TOWARDS SUSTAINABLE WETLANDS IN RIVER DELTAS: THE CASE OF NEW ORLEANS

M.M. Hillen*, R.B. Treffers and W. Ravesteijn

Delft University of Technology
Faculty of Technology, Policy and Management
Department of Technology Dynamics & Sustainable Development
Jaffalaan 5, P.O. Box 5015, 2600 GA Delft, the Netherlands
Phone +31(0)15 27 84910, E-mail W.Ravesteijn@tbm.tudelft.nl
http://www.tbm.tudelft.nl/tdo

Abstract

With approximately 8.6 million km^2, wetlands cover some 6% of the world's land surface. Wetlands have high ecological and economic values. Wetlands provide sources of income like fishery and tourism and are also essential for water purification and coastal protection. Degradation of wetlands is a worldwide problem. Highly populated wetlands endure the most serious degradation. Subsidence and sea-level rise threaten the wetland ecosystems and, consequently, deltas are among the most threatened regions in the world. Deltas are highly sensitive to interventions and their vulnerability emphasizes the need for a sustainable approach. The city of New Orleans (USA) has been built in the wetlands of the Mississippi river delta plain and this plain is one of the fastest degrading areas in the world.

For the Mississippi river delta wetlands the need for a total sustainable approach is illustrated with several examples and an environmental sustainable solution is introduced. Current features of the wetlands are checked with the definition of sustainable development stated by Brundtland. A river diversion to reintroduce natural processes in the wetland area is used as example of a sustainable solution for New Orleans. It is shown that large-scale sediment diversions are a good alternative to reintroduce these natural processes. On the other hand such a solution is only feasible when economic and social-political sustainability are taken into account.

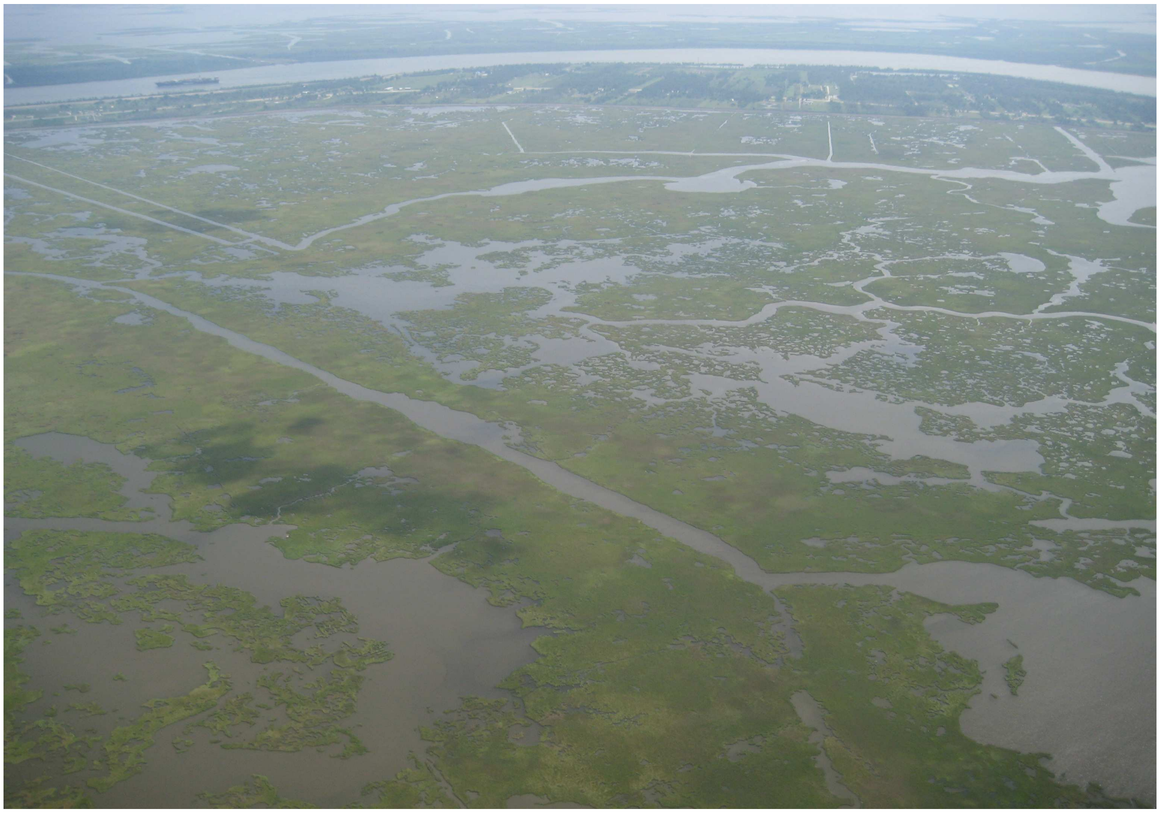

Figure 1: Small channels in the marshes; Mississippi river at top of picture [Hillen and Treffers]

Introduction

At the places where a river enters the ocean, at the borders of water and land, valuable and rich ecosystems are found; wetlands. Most of these coastal wetlands are formed in river deltas. With approximately 8.6 million km^2, wetlands (including inland wetlands) cover some 6% of the world's land surface [[i]]. The characteristics of these areas have always attracted people. Wetlands are valuable areas because of the nutrient grounds and the river and ocean nearby. In the middle of these valuable ecosystems cities were formed and industries were developed over the years. For the last hundred years increasing knowledge in engineering made it possible to defend these urban areas against river flooding and storm surges from the oceans. These areas could also be better adjusted for agricultural purposes and were made accessible for transport purposes and housing. At this moment most of the world's largest cities are situated in delta areas in or close to wetlands and these cities have fast growing populations [[ii]].

