ENTROPIC MANAGEMENT OF WATER IN DECENTRALISED COUNTRIES

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Abstract:

This work presents some insight into the way in which federate countries today, especially developing federate countries, carry out their so-called water management. Reference is also made to one of the concepts that has had the greatest impact over the last decades due to the degree of progress and evolution reached, which is the concept of Integrated Water Resources Management (IWRM). Based on the arguments that support this water management process and acknowledging water and energy resources as critical variables for sustainable development, a methodology is proposed with physical and natural foundations for decision-making. This process consists in using concepts of the environmental economy and above all in optimising the necessary energy to satisfy the water needs for the different uses in a river basin. Finally, it is necessary to underline that this methodological proposal is still in a development and refinement phase within the Inter-American Centre for Water Resources (CIRA-UAEM-Mexico) but whose partial results confer upon it a promising future as well as a rapid evolution and implementation.

Key words: Integrated Management, River Basins, Entropy, Water Quality, Water Value, Decentralised Countries.

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I. INTRODUCTION

It could be said that the International Conference on Water and the Environment in Dublin 1992, saw the rebirth of one of the most transcendental water management concepts that has led to a reconsideration of the organisation of decision-making and management of water resources in any country or region. This concept is called Integrated Water Resources Management (IWRM), defined as "the process of promoting the coordinated development and management of water, land and related natural resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of the ecosystem". Although it can be argued that this concept, or a very similar one, has existed for a long time (BISWAS, 2004; RAHAMAN & VARIS, 2005, EMBID, 2003) the important factor is not when it appeared, but that it has been improved today and is envisaged as a feasible way to solve the indisputable water crisis faced, and above all in decentralised countries.

It is worth mentioning that a classification has been generated, even among decentralised countries, based on the level of existing development. Indeed, the social, economic, educational and development situations present conditions for which the environmental protection and organisation must be simply different. In agreement with recent studies (CAP-NET et al., 2008), the legal framework existing in federate (decentralised) countries is considered as sufficient to support the management and protection of the natural resources of a country. However, in practice, the applicability of this legal framework leaves a lot to be desired. On the other hand, the level of autonomy, which the basin organisations enjoy, is very limited in the best of the cases and generally requires the approval of national agencies, attending to "politically acceptable" reasons in detriment of a management and decision-making that benefits the social-ecosystem.

Some countries, like Mexico and Brazil, have modernised their discourse and even their laws, introducing holistic approaches for managing water resources. Unfortunately, things are very different in reality, as the difference between the objectives, actions undertaken and the results obtained is indisputable. These differences are apparently attributable to the lack of human, economic and financial resources, and to the lack of sufficient technological and institutional coordination to implement this organisation. That is why it is currently necessary to implement participative approach strategic planning processes for integrated water resources management based on a high action output and prioritised integration of components to be considered.

The process required to manage natural resources and especially water, requires a change in the organisational paradigm and above all a change in mindset of each and every one of the members of the society in question. Today the concept of IWRM has been re-orientated based on the framework of participative strategic planning where the changes are gradual, but where, through the tactical planning phase, high impact results can be obtained in the short-run that are consistent with the strategic vision defined.

One of the generalities that arise in decentralised countries is that the water that reaches a river that crosses more than one entity (state or department) becomes federal jurisdiction and this water resource cannot be managed on a local level. It is precisely in this aspect where the methodological management proposal presented here takes on singular importance as, before the water reaches the federal river, the management will be economically more profitable.

Thus, the theory of entropic water management (DÍAZ-DELGADO et al., 2005) is presented within the framework of proposals to implement best water management practices in decentralised countries. This proposal aims to show a methodology which, based on real, physical and natural facts, guides decision-making on water management, avoiding the temptations of economic manipulation through subsidies that make any effort to optimise the system fictitious.

The attribution of value to natural resources is undoubtedly an arduous and difficult task. Firstly, because it is usually measured in monetary terms, and money and nature are governed by different laws. Money is governed by the laws of mathematics, whilst nature is governed by the laws of physics (SOODY, 1926). Mathematics allows the quantities to increase in agreement with the rule of composite interest, and other similar rules, whilst physics is governed by the second law of thermodynamics, namely, entropic degradation. This fundamental dichotomy explains the difficulty that exists to place a monetary value on natural assets and elements.

The quantity of water that exists on the Earth remains relatively stable. In abstract terms, this volume seems to be more than sufficient to satisfy all the human needs both at the present time and in the near future. In fact, the quantities available are much less. Firstly, because the natural function of water is not for the exclusive use by human societies. Water is also the main support for the ecosystems that exist on the planet. This determines that to use water without damaging nature, and thereby, indirectly, human societies, the socio-bio-hydrological cycles must be taken into account. That is why the use of water is limited by the need for the specific configuration of local, regional and global socio-ecosystems.

