from government to keep farming feasible.	• Fluctuating rice prices which are putting pressure on rice production. • Water birds, for instance Flamingos that are responsible for widespread crop destruction. • Low temperatures and strong winds in spring and autumn leading to higher production costs.

3.1 Flood Risk Management

There has been a great amount of urbanization along the Rhone River. This occurrence has caused impediments at Arles and Tarascon and has further led to an increase in flood risk in the study area. The number of the largest floods that have occurred in the past 150 years is sixteen (16) and it has been recorded that seven (7) of these largest floods occurred in the last 15 years. Flooding usually occurs during autumn and spring. Discharges during spring increases to about twice the daily discharge.

For several years, dykes have protected Camargue from flooding, however in 1993-1994, the dykes were breached in the Upper Camargue and the agricultural area and the lagoons were flooded. Because of the decrease in the salinity of lagoons due to flooding, the aqua biotic life was affected. The highest recorded flood had a peak discharge of 13,000 m3/s. On the other hand, in Arles the river width is reduced drastically due to urbanization and the maximum discharge that can be carried through the city is 12,000 m3/s. Overall the flood in this area can affect the agriculture, urban areas and ecosystem.

From all indications, flood risk offers some opportunities. The floodwater can be used to recharge the underground water to prevent the water table drop. In addition, it can be used to prevent the intrusion of salty seawater to the underground water. Moreover, the floodwaters can be used for ecosystems for example to maintain a required level of salinity in the lagoons.

3.2 River Engineering

The Rhone River morphology has been continuously altered by various human interventions into the river like narrowing at specific reaches of the river like in Arles and construction of large dams. Following these interventions, natural and anthropogenic factors have led to the formation of an incised river. Installation of large dams along the river alters the sediment yield in delta from 35×10^6 tonnes per year at the 19th century to 7.39×10^6 tonnes per year at the end of the 20th century (78% reduction), (Arnaud, 2003). The problem of decreased sediment transport causes river bank and bed erosion along with the grand and petit Rhone river reaches and river deterioration in some reaches like erosion of Petit Rhone bank at the river mouth, bank erosion in Grand Rhone river upstream Arles and far downstream at river mouth .Nevertheless, bank instability in meanders near river mouth. This also induces coastal erosion and retreat of coastline in the long term, which could have implications on the social and economic activities along the coast. Furthermore, river aquatic life, which depends on sediment flow downstream the dams in the delta, could be affected. Reduced sediment also reduces the supply of nutrients to the agricultural fields in the delta region.

Inland navigation in Grand and Petit Rhone Rivers are essential to connect the industrial cities of Lyon, Arles, Vienne with coastal ports like Fos and Marseille. Navigation was improved by installing navigation structures along the Rhone River and rehabilitation of the river cross-sections. These measures made the Rhone River including the two branches navigable for big barges along 310 Km until Lyon. However, in the long term, navigation could be affected due to changes in the river morphology. These dynamic changes in river morphology obstruct the navigation besides meandering downstream Petit Rhone (P=1.7). Poor navigation could encourage the shift to other forms of transports that may be more environmentally unfriendly.

As an opportunity, the incised river is better for navigation than a braiding or meandering river. The existing technological facilities also enhance increased monitoring of the river morphology and regular assessment of the river navigability. The high gradient of the river is also good for hydropower generation.

3.3. Urban Water Management

As seawater seeps into groundwater, the salt content of the water increases, which affects the quality of water supply in coastal cities. In densely populated coastal areas, the current flood control measures along the Rhone River are insufficient (≤10 years). Due to climate change and rising sea levels, coastal flooding may become a future challenge for these areas. At the same time, more and more tourist activities, such as unrestrained camping, have encroached on coastal sand dunes, causing them to degenerate. For inland cities, in Arles, the most populous city, dense buildings are concentrated in the city center, which is not conducive to flooding evacuation when it rains heavily. To make matters worse, flooding occurs during periods of high storms in inland urban centers. Due to insufficient capacity of the storm drainage system and traffic interruption, the area will suffer more flood risks. Therefore, these areas may not be able to cope with the increasing flood risk due to future urbanization and climate change.

The progressive economy and technology give support for sustainable urban water management that can ably deal with future uncertainties. The increased revenue can be used to build water supply and wastewater treatment systems to cope with the expected growth in population and urbanisation.

3.4. Hydrology & Water Resources

The Rhone Delta groundwater system has undergone increasing groundwater salinity over time. Increasing groundwater consumption mainly for domestic use, industry and agriculture has led to decreasing levels, ultimately resulting in more seawater intrusion. Furthermore, the low precipitation in the area minimizes the aquifer recharge, making it even more vulnerable to saltwater intrusion. The Camargue is a vast plain comprising large lagoons, with brackish waters (from 14 g/L NaCl in winter up to 50 g/L in summer) that contribute to the formation of saline environments (de_Montety_2008). In addition, contamination from different sources, mainly from agricultural fertilizers deteriorate the quality of water, which can harm the ecosystem and its biodiversity. Finally, the diversity of water users coupled with their inadequate management has led to inaccurate water assessment and allocation in the area.

The continual depletion in the quantity and quality of the available fresh water with time adversely affects the various economic activities being supported as well as the ecosystem. Furthermore, higher deterioration of fresh surface and groundwater necessitates costlier treatment technologies to sufficiently supply water to the various economic activities.

On the other hand, the supply of nutrients from agricultural drainage water into the lagoon is a source of food for the existing aquatic life in the lagoon. The Camargue region also has good ground water recharge potential from precipitation given that it not extensively urbanised. In addition, the delta area receives continual freshwater supply from the Rhone River as well as seasonal water from floods, which can be beneficial for reducing the groundwater depletion.

3.5. Land use and Agriculture

The increase in irrigated agriculture over the time has not been without challenges and/or consequences. For instance, rice yields though being generally low in the Camargue over the past years, yields improved in in the period 1980 up to about 1995 when yields started fall again until the recent past. Reductions in yields experienced after 1995 in rice production had significant financial implications of the families of PACA, as this meant reduced income for many families, which forced farmers to switch to organic farming of wheat, alfalfa and lentils, hoping to stabilize their household incomes. One of the problems attributed to low yields is high soil salinity levels. Agricultural land in the Camargue is dominated by salty soils of heterogeneous distributions. Other problems in the region include eutrophication of fertilizers and chemicals in the downstream lagoons, flooding, and widespread crop damage by water birds.

Eutrophication occurs when chemical or mineral fertilizers discharged from agricultural fields enter water bodies, swamps or wetlands, and lead to overgrowth of vegetation, which in turn over use mineral or gas nutrients, suffocating other organisms. For flooding, this challenge is more likely to affect industries like the salt industries, which equally affected by coastal erosion, and other economic ventures which can be affected in case of a breach of sea protective barriers. This is more of a likely or impending threat to land use and agriculture and will be better tackled in collaboration with coastal department. The challenge posed by water birds, for instance Flamingos, which use rice fields as foraging habitat during a short period in May – June, corresponding to field flooding phase and have been responsible for widespread crop damage (Tourenq et al., 2001).

Rice growing in the PACA is a major activity, with the Camargue accounting for over 90% of the total rice production in France. However, rice fluctuations have been putting pressure on rice production. The good market for organic rice, wheat, alfalfa and lentils, which fetch better market price therefore present a good opportunity to improve the income earnings of farming households. The growing population in the region also presents a good potential market for increased rice productivity. Further, potential subsidies from government are an opportunity to keep farming feasible and ensure continued production of crops.

3.6. Coastal Management

The coastal region has been facing sediment load deficit as most of the riverine sediments are trapped at upstream dams. Moreover, serious sedimentation is observed at the Rhone mouth, which compromises the access of vessels to the Port of Fos. Furthermore, the Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud were assessed and results showed that these points are prone to erosion despite the existing coastal protection. Another issue of concern is the degradation of the dunes due to human activities; however, measures to recover the dunes system are already being implemented but restrictions laws must still be implemented.

On the other hand, the Rhone delta is a promising industrial park development area that may increasingly contribute to the economic growth of the region. Along the coast, the salt industries, touristic resorts, farms and the ecological preserved sites contribute to the economic growth of the region and attract many tourists.

3.7. Environment and Ecosystem

The influence of the river is strongest in northern part of study area. However, the river received a high organic matter and ammonium loads during low flow in summer, especially wastewaters from wine-producing enterprises, cheese factories, and tourist areas, despite the marked change of the wastewater treatment (Olivier et al., 2009). Therefore, the fragile ecosystem may be destroyed due to the poor water quality in river. Meanwhile, the salinity level of lagoons dramatic fluctuated due to dissolution of evaporates and inundation of agricultural drainage water. Wetland was intruded by the rice cultivation, where the natural habitat for water birds is highly complementary with rice fields. Moreover, urbanisation also intrude the wetland. Because the working population in larger cities keep pouring into the small and medium-size towns, and the area of towns is continue increase. Tourism is expanding and there are around 350,000 to 500,000 people visiting the Camargue's beaches each year. Meanwhile, the 400 semi-permanent illegally buildings were set in the protected area, and the natural habitats for winter birds maybe damaged due to anthropic activities.

From the perspective of the environment and ecosystem, there are several opportunities. Firstly, good water quality and stable salinity of lagoons are needed for bio-diversity. Beautiful scenery due to improving ecosystem quality is helpful for tourism extension resulting in developing economies. In addition, the reduction of flood risk is enhanced by the expansion of wetland.

4. EXPECTED TRENDS

If no measures are taken, flood risk within the study area will drastically increase. As the records show, flood frequency has rocketed and this will most likely continue in the years to come. With the advent of climate change, extreme precipitation and more snowmelt are expected to occur, hence leading to an increase in the peak discharge of the river, which in turn brings about an increase in flood occurrences. Urbanization in the location, particularly in the upper areas can also contribute to more flooding, with increased runoff from precipitation. With population growth in France, more people and properties will experience adverse effects of floods and this means flood vulnerability within this region will increase. Locations that adjoin a place like Arles, a densely populated location will most likely be faced with continuous population growth. As a result, such places could be more vulnerable to floods. In addition, flood risk in the future will increase the socio-economic as well as environmental losses.

In addition to the above, if no measures are taken, there will be continual depletion of groundwater and increase in the deterioration of the quality of water resources. All these will accelerate the reduction of the availability of freshwater with time, leading to major harms to all social, economic and environmental sectors by aggravating the limitation of the freshwater consumption needed for population, industries and agriculture. It is also expected that agricultural productivity will remain low and possibly further decrease, due to increased salinity and salt-water intrusion as well as crop destruction by flamingos, among others. This will lead to significant socio-economic challenges in the region. In addition, they will be continued water contamination and eutrophication in Rhone River and Vaccares Lagoon, due to various agricultural practices.

Additionally, trapping sediments upstream of the Rhone river delta would lead to riverbank erosion downstream in Rhone branches, thereby increasing the changes in the river morphology. This also negatively affects the aquatic life in the delta and the fertility of agriculture lands as well. River morphology changes also significantly affect navigation, as erosion downstream, could lead to bank subsidence. Furthermore, the sea level is expected to continuously rise over the years with a rate of 3.4 mm/year, which will contribute to the increase of coastal flooding and the coastal retreat at the erosion-prone areas. Apart from that, it will cause backwaters the river mouth resulting in the increase of the sedimentation rate at the Rhone mouth.

5. INTERLINKAGES BETWEEN DIFFERENT FIELDS

The problems and opportunities in sectors are interlinked either positively or negatively to each other. These problems and opportunities are categorized within six classes to show the interlinkage between them. The six classes are: Agriculture, Water Resource and Ecosystem, Economy, Morphology, Flooding and Sediments (*see **Figure 6***). An explanation of this figure is given below.

The dam constructions upstream the study area that have reduced sediment transport and input into the delta have caused riverbank and bed erosion, altering the river morphology. The resulting problem of unstable river channels poses a big threat to the navigation of big vessels to Lyon, which is an important economic hub. The economy and livelihoods of the urban areas (Arles and Beaucaire) are also vulnerable to flooding as extreme weather events increase due to climate change. The area’s economy is also being affected by reduced rice production due to destruction of crops by flamingos and increasing soil salinity levels. Tourism, a major economic activity is imposing a threat especially to the coastal dune system through the construction of illegal buildings and camping sites, reducing the dune capacity to protect the coast against flooding. All economic activities that require water supply are affected by the existing water resource problems such as increasing water salinity due to seawater intrusion and the ground water level drop. With climate change trends such as increasing sea level rise, and higher peak rainfall and river discharges, the resulting risk of flooding affects all the economic activities in the Rhone Delta. Furthermore, increasing population, industrial expansion and urbanisation, lead to significant land use changes, which disrupt the environment and existing ecosystems.

However, these problems also present significant opportunities. The incision of the river due to river training projects has led to an incised river, which is preferred for navigation of big ships upstream to Lyon. The opportunity to timely monitor the changing river morphology using the latest technologies will provide real time information to enable implementation of bank stabilisation activities and maintenance of draught heights through timely dredging. The use of these technologies will also help to monitor and timely respond to the sedimentation problem along the access to the Port of Fos. Improved navigation along this access and in the Rhone River will encourage expansion of the Port, and urban expansion in Arles and Beaucaire, respectively. This leads to economic growth, which is essential to support the increasing population. Increasing revenue paves way for the opportunity for government subsidies to counter losses incurred in agricultural production. A switch to organic farming which has good market increases the revenue from agriculture and reduces contamination of water from inorganic agricultural practices. Floodwaters can also be used to replenish the ground water table, which helps to counter seawater intrusion and reduce ground water salinity. New technologies can also be employed to treat wastewater to reduce pollution of the environment.

The problems and opportunities are interlinked across the various classes. Careful planning is needed to develop measures that can complement each other, maximising benefits accrued from implementing the ICARM plan in the Rhone Delta.

Figure 6. Interlinkages of the problems and opportunities

6. OBJECTIVES AND PRIORITISATION

This section describes the objectives developed by the firm and their prioritization. Objectives were developed to solve problems identified, respond to the threats and capitalize on opportunities in the study area. Based on these objectives, prioritization was undertaken to identify which objectives are Must-haves, Should-Haves, Could-Haves and Wont-Haves (MoSCoW). A Multi Criteria Approach was developed to aid this prioritization. The criteria used included the potential effects on the environment (25%), human life (30%), economy (25%)

and the initial judgement on Feasibility (20%). Scores were then assigned under each criteria for each objective as shown in ***Table 2*** below.

Table 2: Scores assigned for each objective under each criteria

Score	Meaning
1	Very Negative
2	Moderately Negative
3	Neutral
4	Moderately Positive
5	Very Positive

The corresponding weights were computed for each objective to establish the highest ranked objectives to be carried forward for planning as provided in ***Table 3***. The thresholds used to aid the development of the MoSCoW list were as follows.
The MoSCoW list developed has been provided in Table 4 shown below. It is worthy to note that more in-depth analysis is yet to be done to ascertain the objectives identified, and prioritized under this plan.

