

1 Sensitivity Maps in Environmental Impact Studies

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5

6 **Abstract**

7 Environmental Sensitivity is closely linked to the concepts of reception or absorption
8 (recovery) that have environmental components, such capabilities must be addressed in a
9 holistic and integrated for analysis of constructive alternatives to incorporate
10 infrastructure. Environmental Sensitivity Maps are undoubtedly important to define a priori
11 the contingency plans, corrective actions, mitigation or compensation to the occurrence of
12 damage to the environment. A case study is presents for the installation of production
13 infrastructure; environmental sensitivity is analyzed through physical, biological and
14 socioeconomic factors (landscapes): surface runoff, topography, soil type, flora -wildlife and
15 land uses. For the generation of environmental sensitivity maps a weighted polynomial was
16 used whose weights were defined on the basis of consultations with experts. Four alternatives
17 for an aqueduct were compared, which are analyzed according to the environmental sensitivity
18 of the areas traversed. The alternative path was defined by the engineers, in charge of the
19 hydraulic project aspects, and the application of the optimal path algorithm, using the
20 environmental sensitivity map as friction, to determine traces of each alternative with less
21 sensitivity. Environmental Sensitivity Maps showed consistency in the analysis of alternatives
22 for the location of new infrastructure.

23

24 **Index terms**— environmental sensitivity maps, environmental impact studies, landscapes, gis, optimal path.

25 **1 Introduction**

26 Environmental Sensitivity (ES) is defined as the susceptibility showed by the different components of natural and
27 built environment for the purpose of further action of man or the influence of climatic factors on the system.

28 'Landscape sensitivity relates to the stability of character, the degree to which that character is robust enough
29 to continue and to be able to recuperate from loss or damage. A landscape with a character of high sensitivity is
30 one that once lost would be difficult to restore, and, must be afforded particular care and consideration in order
31 for it to survive'. ??Bray, 2003 cited in Tartaglia ??ershaw L, et al., 2005, p.7).

32 The new sustainable development paradigm, provides the necessary balance between productive activities,
33 social welfare and environmental conservation.

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35 National University, Bolivia Avenue 5150, A4408FV Salta, Argentina. e-mail: nunezv@unsa.edu.ar ES models
36 are the first step in finding this harmony. (Rebolledo, 2009).

37 Thomas and Allison (1993), consider landscape sensitivity as the potential and magnitude of change likely to
38 occur within a physical system, and its ability to resist it, in response to external effects. These may be natural
39 or man induced.

40 The environmental components present unequal levels of prior alterations and different capacities to absorb or
41 assimilate new impacts to which they are subjected. Is now accepted that man has some influence over climatic
42 factors.

4 A) FACTOR 1 -SURFACE HYDROLOGY

43 From the ecology perspective, ES is defined as the ability of an ecosystem to withstand alterations or changes
44 caused by human actions, without suffering drastic alterations that prevent you from achieving a dynamic balance
45 that maintains an acceptable level in structure and function; their identification and measurement depend on the
46 scale of observation (Meentemeyer and Box, 1987).

47 The level of Sensitivity depends on the degree of environmental and ecosystem conservation, especially, of the
48 presence of external actions (anthropogenic).

49 ES is closely linked to the concept of reception capacity (Environmental Tolerance) that the environment
50 (Landscapes), these capabilities must be addressed in a holistic and integrated perspective for the analysis of
51 constructive alternatives to be incorporate in the infrastructure. Quantification landscape reduces the complexity
52 of a set of numerical values or index (Matteucci, 1998).

53 All of the above requires a combination of tangible and intangible aspects in a valid scale for decision-making,
54 according to a new rationality (Saaty, 1996 ??ited in Moreno Jiménez et al., 2001, p.6). (esm) on Environmental
55 Impact Studies (eis) Within the general framework of the EIS, the Environmental Sensitivity analysis (ES) is
56 incorporated in the Effects Prevention Stage, hand in hand, as the prospective process, with the members of
57 the working group for further evaluation of EI. Moreover, the ESM are instrumental simulation models (Moldes,
58 1995) itself, which can be the base for a preliminary assessment of the current conditions of the environment
59 against the actions foreseen in the project's idea stage. ESM also represent an input to perform reports on
60 Environmental Impact Statement (EIS), as required by the relevant public authorities for smaller projects. A
61 case study is presented for the implementation of an ESM for the construction and operation of a aqueduct for
62 the provision of water for an ammonium nitrate production plant, located nearby the town El Tunal, Metán
63 Department, Salta Province, Argentina (Figure ??). Four alternatives were analyzed for mentioned aqueduct
64 traces, depending on the environment sensitivity.

