

Towards a systemic assessment of environmental impact (SAEI) regarding alternative hydrosedimentological management practice in the Canal del Dique, Colombia

Hacia la evaluación sistémica del impacto ambiental (ESIA); alternativas del manejo hidrosedimentológico en el Canal del Dique – Colombia

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ABSTRACT

The Canal del Dique, located on the Colombian Caribbean Coast, can be seen as an "artificial" branch of the River Magdalena. Since its inception in 1650, it has undergone a series of interventions aimed at optimising river navigation between Cartagena and the interior of the country, little consideration having been paid to institutional, economic, social and environmental impacts. This paper presents a systemic assessment of environmental impact (SAEI) methodology, based on systemic parameterisation of the environment, proposed by Vega [2011], for the strategic environmental assessment of policy, plans, programmes or large-scale projects, considering a case study of the Canal del Dique environmental rehabilitation as proposed by the Colombian government. Information arising from the framework of an inter-administrative agreement between the Universidad Nacional de Colombia and the Regional Autonomous Corporation for the Río Grande de la Magdalena (CORMAGDALENA) was used for studying the environmental restoration of and navigation in the Canal del Dique [UN-LEH, 2008]. The authors developed and summarised SAEI regarding six alternatives for hydrosedimentological management in the canal to obtain results concerning environmental impairment or improvement regarding each factor considered, and the degree of aggressiveness or betterment involved in each alternative. Alternative 4, an enhanced version of current condition (ECC) would have produced the greatest environmental benefit (i.e. limited dredging plus optimising channel-wetland interconnection) requiring the narrowing of three straight reaches along the canal and the construction of a sluice-gate system in the Strait of Paracuica (near the town of El Recreo).

Keywords: Systemic assessment of environmental impact, strategic ecosystem, environmental impact, hydrosedimentological management.

RESUMEN

El Canal del Dique, ubicado en la Costa Caribe colombiana, puede considerarse como un brazo "artificial" del Río Magdalena. Desde su creación en 1650, ha sido objeto de una serie de intervenciones orientadas, todas ellas, a optimizar la navegación fluvial entre Cartagena y el interior del país y viceversa, con muy pocas consideraciones generadas sobre los impactos institucionales, económicos, sociales y ambientales. En este artículo se plantea y aplica como estudio de caso para la rehabilitación ambiental del Canal del Dique, propuesto por el Gobierno colombiano, la metodología de Evaluación Sistémica del Impacto Ambiental – ESIA, que basada en el proceso de "Parametrización Sistémica de la Dimensión Ambiental" propuesto por Vega [2011], se concibe como un procedimiento de "evaluación ambiental estratégica" para políticas, planes, programas de desarrollo territorial, y grandes proyectos. En consecuencia, a partir de la información generada en el marco del Convenio Interadministrativo celebrado entre la Universidad Nacional y la Corporación Autónoma Regional del Río Grande de la Magdalena (CORMAGDALENA), para la realización de estudios e investigaciones de las obras de restauración ambiental y de navegación del Canal del Dique [UN-LEH, 2008], se reconocen y sintetizan los principales aspectos relacionados con el proceso de Evaluación Sistémica del Impacto Ambiental para seis diferentes alternativas de manejo hidrosedimentológico en el Canal del Dique, lo que permite mostrar los resultados obtenidos, relacionados con el deterioro y/o mejoramiento ambiental sobre cada factor ambiental considerado y con el grado de agresividad y/o bondad de cada alternativa sobre el medio ambiente. Finalmente, se plantean algunas conclusiones derivadas de este proceso, donde se resalta la alternativa 4 (condición actual mejorada + tres (3) estrechamientos + el sistema esclusa-compuerta en el estrecho de Paracuica), por ser la que más bondades y mejoramientos ambientales generaría.

Palabras clave: evaluación sistémica del impacto ambiental, ecosistema estratégico, manejo hidrosedimentológico.

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of the working and living conditions of the communities settled in the area of channel influence" (MMA-resolution No. 260/1997).

Since this resolution was passed, a series of technical and administrative action by the MMA and CORMAGDALENA led the new Ministry of Environment, Housing and Territorial Development, (MAVDT) to issue resolution 0249/04, ordering CORMAGDALENA to, "define and design alternative sedimentological management practices for the Canal del Dique which, in addition to minimising sediment contribution to the Bay of Cartagena, would ensure the navigability of the channel, a suitable water supply for human consumption and for existing and projected irrigation districts, the prevention and mitigation of environmental impact on fishing, agriculture and livestock and on the life of residents and environmental support for existing species and ecosystems" [MAVDT-resolution No. 0249/2004].

To meet MMA technical requirements and ensure that these aspects were considered and resolved in the alternative sedimentological management scheme for the Canal del Dique, CORMAGDALENA hired the Universidad Nacional de Colombia to conduct studies on the environmental restoration of the Canal del Dique and navigation practice based on previous studies by Universidad del Norte (UNINORTE) [2002]. Such studies had recommended an alternative for hydraulic management, (dubbed "Alternative IV"), based on discharge control, by constructing a gate and lock system at the entrance to the canal in Calamar, with ecological access "ensured" by dredging the "Caño Viejo", an old access to the canal, abandoned years before, which required closing the left arm of Becerra island, upstream from Calamar.

The systemic assessment of environmental impact conceptual and methodological approach

The proposed systemic assessment of environmental impact (SAEI) integrated and parameterised an ecosystem's institutional, economic and social aspects in a particular region or area of influence. It evaluated the most relevant management scenarios and the environmental impact generated by them, defining measures for their prevention, mitigation or elimination, guiding decision-making and defining general and specific guidelines for a region's environmental and territorial development.

The SAEI approach was developed from environmental impact assessment of projects, basically following the typical phases involved in the normal development of an engineering project. Nevertheless, "strategic environmental assessment" methodology and process concerning policy, plans, programmes and projects has a different connotation regarding typical environmental impact assessment.