Table 3. The Multi Criteria Analysis of Main objectives

No.	Field	Criteria	Social		Initial judgement of Feasibility		Environment		Economy		Total
		Weight (Total = 1)	**30%**		**20%**		**25%**		**25%**		**100%**
			Min/Max Score (0 - 5)								
1	Flood Risk	Increase the flood capacity of the river in Arles to carry discharge of 200-year return period flood in 5 years.	5	0.3	3	0.12	4	0.2	5	0.25	**87%**
2	Environment	Maintain a stable salinity in the Vaccarés lagoons (between 5 g/l and 30 g/l) to Improve the biodiversity and ecological quality	3	0.18	4	0.16	5	0.25	5	0.25	**84%**
3	Water Resources	Improve the current groundwater level (>7 m) in the Camargue area as well as reducing the salinity (CL<250 mg/L in the next 30 years.	3	0.18	4	0.16	5	0.25	5	0.25	**84%**
4	River Engineering	Protect against riverbank and bed erosion along the Grand and petit Rhone reaches especially near river mouth for both branches and upstream Arles for Grand Rhone in the next 2 years.	3	0.18	5	0.2	5	0.25	4	0.2	**83%**
5	Agriculture	Reduce the crop damage by flamingos by 50% in 5 years.	3	0.18	5	0.2	4	0.2	5	0.25	**83%**
6	Urban Water Management	Improve the capacity of storm drainage systems in Arles to convey a storm event of 15 years return Period	5	0.3	3	0.12	4	0.2	4	0.2	**82%**
7	Coastal Management	Reinforce the coastal protection at the main coastal areas (Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud) so they resist the effects of sea level rise.	5	0.3	4	0.16	3	0.15	4	0.2	**81%**
8	Agriculture	Maintain soil salinity levels within acceptable limits (ECe 0 – 4 dS/m)	3	0.18	3	0.12	5	0.25	5	0.25	**80%**
9	Environment	Maintain the area of wetland of 50,000 ha during the next 30 years.	3	0.18	4	0.16	5	0.25	4	0.2	**79%**
10	Coastal Management	Reduce the destruction of the dunes system through illegal camping at Gulf of Beaduc by 80% in 5 years.	4	0.24	5	0.2	4	0.2	3	0.15	**79%**

11	Agriculture	Reduce agricultural water contamination levels of the Vaccares Lagoon and Rhone River from the current level (1.6 – 2.7µg/L) to meet European Union permissible limits (0.1 – 0.5µg/L) in 5 years	3	0.18	5	0.2	5	0.25	3	0.15	**78%**
12	Coastal Management	Maintain a minimum draught depth of 3.2 meters on access routes to the Port of Fos.	3	0.18	5	0.2	3	0.15	5	0.25	**78%**
13	Urban Water Management	Reduce flood impacts by increasing the community participation and involvement	4	0.24	3	0.12	4	0.2	4	0.2	**76%**
14	River Engineering	Maintain navigability of wide barges in Petit and Grand Rhone Rivers (Minimum water depth = 3.20 m)	4	0.24	3	0.12	4	0.2	4	0.2	**76%**
15	Flood Risk	Increase the flood capacity of the Petite Rhone in the downstream near the coast to carry a discharge of at least 50-year return period in 3 years.	4	0.24	3	0.12	4	0.2	4	0.2	**76%**
16	Water Resources	Keep the seawater-freshwater interface and salinity at the current 8-10 Km offset from the coastline in the next 3-5 years.	3	0.18	3	0.12	5	0.25	4	0.2	**75%**
17	River Engineering	Cut the meandering downstream Petit Rhone	3	0.18	3	0.12	4	0.2	4	0.2	**70%**
18	Coastal Management	Reduce the underwater erosion (as there is no measures of estimation of its importance)	3	0.18	1	0.04	3	0.15	3	0.15	**52%**
19	Water Resources	Increase the freshwater diameter zone (lenses) near the coastline in the next 50 years until the saline interface will be less than 0.5 km from the coastline.	4	0.24	1	0.04	1	0.05	3	0.15	**48%**

Objective type	**Range**	**Colour code**
Must-haves	>80%	
Should-Haves	75%-80%	
Could-Haves	60% - 75%	
Wont-Haves	<60%	

Table 4. The MoSCoW List

	Must-Have	Should-Have	Would-Have	Wont-Have
Flood Risk Management	Increase the flood capacity of the river in Arles to carry discharge of 200-year return period flood in 5 years.	Increase the flood capacity of the Petite Rhone in the downstream near the coast to carry a discharge of at least 50-year return period in 3 years.		
Environment	Maintain a stable salinity in the Vaccarés lagoons (between 5 g/l and 30 g/l) to Improve the biodiversity and ecological quality	Maintain the area of wetland of 50,000 ha during the next 30 years.		
Hydrology and Water Resources	Improve the current groundwater level (>7 m) in the Camargue area as well as reducing the salinity (CL<250 mg/L in the next 30 years.	Keep the seawater-freshwater interface and salinity at the current 8-10 Km offset from the coastline in the next 3-5 years.		Increase the freshwater diameter zone (lenses) near the coastline in the next 50 years until the saline interface will be less than 0.5 km from the coastline.
River Engineering	Protect against riverbank and bed erosion along the Grand and petit Rhone reaches especially near river mouth for both branches and upstream Arles for Grand Rhone in the next 2 years.	Maintain navigability of wide barges in Petit and Grand Rhone Rivers (Minimum water depth = 3.20 m)	Cut the meander downstream Petit Rhone	
Coastal Management	Reinforce the coastal protection at the main coastal areas (Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud) so they resist the effects of sea level rise.	Reduce the destruction of the dunes system through illegal camping at Gulf of Beaduc by 80% in 5 years.		Reduce the underwater erosion
		Maintain a minimum draught depth of 3.2 meters on access routes to the Port of Fos.		

Landuse and Agriculture	Reduce the crop damage by flamingos by 50% in 5 years.	Reduce agricultural water contamination levels of the Vaccares Lagoon and Rhone River from the current level (1.6 – 2.7μg/L) to meet European Union permissible limits (0.1 – 0.5μg/L) in 5 years		
	Maintain soil salinity levels within acceptable limits (ECe 0 – 4 dS/m)			
Urban Water Management	Improve the capacity of storm drainage systems in Arles to convey a storm event of 15 years return Period	Reduce flood impacts by increasing the community participation and involvement		

7. APPROACH FOR THE PLAN

The approach taken for the plan is **'To develop a climate resilient delta through implementation of proactive adaptation measures'.**

As earlier stated, the Rhone Delta and surrounding areas have previously been victims of floods, most notably, the 2003 flood where the estimated damage was over 30million euros. This single event caused a breach in the upper Camargue and flooded vast agricultural lands and degrading ecosystems in the lagoons downstream due to a sharp decline in salinity. Recently, seven (7) of the sixteen (16) largest floods within the last 150 years, have been recorded within the last 15 years.

The 2014 Intergovernmental Panel on Climate Change (IPCC) synthesis report on climate change stipulates that global warming has escalated since the 1950s arising from increased greenhouse emissions arising from human activities (IPCC, 2014). Accordingly, this has caused sea level rise and the increase in surface temperature. Impacts of climate change have affected the natural and human systems in the recent years. Extreme weather events have become more frequent, with increasing cold and warm temperatures extremes than previously recorded in various regions.

According to the 2014 IPCC report, continued greenhouse emissions are estimated to cause further global warming and climate change. Impacts of climate change are also estimated to escalate with increasing average global sea level rise of 0.25m by 2050. It has also been estimated that the global average surface temperature will increase by 1.8 °C by 2050 and around the study area, the average precipitation is estimated to reduce by 40 mm per day by 2050.

In a study carried out by Ruiz-Villanueva et al (2014), it was estimated that the mean discharge in the Rhone River upstream of Lyon has also been estimated to decrease in the range of 47% to 63% within the period of 2070-2100, with decreasing low and high flows, and more extreme floods. Similar reductions were described for different rivers over France by (Boe´ and Habets 2014) and Chauveau et al. (2013), where a general reduction in annual stream flow of about -25 and -35 % was projected for the horizon 2065. The reduction in mean annual flow will likely be accompanied by a shift in the seasonality of flows and by a smoothening in the regime.

These occurrences will continue to have adverse effects on economic activities such as agriculture, industry and domestic water supply that depend on the water quantity and quality. The ecosystem and environment will also be affected especially with the increased occurrence and frequency of extreme events. **With this in mind, it is therefore imperative that a climate resilient delta is developed to safe guard the population, existing activities and environment from the estimated climate changes.**

Adapting to climate change includes implementation of decisions and actions that help to cope with climate change impacts. Adaptive measures can be undertaken from the individual level to the delta level. Since the Rhone Delta is relatively developed, there is some significant capacity to adapt. However, this does not necessarily translate into action to address climate change impacts. Since climate events are very uncertain, a proactive approach to dealing with them helps to anticipate potential climate events and therefore, provide protection against its impacts in advance.

8. STRATEGY

The ICARM task was designed with strategies that spread across the ***six*** main priority fields, which are *Flood Risk Management*, *Water Resources and Environment, River Engineering*, *Land and Water Development*, *Urban Water Management as well as Coastal and Port Development*. Each strategy enables the generation of measures for each field that are in line with the overall approach of the ICARM plan. Each strategy consists of a programme of proactive adaptation measures that aim at achieving the set objectives under the the estimated climate parameters. The climate parameters as estimated for 2050 were initially considered in the generation of measures. However, these were adjusted deepening on the potential feasibility of the suggested improvements and additional measures.

8.1 Methodology for Developing Measures

For each strategy, the methodology employed in developing the measures for each objective followed the steps given below.

1. Establish the existing measures being employed to respond to the problem at hand
2. Establish the capacity of the existing measures to achieve objectives under the estimated climate parameters.
3. If not adequate, establish whether any improvements can be made to the existing measures to achieve the objectives under the estimated climate parameters.
4. If improvements are not adequate, establish which new measures can be developed to achieve the objectives, under the estimated climate parameters.
5. Prioritisation of measures based on initial judgement on feasibility, cost and effectiveness.

However, some objectives are not directly related to climate change. In this case, care was taken to focus more on measures that capitalize on common practices that may be easier to implement, without incorporating climate change. Strategies and measures developed for each field have been given in the sections below.

9. STRATEGIES AND MEASURES FOR EACH FIELD

This section describes the individual strategies and selected measures for each of the six fields considered in this proposal.

9.1 Flood Risk Management

In order to identify the measures for flood risk management, it was necessary to perform a flood frequency analysis. The discharge data provided is the daily average but for flood frequency analysis, we used the peak discharges of every year. On the other hand, we have the peak discharges of some recorded floods. From these peak floods, we estimated a factor between the peak discharge and the average daily discharge and found it to be ***1.12.*** The average daily data was converted to the peak discharge using this factor. From the new data, the discharges for different return period floods are found and these can be seen in ***Table 5***.

Table 5. Flood frequency analysis

Return period (Year)	**50**	**100**	**150**	**200**
Design discharge (m^3/s)	**11200**	**12200**	**12800**	**13200**

9.1.1 Flood Risk Management Strategy

The strategy is to investigate the capacity of existing measures and estimate the amount of capacity increase for the measures. The strategy further focuses on the selection of the most feasible measures for the reduction of flood risk for the study area.

Table 5.1. Flood Risk Management (Must Have)

Strategy	***Objective***	***Measure***
Implementing new measures to divert the water from the bottleneck at the Arles city.	Increase the capacity of river to carry a discharge of 200-year flood taking into account the climate change in Arles.	Building a bypass channel on the right side of Arles from Petit Rhone to Grand Rhone.

With the existing measures, the river can carry a discharge of 100-year return period (approximately 12,000m^3/s). However, the flood peak in 2003, which was 13000 m^3/s, is almost correspondent to 200-year return period flood (based on the flood frequency analysis as shown in *table 5*). As a result, it is necessary to increase the capacity of the river for 200-year return period flood. To do this, an extra capacity of almost 1,200 m^3/s is needed. As stated earlier, it has been estimated by the IPCC that there will be increase in the peak of extreme flood events. Hence, to accommodate for this, the peak discharge of 13,200 m^3/s was increased by 10%, giving a total discharge of **14,500 m^3/s**. This discharge value served as the basis for the

9.1.2 Flood Risk Management Measures

For flood risk management, different measures can be implemented. These measures are given as follows;

- The first measure suggested is **Dredging the River**. This measure requires repeated implementation due to filling of sedimentation in the areas dredged. In addition, deep dredging within the narrow cross-sections are required, which is not feasible due to the low slope of the river.

- The second measure suggested is **Raising of the Existing Dykes**. This measure has key constraints. In implementing this measure, particularly at narrow cross sections like the bottleneck at the Arles city, which has a width of 150m, a dyke raise of more than 7meters will be needed. As a result, at the narrow cross sections, mobile walls can be used to prevent the flooding. In the wider cross sections where a dyke raising of less than one meter is needed, the dykes can be raised to prevent the flooding.

- The third measure suggested is a **Detention Basin**. The detention base requires a substantial amount of space. The size must be adequately estimated. Using the flood of 2003 as an example, in which the discharge was more than 12,000 m^3/s for more than 24 hour. If 1,500m^3/s discharge for 24 hours is considered as diverted flood to the basin a volume of almost 130,000,000 m^3 is needed. For this case, a detention basin of an area of 50 km^2 and height of 2.6m is required. However, if there are consecutive floods, the retention basin will not be fully empty for new flood, which will cause bring above an overflow from the basin. This basin also needs a very large area and dykes around it, hence making its implantation expensive.

- The fourth measure suggested is the **Construction of a Bypass Channel** at the western side of Arles connecting the Petit Rhone to Grand Rhone. This will aid the diversion of the waters from the bottleneck. From the analysis, the length of the channel will be approximately 4.5 km, and for a discharge of 2,500m^3/s and a flood flow velocity of 2m/s, a width of 200m and height of 6.5m will be enough. ***It is worthy to note that the soil from the diversion channel can be used for dykes raising where required and nourishment of the beach.***

In order to select a feasible measure, a multi criteria analysis (MCA) was performed. This is given as follows;

Table 5.2. MCA Flood Risk Management

Measure	*Technical*	*Economic*	*Environment*	*Social*	*Flexibility*	*Total*
Dredging the River	0	-1	1	2	1	3
Raising the Dykes	1	1	0	1	1	4
Retention Basin	1	-1	1	0	1	2
Bypass Channel	2	1	1	0	2	6

From the results obtained, the highest ranked measure will be to build a bypass channel on the western side of Arles city to divert water from Petit Rhone to Grand Rhone.

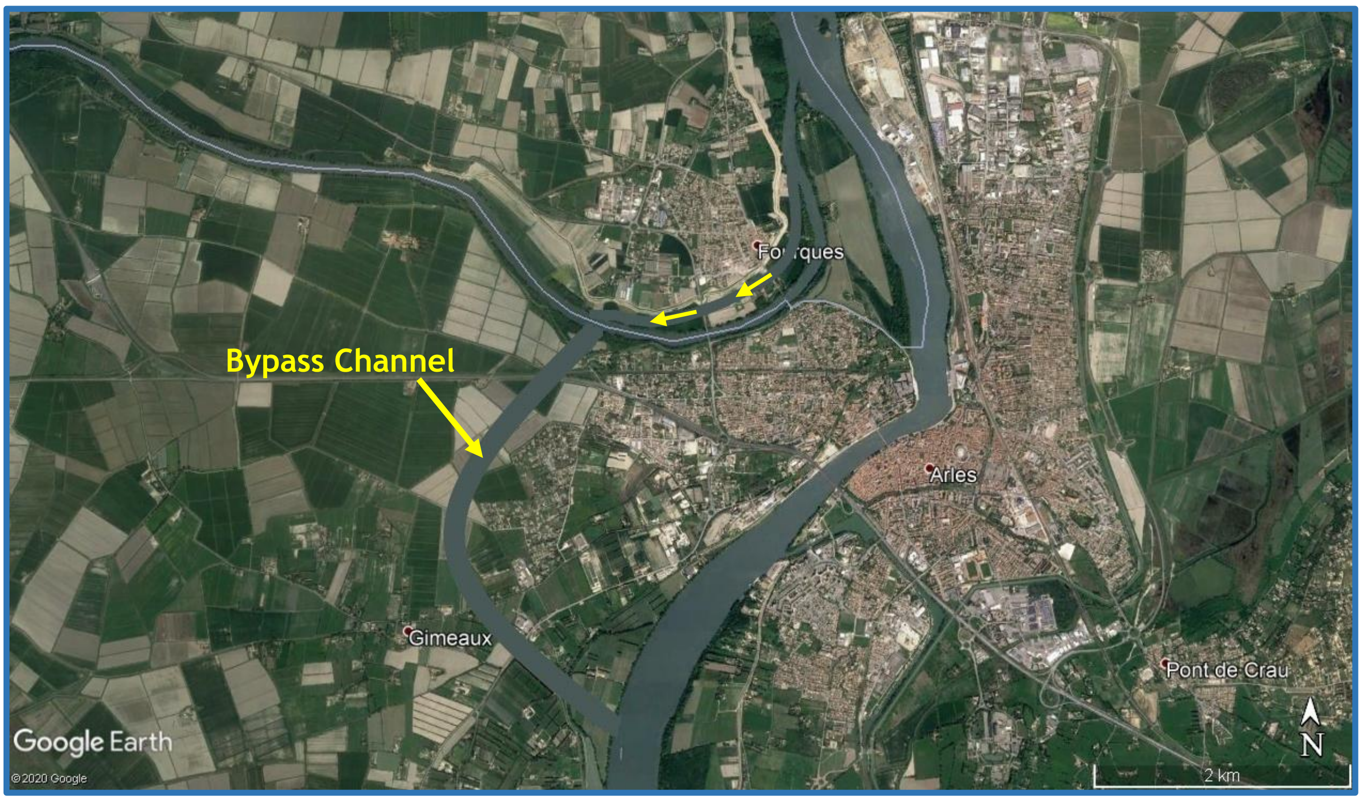

Figure 7. Proposed Bypass Channel

Table 5.3. Flood Risk Management (Should Have)

Objective	**Strategy**	**Measures**
Increase the flood capacity of the Petite Rhone in the downstream to carry a discharge of at least 50-year return period.	Increase the capacity of current measures according to the design flood.	Raising the dykes.

