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A decision framework for wetland management in a river basin context: The "Abras de Mantequilla" case study in the Guayas River Basin, Ecuador

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ABSTRACT

The paper presents the development and implementation of a decision support system (DSS) for wetland management in a river basin context under data scarce conditions. It is shown that by combining hydrological, socioeconomic, institutional and biological indicators in a participative approach, a better understanding of the interactions between the different factors affecting the "wetland socio-ecological system conditions" can be created. For this purpose, mathematical models, expert judgment and stakeholder preferences were combined into an integrated DSS framework.

The DSS for the Abras de Mantequilla-Guayas Basin environment was derived from a generic, conceptual Decision Support Framework developed and proposed within the WETWin project, taking into consideration the specific conditions at the case study site. Standard methodologies for the characterization of wetland ecosystem services were applied and used to evaluate the effects of potential management solutions using appropriate criteria to assess the trade-offs.

In order to account for the interactions between the river catchment and the wetland system, an embedded modeling framework was adopted in which coupled models for rainfall-runoff and hydrodynamics including the wetland and its adjacent rivers provided the inputs to a water allocation model. Using these tools, several management solutions were evaluated, including a baseline scenario where climate changes were combined with the effects of major infrastructure works that are presently envisaged by the local water authority.

As a complementary tool for indicators based on poor quantitative data, expert elicitation was incorporated in the decision making process to capture the potential socioeconomic, institutional and ecological impacts of the various management alternatives. Simultaneously, stakeholder consultation (both users and decision markers) was carried out to derive current and future sets of preferences thus determining the criteria weight sets for different user groups. All these elements served as inputs to the DSS choice phase in order to provide a ranking of the proposed management solutions under each management criterion.

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At present, the option dealing with a moderate landuse substitution and reforestation was the preferred one by local stakeholders. In the future, there could well be an agreement between local actors and governmental agencies when their interests move closer toward more environmentally sustainable landuse. This decision support methodology may facilitate further negotiations toward a sustainable wetland system.

1. Introduction

Traditional studies in the past and some even now have addressed rivers and wetlands separately. In fact, in some early attempts, the European Water Framework Directive (WFD) itself (EC, 2000a) was not clear about wetlands domain and their management policies (EC, 2000b). Before 1996 the RAMSAR convention had not formally recognized a link between wetlands and river basins yet (RAMSAR_Secretariat, 2010). Simultaneously, decision support tools had been developed for catchments, but often with scarce considerations for wetlands (Ast, 2000; Barrow, 1998; Welp, 2001; Williams, 2001). Conversely, sometimes we have seen some DSS just for wetlands but outside a river catchment context (Kirk et al., 2004; Walters and Shrubsole, 2003). As a result of this division between wetland and river system components, often different management strategies, contradicting policy options or potential inapplicabilities in these twinned systems appeared as the most likely scenario.

It is well known that floodplain wetlands provide several benefits for a catchment. For instance, reducing flood discharge peaks and providing habitats for numerous wildlife species. Floodplains also depend on rivers for seasonal recharge. Riparian areas are considered as ‘‘buffer zones’’ between the basin and the aquatic environment (Hattermann et al., 2006). Therefore, wetland models, when working with hydrological and/or river routing models, usually imply a strong interaction between surface flow (runoff), interflow (soil water), and baseflow (groundwater fluxes) (Krause et al., 2007). Recognizing this, some recent approaches emphasize the importance of riparian wetlands for the outer river catchment (Bendjoudi et al., 2002; Blackwell et al., 2006; Hattermann et al., 2006). An overall view of coupled river-wetland systems analyses and management is required, especially facing the potential effects that climate changes have on water quantity and quality (Mynett, 2008). This overall view implies the inclusion of social, eco-hydrological, biological and economical aspects and indicators (Chaves and Alipaz, 2006; Goosen et al., 2007). Indeed, some researches reported embedded models into a catchment framework (Hattermann et al., 2006; Krause and Bronstert, 2004, 2005) conceived under the WFD (EC, 2000a). The European Commission seeks to clarify and enforce this role, in an attempt to insert wetlands into river basin management policies (EC, 2000b). One of the most important recent efforts is the WETWin project (Zsuffa, 2008), on which the current work is based. This European initiative aims to reformulate the role of wetlands in the context of integrated river basin management.

Therefore, an integrated decision support tool is proposed to help in the decision making process. A better wetland management guide can be achieved by adopting an approach that combines several sources of information. It is based on both quantitative assessment and human feedback. In first world countries, with complete datasets and developed models, only the qualitative approach might be needed (Young et al., 2000) to fully characterize an ecosystem and derive potential management strategies. However, in developing regions this is not the case as modeling frequently has to start from scratch. Besides, it is not always possible to find enough data in time and space and in many cases qualitative approaches are the only choice when models cannot provide support. Such application was carried out on the Abras de Mantequilla wetland system, in the Ecuadorian lowlands, one of the case studies within the WETWin project.

2. Objectives and approach

The main goal of the research reflected in this article is to develop a simple and still useful integrated framework or methodology for a coupled wetland-catchment environment, covering both the quantitative and qualitative approaches under data scarcity conditions, incorporating stakeholders' feedback, taking in consideration the pressures on the system and supporting the evaluation of relevant management solutions for a good decision making. Around this general objective specific targets are:

- Establish a set of indicators and define which of them will be assessed in a quantitative or a qualitative form, depending on the data availability. Characterize the system through a modeling framework and explore quantitatively the system behavior facing a general scenario and the performance of the management solutions that are proposed.
- Use expert elicitation as an alternative for those indicators without sufficient quantitative data. Consider different scholar opinions when evaluating the performance of a proposed management solution.
- Determine a final ranking of management solutions via a decision support system, where the feedback of data, models, scientists, stakeholders and decision makers is taken in account.

