Intl. J. River Basin Management Vol. 8, Nos. 3–4 (2010), pp. 295–304

Research paper

Comprehensive system analysis of a multipurpose run-of-river power plant with holistic qualitative assessment

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ABSTRACT

Alpine rivers have been channelized by significant river training works in the past two centuries and are now disconnected from their natural environment. In addition, their flow regime is often affected by hydropower plant operation. Also the risk of flood damages is increasing continuously due to urbanization requiring additional flood protection measures. Nevertheless, such trained rivers still have high potential for renewable energy production. Furthermore, there is often a need for biotope restoration and creation of leisure infrastructures. New hydraulic schemes on such rivers have a chance to obtain public acceptance only if they are designed as multipurpose projects, which can alone ensure high synergies between different goals. Multipurpose projects are complex systems and have to be assessed with an appropriate global approach. Based on a network thinking approach, this article presents a global qualitative system analysis specially adapted for a typical multipurpose run-of-river power plant for the six project themes involved: (1) hydraulic scheme and river flow regime, (2) energy, (3) economy, (4) leisure activities, (5) groundwater and (6) ecology. The qualitative network thinking method developed by Gomez and Probst for business strategies is, for the first time, applied and enhanced for the assessment of such a multipurpose hydraulic scheme. Each theme, i.e. purpose of the project, is analysed separately, followed by a comprehensive study of the six themes combined together. Based on a network representation of the global system, three groups of factors are distinguished describing the sizes, the operations and the goals of the project. The size factors characterize the main geometrical aspects of the hydraulic structures, which can define the best layout of the project. The operation factors allow the optimization of the management of the reservoir. Finally, the objective factors characterize the synergies obtained by the multipurpose project. The developed methodology is illustrated with a case study of a multipurpose hydroelectric run-of-river power plant.

Keywords: Multipurpose run-of-river scheme; complex system analysis; qualitative assessment; network thinking approach; hydropeaking; flood routing; shallow reservoir

1. Introduction

During the past two centuries, river training works in many Alpine valleys provided the means for population growth as well as the development of agriculture and infrastructure. Nevertheless, the space allocated to Alpine rivers was strongly reduced by this urbanization, and as a consequence, many people now live in former flood plains. At the same time, the ecological value of the water course and its interaction with lateral biotopes have been strongly reduced. With increasing density of population and of infrastructures near rivers, extreme flood events have become more dangerous. Even if rivers were canalized in the past for flood protection reasons, typically for 100-year flood events, today their flow capacity is often too small in view of the extremely high damage potential (Schleiss 2004, Jordan *et al.* 2005, Walther 2005). Furthermore, storage power plants can change the seasonal flow regime and generate hydropeaking in the rivers downstream. In addition to the impoverished morphology resulting from river training works, the flow, sediment and temperature regimes of such rivers can be heavily disturbed by such storage power plants (Meier 2002, Meile *et al.* 2005).

Nevertheless, rivers still offer opportunities for development. The growth of electricity demand combined with the willingness

Received 16 September 2008. Accepted 24 July 2009.

ISSN 1571-5124 print/ISSN 1814-2060 online
DOI:10.1080/15715124.2010.517672
http://www.informaworld.com

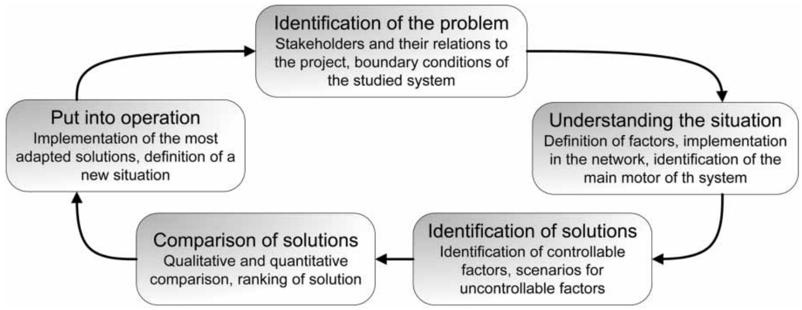

Figure 1 Five steps of the method of Gomez and Probst (1995) for the analysis of a complex system

to reduce CO_2 emissions has increased public interest in hydropower as the most important renewable energy. In urban areas, rivers are also attractive for social activities such as aquatic sports, fishing, biking and hiking along river banks. The creation of new aquatic biotopes is also an issue since such zones disappeared with river training works.

To ensure public acceptance, new river development projects have to consider and combine these different goals in an optimal way. Straightforward solutions rarely exist and a compromise in order to reach a win–win situation is often required. To find the acceptance on reasonable compromises, many participative methods have been developed (Leach and Pelkey 2001, Castelletti and Soncini-Sessa 2006). They involve the most important stakeholders from the beginning of the project. Multipurpose projects can best satisfy broad interests.

Because of their retroactive and coupled effects, such multipurpose projects have to be considered as complex systems. According to Coyle (2000), a complex system should be analysed with a qualitative model followed by a quantitative study. Qualitative modelling is thereby generally performed by a network analysis method.