The main problem that human beings are experiencing with water is above all **quality** and to a much lesser degree, **quantity.** Entropic degradation caused by human consumption intensely affects the quality of water and to a lesser degree the volumes.

The fact is that the natural recycling produced by solar energy (evaporation, photosynthesis) does not manage to purify all the waste water that is continuously produced.

Due to the increasing volumes of wastewater of a human origin, which are also concentrated in relatively small areas, the natural recycling processes are insufficient to purify them. Different types of treatment systems or plants are installed as a way to correct this situation. The treatment processes use, either directly or indirectly, enormous quantities of fossil fuels. It is obvious that fossil fuels are solar energy from the past, accumulated into finite volumes. When the oil, gas and coal run out, this planet will be left with the only realistic source of renewable energy: solar radiation.

In general, what gives value to water is, above all, its quality. Water of certain qualities (for example toxic water) could even have a value definable as “negative”, as it requires large amounts of energy to be eliminated or treated for later use, whilst other waters that do not require any treatment may have a high value. In other words, what gives value to water is above all the “quality in quantity”.

II. CRITERIA AND INDICES TO CHARACTERISE THE QUALITY OF WATER

Determining the quality of water refers in general to the possibility of it being used in economic, social and environmental activities. In qualitative terms, higher quality water is water that has a low salt or dissolved gas content, which does not contain pathogenic micro-organisms, with very low levels of organic matter and with few or no particles in suspension. In general, water with these characteristics is appropriate for human consumption. There are several water quality coefficients, generally calculated based on the determination of the concentrations of salts and different types of contaminants contained therein. The National Water Commission (CONAGUA, Mexico) has used a coefficient that varies from 0 to 100, where 0 is the worst quality. Quality is calculated through the following equation:

$$I = \frac{\sum_{i=1}^{n}\left(I_i W_i\right)}{\sum_{i=1}^{n} W_i}$$

Where: ***I***: General quality coefficient; ***Ii***: Quality coefficient of the considered parameter; ***Wi***: Weighting of the parameter considered. The weighting awarded to the parameters is shown on Table 1.

Water quality is also characterised in agreement with official government regulations that establish maximum admissible limits of contaminants in water for different uses (human consumption, irrigation, discharges into natural water, etc).

Industrial wastewater is also defined in agreement with the different contaminants it contains. Several coefficients have been established to define the degree of contamination; one of them is the *chimiotox*, or toxic weighting factor (Ftox) which was established by the Plan d'action St Laurent de Quebec, Canada. The equation to calculate it is (DENIZEAU & RICARD, 1998):

$$F_{tox\,i} = \frac{1\left(mg/l\right)}{CPS_i\left(mg/l\right)}$$

Where: $\boldsymbol{F_{tox\ i}}$: the toxic weighting factor of parameter ***i***; ***1 mg/l***: an arbitrary reference; $\boldsymbol{CPS_i}$: the most sensitive water quality criterion of parameter ***i***.

Based on the preceding equation the *chimiotox* unit or UC_i is calculated: $\boldsymbol{UC_i = Charge_i \ x \ F_{tox\ i}}$**.** Then the *chimiotox* units of each contaminant are added up to define the *chimiotox* coefficient (IC) and thus know the contaminant charge of an effluent, and therefore, the relative water quality.

Another way of facing up to the problem is via the definition of environmental indicators that indirectly provide the required information. The indicators are variables or values derived from variables that provide information about a phenomenon (BARRIOS ORDOÑEZ and GONZÁLEZ MORA, 1999).

The variables used by the aforementioned authors are BOD_5 (biochemical oxygen demand), $N\text{-}NH_3^-$ (ammoniac nitrogen), DO (dissolved oxygen) and FC (faecal coliforms). This approach facilitates the analysis, although really it only provides elements about the effect of water degradation processes without giving a complete idea of the energy and entropic cycles that take place in water systems.

III. JUSTIFICATION OF AN INSTRUMENT FOR AN ENTROPY ANALYSIS OF WATER

When the time comes to make decisions on water issues, the decision-makers must face up to a wide range of real data and elements, which include geographical, geological, ecological, hydrological, social-cultural and technological aspects, as well as water quality coefficients or indicators, which are not always easy to interpret.

With respect to water, as in other similar fields, the final decisions are usually political ones, and in the majority of the cases, their defining element is an economic one.

However, in economic analyses that lead to the adoption of public water policies, the assessment of the "value" of the resource only takes aspects related to the monetary value into account. To make this situation worse, water is often considered as an inexhaustible resource and that it suffices to construct sufficient capital assets, such as dams or lines of wells, to obtain it. In fact, the loss of value resulting from its use is unknown as is the cost required to return a value to it that will permit its re-utilisation. If a "natural" value can be assigned to water, expressed in one single coefficient that shows the degree of entropic degradation, it will be easier to perform an analysis and make a decision on firm and sure bases.