3. The Abras de Mantequilla case study

The Guayas River Basin (GRB) (34,000 km^2) is the most important riverine system in Ecuador. It is located in the central coastal region and drains southwards onto the Gulf of Guayaquil, on the Pacific Ocean (Arriaga, 1989). The two main

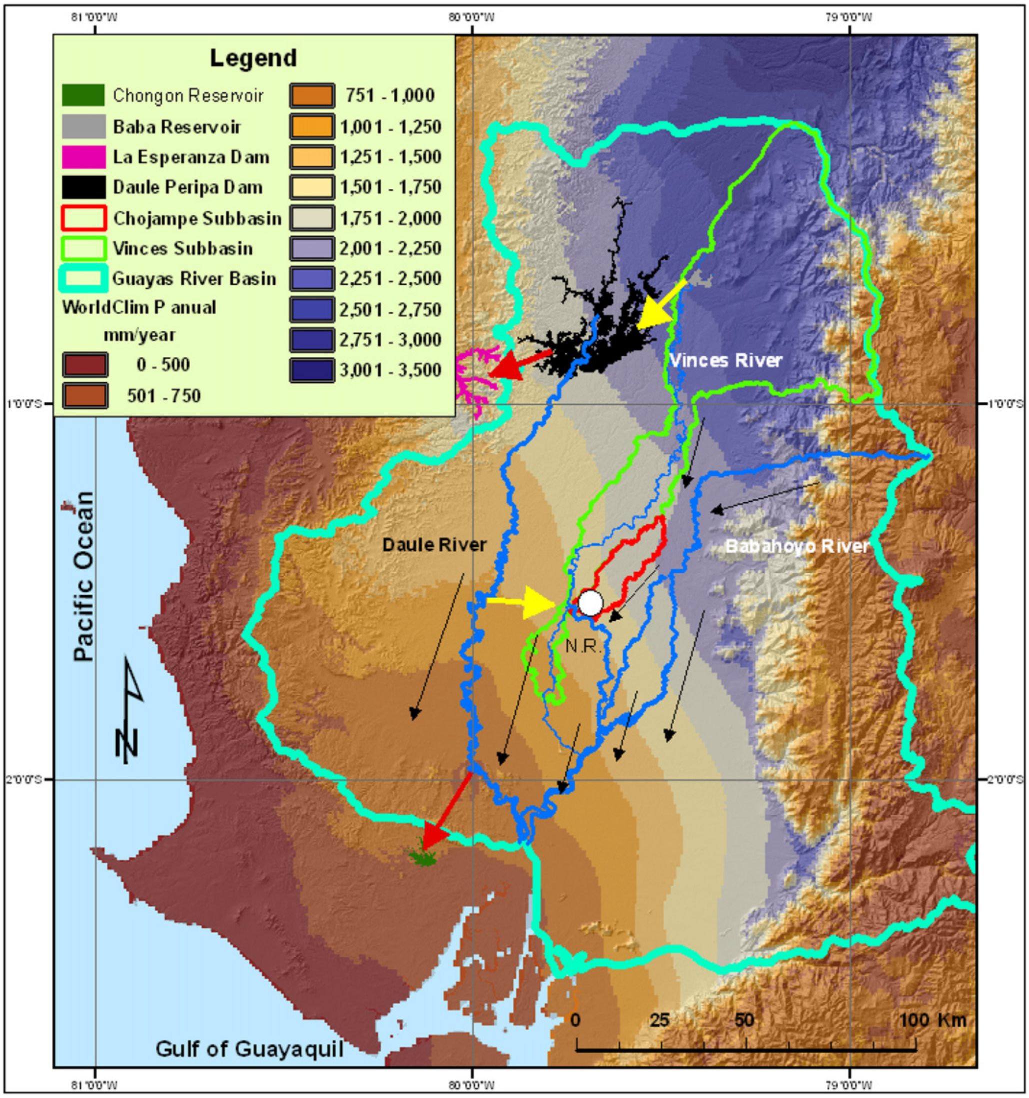

Fig. 1 – Guayas River Basin (Abras de Mantequilla wetland in white spot inside Chojampe subbasin, Nuevo River (NR), south of the wetland). Red arrows show current water transfer projects (Upstream: Daule Peripa to La Esperanza. Downstream: Chongon project, Daule River to Santa Elena peninsula). Yellow arrows mark future infrastructure works: Baba Dam (upstream zone to Daule Peripa) and DauVin transfer project (Daule to Vinces and Nuevo River – NR). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.) Arias-Hidalgo et al. (2011)

tributaries are Daule and Babahoyo (in March: 1043 and 2100 m^3/s respectively); however, during very strong rainy periods (during an El Nino) the Guavas estuary may carry as much as 5000 m^3/s (Waite, 1982). In the middle section of the GRB there is the Vinces catchment (5300 km^2) (CEDEGE, 2002) whose namesake river splits part of its flow onto the Nuevo River (Fig. 1). The Nuevo River interconnects with the Abras de Mantequilla wetland, but the flow direction depends on the seasonality.

The Abras de Mantequilla (AdM) (56,000 Ha) is a wetland system located in the middle part of Los Rios province in western Ecuador (Bird_life_international, 2006). According to the WET-Ecoservices evaluation (Kotze et al., 2008) and since 2000 (Bird_life_international, 2006), AdM was classified as a continental RAMSAR floodplain wetland, mainly because of its relevance as a nesting ground for migratory ornithological and ichthyological fauna. AdM is formed as a natural embankment on the left side of Nuevo River is the lower part of the Chojampe subbasin. The ecosystem services assessment also revealed that the most relevant ecosystem services that the system provides are maintenance of biodiversity, cultivated foods and natural resource extraction, water supply for human use, sediment trapping and erosion control, and streamflow regulation (Fig. 2a).

