

# **THE EXTERNAL IMPACT OF AGRICULTURE ON INLAND WETLANDS: A CASE STUDY FROM ARGENTINA**

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## **Abstract**

We develop a simple model to identify the link between indirect impact of agriculture - soil erosion and the level of damage of inland wetlands by sedimentation. The economic impact of wetland degradation service, specifically flood control, is then estimated. The study area covers 1.4 million ha, located in the south of Córdoba, Argentina. The change in wetlands and croplands between 1975 and 2001 was estimated by multi-period analysis of satellite images. The value loss of cropland is estimated by using real prices 2000, and data from two surveys 1886 and 1999. The results show the loss of wetland services accounted for more than 58,000ha of degraded cropland, with an estimate of land value loss of \$133 million at a 6% of discount rate between 1975 and 2001. If the trend of agricultural modernization and degradation continues the degraded cropland would reach around 120,000 ha and the aggregate value of wetland services loss \$210 million for planning period of 30 years (or \$128 ha-1 year-1). Although agricultural modernization hid the damage of inland wetlands, the environmental units located in the intermediate watershed are critically affected. These finding support the needs to integrate policy of promoting agricultural modernization along with soil conservation and wetlands protection.

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**Keywords:** Agriculture, economic valuation, land degradation, soil erosion, wetlands, Córdoba, Argentina

## **Introduction**

Wetlands can play an important role in controlling floods in a watershed (e.g. Mitsch & Gosselink, 2000). Wetlands can hold and reduce water flows to downstream areas. Ideally, wetlands can retain water precipitation where they occur. A small surface of wetlands can drastically reduce the floods. Wetlands are valuable resources for society (e.g. Turner et al., 2000). However, agriculture may harm wetland services in different ways. A direct impact is the conversion of wetlands to farmland, while the indirect impacts are thorough sedimentation and chemical residuals that degrade the quality of wetlands (e.g. Heimlich, Wiebe, Claassen, Gadsby, & House, 1998).

Soil erosion and water runoff are among the most important off-site impacts of agriculture (e.g. Clark II, Haverkamp, & Chapman, 1986). Sediment, nutrients and pesticides are carried by water to remote places and cause damage to other environments and users. Sedimentation reduces little by little the ecological function of wetland, and the cumulative impact may also overwhelm it (Brenner, Keenan, Miller, & Schelske, 1999). These authors pointed out that the sediment yield and nutrient release varied in different periods, but in general they have increased due to human-made change in the rest of the watersheds.

The indirect impact of agriculture on wetlands has been less studied, but the policy implications are likely to be important since a wetland overwhelmed by sedimentation can reduce or even lose its ecological functions and hence its economic services. The market value of wetlands only accounts for private goods or services and is expected to be lower than the social value (Heimlich et al., 1998). There is some empirical evidence that wetlands are undervalued in the market (Reynolds & Regalado, 2002). The social value of wetlands is important in the context of policy analysis since it allows identification of the public and private value of wetland services and assessment of policy and project, which get the attention of policy makers and the public (Brander, Florax, & Vermaat, 2006; Woodward & Wui, 2001).

Market and non-market methods to value wetlands have become an important branch of economics. Woodward and Wui (2001), reviewed 39 articles that deal with wetland value in the USA. The authors found that net factor income is one of the most frequent methods used to estimate the social value of different wetland services such as flood control, water quality control, recharge and discharge of groundwater, biomass production and

export (plant and animal) and stabilization of sediment. Assuming a flat demand curve, net factor income approximates the social value through producer surplus. Woodward and Wui (2001) found no significant difference among methods such as travel cost, net factor income and contingent valuation, but contingent valuation estimate is lower than replacement cost and hedonic price.

Brander et al. (2006) reviewed 190 studies of wetland valuation in the world. The authors assess the effects of different attributes on wetlands value: Gross Domestic Product per capita, population density, wetlands` location, size, service and type, valuation methods, proportion of wetland in the List of Ramsar. In contrast with Woodward and Wui`s (2001) finding, the results of Brander et al. (2006) showed that the contingent valuation method attached a greater value to wetland services than other valuation methods, which did not differ among themselves. The two meta-analysis studied claimed that site specific studies must be done for wetland valuation since benefit transfer from their results are not precise, particularly in developing countries.

In Argentina, international prices and market forces have been the main factors driving agricultural modernization for the last quarter of the century (Schnepf, Dohlman, & Bolling, 2001). The process of agricultural modernization led to change in land use from pasture to crops, increased use of pesticides and fertilizers, and high specialization in oil crops, such as soybean. Such practices frequently cause more water run-off and are even likely to reduce the long-term productivity of agriculture due to degradation by soil erosion (Cisneros et al., 2004). The harmful side effects of this type of farming also include damage to downstream resources and environments such as wetlands. Sedimentation in inland wetlands reduces water holding and increases floods (Cantero G. & Cantu, 1981; Cantero G. et al., 1998). Floods have been associated to climate and agricultural modernization in the western Pampas Argentina (Viglizzo & Frank, 2006). Floods are likely to increase in the future and so damages.