Although this methodology was based on an adaptation and evolution of the original methodology for identifying and assessing environmental impact by Leopold [1971], Battelle-Columbus [1972], Gómez Orea [1994] and Conesa, [2003], its development has mainly emerged from a research project entitled, "Towards systemic parameterisation of the environment," [Vega, 2011]. This defined methods and tools concerning systemic environmental information regarding resource quantity and quality, to be collected and organised within a state-pressure-management (SPM) framework. This was systematically stored with the help of SPM map-matrix, (see Table 1), using environmental information baselines (EIB) (Figure 2).

Table 1. SPM map-matrix of environmental integration

The environment	Components	Sub Components	Environmental Dimension - SPM map-matrix									
			Environmental State (S)					Anthropic Pressure (P)				
			S ₁	S ₂	S ₃	S ₄	S ₅	P ₁	P ₂	P ₃	P ₄	P ₅
ECOSYSTEM	ABIOIC ENVIRON	Regional and local geology	10					100	100	100	100	100
		Geomorphology	20					200	200	200	200	200
		Geotechnical	30					300	300	300	300	300
		Soil	40	40	40	40	40	400	400	400	400	400
		Petroleum, Coal, Natural Gas, Metal Mineral, Non-Metallic Minerals	50	50	50	50	50	500	500	500	500	500
	BIOIC ENVIRON	Surface Water	60	60	60	60	60	600	600	600	600	600
		Underground Water	70	70	70	70	70	700	700	700	700	700
		Climate	80					800	800	800	800	800
		Air	90					900	900	900	900	900
		Noise	100					1000	1000	1000	1000	1000
CULTURE	PUBLIC ENVIRON	Terrestrial Ecosystems	110	110	110	110	110	1100	1100	1100	1100	1100
		Wildlife	120	120	120	120	120	1200	1200	1200	1200	1200
		Aquatic Ecosystems	130	130	130	130	130	1300	1300	1300	1300	1300
		Strategic Ecosystems	140	140	140	140	140	1400	1400	1400	1400	1400
		Regulation (natural cycles)	150	150	150	150	150	1500	1500	1500	1500	1500
	ECONOMIC ENVIRON	Ecosystem Services	160	160	160	160	160	1600	1600	1600	1600	1600
		Support (biodiversity, provisioning)	170	170	170	170	170	1700	1700	1700	1700	1700
		Control (resilience)	180	180	180	180	180	1800	1800	1800	1800	1800
		Political and Institutional Component	190					1900	1900	1900	1900	1900
		Public Institutional Presence	200					2000	2000	2000	2000	2000
SOCIAL ENVIRON	PUBLIC ENVIRON	Exercise of the environmental authority	210					2100	2100	2100	2100	2100
		Public Space in Urban and Rural	220					2200	2200	2200	2200	2200
		Roads and Transportation Infrastructure	230					2300	2300	2300	2300	2300
		Utilities	240					2400	2400	2400	2400	2400
		Social Services	250					2500	2500	2500	2500	2500
	ECONOMIC ENVIRON	Peace and Development Trends	260					2600	2600	2600	2600	2600
		Forms of Tenure, Ownership, Conflict	270					2700	2700	2700	2700	2700
		Production and Technological Processes	280					2800	2800	2800	2800	2800
		Business Structure	290					2900	2900	2900	2900	2900
		Identification and Characterization of Business	300					3000	3000	3000	3000	3000
SOCIAL ENVIRON	PUBLIC ENVIRON	Supply, Demand and Labor Type	310					3100	3100	3100	3100	3100
		Demographic Component	320					3200	3200	3200	3200	3200
		Characterization Demographic Population Groups	330					3300	3300	3300	3300	3300
		Dynamics of Settlement and Demographic Trends	340					3400	3400	3400	3400	3400
		Unsatisfied Basic Needs	350					3500	3500	3500	3500	3500
	ECONOMIC ENVIRON	Political, Community Organization and Participation Mechanisms	360					3600	3600	3600	3600	3600
		Socialization and Project Feedback	370					3700	3700	3700	3700	3700
		Anthropological Component	380					3800	3800	3800	3800	3800
		Symbolic or Imaginary World Social	390					3900	3900	3900	3900	3900
		Archaeological Component	400					4000	4000	4000	4000	4000

Source: Adapted from Vega, 2011

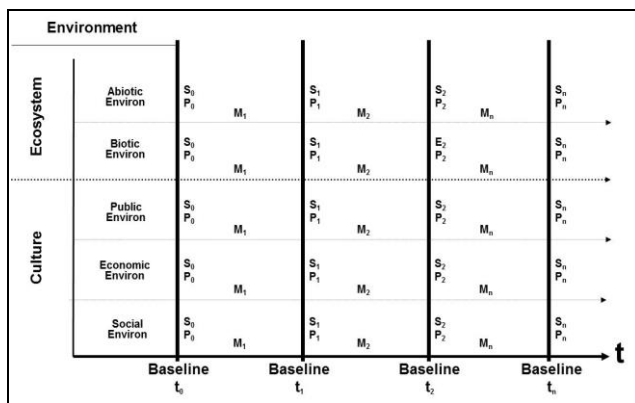


Figure 2. Source: Adapted from Vega, 2011

The SAEI methodology used multi-criteria analysis (MCA), in which each action, (A_i) or scenario of significant anthropogenic management (k), was interrelated in a qualitative, quantitative, stochastic or diffuse manner with each element in the environment (i.e. environmental factors) (F_i) which could have been affected. This allowed the assessment, evaluation and analysis of environmental impact generated by such interaction within a logical framework (summarised in Table 2 and described below).

According to the evaluation and analysis logical framework (Table 2), the total environmental impact (TEI) of a project or alternative (k) could be determined by the weighted sum of the impact value (V_i) of each environmental factor (F_i), as expressed by equation 1:

$$IAT_k = \sum_{i=1}^{i=n} P_i \cdot V_i \quad (1)$$

where:

P_i = weighted environmental importance: the weight or relative importance of each environmental factor concerning the environment being considered. This value could vary from 0 to 1,000, and was mapped by consensus with a panel of experts.

V_i = net impact value regarding each environmental factor F_i.

