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A social-economic-engineering combined framework for decision making in water resources planning

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Abstract

This study presents a new methodology not only to evaluate willingness to pays (WTPs) for the improvement of hydrological vulnerability using a choice experiment (CE) method but also to do a cost-benefit analysis (CBA) of some feasible alternatives combing the derived WTPs with an alternative evaluation index (AEI). The hydrological vulnerability consists of potential streamflow depletion (PSD), and potential water quality deterioration (PWQD) and can be quantified using a multi-criteria decision making technique and pressure-state-response (PSR) framework. PSD and PWQD not only provide survey respondents with sufficient site-specific information to avoid scope sensitivity in a choice experiment but also support the standard of dividing the study watershed into six sub-regions for site-fitted management. Therefore CE was applied to six regions one after the other, in order to determine WTPs for improvements on hydrological vulnerability considering the characteristics which are vulnerability, location, and preferences with regard to management objectives. The AEI was developed to prioritize the feasible alternatives using a continuous water quantity/quality simulation model as well as multi-criteria decision making techniques. All criteria for alternative performance were selected based on a driver-pressures-state-impact-response (DPSIR) framework, and their weights were estimated using an Analytic Hierarchy Process (AHP). In addition, the AEI that reflects on residents' preference with regard to management objectives was proposed in order to incite the stakeholder to participate in the decision making process. Finally, the economic values of each alternative are estimated by a newly developed method which combines the WTPs for improvements on hydrologic vulnerability with the AEI. This social-economic-engineering combined framework can provide the decision makers with more specific information as well as decrease the uncertainty of the CBA.

1 Introduction

Policies directing or guiding every decision by many individuals are usually not developed by the people affected by these policies. Usual studies for input to environmental decision making, including computerized models, often don't involve the relevant stakeholders. At best, experts consult individual stakeholders for their studies or models. At worst, the studies or models are about the stakeholders. These studies are most often performed by experts, after which decision makers weigh the outcomes against society's needs (or political agendas). Consequently, the broader stakeholders don't understand or don't agree with the underlying assumptions, do not agree with the structure of the models, or refuse to accept the outcomes because they feel left out of the decision making process. For these reasons, conflicts are likely to arise during the implementation phase (Cupps, 1977; Rosener, 1982; Thomas, 1990; van den Belt, 2004; Christofides et al, 2005; Raadgever et al., 2008).

To improve decision making for sustainable development, new tools to facilitate common goal development and to test alternative scenarios are needed. These tools must be able to communicate the complexity and associated uncertainties of the decisions and to allow for broad stakeholder participation while integrating different aspects (social, economic and ecological) of the situation involved (Cau and Paniconi, 2007; Bruen, 2008).

The Water Framework Directive (2000/60) has been brought about in the regulation and management of water resources. Major changes include: 1) a requirement for the preparation of integrated river basin/watershed management plans, with remittent extending over point and non-point pollution, water abstraction and land use; 2) the introduction of a basin-wide target of "good ecological status" for all surface water and groundwater; 3) the introduction of full social cost pricing for water use; and 4) the corporation of estimates of economic cost and benefits in catchment management plans. From these reasons, Hanley et al. (2006) derived the values people place on improvements in three ecological indicators and thus on the non-market economic benefits of moves towards good ecological status. This study resulted from the same reasons, but extended the scope to evaluate the economic values of each alternative without stopping estimation of improvements in environmental indicators.

In evaluating some specific alternatives that would improve water resources status, cost-benefit analysis (CBA) is necessary. Even if the estimated monetary value contains uncertainty and then is disputable for CBA, it is essential to estimate the relative importance among different types of environmental issues to enable cost-effectiveness analysis (CEA) in those projects. But it is well known that benefit of nonmarket products can not be estimated easily and so needs the economic valuation techniques.

There are a variety of methods to estimate the economic value of the environment. The contingent valuation method (CVM) is one of the most frequently used methods among them. An individual's willingness to pay (WTP) can be elicited using CVM, but it gives no information on the relative importance among different types of environmental issues. Choice experiments (CEs) potentially outperform CVM with regard to estimating an individual's marginal WTP (MWTP) for each environmental impact, which can then be converted to the relative importance of the different types of environmental issues. Thus CEs have the ability to yield more data than CVM (Nakatani et al., 2007).

There are some drawbacks in CEs. The scope insensitivity (embedding effect) which has long been discussed is said to be the most difficult problem in CVM studies and is also a serious problem in CE studies. According to Harrision (1992), the embedding effect is defined as follows: it occurs when the WTP for one good is found to be insignificantly different from the WTP for a more inclusive good (Nakatani et al., 2007). As Schulze et al. (1998) described, scope insensitivity has generated extreme views that range from the suggestion that embedding effects are so severe that they make CVM useless (e.g., Kahneman and Knetsch, 1992; Diamond et al., 1993) to assertion that embedding can be eliminated by providing sufficient information in a survey (Carson and Mitchell, 1993). But it may be common that scope insensitivity can be diluted only if sufficient information in a survey is provided.

To avoid scope insensitivity in the CE, before economic evaluation, the present spatial hydrologic vulnerability in this study was quantified using a pressure-state-response (PSR) approach and composite programming, a kind of multi-criteria decision making (MCDM) techniques. This hydrologic vulnerability, which was developed in Lee and Chung (2007) and shows the spatial safety for integrated water resource management, consists of water quantity and quality. They can be quantified as potential streamflow depletion (PSD), and potential water quality deterioration (PWQD). Therefore, residents can respond with the correct and realistic WTP in the application of a CE, since they can recognize and confirm the present conditions in their place of residence. In addition, after dividing into sub-regions on the basis of hydrologic vulnerability, each WTP was estimated to consider the spatial vulnerability. Just a single WTP is not realistic since every region is not homogenous.

Furthermore, this paper documents the development of a methodology to assess the prioritization of alternatives using a continuous water quantity/quality simulation model as well as MCDM techniques. All criteria for alternative performance were selected based on the DPSIR (Driver-Pressures-State-Impact-Response) framework, while their weights were estimated using the Analytic Hierarchy Process (AHP). In addition, AEI that reflects residents' preferences for management objectives was proposed in order to induce the stakeholder to participate in the decision making process. Finally, the economic values of each alternative are estimated by a newly developed method which combines values of improvements in environmental indicators with AEI.

This paper presents a methodology not only to evaluate the economic value of improvement of hydrologic vulnerability using the CE but also to do a CBA of some feasible alternatives combining the derived values with the alternative evaluation index (AEI). This study follows the social-economic-engineering combined procedure shown in Fig. 1 in order to allow for broad stakeholder participation (Sects. 6 and 7) while integrating different aspects of the situation involved and its four parts are:

- To spatially identify the grades on hydrological vulnerability (Sect. 5)
- To evaluate the monetary values of improvement on hydrological vulnerability

grade (Sect. 6)

- To derive an AEI to quantify the effectiveness of all alternatives (Sect. 7)
- To combine the derived WTPs with the AEI and do the CBA of feasible alternatives (Sect. 8)

2 Choice experiment

2.1 Overview

Methods for valuing the environment are classified into revealed preference (RP) methods and stated preference (SP) methods, and both methods have advantages and drawbacks. RP methods make use of the actual behavior of people, and examples of these methods include the household production model, travel cost demand model, and hedonic property value and hedonic wage models. SP methods draw their data from people's responses to hypothetical questions, and include CVM and CE. CVM questions ask directly about monetary value for environmental change, while choice experiments do not reveal monetary measures directly (Freeman III, 2003).

