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Planning of areas of influence of reservoirs. Proposal from land carrying capacity

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Abstract: The starting point of this research is the identification of a normative and technical gap in planning areas of influence of reservoirs for power generation, understood these as water bodies in which an important part of water supply resources is concentrated. In this sense, a description of the problem and the importance of considering hydroelectric megaprojects as spatial analysis units is made; then, the determination of the land carrying capacity is proposed as a methodological tool, since it is considered that it functions as an Accumulative Impact Assessment, inasmuch as it allows to understand the configuration of the territory after the start of operation of the hydroelectric project and, based on this information, become an input for decision-making with technical support, that answer the question of what to do sustainably in those territories.

Key words: reservoirs; hydroelectric power; land carrying capacity; cumulative impacts

1 Introduction

The recent academic production and social and community movements against the construction of hydroelectric enterprises have made this issue public and put it on the public agenda, which has had an impact on the decision of the new proposal. However, how to deal with the reservoir in operation has not received the same attention, which is the planning problem related to water management and its application in energy production discussed in this paper. To this end, it proposes a methodology to answer the question of how to generate sustainable power in the upstream area of large projects built for power generation and under the water mirror.

The article is divided into two parts. The first part describes the problem, namely, proposing the minimum approximation of concepts and backgrounds as the discussion framework, and the importance of taking the power generation reservoir as the spatial analysis unit, which require appropriate planning and technical standards to face the challenge of more equitable distribution of their interests and potential to prevent, minimize or reverse tensions and conflicts between the relevant actors. The second part emphasizes the relevance of the territory's reception capacity, and the sequence of methods for implementing the model was defined and described. The model is understood as accumulative impact assessment, and its purpose is to fill the gaps identified. However, since the scope of this article is limited to the description of the problem and the description of the theory and method recommendations, it is not applicable to specific situations. (For some examples, see Ríos, 2014; Perruolo and Camargo, 2017; Alarcon, 2013).

2 Complementary and compatible uses of large-scale energy production projects in rural environments

A reservoir or dam is defined as an infrastructure project that changes the surface flow regime of a basin by obstructing its riverbed (Balairón Pérez, 2002). Its construction is considered as a kind of water resource management and supervision to meet various demands and pressures on water resources (ICOLD, s.f.). Therefore, according to Balairón Pérez (2002:225), "The demand to be met depends not only on the expected resources, but also on the available infrastructure and the level of security to be guaranteed". In this sense, reservoirs are artificial water bodies, in which part of the excess water supply is concentrated. Therefore, as an ecological unit, they are directly related to the catchment area or tributary basins (Hutchinson, 1999; Martínez, 2000).

In the past 50 years, dam construction has been strengthened globally, and the reasons can be distinguished in the context of abundance and scarcity. Therefore, in countries with limited resource supply, the construction of dams follows the logic of optimization and efficiency to balance the opportunities of obtaining resources during drought or lack of rainfall, so the dams are considered as reservoirs (Balairón Pérez, 2002).

In contrast, in countries with extensive resource supply, the construction of dams may be a goal promoted by their governments, such as the goal of providing drinking water for human settlements or large-scale economic utilization, the goal of Latin America, and the operation of large-scale hydroelectric projects (Tundisi and Matsumura -Tundisi, 2003). The financial support provided by some multilateral institutions has also promoted the construction of such large-scale projects, aiming to meet the energy needs of countries in the region and promote the diversification of the global renewable energy matrix (ONU, CEPAL and GTZ, 2004).

In the 1990s, a large number of hydroelectric development projects were evaluated and built around the world, especially in Colombia, which led to significant changes in regional geography and introduced some factors to make people expect complementary and compatible uses of protection and power generation. Therefore, forest plantations and/or the natural forests around the reservoir will be used to protect them, and the establishment of water mirrors can provide environmental services, whether support services (biodiversity, pollination, biological control, nutrient cycling), supply services (genetic resources and raw materials), regulatory services (water and greenhouse gas capture) or culture services (landscape and entertainment), which makes it possible to develop complementary and compatible activities such as tourism, shipping and fishing.

In Colombia, according to IDEAM (2010, 2012), the reservoirs used for power generation are located in areas where the runoff exceeds 1980 mm, which is the national average. However, in addition to the super rainfall runoff data, there are other factors related to the country's cities and production centers, so there is a serious imbalance, which depends on the relevant rainfall basin. Therefore, "the demand related to the geographical distribution of Colombia's population does not match the availability of water resources" (Arévalo, Lozano and Sabogal, 2011: 104). From a geographical point of view, this feature makes us mainly located in rural areas and Antioquia areas in the upper reaches of the Magdalena River. In these areas, reservoirs account for a large proportion of the total area and the number of ore bodies.