Wetlands provide sources of income like fishery and tourism and they are essential for water purification and contribute to coastal protection. The importance of these unique ecosystems is recognized with agreements as the Ramsar Convention in 1971 and with the focus of non-governmental organizations, like Wetlands International and WWF, wetlands are brought to the attention of the public. Actions are taking to maintain these areas and give wetlands back to nature. On the other hand, large inhabited river deltas face the problems of wetland degradation. With increased engineering interventions, the controlling of rivers and other human adjustments in wetlands these ecosystems are at risk. Subsidence and sea-level rise aggravate the situation and, consequently, deltas are among the most threatened regions in the world [[iii]]. Highly populated wetlands endure the most serious degradation. The Mississippi river delta in the United States of America, the Yangtze delta in China and the Ganges-Brahmaputra delta in Bangladesh all have relative sea level rises of around 1 cm per year [[iv]] [[v]] [[vi]] (Figure 2).

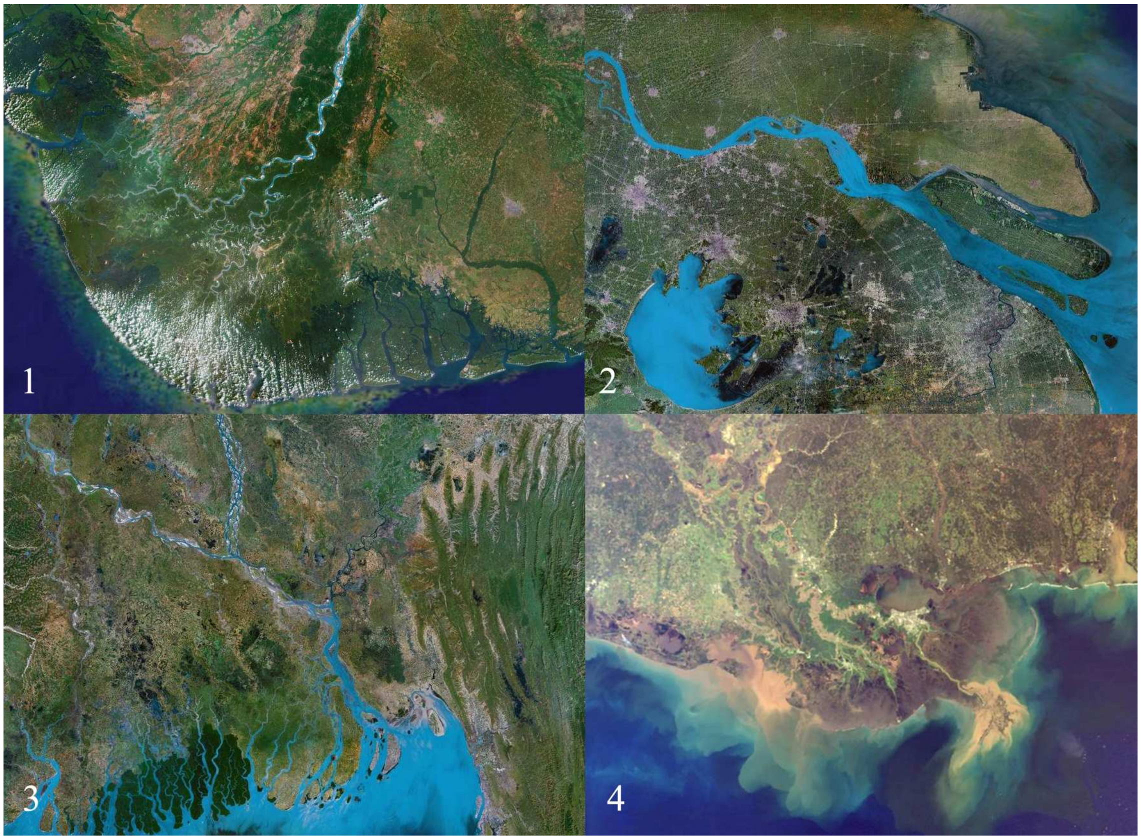

Figure 2: Deltas around the world; 1 Niger delta (Nigeria), 2 Yangtze delta (China), 3 Ganges-Brahmaputra delta (Bangladesh), 4 Mississippi delta (USA)

Wetlands in deltas are highly sensitive to human interventions and their vulnerability emphasizes the need for a sustainable approach. Due to the fact that river deltas are highly populated areas the ecological problems are very complex and interlinked with other. A sustainable approach for wetlands in river deltas would also mean a change in mentality. This paper will show that a sustainable environmental approach only works with the right social and economic infrastructure. Therefore, next to environmental sustainability, also social and economic sustainability is taking into account. To illustrate this approach an environmental solution for the city of New Orleans (USA) and its surrounding wetlands will function as an example.