65 2 II. Environmental Sensitivity Maps

66 The area under analysis is presented in Figure ??, showing the site where the ammonium nitrate production
67 plant will be installed, which requires a permanent water supply.

68 3 Methodology

69 For Environmental Sensitivity analysis an index has been designed, in which three components of Environmental
70 System Matrix Importance (physical, biological and socioeconomic) were considerate.

71 To evaluate Physical Environment sensitivity, these factors were established: hidrology -surface runoff (lotic)
72 and surface water (lentic) -, topographythrough the slope -and finally, soils (Soil Groups and Suitability Classes).

73 To construct the factor for Biological Environment a combination of conservation value index, obtained for
74 plant communities and birds, was used.

75 The Social-economic Environment was assessed in terms of the different land uses in the area and its related
76 infrastructure, reflecting also on the degree of involvement that economic activities may suffer.

77 Factors (criteria) were selected by specialists from an initial hierarchical list, according to the relevance defined
78 for the project objectives.

79 Environmental Sensitivity map (Figure 16) was obtained by the weighted sum of the sensitivity maps for each
80 factor, as shown in Figure 4. Maps of sensitivity for each factor were standardized on a scale of 0 -10, 10 being
81 the maximum value. Analytical Hierarchy Process copes with using original data, experience and intuition in
82 the same model in a logical and through way (Forman, 1999 cited in Büyükyazıcı, Sucu, 2003).

83 Then, a set of weights for each of the factors was established. The analyst worked in group with specialists to
84 complete the comparison matrix in pairs. Wondered to each specialist individually to estimate a rating and the
85 group if it was agreed to start the debate. The consensus was not difficult to achieve with this procedure.

86 4 a) Factor 1 -Surface Hydrology

87 The drainage network was derived from a Digital Terrain Modeling (ASTER satellite, resolutions 30 m -Figure
88 5) and interpreted from high spatial resolution images (CBERS 2B HRC, resolutions 2.5 m Figure ??).

89 Comparisons are made in pairs and concern the relative importance of the two criteria involved in determining
90 suitability for the stated objective. Ratings are provided on a nine-point continuous scale (Eastman et al.,
91 op. cit.). The equation was developed to mitigate the sensitivity to drainage networks environment and to
92 achieve a gradual reduction in sensitivity as a function of distance from the axis of each drainage (talweg). The
93 exponent allows to adjust the spatial scope of sensitivity according to the importance of the hydrology factor in
94 the environmental context (Figure 5). The environmental sensitivity for the physical environment, was directly
95 related to the environmental susceptibility to erosion, capable of generating economic or social involvement and in
96 whose prediction, prevention or correction geomorphologic criteria should be used. For the orderly classification
97 of slopes an exponential function was used $y = 0.1749 e 0.6409x$. Then S factor (steepness: Revised Universal
98 Soil Loss Equation -RUSLE -) was calculated (Foster et al., 2003). Finally, the following linear equation was
99 used: $y = 0.882x + 0.745$, with an $R^2 = 0.942$, for assigning values of topography sensitivity by the S factor.

100 **5 c) Factor 3 -Soils**

101 Considering the characteristics of Soil Associations (Nadir and Chafatinos, 1995) present in the area under
102 analysis the Soils Sensitivity map was generated (Figure 13). In this case, the Soils Group, the Suitability Class
103 and the type of landform that corresponds to each unit were considerate (Table 3).

104 **6 (B)**

105 **7 d) Factor 4 -Flora and Wildlife**

106 Considering both, the importance and the conservation status of different flora and wildliferepresented mainly
107 by birds as indicators of environmental condition-, the fourth factor was built (Table ??). A good environmental
108 quality has a greater number of animal populations.