CE (or choice modeling) is often called choice-based conjoint analysis (conjoint logit model). Conjoint analysis is categorized into compositional and decompositional methods, and the latter are more widely used. Decompositional conjoint analysis is also categorized into full-profile-rating conjoint analysis, contingent ranking, choice experiments and pair-wise choice experiments (pair-wise-rating conjoint analysis). Recently, CE and pair-wise CE are frequently being used and responses to hypothetical questions in choice experiments are more likely to reflect actual behavior of consumers than those in the other types of conjoint analysis (Nakatani et al., 2007).

CE is becoming a popular means of environmental valuation (Bennett and Blamey, 2001; Hanley et al., 2001; Collins et al., 2005; Willis et al., 2005). CE encompasses a variety of multi-attribute preference elicitation techniques widely used by market researchers to evaluate potential new products and new markets for existing products (Garrod and Willis, 1997). CE is a suitable method for valuing environmental goods with multi-attributes (Baarsma, 2003). Recently, this approach was employed as an alternative to CVM and to complement other preferred methods such as the hedonic price model and travel cost method. In addition, the National Oceanic and Atmospheric Administration (NOAA) in the United States has included this technique in its recent rule-making governing natural-resource damage assessments for oil spills (Johnson and Desvousges, 1997).

CE has a number of advantages. Above all, it is easier than other valuation methods in estimating the value of each attribute that makes up an environmental good. This is useful because many policies are more concerned with changing attribute levels, rather than losing or gaining the environmental good as a whole (Hanley et al., 1998). It allows respondents to systematically evaluate trade-offs among multiple environmental and non-environmental attributes. This trade-off process may encourage respondent introspection and facilitate consistency checks on response patterns (Johnson and Desvousges, 1997). In addition, as it does not ask for the WTP of respondents, it reduces the number of protest responses, especially those involving tax increases or willingness to accept environmental degradation in return for payment. It also increases the amount of information obtained from each respondent, thus reducing the required sample, and hence reducing the costs of the survey (Yoo et al., 2008).

In this study, CE is used in order to estimate the economic value of environmental indicator improvement. In brief, a CE asks individuals to choose the most preferred alternative in each choice set. Each alternative consists of several attributes and several choice sets are presented to each individual (Carlsson and Martinsson, 2001). If one of the attributes has a monetary price, then it is possible to calculate the responses' marginal willingness-to-pays (MWTPs) for the other attributes on the basis of the responses.

2.2 Design procedure

The design procedure of CE consists of five stages. The first stage is selection of attributes. This is usually done through literature reviews, focus group discussions or direct questioning. Sometimes they may be self-evident because of the nature of the problem. A monetary cost should be one of the attributes, to allow the estimation of WTP. The second stage is assignment of levels. The attribute levels should be realistic and span the range over which we expect respondents to have preferences, and/or should be practically-achievable. The third stage is choice experimental design. Statistical design theory is used to combine the levels of the attributes into a number of alternative environmental scenarios or profiles to be presented to respondents. Complete factorial designs allow the estimation of the full effects of the attributes upon choices: that includes the effects of each of the individual attributes presented ("main effects") and the extent to which behavior is connected with variations in the combination of different attributes of offered ("interactions"). These designs often produce an impracticably large number of combinations to be evaluated. Fractional factorial designs are able to reduce the number of scenario combinations presented, with a concomitant loss in estimating power, i.e. some of all of the interactions will not be detected. The fourth stage is construction of choice sets. The profiles identified by the experimental design are then grouped into choice sets to be presented to respondents. Profiles can be presented individually, in pairs or in groups according to the technique being used. The fifth stage is measurement of preferences including choice of survey procedure and conduct of survey (Bateman et al., 2002).

2.3 Random utility model

CE shares a common theoretical framework with other valuation approaches. The following parts are obtained from Yoo et al. (2008) which was well described. The random utility model is used to explain individual choices by specifying functions for the utility derived from the available alternatives. This function can be estimated with a multinomial logit (MNL) developed by McFadden (1974). MNL assumes that choices are consistent with the independence from irrelevant alternatives (IIA) property which states that for any individual, the ratio of choice probabilities of any 2 alternatives is entirely unaffected by the systematic utilities of any other alternatives. According to this framework, the direct utility function U_{ij} for each respondent i who chooses alternative j in the choice set C_i can be expressed as

$$U_{ij} = V_{ij}(Z_{ij}, S_i) + e_{ij} \tag{1}$$

The indirect utility function U_{ij} can be decomposed into the deterministic part V_{ij}, which is typically specified as a function of the attributes Z_{ij} in alternative j chosen by the respondent i and the respondent i's characteristic S_i, and the stochastic part e_{ij}, which represents the unobservable influence on individual choice. Furthermore, if $U_{ij} > U_{ik}$ for all $i \neq k$ in the choice set C_i, the probability that respondent i will choose alternative j is given by

$$\Pr(j|C_i) = \Pr(V_{ij} + e_{ij} > V_{ik} + e_{ik}) = \Pr(V_{ij} - V_{ik} > e_{ik} - e_{ij}) \tag{2}$$

In order to deal with this probability, it is necessary to know the distribution of the error term e_{ij}. A typical assumption is that they are independently and identically distributed with an extreme-value (Weibull) distribution, which implies that the probability of any particular alternative j being chosen as the most preferred can be expressed in terms of the logistic distribution (McFadden, 1974). This probability can be expressed as

$$\Pr(j|C_i) = \frac{\exp(V_{ij})}{\sum\limits_{k \in C_i} \exp(V_{ij})} \tag{3}$$

Each respondent's multinomial responses obtained from the questions of the choice experiment scenarios were interpreted as the choice results for the respondents' utility maximization.The log-likelihood function can be written as

$$\ln L = \sum_{i=1}^{N} \sum_{j=1}^{\alpha} (y_{ij} \ln \left[\Pr(j|C_i)\right]) \tag{4}$$

where y_{ij} is binary variable, 2 when the respondent i chooses alternative j among α alternatives and 0 otherwise, and N is the total number of respondents. The parameters of this log-likelihood function are estimated by maximum likelihood estimation.

3 Decision making analysis

3.1 Indicators of Sustainable Development (ISDs)

The 1992 Earth Summit recognized the important role that indicators can play in helping countries make informed decisions concerning sustainable development. This recognition is articulated in Chapter 40 of Agenda 21 which calls on governments at the national level, as well as international, and non-government organizations, to develop and identify indicators of sustainable development (ISDs) that can provide a solid basis for decision making at all levels. Indicators of sustainable development can allow better communication and accessibility to information by bridging the gap between the producer and user of information, i.e. between the information available through scientific resources and the need to use that information in decision making. Indicators can provide crucial guidance for decision making in a variety of ways. They can translate physical and social science knowledge into manageable units of information that can facilitate the decision making process (UNCSD, 2001).