The case of New Orleans

Located in the Mississippi river delta New Orleans struggles with the problems of wetland degradation. The severe impact of hurricanes Katrina and Rita in the late summer of 2005, both on the city and the surrounding wetlands, shows the vulnerability of this area. Over 1,100 people lost their lives and the city and its surroundings were heavily damaged. With this natural and social disaster, the international spotlight was put on this environmental problem. Large parts of the city need to be rebuild and also a lot of adjustments in the local environment are planned. Therefore this is the right moment for a sustainable approach for this area.

The city of New Orleans is situated in South-eastern Louisiana amidst an area of marshes. Marshes are the main wetland ecosystem found in coastal Louisiana. They form the largest coastal wetland area (60%) of North America [**Fout! Bladwijzer niet gedefinieerd.**]. The New Orleans region suffers a great loss of marshes. At this moment the marshes in the Mississippi river delta deteriorate at a rate of up to 115 km^2 per year (Figure 3) [vii]. Although the rates of wetland loss are very high, the area is relatively tectonically stable [viii]. The loss of wetlands can be accounted to wetland deterioration and the very high relative sea level rise (RSLR) in this region. RSLR consists of sea level rise due to global warming, expansion of the oceans and melting of ice on top of Greenland and the Antarctic (1-2 mm per year) [ix] and subsidence mainly due to deeper surface fluid withdrawal (8-9 mm per year) [x] [xi]. With an RSLR of approximately 10 mm per year the Mississippi deltaic plane suffers one of worlds highest RSLR [xii].

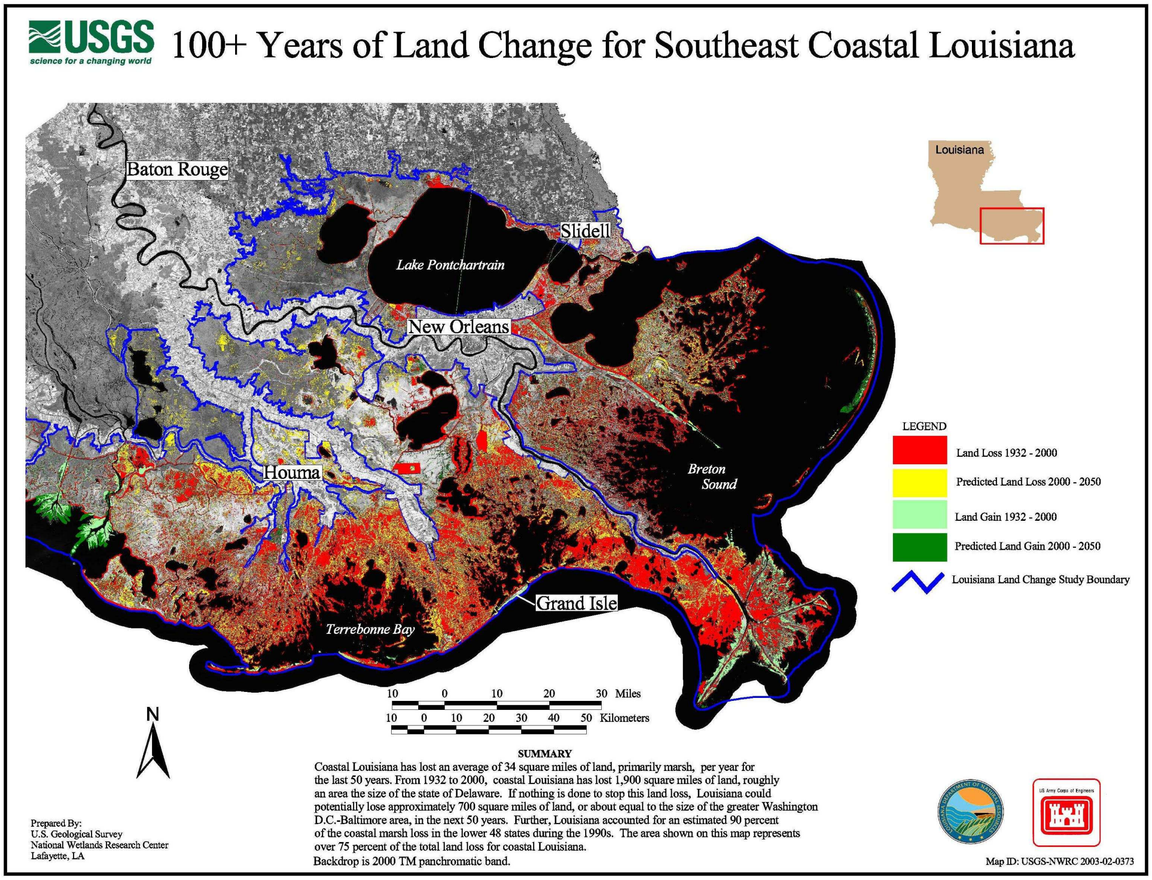

Figure 3: Historical and projected land change trend in Coastal Louisiana, 1932-2050 [U.S. Geological Survey, National Wetlands Research Center]

The marshes in South-eastern Louisiana have great ecologic, social and economic value. With the current rate of loss of marshes valuable ecosystems will be lost, bird habitats will disappear and it will put an extra pressure on several endangered species. From a social and economic point of view critical energy infrastructure may be destroyed and also other facilities, housing and structures will be exposed to the open water of the Gulf of Mexico. Shipping will be similarly affected. As wetlands erode, it will become much more expensive to maintain waterways and ports in South-eastern Louisiana. With continued wetland loss, commercial fishing, which in Louisiana accounts for about 3 billion dollars of the economy of Louisiana, will suffer from reduction in fish availability [xiii]. Over 70% of that amount comes from species such as crawfish and shrimp, which live in the coastal wetlands.