Wetlands can play an important role controlling flood damages; however, soil erosion and its sedimentation on wetlands may jeopardize this public service. Temporary and acute floods call public attention, so actions, such as, building canals have been implemented to alleviate acute damages, but it probably increases damage on other watershed located downstream. Consequently, it is likely that ignoring the chronic impacts of cumulative sedimentation of inland wetlands will increase the temporary floods, inducing a domino effect over watershed located downstream in the long term. The indirect impact of agriculture and its consequences over watershed has been usually undervalued or ignored.

The objective of this paper is to assess the economic impacts across the farmers of indirect effect of agriculture on inland wetlands. A graphic model of the loss of a public wetland service, flood control, guides the empirical valuation, using net factor income. The dynamic elements of wetland degradation are captured by comparing degraded cropland during two periods 1975 and 2001 and loss of net income of croplands. The model and empirical analysis can help policy makers to identify the economic incentive for suitable corrective actions.

The rest of the paper is organized as follows. Section 2 describes the model representing wetland with different level of degradation. In Section 3, data and methodology are described. The results and discussion are presented in Section 4. Finally, a summary of main findings, concluding remarks and limitations of model are presented.

### Conceptual framework: Levels of wetland degradation by sedimentation

In this paper, wetland degradation refers to the sedimentation by soil erosion coming from upstream of the inland wetland in such way that its capacity to control floods as well as the habitat for fish and other biological species is gradually reduced (Brenner et al., 1999) or could be lost (Cantero G. et al., 1988). We use a diagram, Figure 1, to represent an intermediate watershed with inland wetlands. To the left side of the diagram are the upstream areas and to the right, other downstream areas. The portion near the bottom of the diagram shaded may be thought of as a lagoon, a marsh, a floodplain of a stream or another type of inland wetland in a close basin. The surface above the wetland represents the arable land that can be used for pasture or crops, croplands.

The inland wetland services represented by the diagram can be: a) protection of local croplands from flooding in the intermediate watershed; b) protection of the other downstream areas from flooding and sedimentation; and c) provision of other services, such as nutrient recycling, habitat for vegetation and animals, and a place for recreational activities such as fishing and hunting. These are typical services of inland wetland in a close watershed.

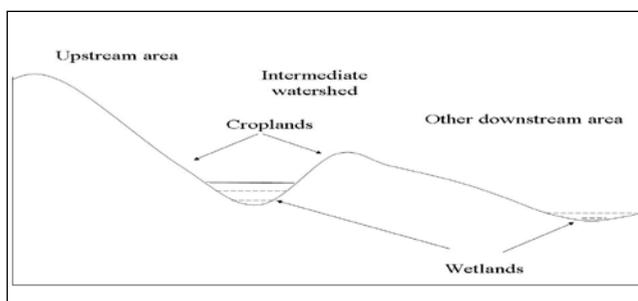


Figure 1. Schematic representation of a watershed

Water runoff carrying sediment, nutrients and pesticides from cropping activities discharge into the wetland, which reduces wetland services. As a result, two types of damages can be identified. Extreme precipitation usually causes damage by temporary flooding on crop land (Figure 2), while the other type of damage is the chronic one due to the cumulative effects of sedimentation. The later effect reduces wetland service gradually by declining its water holding capacity, so flooding damage on croplands become permanent.

The chronic effect may have four different levels of wetland performance, depending on the amount of sedimentation, which range from zero or insignificant silt, Level 1, to a completely lost of wetlands services, Level 4 in Figure 2. The Level 1 represents a watershed in which farmers located upstream and intermediate watershed control soil erosion and water runoff so the inland wetland is not silted. Therefore, wetland services are provides as public good for farmer located in the intermediate watershed and in the other downstream watershed although in extreme precipitation - water runoff can cause some temporary flooding.