Table 2. Logical framework for evaluating and analysing environmental impact evaluation

Environmental Factors	Map #	P (1-100)	PROJECT ACTIONS (ALTERNATIVE i)			Qualitative Rating ENVIRONMENTAL DAMAGE AND/OR IMPROVEMENT	Transformation Functions EA = f(M)	Quantitative Assessment TOTAL IMPACT VALUE ON EACH FACTOR
			A_1	A_2	A_m			
F_1	Map ₁	P_1	I_{11}	I_{12}	I_{1m}	$I_1 = \frac{P_1}{1000} \sum_{j=1}^m I_{1j}$	$EA_{F_1} = f(M_{F_1} - M_{sp_1})$ $EA_{F_1} = \left[\frac{ I_1 }{\max(I_1)} \cdot (EAN_1)^2 \right]^{1/3}$	
			Mcp_{11}	Mcp_{12}	Mcp_{1m}	$Mcp_1 = \sum_{j=1}^m Mcp_{1j}$		
			$ P_{11} = \left[\frac{ I_{11} }{\max(I_{11})} \cdot (EAN_{11})^2 \right]^{1/3}$	$ P_{12} = \left[\frac{ I_{12} }{\max(I_{12})} \cdot (EAN_{12})^2 \right]^{1/3}$	$ P_{1m} = \left[\frac{ I_{1m} }{\max(I_{1m})} \cdot (EAN_{1m})^2 \right]^{1/3}$	$ P_{1j} = \left[\frac{ I_{1j} }{\max(I_{1j})} \cdot (EAN_{1j})^2 \right]^{1/3}$		
F_i	Map _i	P_i	I_{i1}	I_{i2}	I_{im}	$I_i = \frac{P_i}{1000} \sum_{j=1}^m I_{ij}$	$EA_{F_i} = f(M_{F_i} - M_{sp_i})$ $EA_{F_i} = \left[\frac{ I_i }{\max(I_i)} \cdot (EAN_i)^2 \right]^{1/3}$	
			Mcp_{i1}	Mcp_{i2}	Mcp_{im}	$Mcp_i = \sum_{j=1}^m Mcp_{ij}$		
			$ P_{i1} = \left[\frac{ I_{i1} }{\max(I_{i1})} \cdot (EAN_{i1})^2 \right]^{1/3}$	$ P_{i2} = \left[\frac{ I_{i2} }{\max(I_{i2})} \cdot (EAN_{i2})^2 \right]^{1/3}$	$ P_{im} = \left[\frac{ I_{im} }{\max(I_{im})} \cdot (EAN_{im})^2 \right]^{1/3}$	$ P_{ij} = \left[\frac{ I_{ij} }{\max(I_{ij})} \cdot (EAN_{ij})^2 \right]^{1/3}$		
F_n	Map _n	P_n	I_{n1}	I_{n2}	I_{nm}	$I_n = \frac{P_n}{1000} \sum_{j=1}^m I_{nj}$	$EA_{F_n} = f(M_{F_n} - M_{sp_n})$ $EA_{F_n} = \left[\frac{ I_n }{\max(I_n)} \cdot (EAN_n)^2 \right]^{1/3}$	
			Mcp_{n1}	Mcp_{n2}	Mcp_{nm}	$Mcp_n = \sum_{j=1}^m Mcp_{nj}$		
			$ P_{n1} = \left[\frac{ I_{n1} }{\max(I_{n1})} \cdot (EAN_{n1})^2 \right]^{1/3}$	$ P_{n2} = \left[\frac{ I_{n2} }{\max(I_{n2})} \cdot (EAN_{n2})^2 \right]^{1/3}$	$ P_{nm} = \left[\frac{ I_{nm} }{\max(I_{nm})} \cdot (EAN_{nm})^2 \right]^{1/3}$	$ P_{nj} = \left[\frac{ I_{nj} }{\max(I_{nj})} \cdot (EAN_{nj})^2 \right]^{1/3}$		
Qualitative Rating APPROPRIATE ONLY FOR ACTIONS FOR EACH ACTION			$I_{11} = \sum_{j=1}^m P_{1j} I_{1j}$	$I_{i2} = \sum_{j=1}^m P_{i2} I_{ij}$	$I_{nm} = \sum_{j=1}^m P_{nm} I_{nm}$			
Qualitative Assessment ENVIRONMENTAL IMPACT FOR EVERY ACTION AND TOTAL			$EA_1 = \sum_{j=1}^m P_{1j} EA_{1j}$	$EA_i = \sum_{j=1}^m P_{ij} EA_{ij}$	$EA_n = \sum_{j=1}^m P_{nj} EA_{nj}$		$EA_{F_i} = \sum_{j=1}^m P_{ij} EA_{ij}$	

The intrinsic importance of the impact on each environmental factor and net environmental state (condition with project minus condition without project) had a value varying from -1 to 1. Its sign was that of total intrinsic importance I_i and was calculated using equation 2, as follows:

$$|V_i| = \left[\frac{|I_i|}{\max(|I_i|)} \cdot (EAN_i)^2 \right]^{1/3} \quad (2)$$

where:

I_i = the intrinsic importance of impact on each environmental factor F_i . This value was calculated using equation 3 and, depending on the positive or negative sign, was assimilated qualitatively to generate a relative degree of environmental damage or improvement for the environmental factors considered, as follows:

$$I_i = \frac{P_i}{1000} \cdot \sum_{j=1}^m I_{ij} \quad (3)$$

where:

I_{ij} = the intrinsic importance of impact generated by action A_j on environmental factor F_i . This value was calculated using equation 4, relating the intrinsic characteristics of environmental impact and which was evaluated by a panel of experts, with the help of Table 3.

$$I_{ij} = NA_{ij} \cdot (3IN_{ij} + 2EX_{ij} + MO_{ij} + PE_{ij} + RV_{ij} + SI_{ij} + AC_{ij} + EF_{ij} + PR_{ij} + MC_{ij}) \quad (4)$$

EAN_i = net environmental state index for environmental factor F_i . This value ranged from 0 to 1 and was calculated using equation 5:

$$EAN_i = f(\Delta M_i) = f(Mcp_i - Msp_i) \quad (5)$$

where:

Mcp_i = magnitude of environmental factor F_i with project

Msp_i = magnitude of environmental factor F_i without project (baseline)

$f(M_i)$ = transformation function for environmental factor F_i converts dimensional magnitude of environmental factor F_i in terms of a dimensionless environmental state index, as illustrated by the example in Figure 3.