When in summer of 2005 the Mississippi river delta and New Orleans were hit by hurricanes Katrina and Rita some scientists claimed that the loss of wetlands had a serious influence on the height of the storm surge caused by the hurricanes. The magnitude of this influence is still under discussion, but what can be concluded is that the loss of wetland area made the adjacent areas more vulnerable for storm surge because the increased bottom-friction of marshes decreases the height of the storm surge.

Drastic measures are required to maintain the habitat of the Mississippi river wetlands and to keep this area and its social and economic functions from disappearing. As shown in Figure 4 Katrina had a large impact on the marshes in the Breton Sound, South of New Orleans on the East-side of the Mississippi river. The estimated loss of the marshes in the Breton Sound is about 100 km^2 [**Fout! Bladwijzer niet gedefinieerd.**]. Compared to the total marsh area in the Breton Sound this is a reduction of approximately 20-25 percent.

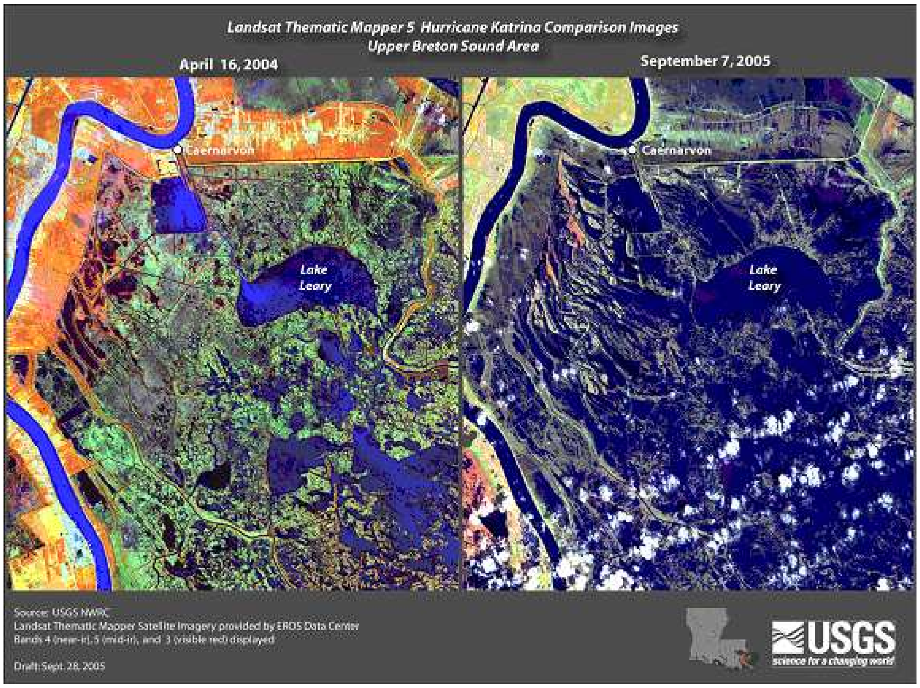

Figure 4: Wetland loss due to Katrina [U.S. Geological Survey, National Wetlands Research Center, Landsat thematic mapper satellite imagery, Sept 28, 2005]

Currently, plans to rebuild the coast of South-eastern Louisiana and the city of New Orleans are made by different agencies and institutes. Combining social, economic and environmental sustainability is needed to help sustain this area. Already a lot of research has been conducted on the marsh ecosystems, wetland loss and subsidence, levee building and many other related topics. One of the major environmental solutions for a sustainable Mississippi river delta and sustainable wetlands, creating major river diversions, will be discussed. This approach is regarded by many as a feasible natural alternative for preserving marshes [xiv] [xv] [xvi]. From an environmental point of view this looks like a feasible solution, which will be shown in *note 1*, but to implement this solution a total sustainable approach is needed. Therefore it will be linked to economic and social-political sustainability to show the importance of a total sustainable approach.

Sustainable development

To determine a satisfying definition for an approach towards sustainable wetlands it is necessary to have a sound definition of sustainable development. A widely accepted definition of sustainable development is given by the United Nations World Commission on Environment and Development commission chaired by Brundtland in 1987 and states: "sustainable development is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [xvii]. This definition of sustainable development is used to give a blueprint for sustainable wetlands and to give guidelines on how to achieve sustainable wetlands. Brundtland states that the field of sustainable development can be divided into three constituent parts, environmental-, economic- and social-political sustainability, which are all linked to each other. In New Orleans, and especially concerning the Mississippi river delta and its wetlands, there is a lack of sustainable development and therefore the wetlands are still in a deteriorating stage. To illustrate this five examples will be given, each concerning a different part of sustainability of the Mississippi delta wetlands.

1. *Cause and effect (environmental sustainability)*

Wetlands deteriorate due to subsidence, wave erosion and lack of fluvial sediment input. The subsidence of the Mississippi river delta causes the formation lakes inside the marshes. Because of these lakes the marshes get more vulnerable to wave-induced erosion and will deteriorate at a larger rate [**Fout! Bladwijzer niet gedefinieerd.**]. Therefore to reduce the deterioration of the marshes only reducing the wave erosion or only reducing subsidence will not be sufficient. In order to create sustainable wetlands the causes of the deterioration should be tackled. This calls for reintroducing fluvial sediments into the marshes and reducing wave erosion and subsidence, instead of dealing with the consequences.