On the right side of Petit Rhone near the coast, the existing dyke has a capacity for a flood of 10-year return period. However, this part is important to be prevented from flooding, because the flood can reach the saltpans and cause environmental and economic problems. Moreover, as can be seen the urbanization is happening on the left side of the Petit Rhone. It can be because of the higher dyke on this side of the river, which gives a feel of safety for people to urbanize. As this area is not inside a city, has wide cross sections, and receives maximum of 20% of the whole discharge, the dykes can be raised. By raising the capacity of this dyke from 10 year to 50-year return period of flood, the saltpans and the agricultural area will be safe and more area will be created for urbanization or tourism facilities.

9.1.3 Additional Investigations for Flood Risk Management

The required additional investigations for each field, proposed in this plan are given as follows;

Proposed Measure:

Building a bypass channel on the right side of Arles from Petit Rhone to Grand Rhone.

Tasks:

- Provision of flood hazard maps for the location using the design discharge value of 14500m^3/s, while considering the existing measures and sea level rise of 0.22m.
- Perform modelling operations to estimate the final location and capacity of the proposed bypass channel, using the design discharge hydrograph.
- Provision of flood hazard maps after incorporating the design bypass channel.
- Determine the size of the dikes to be placed along the proposed bypass channel.
- Assessment of the bank stability of the proposed bypass channel.
- Provision of the structural design of the bypass channel.

Requirements:

- Consider the current and future land use in the area for selecting the location of bypass.
- Analyse the impact of the construction of the bypass channel on the environment and inhabitants of the project location.
- Assess the amount of farmland and buildings that will be lost due to the construction of the bypass.
- Adequate consideration of the effect of the construction on the groundwater recharge.
- Take into consideration the existing infrastructure in the location in the effective implementation of the project.
- Take into account the navigability in both Petit and Grand Rhone.

Deliverables:

- A model setup including the proposed bypass channel.
- The final location for the bypass channel.
- The required dimensions for the bypass channel and its dykes.
- Required intervention to bifurcation before Arles.
- Graphical presentation of the model results on a map.
- Estimated project cost and duration.

9.2 River Engineering

Based on the general strategy of developing a climate-resilient delta through the implementation of proactive adaptation measures, a strategy for achieving the objectives of the river engineering aspect related to the general strategy was proposed. The new strategy is to adapt the Grand and Petit Rhone River against climate change implications on river flow and seawater level rise. The mean average discharge of Rhone River is estimated to decrease by 25% (Ruiz-Villanueva et al., 2015) and the flooding events become less frequent but the peak value of flooding discharge is increased. According to (IPCC, 2014) the seawater level will increase by (+ 0.25) m by 2050 on the coastal line of Rhone delta. All of these implications affect the performance of Grand and Petit Rhone Rivers. Three measures were analysed to overcome the implications of climate change by 2050, within the framework of two objectives as is explained below.

9.2.1 Objective 1: Protection against riverbank and bed erosion

Two measures were proposed to protect against erosion in the erosion-prone areas at Petit and Grand Rhone Rivers. They are as follows;

- **Bank lining at erosion-prone areas and full channel lining around hydraulic structures**

After establishing the 19 dams upstream Rhone delta, the amount of sediment transported to the downstream decreased from 35 x 10^6 tonnes per year at the 19th century to 7.39 x 10^6 tonnes per year at the end of the 20th century (78% reduction). This led to erosion propagating in the bed and the banks of Grand and Petit Rhone Rivers into the Rhone Delta due to the decreased sediment input, for a given sediment transport capacity. Bed and bank erosion are estimated to increase as a result of climate change and increasing peak value of flooding discharge from 12,000 m^3/s to 14,500 m^3/s (Estimated values). The layered banks of Grand Rhone upstream Arles and banks of Petit Rhone and Grand Rhone near the river mouth are the most affected areas to bank erosion according to previous studies (G. Arnaud-Fassetta, 2003). This is shown in figures 8.1 and 8.2. Bed erosion is critical around the foundations of bridges at the Grand and Petit Rhone rivers. With higher peak value of flooding discharge, bank erosion at mentioned locations, and bed erosion around the bridges foundations become more critical. Therefore, riverbank lining is proposed at the mentioned locations. Bank, and bed lining is proposed to be implemented around the foundations of the bridges.

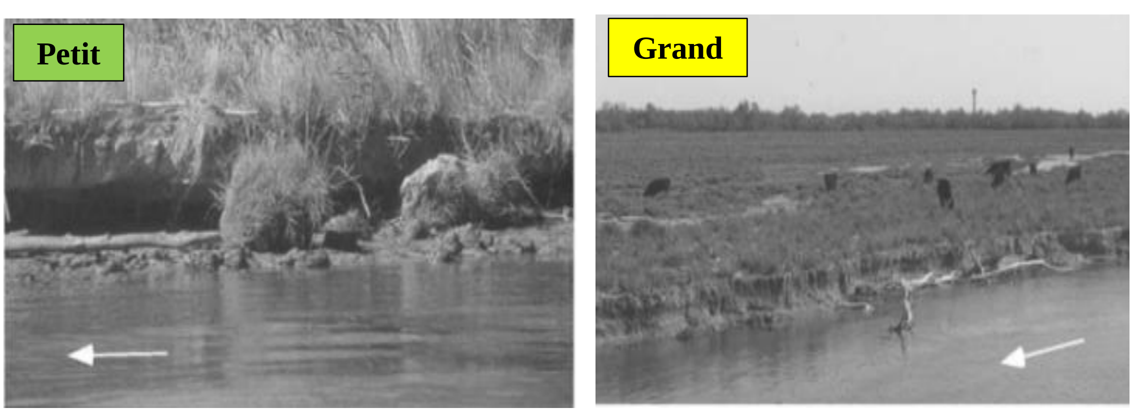

Figure 8.1. Eroded Grand and Petit river banks near to river mouth after, (G. Arnaud-Fassetta, 2003)

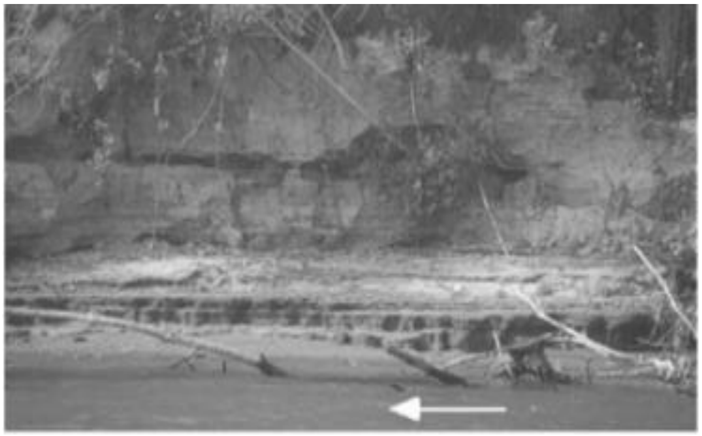

Figure 8.2. Eroded Grand riverbank upstream Arles city after, (G. Arnaud-Fassetta, 2003)

- **Allow sediment flushing to the Rhone Delta**

The current sediment volume in the Rhone delta is less than the sediment transport capacity of the discharge, which causes river incision, bed and bank erosion in Grand and Petit Rhone Rivers. Therefore, it is proposed to allow sediment flushing from the dams upstream to the Rhone delta with the value equal to the river transport capacity and incorporating this into the dam operation procedures. In addition, mechanical sediment facilities could be provided for some dams that do not have any sediment flushing facilities.

9.2.2 Prioritization of the measures for objective 1

Riverbank lining at erosion-prone areas and channel lining around hydraulic structures are economically feasible and easy to implement in a short time, offering immediate results. Bank lining is also advantaged with a wide variety of different lining materials (Riprap, Gabions, or concrete) that can be utilized. Allowing sediment flushing is a measure that requires intensive discussion with all the stakeholders upstream the Rhone delta, to allow for the incorporation of this practice in the dam operations. Furthermore, the impact of releasing more sediment to provide significant bank erosion protection occurs at a longtime scale, taking a lot of time (tens of years). Therefore, allowing sediment flushing was analyzed as less effective and therefore, will not be included under this plan.

9.2.3 Objective 2: Maintain navigability of wide barges in Petit and Grand Rhone Rivers

As it is imperative that the minimum draught height of 3.2m is maintained across the Grand and Petit Rhone, it is essential to identify potential sources of additional sedimentation that may increase the need for more frequent dredging along the river channels. Dredging has been among the practices previously used in the Rhone River as part of river training to increase navigability, from the 19th century (G. Arnaud-Fassetta, 2003). Maintaining navigability in the two river sections is a key priority of the CNR, and as search, it is expected that regular surveys and maintenance are conducted along the river sections. Nevertheless, as impacts of climate change escalate the estimated sea level rise and reduced average discharge will cause sedimentation at the mouths of the two rivers. Overtime, sediment is expected to accumulate in the river channel from the mouth, propagating upstream.

Nevertheless, it is worthy to note that the rate of sea level rise is quite slow (0.34 cm per year), and the morphological response to this rise in the riverbeds, will be quite slow and gradual as well. As dredging has been done before for river training, it is a suitable measure to remove the sediment that could accrue within these areas as explained above. No information was obtained at the time of this study on the current dredging operations and frequency that may be undertaken by the CNR to remove accruing sediment, in a bid to promote navigation. There is real time monitoring of water levels and discharges along the Rhone River . However, no information is currently available on the sediment monitoring and management in the channels. As the CNR has been maintaining navigability in the rivers for a while, it is recommended to continue monitoring sediment and undertaking the corresponding dredging to maintain good navigation.

9.2.4 Final Measures Proposed

The measures proposed under this plan and the corresponding location areas are provided in the Table 6 below and Figure respectively.

Table 6 Strategy, objectives and related measures

Strategy	Objectives	Type	Measures
Adapt the Grand and Petit Rhone rivers against climate change implications on river flow and seawater level	Protection against riverbank and bed erosion along the Grand and petit Rhone reaches especially upstream the river mouth for both branches and upstream Arles for Grand Rhone within 2 years.	Must have	-River Bank lining using riprap in Grand Rhone upstream Arles and downstream near river mouth for both branches and channel lining around bridges and hydraulic structures in the Rhone delta
	Maintain navigability of wide barges in Petit and Grand Rhone Rivers (Minimum water depth = 3.20 m) in response to potential sea-level rise	Should have	-Monitoring and dredging activities to ensure the minimum depth of 3.2m in Grand and Petit Rhone rivers

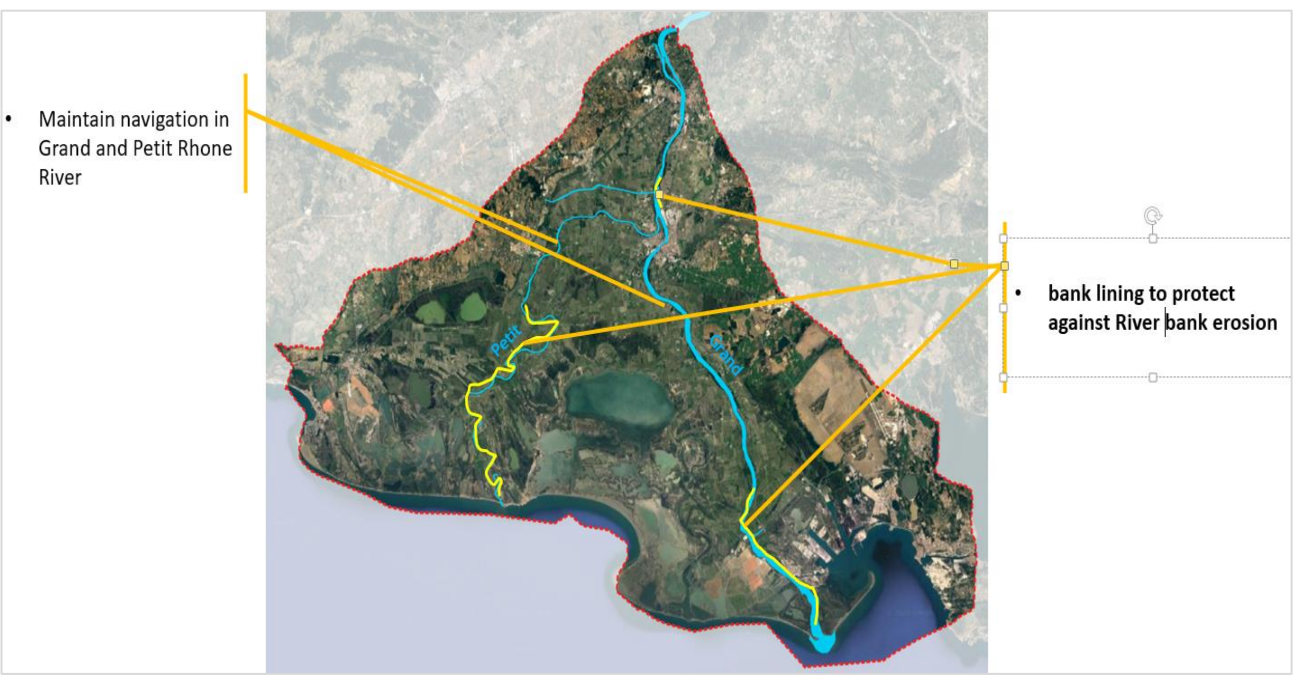

Figure 8.3. Locations of proposed measure

9.2.4 Additional Investigations for River Engineering

Additional investigations have been suggested for bank lining at erosion-prone areas and full channel lining around hydraulic structures as detailed below.

Task 1: 2D modelling to show precisely the actual bank eroded areas along Grand, Petit Rhone River, and estimate bed erosion around the bridges in Grand and Petit Rhone rivers.

Requirements:-

- Consider a wide range of discharge values
- Simulate extreme events according to climate change scenario.
- Current and estimated sea water level.

Deliverables:-

Series of maps show the erosion-prone areas in the Grand and Petit Rhone rivers.
Series of maps show estimation for the bed erosion (Depth and width) around bridges in Grand and Petit Rhone rivers.

Task 2: Determine the design of lining sections and material used for lining.

Requirements:-

- Consider a wide range of discharge values
- Simulate extreme events according to climate change scenario.
- Low capital cost
- Maintain river cross sections

Deliverables:-

- Full design for proposed lining sections including the type of material used
- Estimated cost and duration

9.3 Hydrology and Water Resources

From the hydrology and water resources perspective, the strategy is to **increase water resources reliability and drought resilience.** Hence, protecting and preserving the water resources (quantity and quality) is the main goal. To achieve this, the measures proposed focused on maintaining the current conditions and addressing the concerns related to climatic changes in the future. These measures were suggested based on the evaluation of available data and previous scientific research on the Rhone delta. They were further evaluated based on a series of criteria and their influence on other fields.

As a first step, maintaining and protecting the current situation of the delta water resources quantity and quality (mainly the salinity of groundwater), is paramount. In addition to this process, constituting regulations and legislations for data collection and monitoring arrangements to detect any possible changes that may degrade the quality of water resources is required.

In addition to the above, as a form of accommodating the effects of climate change, adaptation pathways that will aid effective maintenance of the water resources, particularly the groundwater quality and quantity are needed. Measures that will help protect the delta from drought due to lower precipitation and higher evapotranspiration as well as prevent pollution mainly due to seawater intrusion are suggested. Such measures are will be designed to help the delta cope with the demand of water resources for domestic, touristic and industrial development until 2050.

Table 7. Water resources strategy and measures

Objective	Strategy	Measures
Keep the seawater-freshwater interface and salinity at the current 8-10 Km offset from the coastline in next 3-5 years.	Increase water resources reliability and drought resilience	- Construction of injection wells & artificial (Managed Aquifer Recharge (MAR)). - Institute data collection and monitoring arrangements. -Surface water treatment plants extension for population and economic sectors *(industries and touristic activities)*.
Improve the current ground water level (>7 m) in Camargue area as well as reducing the salinity (CL<250 mg/L in the next 30 years.		- Construction of additional injection wells and artificial ponds (MAR). - Institute legislation against unauthorized abstraction.

9.3.1 Measures for Hydrology and Water Resources

The measures are described as follows;

- **Institute data collection and monitoring arrangements**

In order to monitor and assess the existing water resources for the study area, data collection and monitoring should be arranged with a single robust institute, and should be available to the public. These data are beneficial for assessment of the water balance of the delta. It also aids the evaluation of the existing problems related to the quantity as well as the quality of the water resources. It is essential to identify the best actions that should be executed in the current and future time and to determine the effectiveness of the existing measures of the delta.