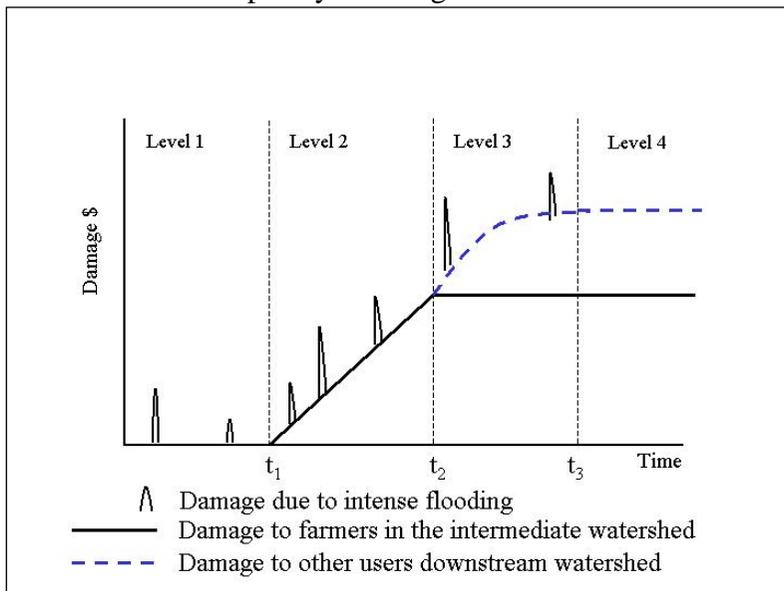


Figure 2. A damage function due to wetland sedimentation

In contrast, farmers can increase soil erosion and water runoff by changing land use or adopting inappropriate management practices. Consequently, cumulative sedimentation in the inland wetland starts to degrade gradually wetland function, which is represented by Level 2 in the Figure 2 (from  $t_1$  to  $t_2$ ). In this Level, farmers located in the intermediate watershed gradually start to lose wetland services such as flood control until it reaches the maximum at  $t_2$ . The damage function is assumed linear for the

farmer located in the intermediate watershed. At this level, farmers in the other downstream areas still are protected by intermediate watershed. However, if the soil erosion and water runoff continues the ability of inland wetlands - intermediate watershed to control flood become reduced and start to damage other users downstream, which is represented by the Level 3 of degradation in the Figure 2. Again, this damage over farmers located in other downstream areas increased gradually until flood control is totally loss in the intermediate water at  $t_3$ , in which Level 4 of wetland degradation is represented. In this level practically maximum damage is reached and wetland functions at least locally are totally lost.

Although the levels described represent a simple hypothetical case and linear relation are used to describe the process, the dynamics and links between wetland degradation and croplands described by the damage function capture the main physical components that may threaten inland wetlands and their services in the long run. It should be noted that cropland located in the intermediate watershed becomes a non-renewable resource, as the phenomenon is virtually non-reversible. Therefore, due to wetland degradation, the farmers affected by flooding lost the current productivity and potential productivity of their land. Also, it is important to note that the loss of inland wetlands in the close basin upstream or intermediate watershed will increase the water runoff and sediment carry out to other downstream areas, degrading other wetlands. We show an illustration to value these effects in the next section.

### **Data and empirical estimation**

The area of study is a watershed made up of the Minor Streams' Watersheds (MSW) in the South of the province of Córdoba, Argentina (see Figure 3). It is located between the parallels  $32^{\circ} 55'$  and  $33^{\circ} 55'$  S and between longitudes  $64^{\circ} 00'$  W and  $66^{\circ} 05'$  W. It lies between the Cuarto river to its North and the Quinto river to its South and is connected through a small canal to the Saladillo - Carcaraña - Parana - Río de la Plata systems that finally debouch into the Atlantic Ocean. The MSW has an area of 1,404,000 hectares.

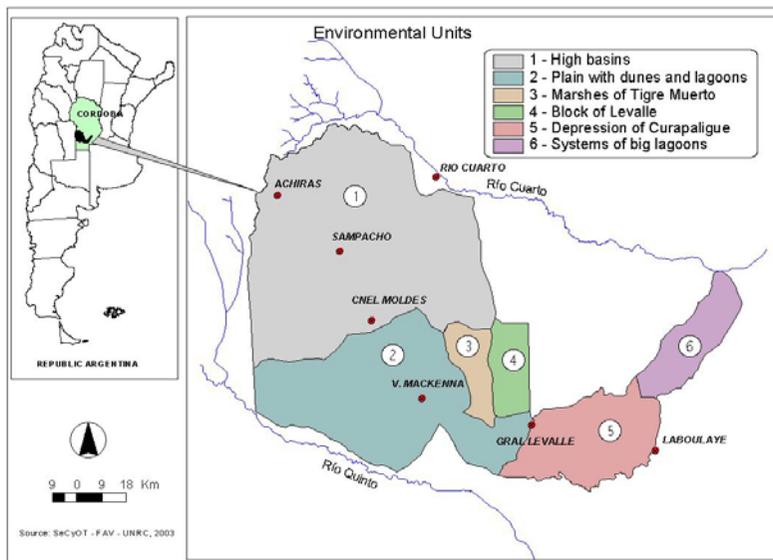


Figure 3. Area of Study: Minor Streams Watershed, Córdoba-Argentina

The landscape of the region is mostly plains with uniform to more complex shapes westward. In the west, the landscape rises gradually to meet the foothills of the Comechingones and in the east, two geological faults control and practically close the drainage system (Cantero G. et al., 1998). The average slope varies between 0.5% and 2% (Degioanni et al., 2005). The soils of the area are developed over thick deposits of loess (silt material deposited by wind thousand of year ago). The normal associations of soils belong to textural classes: sandy-loam, loam and silt-loam (Jarsún et al., 2003). The soils are classified as Mollisols and have few or no limitations for cropping. The other associations of soils are complex near the streams, marshes, spawns and lagoons.

