An Integrated Indicator based on Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index

Henrique M.L. Chaves* & Suzana Alipaz **
**School of Technology, University of Brasilia & **Brazilian National Water Agency-ANA*

Abstract: Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental aspects. However, they are often treated separately, and not as an integrated, dynamic process. In order to integrate the hydrologic, environmental, life & policy issues, as well as the existing pressures and policy responses in one quantitative, dynamic, and aggregated indicator, a watershed sustainability index (WSI), which uses a pressure-state-response function, was developed and is proposed in this paper. Applied to a 2,200 km^2 Unesco-HELP demonstration basin in Brazil (S.F. Verdadeiro), the WSI was 0.65, which represents an intermediate level of basin sustainability.

Key words: hydrology, environment, life, policy, watershed, sustainability index, S.F. Verdadeiro, HELP basin.

1. INTRODUCTION

Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental issues. However, they are often treated separately, and not as an integrated, dynamic process (Viessman, 1990).

Additionally, integrated and environmentally sustainable water management requires more than simply carrying out environmental impact assessments. It requires integration of policy formulation, project appraisal, sound water management laws and institutions, across the breath and depth of the decision-making process regarding the use of freshwater resources (Smith & Rast, 1998).

Although there are environmental and water scarcity indices in the literature, they are not basin-specific, and do not aim to access basin sustainability with respect to integrated water resources management, nor span the different variables of the problem.

Recently, Unesco's International Hydrologic Program-IHP adopted a framework which includes hydrology, environment, life, and policy issues. With this framework (the HELP platform), one aims to break the so called "paradigm lock", which hinders effective and integrated actions by different basin stakeholders (UNESCO, 2005). Last year, more than 60 operational and demonstration HELP basins existed around the world, providing a platform for sharing water resources management experiences.

An integrated basin sustainability index would be helpful to access the level of sustainability of river basins, allowing not only for a comparison framework, but also a tool to identify bottlenecks to achieve basin sustainability.

The objective of this paper was to propose an integrated watershed sustainability index (WSI), based on hydrologic, environmental, life, and water policy issues and responses. In its development, recent indicator and parameter selection criteria were used. In order to demonstrate the applicability of the index, the WSI was applied to the S.F. Verdadeiro watershed, in Southern Brazil. Although this is a HELP basin, the WSI could be applied to other basins, provided the parameter data are available.

2. INTEGRATING THE HYDROLOGY, ENVIRONMENT, LIFE, & POLICY ISSUES IN ONE SUSTAINABILITY INDEX

Sustainability assessments should cut across jurisdictional boundaries. Although they are the natural water resources planning unit, watersheds generally do not align themselves with political governance (Nyerges, 2002). However, seldom are watersheds used as planning and management unit.

Though it is recognized that the sustainability of water resources in a given basin is directly related to its hydrologic, environmental, life, and policy conditions, a few attempts have been made to integrate them in one single and comparable number.

Integrated indices are used for survey and planning purposes. The United Nations has been using the Human Development Index-HDI (UNDP, 1998) for several years. It integrates educational, life expectancy, and income information for municipalities, states and countries. Varying from 0 to 1, the HDI is simple to use, robust and applied worldwide.

Aiming at the estimation of the water scarcity and accessibility to water of poor people, a Water Poverty Index-WPI was developed (Sullivan & Meigh, 2003; Sullivan, 2003). Later, in an attempt to compare the water accessibility level in different countries, Lawrence et al. (2003) found that the WPI was highly correlated with the countries' HDI (r=0.81).

A variation of the WPI is the Climate Variability Index-CVI (Meigh & Sullivan, 2005), which estimates the vulnerability of countries, regions, and communities in relation to water resources. Although both indices are integrative, they aim to identify water accessibility and scarcity problems, and not the overall basin sustainability.

Recently, an Environment Sustainability Index (ESI) was proposed (Esty & Levy, 2004). This index uses 5 components, comprising 21 indicators and 76 variables. Although it was applied to several countries, the high number of indicators and variables hinders its applicability in data-scarce regions.

In addition to being non-watershed specific, both the ESI and the WPI do not take into account cause-effect relationships, or consider the policy responses that are implemented in a given watershed, in a given period.