- **Surface water treatment plants extension for the population and economic sectors (industries and touristic activities)**

People utilize many springs in the areas, but have also drilled wells for water supply purposes. However, the increasing salinity of the groundwater because of seawater intrusion has limited the abstraction of the groundwater, and thus the main water resource for the population and industrial activities is from the surface water (Rhone River). Therefore, more surface-water treatment plants are needed and they will provide freshwater to different stakeholders at the same time hence, limiting the abstraction from springs and drilled wells. This will be beneficial for groundwater level preservation, minimize the seawater intrusion and upcoming saltwater from the deeper aquifer.

- **Construction of injection wells & artificial (MAR)**

In order to protect the groundwater quantity and quality in the current situation (3-5yrs) as well as to deal with future climate change e.g. rainfall reduction by 10mm/yr. for every decade, higher temperature and low river discharge by 25% (IPCC,2014) of the river, the MAR is considered the most effective measure for the groundwater quantity and quality recovery. The MAR measures are considered suitable for the Rhone delta for many reasons including;

- Relative high vertical hydraulic conductivity K_z=2 – 6 m/d (E. Zewdie, 2011) for some open areas near the rivers and far away from the urban areas. This is suitable for the artificial infiltration ponds.
- The deeper aquifer has a high horizontal hydraulic conductivity (Gravel in a high sandy clay matrix, $k_{x,y}$ = 20 – 60 m/d (E. Zewdie, 2011), which is efficient for the injection wells especially around the lagoons.
- Constant fresh water from the rivers is available in the Rhone areas for the MAR purposes, although the discharge of the rivers will decrease by 25% because of the climate change. However, this issue can be managed by increasing the injection in the wet period and decreasing in the dry period;
- High frequency of floods waters especially after 1996 as shown in figure 9. can be utilized for the MAR freshwater resource. The construction of retention ponds in the flood area (figure 9.1), can be used to store water for some time after the flood, as well as for groundwater recharge.

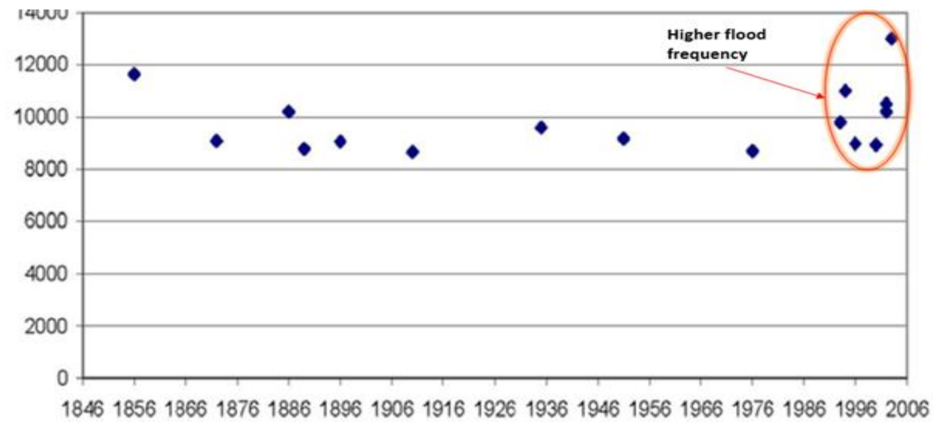

Figure 9. Overview of the 16 most important Rhone floods (maximum instantaneous discharge, m3/s).

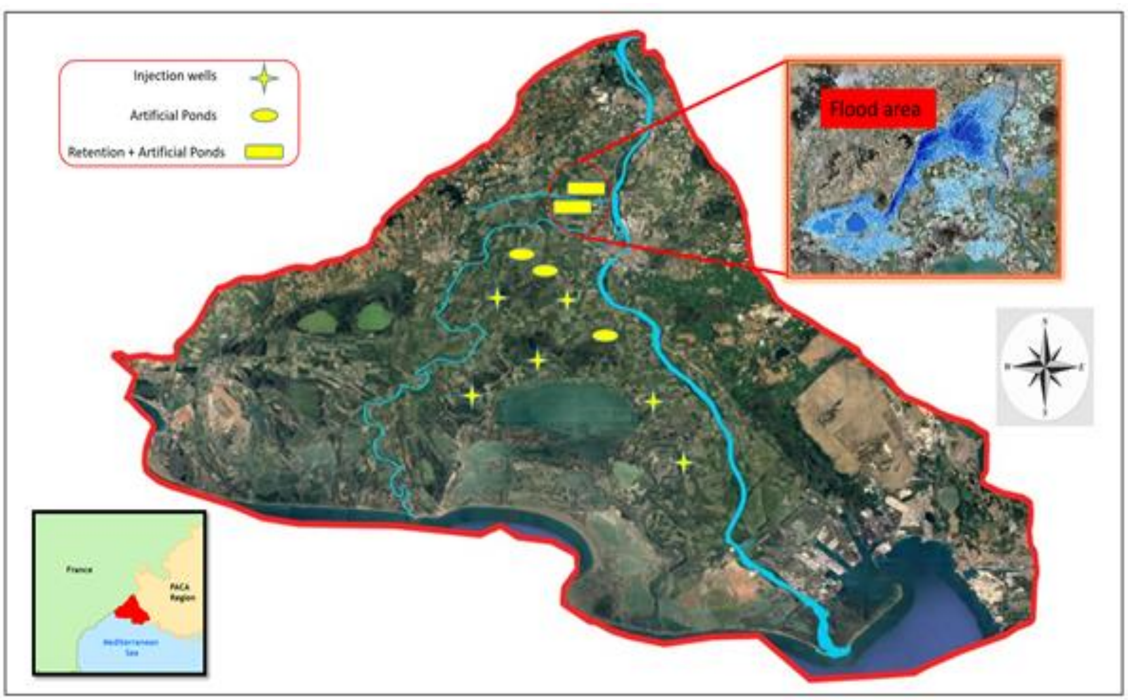

Figure 9.1. The location of the main measure (MAR) and the flood area of the Rhone Delta

- **<u>Decide abstraction threshold and Institute legislation against unauthorised abstraction</u>**

Under climate change, groundwater level salinity fluctuates more and more drastically. Therefore, some actions should be done to ensure the continued effectiveness of other major measures and to accelerate groundwater recovery during droughts period resulting from climatic change. It is imperative to decide a threshold for abstraction and to monitor volumes of extracted water from the aquifer so that unauthorized abstraction of the groundwater mainly in the downstream will be discouraged. This should be managed under a single authorized institute, backed up with relevant legislation for supporting the adequate allocation management of the abstractions, especially for the future economical and agricultural growth.

9.3.2 Additional Investigations for Hydrology and Water resources

To achieve our objectives, a third party should check the effectiveness of our measures. In Water resource department the efficiency of the artificial recharge (MAR), needs additional investigation related to temporal and spatial groundwater level and contaminants transport modelling.

<u>Tasks:</u>

The task required to be performed in the course of the additional investigations are using the 3D Numerical Modelling to simulate the groundwater level & Water balance output using (MODFLOW), and the contaminants transport (mainly the salinity) using SEAWAT in the Rhone delta. Furthermore, the effect of groundwater artificial recharging on the overall hydro-chemical properties of the groundwater using the Phreeqc model.

<u>Requirements:</u>

The requirements from the third party are as follows;

- **To simulate groundwater quantity and quality fluctuation and the water balance in the whole Rhone delta according to climate change scenarios require the following;**
  - The Extreme events of the river e.g. floods as well as the reduction of the river discharge by 25% by 2050 (IPCC, 2014).
  - The precipitation reduction by -10mm/yr. each decade (IPCC, 2014).
  - Higher evapotranspiration (temperature increase by 1.8C^{o} at 2050 in the Rhone delta (IPCC, 2014)).
- **The design of the MAR should be feasible with Low capital and operation cost taking into consideration the following requirements;**
  - The topography of the location should be flat enough for economic excavation.
  - Using a cheap source of energy to convey the freshwater from the rivers to injection wells and infiltration ponds e.g. using the Wind Power.
  - The retention ponds that are used to capture floods excess at the same time for aquifer recharge should be in rectangular shape where the longitudinal length in the direction of intensive agricultural areas so that they can utilise water for irrigation without expensive water supply network from the river.
  - The location of artificial ponds should be in the areas with high vertical hydraulic conductivity to decrease the frequencies of bed clogging. In addition, the injection wells should drilled to the deeper aquifer that has high horizontal hydraulic conductivity for higher capacity of injection and less frequency of clogging. All of which result in less operation cost.

Deliverables:

The expected Deliverables from the third party to achieve our objectives are the following:

- A Series of maps elaborating the possible change in the groundwater level in the upstream and downstream with time before and after MAR Construction.
- Temporal and spatial maps of the salinity transportation in the Rhone area because of seawater intrusion or retreat with time before and after MAR Construction.
- The number and distribution of injections wells and volume and distribution of the ponds as well as the infiltration rate for the MAR and the freshwater quantity needed to cope with the droughts in the area because of simulated climate change.

9.4 Environment and Ecosystem

In terms of environment, the strategy mainly focuses on **the conservation of biodiversity and ecological quality in Rhone delta under climate change through an eco-friendly artificial intervention.** Due to the rapid changes in the global climate, the fragility of ecosystems will increase dramatically, and eco-friendly human interventions are required to help the ecosystem continue to develop in a stable and healthy manner.

The specialized study in the environment focuses on the two objectives, which are **maintaining a stable salinity on the lagoons** and **maintaining the area of wetland**. The urgent task at this stage is to establish a complete control system for regulating the salinity of the lagoon to deal with the drastic fluctuations in the salinity of the lagoon under future climate changes. This project proposes three measures for the achievement of these objectives.

9.4.1 Proposed Measures

The proposed measures are as follows;

- **Construction of control devices of water quantity around Vaccarès lagoon (Must have)**

The Vaccarès lagoon system does not exchange water through the Rhone River and the Mediterranean Sea. It receives water from rainfall and irrigation drainage from the rice field. The water loss of this system is due to the high evaporation caused by the high temperature in summer, which indirectly leads to a large increase in the salinity and pollution concentration of the lagoon. According to figure 10, the northern part of the lagoon is a large area of rice fields and irrigation drainage from this area into the lagoon to dilute the salinity whereas, in southwestern parts, the runoff could be returned to the Mediterranean Sea by this measure.

To create the salinity control system (construction of control devices of water quantity) around Vaccarès lagoon, the following are required;

- Firstly, establish control facilities for the drainage outlets of farmland around the lagoon to control and monitor the total drainage volume of the rice field
- Secondly, build water exchange equipment between the Rhone River and the lagoon in the southeast and north of the lagoon
- Thirdly, there is an existing sluice located at the southwest of the lagoon connected to the Mediterranean Sea. This gate and the above-mentioned equipment are combined to form a complete control system.

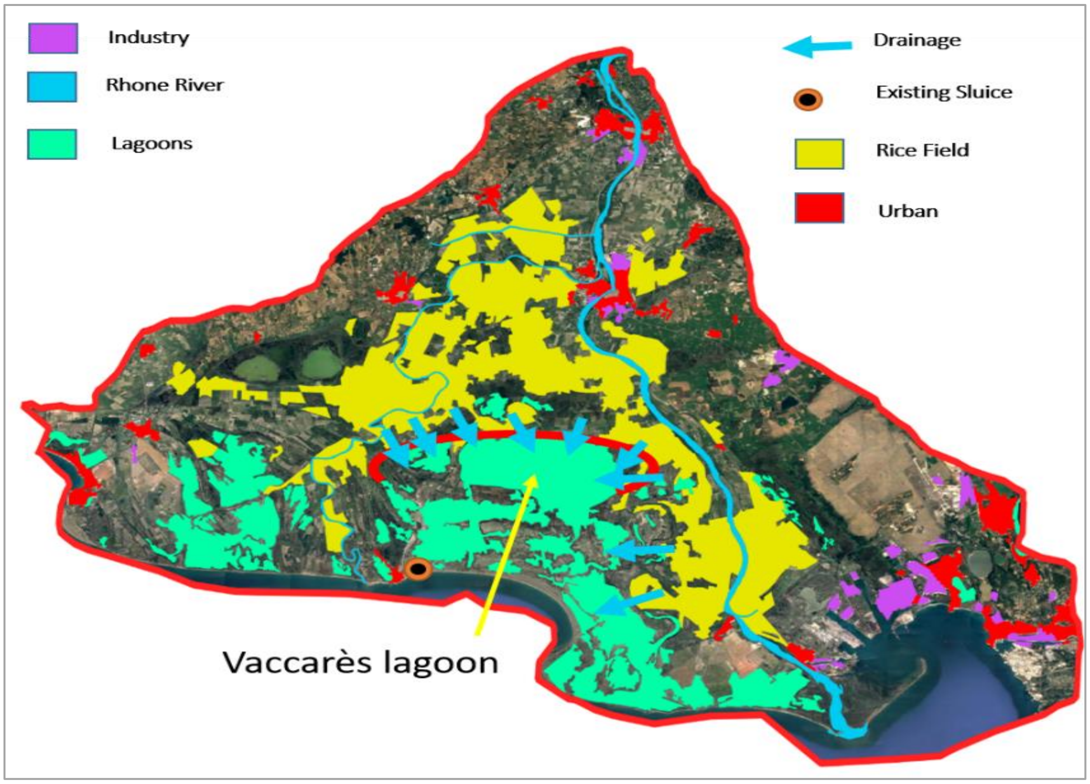

Figure 20. Location of irrigation drainage and location of existing sluice

This system will help the lagoon have a relatively stable salinity and lower pollution concentration to improve the ecological quality of the area and ensure a healthy and complete ecological chain. The location of the new system can be seen in figure 10.1.

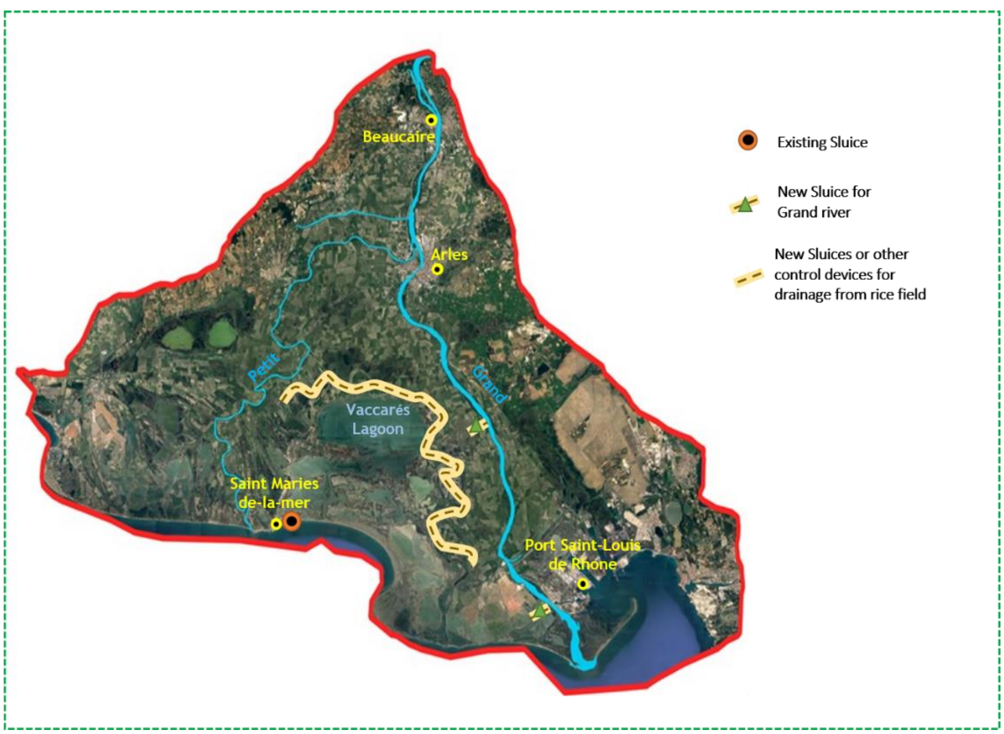

Figure 10.1. Salinity control system

- **<u>Maintain the salinity and nitrate concentration of *Vaccarès* lagoon by operating control devices</u>**

As a way of coping with climate change, the above-mentioned system, serves as an effective measure in doing so. For better understanding on the functionality of this measure, the following scenarios are described.