The climate of the region is characterized by temperate, sub-humid summers and cool, mild winters (Cantero G. et al., 1998; Seiler, Fabricius, Rotondo, & Vinocur, 1995). The annual rainfall means range from 675 mm in the southwest (Chajan) to 800 mm in the east (Laboulaye). This is above the minimum needed for non-irrigated crops, but the annual rainfall varies, causing occasional severe conditions of drought, more intense in the southern and central parts of the MSW, and excessive water and flooding in the eastern part. For example, in 94 years of rainfall recorded in Laboulaye, there are seven years over 1100 mm and seven years under 530 mm. The range of mean rainfall for summer months is about 70-130 mm, while that for winter months is about 0-20 mm. Winds are frequent and intense between August and November, and the dominant wind direction is NE-SW (Seiler et al., 1995).

There are seventeen towns and two cities, Coronel Moldes and Laboulaye, located in this area and approximately 2780 farmers (own estimation with data of SAyG-MP, 1999). The economics of the MSW is based on agriculture, trade, and some light industrial development. Agriculture includes harvesting crops (soybeans, corn, wheat, sorghum, peanuts and sunflowers) and rearing and management of livestock (beef and dairy cattle production). Farming activities are predominantly carried out under dry land conditions.

### Method to estimate degraded cropland

By multiperiod analysis of satellite images (Landsat MSS and TM) and auxiliary cartography (e.g., Soil survey, Topographic Map) we identified and classified the wetlands, following the Convention of Ramsar on Wetlands (the Ramsar Convention Bureau, 2003). Wetlands expanded and degraded other land between 1975 and 2001. In order for 2001 wetlands to be included in the category of degraded cropland, they must fill the following three criteria: First, in 2001, the wetlands are located in an area that has soil classified mostly as Mollisol or Entisol without hydromorphic genesis according to the soil survey by Jarsún et al. (2003). Second, these 2001 wetlands also showed cropland patterns in the previous satellite images (1995 or 1975). Third, local testimonies (from interviews with farmers or professionals) have confirmed that these 2001 wetlands were used for crops before 2001. If a lands affected by water fulfill these three criteria in 2001, they are classified as the degraded croplands, which are used for estimate the damage of wetland degradation. Simplification and assumption are made to deal with some data limitation. Let  $L^d$  degraded cropland represented by Equation (1) be estimated as:

$$L^d_i(2001) = L^c_i(1975) - L^c_i(2001), \quad (1)$$

where subscript  $i$  is an index for environmental units,  $L^c$  represents the cropland used for crops and pastures, and in parentheses time in year. The annual rate of degraded cropland,  $l^d$ , is assumed to be linear between 1975 and 2001. The prediction of degraded cropland can then be stated as:

$$PL^d_i(t) = L^d_i(2001) + (t) l^d_i. \quad (2)$$

where  $t$  represents time measured as number since 2001. To estimate the time ( $t = \tau_i$ ) for  $PL^d$  to reach the steady state (total degradation of cropland in the intermediate watershed), which represent the cropland in 2001 is divided by the annual rate of degraded croplands and takes the form:

$$\tau_i = L^c_i(2001) / l^d_i \quad (3)$$

For simplicity, it is assumed that the intermediate watershed can be totally degraded.

## Economics impacts

We estimate net income loss using the historical trend in agriculture in each environmental units of the MSW. Let  $ni_i(t)$  be the net income per hectare at time  $t$ . The damage function,  $DF$  for the unit  $i$ , then takes the form:

$$DF_i(t) = \partial_i ni_i(t) L_i^d(t), \quad (4)$$

where  $\partial$  represents the proportion of net income loss in degraded cropland. The aggregate net income at any time depends on the farming systems, yields, and prices.