IV. WATER MANAGEMENT THEORY: ENTROPIC MANAGEMENT

1. THE CONCEPT OF ENTROPY

Entropy is a complex concept that aims to describe the natural direction of physical processes in the universe. These tend to occur in an organised and disorganised fashion as well as heterogeneously and homogeneously. The energy concentrated somewhere in space tends to diffuse in all directions. This diffusion can locally be hindered by other physical forces, such as gravitational attraction. These barriers to the global dissemination of energy produce almost closed systems that form circumscribed areas where the law of entropy acts. If the celestial bodies were not to emit or receive energy (or its concentrated version: matter) they could be considered as closed systems and for these cases the Second Law of Thermodynamics could be applied, whose formulation sustains: **"The entropy of a closed system never decreases and whenever possible it increases".** Really, the only entirely closed system is the entire universe, and this is where the aforementioned concept is applied.

The concept of entropy is also applied to open (or half-open) systems. Likewise, these tend to become disorganised and unify their matter and energy levels. Due to their open character, they may experience local entropy reduction processes that are explained by an increase in entropy elsewhere. The general balance is an increase of entropy. The geological evolution of the Earth is the result of the interference of two entropic tendencies, that of the Sun, which in its maturity diffuses and therefore “shares” its energy, and that of the Earth itself, which, similarly, although in a less intense manner, is continually and sometimes obliviously radiating its energy flow. From the practical viewpoint, entropy is expressed in a series of physical phenomena which, given the appropriate conditions, take place in one single direction.

2. THE ENTROPIC VALUE OF WATER

The volume of water on the planet is finite but its theoretic potential for use is unlimited. What is really measured is the speed of flow. This depends mainly on energy and the energy available on the Earth’s surface is limited, almost entirely supplied by solar radiation. Another long-term limiting factor is the final irreversibility of its entropic degradation, which, although expressed above all at very large time scales, may be accelerated via human intervention.

Environmental contamination can be perceived as the result of the material and heat discharge in the environment (water, air and/or soil) due to antropic production or consumption activities. When a compound is added to water, the component dissolves and mixes in the medium. This dissolution and mixture implies an increase in the entropy of the solution and an increase in the degree of contamination, which suggests that an increase in entropy implies water contamination. Water contamination can, then, be seen as a process where water that initially has low entropy, eventually returns to the medium with higher entropy due to the antropic use that is given to it and therefore the entropy of the environment that receives it increases. (SING, 2000).

The **entropic value** of water is really its value assessed in the framework of the entropic evolution of life on the planet. It is a value that decreases as the entropy increases and which therefore could be called more correctly: “anti-entropic” value. As human beings consider that entropy is in fact a devaluation of the resources, the expression, entropic value, will be used to define the absence of devaluation, or in other words, the absence of entropy.

The entropic value of water is related to the consumed / used energy to take the liquid to a state of lesser entropy that is sought to be established. In that regard, the entropic value comes from the energy required to obtain a specific quality of water based on a reference level.

In natural systems, the greater entropic value is achieved from the condensation of the water vapour of the atmosphere in the clouds and its precipitation by way of rain, snow or hailstone.

The falling of water as well as its subsequent run-off towards lower potential energy levels, implies an increase in entropy and therefore a loss of the entropic value of the resource.

Following the precipitation, the rainwater runs off and/or infiltrates. Substances are dissolved and incorporated into its flow giving rise to additional losses of its entropic value. As it flows, the water is transformed into a more and more suitable medium for the development of live organisms. The physiological photosynthetic functions may locally produce an entropic valuation of the resource, whilst the remaining metabolic functions tend to reduce the value. The accumulated effect of these processes leads to an increase in the entropy of the water.

On the other hand, the human use of water is a factor that accelerates the increasing deterioration of its value, which is added to the degradation due to natural processes.

Irrigated farming, which uses a lot of water when considered in terms of volume, uses water of a certain quality and returns it to the natural medium with a lower quality. The value loss due to agriculture depends on the irrigation practices and systems used. In some cases, high quality water (greater entropic value) is used and when discharged it is highly contaminated with agrochemicals or salts (less entropic value). In that case, the value loss is very great.

Cities, on the other hand, despite consuming less water than agriculture, tend to be great water degrading factors. The majority take water from nature, submit it to certain potabilisation treatments (that consume energy), raising its entropic value and then return it to the medium charged with numerous contaminants. The re-utilisation of urban wastewater, which means raising the entropic value again, requires larges quantities of energy, which are often out of reach of the societies in question.

Industrial activities, on the other hand, generally but not always have intensive harmful effects on water resources. The water degradation potential by the industrial activity is very great.