- When rainfall decreases and the temperature rises, the salinity of the lagoon will greatly increase, most likely to be higher than 30g/l due to high evaporation. At this time, water is pumped from the Rhone River to reduce the salinity of the lagoon through this control system. Alternatively, the lagoon can be replenished by groundwater in advance in winter to ensure that the salinity of the lagoon is below 30g/l in summer.
- During floods, this area is also a good flood discharge area. The system quickly drains the water from the Rhône River into the lagoon and then into the sea, as shown in figure 10.2.
- Although the region adopts organic agriculture and rarely uses chemicals such as pesticides and fertilizers, the potential risks of eutrophication are allowed under climate change. Therefore, when nitrate higher than 50mg/l is detected, the system draws water from the river or groundwater to dilute the nitrate concentration.

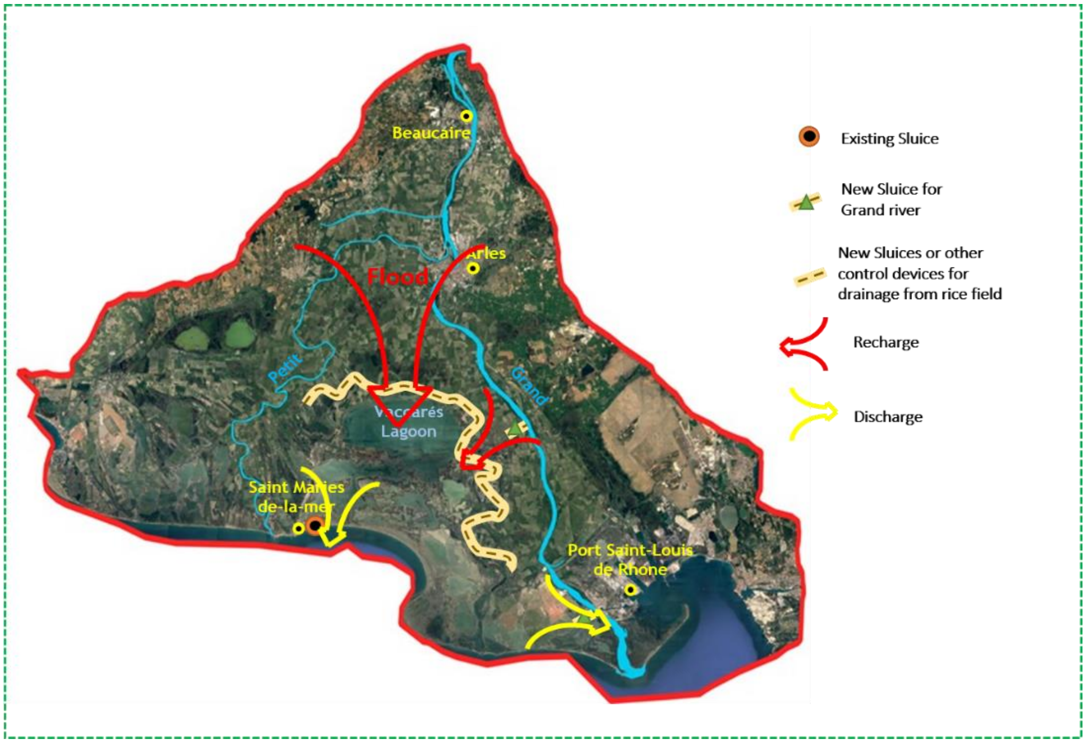

Figure 10.2. The control system during flooding

- **<u>Review and improvement of monitoring network around Vaccarès Lagoon (both water quality and quantity) (Must have)</u>**

Review the water quality and quantity-monitoring network of the area to check whether the obtained water balance and water quality of wetland and lagoon are within the acceptable range. These measures focus on checking whether there are monitoring blank areas and unreasonable monitoring sites, and improve these problems.

- **<u>Real-time monitoring of drainage from rice filed and salinity in the lagoon</u>**

Under climate change, the lagoon's salinity fluctuates more and more drastically. Due to the decrease in rainfall in the future, the reduction of the drainage from rice field and the frequent occurrence of extreme floods. Therefore, this method can monitor incoming water and salinity in real-time to ensure that the previously mentioned control system operates in time to maintain salinity and the fragile ecological balance of the area.

- **<u>Institute policy to gazette the current wetland area</u>**

Between 1985 and 2000, a wetland agricultural expansion area were partially converted wetlands into agricultural production fields (mainly rice). At the same time, the surface area of Camargue's reed beds decreased slightly during the period 1975-2006. Fortunately, since 2000, natural wetlands have been partially restored. The local government and UNESCO implemented programs such as the Man and the Biosphere (MAB) program, which reduces the encroachment of wetland by other land uses.

This measure will ensure that the wetland maintains its current area and reduce further encroachment on the wetlands by other land uses. In addition, it plays a vital role in the habitat and protection of flamingos and other creatures.

- **<u>Adjust the area of wetland under the climate change</u>**

This measure will also be adjusted and changed with climate change. When urban and agricultural water is insufficient due to climate change, the wetland area and ecological water consumption can be reduced appropriately to ensure other water use.

Table 8. Strategy and measures for Environment

Strategy	Objective Type	Objective	No.	Measures	Threshold
The conservation of biodiversity and ecological quality in Rhone delta under climate change by eco-friendly artificial intervention	Must have	Maintain a stable salinity in the Vaccarés lagoons to Improve the biodiversity and ecological quality	1	Construction of control devices of water quantity around the lagoon	Salinity (5 g/l< CL > 30 g/l) Nitrate(CL < 50mg/l)
			2	Review and improvement of monitoring network around the lagoon (both water quality and quantity)	
	Should have	Maintain the area of wetland during next 30 years.	1	Institute policy to gazette the current wetland area and adjust the area under the climate change	the area of wetland of 50,000 ha

9.4.2 <u>Prioritization of measures</u>

The priority of these measures is mainly determined based on the degree of adaptation of the measures to climate change and whether such measures already exist. Thus, it is most important to construct a water volume and salinity control system. The second is to improve the accuracy of the monitoring network to ensure that there is an accurate result for decision-making under future climate changes.

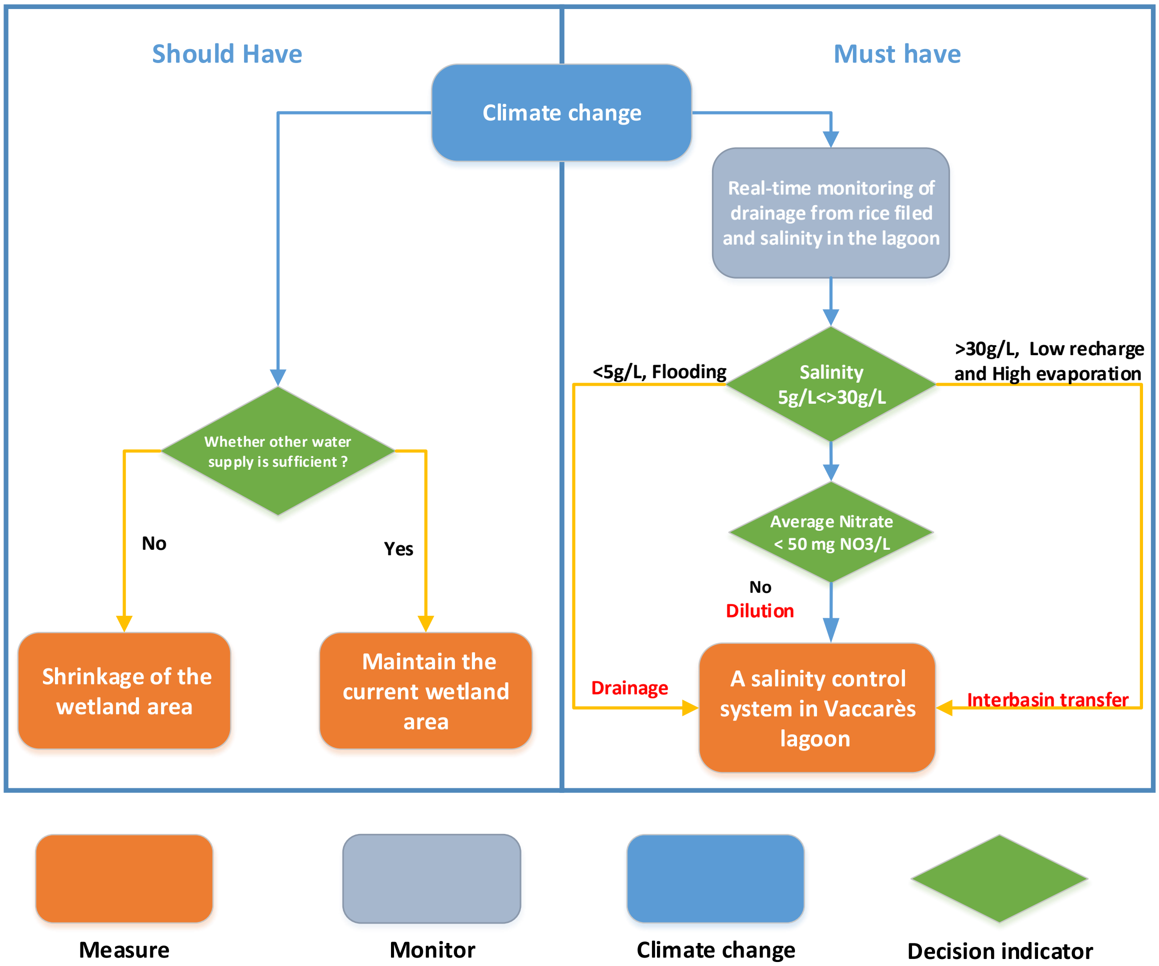

Figure 10.3. Response system for climate change

9.4.3 Response system for climate change

The response system uses the linkage response of the above measures to weaken the impact of climate change (decreased incoming water and flood inundation) on the ecological environment and the salinity of the lagoon, as shown in the diagram.

The flow chart (figure 10.3) is divided into two parts that should have and must have. In must have, after climate change, the monitoring system first monitors the changes in the salinity of the Vaccarès Lagoon and judges whether salinity adjustment is necessary. In addition, if the salinity of the lagoon is higher than 30g/l caused by low rainfall and high evaporation, the salinity control system needs to divert water from the river to adjust the salinity. If the salinity of the lagoon is lower than 5g/l due to flooding, the salinity control system needs to open sluices to drainage to ensure ecological balance. Again, when eutrophication (>50mg NO3/L) occurs under climate change, this is also regulated by the salinity control system, which dilutes the nitrate concentration by pumping river water or groundwater to replenish the lagoon.

In should have, the system assesses whether the supply of drinking water and other water supplies are in short supply after climate change. If there is a shortage, the wetland area will be reduced to reduce ecological water consumption to meet other water supplies. On the contrary, the wetland area will maintain the status quo.

9.4.4 Additional Investigations for Environment and Ecosystem

Proposed Measure:

- Construction of control devices of water quantity around the lagoon
- Review and improvement of monitoring network around the lagoon (both water quality and quantity)

Task:

- Review the distribution of monitoring stations and optimize the distribution
- Establish a hydraulic model with water quality analyse in 2d to quantify salinity, recharge and discharge for lagoons
- Carry out salt balance and water balance in lagoons
- Construct a salinity control system in lagoons

Requirements

- Focus on checking the distribution of stations used to monitor the drainage network in rice field to ensure the accuracy of inflow data
- Modelling based on historical rainfall and runoff data considering the climate change.
-
- Use hydraulic models to compare changes in lagoon water balance and salinity before and after the salinity control system built to evaluate the feasibility of the scenarios

Deliverables

- An optimized monitoring network map
- A Model Setup with boundary conditions for calculating the water demand in salinity variation in the lagoon taking into account the climate change A salinity variation map with showing inflow and outflow in lagoons
- A salinity control system with several new sluices or control devices for drainage from rice fields or river
- The extent of change in salinity due to various scenarios

9.5 Urban Water Management

The strategy focuses on the management of the storm water to minimize urban flooding risk in the future by introducing grey-green infrastructures. The opportunity map (*figure 11*) shows the areas in which green infrastructures or other adaptive measures that will help the location cope with climate change, can be introduced. To make the limited area more beneficial, it is necessary to exploit the deserted areas and also improve the functionality of the recreational areas, for example, convert the existing playground into a pool that can store rainwater in the rainy season. In the areas indicated with blue colour, can serve as areas where adaptive measures can be implemented in the future. Due to the uncertainty of climate change, there is a great need to evaluate the entire city consistently. This is because the development of a new plan may be necessary for future climate change.

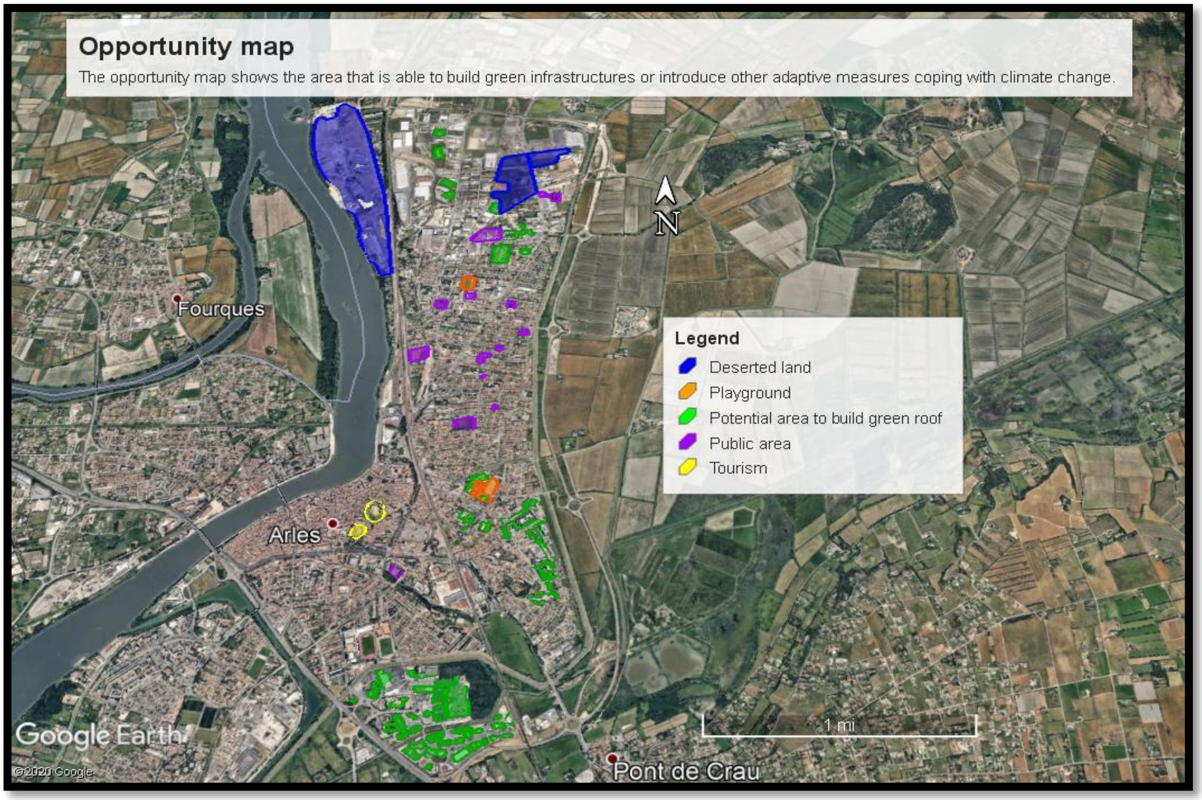

Figure 11. Opportunity map in Arles

- **<u>Build detention ponds using public areas such as the existing playground in Arles to store rainwater in the rainy sea.</u>**

The feasible locations for the detention ponds are presented on the opportunity map with purple polygon and the depth of detention pond is around 30 cm. Detention ponds (*figure 11.1*) are usually dry, except during or after rain. Their purpose is to slow down the flow of water and keep it for a short period, such as 24 hours. Urban areas rely on these structures to reduce storm-related peak runoff, thereby reducing flood damage. Although the size and shape of detention ponds may vary, they can sink rainfall particles and reduce peak discharge. All ponds should be designed separately from the local groundwater to prevent the transfer of dissolved pollutants from the surface water to the groundwater source.

Figure 11.1. Detention pond

- **<u>Introduce green roofs on flat resident buildings, and introduce rainwater harvesting system on pointed roof</u>**

In Arles, the population is very dense, and the city will be in danger when there is water shortage or urban flooding. On the one hand, in order to reduce the risk of flooding and alleviate water shortages, the concept of green roofs is introduced in dense housing areas with slight slopes (*figure 11.2*). On the other hand, a rainwater collection system can be introduced in the community, that is, rainwater is temporarily collected for irrigation of surrounding vegetation (figure *11.3*).