In addition, taking into account the increasing demand for energy in the context of highly concentrated space such as cities, it can be said power generation reservoirs are part of urban infrastructure as long as they are built to support and provide typical urban services (Ansar et al., 2014; Scudder, 2017). Therefore, the only rural area is its location. According to the above situation, reservoirs, as a territorial fact, although established on the basis of typical urban external rationality, operate as a transformation factor in rural areas, and change the special conditions of these territorial areas to make them unique, because they are not constrained by rural traditional logic or any other water logic.

However, the distinction between urban and rural areas has traditionally been considered in a dichotomy (Pérez, 2016), it must be emphasized that, according to Agudro Patiño(2006), it is impossible to talk about a single type of rural areas in order to keep it effective, because the process contained in the universal denominator will have very different territorial groupings with different needs. Therefore, we can talk about several types of environments or villages: marginal rural areas (areas located in the central environment of large cities), agricultural rural areas, agricultural industrial rural areas, mining rural areas, and ethnic minority rural areas. In the case of this study, the rurality of hydroelectric mega-projects can also be included.

Nevertheless, in these environments, some characteristics are common. These characteristics are considered to be typical of rural areas, so their residents are in the most urgent and contradictory fragile conditions. They are ignored and marginalized as political actors (Salas, 2016; CNMH, 2013; PNUD, 2011). However, if large-scale hydroelectric projects suitable for rural environment are added on the basis of these characteristics, namely, the construction and operation of dams, a series of social and political pressures will be brought to hydroelectric stations.

In most cases, this development has deepened the crisis and spatial imbalance. Different views on the necessity and benefits of the project for the affected people indicate that there are serious tensions between local, national and international interests (WCD, 2001). Even since the reservoir is part of the urban infrastructure, rural communities located in the upstream area of the hydroelectric project subsidize urban development and its population, which has a positive impact on the expansion of industrial and other productive activities (Acosta, 2004).

In short, the rural environment of large-scale hydroelectric projects concretizes the countryside by clarifying the environmental impact on water resources and their use pressures, including a relevant territorial actor: the construction or power generation companies, depending on the stage of the project (Barone and Draganchuk, 2011). These two variables put forward the distributive ecological conclusion related to the insecurity of resource disposal, "because the water dynamics of the flood plain and the whole basin depend on the external control of the upstream, and the external control changes due to the energy demand" (Roa and Duarte, 2012:26). And according to their complementary and compatible uses, they are objectively turned into the expectation and conclusion of future benefits generated by their operation. Therefore, this is "a distributive struggle against unequal access to opportunities, as well as a political struggle against discrimination or expulsion of specific groups" (Roa and Duarte, 2012:26).

Recent scientific research has described the problems of hydroelectric production and its environment, which is quite critical for the construction and use of the reservoir. They have had some impacts, such as questioning the calibration of green or sustainable energy, placing the discussion on national and international agendas, and drawing almost unanimous conclusions based on the quantitative summary of environmental and social risks, negative impacts and problem impacts by case studies, that geological and financial workers far exceed the advantages of intervention (Scudder, 2017; Ahlers et al., 2017; Ansar et al., 2014). However, the key production ignores a central issue: how to deal with the existing reservoir in terms of management.

Therefore, as far as the planning of the upstream area of the reservoir is concerned, it is recommended to determine the investment by region. Specifically, in the case of Colombia, it is possible to point out that in the existing reservoir environment, the planning, construction and initial operation stages are supervised by regulations related to environmental impact studies, environmental improvement and environmental management plans, respectively. However, in the long run, the operation of these reservoirs has caused a fundamental change in the geography of the cities concerned, which is not foreseen by these provisions. At present, there is no mechanism to implement a method to evaluate and regulate this change. In other words, the territorial impact of the development and operation of hydroelectric projects has not been regulated in the country. These gaps extend not only to the environment, but also to social, economic and political aspects.

However, if the technical and regulatory gaps related to reservoir management and regulation are to be filled, two complementary actions are needed: first, develop a technical approach that allows people to access the potential and limitations of the reservoir and its downstream areas to develop complementary or compatible uses, which takes into account their specificities, so that there are objective criteria to answer the question of how to proceed in a sustainable manner in the reservoir, while considering not only operational constraints, but also social, environmental and economic constraints. Second, develop a strategy to incorporate these standards into the legal system and make them binding on territorial actors. Only in this way can technical planning be translated into territorial planning and management, and problems related to water resources, infrastructure construction and pressure and tension in surrounding protected areas can be solved from a comprehensive perspective.