Due to available data, two periods 1986 and 1999 farming systems (FS) are used in order to identify the trend of net incomes and productivity growth (MAGyRR, 1986; SAyG-MP, 1999). The differences between 1986 FS and 1999 FS are: a) the land assigned to crops or pasture; b) the yield of each crop; c) technology used for crops; and d) input and output prices. In order to account for technical progress, an annual growth rate of agricultural productivity for the  $i^{th}$  environmental unit,  $g_i$ , Boardman et al. (1996) is estimated as:

$$g_i = \left( \frac{ni_i(1999)}{ni_i(1986)} \right)^{\frac{1}{13}} \quad (5)$$

Then, the predicted value for net income at time  $t$ ,  $pni_i$ , is estimated as follows:

$$pnb_i(t) = ni_i(1999)(1 + \alpha_i g_i)^t, \quad (6)$$

where  $\alpha$  accounts for net income growth adjustment, which may vary across areas. Farmers may assign degraded cropland to alternative use, for example, cow-calf breeding. Wetlands and degraded croplands are extensively used for livestock activities, and the market prices for such land sold or rented have been reduced by 55% - 85% according to local testimonies. The source of information is personal interviews in 2003 with farmers Jorge and Bautista Ferrero, Arturo Bilinsky, Pelliza and Agricultural Engineers Adrian Milanese and Sergio Rang about land price and rent price in the Colonia Santa Ana, located in the DC, which has a significant amount of degraded cropland. Hence,  $\partial=0.7$  accounts for the average situation. In contrast, if the land productivity was totally lost for farming activities (for example, as for cropland with permanent surface water),  $\partial=1$ .

If the historical trend is expected to continue at the same rate of net income growth, then  $\alpha=1$ . This scenario is likely to happen in areas where agricultural modernization has recently started and farmers can still convert pasture to crops (oilseed crops specifically). In contrast, in areas where crop specialization was already high,  $\alpha$  must be smaller than one because the agricultural growth rate depends practically on yields.

Using Equations (2) and (6), the aggregate predicted damage at any time  $t$  is equal to:

$$PDF_i(t) = \partial_i p n_i(t) PL_i^d(t) \quad (7)$$

The income per hectare for each county was estimated with the data of the 1986 and 1999 surveys of agriculture (SAyG-MP, 1999) and 2000 real price averages, using the general price index from the AACREA (2003). Net income for livestock and costs of inputs for crops were taken from an average of the four representative farming systems, namely Models 15, 16, 17 and 18 reported by Peretti et al. (1999). Fixed proportions of variable costs and livestock net income relative to crop revenue are used to estimate the net income for 1986 and 1999.

### Baseline for policy analysis

The framework of benefit cost analysis is used to build a baseline for policy analysis: recovering wetland functions and so degraded croplands,  $L^d$ , (Equation 8) and avoiding future wetlands degradation and so cropland,  $PL^d$  (Equation 9). The loss of cropland value,  $LR(2001)$ , is estimated using the present value of damage function (Equation 4) that grow at a constant rate,  $g$ , in perpetuity (Boardman et al., 1996). It takes the forms:

$$LR(2001) = \sum_i^N \frac{DF_i}{r - \alpha_i g_i}, \quad r > \alpha_i g_i. \quad (8)$$

The other benefit will be stopping future cropland degradation. The net present value loss is the discounted value of the predicted damage stream plus the discounted value of the new degraded cropland at the end of the planning period and is represented by:

$$NPVL = \sum_{t=1}^T \sum_{i=1}^N PDF_i(t) \rho^t + \sum_{i=1}^N LR_i(T) \rho^T \quad (9)$$

where  $\rho = 1/(1+r)$ .

## Results and discussion

### Wetlands and degraded cropland

Wetland area increased between 1975 and 2001; however, the changed does not mean improvement of the wetland services. In Table 1, the results show that wetland areas increased by almost 90,495 (from 259 to 350 mil ha) ha degrading croplands by almost 58,196 ha and rangeland by 32,299 ha. Wetlands, areas affected by water, have increased from 18% to 25% of the MSW.

The area covered by wetlands in the MSW is significantly higher than the world's average (4-6% of the watershed; Mitsch and Gosselink, 2000) and also higher than that suggested in the literature to control floods

(De Laney, 1995; Mitsch & Gosselink, 2000). De Laney (1995), based on literature stated that less than 10% of the wetlands in a watershed can attenuate floods, capture and recycle nutrients and retain sediments. Mitsch and Gosselink (2000), reviewing literature on temperate climates, suggested that wetland proportion for watershed management must be between 3% and 7% of total land, depending on the types of services. In the MSW, wetlands cover more than twice the area recommended by the studies mentioned above. However, the wetland services have been reduced or lost in the last 26 years. Consequently, the amounts of wetlands in the watershed have not fully protected farming activities.

Table 1: Change in wetland, cropland and rangeland between 1975 and 2001 in the MSW, Córdoba, Argentina

Type	Year 1975		Year 2001		Change (2001– 1975)	
	Nº	Area (ha)	Nº	Area (ha)	Nº	Area (ha)
Wetlands	209	259,429	654	349,924	445	90,495
Croplands		1,060,000		1,002,709		-58,196
Rangelands		79,666		47,367		-32,299
		Length (km)		Length (km)		Length (km)
Streams (M and N)	23	810	26	987	3	177
Canals	1	97	16	504	15	406

Note: M: Permanent rivers/streams/creeks, and N: Seasonal/intermittent/irregular rivers/streams/creeks.