Because sustainability is a function of various economic, environmental, ecological, social and physical goals and objectives, water resources management must inevitably involve multi-objective tradeoffs in multi-disciplinary and multi-participatory decision making process. Therefore, various ways to measure sustainability have been developed. One way is to express relative levels of sustainability as separate or weighted combinations of reliability, resilience, and vulnerability measures; these various criteria contribute to human welfare and vary over time and space.

There are basically two types of indices. One measures changes in the status of a system or sub-system which an organization or several organization have responsibility, e.g., a watershed. Indicators used in this type of monitoring are known as status indicator. The second measures the performance of a policy intervention, program, project, function, or process for which a specific organization (or organizations) has responsibility in converting inputs into outcomes or results (Economic and Social Commission for Asia and the Pacific, 2004). These two types of indicators were used in this study. The status indicator using PSR and the performance indicator using DPSIR were introduced into Sects. 5 and 7, respectively. The concepts of PSR and DPSIR are explained as follows.

3.1.1 Pressure-State-Response (PSR)

There are several frameworks around which indicators can be developed and organized for sustainability evaluation. There is no unique framework that generates sets of indicators for every purpose. A framework may also change over time as scientific understanding of environmental problems increases and as societal values evolve. In the context of the work of the Group on the State of the Environment, the PSR framework has been used. The PSR considers that human activities exert pressures in the environment and affect its quality and the quantity of natural resources (state); society responds to these changes through environmental, economic and sectoral policies and through changes in awareness and behavior (societal response). The PSR has the advantage of highlighting these links, helping both decision makers and the public recognize environmental and other issues as interconnected (OECD, 1993; OECD, 1998).

3.1.2 Driver-Pressure-State-Impact-Response (DPSIR)

DPSIR framework was originally developed by the European Environment Agency (1999) for environmental reporting purposes, as result of environmental monitoring, on different environmental assessment tools like environmental impact assessment, and structures the description of the environmental problems, by formalizing the relationships between various sectors of human activity and the environment as causal chains of links.

The environmental management process under the DPSIR framework, may thus be described as a feedback loop controlling a cycle consisting of five stages (Economic and Social Commission for Asia and Pacific, 2004).

- *Drivers* are the underlying causes, which lead to environmental pressures. Examples are the human demands for agricultural land, energy, industry, transport and housing
- These driving forces lead to *Pressures* on the environment, for example the exploitation of resources (land, water, minerals, fuels, etc.) and the emission of pollution.
- The pressures in turn affect the *State* of the environment. This refers to the quality of the various environmental media (air, soil, water, etc.) and their consequent ability to support the demands placed on them (for example, supporting human and non-human life, supplying resources, etc.).
- Changes in the state may have an *Impact* on human health, ecosystems, biodiversity, amenity value, financial value, etc. Impact may be expressed in terms of the level of environmental harm.
- The *Responses* demonstrate the efforts by society (e.g. politicians, decision makers) to solve the problems identified by the assessed impacts, e.g. policy measures, and planning actions.

3.2 Multi-criteria Decision Making (MCDM) techniques

Environmental decisions are often complex and multifaceted and involve many different stakeholders with different priorities or objectives – presenting exactly the type of problem that behavioral decision research has shown that humans are poorly equipped to solve unaided. Most people, when confronted with such problems, will attempt to use intuitive or heuristic approaches to simplify the complexity until the problem seems more manageable. In the process, important information may be lost, opposing points of view may be discarded, and elements of uncertainty may be ignored. In short, there are many reasons to expect that, on their own, individuals (either lay or expert) will often experience difficulty making informed, thoughtful choices in a complex decision making environment involving value trade offs and uncertainty (McDaniel et al., 1999).

The MCDM process generally follows the sequence of (1) identifying DMs (final decision makers), actors (people involved in the decision analysis process), and stakeholders (anyone involved in the decision analysis process); (2) selecting criteria; (3) defining alternatives; (4) choosing an MCDM technique(s); (5) weighting the criteria; (6) assessing the performance of alternatives against the criteria; (7) transforming the criteria performance values to commensurable units, if required; (8) applying the selected MCDM technique(s); (9) performing sensitivity analysis; and (10) making the final decision. Weighting the criteria and assessing the performance of alternatives against the criteria are two of the most important and difficult aspects of applying the MCDM methodology and are potential sources of considerable uncertainty (Roy and Vincke, 1981; Larichev and Moshkivich, 1995). This study transforms above procedure and performs in Sects. 5 and 7.

3.2.1 Composite Programming (CP)

Composite programming (CP), which is a multi-level/multi-objective programming method, was introduced as an empirical technique to resolve a geological exploration problem by Bardossy and Bogardi (1983). A general multi-objective problem can be transformed to a single objective problem. This transformation is done via a step-by-step regrouping of a set of objectives into a single objective.

Once the relevant indicators, associated boundary values (ideal and worst values), actual values and weights are determined, the first step is to normalize the basic values (transposing them into the range of 0~1). This is undertaken to make all indicators comparable to each other, thereby avoiding differences in units. Given the ideal value ($f_{i,j}^{\text{ideal}}$), and the worst value ($f_{i,j}^{\text{worst}}$), the normalized value of an actual indicator value ($f_{i,j}(a)$) of alternative a can be calculated. The next step is to calculate second-level composite distances for each second-level group of basic indicators using the following equation:

$$L_j(a) = \left(\sum_{i=1}^{N_j} w_{ij} \left(\frac{f_{i,j}^{\text{ideal}} - f_{i,j}(a)}{f_{i,j}^{\text{ideal}} - f_{i,j}^{\text{worst}}} \right)^{b_j} \right)^{1/b_j} \qquad (5)$$

where i is the sequential number given to a basic indicator, j the sequential number of a certain group of basic indicators, $L_j(a)$ the distance from the ideal point in second-level group j, N_j the number of basic indicators in a second-level group j, w_{ij} the weights expressing the relative importance of the N_j basic indicators in group j, the sum of weights in any group being equal to one, b_j the balancing factor, which is equal or greater than 1, among indicators within the group j. The consecutive computations of higher-level composite indices are made in the same manner until a final composite distance for a system is reached. $L_j(a)$ will be values of PSD, and PWQD. The additional information can be obtained by Hartmann et al. (1987). CP uses indicators from different categories to calculate a composite distance, which identifies the distance of the actual system from the ideal state. Hence, schemes with small composite distances are closer to the ideal state than those with large composite distances (Yudusev and O'Connel, 2005).

3.2.2 Analytic Hierarchy Process (AHP)

AHP is a mathematical tool that enables the explicit ranking of tangible and intangible factors against each other for the purpose of resolving conflict or setting priorities. It combines qualitative and quantitative approaches and has the following benefits (Satty, 1980): 1) it helps dissect the problem and structure it into a rational decision hierarchy;

2) it gives an insight about the right data that needs to be collected for the alternatives at hand by the pairwise comparisons concluded under each criterion or subcriterion; 3) it prioritizes alternatives according to the preweighted criteria or makes a decision out of different scenarios; and 4) it examines the validity of the comparisons made between alternatives by testing these comparisons with consistency measures.