The present paper focuses on a comprehensive qualitative system assessment of run-of-river power plants creating a shallow reservoir with a relatively large surface for flood routing, restoration of downstream flow regime, energy production, leisure activities and lentic biotope development.

Based on a network thinking approach used mainly for developing business strategies, a specially adapted methodology for hydraulic schemes is developed and then applied to a case study on the heavily canalized Upper Rhone River in Switzerland (Bollaert *et al.* 2000, Heller et al. 2005). Owing to the presence of a large number of storage hydropower plants in the catchments area, the flow regime of the Rhone River is considerably influenced by daily hydropeaking and seasonal discharge changes. Since the Rhone catchments area is 16% covered by glaciers, the water is also highly charged with suspended sediments, called glacier milk.

2. Assessment of complex problems by the adapted Gomez and Probst method

A complex problem is defined as a system which contains a large number of factors strongly, dynamically and reciprocally related. Therefore, a systematic and global approach is required. The network thinking approach, developed by Gomez and Probst (1995), consists of five steps as illustrated in Figure 1: (1) identification of the problem through the expectations of stakeholders, which allows an understanding of the relationships between the different factors; (2) set-up of a relational network; (3) identification and (4) analysis of potential solutions and (5) implementation. The analysis of the system may need several cycles of those five steps. At the beginning, boundary conditions of the problem have to be fixed and reasonable assumptions with the help of hypothetical scenarios have to be made regarding external factors which cannot be influenced.

The factors of the system are obtained by the analysis of the stakeholders' perceptions and their expectations related to the project. In a second step, these factors are combined into an influence diagram as shown in Figure 2.

The influences between factors are modelled by three parameters: direction (increasing or decreasing), intensity coefficient (weak, medium, strong) and time effect (short, medium or long term). The direction of influence indicates whether the relationship is proportional or inversely proportional between two factors. The intensity coefficient, chosen by expert consultation, distinguishes, on an arbitrary scale, a weak, medium or strong influence (weight of 1, 2 and 3, respectively). The impacts of these subjective choices are deeply investigated through a sensitivity analysis (Section 4.1). The time effect provides an indication about the propagation speed of influence. Theoretically, the measure of an influence represents the partial derivative function between two factors. According to

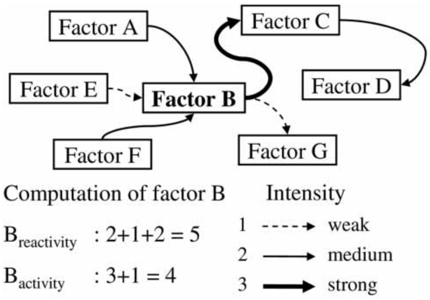

Figure 2 Example of a network and computation of influence

Figure 2, this measure between factors A and B is given as follows:

$$g = \frac{\partial f(A, E, F)}{\partial A}, \tag{1}$$

where f is the mathematical relationship linking the factors A and B and g is the relative influence measure expressed by the mathematical derivation of this relationship. As many relations between factors cannot be easily described quantitatively, they are replaced by an intensity coefficient (Gomez and Probst 1995). Thus, a comprehensive diagram connecting all factors related to the problem provides a complex relative model of the reality based on qualitative partial information (Sterman 2000).

As illustrated in Figure 2, the active influence measure of a factor, also called activity, is calculated as the sum of the intensity coefficient of outgoing relations. The reactive influence measure of a factor, also called reactivity, is obtained similarly by using incoming relations.

Comparing activity and reactivity between factors allows their ranking. The importance of each factor can be represented in an influence diagram (Figure 6). The horizontal axis indicates the capacity of a factor to influence others (activity), while the vertical axis gives the capacity of a factor to be influenced by others (reactivity). To produce comparable diagrams, activity and reactivity are normalized with their respective maximum values.

The influence diagram is divided into four zones, representing active, reactive, critical and inertial factors. Factors with large activities can be considered as levers of the system. Factors with a large reactivity are indicators of the state of the system. Levers of the system, if they can be influenced, are key factors through which the system can be modified. Effects of these modifications are normally reflected by the indicators corresponding to factors which can be quantified. Factors with both large activity and reactivity should be treated with care since they are critical for system behaviour. They can create chain reactions. Factors with both low activity and reactivity are called inertial factors. They are factors of minor interest for system analysis.

Complex models based on physical approaches include a large number of factors. As a result, non-inertial factors are separated from each other by many inertial factors of minor interest. Thus, taking into account only direct influences as proposed by Gomez and Probst (1995), illustrated in Figure 2, is not sufficient for a global analysis. Therefore, to consider the indirect influences from and towards indirect factors, according to Figure 2, the activity of factor A on factors B–D is introduced and expressed as follows:

$$A_{\text{Activity}} = \alpha \cdot I_{AB} + \beta \cdot I_{AB} \cdot I_{BC} + \beta \cdot I_{AB} \cdot I_{BG} + \gamma \cdot I_{AB} \cdot I_{BC} \cdot I_{CD}, \tag{2}$$

where I_{AB} is the intensity coefficient between factors A and B, I_{BC} the intensity coefficient between B and C, I_{BG} the intensity coefficient between B and G and I_{CD} the intensity coefficient between C and D. The indirect influences are computed as the product of the intensity coefficients. The total activity (or reactivity) of a factor is then obtained by summing the direct and indirect product of intensity coefficients weighted by the scheme coefficients (Table 1). These scheme coefficients consider two effects: the numerator gives importance according to the influence proximity (2^2, 2^1, 2^0) and the denominator produces a dimensionless coefficient and is defined as the maximum indirect product of intensity coefficient (3^0, 3^1, 3^2, with a maximum intensity coefficient of 3). The complex system can thus be analysed according to the deepness of influence (called primary, secondary and tertiary evaluation scheme).