3.1. *System evaluation*

In terms of biodiversity, AdM is part of the upstream bioregion of the Gulf of Guayaquil. There are dry forest remnants in the wetland's surroundings (specifically in the lower lands),

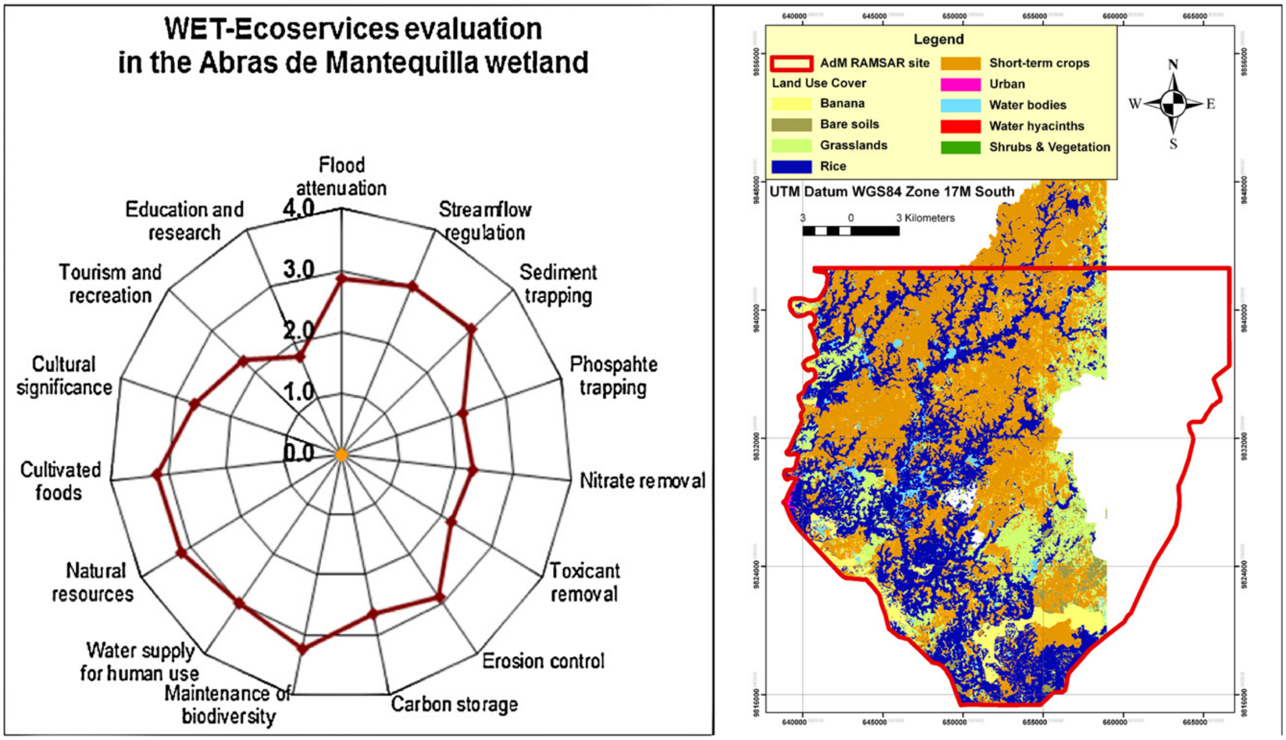

Fig. 2 – Left, (a) WET-Ecoservices evaluation in AdM; right, (b) landuse composition in AdM.

including some forests that flood periodically during the rainy season. In these forests there are over 728 registered species of vascular flora, classified into emerging species, canopy and lianas, which serve as water and nutrient sources for the species that dwell in the wetland ecosystem. Several plants develop in the riparian area, namely *Crataeva Tapia*, *Guadua angustifolia*, *Prosopis juliflora*, *Capparis angulata* and Mutingia calabura (Bird_life_international, 2006; Quevedo, 2009).

The WET-Health assessment (Macfarlane et al., 2008) was also carried out on AdM to obtain a firsthand assessment of the current status of the ecological system. Based on current information, the analysis performed by these researchers estimated that both the hydrologic and geomorphologic conditions of the system are currently in an acceptable status, with only moderate modifications due to anthropogenic activities. On the other hand, the level to which natural vegetation has been degraded as a consequence of agricultural activities is also remarkable. Actually, the score was ''F'' on the WET-Health scale, equivalent to critical levels of degradation. This output can be easily confirmed by the land use cover (LUC) map shown in Fig. 2b. The LUC map shows that forest land covers little more than 2% of the total area. The predominant land uses in the system are currently rice and maize crops, with an important presence of perennial pastures for cattle (they combine to almost over 88% of the total LUC) and banana crops in the south-western portion of the wetland (4% of LUC). In addition, there are several related issues affecting the wetland ecosystem's state, such as the extensive use of pesticides and fertilizers (yellow and red label pesticides are sprayed in large extensions of short-term crops) and the piling and burning of more than 50,000 Ha of short-term crop waste every year in the AdM.

Furthermore, there are upstream infrastructure works planned by the basin water authority. The construction of the Baba Dam (a multipurpose reservoir) and the Dauvin transfer project (Daule to Vinces, Nuevo & Puebloviejo Rivers) has started recently and may introduce noticeable effects on the entire system. Particularly the Baba Dam, which will divert a maximum of 234 m^3/s to the Daule-Peripa Reservoir, i.e. taking water out of the present system (Efficacitas, 2006).

4. DPSIR, scenario and management solutions

The DPSIR causal chains evaluation (Zsuffa and Cools, 2011) and the rest of the baseline results were presented to the Technical Secretariat of the AdM Commonwealth of Municipalities. This governance body collaborated with ESPOL (Ecuadorian University, a WETWin partner) staff to devise a set of management options (MO). These MOs focused mainly on minor hydraulic works and landuse improvement as follows:

- Option 0 – Business As Usual (BAU) or Baseline: based on the current system status while considering the effects of climatic variations on the system, no further management interventions should be implemented. More specifically, the two possibilities in mention, embedded in one general scenario were: (i) an expected increment in precipitation across the Ecuadorian coastal region (Nieto et al., 2002); and (ii) the Baba multipurpose dam project.
- Option 1 – local scale hydraulic gates: keeping water for dry season (June to December). With this alternative, an average of 22–25 Hm^3/year is expected to be contained in the

wetland. This should ensure navigability as well as reasonable water storage for environmental flows.

- Option 2 – agricultural practices: this option considers the adoption of an agricultural practices improvement plan at a local scale for short-term crop farmers (prohibition of red and yellow label pesticide use, compost elaboration, crop waste management, etc.). It is assumed as a policy compromise that 10% of the total LUC surface of the wetland will be available for this regime each decade.
- Options 3 & 4 – substitution of short-term crops for perennial agroforestry (e.g. cocoa & fruit trees). Option # 3 aims to substitute 10% of the short-term LUC extension per decade, whereas option # 4 increases that rate to 20%. Both have a cumulative effect.
- Option 5 – natural vegetation reforestation through ecological corridors, by substituting short-term-crop LUC at 5% rate per decade.