The AHP is a stable process, which uses basic steps that can be summarized as follows (Satty, 1980): 1) define the problem and structure the hierarchy using criteria and possible solutions; 2) construct a pair-wise comparison matrix of alternatives for each criterion or subcriterion; 3) calculate priorities; and 4) determine consistencies. To define the problem, assessors have to make sure that they understand what it is. They also need to know what alternatives are available to solve the problem. Using these alternatives and the predetermined criteria, the hierarchy can be built. Each criterion in this level is decomposed into subcriteria at the next level and so on. The alternatives lay at the bottom of the hierarchy. Key to the entire AHP methodology us the determination of the respective weights of criteria and subcriteria. One common method of determining weights is through a process of comparison.

4 Study watershed description

The Anyangcheon watershed (AY) was selected in this study. The Anyangcheon (stream) is the first tributary of the Han River in Korea. It has a length of 32.38 km. The watershed is bounded by latitudes of 37°18′N and 37°33′N and longitudes of 126°47′E and 127°04′E. The average annual precipitation from 1972 to 2001 is 1325.2 mm which 69.9% occurs during monsoon months from June to September, and 30.1% the rest from October to May. But it has been changed during the next five years (2002–2006). The average annual precipitation has increased as 1468.4 mm, and the occupancy of monsoon months as 73.8%. That is, since the intensity of summer season become higher but, the rainfall of the rest months decreased (391.5 mm to 385.4 mm), water resources management is more difficult. Based on the digital elevation model

(DEM), stream network, and storm sewers, the study watershed was divided into 11 sub-watersheds: OJ, WG, DJ, SB (upstream), HU, SA, SB1, SS (middle-stream), SH, MG, DR (downstream). The watershed area, in which approximately 387.6 million people reside, is 287.15 km^2 (population density: 13 527 persons per km^2). Primary land cover types within the watershed (as of the year 2000) consist of 43.03% urbanized, 39.79% forest and 12.95% agricultural areas.

5 Identification of hydrologic vulnerability

Based on the concept of the PSR framework, all criteria (indicators) to quantify PSD and PWQD are carefully determined by some experts, who are researchers and local governmental officials, since this process requires discussion and refinement. The structure of the selected criteria is shown in Fig. 2.

All the weights of the criteria and sustainability components (pressure, state, and response) of PSD and PWQD were established using the AHP. A survey was conducted on 50 local governmental officials and researchers in the field of river management. The weighting values were averaged using results to satisfy that the consistency ratio is below 0.15. All data were obtained by literature review, site survey, and computer simulations.

The values of PSD and PWQD were calculated using composite programming. Hartmann et al. (1987) proposed that all the alternatives can be classified into three groups ("Sound," "Acceptable," and "Poor") from the values obtained by composite programming. Therefore, this study classified the alternatives into five groups ("A"∼"E"), with the specific groupings as follows: A (0∼0.3, very sound); B (0.3∼0.4, quite sound); C (0.4∼0.5, Moderate); D (0.5∼0.6, quite poor); and E (0.6∼1.0, very poor). The PSD and PWQD and their spatial grades of all the sub-watersheds are shown in Table 1.

From Table 1 and their locations, all the sub-watersheds can be divided into six regions as follows: Region I (WG, OJ); Region II (DJ, SB); Region III (HU); Region IV (SA, SS, SB); Region V (MG); Region VI (DR, SH). Regions I and II are located in the upstream and “D” grade of PSD but have quite different water quality grades. Region I is “C” but II is “E”. Regions III and IV are located in the middle-stream but have totally different vulnerability. Region III is very good (both “A”) but IV has “C” or “D” of PSD and “D” of PWQD. Regions V and VI are located in the downstream but have different vulnerability in PSD. Region V is “D” grade but VI “E”. This classification supports the spatial information as well as the site-fitted management strategies.

6 Economic evaluation of hydrologic vulnerability improvement

6.1 Selection of attributes and assignment of levels

The attributes should be selected based on the five following criteria. First, the attributes should be independent or nearly independent of one another (Kwak et al., 2001). Second, there should only be a small number of attributes, preferably not more than six, because trade-offs become difficult to understand and to show to respondents in a comprehensible form if there are too many attributes (Phelps and Shanteau, 1978). Third, attributes should be describable by combining simple explanations and visual instruments, such as photographs, charts, and pictures. Fourth, attributes should be scientifically meaningful and important facts should not be omitted. Fifth, attributes should have some meaning to people and relate to their reasons for having the WTP to avoid mental impact (Yoo et al., 2008).

The attributes of this study were selected from hydrologic vulnerability components that represent PSD and PWQD. Their levels were divided into six grades on the basis of Sect. 5’s grades “A”~“E”. The “AA” grade was added as a sixth grade to represent the ideal condition. Each has its own target grade, since every sub-watershed cannot be an “AA” grade. Since all the sub-watersheds were divided into six regions in the Sect. 5, six experimental designs were necessary in this study. The levels and values of the attributes for the six regions are shown in Table 2.

The amounts of additional tax payment per household were set at three levels: 2500, 5000, and 10 000 won/household (1 US dollar corresponds to 1000 won as of May 2008). These amounts were set on the basis of the acceptability of an annual payment per household. Although the amounts actually bore no relation to the costs of the projects, respondents were asked to assume that the additional tax would be used only for implementing the projects for prevention of streamflow depletion and water quality enhancement. A result of CVM (Kong et al., 2006) in the study watershed and some preliminary surveys were used to determine the range of public payment acceptability.

6.2 Choice of experimental design and construction of choice sets

A choice set must obey the "independence from irrelevant alternatives" (IIA) property. This property states that the relative probabilities of two options being selected are unaffected by the introduction or removal of other alternatives. This property follows from the independence of the error terms across the different options contained in the choice set.

In designing a CE, it is important to carefully define the attribute space (including attribute and range) such that the attribute space includes the portion relevant to the policy questions being asked. Furthermore, a CE involves the use of statistical design theory to construct choice sets that can yield coefficient estimates that are not confounded by other factors. In this study, SAS Macro OPTEX procedure for a D-efficiency design was used in order to obtain an orthogonal design for IIA.

For most practical purposes, fractional factorial designs must be used. Fractional factorial designs are generated by selecting subsets of choice sets from the full factorial design. The two most common fractional factorial designs are the main effects only and main effects+two way interaction effects designs. In a main effects only design, a sub-set of the full factorial design is selected such that all the main effects (or linearly additive utility terms) are identifiable and completely orthogonal with each other. Employing a main effects only design drastically reduces the number of choice sets needed in an analysis.

Although employing main effects designs reduce the number of choice sets in a

CE application, the resulting design may still be too large from a practical application standpoint. Kuhfeld et al. (1994) proposed a method of selecting options from the full factorial design by minimizing the D-efficiency criterion. With these types of designs, a minimum number of observations, denoted as M, needed to identify the parameters of interest is selected, – i.e., a design with the minimum number of degrees of freedom (Kuhfeld, 2003).