Figure 11.2. Potential building to introduce green roofs

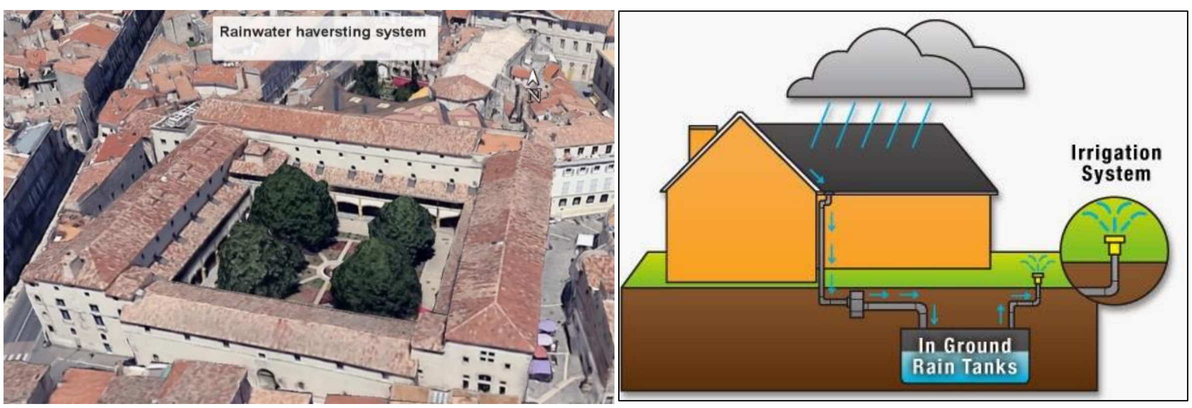

Figure 11.3. Potential areas to introduce rainwater-harvesting system

- **<u>Increase the permeability of pavements and roads in crowded resident</u>**

In the densely populated city center of Arles, many roads have low permeability, as shown in figure 12.4, and this causes rainwater to penetrate the soil slowly. Population growth, urbanization and rising temperatures will increase the risk of urban floods. Urban floods can be controlled by increasing the porosity of the road surface to reduce surface runoff. However, green infrastructures have a certain life cycle, and if too many flood response methods are introduced too early, it will bring about a waste of funds. Therefore, the method of increasing the porosity of the pavement could be an adaptive method in the future. ***This measure can be implemented few years after the implementation of the previous measures suggested. They should be implemented according to future rainfall events, building conditions, location of roads and sidewalks with high permeability.***

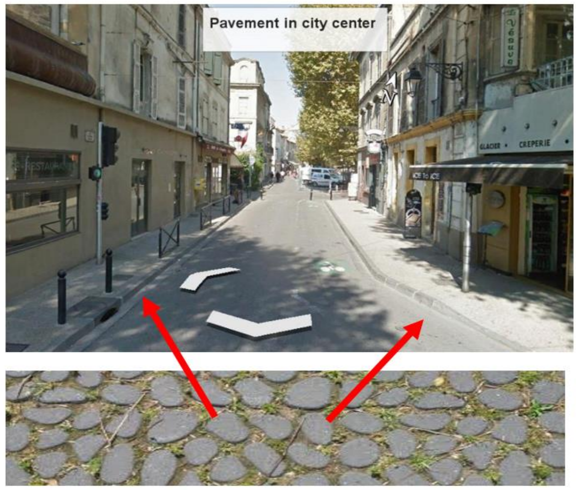

Figure 11.4. Walk sides of roads in Arles now (above) and expected (bottom)

- **Increase the resilience of community by involving the public in the decision-making process**

Community resilience is the ability to maintain the basic functions of the community under severe conditions and the ability to recover quickly after a disaster. Since it is a process of self-adaptation and self-recovery in a community after a crisis, it almost depends on human behavior. This can play an important role in the process of adapting to climate change in future cities. The decision-making process affects the resilience of the community because it depends on the participation of residents. The higher the participation of the people or people's representatives, the more they understand the needs of citizens, the higher the satisfaction of citizens, the more capable they are to motivate them to participate in the problem-solving process. Frequent meetings can be held with the people on matters regarding resilience of the community.

9.5.1 Additional Investigations for Urban Water Management

From the perspective of urban water management, the flowing additional investigation must be performed for the suggested measures;

Measure 1: Build detention ponds in public areas such as the existing playground in Arles to store rainwater when rainy

Tasks:

- Rainfall runoff assessment of 10-year rainfall of the urban area.
- Assess the infiltration rate of the detention pond to
- Calculate the retention time and maximum storage volume.

Requirements:

- Account for the impact of the whole detention ponds on the drainage system.
- Account for storm water discharge scenarios based on different rainfall events.
- Consider the impact of topography on the detention pond.

Deliverables:

- The volume of the whole detention ponds on decreasing flood
- The recharge amount of detention ponds to underground aquifer

Measure 2: Introduce green roofs on flat resident buildings and introduce rainwater-harvesting system on pointed roof

Tasks:

- Determination of types of plants suitable for green roofing
- Assess the location that is suitable for building rainwater harvesting system.
- Assess the volume of harvested rainwater.
- Assessment of total expected volume of rain water which can be harnessed from pointed roof buildings of the city per year

Requirements:

- Considering the weather condition of Arles city
- Low weight plants
- Minimal capital cost
- Minimal maintenance requirements

Deliverables:

- List of plants and type of green roofs
- Respective detailed cost for green roofs and rainwater harvesting system
- The volume of expected rainwater which can be harnessed

9.6 Coastal and Port Development

In order to reduce the coastal vulnerability in line with the project approach, which focuses on developing a climate resilient delta through the implementation of proactive adaptation measures, the coastal department developed a strategy that consists of **reducing coastal retreat risk by increasing resilience towards sea level rise.** Therefore, the main target points of the coast are zones that present higher proneness to erosion which are Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud *(see figure 5*). Moreover, the three locations are of great importance at the Rhône Delta as they comprise of economic and touristic (salt industries and farms as well as the cities, resorts and the artificial marina of Port Camargue) activities, as well as ecological (natural landscapes, wetlands, water birds) locations, which must be preserved along the years *(figure 12).* Hence, the retreat of the coastline poses a threat to the coastal development as it reduces the beach width. Another point of interest is the Gulf of Beauduc, which is currently facing dunes destruction caused by unregulated camping. Amongst the identified objectives for coastal management, only two (2) were taken as the most important as they relate directly with our approach: the reinforcement of the coastal protection at the erodible points and reduction of dunes destruction through illegal camping.

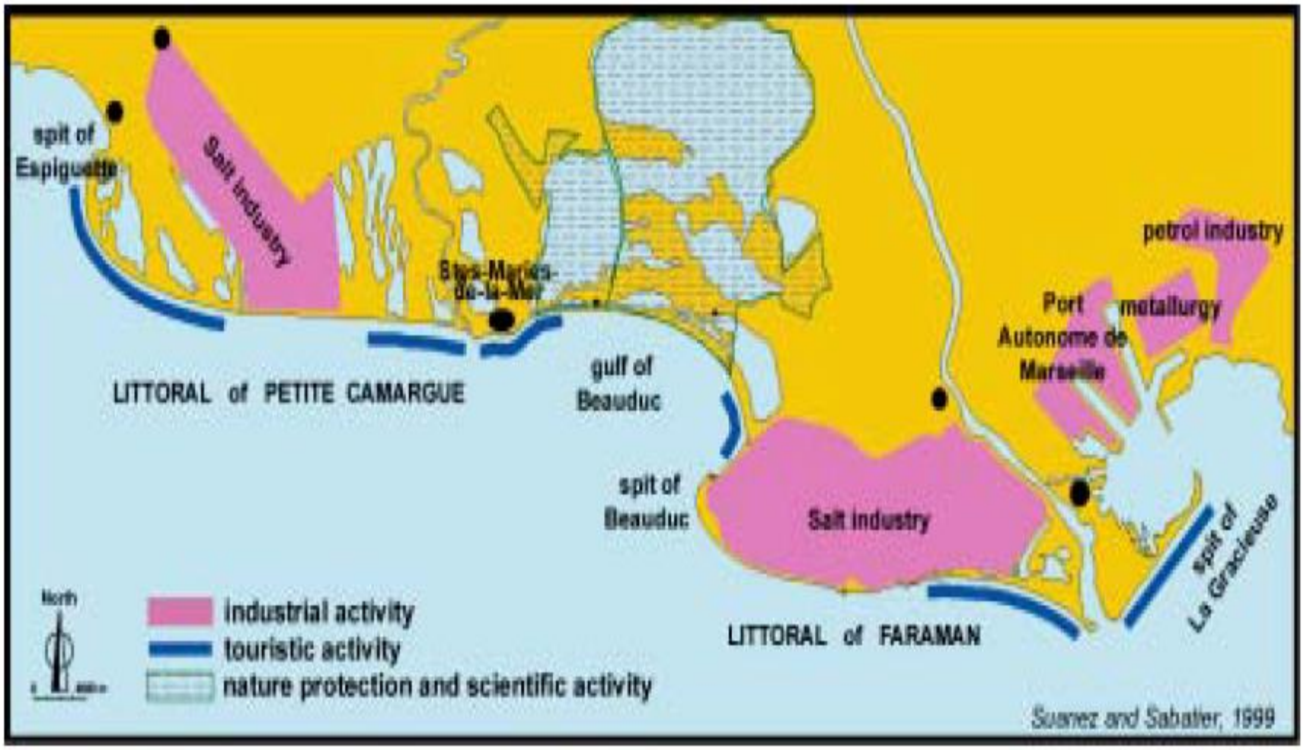

Figure** 12**: Spatial distribution of activities on the Rhone delta

- **<u>Must Have objective - Reinforce the coastal protection at the main coastal areas</u>**

These locations present existing coastal protection measures such as groynes, dykes, breakwaters and seawalls. Beach nourishment implementation was considered as the most practical adaptive solution for the coastal protection reinforcement as it is economically feasible and can be done continuously along the years without radically changing the existing coastal protection. Considering the future holds many uncertainties, a preliminary estimation of the coastal vulnerability was made using Geographical Information System (GIS) tools. The target sea level rise of 0.25 meters and a testing highest spring tide of the region (of year 2020) of about 0.56 meters were considered. A digital elevation model (DEM) was used to estimate the extent to which the coast will be inundated. The summation of the sea level rise and high tide were subtracted from the elevation data covering the study areas with particular focus on the coastal areas. This was done using the raster calculation tool in ArcGIS (ArcMap). The results showed that if no extra protection measures are taken into consideration, the water level will increase and thus, the coastline will recede and certain inland areas of Petite Camargue coast, the city of Saintes-Maries-de-la-Mer and Paraman coast will be covered by water. The areas vulnerable and non-vulnerable along the coast are indicated in red and green colours respectively *(See figures 12.1,12.2 and 12.3)*

It is of utmost importance to note that this preliminary assessment is limited as it can only show the coastal points covered by water but cannot quantify the water depth and water velocities of the flooded areas. Therefore, beach nourishment will increase the beach width along the coast, increase sediment volume reducing the probabilities of erosion and flooding as well as enhancing the resilience of the sensitive points in relation to the sea level rise effects. The table 8 illustrates the measures regarding the reinforcement of the coastal protection.

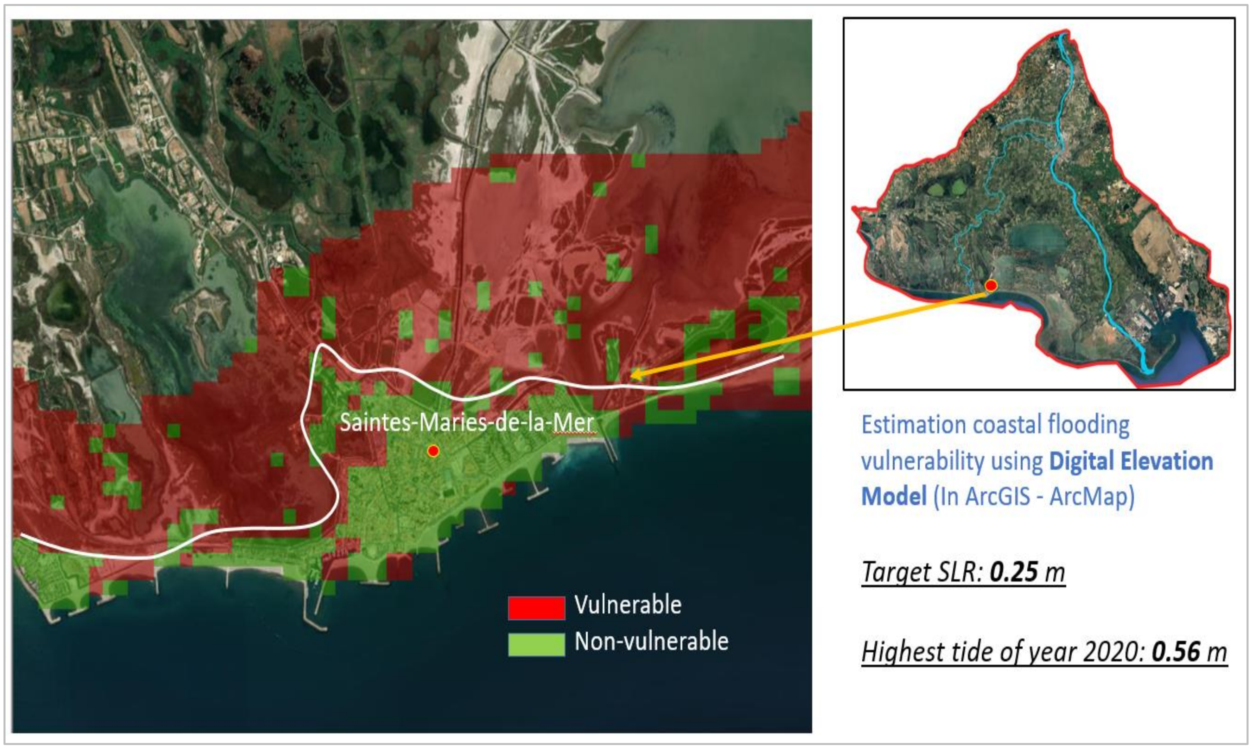

Figure 12.1: Coastal flooding vulnerability at Saintes-Maries-de-la-Mer city (below the white line zoning)

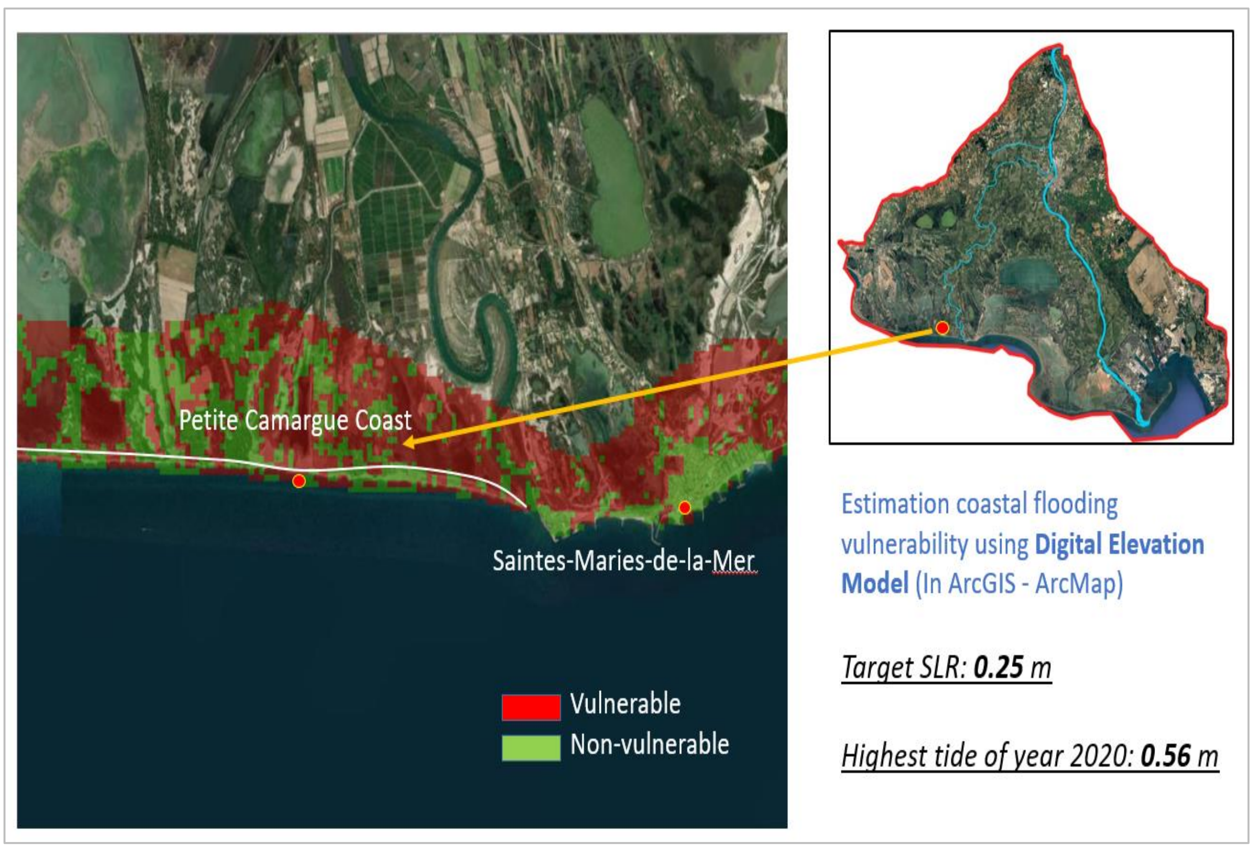

Figure 12.2: Coastal flooding vulnerability at Petite Camargue Coast (below the white line zoning)