These MOs were combined into management solutions (MS) as follows:

- MS0: BAU (already including climate changes and major infrastructure works).
- MS1: O1 + O2.
- MS2: O1 + O2 + O3.
- MS3: O1 + O2 + O4.
- MS4: O1 + O2 + O3 + O5.
- MS5: O1 + O2 + O4 + O5.

O1 (water storage) and O2 (agricultural practices) were considered as the most important management options and hence they had to be present in every proposed management combination/solution. Reasons for that are:

- It is expected that the improvement in water quantity and water quality is achieved most effectively when water storage is incorporated.
- The enhancement of agricultural practice is nowadays a government policy; therefore it is advisable to match this national interest with local regulations and practices.

5. The modeling framework

Two main drivers were identified on the riverine-wetland system. According to the DPSIR chains (Zsuffa, 2008; Zsuffa and Cools, 2011) these were the major infrastructure works (a dam and a water diversions) envisaged by the basin authority (SENAGUA, National Water Ministry) and the landuse degradation. In order to quantify the pressures, a modeling framework was adopted considering the Vinces, the Nuevo River and the wetland itself. From this physical point of view, two quantitative indicators were assessed: water quantity and quality. This evaluation was carried out by means of a series of interconnected simulations. From a hydrological point of view, this embedded modeling framework was adopted to synthesize the scenario that resulted from the evaluation of the baseline and the application of management solutions for the two aforementioned indicators.

The proposed modeling scheme and its domain are shown in Fig. 3a and b, resp. Two rainfall-runoff models,

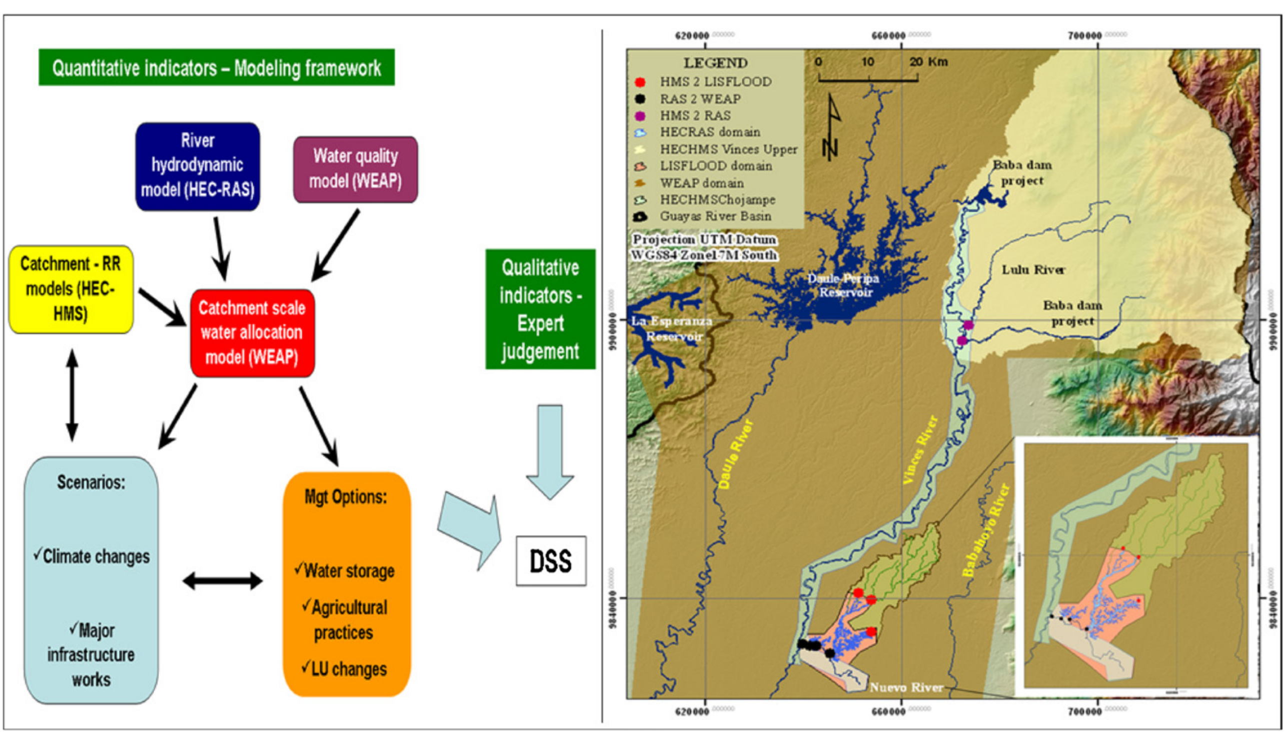

Fig. 3 – (a, left) modeling framework and expert elicitation toward a Decision Support System; (b, right) models domains and connection points between models.