2. Effects industry on wetlands (economic sustainability)

The fishery industry uses the marshes for crawfish and oyster fishery and therefore requires a certain (brackish) marsh climate. Oysters grow at the border of fresh and salt water. Marsh degradation causes changes in this climate. An area beneficial for oysters at this moment is therefore not sustainable on the long run. This marsh degradation is enhanced by the oil and gas industry by subtracting oil and gas from the deeper surface [Fout! Bladwijzer niet gedefinieerd.]. The dependency of several industries on the Mississippi river wetlands puts pressure on the wetlands and not much attention is paid to the future. Basic economy says that natural resources should be exploited to increase today's benefits. However, if compromising future generation to gain the same benefits, this is not a sustainable solution. Thus to protect and stimulate development the decision-making and law-making processes should completely integrate the economics and ecology.

3. Cultivation Mississippi river (economic sustainability)

After some major floods at the end of the nineteenth and the beginning of the twentieth century, the Flood Control Act was established in the USA in 1928. A system of levees was built with a length of 3,500 kilometers of which 2,600 kilometers along the Mississippi river itself, the rest along its tributaries. Due to this extensive levee system the river is contained and this prevented sediment to settle in the wetlands, bringing the natural system out of balance [xviii]. Because wetlands reduce storm surges this endangered the New Orleans community [Fout! Bladwijzer niet gedefinieerd.]. To have sustainable wetlands an assessment has to be made to find a balance between the benefits to the industry and the benefits for the community of New Orleans. Economic sustainable solutions for these wetlands cannot be achieved if the costs of deteriorating wetlands are not taken into account.

4. Politics (social-political sustainability)

Wetlands operate not merely within but also between governmental boundaries. Subsidence occurs at a large area exceeding governmental boundaries and hence the responsible governmental institute is hard to determine. In New Orleans for example there is not one governmental institute that has the full responsibility for the Mississippi river marshes; therefore the responsibility for the marshes is fragmented between several governmental institutes. Also the uneven political development and uneven power distribution, for example the large influences of lobbies of the oil and gas industry and fishing industry, puts large stresses on the wetlands [xix]. The dredging of channels in the marshes to build gas and oil pipelines and for navigational purposes increases the effects of salt intrusion and contributes to the deterioration of marshes [Fout! Bladwijzer niet gedefinieerd.].

5. Social tension (social-political sustainability)

In the aftermath of hurricane Katrina the only consensus among local, state and federal official was that the system had failed. The local and federal officials where accusing each other of blocking aid efforts for the victims of Hurricane Katrina. According to the Homeland Security secretary the local and state resources where dramatically weakened and therefore were unable to cope with the scale of the disaster and that the federal authorities had to take a more upfront role earlier. The local and state officials insisted that the Federal Emergency Management Agency failed to deliver urgently needed help and even blocked others' efforts to help. According to the mayor of New Orleans, Ray Nagin, and Governor of Louisiana, Kathleen Blanco, the problem was authority: "the state and federal government are doing a two-step dance" [xx].

With these examples it could be argued that the uneven political development and distribution of power and the fragmented responsibility is the underlining principle of wetland deterioration for the case of New Orleans. Since the wetlands around New Orleans are deteriorating rapidly current (over-) exploitation might, if nothing is done to prevent further deterioration, compromise the future generations to exploit these wetlands as is done now. Wetlands will have to be arranged in such a way that the benefits nowadays gained from the wetlands will be equally divided amongst the current generation but also that the benefits in the future will not be compromised by current exploitation.

Mississippi river diversions; a sustainable solution?

A sustainable solution for the marshes around New Orleans could be the use of a Mississippi river diversion to reintroduce natural flooding processes. Marshes grow when a river floods the marsh area during high water level. Riverine inputs increase vertical accretion and bulk density of the marshes due to mineral sediments deposition. The flooding also enhances plant growth due to inflow of nutrients and the fresh river water forms a buffer against saltwater intrusion. Riverine flooding events into subsiding marsh areas are therefore essential to sustaining elevation and productivity, plant growth, of marshes. However, human intervention in the natural process of delta forming caused a net overall loss of deltaic plane (Figure 5) [xviii]. Human intervention on two distinct properties of wetland areas can be seen: cultivation of the river (1) and severe adjustments of the wetland area (2).

1. The loss of marshes in the Mississippi birdfoot, South of New Orleans, shows the impact of cultivating the Mississippi river. The process of delta forming by the Mississippi river, which has propagated to the edge of the continental shelf where new marshes cannot be created due to the depth of the water, was disturbed. Since this disturbance of the Mississippi river the wetlands were excluded from riverine sediment input and therefore the decay of the Mississippi delta increased. The last century almost only marsh loss can be observed in this area.

2. Not only the source of wetland growth has been cut off, also the conditions for wetland preservation have been harmed. The many dredged made navigation channels in the wetland area cause saltwater intrusion in the Mississippi delta. One of the major channels is the Mississippi River Gulf Outlet (MRGO), dredged in 1963 to reduce the distance that ships have to travel to New Orleans. This is an example of one of the many human made canals that enhance the marsh deterioration via salt intrusion. In its 40 years of existence 81 km^2 of marshes deteriorated because of the MRGO [**Fout! Bladwijzer niet gedefinieerd.**]. In Figure 1 the vast amount of small channels, which open the wetland area to salt water intrusion and wave erosion, is shown. Of course there are more changes in the river delta that contribute to the degradation, but these can mostly be quantified as part of the two above mentioned main properties, or are of less importance.