Sustainability indicators and parameters shall meet some basic criteria if they are to be useful. According to HCTF (2003), watershed indicators shall be:

- Available: the indicator data shall be available and easily accessible. They shall be collected throughout the watershed, published in a routine basis, and made available to the public;
- Understandable: indicators shall be easily understood by a diverse range of non-technical audiences;
- Credible: indicators shall be supported by valid, reliable information, and interpreted in a scientifically defensible manner;
- Relevant: indicators shall reflect changes in management and in activities in the watershed. They shall be able to measure changes over time;
- Integrative: indicators shall demonstrate connections among the environmental, social & economical aspects of sustainability.

Applied to watersheds, an index formed by indicators meeting the above criteria could be universally applied, which would significantly increase their usefulness in establishing the sustainability of water resources in river basins.

Considering that the basin management is dynamic and holistic process, and assuming that the water sustainability of a watershed is a function of its hydrology (H), environment (E), life (L), and water resources policy (P), a dynamic, pressure-state-response model (OECD, 2003) was applied to those four indicators (H, E, L, P) in a matrix scheme. As a result, a watershed sustainability index-WSI was obtained. Numerically, the WSI is given by:

$$WSI = (H+E+L+P) / 4 \qquad [1]$$

Where WSI (0-1) is the watershed sustainability index; H (0-1) is the hydrologic indicator; E (0-1) is the environment indicator; L (0-1) is the life (livelihood) indicator; and P (0-1) is the policy indicator. In order to facilitate the estimation of the parameter levels by the users, both the quantitative and qualitative parameters were divided in 5 scale scores (0, 0.25, 0.50, 0.75, and 1.0). This allows for the use of spreadsheets instead of equations or other complex functions.

As seen from equation [1], all indicators have the same weight, since there is no evidence that it be otherwise (Harr, 1987). Although it is recognized that the indicator weights may vary from basin to basin, and should be chosen by consensus among stakeholders, using the same weight avoids skewing of the results (Heathcote, 1998), and allow for mutual respect among the different sectors (hydrologists, sociologists, environmentalists, water users, and policy makers).

The linear and averaging structure of equation [1] is simple and transparent, allowing for error compensation in the indicators and parameters. This is an important issue in model development, but often overlooked by modelers (Chaves & Nearing, 1991).

Since basin management at the local and regional level is more effective in watersheds up to 2,500 km^2 (Schueler, 1995), this is the upper limit suggested for the application of WSI in the estimation of basin sustainability. However, if larger watersheds are to be scored with the WSI, they could be divided in sub-basins, and the overall score computed with the individual WSI scores.

Table 1 presents the WSI parameters relative to each of the four indicators (H,E,L,P). The proposed parameters were selected according to the HCTF's (2003) criteria (above), in addition to their ability to adequately represent the individual processes.

The parameters were divided in 3 levels, comprising *Pressure*, *State* and *Response* (PSR). The advantage of using a PSR model is that it incorporates cause-effect relationships, helping stakeholders and decision-makers to see the interconnections between the parameters (OECD, 2003).

Table 1. Indicators and parameters of the Watershed Sustainability Index

	Pressure	***State***	***Response***
Indicators	***Parameters***		
Hydrology	- Variation in the basin's *per capita* water availability in the period; - Variation in the basin BOD5 in the period	- Basin *per capita* water availability (long term average) - Basin BOD5 (long term average)	- Improvement in water-use efficiency (last 5 yrs.); - Improvement in sewage treatment/ disposal (last 5 yrs.)
Environment	- Basin's EPI (Rural & urban) in the period	- % of basin area with natural vegetation	- Evolution in basin conservation (% of protected areas, BMPs) in the period
Life	- Variation in the basin per capita income in the period	- Basin HDI (weighed by county population)	- Evolution in the basin HDI in the period
Policy	- Variation in the basin HDI-Education in the period	- Basin institutional capacity in IWRM	- Evolution in the basin's IWRM expenditures in the period

To each combination of indicators and parameters, a score between 0 and 1 is assigned. A value of 0 is assigned to the poorest level, and 1.0 to optimum conditions. The full description of levels and scores of all WSI parameters is presented in Tables 2, 3, and 4, respectively. These parameters are discussed in detail below.