Using a D-efficiency design, a number of profiles, in addition to "the status quo alternative," were selected from the number of possible combinations of attribute levels. The results are 2 Choice sets ×9 Questions for Regions I, II, IV, V, and VI and 2 Choice sets ×6 Questions or Region III. Each of the questions contained three alternatives, with two positive payments and the status quo choice. Six types of questionnaires were drawn up and 6 or 9 choice sets (conjoint questions) were included in each questionnaire.

6.3 Model of this study

The utility function of the model without covariates, with the exception of the error term e_{ij}, can be expressed as a linear function of an attribute vector ($\boldsymbol{S}_1$, $\boldsymbol{S}_2$, $\boldsymbol{Q}_1$, $\boldsymbol{Q}_2$, $\boldsymbol{T}$)=(PSD$_1$, PSD$_2$, PWQD$_1$, PWQD$_2$, Tax). It includes one alternative-specific constant (ASC), which represents a dummy for the respondent's choosing the status quo alternative in the choice set. ASC captures the utility of the alternative that the attributes fail to capture (Adamowicz et al., 1994).

But, in order to explain the preference heterogeneity and the WTP variations among individuals, it is useful to use alternative model specifications where some individual-specific variations are taken into account. The individual-specific variables include the residents' sex, age, number of family members, education, visit of stream, income, NGO registration, concerns about development and preservation, length of marriage and residence period.

Two versions of alternative models with covariates have been suggested. First, Greene (2002) proposed multiplying demographic variables by dummy variables for each choice within a set. However, if residents need to answer multiple questions, it would be impractical to use this model because separate dummies would be required for each distinct alternative to the status quo alternative faced by each individual. Second, Gordon et al. (2001) presented the idea of making the individual-specific variables interact with ASC terms in the utility function. Since this is ideally suited for our data, we chose to make the nine individual-specific variables interact with ASC. This can be formulated through the following utility function:

$$V_{ij} = \mathrm{ASC}_j + \beta_1 \boldsymbol{S}_{1,ij} + \beta_2 \boldsymbol{S}_{2,ij} + \beta_3 \boldsymbol{Q}_{1,ij} + \beta_4 \boldsymbol{Q}_{2,ij} + \beta_5 \boldsymbol{T}_{ij} + \sum_{s=1}^{9} \phi_s \mathrm{ASC}_i K_{si} \tag{6}$$

where the βs are the parameters to be estimated for each attribute that influences the respondent's utility, K_{si} is the individual-specific variables and ϕ_s is the parameter to be estimated for the individual-specific variables multiplied by ASC.

If we are calculating the MWTP from the status quo level of each attribute and assume that all of the following MWTP can be found by totally differentiating Eq. (6) and omitting i for brevity:

$$\begin{aligned} \mathrm{MWTP}_{\boldsymbol{S}_1} &= -(\partial V/\partial \boldsymbol{S}_1)/(\partial V/\partial T) = -\beta_1/\beta_5, \\ \mathrm{MWTP}_{\boldsymbol{S}_2} &= -(\partial V/\partial \boldsymbol{S}_2)/(\partial V/\partial T) = -\beta_2/\beta_5 \\ \mathrm{MWTP}_{\boldsymbol{Q}_1} &= -(\partial V/\partial \boldsymbol{Q}_1)/(\partial V/\partial T) = -\beta_3/\beta_5 \\ \mathrm{MWTP}_{\boldsymbol{Q}_2} &= -(\partial V/\partial \boldsymbol{Q}_2)/(\partial V/\partial \boldsymbol{T}) = -\beta_4/\beta_5 \end{aligned} \tag{7}$$

The MWTPs of each attribute represent the marginal rate of substitution between the price and each attribute.

6.4 Survey method

Since this study is the first study that used a CE for evaluating the environmental costs of hydrologic vulnerability in water resource planning, it was not clear whether the respondents had fully understood the trade-offs between price and the hydrologic attributes described in the questionnaire. Therefore, we conducted person-to-person interviews where we gave detailed questions to respondents in order to obtain higher effective response rates. We presented two indices and relevant pictures showing the present conditions of all sub-watersheds.

One hundred respondents of each questionnaire were sampled at random from the official resident registration of the city, in which all the residents of the city are recorded. If one of the questions was irrationally answered, the questionnaire was regarded as an ineffective response.

6.5 WTP estimates of each attribute

The choice data were analyzed using SAS 9.1. Some of the coefficients of covariates are not significant at the 10% level. However, most coefficients are statistically significant at that level. Most of the individual-specific variables for the six regions are not consistent because residents' inclination to stream is quite different for their regions. The socio-demographic and attitudinal variables have different impacts on the respondents from different regions. Overall, these models show an improvement, with a pseudo-$R^2>0.2$ and a pseudo-R^2 approaching 0.4, which is usually considered an exceptionally good fit (Hensher and Johnson, 1981).

The MWTP of respondents for obtaining one unit increase from the less preferred level of each attribute can be calculated by using Eq. (7). The results of MWTP estimates of the model with no covariates are shown in Table 3. For example, the MWTPs for water quality enhancement in region VI are 598.4 won for level 1 up and 4569.7 won for level 2 up. These results present the graded WTP based on the present conditions. In general the WTPs for water quality enhancement are larger than those for prevention of streamflow depletion except region I and IV. The WTPs of downstream watershed (region V and VI) are high, but upstream (region I and II) and middle-stream watershed (region III and IV) low. People in the region I have the largest WTP for environmental improvement but residents in the region III showing both "A" grades have the smallest

WTPs.

The monthly WTPs for all the households in the six regions can be calculated by multiplying the average household's monthly WTP by the number of households for each of the six regions, respectively. Since there are 2.95 persons/household according to the Korea National Statistical Office, the total WTPs for the six regions can be calculated by the multiplying the WTP by the total number of households. The results are shown in the last column of Table 3. The total WTP of region VI is the largest because of large population. These values can be efficiently used for an alternative selection or budget appropriation.

7 Calculation of AEI

In many cases, budget and resources are generally limited and thus all feasible alternatives are seldom accepted simultaneously. Managers should therefore find a set of alternatives that maximizes the desired objectives (i.e., maintenance of the minimum instreamflow and water quality enhancement). However, ranking feasible alternatives might be preferred to finding an optimal solution, particularly when the constraints are uncertain. This would also allow decision makers to be able to execute a water resources project according to the rankings of alternatives, depending on the available budget and resources.

The AEI may be assumed to be linear combination with evaluation values of water quantity and quality. Therefore the AEI, $f(a_i)$ can be derived as follows.

$$f(a_i) = \alpha_1 f_1(a_i) + \alpha_2 f_2(a_i) \tag{8}$$

where $f_1(a_i)$, and $f_2(a_i)$ are evaluation values of water quantity and quality and α_1 and α_2 ($\alpha_1+\alpha_2=1$) are the relative importance (weights) of water quantity and quality. $f_1(a_i)$, and $f_2(a_i)$ can be derived to consider the sustainability of the DPSIR framework as follows:

$$f_j(a_i) = b\mathrm{DR}_{j,i} + c\ \mathrm{PR}_{j,i} + d\ \mathrm{ST}_{j,i} + e\mathrm{IM}_{j,i} + f\ \mathrm{RE}_{j,i}, \quad j = 1,\ 2 \tag{9}$$

where, j is the effectiveness (1: water quantity, 2: water quality); DR, PR, ST, IM and RE the values of driving force, pressure, state, impact and response components, respectively; and b, c, d, e, and f the weighting factors ($b+c+d+e+f=1$). It is the role of the manager to select the indicators for the driver, pressure, state, impact, and response.