According to the *National Policy on Integrated Water Resources Management* (Ministry of Environment, Housing and Territorial Development, 2010), water is considered as a renewable natural resource and has a strategic position because it is directly related to the social, cultural and economic development of the country and contributes to life, well-being, food security and the maintenance and normal operation of the ecosystem. In this sense, Colombia has a constitutional and legal mandate that all authorities and individuals must comply with, aiming at the protection and equal use of water resources. Therefore, the scientific indicators of water use are determined by the multiple uses of water, that is, if it is regarded as a specific water body, as long as the resources are used more effectively, their use will be equal. In addition, this scientific condition and task is a challenge for water users and countries as regulatory agencies, because the multiple uses of water will affect the potential interference of one use with another, as well as the impact of this diversity on the natural water cycle (Tundisi and Matsumura Tundisi, 2011).

Water can perform biological functions (basic needs of humans and animals), ecosystem functions (as a means of reproduction of aquatic species), technical functions (raw materials for housing, industry or production activities) and symbolic functions (uses related to cultural values) (Tundisi and Matsumura-Tundisi, 2011). These functions may be compatible, incompatible or complementary according to their specific characteristics. Therefore, in each specific case, it is necessary to describe and classify their uses, so that when making conclusions, some elements and tools can solve and eliminate them.

In the case of reservoirs, the main use category will retain its purpose of construction and will serve as a reference for determining other uses that are compatible, conditional or prohibited. Therefore, when regulating these uses, it is necessary to specifically analyze the particularity of each reservoir and recognize its potential and current situation. At this point, the main restrictions and gaps in Colombia are found, because reservoirs are not considered as specific territorial facts, so there will be no difference compared with any other water bodies when analyzing what can be done in their environment without standards, resulting in the coexistence of quite problematic powers and authorities (Roa and Duarte, 2012).

3 Reception capacity as a planning tool

For the planning of large hydroelectric projects, the assumption is that the reservoir is the device that generates the process of territorial reconstruction, which needs to be known for intervention and guidance. The origin of this re-guarantee is that this infrastructure is not only a mechanism for water management, administration and economic utilization, but also related to the specific environment in which they are located. It also has an impact on the environment, economic activities and the social, political and cultural structures around them.

According to the above situation, from the perspective of epistemology, the area affected by its construction and use is considered as the unit of spatial analysis, so it can be rationalized by establishing measurable quantitative variables organized by models (Hartshorne, 1939; Harvey, 1969). In addition, because spatial transformation is generated through specific technical intervention, changes are common to the territory under similar conditions, because the reservoir makes inserted space unique and form a unit that can be decomposed, quantified and summarized through replicable models, which in turn makes knowledge systematic and comparable to verify the overall trend, thus further allowing the planning for the development of human intervention in such spaces. As far as Ramírez and López are concerned (2015:28), spatial analysis opens up the possibility of "building models to explain, analyze, predict, establish patterns, trends and make decisions on reality". This makes spatial analysis a basic tool for planning.

Therefore, in order to understand and plan the space generated by large hydroelectric projects, it is necessary to conduct a subsequent assessment, and regard the operation of the project and its relationship with the territory inserted into the project as a time frame, which means integrating the complex system generated after the completion of the reservoir through the spatial analysis unit. In addition, the goal of the plan also includes using spatial knowledge to allocate compatible and complementary land use for power generation and environmental protection.

One of the approaches that can make this approximation is the cumulative impact assessment (Cooper and Sheate, 2002; Brismar, 2004), in which spatial analysis is used to determine the structure and morphology of space at a specific time. Cumulative impacts are regulated by the *U.S. National Environmental Policy Act.* For example the incremental impact of actions on the environment includes the impact of past, present and reasonably foreseeable future actions. Cumulative impacts may come from a combination of minor actions considered separately, which are not important but are relevant when considered collectively over a period of time (U.S. Environmental Protection Agency, 1999).

A series of fairly accurate technical procedures for cumulative impact assessment have been developed (California Department of Transportation, 2012; Hegmann, et al, 1999; Smith and Spaling, 1995), such as multi-scale analysis of ecological networks (Chen, Chen and Su, 2011). However, as far as the current situation is concerned, it intends to develop a technical method to describe the reservoir environment of hydropower so as to take its particularity into account and have objective criteria to answer the question of how these territories are constituted, as well as their potential and limitations.