Different methodologies have been applied in practice to calculate the value of water quality. Although a method based on the entropic value cannot be easily expressed in quantitative terms, it is an instrument that can be used to define, though qualitatively, the value scales required to formulate appropriate strategies to optimise the use of available water resources.

V. THE ENERGY CYCLE OF WATER

One way of presenting the water cycle is via the energy exchanges that take place in the different processes whereby water changes state, physical or chemical properties, or its position in space. The majority of the energy consumed in the water cycle comes (directly or indirectly) from solar radiation. However, there is a smaller proportion that comes from geothermal sources, giving rise to the heating of groundwater, and of certain hydrothermal springs. A list of energy-hydrological cycle phenomena and processes are shown in Table 2 and Figure 1.

1. NATURAL RECYCLING SYSTEMS

All the wastewater that is not artificially recycled is integrated into the hydrological cycle and subjected to natural recycling systems. The planet's capacity to naturally recycle water is limited, both locally and globally. On a local level, water is usually left for a certain period of time with deteriorated quality conditions, until discharged to the sea or evaporated. In both cases it is reintegrated into the natural system in the form of rain, snow or hailstone.

On a global level, untreated wastewater tends to be dissolved in oceans, seas and lakes, being incorporated into them and reducing their quality. This process is clearly visible near the coasts where the characteristics of sea water are considerably deteriorated due to the contributions of cities and industries. Seawater is surface water with high entropy (and therefore with a low entropic value). This natural value, which has already been reduced, is decreased even more by human action.

WATER CLASSIFICATION CRITERIA

A series of criteria have been used to classify water according to its entropic value. These are in turn associated with entropic type processes and with the necessary energy requirements to take the water from the lower levels (with less entropic value) to other higher levels. In some cases, when the processes are irreversible, this "elevation" in entropic level may not be feasible.

The following major criteria are used:

- ☑ The entropic value tends to drop as the water descends, releasing potential energy. The water from the clouds and mountains is more valuable than the water from the rivers, sea or plain aquifers;
- ☑ The entropic value also decreases when the concentration of dissolved substances increases;
- ☑ The entropic value decreases when the heterotrophic (non photosynthetic) organisms increase. Photosynthetic organisms have the opposite effect during the time the photosynthetic function takes place. The entropic value also decreases when the organic matter concentration increases. After a certain threshold, the increase in entropy (consequently decrease of its entropic value), may lead to the reduction and even disappearance of the vital processes and organic matter;

- ☑ The entropic value decreases as the water contamination increases (toxicity for different forms of life).
- ☑ There are several reasons for a reduction in the quality of water. Some are natural and others are derived from the type of use. Therefore, there can be water with very different characteristics that is classified at the same level. The reason is that all types of water require comparable quantities of energy to be taken to the levels of reference.

Table 3 shows the different types of waters classified in agreement with their level (value), as well as the possible use, geological position and presence of life.

AWARDING THE ENTROPIC VALUE

To calculate the entropic value a mixed, qualitative – quantitative, method is proposed. Firstly the entropic values are awarded to the waters in agreement with the aforementioned criteria, granting 10 to the maximum entropic value (water from high, newly condensed clouds) and 0 to non-contaminated seawater with medium salinity. The intermediate values are assigned by combining different quantitative and qualitative criteria. Negative values are awarded to hypersaline or highly contaminated waters. The following equation is proposed to calculate the entropic value:

$$VE = 1 - \left(\frac{10\left(10 - NE\right)^2}{Mc} \right)$$

Where: ***VE***: is entropic value; ***NE***: is entropic level (defined qualitatively) and ***Mc***: are the megacalories required to evaporate 1 m^3 of water at a temperature of 15º C and at water level pressure. In agreement with the above equation, the different entropic levels would correspond to the values presented in table 4.

PARAMETERS TO DEFINE THE ENTROPIC VALUE LEVELS

The decrease in entropic value is a natural phenomenon that occurs from the moment that water vapour condenses forming clouds, and especially when it falls to the ground in the form of rain. At that time the waters begin to flow, losing potential value, salinity increases and it is charged with organisms and organic matter. The process is usually reverted locally and temporarily, for example, due to the photosynthetic action of algae or other plants, due to water filtration in certain appropriate geological formations, or to the interaction of the latter or other factors. This occurs in those cases where salinity is too high, or any other physical-chemical condition such as the pH or the temperature, which are, in general, limiting conditions for life. The general tendency of earth landscapes, in normal conditions, is towards an increase in salinity and organic matter content.

Thus, entropic quality can be measured via a mixed scale based on total dissolved solids (TDS) and/or on the biochemical demand of oxygen (BDO).

Normally, the antropic use of water produces an acceleration of these processes and therefore it is possible to use the same method to assess the quality of liquid waste.