Although the relationships between the levels and scores of Tables 2, 3, and 4 are arbitrary and could vary from basin to basin, they were proposed based on possible ranges and thresholds of the selected parameters, spanning a broad range of watershed conditions.

Table 2. Description of WSI Pressure parameters, levels, and scores.

Indicator	***Pressure Parameters***	*Level*	*Score*
Hydrology	Δ1- Variation in the basin *per capita* water availability in the period studied, relative to the long-term average (m^3/person.yr)	Δ1< -20% -20%< Δ1 < -10% -10% <Δ1< 0% 0 < Δ1 < +10% Δ1 > +10%	0.00 0.25 0.50 0.75 1.00
	Δ2- Variation in the basin BOD5 in the period studied, relative to the long-term average	Δ2>20% 20%>Δ2 > 10% 0 < Δ2 < 10% -10%<Δ2 < 0% Δ2 < - 10%	0.00 0.25 0.50 0.75 1.00
Environment	- Basin E.P.I. (Rural & urban) in the period studied	EPI>20% 20%<EPI > 10% 10%<EPI<5% 5%<EPI<0% EPI<0%	0.00 0.25 0.50 0.75 1.00
Life	- Variation in the basin per capita HDI-Income in the period studied, relative to the previous period.	Δ< -20% -20%< Δ < - 10% -10%<Δ< 0% 0 < Δ< +10% Δ >+10%	0.00 0.25 0.50 0.75 1.00
Policy	- Variation in the basin HDI-Ed in the period studied, relative to the previous period	Δ<-20% -20%<Δ < - 10% -10%<Δ< 0% 0 < Δ < +10% Δ > +10%	0.00 0.25 0.50 0.75 1.00

Table 3. Description of WSI State parameters, levels, and scores.

Indicator	***State Parameters***	*Level*	*Score*
Hydrology	- Basin *per capita* water availability (m^3/person.yr)	Wa < 1,700 1700<Wa<3,400 3400<Wa<5,100 5,100<Wa<6,800 Wa>6,800	0.00 0.25 0.50 0.75 1.00
	- Basin Long Term BOD$_5$ (mg/l)	BOD>10 10<BOD<5 5<BOD<3 3<BOD<1 BOD<1	0.00 0.25 0.50 0.75 1.00
Environment	- % of basin area under natural vegetation (Av)	Av<5 5 < Av < 10 10 < Av < 25 25 < Av < 40 Av > 40	0.00 0.25 0.50 0.75 1.00
Life	- Basin HDI (weighed by county pop.)	HDI<0.5 0.5<HDI <0,6 0.6<HDI<0.75 0.75<HDI<0.9 HDI >0.9	0.00 0.25 0.50 0.75 1.00

Policy	- Basin institutional capacity in IWRM (legal & organizational)	Very Poor Poor Medium Good Excellent	0.00 0.25 0.50 0.75 1.00

Table 4. Description of WSI Response parameters, levels, and scores.

Indicator	***Response Parameters***	*Level*	*Score*
Hydrology	- Improvement in water-use efficiency in the basin, in the period studied	Very Poor Poor Medium Good Excellent	0.00 0.25 0.50 0.75 1.00
	- Improvement in adequate sewage treatment/ disposal in the basin, in the period studied	Very Poor Poor Medium Good Excellent	0.00 0.25 0.50 0.75 1.00
Environment	- Evolution in basin conservation areas (Protected areas & BMPs) in the basin, in the period studied	$\Delta <$ -10% -10%< Δ< 0% 0 < Δ < +10% +10% > Δ > +20% Δ> 20%	0.00 0.25 0.50 0.75 1.00
Life	- Evolution in the basin HDI in the basin, in the period studied	$\Delta <$ -10% -10%< Δ< 0% 0 < Δ < +10% +10% > Δ > +20% Δ> 20%	0.00 0.25 0.50 0.75 1.00
Policy	- Evolution in the basin's WRM expenditures in the basin, in the period studied	$\Delta <$ -10% -10%< Δ< 0% 0 < Δ < +10% +10% > Δ > +20% Δ> 20%	0.00 0.25 0.50 0.75 1.00

2.1. Hydrology Parameters

In the **Hydrology** indicator, there are 2 sets of parameters: one relative to water quantity and the other to water quality. In the case of *water quantity*, the parameter is the per capita water availability per year in the basin. According to Falkenmark & Widstrand (1992), water stress occurs when water availability falls below 1,700 m^3/person.yr. Therefore, 5 levels of per capita water availability were used: a) W_a < 1,700 m^3/inhab.yr, b) 1,700 < W_a < 3,400; c) 3,400 < W_a < 5,100; d) 5,100 > W_a > 6,800 m^3/person.yr, and e) W_a > 6,800 corresponding to very poor, poor, medium, good, and excellent per capita water availability, respectively.