109 **8 (B)**

110 Table ?? : Values assigned to the categories of factor 3: Sensitivity for Flora and Wildlife Units.

111 **9 Flora and**

112 **10 f) Alternatives Trace**

113 As it has already been said, four alternatives of the aqueduct trace were compared, such alternatives are analyzed
114 according to environmental sensitivity of the areas traversed. The alternative path was defined by the engineers
115 in charge of the hydraulic aspects project, taking into consideration the possible water taking sites (Figure 10).

116 **11 (B)**

117 e) Factor 5 -Land Use Considering Land Use, the fifth sensitivity factor was created that includes the categories
118 listed and valuated in Table 5. As part of alternatives analysis, the optimal path algorithm (PATHWAY: IDRISI
119 Taiga V. 16.05) was applied, using the Environmental Sensitivity map as friction (Figure 16).

120 IV.

121 **12 Results**

122 Below are the sensitivity maps obtained for each factor. For Environmental Sensitivity analysis a sample at
123 random points 100 was extracted, probability distribution is shown in Figure 17, while the descriptive statistics
124 are presented in Table ??.

125 **13 Frecuency**

126 **14 Class**

127 **15 Environmental Sensitivity**

128 The average of environmental sensitivity is within the interval ± 0.22 respect to the average of the sample with
129 a probability of 95%.

130 **16 a) Alternatives Trace Analysis**

131 All alternatives trace run through areas with medium to low environmentally sensitivity. The greater
132 environmental sensitivity is present in the trace for Alternative 3, followed by 4, then 2 and finally 1. It should
133 be taken into account that: Alternatives 1, 2 and 4 have values close to environmental sensitivity and did
134 not differ between them in more than 23.7%. (Table 7 and Figure 18). To the traces defined by Optimal Path,
135 Environmental Sensitivity decreases for all alternatives, although that increases the length of the trace 3p and 4p.
136 (Table 7 and Table 8). Comparing the alternatives 1 and 1p, the second reduced 29% environmental sensitivity
137 respect to the first. Finally we conclude that the trace 1 and 1p presents the lowest environmental sensitivity.
138 Managers must be decide what is the final trace, taking into consideration other criteria such as the costs of
139 construction and operation.

140 V.

141 **17 Discussion**

142 Environmental Sensitivity is a concept closely linked to landscape as a complex system. Quantifying the landscape
143 through indexes, reduces system complexity allowing spatial pattern analysis, and process alterations under study.

144 Environmental Sensitivity Maps are an instrumental model that provides adequate and sufficient information
145 for understanding current conditions and the ability of the landscape to absorb new actions.

146 Environmental Sensitivity analysis can be incorporated into the forecast stage of Effects on Environmental
147 Impact Studies. Environmental Sensitivity Maps represent an input for carrying reports on Environmental Impact
148 Statement.

17 DISCUSSION

149 Hydrological Sensitivity equation allowed to integrate spatially the hydrologic factor as a decreasing continuous
150 variable from drainage networks and water bodies. This function solves the problem of localized effect of the
151 valuation of discrete entities.