Table 3. Qualitative evaluation guide for intrinsic impact features

FEATURE	DESCRIPTION	QUALITATIVE ASSESSMENT
I INTRINSIC IMPORTANCE	Qualitative measure of the impact from the degree of incidence of the disorder and its effects produced	Irrelevant 0 - 25 Moderate 25 - 50 Severe 50 - 75 Critical 75 - 100
NA NATURE	Beneficial or prejudicial character impact	Beneficial 1+ Prejudicial 1- Low 1 Medium 2 High 4 Very High 8 Total 12
IN INTENSITY	Degree of impact of the action on the factor (from minimal to total destruction)	Punctual 1 Partial 2 Extensive 4 Total 8 Critical 4+
EX EXTENSION	Expected area of influence in relation to the project environment that can be represented as a percentage	Long Term 1 Medium Term 2 Immediate 4 Critical 4+
MO MOMENT	Time from the onset of action and the beginning of the impact it makes. Short term (less than a year), medium term (1 to 5 years), long term (over 5 years)	Fugaz 1 Temporary 2 Permanent 4 Short Term 1 Medium Term 2 Long Term 4 Critical 4+
PE PERSISTENCE	While the impact is expected to remain as they arise. Fugaz (less than 1 year), temporary (1 to 10 years), Permanent (more than 10 years)	Fugaz 1 Temporary 2 Permanent 4 Short Term 1 Medium Term 2 Long Term 4 Critical 4+
RV REVERSIBILITY	Possibility of reconstructing the factor affected by natural means. Short term (less than a year), medium term (1 to 10 years), long-term (10 years)	No Synergistic 1 Synergistic 2 Highly Synergistic 4 Simple 1 Cumulative 4
SI SYNERGY	Two impacts are synergistic if its manifestation joint is higher than the sum of the separate manifestations. If there is weakening, the synergy is negative	Indirect 1 Direct 4 Irregular 1 Periodical 2 Continuous 4 Immediate 1 Medium Term 2 Mitigable 4 Irrecoverable 8
AC ACCUMULATION	A cumulative impact is whether the continued presence of the action makes the impact grows over time	
EF CAUSE / EFFECT	Direct if the action itself that causes the impact. Indirect impact if other	
PR PERIODICITY	Regularity of the demonstration of the impact	
MC RECOVERABILITY	Ability to Rebuild the factor affected by environmental management	
$I_i = NA_{ij} (3IN_{ij} + 2EX_{ij} + MO_{ij} + PE_{ij} + RV_{ij} + SI_{ij} + AC_{ij} + EF_{ij} + PR_{ij} + MC_{ij})$		

Source: Conesa V., 2003

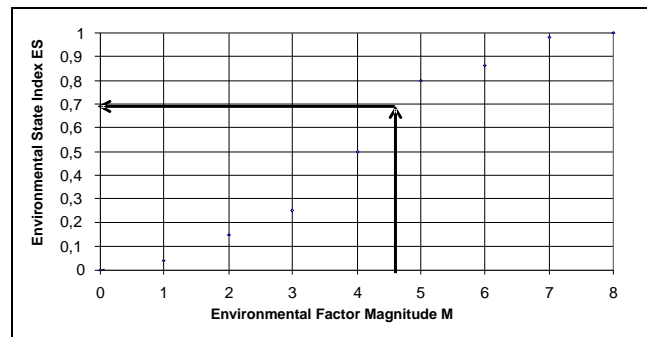


Figure 3. Graphic model of transformation functions.

The evaluation analysis framework (Table 2) was also used for determining the intrinsic importance of the environmental impact generated by each action A_j . This value was calculated by using equation 6 and, depending on the positive or negative sign, could be qualitatively assimilated to generate the relative degree of environmental damage and/or improvement for each action on the environment in question, as follows:

$$I_{Aj} = \sum_{i=1}^n P_i \cdot I_{ij} \quad (6)$$

Using SAEI methodology for evaluating hydrosedimentological management alternatives for the Canal del Dique.

Depending on the development phases of a plan or programme being considered, the evaluation methodology would involve evaluation and analysis of environmental impact; it would be qualitative for the feasibility phase and the selection of alternatives and quantitative for the feasibility phase of the selected alternative. This logical framework is summarised in Table 4.

Table 4. SAEI methodological process

CYCLE PROJECT PHASES	ENVIRONMENTAL COMPONENTS STAGE	ENVIRONMENTAL IMPACT ASSESSMENT PROCESS	ACTIONS
IDEA OF THE PLAN AND / OR PROGRAMME	ENVIRONMENTAL VISION PLAN AND / OR PROGRAMME	ESDA PROCESS BEGINS	Environmental License Application Environmental Impact Studies
FEASIBILITY Alternatives Evaluation and Selection of optimal Anthropogenic Management Scenario	ENVIRONMENTAL ASSESSMENT OF ANTHROPIC MANAGEMENT ALTERNATIVES OR SCENARIOS	OVERVIEW OF THE PLAN AND / OR PROGRAMME AND THE ENVIRONMENT	Description and Analysis of Anthropogenic Management Alternatives or Scenarios Legal and Regulatory Framework Systemic Parameterization of Environmental Dimension
		QUALITATIVE ASSESSMENT AND ANALYSIS IMPACTS OF ALTERNATIVES CONSIDERED	Impact Identification and Forecast Intrinsic Importance of Impacts Total Qualitative Analysis
			Dimensional Quantitative Assessment Quantitative assessment dimensionless Total Quantitative Analysis
FEASIBILITY Basic Designs of Engineering	ENVIRONMENTAL IMPACT STUDY OF SELECTED ALTERNATIVE OR SCENARIO	QUANTITATIVE ASSESSMENT AND ANALYSIS IMPACTS OF SELECTED ALTERNATIVE	Environmental Management Plan Formulation Formulation of Environmental Monitoring Program
DESIGN Detailed designs		ENVIRONMENTAL MANAGEMENT PLAN	Environmental Licensing Environmental Monitoring
CONSTRUCTION AND OPERATION	ENVIRONMENTAL MONITORING	ENVIRONMENTAL MONITORING	

The hydrosedimentological management scheme for the Canal del Dique was only systematically evaluated for the feasibility phase (highlighted in grey in Table 4), involving qualitative environmental assessment of alternatives. This implied describing the project and the environment through systemic parameterisation of the ecoregion's environment [Vega, 2011] and identifying, assessing and the qualitative analysis of the environmental impact of the alternatives generated in each scenario considered, as described below.