In the case of *water quality*, since biochemical oxygen demand (BOD_5, in mg/l) information is often available in watersheds, and due to its high correlation with other important water quality parameters (e.g. dissolved oxygen, turbidity), it was selected as the quality parameter. In addition to point-source pollution, other non-point loadings, such as pollution by nutrients and pesticides, are often positively correlated to BOD.

Since it compares the water availability information in the period analyzed (say, a 5-year period) with the long-term average, the hydrologic *Pressure* parameters have the advantage of incorporating eventual climate variability/change impacts which, in certain conditions, could significantly affect water availability in the watersheds, in both quantity and quality.

2.2. Environment Parameters

As with Hydrology, the Environment parameters were divided in *Pressure*, *State*, and *Response* levels. In Table 2, the *Pressure* parameter for the Environment indicator is a modified version of the *Anthropic Pressure Index-API* (Sawyer, 1997), and is estimated by the averaged variation of the basin agricultural area and urban population (in percent) in the period studied:

$$\text{EPI} = (\%\text{ variation of basin agric. area} + \%\text{ variation of basin urban pop.}) / 2 \qquad [2]$$

The proportion of agricultural and urban areas in a given basin is correlated with its water quality (Hunsaker & Levine, 1995). Additionally, since the former are easy to obtain from agricultural and population censuses, and since other environmental parameters, such as water biotic indices, riparian habitat integrity, etc. are seldom available in many basins, particularly in developing countries, the first were selected as parameters.

EPI can be positive, negative, or zero. Positive values indicate higher pressures over the remaining natural vegetation of the basin (Environmental *State*). This *State* parameter is, in turn, highly correlated to flora and fauna biodiversity, being an indicator of the basin overall environmental integrity (Emerton & Bos, 2004).

2.3. Life Parameters

The parameters of the **Life** indicators are related to the basin's human life quality. Therefore, the parameter selected for **Life** *State* was the basin Human Development Index-HDI, in the year before to the period studied. The **Life** *Response* parameter is the % variation the basin HDI in the period studied, which gives an indication of the evolution (positive or negative) of the life quality in the basin.

In the case of the **Life** *Pressure* parameter, it was assumed to be the variation of the HDI-Income, a HDI sub-indicator which accounts for the population income, in period studied. Negative values of this parameter indicate that the population became poorer in the period, and vice-versa. Variation in the populations' average income can, in turn, impact basin sustainability as a whole, since it is known to strongly affect social indicators, such as health and education.

The advantage of using the HDI and its sub-indicators as **Life** parameters is that they are often available, on a county basis. They can be, in turn, easily averaged for the basin, using the county population as the weighing factor.

2.4. Policy Parameters

The **Policy** *Pressure* parameter was assumed to be the variation in the basin Human Development Index's education sub-indicator, in the period studied. Since this indicator measures the population educational level, positive values of HDI-Education would correlate with the ability and willingness of the population to become involved in the watershed management, putting more pressure on the decision-makers. This correlation was observed in several basins in Brazil, where higher societal involvements in WRM occurred in basins with higher educational levels (The World Bank, 2003). Furthermore, it is a simple and available parameter, which facilitates its use.

The *State* policy parameter is the basin institutional capacity in integrated water resources management (IWRM), given by the level of adequate legal and institution framework, as well as participatory management, in the period studied. It is one of the few qualitative parameters of the WSI, varying form very poor (0) to excellent (1.0).

The *Response* parameter is estimated by the evolution in the basin IWRM expenditures in the period studied. It reflects the response by stakeholders and decision-makers in tackling water resources problems. The higher the expenditures in IWRM, the higher the chances the basin will meet its water-related goals and objectives, and vice-versa. It can be positive or negative, which will result in scores varying from 0 to 1.