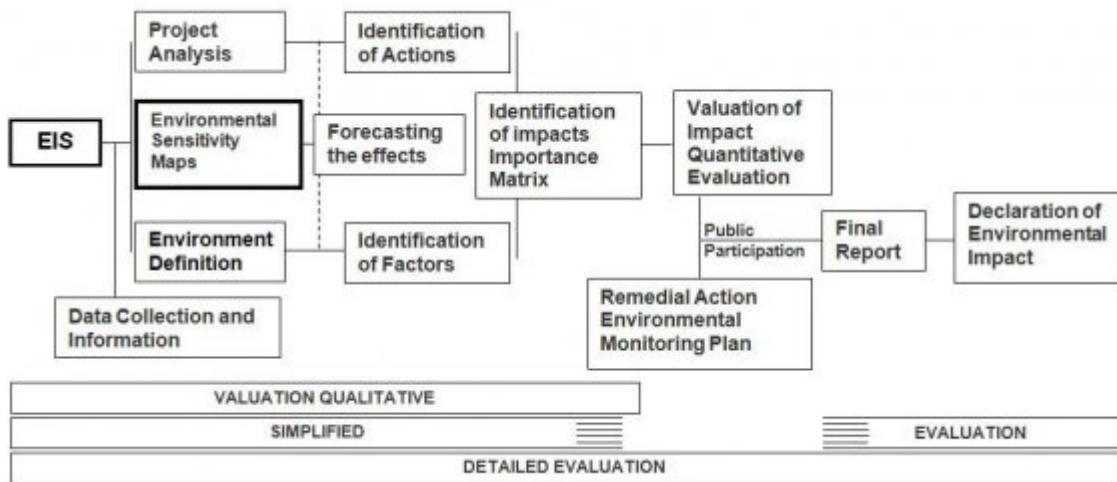
152 Environmental Sensitivity Maps showed consistency in the analysis of alternatives for the location of new
153 infrastructure. The combined use of environmental sensitivity map and the Pathway method allowed to define
154 alternatives of trace for the aqueduct more efficiently from environment perspective.

VI.



Figure 1: Figure 1 :

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Figure 2: Figure 2 :Figure 3 :

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Figure 3: Figure 4 :

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Figure 4: Figure 5 :



6

Figure 5: Figure 6 :

1

Figure 6: Table 1 :