Doubts emerged while conducting the studies concerning the relevance and efficiency of alternative IV as initially proposed by UN-INORTE (2002). These were corroborated by the modeling results [UN-LEH, 2008] which indicated that the proposed alternative would fail because the entrance to the canal would be blocked by coarse material which would impede vessels' entry to the sluice. Flow speed and sedimentation of the return flow around the left arm of Becerra Island was also found to cause rapid obstruction of the passage, due to the accumulation of fine sediment and vegetation, as well as the likely destabilisation of the river upstream and downstream from Calamar.

This alternative was discarded, in agreement with CORMAGDALENA, and, four new alternatives were proposed instead and defined for preliminary evaluation: Alt. 1, current condition; Alt. 2, enhanced current condition; Alt. 3, enhanced current condition + placing a sediment excluder at the entrance in Calamar; and Alt. 4, discharge and sediment entrance control by placing a gate and lock system in Calamar.

The evaluation made it clear that the canal's current operating conditions, involving minimum periodic dredging and impaired flow connections with the peripheral system of wetlands, were harmful to the environment and the welfare of its population. It was also concluded that, although the other alternatives involved substantial net benefits and improvements for the environment, none of them would be optimal without effective government presence in the ecoregion, through environmental agencies.

Taking into consideration the principles of caution, gradualism, cost-effectiveness and continuous improvement, the Universidad Nacional de Colombia recommended a stepped solution. This involved the immediate implementation and development of Alt. 2, since its management practice was common to all the other alternatives considered and represented significant improvement

which did not require large investment, while allowing for the continuation of studies regarding other management alternatives, and in-depth evaluation of yet-to-be considered elements.

CORMAGDALENA thus commissioned the Universidad Nacional de Colombia to continue research into two new alternatives, insisting on the reduction of discharge in the channel, but allowing the university to try an approach different from a gate and lock system by narrowing different sectors of the canal and building a different gate-lock system at the end of the alignment in the Paricuica Strait rather than at the beginning of it. This involved a solution that allowed a large portion of the flow to be evacuated to the sea through the Bay of Barbacoas without reaching Cartagena with its sediment load, thus making the reduction of discharge smaller and better accepted by the canal-wetland system.

The university identified and selected six new hydrosedimentological management alternatives (see Table 5).

Table 5. Hydrosedimentological management alternatives

Stage	Alternatives Considered	Features
Operation	1. ALT1: CURRENT CONDITION	Without narrowings or sluice gate
	2. ALT2: CURRENT CONDITION ENHANCED AND SLUICE GATE IN PARICUICA RIVER (B) REVER	Interconnections swamp - channel optimized. Alternative 2 includes only the gate in the K104, have a depth of 5.80 m from the channel bed to the crown, and on the crest length of approximately 104 meters.
	3. ALT3: CURRENT CONDITION ENHANCED AND 3 NARROWINGS	Interconnections swamp - channel optimized. Narrowing No. 1: Km 0 - Km 6 Length = 6 Km Narrowing No. 2: Km 45 - Km 48 Length = 3 Km Narrowing No. 3: Km 72 - Km 77 Length = 5 Km
	4. ALT4: CURRENT CONDITION ENHANCED, SLUICE GATE IN RCT104 (B) REVER AND 3 NARROWINGS	Interconnections swamp - channel optimized. The sluice gate RCT104 evaluated at Kilometer have a depth of 5.80 m from the channel bed to the crown, and approximate length of 104 meters crest. Narrowings 1, 2 and 3.
	5. ALT5: CURRENT CONDITION ENHANCED AND SLUICE GATE IN RCT110 DOWN LEQUERICA	Interconnections swamp - channel optimized. The sluice gate RCT110 evaluated at Kilometer have a depth of 3.55 m from the channel bed to the crown, and approximate length of 94 meters crest.
	6. ALT6: CURRENT CONDITION ENHANCED, SLUICE GATE IN RCT110 AND 3 NARROWINGS	Interconnections swamp - channel optimized. The sluice gate RCT110 evaluated at Kilometer have a depth of 3.55 m from the channel bed to the crown, and approximate length of 94 meters crest. Narrowings 1, 2 and 3.

The preliminary location of the narrow channel sectors and the location of the new lock-gate system at Paracuica are shown in Figure 4 as a result of the university's hydraulic modelling.

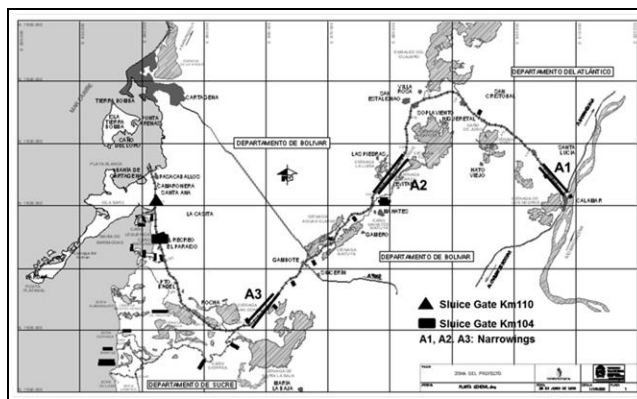


Figure 4. General location of the sluice gate and narrowings

An expert panel⁴ identified and weighted environmental factors likely to be affected in accordance with the environmental protection requirements set out in MAVDT resolution 0249/04, (Table 6) and characterised significant environmental impacts for each alternative considered (Table 7).