2.5. Overall WSI Computation

After the parameters of all four indicators are obtained, and after selecting a specific period for the analysis (say, a 5-year period, which could coincide with the available HDI and census data), the WSI is calculated, according to equation [1]. A spreadsheet can be used in order to facilitate the computation.

3. APPLYING THE WSI TO THE S.F. VERDADEIRO RIVER BASIN

To exemplify the utilization of the WSI, it was applied to the SF Verdadeiro River basin, a 2,200 km^2-wide watershed in Southern Brazil. The period studied was the 5 years between 1996 and 2000, where environmental and social data were available. Since WSI is formed by 4 indicators, each of them will be presented separately, and the overall sustainability index computed in the end.

3.1 Hydrology Indicator

The hydrology indicator score was simply the average of the basin's quantity and quality parameters. In the case of the water quantity sub-indicator, since the dominant water use in the basin is surface water, the per capita water availability (*State*) is simply the long-term river mean flow rate, divided by the basin population.

The SF Verdadeiro river flow rate has a long term average of 39 m^3/s. Divided by a total basin population of 167,083 inhabitants (year 2000 basis), the per capita water availability (*Wa*) is 33,600 m^3/person.yr. According to Table 4, the score for the *State* quantity parameter is 1.0 (excellent).

In the case of the water quantity *Pressure* parameter, the variation in W_a in the 5 yr period studied, with respect to the long-term average, was +4.8%. This, according to Table 2, results in a pressure score of 0.75. In the case of quantity *Response*, in the 5 year period considered, there was some improvement in water use efficiency in the basin, which corresponds to a score of 0.5. Therefore, the averaged *Pressure*, *State*, and *Response* parameters for water quantity was (1.0 + 0.75 + 0.5) /3 = 0.75.

In the case of the water quality sub-indicator, *Pressure* corresponds to the variation in the basin BOD_5 in the 5 yr period (+4.6%), yielding, according to Table 3, a score of 0.5. The *State* parameter for quality (the basin's BOD5 long-term average) was equal to 1.3 mg/l (Figure 1). This results in a *State* score of 1.0.

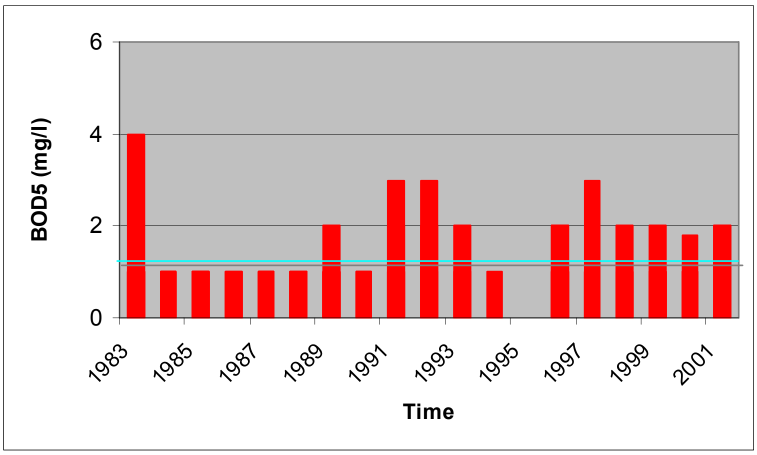

Figure 1. Yearly BOD5 values in the low SF Verdadeiro river, with a long-term average of 1.3 mg/l.

The *Response* for the water quality sub-indicator resulted in a score of 0.25 (poor improvement in sewage treatment/disposal in the 5 yrs studied). The quality sub-indicator is therefore (0.5+1.0+0.25) / 3 = 0.58.

Hence, the overall Hydrology indicator value is simply the average of the quantity and quality sub-indicators, or (0.75+0.58) / 2 = 0.67.

3.2 Environment Indicator

Similarly to the Hydrology indicator, the *Environment* indicator was computed as the average of its *Pressure, State*, and *Response* parameters. In the case of *Pressure*, the combined basin variation (increase) in agricultural area and urban population in the period studied was 13% and 9%, respectively, yielded an EPI value of (13%+9%)/2 = 11%. This corresponds to an environmental *Pressure* score of 0.25.