According to what was said in the previous section, it is insisted that the reason for the lack of such experience in the national context is that there is no legal obligation to study the long-term impact of these interventions, and reservoirs are not treated differently in terms of territorial management. Therefore, standards and models are used in allocating lands.

In this work, it is recommended to use multi-criteria assessment (EMC) and multi objective assessment (EMO) tools, and integrate them into the system of geographic information (SIG), and use the host capacity method as the assessment of cumulative impact on the reservoir environment. At the same time, people can understand the situation of the territory after the hydroelectric station is put into operation so as to determine the possible land use (Aguilar, 2012).

The proposal to implement the carrying capacity model is mainly a territorial diagnosis (Gómez, 2007). Functionally, the diagnosis is realized through planning, that is, seeking to understand and explain the spatial dynamics to avoid on-demand use. At this point, the applicability of the model to other alternatives are emphasized. First, for it does not intend to explain the location of activities, land use and its impact, such as activities inspired by Thünen's concentric ring model, land use and its impact (Walker, 2001; 2012; Caldas et al., 2007; De Carvalho, 2013; Phelps et al., 2013; Wästfelt and Arnberg, 2013). In Alfred Weber's position theory (Scott and Angel, 1987; Vitrox, 2000; McCann and Sheppard, 2003; Lall and Chakravorty, 2005) or Walter Christaller's central position theory (Pumain and Saint-Julien, 2014; Wanmali and Islam, 1995; Dennis, et al., 2002; Openshaw and Veneris, 2003; Barnes and Minka, 2013). Similarly, since the reservoir has been built and its purpose is to use it as the potential for developing other activities, it is impossible to determine the land use allocation through the location optimization model in the geographic information system, such as linear programming using heuristic technology (Fernández, et al., 2013; 2014; Delgado-Osuna et al., 2016; Haque and Asami, 2014; Datta et al., 2006).

Finally, considering that these are fragile spaces and involve the protection of strategic resources such as water and soil through natural forests or plantations, it is necessary to incorporate sustainability and sustainability criteria to make the results conservative so as to ensure the development of major activities, namely, power generation and environmental protection. The above refers to social standard categories beyond land use allocation, such as load, adaptability or potential use. Therefore, it is emphasized that the reservoir may become the catalyst of the emerging regional system, and its natural space content is attractive, which may require activities related to leisure, tourism and entertainment. This suggests forecasting its management. Therefore, the reception capacity model can well guide its development to determine appropriate regions, distribution of impacts and entertainment opportunities, because the territorial subsystem has different responses to the imposition of progress.

The accommodation capacity of a territory refers to the suitability or accommodation of the territory for activities. It takes into account the extent to which the territory meets the location requirements of activities (capabilities) and their impact on the environment (impact or vulnerability), and therefore is an indicator for the better use of the territory in accordance with its sustainability (Antequera, 2008). Suitability refers to the suitability of the territory in its environmental supply, that is, once its demand is activated, what capacity it has to provide a service or a set of services, namely the so-called capacity. Impact refers to the affect that these activities may have on the environment, that is, the degree of interference caused by such occupation, that is, the so-called vulnerability. According to the above situation, the reception capacity is also expressed as the level of activities that the environment can withstand without significant negative impacts due to human actions on it (Ramírez et al., 2011). Therefore, capacity is the result of adaptive capacity minus vulnerability.

In this proposal, carrying capacity is interpreted as a combination of two requirements or factors affecting reception capacity (Antequera, 2008): the capacity of the territory to support activities in material terms, and the vulnerability or impact of the natural environment on specific activities or uses. The impacts considered are those arising from the implementation and subsequent use of the activities. Capacity and vulnerability assessments are conducted at five levels: very high (MA), high (A), medium (M), low (B), and very low (MB). To apply this approach, it is necessary to select the activities to be assessed, the factors that determine capacity and vulnerability, and a set of procedures that integrate all available thematic information.

Therefore, the proposed carrying capability model generates six scenarios for each separately considered use (see Table 1). Therefore, after the technical feasibility study, if the limitation is based on capability, the intermediate situation between capability and vulnerability will allow specific use, and if the limitation is based on vulnerability, the environmental feasibility will be allowed.

Table 1. Assess capacity and vulnerability of different activities
in the reservoir protection area

Capacity	Vulnerability		
	low	Media	High
High	Up	A(EIA)	DES
Medium	A(IVT)	A(EIA+IVT)	
Low	NP		

Source: self-made since Antequera (2008).

UP: Allow unlimited use. There are no economic and technological restrictions, nor environmental restrictions.

A(EIA): Accepted for use, but an environmental impact study must be conducted to explain the measures taken to correct the expected impact.