The panel of experts characterised and determined the intrinsic importance of each identified impact, in accordance with equation 4 and the guidance of intrinsic qualitative assessment of impact

⁴ The panel consisted of Dr. Jaime Iván Ordoñez, I.C. PhD. Hydraulic Engineering and Physical Modeling; Dr. Gabriel Pinilla, Biologist, MSc. PhD. Limnology; Dr. Luis Alejandro Camacho, I.C. MSc. PhD. Mathematical Modeling; Geol. Manuel Moreno,

Geology, MSc. Geomorphological Processes; and Dr. Leonel Vega Mora, MSc. PhD. Water Resources and Environmental Engineering.

(Table 3), using an Excel application specifically designed for processing information. Mathematical modelling [Camacho, 2008],

Table 6. Identifying and weighting environmental factors

Development sectors	Goods and Services	Environment	Environmental Factors	P [0-100]		
Ecosystems	Natural renewable resources	Water	F1 Irrigation water availability (1)	20		
			F2 Availability environmental flow water bodies (2) (11)	100		
			F3 Water availability for human consumption (4)	50		
			F4 Surface Freshwater Bodies salinization (3)	50		
		Regulation	F5 Brackish Water Bodies salinity (mangroves) (3)	30		
			F6 Subsurface salinization of Porous Medium (3)	30		
			F7 Navigability in the channel (18)	50		
			F8 Sedimentation in Rio Magdalena (Calamar) (9)	10		
	Environment-related services	Support	F9 Sedimentation in the Upper Channel (9)	10		
			F10 Sedimentation in the Middle Channel (9)	10		
			F11 Sedimentation in the Lower Channel (9)	10		
			F12 Sedimentation in the Cano Cornea (9)	10		
			F13 Sedimentation in the Caño Matunilla (9)	10		
			F14 Sedimentation in the Caño Lequerica (9)	10		
			F15 Sedimentation in the Swamps of the Upper Channel (9)	10		
			F16 Sedimentation in the Channel Middle Marshes (9)	10		
			F17 Sedimentation in the Lower Marshes Channel (9)	10		
			F18 Sedimentation (thick depositable) in Cartagena Bay (9)	100		
			F19 Sedimentation (fine not depositable) in Cartagena Bay (9)	50		
			F20 Total deposition (thin + thick) in Bay BBO (9)	50		
			F21 Total Sediment (fine + coarse) to the sea by pipe strap (9)	30		
			F22 Sedimentation Coral Sea sediments (13)	20		
SUBTOTAL ECOSYSTEM				680		
Public sector			Environmental management-related institutional resources	Human beings Laws and regulations/International and national standards Organisational and administrative Scientific - technological Economic instruments Financial instruments Policy, plans, programmes, measures	F23 Exercise of the Environmental Authority (16)	100
SUBTOTAL PUBLIC SECTOR					100	
Productive sector	Goods and services created for production sector-related ends	Productive Infrastructure, Roads and Transportation, Energy, Science and Technology, Finance	F24 Fishing Productivity (12)	70		
			F25 Agricultural Productivity (12)	20		
			F26 Shrimp productivity (12)	10		
			SUBTOTAL PRODUCTIVE SECTOR		100	
Civil society			A particular population's human, political and symbolic resources	Demography, Health, Food, Housing, Employment, Public Services, Participation, and so on.	F27 Flood Risk in Urban Areas	20
	F28 Living Conditions of Population (16)	100				
	SUBTOTAL CIVIL SOCIETY				120	
	TOTAL P				1680	

Table 7. Impact identification matrix

ENVIRONMENTAL FACTORS	P [0-100]	ALTERNATIVES CONSIDERED					
		ALT.1 CURRENT CONDITION	ALT.2 CURRENT CONDITION ENHANCED AND SLUICE GATE IN PARICUICA RK104 BY PIPE STRAP	ALT.3 CURRENT CONDITION ENHANCED AND 3 NARROWINGS	ALT.4 CURRENT CONDITION ENHANCED AND SLUICE GATE IN PARICUICA RK104 BY PIPE STRAP AND 3 NARROWINGS	ALT.5 CURRENT CONDITION ENHANCED AND SLUICE GATE IN PARICUICA RK104 BY PIPE STRAP AND 3 NARROWINGS	ALT.6 CURRENT CONDITION ENHANCED AND SLUICE GATE IN PARICUICA RK104 BY PIPE STRAP AND 3 NARROWINGS
F1 Irrigation water availability (1)	20						
F2 Availability environmental flow water bodies (2) (11)	100						
F3 Water availability for human consumption (4)	50		*	*	*	*	*
F4 Surface Freshwater Bodies salinization (3)	50		*	*	*	*	*
F5 Brackish Water Bodies salinity (mangroves) (3)	30		*	*	*	*	*
F6 Subsurface salinization of Porous Medium (3)	30		*	*	*	*	*
F7 Navigability in the channel (18)	50		*	*	*	*	*
F8 Sedimentation in Rio Magdalena (Calamar) (9)	10		*	*	*	*	*
F9 Sedimentation in the Upper Channel (9)	10	*	*	*	*	*	*
F10 Sedimentation in the Middle Channel (9)	10	*	*	*	*	*	*
F11 Sedimentation in the Lower Channel (9)	10	*	*	*	*	*	*
F12 Sedimentation in the Cano Cornea (9)	10	*	*	*	*	*	*
F13 Sedimentation in the Caño Matunilla (9)	10	*	*	*	*	*	*
F14 Sedimentation in the Caño Lequerica (9)	10	*	*	*	*	*	*
F15 Sedimentation in the Swamps of the Upper Channel (9)	10	*	*	*	*	*	*
F16 Sedimentation in the Channel Middle Marshes (9)	10	*	*	*	*	*	*
F17 Sedimentation in the Lower Marshes Channel (9)	10	*	*	*	*	*	*
F18 Sedimentation (thick depositable) in Cartagena Bay (9)	100	*	*	*	*	*	*
F19 Sedimentation (fine not depositable) in Cartagena Bay (9)	50	*	*	*	*	*	*
F20 Total deposition (thin + thick) in Bay BBQ (9)	50	*	*	*	*	*	*
F21 Total Sediment (fine + coarse) to the sea by pipe strap (9)	30	*	*	*	*	*	*
F22 Sedimentation Coral Sea sediments (13)	20	*	*	*	*	*	*
F23 Exercise of the Environmental Authority (16)	100	*	*	*	*	*	*
F24 Fishing Productivity (12)	70	*	*	*	*	*	*
F25 Agricultural Productivity (12)	20	*	*	*	*	*	*
F26 Shrimp productivity (12)	10	*	*	*	*	*	*
F27 Flood Risk in Urban Areas	20	*	*	*	*	*	*
F28 Living Conditions of Population (16)	100	*	*	*	*	*	*