3. Case study on the Swiss Upper Rhone River

The Swiss Upper Rhone River is influenced by hydropeaking that produces strong fluctuations in daily flow. The creation of a multipurpose reservoir on the Rhone River could mitigate these daily water level fluctuations and thus restore a near-natural flow regime. Nevertheless, to increase the public acceptance, such a reservoir has to be designed as a multipurpose project. In general, the possible purposes of a run-of-river dam projects can be divided into three main categories (Flug *et al.* 2000, Cai *et al.* 2004): (1) hydraulic purposes for hydropower production, flood protection, irrigation and navigation; (2) ecological purposes for aquatic ecology, mitigation of hydropeaking and creation of small water biotopes; (3) social purposes for leisure activities (fishing, water sport) and enrichment of landscape. Figure 3 integrates the general layout of a multipurpose run-of-river power plant on the Rhone River investigated in the framework of the case study.

The reservoir has an average surface of 1 km^2 with a total volume between 8 and 9 million m^3. The mean annual energy production obtained by a 10 MW powerhouse reaches about

Table 1 Matrix of scheme coefficients

	Direct, $A \Rightarrow B$ α	Indirect first level, $A \Rightarrow B \Rightarrow C$ β	Indirect second level, $A \Rightarrow B \Rightarrow C \Rightarrow D$ γ
Primary scheme	4/1	–	–
Secondary scheme	4/1	2/3	–
Tertiary scheme	4/1	2/3	1/9

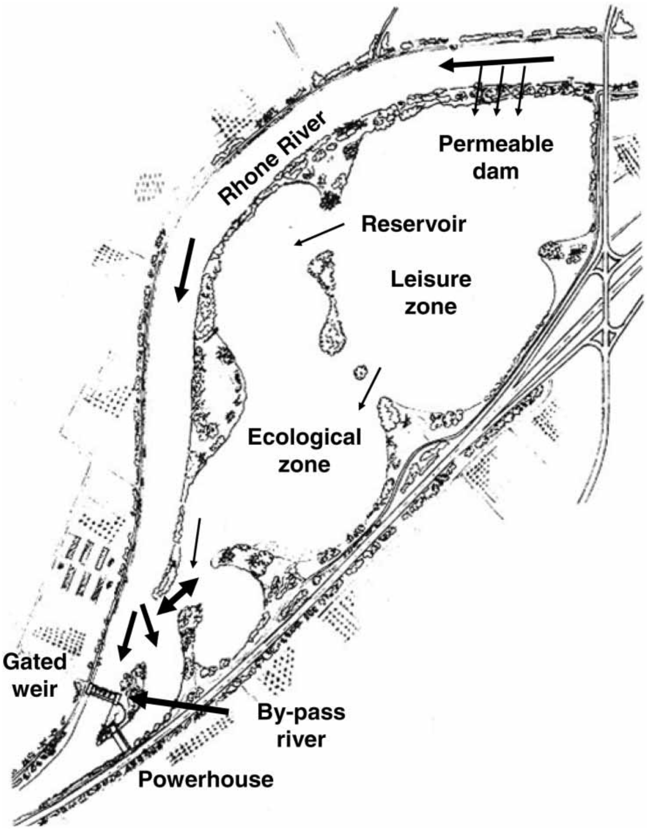

Figure 3 Layout of a multipurpose project on the Rhone River

50 GWh. Extreme flood peaks can be reduced by almost 200 m^3/s. This reduction represents about 20% of a 100-year flood event in the Rhone River. During the winter season, mitigation of the daily hydropeaking can be obtained by water-level variations in the reservoir by a maximum of 70 cm. The mitigation of the weekend hydropeaking generates a water-level variation of 2.5 m in the reservoir. During the summer season, daily water-level fluctuations in the reservoir are smaller than 10 cm and of the same order during weekends.

The actors which are involved in such a multipurpose project can be divided into four groups. The first one consists of political stakeholders (government), whereas the second group consists of economic stakeholders. The latter comprised agriculture, construction, electricity producers, finance, tourism and promoters of the project itself. The third group consists of environmental stakeholders who can be regrouped at a global and a local level. The last group represents the local population concerned by the project, consisting of local authorities and directly influenced riparian residents. For each stakeholder, his major interests related to the multipurpose project are given in Table 2.

An analysis of all the 15 considered actors and their about 50 related interests allows the identification of the 40 most important factors of the system. Based on the physical behaviour of the multipurpose scheme, the factors of the system can be divided into six themes: hydraulic, energy, finance, socio-economy, ground water and ecology (Table 3).

All factors of the system have to be linked in the network representing the complexity of the project. The network of the case study is shown in Figure 4.