In the case of environmental *State*, the basin had 26% of its original vegetation cover in the year 2000, which, according to Table 3, results in a value of 0.75. Remaining natural vegetation cover in a basin was estimated by remote sensing techniques (NDVI), and through secondary data (agricultural census).

The environmental *Response* (evolution in protected areas and areas with BMPs) was 2% in the basin, resulting, according to Table 4, in a value of 0.75. Therefore, the overall score for the Environment indicator was (0.25+0.75+0.75) / 3 = 0.58.

3.3 Life Indicator

Life *Pressure* in the basin was estimated by the variation in the basin's HDI-Income sub-index in the 5 yr period (1996-2000). In that period, there was an increase in HDI-Inc of 3.4% (UNDP, 2004), resulting, according to Table 3, in a score of 0.75 (Good) for that parameter.

In the case of Life *State* parameter, the basin HDI in the year previous to the period studied was 0.81, resulting in a value of 0.75, according to Table 4. Figure 2 presents the distribution of HDI in the SF Verdadeiro basin in the year 2000. The overall basin HDI was the weighed average of the HDI values of each municipality and its corresponding population.

Life *Response*, i.e., the evolution of the expenditures in WRM in the basin, was +5% in the 5-yr period, resulting in a parameter value of 0.75 (Table 5). Therefore, the overall **Life** score for the basin was (0.75+0.75+0.75) / 3 = 0.75.

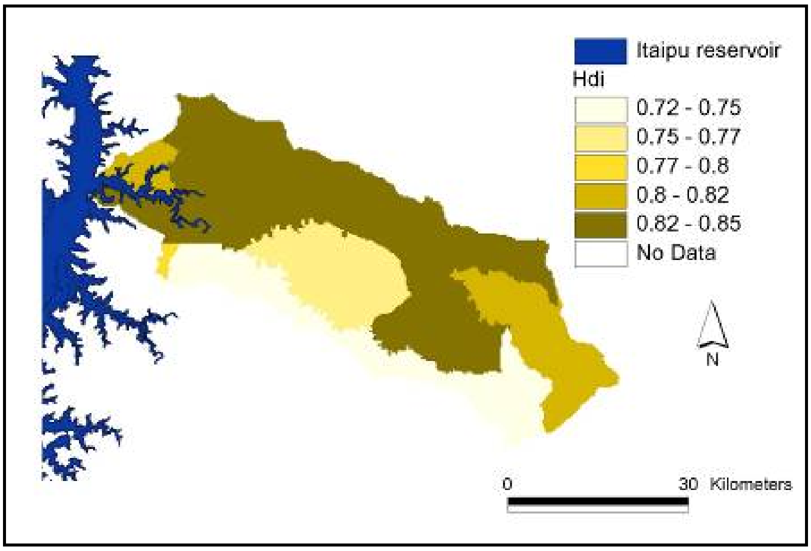

Figure 2. Spatial distribution of the Human Development Index (2000-basis) in the SF Verdadeiro basin.

3.4 Policy Indicator

The policy *Pressure* value (variation in the HDI-Education sub-indicator in the 5-yr. period) for the basin was +6.3%, resulting in a parameter score of 0.75 (Table 3). This indicates that, in the period studied, there was a significant increase in the educational level of the basin, which would have contributed to the societal participation in WRM in the basin.

As for the policy *State* parameter (basin institutional capacity), although there is a legal framework available (federal & state water & environmental laws & regulations), little was accomplished in participatory water resources management in the period studied. The SF Verdadeiro basin still lacks a watershed committee or organization, which is, according to the law, the institution responsible for the water management at the basin level. As a consequence, the basin was ranked poor in this item, with a corresponding parameter level of 0.25.

With regard to policy *Response*, the evolution in the basin expenditures in WRM was +5% in the 5-yr period, yielding a value of 0.75 for this parameter. The overall Policy indicator was the average of the 3 parameters, i.e., (0.75+0.25+0.75) / 3 = 0.58.

3.5 Watershed Sustainability

The WSI is simply the global average of the 4 indicators. Applying equation [1], with the help of an electronic spreadsheet, a WSI score of 0.65 was obtained for the SF Verdadeiro basin. Table 5 below presents the levels, scores, and the overall WSI for the basin.

Table 5. Levels & values for the parameters, and the basin WSI.