physical modelling [Ordóñez, 2008] and limnological modelling [Pinilla et al., 2010] were firmly taken into account during this step.

Intrinsic importance impact F_i for each environmental factor and the intrinsic importance of the environmental impact generated by each alternative A_j were calculated, following the logical framework for assessment, evaluation and analysis set out in Table 2.

Results and Discussion

The relative values for intrinsic importance of impact on each environmental factor (F_i) for each of the six alternatives considered are illustrated in Figures 5, 6, 7, 8, 9 and 10. The data were qualitatively assimilated to generate a relative degree of damage or improvement concerning each environmental factor considered.

Figure 10 represents relative intrinsic values for the environmental impact generated by each alternative considered. These values

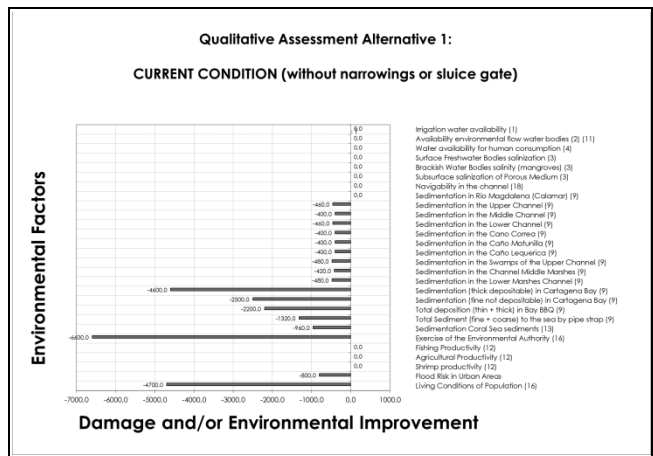


Figure 5. Environmental damage or improvement from Alt. 1: the current condition

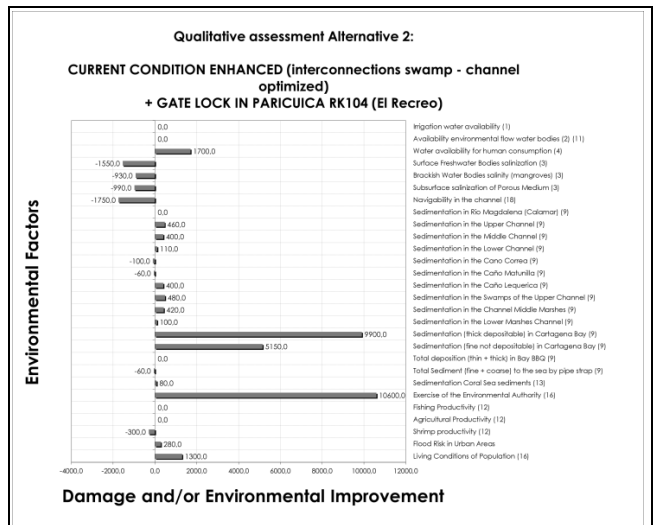


Figure 6. Environmental impact from Alt. 2: enhanced current condition (ECC) and a sluice gate in Paricuica RK104

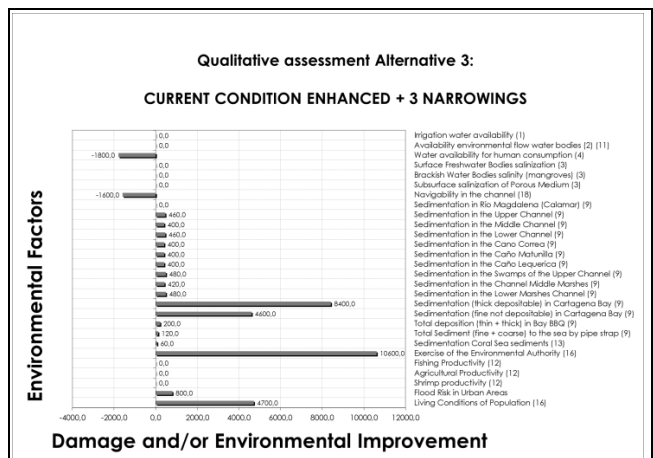


Figure 7. Environmental impact from Alt. 3: ECC and three narrowings

were qualitatively assimilated to generate a relative degree of environmental damage or improvement due to each alternative.

Figures 5 to 10 show that all the alternatives produced net environmental damage and improvement for each environmental factor evaluated here. However, Alt. 4 (enhanced current condition, the three narrowed straits and a sluice-gate system in the strait of Paricuica) produced only net improvement, as displayed in Figure 8.

Figure 11 shows the comparative analysis between damage and benefit for each alternative highlighted the Universidad Nacional de Colombia's Alt. 4 as being the most suitable alternative as it provided the greatest benefit for the environment. This should guide decision-making towards such alternative.

It is clear that any alternative which is finally selected should further undergo a detailed environmental impact evaluation to facilitate the formulation of an environmental management plan to effectively ensure the prevention, elimination, mitigation or control of impacts. Consequently, if the alternative chosen does not meet expectations regarding efficacy and efficiency, the management practice chosen must have a high degree of reversibility, so that it can be removed easily, and at minimal cost.