4. Sensitivity analysis of the network

As an enhancement of the Gomez and Probst method, two sensitivity analyses have been defined, namely on the intensity coefficients chosen by experts and on the evaluation schemes (primary, secondary and tertiary). They are illustrated in the following for the network of the case study (40 factors). The obtained relative mean and extreme displacements of all 40 factors are compared in the influence diagram independently on the two axes (activity

Table 2 Stakeholders of the project with their major interests

Category	Stakeholder	Interests
Government	Energy	Production of indigenous energy, low-cost energy, grid security
	Landscape	Integration of civil works, respect of natural landscape
	Ecology	Preservation of fauna and flora, sustainable development
	Agriculture	Flood safety, arable fields, maximization of production
	Economy	Generation of employment, perception of taxes, tourist development
Economy	Agriculture	Quality and quantity of land, ability to sell products, ability to sell or buy land
	Tourism	Local promotion, leisure infrastructures
	Energy producer	Energy production infrastructure, freedom in river management, profitability
	Construction	Development of projects
	Finance	Opportunities of investments, profitability
	Project promoter	Profitability, social acceptability, economic development, political support
Ecology	Ecological NGO	Preservation of fauna and flora, sustainable development, social acceptability
	Local organization	Preservation of landscape particularities, fauna and flora habitats, fish development
Local	Local authorities	Local development, population growth, perception of taxes
	Riparian	Leisure infrastructures, social and economical development, security, employment, water quality

Table 3 Factors of the system for the six analysed themes

Hydraulic	Energy	Socio-economy
By-pass river	Hydropower benefit	Agricultural production
Dam height	Energy price	Agricultural promotion
Hydropeaking mitigation	Energy production	Employments
Lateral drainage channel	Flexibility	Landscape integration
Min downstream discharge	Installed power capacity	Legal/political aspects
Flood routing	Operations costs	Leisure infrastructures
Permeable dam flow	Promoter investment	Project residual risks
Reservoir fluctuations		Tourist development
Reservoir surface		
Reservoir volume		
Ecology	**Ground water**	**Finance**
Algae	Embankment permeability	Financial impacts
Ecotonal diversity	Flood plain elevation	Public investments
Fish diversity	Neighbourhood occupation	Flood protection cost
Macro-invertebrates	Soil permeability	Taxes
Suspended sediment load	Influence of groundwater	
Water temperature		

and reactivity). Theses displacements are expressed as the percentage of variation with respect to the maximal value of each axis (ΔX according to 100% x and ΔY according to 100% y). The results also consider changes in the ranking of factors. In addition, importance is given to the ability of factors to stay in the same zone of the influence diagram. Figure 5 illustrates the displacements of three factors, the change of zone (factor *B*, from reactive to critical zone) and the related rank permutation (on the *Y*-axis, *A* is ranked at the second position of reactivity and A', due to *C* displacement, at the third; displacement on the *X*-axis does not induce a rank permutation of activity).

4.1 *Sensitivity analysis on intensity coefficients*

The purpose of this sensitivity analysis is to quantify the impact of the subjective expert choices on the results. Thus, for each scheme (primary, secondary and tertiary; Table 1), the results obtained with the intensity coefficients defined by expert consultation (weight of 1, 2 or 3) are compared with those obtained with a constant intensity coefficient for each influence (weight of 2). Table 4 illustrates the results computed with all 40 factors and Table 5 those computed with only the non-inertial factors. Bold values indicate the maximum obtained.

For the three schemes and the two axes, the maximum mean variation is equal to a displacement of 10% of the maximum activity or reactivity values in the influence diagram. According to the rank definition, for all 40 factors used for this analysis, the maximum mean permutation (3.4 positions, second line, third or fifth columns in Table 4) is equal to 9% (3.4 divided by 40 factors).

The maximum variation is equal to 40% and corresponds, for the considered factor, to a rank permutation of three positions (tertiary model, active axis, by-pass river). The maximum rank permutation of 13 positions corresponds to a variation of 14% on the active axis (tertiary model, active axis, agricultural promotion). Since this factor is situated in the inertial zone which contains a large number of factors, a small variation leads to a large change in its ranking. This result reflects the number of factors of second interest due to the physical approach.

The same analysis is then performed with the non-inertial factors (Table 5). Slightly higher mean variations and equivalent maximum values are obtained. Nevertheless, the change in ranking (mean and extreme) is significantly reduced. Therefore, the relative position of the factors on the influence diagram is much more stable.

4.2 *Sensitivity analysis on evaluation schemes*

The purpose of this analysis is to evaluate, with the primary evaluation scheme as a reference, the sensitivity of the different schemes (e.g. the impact of the deepness of influence). The results are computed with the intensity coefficients defined by expert consultation. Table 6 illustrates the results obtained with all 40 factors and Table 7 those obtained with only the non-inertial factors.

The maximum mean difference, obtained by the tertiary scheme, is equal to 6% of the maximum activity. The maximum mean change of ranking is 1.3, which represents, in percentage value, a slightly smaller variation (about 3% with the 40 factors used). The maximum results have larger variations for the same reasons as explained previously. An analysis based on the non-inertial factors (activity or reactivity greater than 50%) produces similar results (Table 7).