	Pressure		***State***		***Response***		*Result*
	Level	**Value**	**Level**	**Value**	**Level**	**Value**	
	4.8%	0.75	33,600	1.00	Medium	0.50	
	4.6%	0.50	1.3	1.00	Poor	0.25	
Hydrology		0.63		1.00		0.38	0.67
Environment	11%	0.25	26%	0.75	2%	0.75	0.58
Life	3.4%	0.75	0.81	0.75	5.1%	0.75	0.75
Policy	6.3%	0.75	Poor	0.25	5%	0.75	0.58
Result		0.59		0.70		0.66	**0.65**

Using a similar classification as the UNDP's HDI (low for HDI <0.5, intermediate for HDI between 0.5 and 0.8, and high for HDI >0.8), the WSI obtained for the SF Verdadeiro basin (0.65) would fall in an intermediary level. Additionally, according to Table 5, the indicators with the lowest scores were *Policy* and *Environment* (0.58), and the highest was *Life* (0.75).

In terms of the overall Pressure, State, and Response columns, the lowest score was obtained for Pressure (0.59), and the highest for State (0.70). This indicates that although the present basin conditions (*State*) are relatively good, there are pressures (particularly environmental) which threaten the basin sustainability.

More specifically, the poorest indicator combinations in Table 5 were Environmental *Pressure* (0.25), Policy *State* (0.25), and Hydrology *Response* (0.38). Therefore, in order to improve the overall watershed sustainability, stakeholders and decision-makers shall work more effectively to reduce the pressure over the remaining vegetation, to enhance the IWRM institutional capacity, and to improve sewage treatment in the basin, respectively.

4. DISCUSSION

In order to allow for simplicity and wide applicability, the watershed sustainability index proposed here uses a relative small number of indicators and parameters. Also, an additive structure, with equal indicator weights, as well as a cause & effect (pressure-state-response) function were preferred, since they make the index more transparent and acceptable to different stakeholders and decision-makers. These are important, but frequently underestimated issues in modeling.

Another advantage of the additive structure and scoring characteristics of the WSI is that eventual parameter estimation errors may be compensated. The scoring allows eventual over /underestimations of parameter levels to converge into one of the five score intervals, without changing it.

Since the parameters of equation [1] have the same weight, and considering that the indicators and parameters are random variables (with corresponding distributions), Shannon's principle of maximum entropy warrants that the probabilities of parameter under and overestimation are the same (Harr, 1987). Furthermore, the averaging structure of equation [1] allows for error compensation of the parameter and indicator values.

Although its four indicators and 15 parameters may not span the whole sustainability spectrum, the use of more indicators and variables would hinder its applicability, particularly in data-scarce basins. Additionally, the more indicators and variables used, the higher the probability of multicollinearity (Netter et al., 1985).

Although the structure of the WSI may, in some cases, yield high scores while one of its indicators is low, since each indicator score is the average of 3 parameter values (pressure, state, & response), it is unlikely that all three will be low at the same time.

Applied to different time intervals, the WSI can give an idea of the evolution of the watershed sustainability along the years, helping stakeholders and decision-makers in their planning and decision-making process, providing for an adaptive management tool for the basin's water resources.

Though the results of only one basin were presented, the WSI is being applied to other basins in South America, Africa and Oceania. The results of these basins will provide for a sustainability comparison among basins.

5. CONCLUSIONS

Several issues impact the water sustainability of a river basin. Among them are the social, economic, and environmental issues. However, they are often treated separately, and not as an integrated, dynamic process.

In order to integrate the hydrologic, environmental, life & policy issues, as well as the existing pressures and policy responses in one quantitative, dynamic, and aggregated indicator, a watershed sustainability index (WSI) was proposed for river basins. This index is simple, and uses readily available information. Its dynamic characteristics allow for the estimation of human, environmental, and climate-related pressures and responses, which can affect basin sustainability.

Applied to the SF Verdadeiro basin (Southern Brazil), in the period between 1996 and 2000, the WSI score was 0.65, which represents an intermediate level of basin sustainability. Aspects needing attention by decision-makers are those related to Environmental *Pressure*, Policy *State*, and Hydrology *Response*, namely, conserving the remaining forest cover, improving the actual water resources management policies, and reducing the sewage pollution, respectively.

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