A(IVT): After receiving a favorable technical and economic feasibility report, it shall be accepted for use.

A(EIA+IVT): It is allowed to use after the technical and environmental feasibility report.

DES: It is not recommended to use because it will cause considerable or irreversible damage and is incompatible with environmental protection.

NP: Not allowed.

Before applying the capacity model, it is necessary to exclude all cases where supplementary and compatible system use activities are not allowed from the territorial analysis unit, whether due to the legal status of the property, the high risks in the commercial operation of the reservoir (operation and monitoring area) or the natural characteristics of the area (non mitigable high-risk area or nature reserve).

The sequence of methods to meet the proposed objectives means that at least the following activities are to be fully used:

• Identify possible uses and activities in the reservoir area, i.e. water mirror and affected area, although this may depend on the special situation of each water body. In general, tourism, navigation, fishing, entertainment, urban and mining purposes must be considered (see Table 2)

• Investigate the existence, access, relevance and quality of information related to the purpose to be analyzed, and consider the scale of basic data to be generated and the identification effectiveness and other details.

• Identify variables, define their attributes, and assign associated classes related to capacity conditions and vulnerability conditions for each use and activity to be evaluated.

• Standardize, unify and debug the digital working format, which is necessary for the subsequent integration into SIG.

• Seek expert advice on the importance, classification and ranking of each capacity and vulnerability variable, which considers uses and activities. In such a way, it generates a weight, sorts variables, and allows to build corresponding algorithms in SIG.

• Integrate map information into GIS.

• Develop and implement mathematical algorithms, mapping algebra, and multiple criteria decision making.

• Generate topic maps by variables and activities.

• Determine the hosting capability of each activity through the composite diagram.

• Carry out multi-objective analysis, which is necessary to determine privileges when two or more activities are presented in similar favorable conditions and the same space.

• Cartographic synthesis of territorial occupation patterns, which is a subregional proposal, including the allocation of the best use or combination of them derived from the hosting capacity model after resolving tensions or conflicts between activities.

Table 2. Use and activity groups

Use	Activities
Tourism	Camping, hiking, horse riding, bicycle riding.
Navigation	Commercial, sports.
Fishing	Aquaculture, sports, handicrafts.
Entertaining	Swimming, navigation, fishing.

Urban	Campaign partnerships
miner	Gold mining, aggregates and sand mining

Source: Author

DOI: https://doi.org/Tabla2

The activities to develop this approach can be summarized as:

• Design a conceptual model, including: selecting the use to be evaluated; define the limits or variables that should not be considered in the analysis, because no use other than protection is allowed; define their ability and impact criteria for each application; calibrate or weight these standards according to expert consultation; determine the objectives for the best use of the identified territories; prioritizing the uses assessed based on their contribution to achieving the stated objectives.

• Develop a logical model, in which SIG tools suitable for conceptual model designed based on ArcGIS platform and its model builder application program are selected, used to create, edit and manage models, and defined as workflows linking geoprocessing tool sequences.

• Implement the cartographic model as a means of validating the conceptual and logical models (see Fig. 1).

Definition of restrictions, uses and activities

In the reservoir	Within the scope of influence

Definition of capacity and vulnerability variables

Capability: according to the conditions for activities and uses	Vulnerability: according to the impact of activities and uses

Definition and evaluation of standards

Determine identification criteria for high, medium and low capacity and vulnerability

Weighting criteria

Consult experts to classify benefits

Draw maps

capability	Vulnerability	Fitness map synthesis

Multi objective evaluation

Determine the optimization target of territory use	Classify the purpose or activities

Career model

Territorial subdivision

Exploration and adjustment

Validate occupancy model with expectation and context

Fig. 1. Synthesis of methodological proposals

Source: Author

4 Conclusion

Once the environment of large hydroelectric projects is described as a spatial analysis unit, adequate territorial diagnosis is required and can play a role in planning. Reception capacity is emphasized as a powerful tool for such territorial analysis. This approach represents the possibility of planning and management in the reservoir environment by systematically taking into account the environmental and operational constraints of these areas, which are often vulnerable due to the cumulative territorial impacts, and the ecosystem goods and services they provide.

Municipalities, environmental authorities and power generation companies, as the main territorial actors, are required to lead the planning and management process in the reservoir area in order to address or avoid the consequences of multiple uses of water in these environments. This is also a way to connect the communities affected by their construction and operation and distribute their benefits and potential more equitably. In other words, only when the reservoir is properly planned, managed, can its comprehensive sustainable development be considered from the social, environmental and economic aspects.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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