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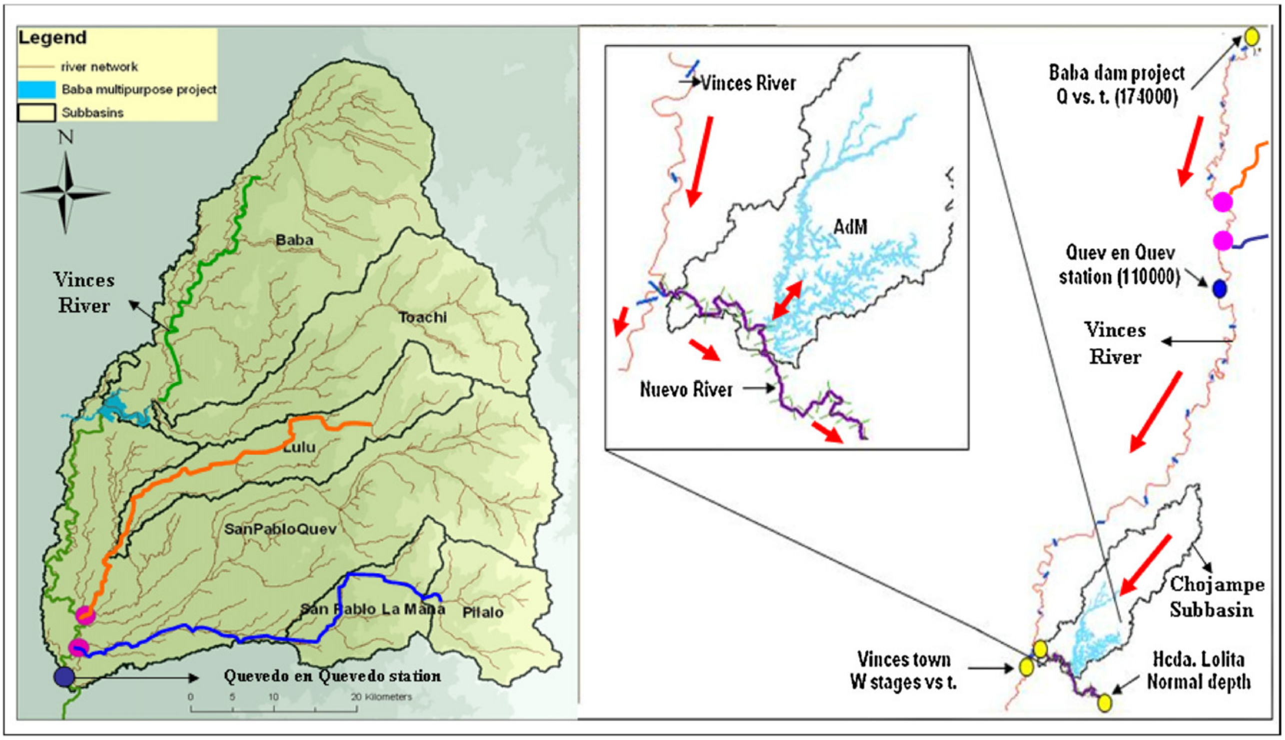

Fig. 4 – Left, (a) HEC-HMS model setup (Vinces upper catchment). Lulu River (highlighted in orange) & San Pablo River (in blue) connect to Vinces River (in dark green) at the purple spots; Right, (b) HEC-RAS model setup (including a zoom to Chojampe Subbasin & AdM system in its lower part). Red arrows indicate flow directions. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

using HEC-HMS (Sharffenberg and Fleming, 2010), computed river discharges from meteorological data, in the Vinces upper catchment (Fig. 4a) and the Chojampe subbasin, respectively. With these outputs, a river unsteady simulation employing HEC-RAS (USACE, 2010) was conducted along the Vinces, Nuevo River and AdM (Fig. 4b). Its main outcome was the flow exchange between the last two. Both simulations fed a water allocation model, WEAP (SEI, 2009). The latter assisted in the evaluation of the influence of climate change and major hydraulic projects in the basin as well as the proposed management solutions in the area.

5.1. *Rainfall-runoff simulation*

The model features are described in the supplementary file (Appendix A).

5.2. *Hydrodynamic model*

The model features are described in the supplementary file (Appendix B).

5.3. *Water allocation model*

The model features are described in the supplementary file (Appendix C).

5.4. *Quantitative outcomes*

Once the Baba Dam was included in the allocation model, there was a decrement of around 70% along Vinces River downstream from the future reservoir. However, this was compensated by the inflows from Lulu and San Pablo Rivers, especially when the climatic variations were inserted in the analysis. Nonetheless, there is still a strong effect (−43%) downstream at the split with Nuevo River, causing a decrement in the Nuevo River flows and the consequent discharge onto the wetland (Fig. 5a). Furthermore, through the allocation model it was found that DauVin has neither positive nor negative effect on the system, for the design along Nuevo River old bed route do not interfere with the flows currently entering and leaving the wetland. Actually, its design follows an old river path in Nuevo River and thus bypasses any intersection points. Climatic variations, on the other hand, mitigate the negative effects of the Baba Dam. For instance, along the Nuevo River, it was observed that starting from the third decade (2021–2030), the models predicted increments ranging from 11 to 23% in flows compared with the base year (2006). Furthermore the rising ratio between volumes from the 4th decade and year 2006, rose to 29 and 43% (Appendix D, Fig. D.1). This rising tendency was in agreement with local literature (Nieto et al., 2002). Ultimately, when both scenarios were combined there was a general recovery along Vinces and Nuevo Rivers of 18%.

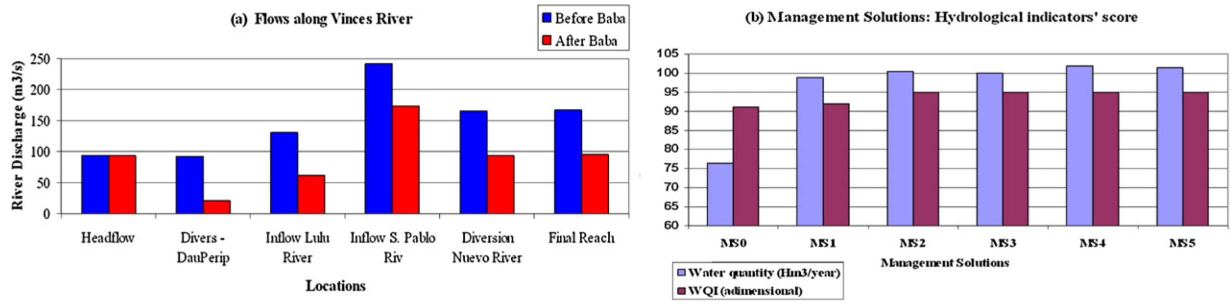

Fig. 5 – Left, (a) reduction of flows in Vinces river due to Baba Dam; right, (b) performance of MS in the wetland area.