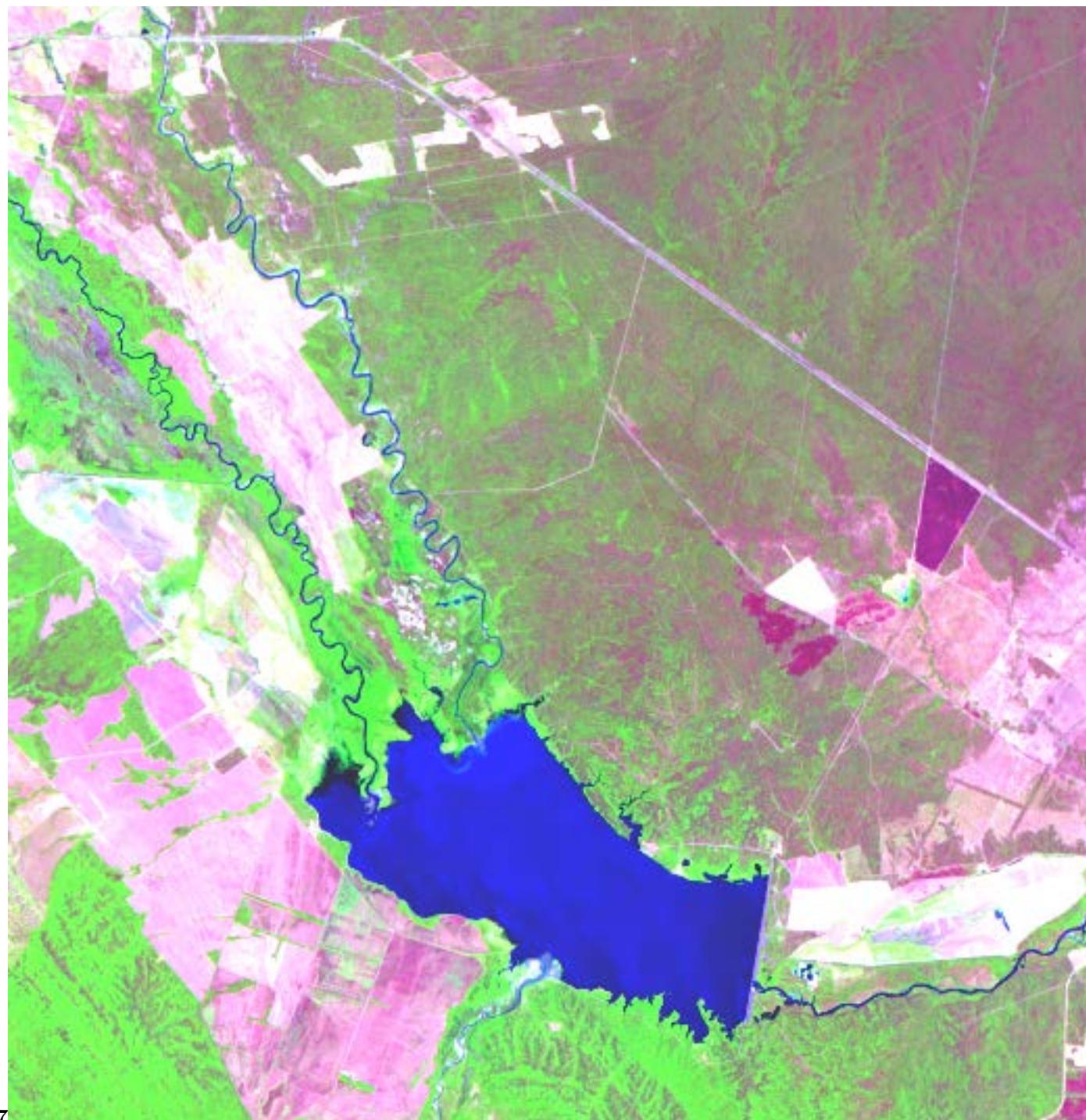
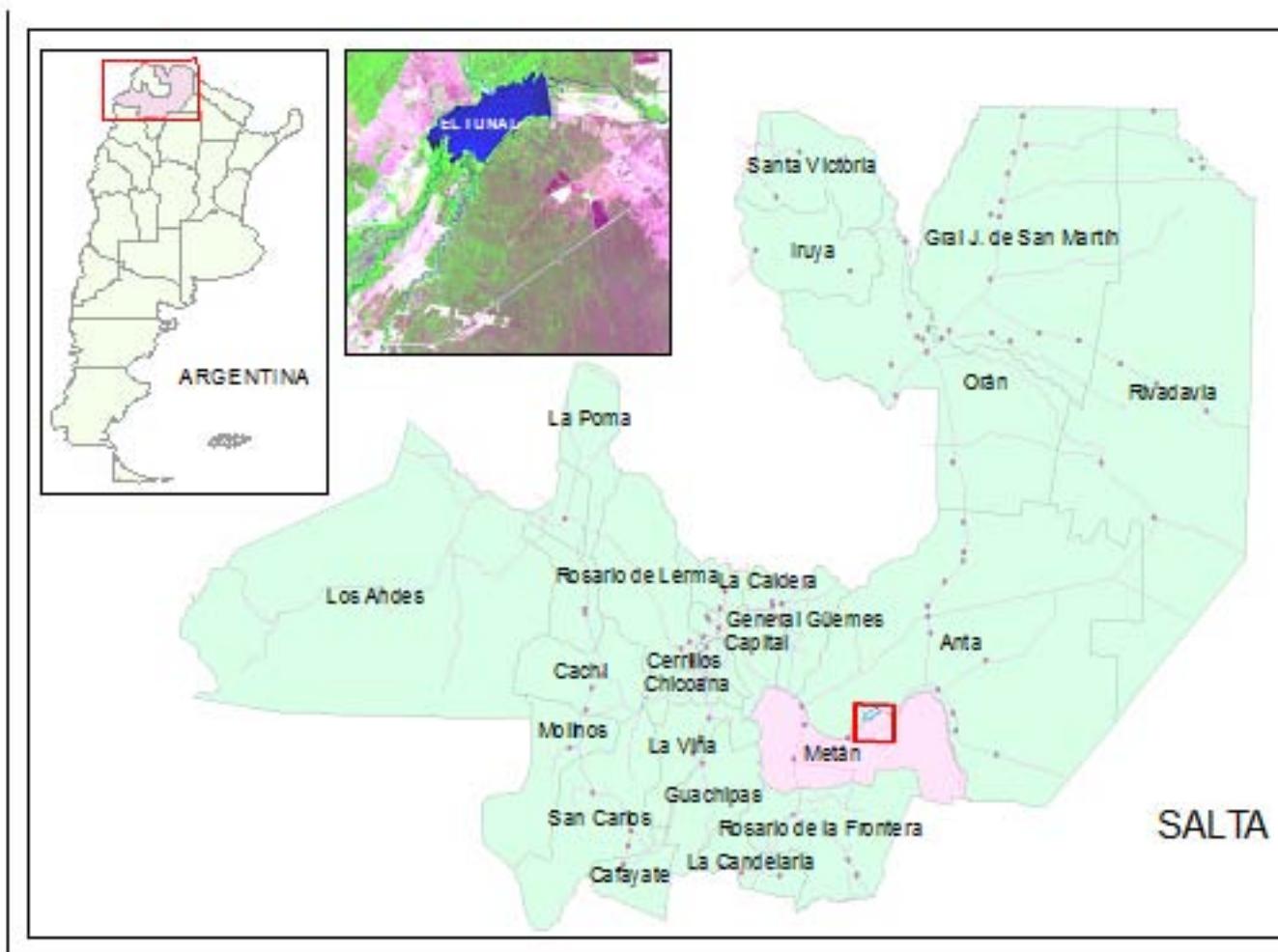