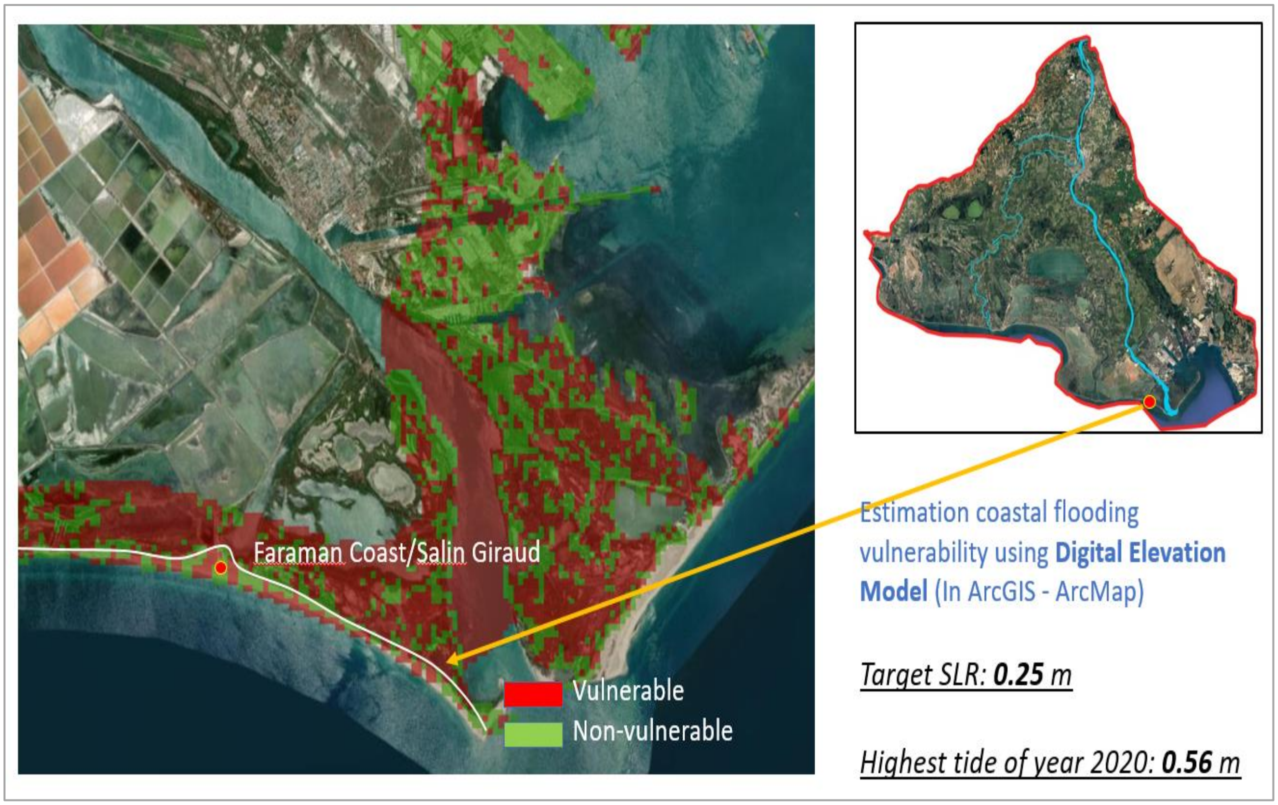

Figure 12.3: Coastal flooding vulnerability at Petite Camargue Coast (below the white line zoning)

- **Should Have Objective - Reduce the destruction of the dunes**

Furthermore, the preservation of dunes is very important as they also provide a defence system to the coast. Despite of the great effort of the regional authorities in recovering the dunes, 400 semi-permanent dwellings have been built illegally at the dunes area of Gulf of Beauduc, which contributes for the degradation of the dunes system. Hence, it is important that regulating laws are implemented to avoid illegal camping and the existing semi-permanent dwellings will only be allowed to be installed during the summer season. The table 9 illustrates the measures regarding the issue of the degradation of dunes.

Table 9: Objectives and applicable measures for Coastal Management

Priority	Objectives	Measures
Must Have	Reinforce the coastal protection at the main coastal areas (Petite Camargue, the beaches of Saintes-Maries-de-la-Mer and the coast of Faraman/Salin de Giraud) so they resist the effects of sea level rise	• Beach Nourishment which will endure a SLR=0.25m
Should Have	Reduce the destruction of the dunes system through unregulated camping by 80% in 5 years in Gulf of Beauduc	• Implement restriction laws for beach camping in the Gulf of Beauduc including heavy fines • Restriction for temporary camping, restaurants and wooden houses to only occur during summer season.

9.6.1 Additional Investigations for Coastal Development

The required additional investigation are given as follows;

Tasks:

- Perform 2D modelling simulation to estimate a more realistic extent of flooding at Petite Camargue, Saintes-Maries-de-la-Mer and at the Faraman Coast considering not only the sea level rise (a set of different SLR values) and peak tides but also extreme events: (1) without taking any measure into account and (2) implementing beach nourishment at the target areas.
- Assess the maximum SLR to which beach nourishment is applicable to protect the coast.
- Determine the initial necessary volume of sand for beach nourishment.
- Monitoring program (during off-season camping) of the dunes growth due to nourishment and reduction due to wind.

Requirements

The requirements are

- Wave climate data of the area
- Bathymetry and wind data

Deliverables

- Volume of erosion that satisfies the condition given
- Volume of necessary beach nourishment and evidence of its effectiveness

9.7 Land and Water Development

Agriculture is one of the most important activities of the Camargue and is hence recorded in the terms of reference as the major element of development that has occurred in the area for centuries. Further, it is also envisaged the agriculture will continue being one of the major drivers of the regional economy for many years to come. However, this sector, suffers from the challenge of low yields, especially in rice production, which is attributed to a number of causes, including soil salinity, mono cropping, poor irrigation practices and damage by flamingos. Further, this sector is also responsible for the contamination of the Rhone River waters and that of the Vaccares lagoon.

Land use and agriculture department, after considering the challenges above, and in line with our firm's approach**; to develop a climate resilient delta through implementation of proactive adaptation measures**, has proposed a strategy; **adaptive agricultural development using nature based solutions to address yield loss and water contamination challenges**. Going by this strategy, the current problems and those that might arise in a near future will be solved mostly by using nature based solutions and enhancement of some current measures. The proposed measures in response to our objectives are given in the table below and further elaborated in the chapters that follow below. Further, measures were prioritized according to the expected impact that they will have when implemented. Therefore, the measures selected are expected to have significant impact in addition to what is already being done on the ground. In addition, some of the measures listed but not prioritized could already be in use and only require regulation enforcement or consistence to continue working well.

Table 10: Land use and Agricultures – Strategy and Measures

Strategy	Objectives	Measures
Adaptive agricultural development using nature based solutions to address yield loss and water contamination challenges <u>Part one (1):</u> <u>First priority measures</u>	1. Maintain soil salinity levels within acceptable limits (EC_e 0 – 4 dS/m).	Improve the Drainage system
	2. Reduce agricultural water contamination levels of the Vaccares Lagoon and Rhone River from the current level (1.6 – 2.7µg/L) to meet European Union permissible limits (0.1 – 0.5µg/L) in 5 years.	Use nature based solutions: • Introduce Ducks for weed control. • Switch to organic farming
	3. Reduce the crop damage by flamingos by 50% in 5 years.	• Planting Hedges
Adaptive agricultural development using nature based solutions to address yield and water contamination challenges <u>Part two (2):</u> <u>Second priority measures</u>	1. Maintain soil salinity levels within acceptable limits (EC_e 0 – 4 dS/m)	• Monitor and control irrigation practices through precision irrigation. • Regular leaching of soils
	2. Reduce agricultural water contamination levels of the Vaccares Lagoon and Rhone River from the current level (1.6 – 2.7µg/L) to meet European Union permissible limits (0.1 – 0.5µg/L) in 5 years.	• Crop rotation (rice with wheat, oil crops, legumes, vegetables) • Inter-cropping (rice with chillies, flowers) • Strip cropping with grass water-way to filter agrochemicals
	3. Reduce the crop damage by flamingos by 50% in 5 years.	Use scaring methods: flashing lights, handheld halogen, flood lights, flares etc.

<u>Maintain soil salinity levels within acceptable limits</u>

Many crops including rice are negatively affected with increasing soil salinity such that, yields reduce significantly at high soil salinity levels. According to the terms of reference (TOR) given, the agricultural land in the Camargue is dominated by salty soils with heterogeneous distributions depending on the geologic origin of the Rhone Delta soils. High soil salinity is one of the major factors that has been observed (Gay et al., 2010) as the major hindrance to growing of other crops and to increased rice productivity in the Camargue. The tolerance levels for rice are quite low, ranging only from zero (0) to about three (3) dS/m.

Soil salinity levels the Camargue fields will be controlled and maintained within acceptable levels that accommodate many crops including rice, by enhancing measures that are or could be currently been used, for instance, leaching of soils, correct irrigation and drainage practices , and additional measures like improvement or reconstruction of the current drainage system. Poor irrigation systems contributes to high soil salinity levels because it contributes to raising of the ground watertable, which usually brings salts as saline groundwater comes into the root zone. Control of salinity in the Camargue fields will ensure not only higher yields of rice but also other crops, which we propose as rotation or diversification crops with rice, which as consultants we feel is the future of agriculture in the region. Regular leaching of soils, monitored and controlled irrigation practices and reconstruction of the drainage system if required, will help to maintain salinity within our target acceptable limits (EC_e 0-4 dS/m).

Further, we are told in the terms of reference provided that, though systematic studies have not been conducted to assess the main causes of low rice yields in the Camargue, it is understood the high salinity levels is root cause of the problem. It is also not very clear in the terms of reference or literature, what the current levels of salinity are in the soil. Therefore, the agriculture department, has decided to outsource another firm (Wageningen University) to conduct an investigation in order to ascertain the exact current soil salinity levels. The university is also tasked to assess the how the current measures are performing and the adequacy levels of the current drainage system. If required, the external consultants will also propose designs of a new or rehabilitated system. The details of this task(s) given to the private consultant are explained in detail in the separate document (proposal) to the firm.

Control damage by flamingos

Flamingos visit the paddies mostly between sunset and sunset, soon after farmers finish planting their rice in April, during germination days and will only stop visiting fields in June (Tourenq, Aulagnier, et al., 2001). Other researchers (Curcó, Vidal, & Piccardo, 2009) have added on the subject that, during the first phase of rice growth (April-June), the Greater Flamingos can cause damage to the rice fields, sometimes causing losses of production or additional costs of replanting. With their webbed feet, they trample the grain therefore preventing germination (Mathevet et al., 2002). In the Camargue, flamingo are reported to cause as much as 1000 ha to be re-sown annually The flamingos visit fields in small groups of less than 50 individuals but it is reported (André & Johnson, 1981) that flocks of up to 200 individuals have also been observed.

Damage by flamingos will be controlled by planting of hedges in the rice field portions boundaries. This will be the main strategy and will have a major impact if it is implemented on a large scale, covering all the Camague rice fields. It has been shown (Tourenq, Aulagnier, et al., 2001) that reduced surface area of paddies, distance from natural marshes and of wooded margins act to reduce flamingos visits. In addition, Tourenq et al., 2001 affirms that Incursions of flamingos could be prevented from surrounding rice fields with hedgerows. Tourenq et al., 2001, further suggested that hedgerows are also likely to enhance local biodiversity in agro-ecosystems and offer agronomic advantages as physical buffer and against wind mechanic and thermal stress. And on the contrary, larger fields are said to be preferred by flamingos because they allow the birds to detect predators at a greater distances and that the absence of the hedges increases all-round visibility, reducing the risk of surprise attacks from predators and facilitates take off (Barnard & Stephens, 1983). Restoration of hedges could limit flamingo incursions in the more threatened rice fields, and this is actually one of the prescribed agro-environment schemes promoted by the European community (Ovenden, Swash, & Smallshire, 1998).

To discourage visits in the night by flamingos, park organizes spring scaring campaigns using flashing lights, hand-held halogen floodlights, and flares in the affected areas (Curcó et al., 2009). These scaring methods will therefore continue to be promoted and adopted by farmers for control the flamingos as an adaptive structure, which they also mitigate the conflict between farmers and conservation objectives.

Control contamination of water in Vaccares Lagoon and Rhone River from Agrochemicals using Nature based solutions.

- **Organic Farming (including crop rotation)**

One of the effective ways in which water contamination by Agro-chemicals is controlled is by switching the farming practices in the Camargue to organic farming. To provide the definition of an approach such as organic farming, just like the concept of sustainable framing is always difficult (Rigby & Cáceres, 2001). However, an authoritative definition is given (Lampkin, 1994), which states that, ‘ the aim of organic farming is to create integrated, humane, environmentally and economically sustainable production systems, which maximize reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable levels of crop, livestock and human nutrition, protection from pests and disease, and an appropriate return to human and other resources. Organic farming entails among things nitrogen self-sufficiency through legumes and biological nitrogen fixation, recycling organic materials using crop residues and livestock manures. Our target in controlling the current water contamination in the lagoon (which is on average 1.6 – 2.7µg/L) is to reduce it to acceptable levels (0.1 to 0.5µg/L), according to European Union standards (Council Directive 98/83/EC, EU 1998). Organic farming does not employ the use of chemical fertilizers or agro-chemicals, which are reported in the terms of reference as the major source of water contamination in the Vaccares lagoon and Rhone River. On weed control, disease and pest control, this is achieved using crop rotations, natural predators, organic manuring, resistant varieties, and sometimes minimal biological and chemical intervention.

The above mentioned practices (including crop rotation or inter-cropping) for fertilization and weed or pests control, as employed in organic farming, when implemented in the Camargue, will adequately address the problem of water contamination that has been observed in both the Vaccares Lagoon and Rhone River. Crop rotation will also be incorporated in the management of agro-chemicals. Crop rotation and/or crop diversification involves growing different crops on the same piece land but at different times, which helps control pests and diseases and adds nutrients in the soil, entailing less use of chemicals and fertilizers, which is good for the environment. Inter-cropping is growing different crops in the same portion or field, side by side. This method also helps to control movement of pests around the field as different pests attack different crops, while other crops (e.g. Chilies) completely repel pests, which is good for pest control.

Though it is mentioned in the terms of reference that Organic farming is being already practiced in the Camargue, the levels are very low (2800 ha, representing 3% of surface in rice), which cannot have a significant effect on reducing the levels of water contamination. Therefore, to yield meaningful reduction in agrochemicals in the lagoon and Rhone River, the government need to provide incentives and compel farmers through strong legislation for more land in rice fields to be brought under organic farming. Moreover, organic farming also comes with a benefit of increased market price of organic rice (Rigby & Cáceres, 2001), which can address the challenge of low or fluctuating prices which farmers are suffering from in the Camargue. Crop diversification (rotation) is also the answer for future uncertainties due to climate change, as it also entails growing other crops other rice, which demand less water, useful in case of drought years and those fetching good money to counteract the problem of low prices of rice.