The majority of domestic wastewater is charged with organic matter and decomposing organisms (e.g. bacteria and protozooaria) and it normally has higher total dissolved solid rates than the original water. In those cases, the levels of TDS and BDO are to a great extent the reason for the change in quality.

The admissible BDO levels (in mg/l) in agreement with Official Mexican Standards, for water discharged into natural waterbodies must be less than 150 in river water used for irrigation, 75 in water for urban use, 30 in rivers used for aquatic life protection, 75 in coastal waters used for leisure and zero in drinking water (NOM, 1996).

However, certain wastewaters, above all from industry, have a toxicity that may prevent the life of organisms. In those cases, the BDO is not an appropriate measure to determine non-biodegradable organic matter and may be replaced by Chemical Demand of Oxygen (CDO).

Other processes to reduce the entropic value are added in certain situations, which are difficult to quantify via BDO and CDO. These are cases where the presence of metals and other potentially toxic contaminants are in suspension or in solution in the water.

In those cases, it may be necessary to add an additional compound parameter (metals and other contaminants: MOC) including metal concentrations (e.g. Zn, Cu, Pb, Hg, Cd, Cr, Ni, Fe and Al) and other toxic substances (arsenic, cyanide, phenols, etc.). The concentrations corresponding to each one of the entropic levels are presented in Tables 5, 6, 7 and 8.

Table 5 presents the maximum permissible concentrations of metals and other contaminants for the water to be able to be discharged into the urban or municipal sewage systems in agreement with Mexican standards (NOM, 1996). Table 6 shows the maximum permissible concentrations for water to be able to be discharged into natural waterbodies and Table 7 includes the maximum permissible concentrations for drinking water. The approximate levels of TDS, BDO, CDO and MOC proposed for each type of entropic quality of water are presented in Table 8.

The potential energy conditions, related to the gravitational position of the water considered must be added to this. This position is expressed in height in metres above the local base level of the basin. This energy can be positive in the case of surface water and shallower groundwater, or negative in deeper groundwater.

As the entropic value of water drops it becomes more onerous, from the viewpoint of the energy required, to return it to optimal conditions of use. Saltwater can be desalinised either naturally or artificially and energy is required in both cases. Water with a higher BDO or CDO can be treated as a result of natural processes (based on solar energy) or treated artificially in appropriate plants, whose operation also requires energy. The biological or chemical treatment of water that contains metals or other similar toxic substances, on the other hand, may give rise to toxic accumulations in the biota, in the soils and / or in sediments. This water can be treated and, consequently, the metal or toxic substance concentration can be reduced. Anyway, the processes required to achieve a significant decontamination usually entail an astronomical energy cost.

Finally, as a result of the gravitational flow (potential energy loss) water also becomes more “expensive” in energy terms, as to be used the water must be “elevated” physically to the consumption places with the subsequent increase in cost.

APPROXIMATE RELATIONSHIP BETWEEN THE ENTROPIC VALUE, THE BDO AND THE CDO

An attempt has been made to establish a relationship between the Entropic Level, the Entropic Value calculated via the aforementioned equation, and the BDO and CDO that are observed in natural and / or waste water. This relationship is approximate, but it permits presenting the different levels and values in quantitative terms. The equivalences proposed between these levels and parameters are presented in Table 9.

ENERGY COST

The energy cost required to raise the water quality from one level to another varies depending on the type of entropic degradation that the water has undergone and on the technology used. In natural environments, recycling takes place naturally and the energy expenditure is the radiant solar energy required to evapotranspire or oxygenate the degraded water, taking it to the necessary level of reference. In artificial systems, the recycling or potabilisation takes place by treating water, using different methods and energy sources. The energy expenditure to evaporate water from natural waterbodies at an ambient temperature of 20° C is 600,000 kcal per m^3.

THE COST OF ARTIFICIAL RECYCLING

Degraded or salinated water (with low entropic level) can be recycled or potabilised via artificial procedures. Different technologies can be used, the most economic methods being biological methods (e.g. stabilisation lagoons), which are generally appropriate for small flows (small and medium towns). More complex treatment plants with both biological and physical-chemical processes are normally used for larger flows, from large urban and industrial areas. These processes include recycling, elimination and / or incineration of waste sludge. In both cases (biological and physical-chemical methods), the product obtained do not have drinking quality. To achieve this, even more sophisticated methods that use more energy are required.

The difference between these methods is the cost. Biological methods are more economical and, in general, require minimal operation expenses. These variables depend on the geographical conditions of the place, but are normally less than US$ 0.01 per m^3.