Having in mind these effects, the use of gates to keep water in the wetland during the dry season was justified. Once the simulations were carried out, a summary of results in the water allocation model is shown in Fig. 5b. In general, remarkable increments in water quantity (+28%) can be observed between MS0 (BAU) and MS1 when the gates were employed. Indeed, strong interactions were confirmed during the rainy season between Nuevo River (from Vinces) and the wetland, reaching almost 14 m^3/s (peak in March 16th) and 4 m of water difference relative to the natural embankment. Nevertheless, since the magnitude of water retention and diversion is larger than that caused by land uses, there is a reduction in the increment of water quantity for the rest of options (MS2–MS5). It is noteworthy that even more aggressive landuse substitutions (MS3 vs. MS2) not necessarily mean improvement in water quantity; in fact, long-term crops (e.g. cocoa) also require massive amounts of water. Therefore, MS2 is better than MS3 in that sense. A similar result was observed when comparing MS4 (MS2 + reforestation) with MS5 (MS3 + reforestation), where MS5 might be more expensive in terms of time and money than MS4.

The Water Quality Index (WQI) (Brown et al., 1970) methodology was adopted to establish acceptance levels in the wetland area. In general, WQI levels are very high and still are consistent with previous studies (Prado et al., 2004). Unlike the case of water quantity, more noticeable improvements are observed not when water is retained but when better agricultural practices are introduced and even more (3%, MS1–MS2) when those are combined with crop substitution. Thenceforth, the situation remains more or less similar (WQI around 95) for the other options (e.g. MS4 and MS5), perhaps due to an insufficient reforestation rate (5% per decade). Therefore, MS4 emerges, from the hydrological point of view, as the best alternative to improve the two quantitative indicators in the system.

The aggregated crop production impact was simulated using the *Agrobasinmod* model (Appendix D). This dynamic simulation was based on an econometric estimation of spatial climate trends (precipitation, temperature) and other variables related to crop production for the representative producer of each crop type. Nonetheless, due to the data resolution for this indicator, it was only possible to use the simulations at a basin scale. Moreover, all MS considered the planning horizon that included the climatic scenario A2-N2 inside the BAU. The results implied a reduction compared to the 2006 GDP by 2030 and 2040 of around 13% and 33% (Appendix D, Fig. D.1), respectively. These were the expected impacts on the wetland agricultural sector due to climatic variations and population growth, according to the simulations.

In order to translate different magnitudes into a standardize "scale" (0–1), transfer value functions were adopted, one for each variable. For instance, for water quantity a minimum threshold of 5 m^3/s was selected ($F((Q = 5) = 0)$, based on ecological flows in Vinces River (10 m^3/s), suggested by previous environmental impact assessments (Efficacitas, 2006). For navigability purposes and irrigation in riparian areas and in absence of better judgment, $F((Q = 10\ m^3/s) = 0.3)$. Moreover, for discharges up to 15 m^3/s (irrigation for larger riparian areas), $F((Q = 15) = 0.6)$. Finally, $F(Q >\ = 50\ m^3/s) = 1$. Between the mentioned values, the function behavior was assumed linear. On the other hand, for water quality, the value function of the US National Foundation for Sanitation was chosen (Oram and Alcock, 2010).

Nevertheless, a complete analysis cannot be based only on quantitative indicators. Firstly, insufficient data leads to the necessity of expert judgment or "*human feedback*". Secondly, the inherent nature of socio-economic indicators makes the opinion of stakeholders and experts crucial to complement the hydrological considerations that the management solutions (e.g. MS2 or MS5) initially emphasize. Hence, more clarification on the appropriate ranking of solutions is still required.

6. Expert judgment for qualitative indicators

For those identified indicators with insufficient or no data, a qualitative assessment was carried out (Fig. 3). Elicitation of expert judgment was applied as suggested by previous researches in hydrological and environmental sciences (Brown and Heuvelink, 2006; Morgan et al., 2001). The set of 16 indicators (Appendix E, Table E.1) include agricultural opportunity costs and productivity, biodiversity, tourism potential and eutrophication. A questionnaire was used for interviewing a panel of 10 multi-disciplinary and multi-institutional experts in various fields (biology, agricultural production, stakeholder dynamics, etc.). The experts belonged to the following institutions:

- Ministries of Agriculture and Environment.
- Local municipalities.

- United Nations Development Program.
- Academic staff of local universities.

All indicators are individually presented in a centered Lickert scale (1–5) (Burns and Bush, 2008), where 1 meant the worst and 5 the best. Since there was more than one expert for each indicator, the arithmetic mean of all the responses was taken as the aggregate indicator value. This was done since there was no a priori reason to overweight one expert opinion over another, as they were both experts on the domain the indicator was meant to capture. The actual meaning of each scale value depended on the specific indicator, but all of them follow one of two possible schemes:

- Socioeconomic, stakeholder, and ecological indicators were measured under all MS through qualitatively comparing their relative value to the BAU scenario.
- Institutional indicators measure absolute values and refer to the institutional capacity to adopt each proposed alternative.

In most of the indicators MS5 & MS4 were the preferred by most of the consulted (Appendix E, Fig. E.3). There seems to be a tendency toward food safety and the biodiversity. For the first indicator, the experts considered that highly elaborated management solutions may provide food sources to a greater extent, through a more aggressive crop substitution and the reforestation. As for biodiversity, larger weight was granted to those alternatives dealing with ecological corridors as potential hubs for species. Nevertheless, there were some exceptions; especially in those related with costs (e.g. Crop investment/sowing per Ha.) for the MS4 & 5 alternatives may require higher initial investments to be operative than for the simpler choices MS1 & 2.

7. The decision support framework

The socioeconomic context of the wetland encompasses a total of 9 municipalities where the Baba, Pueblo Viejo and Vinces are the most active ones. These municipalities pooled together in 2008 to form a commonwealth to address land use and waste disposal issues. In 2010, this process (which already included most of the other 6 municipalities) gained legal status. In view of these developments, ESPOL (partner of the WETWin project) established a cooperation agreement with this legal body, under which the implementation of a participatory Decision Support System (DSS) for LUC-related planning was envisaged. The proposed DSS was conceived in the context of the framework proposed under the WETWin project (Zsuffa et al., 2010), adapted for the data scarce conditions present in Ecuador. By combining hydrological, socioeconomic, institutional and ecological indicators in a participative approach, a better understanding of the interactions and trade-offs between the different factors affecting the ''wetland socio-ecological system conditions'' was achieved. To that end, mathematical models, expert judgment, and stakeholder preference elicitation schemes (similar to Fig. 2a) were employed.