In this period, new sites classify as wetlands using Ramsay Convention increased from 209 to 654 (Table 1). During sporadic flooding, farmers and rural communities have pushed the state and government to build canals to get rid off temporary flooding and sedimentation from farmland. The emergency canals were connecting inland wetlands to other downstream areas. Canals have increased their length from 97 km in 1975 to 504 km in 2001. These actions are in line with the Level 3 of wetland degradation explicit in the conceptual model. This canalization changed watershed hydrologic parameters, causing higher water runoff and peak flow to other downstream areas. As a result, farmers and other people located downstream areas started to have even more damage due to flooding and sedimentation.

These emergency actions that deal with symptoms instead of causes of loss of wetland service have been the policy rule, causing a vicious circle, which is moving the region to an undesirable steady state in which most of the wetland services will be totally lost and an important area of cropland

degraded. This finding shows a domino effect of inland wetland degraded that was accelerated by public pressure and policies over temporary flooding.

### Economic impacts

Although agricultural modernization has increased net income in the MSW the lost of wetland services have reduced gradually it. The sources of growth of agricultural income have been changes of land uses, oil crops specialization and higher yields of crops while commodity prices went down during the 1990s. In 1986, the average farmer used to assign 68% of the farmland to livestock activities and 38% to crops, while in 1999 the average farmer assigned 49% of the land to livestock activities and 51% to crops.

Net incomes per hectare has increased from 1986 to 1999 (Table 2) due to agricultural modernization. The annual growth of net income,  $g$ , was on average 3.9%. It varies among environmental units. In the RBL, SBL and MTM,  $g$  was around 5%, which is accounted for by higher level of agricultural modernization in the MSW. In contrast, the farmers in the HB have presented the lowest  $g$  (2%). Using  $g_i$  estimated between 1886 and 1999, the net income for 1975 and 2001 are predicted *ceteris paribus* other variables. We can observe that in average net income predicted pass from \$48 to \$130 per hectare between 1975 and 2001.

Table 2: Net income and productivity growth by environmental units

Environmental unit	Net income from survey data		$g_i$	Predicted Net income (pnb)	
	1986 \$ ha <sup>-1</sup> year <sup>-1</sup>	1999 \$ ha <sup>-1</sup> year <sup>-1</sup>		1975 \$ ha <sup>-1</sup> year <sup>-1</sup>	2001 \$ ha <sup>-1</sup> year <sup>-1</sup>
High basins	74	96	2,02%	59	100
Plain with dunes and lagoons	70	108	3,39%	49	115
Raised block of Levalle	80	154	5,17%	46	170
Depression of Curapaligue	68	109	3,70%	46	117
Systems of Big lagoons	91	171	4,97%	53	188
Marshes of Tigre Muerto	74	137	4,85%	44	151
Total	73	120	3,90%	48	130

Note:  $g_i$ = annual growth rate of net income, Equation 5.

The aggregate net income in the watershed increased due to agricultural modernization and hidied the effects of cumulative erosion and loss of wetland services. Between 1975 and 2001, the aggregate net income has practically doubled (from \$58 million to \$109 million) in the MSW (Table 3). What would the aggregate net income be without cropland degradation?

Table 3: Net income with and without degraded cropland in 2001 by environmental units in the MSW, Córdoba, Argentina

Environmental unit	Net income with degraded cropland \$ year <sup>-1</sup>	Net income without degraded cropland \$ year <sup>-1</sup>	Damage due to degraded cropland (1)	
			\$ year <sup>-1</sup>	%
High basins	61,424,181	62,010,808	586,628	1%
Plain with dunes and lagoons	34,750,481	36,366,450	1,615,969	5%
Raised block of Levalle	8,227,564	8,969,112	741,548	9%
Depression of Curapaligue	3,704,129	6,401,463	2,697,334	73%
Systems of Big lagoons	1,116,758	2,576,927	1,460,169	131%
Marshes of Tigre Muerto	174,061	657,769	483,708	278%
Total	109,397,174	116,982,529	7,585,355	7%

Note: (1) Net income from agriculture is totally lost in degraded cropland  $\partial=1$ .

It would be around of \$117 million instead of \$109 millions in 2001 (see details in the fourth columns of Table 3). Thus, the damage due to cropland degradation was around \$7.6 million per year for 2001 (7% of the aggregate net income in the MSW). Although the aggregate net income loss was relatively low, the farmers in the intermediate watershed are critically affected (Table 3). For example, in the DC the aggregate net income in 2001 was \$3.7 million and the damage was around of \$2.7 million and in the MTM, the damage was 278% higher than the aggregate net income in 2001.