On the basis of the concept of the DPSIR approach, all criteria (indicators) to quantify the AEI were determined with care by experts such as researchers and local governmental officials, since this process requires discussion and refinement, as discussed in the Sect. 5. The criteria are selected as follows: Population and population density are picked out for drivers in water quantity and quality since they lead to environmental pressures. Urban area ratio, streamflow seepage, slope of watershed, and groundwater withdrawal assumed to be the pressure in water quantity. The loadings of BOD, COD, SS, TN, and TP, untreated wastewater intrusion, and ratio of covered stream interval assumed to be the pressure in water quality. These pressures affect the state which can be ratio of drought flow to hydrological instreamflow in water quantity and ratio of BOD average concentration to target concentration and ratio of BOD total daily load to TMDL in water quality. Since changes in the state may have an impact on environmental harm, number of days in a year to satisfy the target amounts of water quantity and quality were selected. Since responses means the measures and planning actions, this study selected the transformation ratios of indicators of state and impact.

All the weights of the criteria and sustainability components (driver, pressure, state, impact, and response) were established using the AHP. A survey was conducted among 50 local governmental officials and researchers working in the field of river and water resources management.

All possible alternatives were proposed by local governmental officials, residents and experts considering hydrological vulnerability grades of all sub-watersheds. However, because there are too many possible alternatives to be analyzed in detail, some feasible alternatives were screened according to three basic criteria, those of technical, economical, and environmental feasibility. As a result, the feasible alternatives consist of as follows:

- four reservoir redevelopment (R1: OJ, R2: HU, R3: SS, R4: GS)
- five restoration of covered stream (S1: DJ, S2: SB, S3: SA, S4: DR, S5: DR)
- five reuse of wastewater treatment plant effluent (I1: HU, I2: SS, I3: SS, I4: SA, I5:SB1)
- four use of groundwater collected by subway stations (U1: HU, U2: DR, U3: DR, U4: DR)
- a construction of small wastewater treatment (W1: DR)

The continuous water quantity and quality simulation model, HSPF (Hydrological Simulation Program – Fortran), was applied for analyzing the hydrological effectiveness of the alternatives. Each alternative was systemized into the HSPF and individually simulated. Therefore, the decision matrix for the water quantity and quality can be formulated using simulated values. The values of DR and PR were obtained from a national report and websites and those of ST, IM, and RE from the HSPF simulation. The instreamflow requirements (t_1), target concentrations (t_2), and TMDL (t_3) were obtained from Lee and Chung (2007). The values of instreamflow requirements, which are by monthly, were calculated by comparing the hydrological drought flow (Q_{355} of the flow duration curve) with the monthly ecological flow, while the target quality was stipulated by the local government. TMDLs were obtained by multiplying t_1 by t_2.

The results from the composite programming are shown in Table 4. According to the AEI values, all alternatives are similarly divided into three groups: Poor ("P", 0~0.3), Acceptable ("A", 0.3~0.6), and Good ("G", 0.6~1) as Hartmann et al. (1987) suggested. Using this classification criterion, all of the alternatives for this present study are as follows: G (S1, S4, S5, S4+U3, S5+U4), A (R1, R2, R4, S2, S3, I2, S3+I4, I5, U2, W1), P (R3, I1, I3, U1).

Interested and affected parties are generally unable to state explicit objectives in terms of measurable system attributes. Nevertheless, it is possible to identify the main concerns. For example, with the environmental group, it was evident that the flow regime patterns were extremely important (both in their own right and as a general predictor of water quality), where flow regime included consideration of both low flow levels in the dry winter season and the desirability of some flooding in the wet summer season. These concerns can be turns into surrogate objectives, not for the purposes of selecting an optimal policy, but for the more modest purpose of selecting the objectives (Stewart and Scott, 1995). Therefore, this concept can be applied to calculate each AEI using different weights of Eq. (8). Note that in most cases the objective preferences may be diametrically different in every region; for example, water quality enhancement may be preferred in downstream region but prevention of streamflow depletion may be highly desirable from the view point of upstream region residents.

This study achieved it by calculating the pairwise comparison of prevention of streamflow depletion and water quality enhancement. If the preferences with regard to management objectives can be quantified and introduced into the weights, the AEIs can also be used as management prioritization index. The weights of preferences with regard to prevention of streamflow depletion and water quality enhancement were quantified by stakeholder participation which is a survey of resident and are shown in Table 5. The number of data of each region is 300. The AEIs were recalculated by linearly combining the results of composite programming (b=1) and weights of resident preferences, as shown in Table 4. While the rankings were not significantly different, small differences may be important in special situations such as cases with budget limitations, because even small differences can alter overall performance. The poorly-effective alternatives were removed among the feasible since they are not available in view of the engineering efficiency.

8 Economic valuation of all alternatives

Economic values of hydrological vulnerability improvement and the AEI can be integrated to evaluate the monetary effectiveness of all feasible alternatives. The derived WTPs are discrete, but the continuous WTPs are necessary because the exact effectiveness of alternatives is also continuous. Therefore this study developed the following equations to derive the continuous benefit combining the WTPs with the AEIs. These concepts are shown in Fig. 3.

$$B(i) = (B_1(i) + B_2(i)) \times \mathrm{PH}_i \tag{10}$$

$$\begin{aligned} B_1(i) &= \mathrm{WTP1}_{1,i} \times 2 \times f'_{1,i} && 0 \le f'_{1,i} \le 0.5 \\ &= \mathrm{WTP1}_{1,i} + 2 \times \mathrm{WTP2}_{1,i} \times (f_{1,i} - 0.5) && 0.5 < f'_{1,i} \le 1.0 \end{aligned} \tag{11}$$

$$\begin{aligned} B_2(i) &= \mathrm{WTP1}_{2,i} \times 2 \times f'_{2,i} && 0 \le f'_{2,i} \le 0.5 \\ &= \mathrm{WTP1}_{2,i} + 2 \times \mathrm{WTP2}_{2,i} \times (f_{2,i} - 0.5) && 0.5 < f'_{2,i} \le 1.0 \end{aligned} \tag{12}$$

where $B(i)$ is the total benefit of the alternative i; $B_1(i)$, and $B_2(i)$ the benefits per household of alternative i to water quantity and quality, respectively; $f_{1,i}$ and $f'_{2,i}$ the standardized values of $f_{1,i}$ and $f_{2,i}$; $\mathrm{WTP1}_{1,i}$ and $\mathrm{WTP2}_{1,i}$ two step WTPs for water quantity improvement; $\mathrm{WTP1}_{2,i}$ and $\mathrm{WTP2}_{2,i}$ two step WTPs for water quality enhancement; PH_i the number of household of the watershed alternative i is applicable.