Figure 7: Figure 7 :



8

Figure 8: Figure 8 :

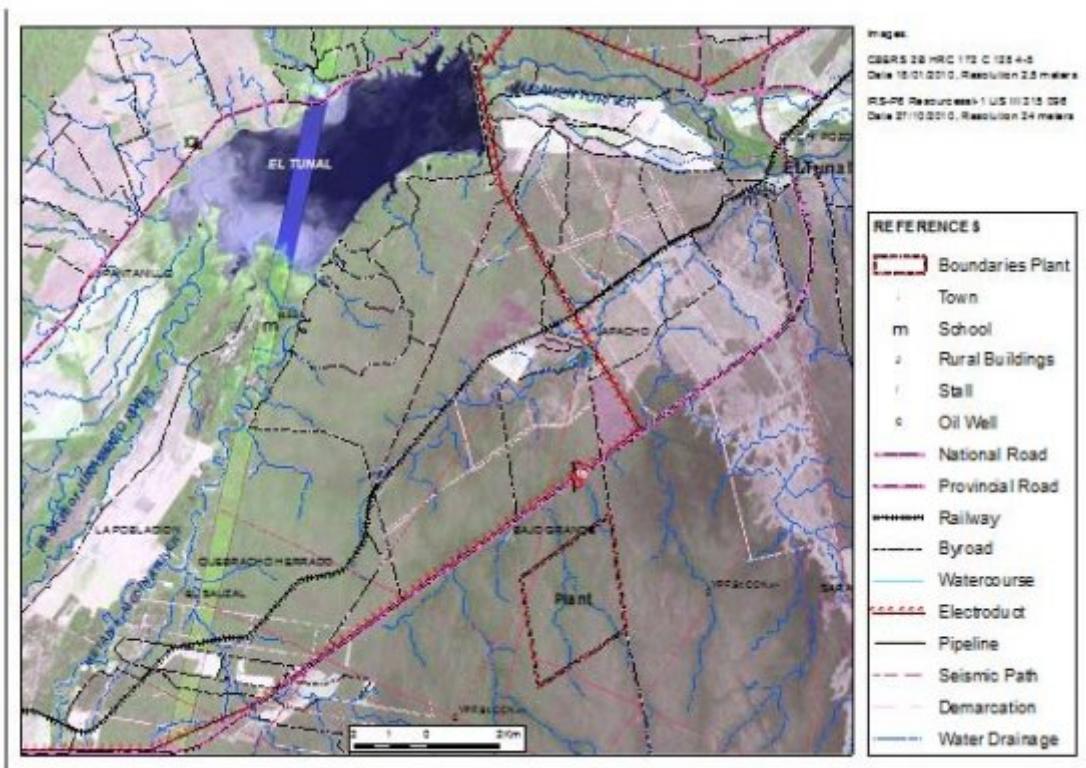
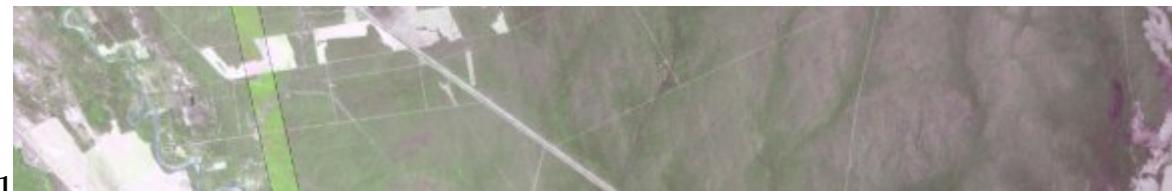