Figure 5: Wetland loss due to human & natural causes [U.S. Geological Survey, National Wetlands Research Center]

As stated before, to counter the loss of marshes with a sustainable approach, both two properties need to be changed. Riverine inputs should be re-introduced into the Mississippi delta and the conditions of the natural wetland system need to be restored. To start the restoration of large wetland areas and to restore the original salt-fresh balance large river diversions are needed. Taking into account the global climatic change and the increase of energy costs, which in time have a big impact on restoration of the Mississippi delta, a natural solution is required. Smaller Mississippi river diversions for marsh preservation, like the Caernarvon freshwater diversion and the Davis Pond diversion, show promising results. The simulation of flooding events by these diversions causes wetland growth [xxi]. Diversions are seen as the major management approach to reconnect the river with its delta [**Fout! Bladwijzer niet gedefinieerd.**]. The input of nutrients and sediments into the delta will help marsh restoration.

Note 1: Example of large-scale sediment diversion for marsh restoration

*Large sediment diversions in the Mississippi river delta are not yet created. Sustainable marsh restoration by reconnecting the river to the deltaic plain via diversions, reopening of old distributaries and crevasse-splay development to reintroduce flooding events to the marshes will have to be done on a large scale [**Fout! Bladwijzer niet gedefinieerd.**]. The following hand-calculation for a sediment diversion South of New Orleans, in a not very populated area illustrates the possibility of a large sediment diversion to restore wetland areas.*

For this example an arbitrary location for a river diversion is chosen. The fictitious diversion will be constructed near Port Sulphur (see Figure 6) halfway the Mississippi river birdfoot.

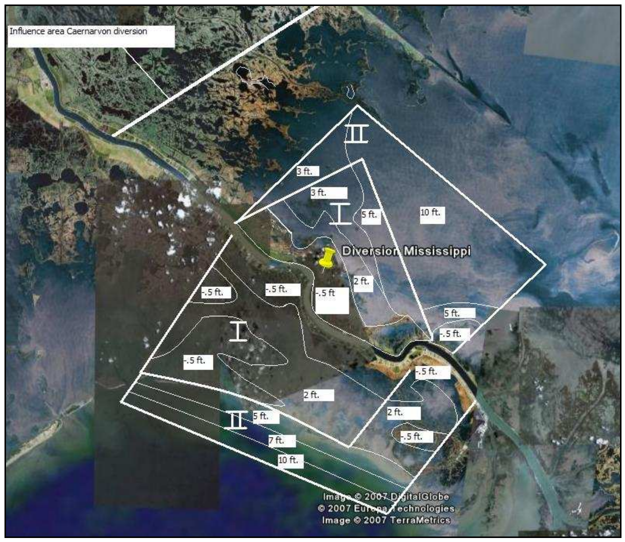

Figure 6: Location large-scale diversion Mississippi river birdfoot

The diversion will influence both the east and the west side of the Mississippi river birdfoot. The influenced area at each side is divided in two different parts. This division is based on depth and the presence of existing marshes. The first part (I) is the area that will be directly influenced by the diversion and where on a short time period marsh restoration should be visible. The second part (II) is the area with a larger depth and located further from the diversion.

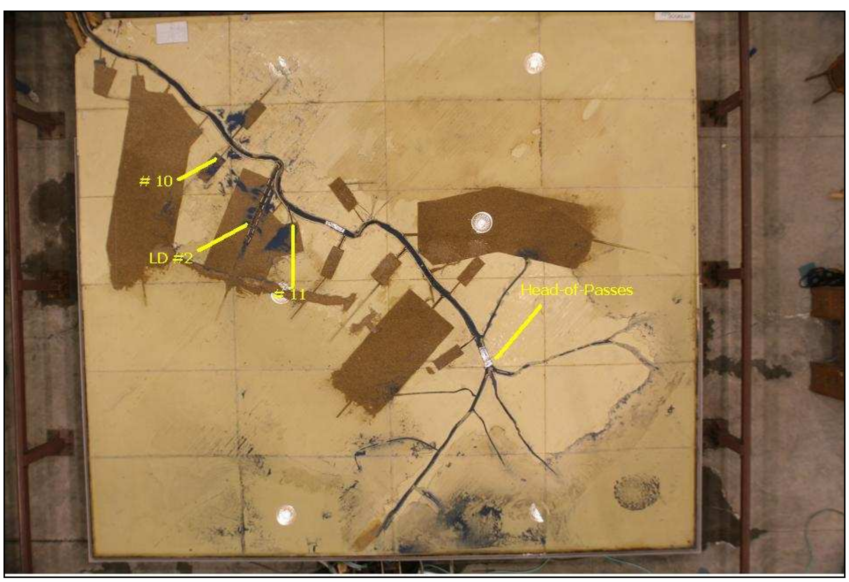

Figure 7: The small-scale physical model with the last 122 km. of the lower Mississippi river with the diversions (#10, #11 and LD#2) indicated [Clint Willson, Louisiana State University]

Geometry of the influenced area by the Port Sulphur diversion:

East of the Mississippi River Birdfoot

Area 1:

Total area: 330 km^2

Depth contours:

Depth:		Area:	
-0.5	ft.	110	km^2
2	ft.	78.5	km^2
3	ft.	73	km^2
5	ft.	67.5	km^2
Total area		330	km^2

Area 2:

Total area: 726 km^2 (including Area 1)
396 km^2 (excluding Area 1)

Depth contours:

Depth:		Area:	
-0.5	ft.	12	km^2
3	ft.	45.5	km^2
5	ft.	14	km^2
10	ft.	324.5	km^2
Total area		396	km^2

West of the Mississippi River Birdfoot

Area 1:

Total area: 489 km^2

Depth contours:

Depth:		Area:	
-0.5	ft.	217	km^2
2	ft.	272	km^2
Total area		489	km^2

Area 2:

Total area: 837 km^2 (including Area 1)
348 km^2 (excluding Area 1)

Depth contours:

Depth:		Area:	
-0.5	ft.	51	km^2
2	ft.	77	km^2
5	ft.	80	km^2
7	ft.	70	km^2
12	ft.	70	km^2
Total area		348	km^2

For these basic calculations some assumptions are made based on literature:

- *Marshes can only grow when the water depth does not exceed two feet or 0.5 meter [xxii]. Therefore the second area will have a longer deposition process before the marshes can grow.*
- *The area that will be influenced by the diversion is assumed as seen in Figure 6 and sediment will distribute evenly over this area. The influenced area will first need to be filled up by river sediments to the height that actual marsh growth can occur.*
- *Only mineral sediment is taken into account, since this is the determining factor for marsh growth [xxiii].*
- *Wave erosion is neglected and the possibility that a hurricane strikes the area within the restoration time is not taken into account.*
- *RSLR is taken into account.*
- *An average sediment concentration in the Mississippi river: 250 $^{g}/_{m^3}$ [xxiv].*
- *A retention rate of sediment (sediments that will actually settle in the marshes): 40% [xxv].*

For three different time frames the discharge is determined that is needed to achieve marsh growth:

- *For a 50-year time period the discharge in the east direction should be 3,404 m^3/s and in the west direction it should be 1,221 m^3/s. Combined diverted discharge through the Port Sulphur diversion should then be 4,625 m^3/s.*
- *For a 40-year time period the discharge in the east direction should be 4,227 m^3/s and in the west direction it should be 1,438 m^3/s. Combined diverted discharge through the Port Sulphur diversion should be 5,665 m^3/s.*
- *For a 25-year time period the discharge in the east direction should be 6,695 m^3/s and in the west direction it should be 2,090 m^3/s. Total discharge should then be 8,785 m^3/s.*

These diversion discharges were checked with a small-scale physical model of the lower Mississippi river at the Louisiana State University (Figure 7). The amount of diverted sediment matched the calculated quantities.

This example is only intended to show that marsh restoration on a large-scale is possible with a large-scale sediment diversion. Note that the location of Port Sulphur is chosen arbitrarily and that the results of marsh restoration depend on the state of the marshes in the receiving basin.

A lot of research has been conducted to test the effects of river diversion on marsh restoration. The above example is indicative and shows that a large-scale natural solution is a possibility for the New Orleans area. This solution is environmental sustainable since it simulates natural flooding events of the Mississippi river, and thereby reintroduces sediments in the marsh area. But as seen in the examples of the influence of economics and politics on sustainability, an environmental sustainable solution by itself is not sustainable. To implement an environmental solution on this scale it is important to also investigate the economic and social-political feasibility.

The creation of a river diversion will have a serious impact on the local economy. It will influence the navigability of the river, causing extra dredging costs, and affects the fishery in the receiving basin, creating a new marsh climate. On the long-term this solution will help to maintain the area and thereby the industry. Although the diversion will have increased costs on the short term, the costs of marsh deterioration cannot be neglected making the diversion economically feasible on the long term. The creation of a large-scale river diversion will also demand political consensus. The importance of the wetland ecosystem should be recognized at high political level and the different involved institutes should work together on a total sustainable solution for the area.

Conclusion

Around the Mississippi river delta society has failed to give the responsibility for preventing environmental damage to the local governments whose policies cause the marshes to deteriorate. To anticipate and prevent future environmental damage to the Mississippi river wetlands it is required that the ecological dimensions of policy be considered at the same time as the economic, trade, energy, agricultural, and other dimensions. Thus, restoring the Mississippi river wetlands needs integral solutions instead of dividing small-scale solutions presented by fragmented governmental institutes. To achieve sustainable wetlands involves a progressive transformation of economy and society. A development that is sustainable in a physical sense could theoretically be pursued even in a rigid social and political setting. But environmental sustainability cannot be secured unless development policies pay attention to considerations of changes by making costs and benefits analysis to determine the effects of deteriorating marshes for current generation and future generation. Environmental sustainability implies a concern for social equity between generations and obviously a concern to equity within each generation.

Sustainable marsh restoration implies that there should not only be looked at the environmental aspects of marsh restoration. It is a balance between and a weighted average of the environmental, social and economic gain created by these restorations. Some references to the social-political impact have already been made [[xxvi]], but it is important to have a solution at the level of the problem. Therefore wetlands will have to be arranged in such a way that the benefits (environmental, economic and social) nowadays gained from the wetlands will be equally divided amongst the current generation but also that these benefits in the future will not be compromised by current exploitation.