The benefits of ten feasible alternatives of Sect. 7 were calculated using Eqs. (10), (11) and (12) as shown in Table 6. The net benefit is necessary to determine the outstanding alternatives since the high benefit alternative usually requires high cost. The results of net benefit and BC ratio estimation are shown in Table 7, with interest rate 5%, endurance period and maintenance cost. As a result, U2, W1 and R4 can be proposed as the final candidates to decision makers since they are turn out to be both economic and effective from this new procedure. That is, this study shows not that these three alternatives are so perfect to be performed as soon as possible, but that these become just feasible candidates for the consideration of decision makers.

9 Conclusions

This study proposed the social-economic-engineering combined framework of the combination of a choice experiment and indicators of sustainable indicators to evaluate the economic value of hydrologic vulnerability improvement. The indicators were PSD and PWQD which show the hydrologic vulnerability in water resource planning. All the components of PSD and PWQD were selected by PSR framework, and calculated by composite programming, a type of MCDM techniques. These indices can not only give site-specific information to the respondents of a survey to avoid scope sensitivity in the choice experiment, but also support the standard to divide the study watershed into similar sub-regions. Therefore, residents can respond with a realistic WTP for the correct application of the CE, since they can recognize and confirm the present condition of their place of residence. In addition, after dividing into sub-regions on the basis of hydrologic vulnerability and location, each WTP was estimated to consider the spatial characteristics. A single WTP is not realistic, since the regions have different conditions. Therefore, this combination of composite programming and a choice experiment can make an improvement in the precise estimation of site-specific WTPs. Furthermore, combination of the WTPs and the AEIs to estimate the exact economic valuation of all feasible alternatives is the most original in this study. The CE just shows the economic values of several alternatives and improvement of environmental attributes. But this study proposed the methodology to contain strengths of the CE. This approach can provide the economic values of all alternatives from the values of environmental attributes improvement and the AEI.

This study develops an appropriate method in which stakeholder opinions or preferences are quantitatively reflected on management objectives, weights of indicators and monetary values of environmental improvements. This systematic screening procedure will provide decision makers the flexibility to obtain stakeholders' consensus for water resources planning.

Some choice experiment applications already exist, but a combination of hydrologic vulnerability grading and a choice experiment supplied with exact and concise information are proposed for the first time in this study. Lastly, this research provides a useful social-economic-engineering combined framework for incorporating such quantitative information into the evaluation of various policies with regard to water resource planning and management.

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Table 1. Indices and grades of PSD, and PWQD using composite programming.

Name of sub-watershed	PSD				PWQD			
	b=1	b=2	Average	Grade	b=1	b=2	Average	Grade
WG	0.490	0.676	0.583	D	0.345	0.562	0.453	C
OJ	0.474	0.612	0.543	D	0.368	0.567	0.467	C
DJ	0.508	0.616	0.562	D	0.565	0.678	0.622	E
SB	0.457	0.575	0.516	D	0.570	0.676	0.623	E
HU	0.236	0.332	0.284	A	0.153	0.212	0.182	A
SS	0.337	0.542	0.440	C	0.365	0.563	0.464	C
SA	0.466	0.630	0.548	D	0.364	0.562	0.463	C
SB1	0.446	0.605	0.525	D	0.342	0.560	0.451	C
SH	0.688	0.780	0.734	E	0.650	0.755	0.703	E
MG	0.536	0.618	0.577	D	0.582	0.676	0.629	E
DR	0.791	0.816	0.804	E	0.840	0.875	0.857	E
Average	0.49	0.63	0.56	D	0.48	0.63	0.55	D

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Table 2. Level and values of attributes.

Attribute	Levels	I	II	III	IV	V	VI
PSD	Dangerous (5)						Base
	Partiallydangerous (4)	Base	Base		Base	Base	B1
	Moderate (3)	B1	B1		B1	B1	B2(Target)
	Partially safe (2)	B2(Target)	B2(Target)		B2(Target)	B2(Target)	
	Safe (1)			Base			
	Ideal (0)			B1(Target)			
PWQD	Dangerous (5)		Base			Base	Base
	Partially dangerous (4)		C1			C1	C1
	Moderate (3)	Base	C2(Target)		Base	C2(Target)	C2(Target)
	Partially safe (2)	C1			C1		
	Safe (1)	C2(Target)		Base	C2(Target)		
	Ideal (0)			C1(Target)			

Table 3. Estimates of implicit prices and total WTPs of six regions.

Region	Attribute	Present Level	Target Level	Implicit Prices (won/month-household)	Total WTP (Korea won)
I	PSD	4	3	4941.1	56 703 729
			2	10 082.1	115 701 496
	PWQD	3	2	2356.2	27 039 591
			1	5915.8	67 889 320
II	PSD	4	3	1670.0	123 025 220
			2	2594.2	191 108 998
	PWQD	5	4	5811.6	428 127 767
			3	8599.2	633 484 117
III	PSD	1	0	244.2	25 803 165
	PWQD	1	0	1512.3	159 795 770
IV	PSD	4	3	2115.6	92 463 911
			2	5480.7	239 538 174
	PWQD	3	2	829.3	36 245 189
			1	4616.8	201 780 765
V	PSD	4	3	2057.5	329 951 162
			2	6528.3	1 046 911 383
	PWQD	5	4	5150.0	825 880 186
			3	7625.5	1 222 863 954
VI	PSD	5	4	1745.9	581 653 391
			3	3495.1	1 164 406 190
	PWQD	5	4	598.4	199 358 293
			3	4569.7	1 522 413 369

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Table 4. Two kinds of AEIs, ranks, and grades.

Name of alternative	Composite Programming (*b*=1)	Rank	Grade	AEIs of resident preference	Rank	Grade
R1	0.372	14	A	0.365	15	A
R2	0.476	11	A	0.467	11	A
R3	0.288	17	P	0.291	17	P
R4	0.515	10	A	0.503	10	A
S1	0.613	4	G	0.642	4	G
S2	0.595	6	A	0.626	5	G
S3	0.538	9	A	0.536	8	A
S4	0.657	3	G	0.667	2	G
S5	0.666	2	G	0.666	3	G
I1	0.221	18	P	0.248	18	P
I2	0.367	15	A	0.297	16	P
I3	0.292	16	P	0.376	14	A
S3+I4	0.428	13	A	0.438	13	A
I5	0.448	12	A	0.453	12	A
U1	0.209	19	P	0.242	19	P
U2	0.54	8	A	0.517	9	A
S4+U3	0.61	5	G	0.610	6	G
S5+U4	0.685	1	G	0.680	1	G
W1	0.585	7	A	0.554	7	A

Table 5. Preferences of six regions on management objectives.

Region	Water Quantity	Water Quality
I	0.383	0.617
II	0.271	0.729
III	0.247	0.753
IV	0.519	0.481
V	0.238	0.762
VI	0.409	0.591
Average	0.345	0.655

Table 6. Estimation of feasible alternatives benefit.