Figure 9: Figure 9 :



10

Figure 10: Figure 10 :



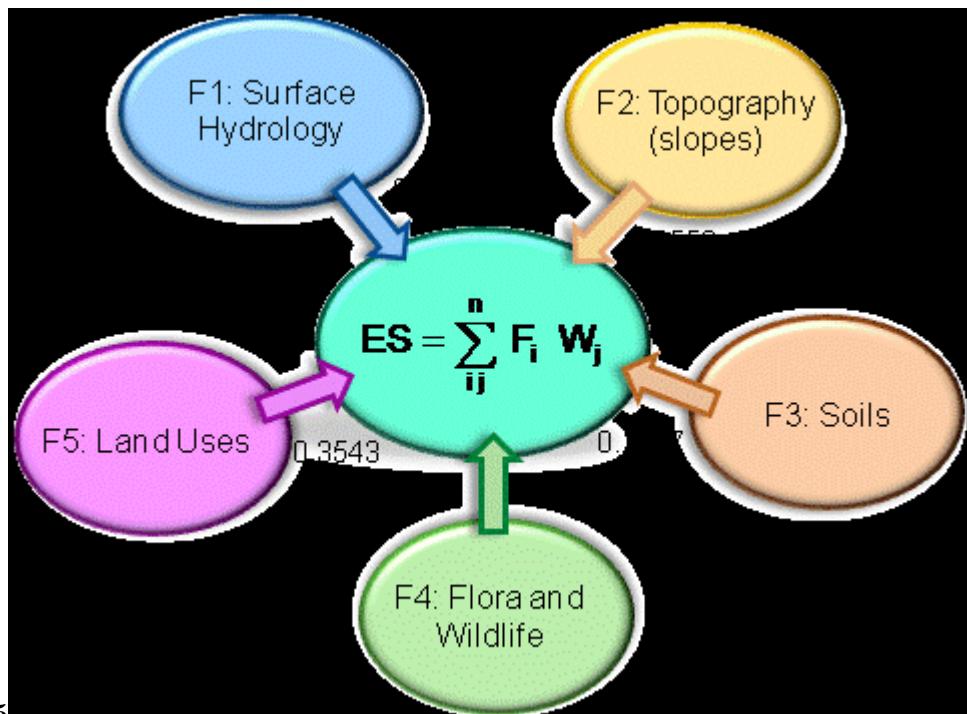
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Figure 11: Figure 11



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Figure 12: Figure 13 :Figure 14 :



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Figure 13: Figure 15 :

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Figure 14: Figure 19 :

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Figure 15: Figure 20 :

2

Class	Slope (%)	Topographic sensitivity (slope).		
		S	Factor	Sensitivity
RUSLE				
1	0.0 -0.3 %		0.06	0.01
2	0.3 -0.6 %		0.09	0.08
3	0.6 -1.2 %		0.16	0.27
4	1.2 -3.0 %		0.35	0.64
5	3.0 -6.0 %		0.68	1.25
6	6.0 -9.0 %		1.01	2.16
7	9.0 -12.0 % 1.50			3.43
8	12.0 -25.0 % 3.57			5.12
9	25.0 -50.0 % 7.01			7.29
10	> 50.0 %		11.38	10.00

Figure 16: Table 2 :

3

Code	Soils Associations	Soils Group	Sensitivity
Ao-Lpb	Arrocera -La Población	C	3.92
Cho	Chorroarín	C	3.92
Lvi	Las Víboras	E	1.68
Oll-Etu	Olleros -El Tunal	B-C	5.28
Sig	San Ignacio	B	7.22
Sma	Santa María	C	3.92
Ts-Sun	Tuscal -Sunchal	C	3.92

Figure 17: Table 3 :