In order to standardize the different sources of information, various alternatives for a normalized value function choices were considered. The AdM Commonwealth and the stakeholders were asked to select the ''best'' choice out of the following proposed 4 options (Appendix E, Fig. E.2), as was the case of the qualitative indicators: (i) Quadratic; (ii) 1 + Log; (iii) Potential; and (iv) Linear.

For the quantitative indicators (e.g. water quantity), the normalized value function behaved mostly linearly. As for the degradation index, it used the decreasing function suggested by the WET-Health methodology (Macfarlane et al., 2008). To derive weight sets for the criteria, separate workshops were conducted with local stakeholders and the AdM Commonwealth of Municipalities. Each group was asked to prioritize the management domains (Appendix E, Table E.2). The fact that some fields such as carbon storage, water supply and flood control have weights equal to zero was because either data were insufficient to derive a weight or there was no available expert opinion. As shown earlier by the WET-Ecosystem evaluation, this does not mean that these domains were not important for the AdM wetland management. Since each indicator category is known, it was possible to derive the corresponding influences by means of *hierarchical weighting* of: (a) each management domain and (b) each indicator within each domain category. Stakeholder workshops were used to elicit preferences of local stakeholders (voting) with respect to current and future management domains.

All these elements were combined through the *mDDS* 5 tool (Giupponi and Cojocaru, 2010). Indicator values for each MS were used to form the *analysis matrix* (several sources, several scales) and later translated to a normalized *evaluation matrix* (0–1) using the value functions described above. For the Multicriteria Analysis, this research used the Multiple Attribute Decision Making (MADM) and as decision rule the Simple Additive Weighting technique (SAW) (Sen and Yang, 1998). Perhaps these approaches may seem too simple or outdated but given the low data availability and the scarce previous experiences in the study area, a balance was sought between sophistication and applicability of the modeling framework and the DSS process. Currently this is a major issue to tackle between two tendencies: the studies when scientific discovery or breakthrough is the sole target and those which aim to more practical applications (Clement, 2011). Finally, for the choice phase of the DSS, each criterion weight set was used to obtain a MS ranking for each decision group.

After the analysis, it appeared that priorities between the local management structure and local stakeholders were not compatible. The latter preferred MS4 which was consistent with what was found by the WET-Ecosystem evaluation, especially linked to cultivated foods (crop substitution & agricultural practices) and maintenance of biodiversity (reforestation). Indeed, the crop maintenance and investment costs/Ha held the largest weights (in average amongst the MS) with 16 & 15% resp. (which actually meant more reduction on costs according to the stakeholders in the interviews), followed by water quantity (8%, related to crop irrigation). Although biodiversity (ecological corridors) introduced an important contribution to the preferences (MS5 is the second best in the ranking), MS4, with its moderate crop substitutions and less crop costs (compared with MS5), still

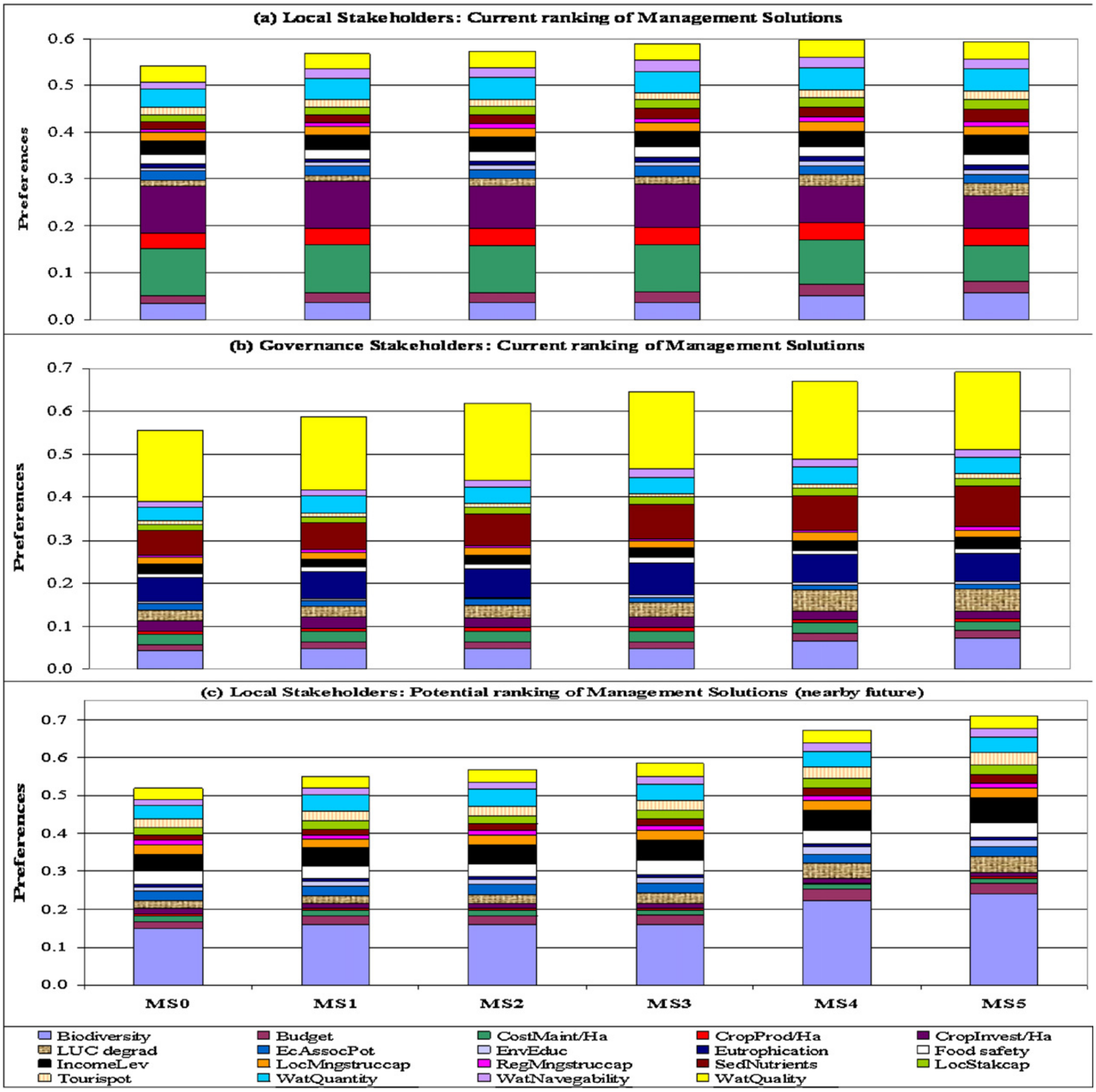

Fig. 6 – Above, (a) local stakeholders current MS preferences; middle, (b) Government stakeholders MS preferences; below, (c) local stakeholders potential MS preferences.

remained as the preferred management solution by the local actors (Fig. 6a).