Name of Alternative	Alternative Evaluation Index (AEI)		Standardized AEI		WTP (won/year)	Estimated number of household	Benefit (1000 won/year)
	Quantity	Quality	Quantity	Quality			
R4	0.537	0.493	0.13	0.27	3296.0	3430	11 305
S1	0.549	0.676	0.18	0.88	8531.4	28 790	246 617
S2	0.527	0.663	0.09	0.84	8 237.5	44 878	369 680
S3	0.504	0.572	0.00	0.53	1056.6	16 936	17 894
S4	0.604	0.711	0.40	1.00	5966.4	9241	580 179
S5	0.662	0.67	0.63	0.86	5677.2	87 767	498 274
U2	0.664	0.415	0.64	0.00	2235.7	333 154	744 824
S4+U3	0.612	0.608	0.43	0.65	6078.2	97 241	591 044
S5+U4	0.712	0.658	0.83	0.82	6054.9	87 767	531 422
W1	0.754	0.415	1.00	0.00	3495.1	333 154	1 164 406

Table 7. Net benefits and BC ratios of all feasible alternatives.

Name of Alternative	Period (years)	Net Benefit (1000 won)	BC ratio
R4	25	25 766	1.18
S1	100	–10 421 993	0.33
S2	100	–17 569 230	0.30
S3	100	–7 624 735	0.05
S4	100	–28 018 277	0.30
S5	100	–33 179 149	0.24
U2	25	8 717 984	4.40
S4+U3	100	–28 834 151	0.30
S5+U4	100	–33 530 475	0.25
W1	25	4 443 519	1.34

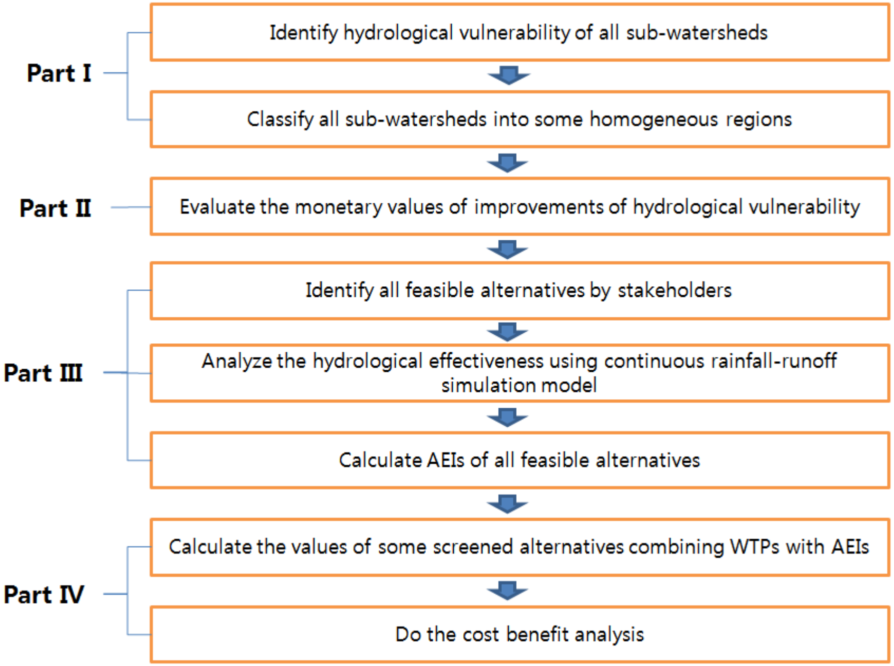

Fig. 1. Procedure of the economic-engineering combined framework.

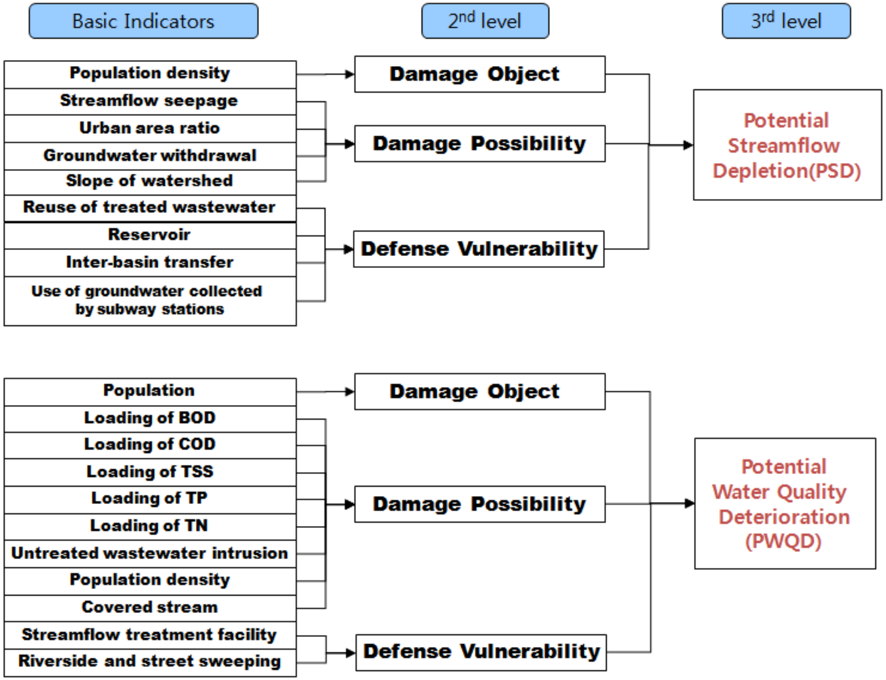

Fig. 2. The indicator structure of indices.

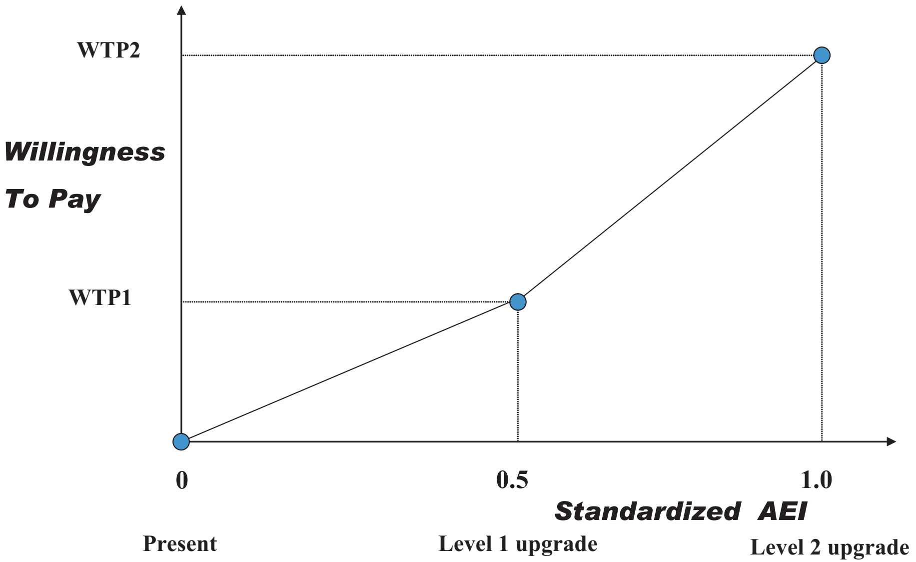

Fig. 3. Concept of continuous WTP estimation.