The physical-chemical methods (industrial origin water) require considerable investments or around 1 to 2 billion dollars for a waste water flow of 5 to 10 m^3 per second. The operating expenses vary according to the conditions of each case but on average they are estimated at US$ 0.03 per m^3 of treated water. If the capital depreciation cost is added, the cost would be somewhat higher, around US$ 0.05 per m^3 (CUM, 1999; TRIPOWER SYSTEMS, 1997, SATO et al., 2007).

Evaporative systems are even more costly. The desalination of 1 m^3 of seawater costs around US$ 3 per cubic metre using solar energy, whilst using fossil fuels or electricity, the cost would be several times greater (US$ 10 to 50 per m^3 depending on the cost of oil or electricity in each place and not considering State subsidies in the energy cost).

In terms of entropic levels, treated industrial and urban water does not exceed the entropic level of 4 or 5, whilst evaporated/distilled water reaches a level of 8 or 9. This shows the limitations of technology, which is still very strongly dependent on the natural cycle.

Thus, costs increase logarithmically as the entropic level rises. With the available technology, taking water from level 1 or 2 to level 4 costs approximately US$ 0.03-0.05 per m^3, whilst taking it to level 8 costs 100 to 300 times more (US$ 3 to 10).

Table 10 shows how, as an approximate general rule, the value in US$ is doubled or trebled for each level, in other words, it decreases two or three times in value when it drops one level. The monetary cost really depends on the technology and the amounts of wastewater produced/treated in a given place.

New and more appropriate technologies could, undoubtedly, reduce that difference to 1.5 or 1.8 between the levels.

The above depends on several elements that can substantially modify the results, the most important element being technology. The technological cost geometrically increases every time an attempt is made to raise the water quality one more level. A technological coefficient must thus be applied to give the entropic value meaning and an illustrative dimension.

The proposal is then to multiply the entropic value *Ve* by a technological coefficient of value 1 for water with entropic value 0 (sea water), doubling this for each successive increase in level. This doubling aims to respond to the increasing technological difficulties involved in the attempt to increase the quality of water. In the last change (from level 9 to level 10; equivalent the entropic values of 0.99 and 1.00 respectively), the technological coefficient calculated is equal to 512. Thus the corrected value *Vc* is obtained by multiplying the entropic value by the technological value. Table 11 shows the technological coefficients usable for each level, and the corrected value in agreement with the following equation:

$$Vc = Ve\left(Ct\right)$$

Where, ***Vc*** : is the corrected value; ***Ve*** : is the entropic value; and **Ct** : is the technological coefficient.

CONCLUSIONS

There is no doubt about the complexity of the water problem in the majority of developing countries, or about the increasing scarcity of available fossil energy, and these aspects have become critical development variables for these people. Indeed, in these decentralised countries, some of which are characterised by the scarcity of water resources and others by the excess or high degradation of the resource, in all the cases there is an imminent need to coordinate and organise on an intersectoral, social, scientific and political level to be able to improve the decision-making. The only way to solve water problems is within a scenario of consensus and rationality, and sustainability will only be possible by creating and / or strengthening local capacities with a regional approach based on the management and appropriation of knowledge.,

It is finally necessary to point out that it is not a question of modifying the existing sectoral structure, or of dividing the powers and responsibilities, and much less of the disappearance of the institutions, but rather giving them the meaning for which they were designed and constituted, combining efforts, coordinating plans, programmes, projects and actions to maximise the benefits and social and environmental welfare with the least possible investment.

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Table 1. Weighting of the water quality parameters

Parameter	Weighting	Parameter	Weighting	Parameter	Weighting
1. pH	1.0	7. Electrical		13. Chlorides	0.5
2. Colour	1.0	conductivity	2.0	14. Dissolved	
3. Turbidity	0.5	8. Alkalinity	1.0	oxygen	5.0
4. Fats and oils		9. Total hardness	1.0	15. BDO	5.0
5. Suspended	2.0	10. Nitrate N	2.0	16. Total	
solids		11. Ammoniac N	2.0	coliforms	3.0
6. Dissolved	1.0	12. Total	2.0	17. Faecal	
solids		phosphorus		coliforms	4.0
	0.5			18. Detergents	3.0

Table 2. List of phenomena and processes from the energy – hydrologic cycle

Phenomena and processes	**Energy behaviour associated with the phenomenon / process**	Symbol
Condensation of atmospheric water vapour	Absorbs	Cva
Precipitations	Releases potential energy, kinetics	P
Evaporation during fall	Absorption of energy	Ep
Impact of precipitation	Release of energy	I
Evaporation associated with plant interception	Absorption	Ei
Infiltration	Releases potential energy	In
Runoff	Releases potential energy, kinetics	es
Erosion and transport of materials in suspension	Releases potential energy, kinetics	et