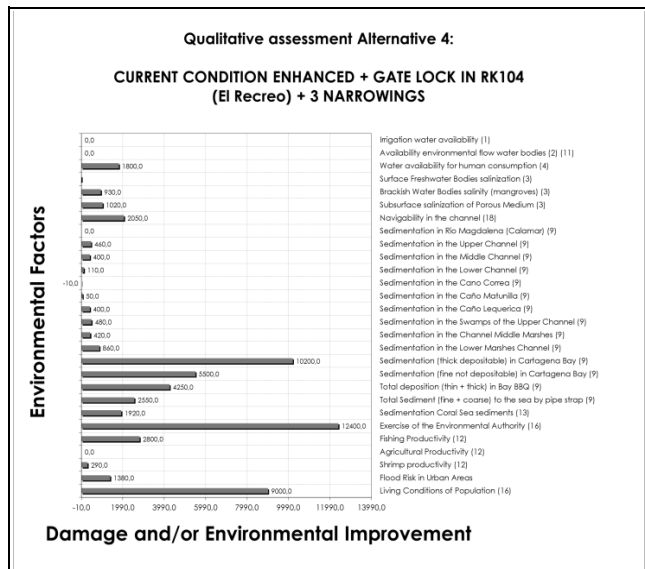


Figure 8. Environmental impact from Alt. 4: ECC, a sluice gate in RK104 (El Recreo) and three narrowings

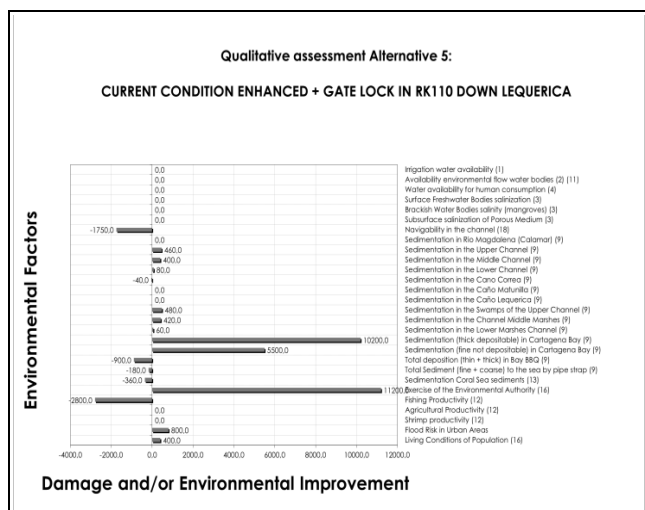


Figure 9. Environmental impact from Alt. 5: ECC and a sluice gate in RK110 downstream from Lequerica

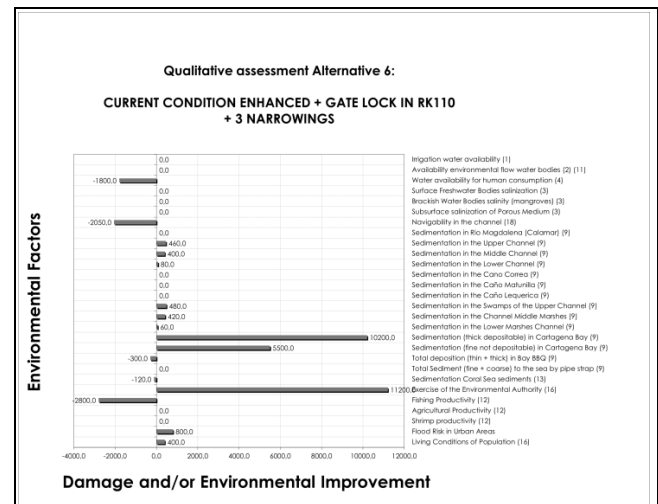


Figure 10. Environmental impact from Alt. 6: ECC, a sluice gate in RK110 and three narrowings

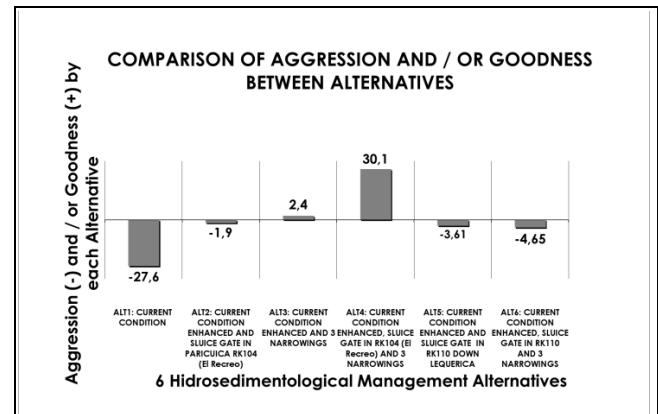


Figure 11. Aggression or benefit generated by each alternative

Conclusions and recommendations

The systemic environmental impact assessment (SEIA) developed and used here for assessing hydrosedimentological management alternatives for the Canal del Dique represented a valid option for environmental impact assessment.

It required the availability of abundant high-quality information. However, once such information was collected, aggregated and organised within the SPM framework, the identification and valuation (qualitative and quantitative) of environmental impact through MCA and the indicative systematisation of these results greatly facilitated analysis and decision-making regarding environmental impact evaluation.

The following actions are recommended prior to decision-making and development concerning environmental licensing of any alternative selected and in accordance with the principles of caution, gradualism, cost-effectiveness and on-going improvement.

The enhanced current condition should immediately be adopted, i.e. optimising dredging and that of the channel-wetland interconnections. In addition to being urgent and common to all the alternatives, developing these interconnections represents a significant improvement which will not require major investments or cause an irreversible impact. Moreover, this development will facilitate ongoing study of alternative management practice and assessment

of yet-to-be considered elements.

Experimentation and investigation *in situ* should be continued to facilitate monitoring, tracking and evaluating ECC and its subsequent complementation with other action which should continue to be the subject of evaluation and study.

The authors thus recommend not one alternative or optimal hydrosedimentological management practice, but a fundamental environmental management plan for the sustainable development of the Canal del Dique ecoregion and its water sources.

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