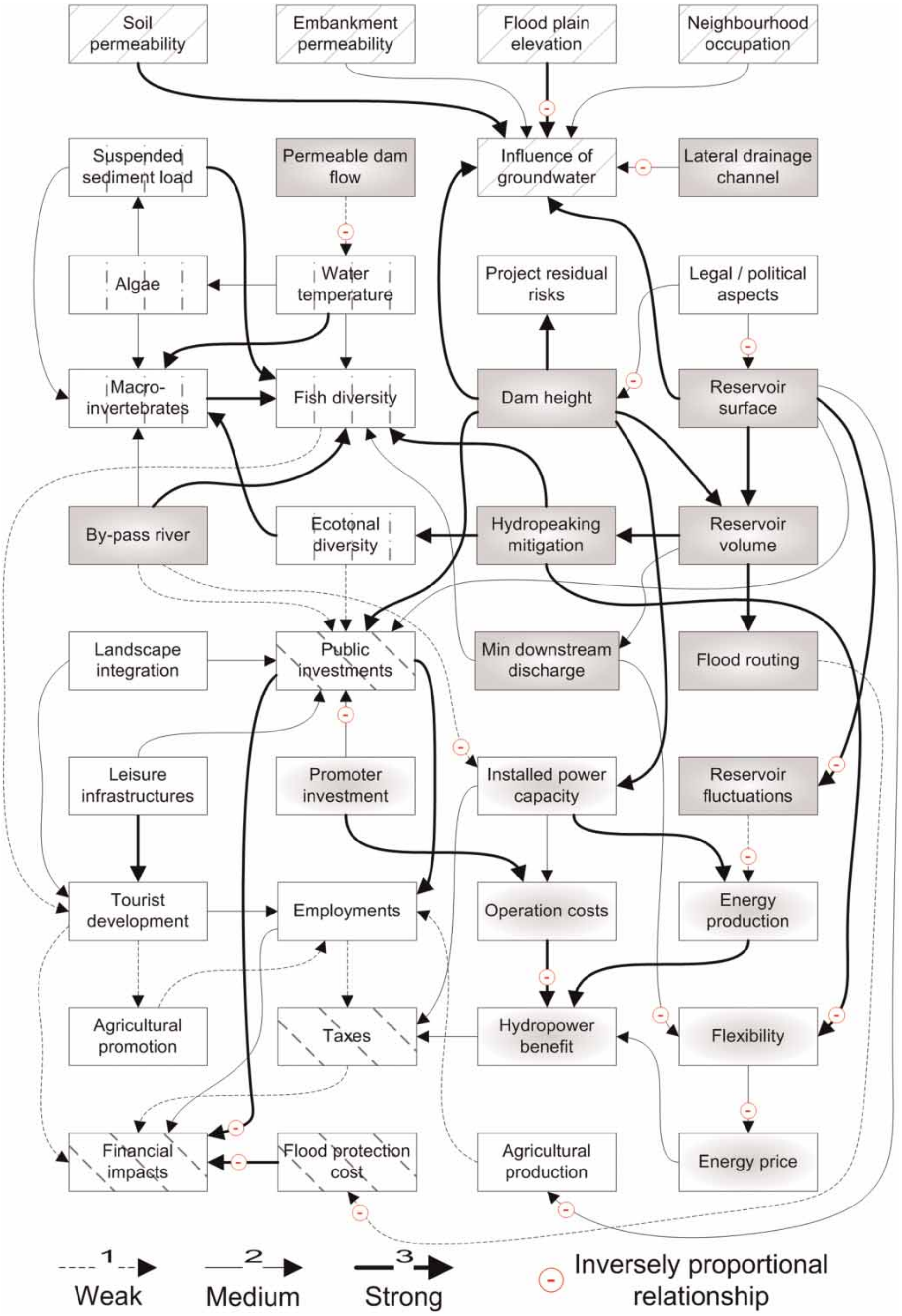

Figure 4 A network of the complex system of a multipurpose run-of-river project

4.3 *Conclusions of sensitivity analysis*

The developed sensitivity analyses on intensity coefficients and evaluation schemes allow the following conclusions: (1) if the method is limited to the non-inertial factors, it ranks them reliably independently from the chosen evaluation scheme; (2) the ranking remains almost unchanged even for different chosen intensity coefficients as given by experts; (3) the border between the four zones of the influence diagram (active, reactive, critical and inertial zones) should not be fixed sharply at 50% but rather as a band with a width of about 10%. Thus, it may be concluded that for the non-inertial factors of the system, a subjective choice of intensity or scheme coefficients has only minor effects on the results of the system analysis. The expert increase in value is then rather defined by the network design (choice of factors and existence of an influence between them) than by the intensity coefficients (weight of the influence).

5. Network analysis for the case study

In the following, the tertiary evaluation scheme, with intensity coefficients defined by experts, is selected to rank the factors. Each theme is first analysed separately (but still considering the connections to other fields). Then, a global analysis is performed. Only the hydraulic and the global analyses are presented below.