Dissolution and transport of dissolved salts	Absorption and release of chemical energy, release of potential energy	Dt
Direct evaporation of continental water	Absorption	Ed
Transpiration (biological)	Absorption	T
Photosynthesis (development of autotrophic organisms)	Absorption	F
Metabolism of autotrophic organisms	Release of chemical / thermal energy	M
Decomposition and metabolism of heterotrophic organisms	Release of chemical / thermal energy	D
Oceanic evaporation	Absorption	Eo
Convective ascent	Absorption	Ac
Geothermal heating	Absorption	Cgt
Hydrothermal and volcanic ascent	Absorption	Ahv

Table 3. Entropic level of water

Entropic level	**Natural water**		**Use of natural water**	**Waste or contaminated water**	**Geological position**	**Presence of life**
	Atmospheric, surface water	**Groundwater**				
10	High, newly condensed clouds		Distilled water		High, atmospheric	Very few organisms, few nutrients
9	Low clouds, rain, snow		Drinking water		Low, atmospheric	Few organisms, few nutrients
8						
7	Springs, mountain torrents		Thermal water		Summits, headwaters, valleys	Organisms of low to intermediate abundance
6	High river courses, mountain lakes	Fresh water hypodermal layers	Water for irrigation	Moderately acid rain	Mountain areas, mountain ranges, high hills, , plateaux	Organisms of intermediate abundance

5	Intermediate river courses, lakes, intermediate lakes, effluents of certain wetlands	Hypodermal layers, non-contaminated quite shallow aquifers	Water for irrigation	Very acid rain	Hilly areas, low mountain ranges, quite shallow subsoil	Abundant organisms
4	Low river courses, plain lakes, oxygenated wetlands	Fresh deep groundwater. Slightly brackish and quite shallow.	Water for irrigation	Irrigation drainage, treated waste water	Plains, low hills, intermediate to very deep subsoil.	Very abundant organisms in rivers and lakes, locally excess of nutrients. Discharges of irrigation water may cause eutrophication processes.
3						
2	Eutrophicated lakes and wetlands. Brackish lakes.	Slightly brackish deep groundwater; brackish not very deep water	Water for washing	Irrigation drainages, partially treated waste water	Low, arid areas, subsoil of variable depth	Very abundant organisms in brackish lakes. Discharges of irrigation water may cause eutrophication.
1						
0	Seas and salted lakes	Salted groundwater.	Spa water	Intermediate urban and industrial discharges	Sea level, depressed continental areas, subsoil of variable depth	Very abundant organisms in seas and lakes, few in urban discharges. Urban discharges cause frequent eutrophication processes.
0 a - 5	Brine	Ground brine water	Salt production	Highly contaminated urban and industrial discharges	Ground brine water	Few organisms due to toxicity, possible local eutrophication processes
< -5	Saline	Salt deposits	Industrial salt production	High toxicity industrial discharges	Salt deposit	Absence of organisms

Table 4. Relative entropic value for each entropic level

Entropic level	Relative entropic value

10	1.00
9	0.99
8	0.96
7	0.91
6	0.84
5	0.75
4	0.64
3	0.51
2	0.36
1	0.19
0	0
0 a –5	-0.21 a -2.25
< -5	< -2.25

Table 5. Permissible limits of metals and other contaminants in waste water discharges to urban or municipal sewage systems (MOC, daily mean, in μg/l)

Metals	**Maximum permitted value (μg/l)**
Zinc	9.0
Copper	15.0
Cadmium	0.75
Hexavalent chrome	0.75
Lead	1.5
Total nickel	6
Mercury	0.015
Other contaminants	
Total arsenic	0.75
Total cyanide	1.5
Fats and oils	75

Source: Official Mexican Standard NOM-002-ECOL-1996

Table 6. Permissible limits of metals and other contaminants in treated waste water discharged into rivers, to protect aquatic life (MOC, daily mean, in μg/l)

Metals	**Maximum permitted value (μg/l)**
Zinc	20
Copper	6
Cadmium	0.2
Total chrome	1
Lead	0.4
Total nickel	4
Mercury	0.01
Other contaminants	
Total arsenic	0.2
Total cyanide	2

Source: Official Mexican Standard NOM-001-ECOL-1996

Table 7. Permissible limits of metals and other contaminants for drinking water (MOC, daily mean, in μg/l)

Metal	**Maximum permitted value (μg/l)**
Zinc	5.0
Copper	2.0
Iron	0.3
Aluminium	0.2
Manganese	0.15
Total chrome	0.05
Lead	0.025
Mercury	0.001
Other contaminants	
Arsenic	0.05
Cyanide (CN-)	0.07
Nitrates (as N)	10.0
Nitrites (as N)	0.05
Phenols or phenol compounds	0.001

Source: Official Mexican Standard NOM-127-SSA1-1994

Table 8. Entropic level of water measured based on BDO, CDO, STD and MOC.