5

Land Use	Sensitivity

[Note: 4 8 Intensive and extensive farming, intensive livestock: patch, dams, paddocks, stockyards, drinking trough, electric herdsman, ponds: FARMING. 39 Purpose without: exploration path, demarcations and badlands: BADLANDS. 1]

Figure 18: Table 5 :

1

Average	3.36037583
Standard error	0.11033639
Median	3.44382751
Mode	1.46900749
Standard Deviation	1.10336387
Sample variance	1.21741184
Kurtosis	-0.41780406
Asymmetry coefficient	0.17337022
Rank	4.21480226
Minimum	1.37450743
Maximum	5.58930969
Sum	336.037583
Account	100
Confidence level (95.0%)	0.21893137

Figure 19: Table 1 :

7

Environmental
Sensitivity

Figure 20: Table 7 :

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162 .2 Defined by Engineers

163 Alternative Trace: Area (ha) * Sensitivity

164 [Hacettepe Journal of Mathematics and Statistics] , *Hacettepe Journal of Mathematics and Statistics* 32 p. .

165 [Thomas DSG, Allison RJ ()] , *Landscape Sensitivity. Environmental Conservation. England, UK* Thomas DSG,
166 Allison RJ (ed.) 1993. 20 p. .

167 [Eastman et al. ()] , J R Eastman , Jin W Kyem , Pak Toledano , J . 1995.

168 [Calatayud (2009)] , Spain Calatayud . September 2009. p. .

169 [Saaty ()] 'A Scaling Method for Priorities in Hierarchical Structures'. T L Saaty . *J. Math. Psychology* 1977. 15
170 (3) p. .

171 [Matteucci (ed.) ()] *Complex environmental systems: spatial analysis tools*, S D Matteucci . Matteucci SD, Buzai
172 GD (ed.) 1998. p. . University of Buenos Aires (Quantifying landscape structure)

173 [Forman ()] *Decision by Objectives*, E H Forman . 1999. Text Books. George Washington University (unpublished)

174 [Saaty ()] *Decision Making with Feedback: The Analytical Network Process*, T L Saaty . 1996. Pittsburg, PA:
175 RWS Publications.

176 [Kershaw ()] 'Developing the Approach to Strategic Landscape Sensitivity'. Tartaglia Kershaw , L . *Hampshire
177 County Council. UK* 2005. 54.

178 [Meentemeyer and Box (ed.) ()] *Landscape Heterogeneity and Disturbance*, V Meentemeyer , E O Box . Monica
179 GT (ed.) 1987. New York: Springer -Verlag. p. . (Scale effects in landscape studies)

180 [Fernández Vitora ()] *Methodological Guidelines for Environmental Impact Assessment*, Conesa Fernández Vitora
181 , V . 1997. Bilbao, Spain: Mundi Prensa. p. 338.

182 [Raster Procedures for Multi-Criteria/Multi-Objective Decisions Photogrammetric Engineering and Remote Sensing]
183 'Raster Procedures for Multi-Criteria/Multi-Objective Decisions'. *Photogrammetric Engineering and Remote
184 Sensing* 61 (5) p. .

185 [Rebolledo ()] *Remote Sensing: Water and sustainable development. XIII Congress of the Spanish Association
186 of Remote Sensing*, R Rebolledo . 2009.

187 [Foster ()] *Revised Universal Soil Loss Equation, Version 2. User's Guide*. USDA-Agricultural Research Service,
188 G R Foster . 2003. Washington, D.C. 77.

189 [Moreno Jiménez ()] 'Scientific method in environmental assessment and selection'. J M Moreno Jiménez .
190 *Operational Research* 2001. 1 (1) p. . (Zaragoza, Spain.)

191 [Nadir and Chafatinos (ed.) ()] *Soils of the NOA*, A Nadir , T Chafatinos . Nadir, Chafatinos (ed.) 1995. Salta
192 y Jujuy; Salta, Argentina. 3 p. .

193 [Moldes ()] *Technology of Geographic Information Systems*, Fj ; Ra-Ma Moldes . 1995. Madrid, Spain. p. 146.

194 [Büyükyazici and Sucu ()] *The analytic hierarchy and analytic network processes*, M Büyükyazici , M Sucu .
195 2003.