The wetlands should be self-sustained by natural processes from an environmental point of view. Large-scale sediment diversions are a good alternative to reintroduce these natural processes and to provide the sediment and nutrients from the river water to restore the wetlands. From a social-political and economic point of view, wetlands need to be safe places to live and provide a source of income for the inhabitants on the long-term. Therefore fishery and other wetland-specific sources of income should be ensured on the long-term and also the positive natural benefits of marshes, like coastal protection, should be taken into account. To have a sustainable solution, besides this environmentally sustainable approach also an economic consideration should be made whether or not large-scale diversions are feasible taking into account the cost of deteriorating marshes. All this should be done in a social and political sustainable approach. Governmental institutes should be combined to have one institute that monitors the wetlands and introduces sustainable solutions for the wetland problem. The benefits gained and lost from the marshes should be equally shared amongst the current generations and not be distributed amongst those with lots of influence.

[i] Mitsch, W.J. and J.G. Gosselink, "Wetlands", John Wiley & Sons, New York, 2000

[ii] World Coast Conference 1993, "Conference Report", http://www.netcoast.nl/projects/netcoast/info/history/wccpdf.htm, 1994

[iii] Millennium Ecosystem Assessment 2005, "Ecosystems and Human Well-being: Wetlands and Water Synthesis", http://www.maweb.org/documents/document.358.aspx.pdf, 2005

[iv] Day J.W. Jr. et al., "Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita", Science, Vol. 315, Iss. 5819, pp. 1679-1684, 2007

[v] Milliman, J.D. et al., "Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples", Ambio, Vol. 18, No. 6, pp 340-345, 1989

[vi] Xiqing, C., "Changjian (Yangtze) River delta, China.", Journal of Coastal Research, No. 14, pp 838-858, 1998

[vii] Barras, J.A., et al., "Land loss in coastal Louisiana 1956-90.", National Biological Survey, National Wetlands Research Center Open File Report 94-01

[viii] Tornqvist, T.E. et al., "How stable is the Mississippi Delta", Geology, Vol. 34, No. 8, pp 697-700, 2006

[ix] IPCC, Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., Qin, D. & Woodworth, "Climate change 2001: the scientific basis., P. L. 2001 Changes in sea level. In Climate change 2001: the scientific basis.", Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change (ed. J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell & C. A. Johnson), Cambridge: Cambridge University Press, p. 881, 2001

[x] Morton, R.A. et al., "Causes of hot-spot wetland loss in the Mississippi delta plain.", Environmental Geosciences, Vol. 10, No. 2, pp 71–80, 2003

[xi] Morton, R.A., "Evidence of regional subsidence and associated interior wetland loss induced by hydrocarbon production, Gulf Coast region, USA" , Environmental Geology, Vol. 50, pp 261–274, 2006

[xii] Coleman, J.M. et al., "The Mississippi River delta: an overview" , Journal of Coastal Research, Vol. 3, pp 698-716, 1998

[xiii] B. Good et al., "Coast 2050: Toward a Sustainable Coastal Louisiana", Report by the Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998

[xiv] Martin, J.F., "Emergy valuation of diversions of river water to marshes in the Mississippi River Delta", Ecological Engineering, Vol. 18, pp 265–286, 2002

[xv] Day, J.W. et al, "Implications of global climatic change and energy cost and availability for the restoration of the Mississippi delta.", Ecological Engineering, Vol. 24, pp 253–265, 2005

[xvi] Stokstad, E., "Louisiana's Wetlands Struggle For Survival", Science Magazine, Vol. 310, pp 1264-1266, 2005

[xvii] G.H. Brundtland, "Our Common Future / World Commission on Environment and Development", Oxford University Press, 1987

[xviii] Day, J.W., "Pattern and process of land loss in the Mississippi delta: A Spatial and temporal analysis of Wetland habitat change", Estuaries, Vol. 23, No. 4, pp 425-438, 2000

[xix] Ko, J., and Day, J.W., "A review on ecological impacts of oil and gas development on coastal ecosystems in the Mississippi delta", Ocean & Coastal Management, Vol. 47, pp 567-623, 2004

[xx] Shane, "After failures, Governmental Officials Play Blame Game", The New York Times, September 5, 2005

[xxi] Snedden, G.A., "Sediment discharge into a subsiding Louisiana deltaic estuary through a Mississippi River diversion", Estuarine, Coastal and Shelf Science, Vol. 71, pp 181-193, 2007

[xxii] Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) Model of Louisiana Coastal Area (LCA) Comprehensive Ecosystem Restoration Plan: Volume II – Tasks 9-15, Louisiana Department of Natural Resources, 2004

[xxiii] Nyman, J.A. et al., "Wetlands Soil Formation in the Rapidly Subsiding Mississippi River Delta Plain: Mineral and Organic Matter Relationship", Estuarine, Coastal and Shelf Science, Vol. 31, pp 57-69, 1990

[xxiv] Mossa, J., "Sediment Dynamics in Lowermost Mississippi River", Engineering Geology, Vol. 45, pp 457-479, 1996.

[xxv] Louisiana Coastal Area (LCA), "Louisiana Ecosystem Restoration Study", U.S. Army Corps of Engineers, New Orleans District, 2004

[xxvi] Templet, P.H., "Louisiana wetland loss: A regional water management approach to the problem", Environmental Management, Vol. 12, No. 2, 1988