Entropic level	Natural surface water		Waste or contaminated water				Groundwater	Salinity STD, ppm
	Type of surface water	BDO_5	Type of wastewater	BDO_5 *	CDO *	MOC Metal and other contaminants		
10	High, newly condensed clouds	0						0-10
9	Low clouds, rain, snow	0						10-40
8		0						40-80
7	Springs, mountain torrents	<10 mg/l				Below limited established in level 7		80-150
6	High river courses, mountain lakes	10-20 mg/l	Moderately acid rain	0		Maximum limits for drinking water (See Table 5)	subsurface flows, fresh water springs	150-300
5	Intermediate river courses, intermediate lakes, effluents of certain wetlands	20-30 mg/l	Very acid rain	0		Intermediate concentrations between levels 2 and 6	Fresh, quite shallow groundwater	300-600
4	Low river courses, plain lakes, oxygenated wetlands	30-45 mg/l	Irrigation drainage, treated wastewater			Intermediate concentration between levels 4 and 7		
3		45-60 mg/l		0-60 mg/l	0-120 mg/l		Quite shallow, slightly brackish groundwater; fresh deep groundwater	600-1000
2	Eutrophicated lakes and wetlands, Slightly brackish lakes	60-80 mg/l	Irrigation drainages, partially treated wastewater	60-80 mg/l	120-160 mg/l	Maximum limits for discharges into rivers (See Table 6)	Slightly brackish, deep groundwater; quite shallow, brackish water	1000-2500

1								2500-5000
0	Brackish lakes and seas	<60 mg/l	Intermediate urban and industrial discharges	80-200 mg/l	160-400 mg/l	Intermediate concentration between levels 2 and y 4	Salted groundwater	5000-35000
0 a –5	Brine	0	Highly contaminated urban and industrial discharge	>200 mg/l	>400 mg/l	Maximum sewage discharge limits, See Table 7	Ground brine water	35000-300000
< -5	Saline	0	High toxicity industrial discharges			Above limit established in level 2	Salt deposits	>300000

* for merely estimation purposes it has been established that BDO/ CDO = 0.5

Table 9. Relationship between Entropic value, BDO_5 and CDO.

Entropic level	**Entropic value**	**BDO_5 Natural water**	**BDO_5 Wastewater**	**CDO Wastewater**
10	1.00	0	Levels 4 to 10 do not correspond to wastewater	Levels 4 to 10 do not correspond to wastewater
9	0.99	0		
8	0.96	0		
7	0.91	< 10 mg/l		
6	0.84	10-20 mg/l		
5	0.75	20-30 mg/l		
4	0.64	30-45 mg/l		
3	0.51	45-60 mg/l	0-60 mg/l	0-120 mg/l
2	0.36	60-70	60-70 mg/l	120-140 mg/l
1	0.19	70-80	70-80 mg/l	140-160 mg/l
0	0	< 80 mg/l	80-200 mg/l	160-400 mg/l
0 a –5	-0.21 a –2.25		> 200 mg/l	> 400 mg/l
< -5	< –2.25	Tends to 0	Tends to 0	

Table 10. Approximate cost to raise the entropic value of water

Entropic level	**Entropic value**	**To raise from the relative level to level 8 (potable) (several methods)**	**Biochemical methods to raise from relative level to level 5 (for irrigation)**	**Biological methods to raise from relative level to level 5 (for irrigation)**
		Approximate cost per m^3 in US$	***Approximate cost per m^3 in US$***	***Approximate cost per m^3 in US$***
10	1.00	■	■	■
9	0.99	■	■	■
8	0.96	■	■	■
7	0.91	< 0.05	■	■
6	0.84	0.05-0.3	■	■
5	0.75	0.1 to 0.5	■	■
4	0.64	0.2 to 1	0.01-0.10	
3	0.51	0.4 to 3	0.02-0.15	
2	0.36	1 to 10	0.03-0.20	0.005- 0.10
1	0.19	3 to 30	0.05-0.20	0.01- 0.20
0	0		0.10 to 0.5	
0 to –5	-0.21 to –2.25	> 30	0.5 to 10	
< -5	< –2.25		> (0.5 to 10)	

Table 11. Entropic value corrected by technological advance

Entropic level	Entropic value	Technological coefficient	Corrected value (due to technological coefficient)
10	1.00	1024	1024
9	0.99	512	507
8	0.96	256	246
7	0.91	128	116
6	0.84	64	54
5	0.75	32	24
4	0.64	16	10
3	0.51	8	4
2	0.36	4	1.4
1	0.19	2	0.38
0	0	1	0
0 a –5	-0.21 to –2.25	2 to 32	- 0.42 to - 72
< –5	< –2.25	> 32	> -72

Figure 1. Energy – hydrologic cycle diagram