- **Weed and Pest control using Ducks**

Ducks will be used to control weeds and pests in the rice fields. This will have a positive impact on our ambition to reduce agrochemicals use in the Camargue, in that instead of us spraying chemicals in the field, ducks will eat most of the weeds and pests and at the same time help fertilizing the soils by their droppings. The rice-duck integrated farming was created in Kyushu, Japan in 1991 and rapidly spread to other areas of the country due substantial economic and ecological benefits (Teng et al., 2016). Researchers (Teng et al., 2016) have also indicated that in Japan, the system has been further improved with time, whereby, three-week-gucks with a density of 225 per ha are put into the direct-seeded paddy fields, with rice seedlings growing for 20-25 days. This is a common nature-based solution, as reported (Men, Tinh, Preston, Ogle, & Lindberg, 1999) from the Mekong Delta that one strategy already known by many producers was the use ducklings to control pests and weeds. It is further reported in the same publication (Men et al., 1999) that local farmers in the Mekong Delta could easily raise and manage 500 local ducklings per hectare of growing rice to control pests and weeds. In South China, researchers (Li et al., 2019) conducted a similar experiment I which they reported that, seven days after transplanting the rice, ducklings were released into the combination treatment plots at a density of 375 duck individuals per hectare and the ducks were kept in the field until the heading stage. Further, information is provided (Lizhang, 2012) that, so far, the area of paddy rice fields in Southeast China, on which this system of integrated farming has been practiced is 700 and 3500 ha in Anhui and Jiangsu provinces, respectively.

The above examples, where this method has been used and its subsequent favourable results in the trials prove that indeed this a working solution. Therefore, this system will be implemented on a massive scale (covering an area around 7000 ha/year in succession) in the Camargue with the Duck density rate of 225 individuals/ha, in order to address the negative effects that come with agrochemicals use in fields,

10. FINAL MEASURES AND INTERLINKAGES

Upon the prioritization of the objectives, the strategies were conceived. The strategies cut across the six main fields of; *Flood Risk Management, Water Resources and Environment, River Engineering, Land and Water Development, Urban Water Management as well as Coastal and Port Development*. These strategies were determined based on the prioritized objectives and with this, the measures were defined accordingly as shown in Table 11 below. Figure shows the interlinkages across various fields and the proposed measures as well as their interdependency. It also shows the five main interest categories of the ICARM plan: Flood protection, Water resources replenishment and maintenance, Institutional reforms, Ecosystem preservation as well as the Maintenance of the economic activities.

For instance, making a diversion channel directly affects on flood protection aspect and indirectly maintaining the economic activities within the potentially flood risked areas like Arles city. Furthermore, the flood waters are being used to replenish the water required for the Managed Aquifer Recharge measure, as a form of interdependency response to climate change impacts. Every measure considered has an impact in the different strategies and must be implemented considering every single impact on other systems, i.e., it may impact positively to one system and affect negatively the other.

Table 11: Final Measures under the Plan

FIELD	**PROPOSED MEASURES**
Agriculture	Improve drainage system
	Planting of Hedges for flamingos control
	Organic farming to control agrochemicals water contamination
	Introduce Ducks for weed and pests control
Sustainable Urban Water Management	Build detention ponds
	Introduce green roofs and a rainwater harvesting system
	Make the public involved in the decision-making process
River Engineering	River bank and channel lining at some reaches
	Monitoring and dredging activities at Grand and Petit Rhone rivers
Flood Risk Management	Diversion Channel in West of Arles, to divert water from bottleneck
Coastal Management	Reinforce the coastal protection at the main coastal
	Reduce the destruction of the dunes system through unregulated camping
Water Resource and Environment	Construction of injection wells & artificial (MAR)
	Surface water treatment plants extension for population and economic sectors (industries + touristic activities).
	Institute data collection and monitoring arrangement
	Construction of a salinity control system around lagoon

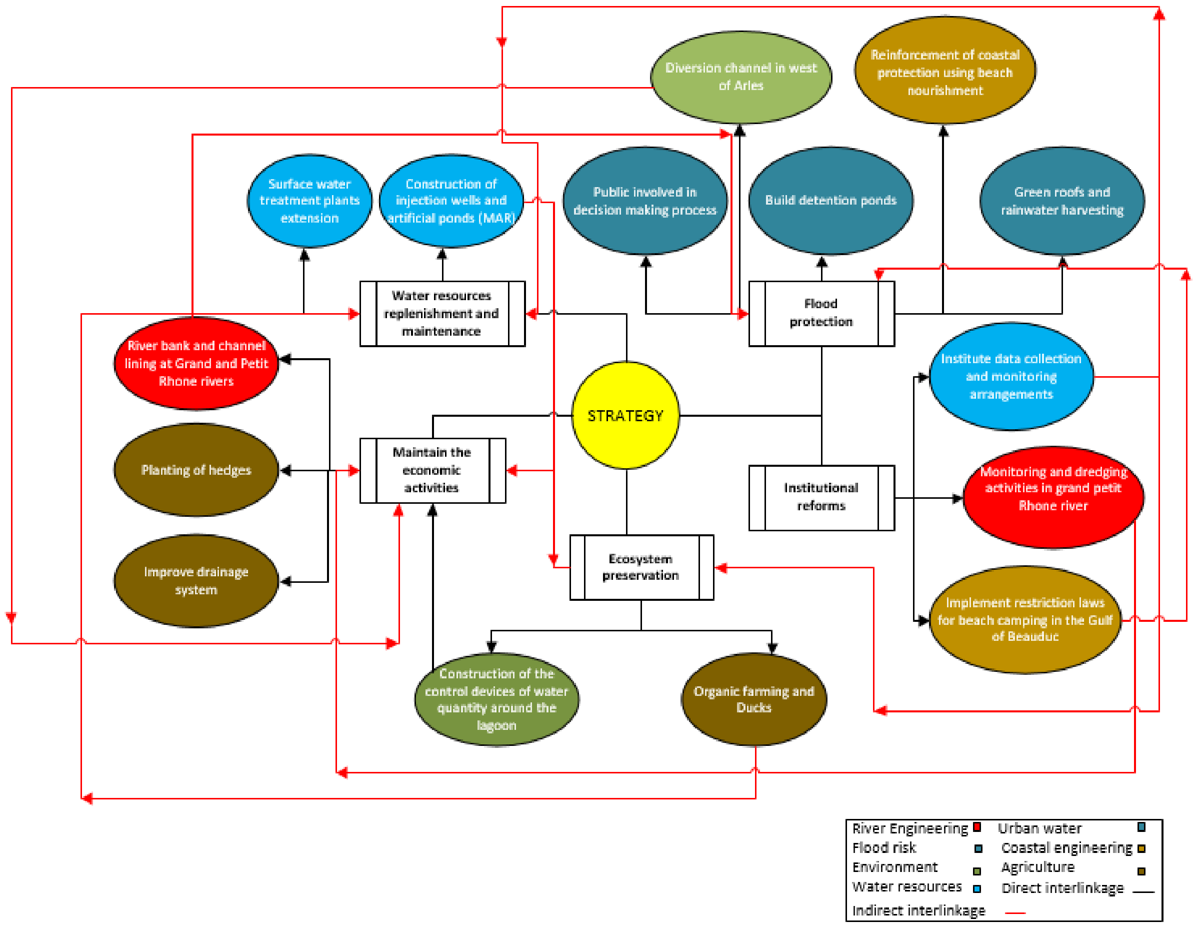

Figure 13 Interlinkage of Final Measures

11. IMPLEMENTATION ARRANGEMENTS

This ICARM plan has been prepared to withstand estimated climate change impacts within the next 20 – 30 years. As climate change is very uncertain, the plan provides some comfort that there is added protection on the existing measures to deal with potential impacts. A summary of the final measures analyzed for implementation and corresponding timelines per field has been provided in ***Table 12.0***. A year has been provided to undertake all the additional investigations that are required to assess the suitability of the measures proposed to achieve the objectives. The majority of the measures are envisaged to be implemented within 5 years while others require regular implementation (such as monitoring activities).

11.1 Legal Considerations

The ICARM has taken into account the relevant policies applicable to the study area. For instance, the European Framework Directives' 2015 target of ensuring natural waters maintain good ecological status and the requirements for river levels and dam releases to support environmental flows are considered. Similarly, the European Habitats Directive for the protection and maintenance of natural habitats and wild species were adapted for the ICARM. Other policies considered include; the European's Common Agricultural Policy (CAP) and the National Transport Policy, with respects to requirements for agricultural production, and navigability, respectively. However, it is worthy to note that a comprehensive legal and institutional analysis was not undertaken in the preparation of this plan.

11.2 Stakeholder Participation

The potential stakeholders involved have also been listed in Table 12. for each measure. These will either be responsible for implementing the measure, or will need to participate, be informed or consulted throughout the implementation period. The Regional Council of the PACA will be in charge of overseeing the implementation of this ICARM plan. It is worthy to note that a stakeholder analysis is important to identify the extent to which measures will affect the different stakeholders. Activities for inclusion and participation of stakeholders can then be developed and implemented along with the measures under this plan. An initial stakeholder mapping analysis to further inform the stakeholder involvement activities has been done and is summarized in **Error! Reference source not found.**.

Table 12. Preliminary implementation plan

Field	Proposed measures	Stakeholders										Duration (Years)						
		Regional Council of the PACA	The Compagnie Nationale du Rhone (CNR)	SYMADREM	Natural Conservation Group	Environmental Protection Agency	Ministry of Agriculture	Inhabitants	Local Farmers Associations	Ministry of Tourism	Private Sectors and Consultants	1	2	3	4	5	6	> 6
Agriculture	Improve drainage system	o					●		o									
	Planting of Hedges for flamingos control	o			o				●									
	Organic farming to control agrochemicals water contamination	o			o	x	●		●									
	Introduce Ducks for weed and pests control	o			o	o	●		o									
Sustainable Urban Water Management	Build detention ponds	●			`	x		x		o								
	Introduce green roofs and a rainwater harvesting system	o			x	x	x	●			●							
	Make the public involved in the decision-making process	●			*	*		x			●							
River Engineering	River bank and channel lining at some reaches	o	●					x			●							
	Monitoring and dredging activities at Grand and Petit Rhone rivers	●	●					x		x								
Flood Risk Management	Diversion Channel in West of Arles, to divert water from bottleneck	o	o	●			*	*			●							
Coastal Management	Reinforce the coastal protection at the main coastal	o									●							
	Reduce the destruction of the dunes system through unregulated camping	●						x		x								
	Construction of injection wells & artificial (MAR)	●			x						●							

Water Resource and Environment	Surface water treatment plants extension for population and economic sectors (industries + touristic activities).	●	o				x	x		x								
	Institute data collection and monitoring arrangement	●																
	Construction of a salinity control system around lagoon	o			x	x				x	●							

●	**Responsible**	Main stakeholder responsible for this activity but will involve other stakeholders in the decision making process and the implementation of the measure.
o	**Co-operating Partner**	Stakeholder is involved in the measure but does not have the ultimate responsibility; he will be consulted and his opinion will be seriously taken into account by the main partner responsible; he might also take care of part of the implementation
x	**Consulted Partner**	Stakeholder is not responsible for the decision or the measure but will be affected by the measure; the main stakeholder responsible will consult him before the decision is taken or before the measure is implemented.

Implementation

Additional investigations

11.3 <u>Other Considerations</u>

As a number of measures still require additional investigations to judge their appropriateness, an initial estimation of a budget for the plan was not undertaken. However, care was taken to have as many cost effective measures as possible. Final costing shall be possible after the additional investigations are finalized. Furthermore, it is assumed that the PACA shall source the funding required to implement the measures.

It is worthy to note that this is the preparation of the implementation plan for the Rhone Delta. The process to realize the intended benefits still involves stakeholder participation, detailed feasibility studies and designs, actual implementation, monitoring and evaluation as proposed in Figure . As this is the planning phase, the plan is yet to be presented to stakeholders to outsource their opinions on the measures to be implemented in order to ensure overall plan success.

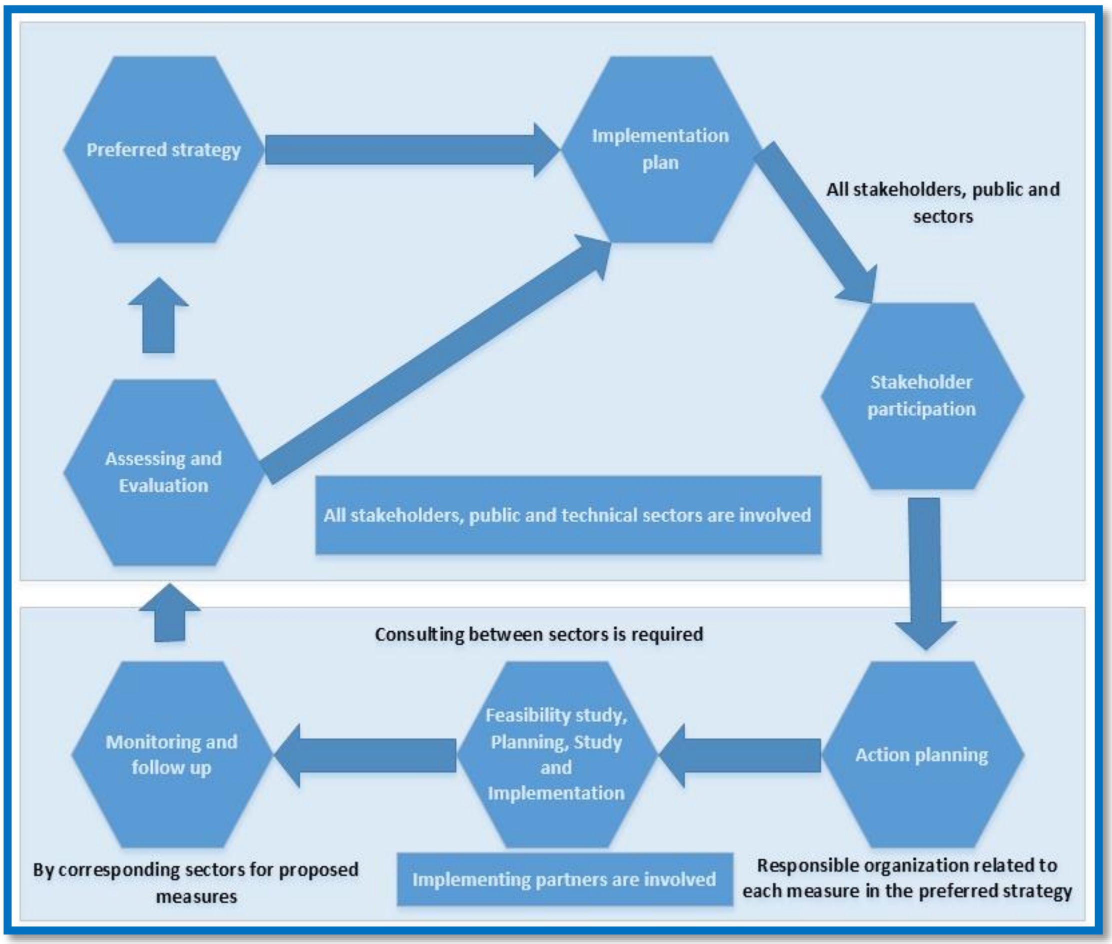

Figure 14 Proposed Planning and Implementation Cycle

12 CONCLUSIONS

The Integrated Coastal Area and River Basin Management (ICARM) Plan has been prepared with the approach to develop a climate resilient delta through the implementation of proactive adaptation measures. The plan covers the six main fields of *Flood Risk Management, Water Resources and Environment, River Engineering, Land and Water Development, Urban Water Management as well as Coastal and Port Development*.

Based on the problems, threats and opportunities identified in each field, a strategy was developed with corresponding measures that are in line with the overall approach. Additional investigations have been proposed to further study the suitability of some measures.

Integration between all the fields was a major focus throughout the preparation of the plan. Various interlinkages between problems, opportunities, threats, and proposed measures have been elaborated.

13 RECOMMENDATIONS

As the plan is geared towards protection against potential climate change impacts, it is suggested that the Delta institutes a climate change unit. The unit will be charged with monitoring climate change events and estimating their potential impacts on the economy and livelihoods of the Rhone Delta. The unit will also be charged with adequately advising the Regional Council of the PACA on the implementation of additional measures when necessary.

It is also recommended that after additional investigations are concluded to stipulate the final measures, comprehensive environmental impact assessments are undertaken. The presence of extensive wetlands in the Camargue area makes it even more crucial to assess impacts on the existing ecosystem. For protected areas, the final measures for implementation should have no adverse effect on the integrity of the sites, unless there are no alternatives and imperative reasons for overriding public interest and, as Europe's nature conservation policy requires.

Periodic assessment of residual impacts of measures during implementation by the responsible authorities is recommended. This should enable the development of plans to mitigate the identified residual impacts on different aspects of the Delta region arising from the measures.

It is imperative, that stakeholders are consulted on the specifics of this plan to secure their cooperation prior to the implementation of the final measures. As different stakeholders will be affected differently by various measures, their involvement in the finalization of the planning all through to the implementation will contribute greatly to overall success of the plan.

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