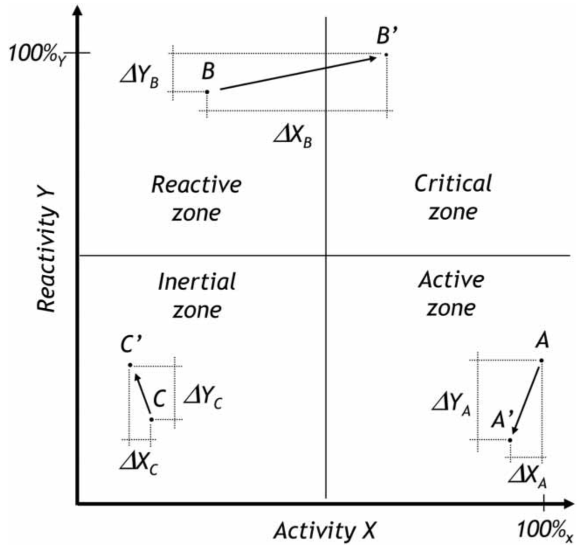

Figure 5 An example of displacement of factors as a result of the sensitivity analysis of the network

5.1 *Analysis of hydraulic factors*

Two active (reservoir surface and dam height), two critical (reservoir volume and hydropeaking mitigation), three reactive (flood routing, minimum downstream discharge and reservoir fluctuation) and three inertial factors (permeable dike flow, lateral drainage channel and by-pass river) can be identified in Figure 6.

With an activity of 100%, the dam height is the most active factor, representing the key hydraulic system factor. In a run-of-river power plant, the dam height directly influences the energy production and the available storage volume for flood and hydropeaking mitigation. Furthermore, the cost of the project mainly depends on the height of the dikes forming the reservoir as well as the weir and the powerhouse. The dam height also has a direct influence on the groundwater level and the required mitigation measures. The slight reactivity of dam height results from constraints like legal or political aspects which are uncontrollable for the project.

Table 4 Sensitivity analysis on intensity coefficients computed with all the 40 factors

	Primary		Secondary		Tertiary	
	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY
Mean	*Rate variation (activity or reactivity)*					
	9%	4%	9%	4%	**10%**	5%
	Change of ranking (activity or reactivity)					
	1.7	0.8	**3.4**	1.2	**3.4**	1.7
Max	*Rate variation (activity or reactivity)*					
	33%	28%	37%	18%	**40%**	31%
	Change of ranking (activity or reactivity)					
	7	3	12	10	**13**	10

Table 5 Sensitivity analysis on intensity coefficients computed with non-inertial factors

	Primary		Secondary		Tertiary	
	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY
Mean	*Rate variation (activity or reactivity)*					
	13%	9%	13%	11%	**15%**	14%
	Change of ranking (activity or reactivity)					
	0.7	0.5	0.6	1.5	0.7	**2.2**
Max	*Rate variation (activity or reactivity)*					
	33%	28%	37%	18%	**40%**	31%
	Change of ranking (activity or reactivity)					
	3	1	2	2	**3**	**3**

Table 6 Sensitivity analysis on evaluation schemes computed with all the 40 factors

	Secondary		Tertiary	
	ΔX	ΔY	ΔX	ΔY
Mean	*Rate variation*			
	5%	4%	**6%**	**6%**
	Change of ranking			
	1.1	1.1	**1.3**	**1.3**
Max	*Rate variation*			
	26%	27%	**35%**	**35%**
	Change of ranking			
	8	3	**9**	4

Table 7 Sensitivity analysis on evaluation schemes computed with non-inertial factors

	Secondary		Tertiary	
	ΔX	ΔY	ΔX	ΔY
Mean	*Rate variation*			
	6%	14%	8%	**20%**
	Change of ranking			
	0.7	1.8	0.6	**1.8**
Max	*Rate variation*			
	11%	27%	13%	**35%**
	Change of ranking			
	2	3	2	**4**

The second highest active factor is the reservoir surface with an activity of 78%. According to the main purpose of hydropeaking mitigation, the reservoir surface represents a key factor to reduce both downstream hydropeaking in the river as well as level fluctuations in the reservoir. The reservoir volume and ground water infiltration are directly proportional to the surface. Nevertheless, according to the moderate price of agricultural land, reservoir volume can be probably increased more economically by the reservoir surface than by dam height. Hence, the reservoir surface activity is slightly below that of dam height.