#### 4.3. Loss of the land value due to wetland degradation

The wetland degradation is a chronic effect and the loss of net income in degraded cropland is permanently. To account for these damages we estimate LR and NPVL. The LR is estimated with different hypothesis of net income loss, and productivity growth (see details in the Table 4). With loss of 70% of net income per ha in degraded cropland,  $\partial=0.7$ , and 50% of the historical productivity growth,  $a=0.5$ ,  $LR_{6\%}$  was around \$134 million (\$2,238 ha<sup>-1</sup>) while it is around \$467 million for  $\partial=1$  and  $a=1$ ,  $LR_{6\%}$ .

Table 4: Land value loss due to degraded cropland per environmental unit

Environmental units	Land degraded Ha	LR <sub>6%</sub>	LR <sub>6%</sub>	LR <sub>6%</sub>
		(1) \$ ha <sup>-1</sup>	(1)\$	(2)\$
High basins	5,871	1,402	8,231,187	14,748,115
Plain with dunes and lagoons	13,997	1,878	26,281,776	61,960,067
Raised block of Levalle	4,354	3,490	15,193,324	89,016,231
Depression of Curapaligue	23,013	1,976	45,476,441	117,082,543
Systems of Big lagoons	7,749	3,754	29,086,996	142,038,703
Marshes of Tigre Muerto	3,212	2,950	9,473,643	42,129,035
Total	58,196	2,238	133,743,366	466,974,692

Note:  $L^d$  = cropland degraded between 1975 and 2001. LR= the loss of land value: Equation 6.(1)  $\partial=0.7$  and  $a=0.5$ ; (2)  $\partial=1$  and  $a=1$ .

Although the upstream watersheds have been canalized to get off water runoff and temporary flooding to the intermediate watershed, the damage due to cropland degradation is still relatively high.  $LR_{6\%}$  accounted for \$8.2, \$26 and \$15 million in the HB, PDL and RBL respectively. These values should be considered to take action to restore inland wetlands in upstream watershed, which will reduce damage *in situ* and the cost of building and maintenance of canals. In contrast, although the aggregate net income of recovering wetlands in the intermediate watershed is higher it will depend also on action taking in upstream watershed, requiring a more integrated policy.

There are some experience that show that a restored wetland can provide benefits similar to a natural one (Gutrich & Hitzhusen, 2004; Kirk, Wise, & Delfino, 2004). Locally, they are technical experiences to recover degraded cropland and wetlands, by ordering land use, adjusting grazing systems and tillage systems, recovering vegetation in bare soil, managing soil and water runoff, and using mulch (Cantero G. et al., 1998).

If it is economically feasible to restore wetland service, it is likely that the incomes of cropland will be an excellent motivation for the overall economy, but the policy design must establish proper incentive for individuals to act over the causes of wetland degradation instead of symptoms.

### **Recovering wetland services and avoiding future cropland degradation**

In the Table 5, with 30 year planning horizon, the present value of the damage including the cropland already degraded and the new cropland degraded will add up to more than \$210 million of present value at 6% discount rate. It represents an average damage of \$1,759 per hectare for current and potential degraded cropland. These values can be used also as the baseline for the policy, which includes both recovering the wetland function/degraded cropland since 1975 and stopping future land degradation would avoid these damages.

Our estimates of damage are in the lower bound of wetland services founded in the literature. The average damage of current and potential cropland degraded is around \$128  $ha^{-1} year^{-1}$  at the 6% of discount rate in the MSW (vary between \$78 and \$254  $ha^{-1} year^{-1}$  for different units). These damages for losing wetland services are lower than the estimates of wetland services in temperate climates. According to Woodward and Wui (2001), the predicted values for flood control was \$982  $ha^{-1} year^{-1}$  with the 90% confidence interval \$222 to \$4,367  $ha^{-1} year^{-1}$ . Contrasted with the average value for flood control, the estimate of \$128  $ha^{-1} year^{-1}$  in the MSW is seven times lower although the annual damages for SBL and MTM are similar to the lower bound for the confidence interval established by Woodward and

Wui (2001). Brander et al. (2006) reported the average wetland value of \$2,800 ha<sup>-1</sup> year<sup>-1</sup> and the median value of \$150 ha<sup>-1</sup> year<sup>-1</sup> of a set of 190 articles around the world. Our estimates are in the lower ranges of the value presented by Brander et al. (2006). Brander et al. noted that the density of population and Gross Domestic Product (GDP) vary between countries, and in South America the value of wetland services has been relatively lower than in North America.