On the other hand, it was observed that governance stakeholders (AdM municipalities) gave more importance to water quality (sanitation) issues than other domains (27% of the total, in average for each MS). This is consistent with other resultant weights such as nutrient/sediment retention (11.8%) and reduction of eutrophication (10.4%). But they also regarded biodiversity and lower LUC degradation indices as one source of higher income levels and development of touristic potential. Moreover, the weights increased when moving toward more elaborated MS (3, 4 & 5). Hence, their selected choice was MS5 (i.e. intensive landuse substitution and use of ecological corridors) (Fig. 6b).

In general, there was a balance between indicators with quantitative and qualitative background. There was no clear correlation between lack of quantitative data and low weights. First of all, in the current local stakeholder view, criteria such as cost maintenance & investment/Ha (based on expert opinion) had large weights compared to others (Fig. 6a). A similar situation was observed in the current government view (Fig. 6b) where eutrophication (low data availability) and budget (expert judgment) had a strong influence. The latter was not surprising since money is frequently a key issue when dealing with authorities. Finally, biodiversity, another criterion with insufficient quantitative data, had a large weight in the future view of local stakeholders (Fig. 6c). This was in strong correlation with ecotourism, one of their envisaged potential income activities.

Notwithstanding these preliminary different preferences, future expectations of local stakeholders show that if reinforcement and management are sustained, the current local vision may match with the government stakeholders current policy views. It was found that biodiversity in the nearby future is a major concern of local farmers and fishermen (in average 30.1% of the total weight). Secondary major factors were the income level and food safety, which may suggest a potential shift in their daily activities. The touristic potential also contributes to the top ranking of the MS5 option, since several stakeholders consider ecotourism as an important source of revenues in the upcoming years (Fig. 6c). This fact has a potential for engaging in negotiation processes directed to facilitate the territorial ordering process that is currently taking place in the AdM municipalities by command of the central government in Ecuador.

8. Conclusions, recommendations and lessons learned

A set of drivers, pressures, states, impacts and responses was identified for the riverine-wetland system of Abras de Mantequilla. They were influenced by two major factors: firstly, the construction of large-scale infrastructure works in the basin, and secondly, substantial landuse degradation. For those indicators that could be quantified (i.e. water quantity and quality), an integrated and adaptive modeling framework was applied where hydrological, hydrodynamic and water allocation approaches simulated how the system works at present and may behave in future. Considerable interactions between the wetland and the river depending on the seasonality were confirmed. The effects of the Baba Dam, although initially high along the upper Vinces River, are attenuated by its two main tributaries. Moreover, the DauVin project seems to have negligible influence on the system. Finally, climate changes in the study area tend to increase the water volume, mitigating somehow the flow reduction due to the infrastructure works. To translate different values and scales to the DSS a normalized value function was selected depending on the indicator and previous evaluations (such as the WET-Health).

Despite this proposed conceptual methodology, there is still room for further development on the modeling framework, for instance with emphasis on improving the models interconnection. Since several assumptions and simplifications had to be incorporated along the modeling chain, it is advisable to implement an uncertainty propagation analysis to provide a suitable probabilistic support to the decision maker. In this regard, reducing assumptions and increasing data density (e.g. groundwater) may entail: (i) an enhancement on the analysis of the current quantitative indicators (e.g. water quantity) and their respective management options (e.g. water storage); (ii) that some current qualitative indicators might be objectively quantified (e.g. sediment trapping capacity); (iii) the consideration of complementary management options related to those ''new'' quantitative indicators; and (iv) a potential refinement on the final ranking of solutions.

For evaluation of the qualitative indicators (which were the majority), expert judgment and stakeholder feedback were found to be useful. Expertise from scholars and local people about the system and their opinion about the five proposed management solutions gave a number of scores and consequently led to some sort of quantification. In addition, stakeholders provided their views with respect to the wetland ecosystem services and to what kind of normalized value function was the most appropriate to describe the ranking amongst the MS. For the consulted experts MS5 and MS4 were ranked as the most relevant measures for the wetland management. It is interesting to note that, although following different approaches, the quantitative and qualitative techniques gave similar results.

Furthermore, the most elaborate and complex option (MS5) was preferred amongst governance stakeholders (mainly municipalities). On the other hand, the local stakeholders (mostly farmers), when consulted about their present and future interests, are of the opinion that small-scale crop substitution and some reforestation would be the best way to restore the wetland. At the same time, they also regard AdM as a potential ecotourism hub for Los Rios Province in a near future, and are willing to consider more radical changes in landuse cover (e.g. cocoa instead of corn); thus MS5 may also be their choice for the longer perspective. Globally, the DSS tool developed by the WETWin project remains open for more and better data and enhancement, for instance, to clarify even more the evaluation of some management axes/indicators (e.g. flood control). By allowing space for future negotiations among the actors, this methodology is amenable to continuous enhancement toward better wetland and river system management, despite the initial problem of data scarcity.

Finally, from a regional perspective, in Latin America it is still difficult to devise long-term policies because authorities frequently do not consider about what may happen after their government period. That is the reason why the future views of the government stakeholders could not easily be measured. In this regard, the Ecuadorian government is nowadays seeking for stronger and longer-term policies on agricultural practices, environmental protection and rights of nature (National_Assembly, 2008). In addition, manifold perspectives are taken in account by the national authorities, integrating several ministries and public dependencies and dividing the country into separate river basins to enhance the management of natural resources.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2012.10.009.

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