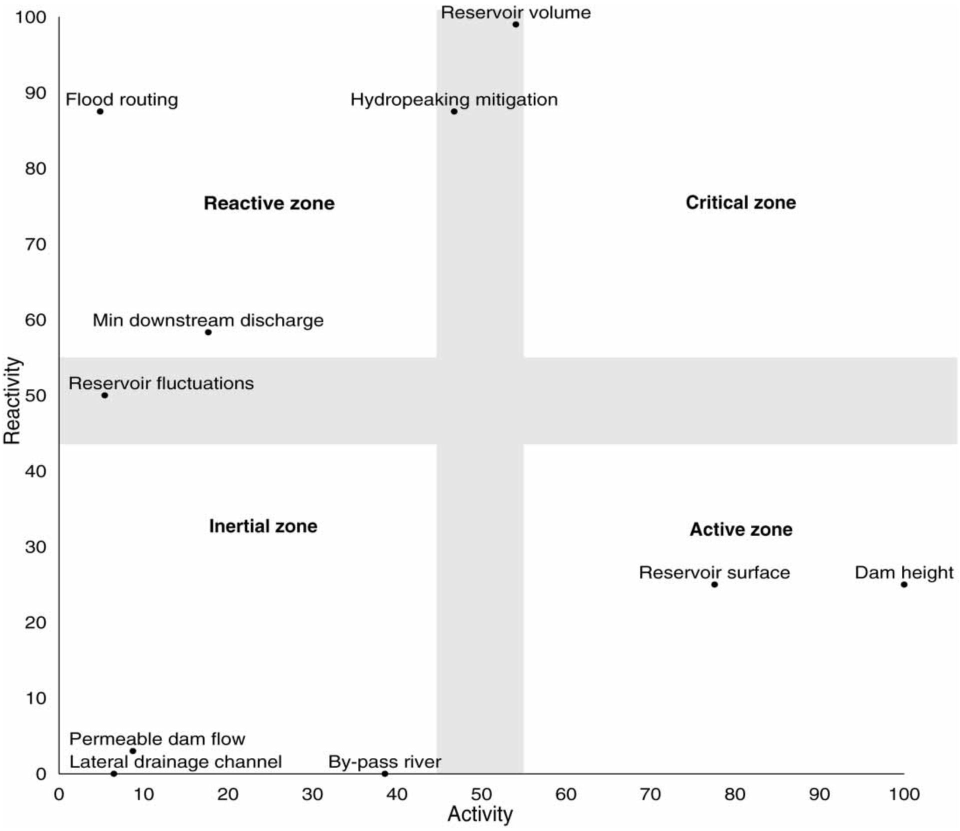

Figure 6 Influence diagram with hydraulic factors

Reservoir volume corresponds as a product of dam height and reservoir surface, and therefore is not a direct key factor. Its critical position in the influence diagram represents a transition factor.

The factor 'hydropeaking mitigation' is situated near the reservoir volume. It is the result of reservoir management limited by the reservoir volume and its maximal water level. It directly influences downstream ecological aspects. The minimum required hydropeaking mitigation in the downstream portion of the river has a direct influence on the needed reservoir volume. Since hydropeaking mitigation reactivity is higher than the reservoir fluctuation reactivity (88% against 50%), priority should be given to the ecological aspects of the downstream portion of the river. Thus, the development of the social and ecological aspects near the reservoir requires the appropriate design of the shore in light of significant water-level fluctuations.

The factor 'flood routing' has a reactivity of 88% which corresponds to the same passive position as hydropeaking mitigation. Beside hydropower generation, they both reflect, at the same level of importance, the two main hydraulic goals of the project. However, the two factors modelling reservoir operations during normal flow conditions, 'hydropeaking mitigation' and 'minimum downstream discharge', can be grouped into a single factor, 'downstream flow'. This factor defines the operational variable of the reservoir. According to the importance given to this factor, the reactivity of flood events is consequently reduced. Therefore, the flow regime restoration can be considered as the most important hydraulic objective of such a multipurpose scheme. This priority has a large influence on the selection of the reservoir site.

Finally, the other three hydraulic factors, such as permeable dike flow, lateral drainage channel and by-pass river for fish migration, are factors of minor interest. Since these factors are purely active (reactivity equal to 0%), they have to be seen as constraints of the project. They are necessary to ensure a minimum flow velocity in the reservoir in order to avoid deposition of suspended load, to limit the increase of ground water levels and to guarantee the longitudinal connectivity of the river.

5.2 *Global network analysis*

The global network analysis reveals five active, eight reactive but no critical factors. Many factors are situated in the inertial zone of the influence diagram as illustrated in Figure 7.

The dam height preserves its maximum activity of 100% as in the previous analysis. The activity of all other hydraulic factors remain then at the same position. Nevertheless, their reactivity is reduced four-fold since the new major reactive factor is fish diversity instead of reservoir volume (reactivity reduced to 27%). The hydraulic factors remain as the main levers of the system, which is confirmed with a low value of reactivity for all of them. With the lateral channel and powerhouse design, they constitute the size variables of the project.

Similar to hydraulic factors, legal and political aspects also have large activity but no reactivity. Nevertheless, they cannot