Table 5: Baseline for off-site effects of soil erosion in the MSW, Córdoba, Argentina

Environmental units	Degraded cropland		LR + NPVL at 6% of discount rate		
	2001 Ha	2031 Ha	\$	\$ ha <sup>-1</sup>	\$ ha <sup>-1</sup> year <sup>-1</sup>
High basins	5,871	12,621	13,494,898	1,069	78
Plain with dunes and lagoons	13,997	30,227	45,295,087	1,498	109
Raised block of Levalle	4,354	9,364	13,120,438	1,401	102
Depression of Curapaligue	23,013	49,623	78,864,435	1,589	115
Systems of Big lagoons	7,749	13,411	46,877,548	3,495	254
Marshes of Tigre Muerto	3,212	4,204	12,485,939	2,970	216
Total	58,196	119,450	210,138,345	1,759	128

Note:  $\delta = 0.7$  and  $a = 0.5$ .

We speculate also that our estimates may be understated wetland services for three reasons. The estimate accounts just for one specific service, flood control and the wetland provides other services, such as, pasture for breeding animals, cycling nutrient, habitat for biodiversity that have not been accounted. Second, our study considers just one type of user, farmers. Although farmers are the main landowner in the south of Cordoba there are other users of inland wetlands, such as, rural and urban communities, and people who use some inland wetlands for recreational activities. Third, the method used takes into account an indirect measure of wetland degradation: the loss of marketable products in degraded cropland but sedimentation by soil erosion causes other impacts on inland wetlands, such as, water pollution, invasion of alien weeds other chronic impacts that were not taking into account.

Nonetheless, the conceptual model and the value attached to the public service of inland wetlands in the MSW show the chronic effects of sedimentation, lessening the ability of wetlands to regulate the water cycle and the need for policy change. This policy change should focus on causes of wetland degradation instead of symptoms.

## Conclusion

In this paper, the indirect effect of agriculture on wetlands and its dynamic was identified by a simple model that account for damage on cropland and then valued it. Between 1975 and 2001, loss of wetland

services has permanently degraded 58 thousand ha of cropland, whose net income has been reduced by about 55-85%. If the trend of soil erosion-sedimentation loss of wetland services continues, the degraded cropland would reach 119 thousand ha in 2031.

During the 26 year period and more specifically in the 1990s, individuals and government actions have been motivated by market forces, increasing substantially agricultural incomes but at the cost of losing public service of wetlands. Wetlands have been usually undervalued and their functions gradually degraded. Policies have been pushed by public pressure to control symptoms of the problems, such as, temporary floods instead of causes soil erosion-sedimentation and wetland degradation. As a result, more areas have been affected by flood, salinization, and sedimentation. The external cost imposed by agriculture on wetlands has been slowly increased by such actions for a long time. If this behavior of farmers and government continues in the future, the intermediate watershed would reach the steady states in which most of the wetland services to farmers will be lost. As a consequence, the severity and frequency of floods in wet periods and of drought in dry periods is likely to increase.

Between 1975 and 2001 agricultural modernization has doubled the net income in the MSW and hidden the chronic effects of degradation of wetland services. The damage of wetland services measures as the asset value loss of current and potential degraded cropland has been estimated around \$210 million at a 6% discount rate. Although the damages are distributed among environmental unit, the farmers located in the intermediate watershed have been more affected by wetland degradation. More fundamentally, rural communities located in the intermediate watershed depend strongly on agricultural incomes, which are drastically being reduced by action taking far away of their own control.

The magnitude of damage that soil erosion-sedimentation causes off-farm should call the attention of farmers, the public, and government to the need to control soil erosion and to establish a proper policy incentive to internalize the off-site cost of agricultural modernization. Under classic economic assumptions, if farmers are induced only by market price, they will adopt the level of conservation practices whose marginal benefit offsets the marginal cost of soil erosion on-site, ignoring the off-site damage. Consequently, it is likely that farmers will adopt fewer conservation practices than those socially needed. Therefore, government policy should establish the proper economic incentive to the farmers, taking into account for both effects of soil erosion: on-site and off-site.

A policy is also needed to protect and enhance wetland services. By reducing soil loss, farmers will reduce the amount of sediment that can potentially arrive in the wetlands. Wetlands must function correctly to

accommodate the cumulative amount of sediments and water runoff over time in order to avoid or reduce future damage. The wetland policy should establish proper economic incentives for landowner and user of wetlands to deal with the public nature of wetland services. The policy should focus on protecting, conserving and enhancing natural or constructed wetlands because the current amount of wetlands working properly can apparently accomplish the basic function of buffering the water cycle, reducing the severity and frequency of floods and droughts.

Although the findings in this paper are in line with other articles in the literature, the reader should be aware that this study has some limitations. As noted before, there are other services that wetlands provide and other users that are not considered in this paper. There were also data limitations in distinguishing the specific contribution of farmland soil erosion from other sources of wetland sedimentation and the specific links between sedimentation and cropland degradation.

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