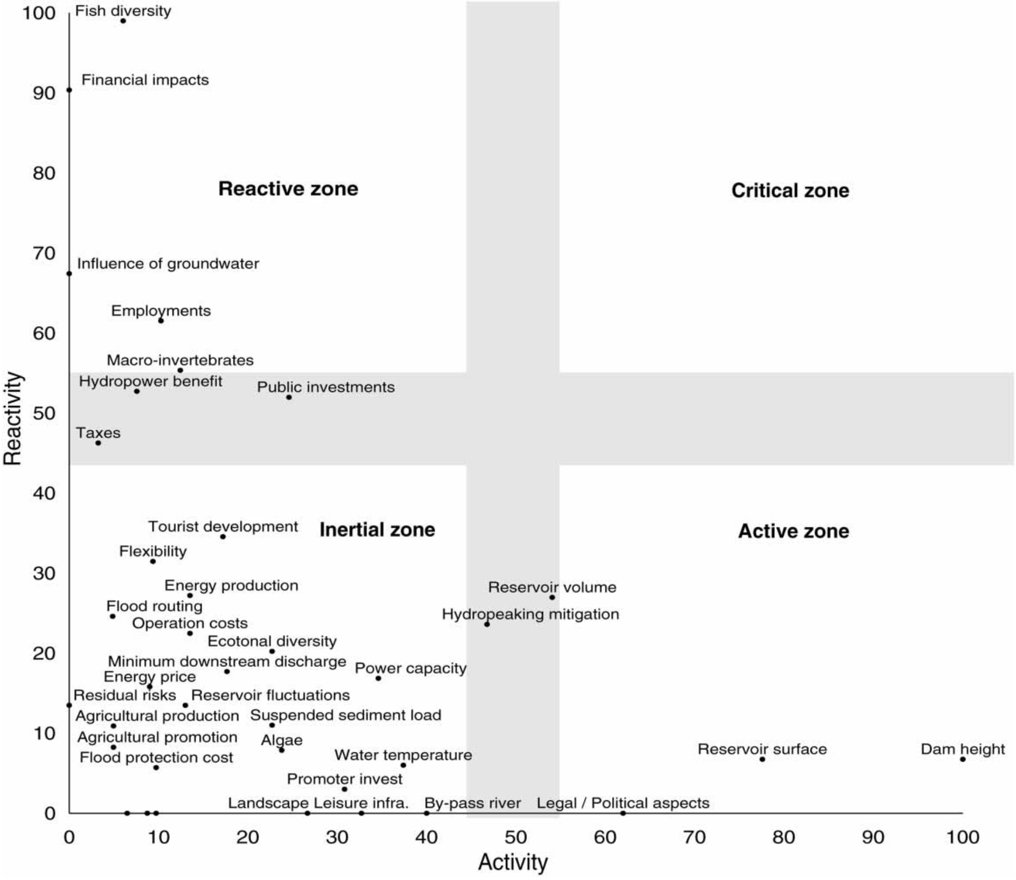

Figure 7 Influence diagram with all the 40 factors of the system

be directly influenced inside the system. These aspects have to be therefore considered as constraints given by the legal and political environment. Thus, reasonable limit values should be chosen for the factors they influence (dam height, reservoir surface, flow of by-pass river and ground water level).

The reactive factors comprise different aspects of the project: (1) ecology with fish diversity (100% of reactivity) and macro-invertebrates (55%), (2) funding with financial impacts (91%), taxes (46%) and public investments (52%), (3) ground water level with the influence of groundwater (67%), (4) socio-economy with jobs (61%) and finally (5) energy with hydropower benefit (53%). According to the six initial themes, five of them constitute direct goals of the project and can be described by only eight factors. These factors constitute the objectives variables of the system. Thus, the purpose of the project can be redefined as the maximization of ecological benefits by limiting global project costs and the constraints related to ground water. Socio-economic aspects and energy production can benefit from such a multipurpose project and should be considered as opportunities.

6. Conclusions and perspectives

For the assessment of multipurpose schemes, a qualitative analysis according to a network thinking approach is essential to understand the complexity of the project with the involved factors and the relationships among them. In this paper, the qualitative Gomez and Probst method, normally used for business strategies, is successfully enhanced and adapted for the assessment of multipurpose hydraulic schemes. The qualitative method could be very useful when implemented in the initial reconnaissance phase of procedures for integrated and participatory planning (Soncini-Sessa *et al.* 2007).

The project variables of various scales and units can be compared in view of their influence on the entire system. Dividing the global system into interconnected thematic networks allows a better understanding of each part of the system. In addition, with a global analysis, the different themes can be compared and the system factors can be ranked. In order to validate the developed network describing the complex system, sensitivity analyses regarding the intensity coefficients and the evaluation schemes are performed.

The application of the enhanced method to a real case is helpful to divide factors into three groups enables to distinguish size, operation and objective factors. The first group of factors defines the size of the project. For the presented case study, the most important ones are dam height, reservoir surface, by-pass river flow and power-plant discharge. The second group of factors defines the management of the project. This group is represented in the case study by the discharge downstream of the dam. According to the upstream inflow, reservoir level, energy production and hydropeaking mitigation have a direct influence on the tailwater discharge. The third group, composed of hydraulic, energetic, social, ecological and financial factors, can serve as indicators for the quality, i.e. goals achieved by the project. The proposed comprehensive system analysis based on a holistic qualitative assessment is an important and necessary step in understanding the complexity of the system and the preparation of a functional quantitative model as proposed by Heller *et al.* (2006) and Heller (2007).

Acknowledgements

This research project is supported by the Swiss Agency for Innovation and Promotion (Project No. 6794.1 FHS-IW), in partnership with the Forces Motrices Valaisannes (Switzerland), Canton of Wallis (Switzerland) and Federal Office for the environment (Switzerland). The Laboratory of Ecosystem Management (EPFL, Switzerland), STUCKY Engineers Consulting and ANDRITZ-VATECH Group provided advice on ecological and technical issues, respectively.

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