Hydrologic Design That Incorporates Environmental, Quality, and Social Aspects

An integrated procedure for hydrologic engineering projects

This article discusses hydrologic and hydraulic projects and their relationship to quality and environmental management systems. It presents an integrated procedure for designing engineering projects that incorporate quality and environmental protection by utilizing the approaches set out in International Organization for Standardization (ISO) standards 9001:2000 (quality) and 14001:2004 (environment).

Hydrologic design can be integrated in a way that satisfies the quality and environmental management system (QEMS) of any organization. The suggested procedure discussed here includes several steps:

- obtaining information on watershed hydrologic features (e.g., time of concentration and peak discharge);
- designing detention basins;
- performing channel routing;
- establishing subsurface drainage; and
- ensuring public involvement in the process of planning and decision making.

Background: QEMS and Engineering Firms

Quality and environmental management systems deserve greater attention from professional and business organizations, especially engineering firms.

Since the 1980s, a great deal has been said about sustainable development. However, little has been done to a strong contribution toward achieving sustainable development. Fortunately, the QEMS approach has been adopted by many civil engineering organizations, including entities involved in consulting, project planning, and construction.

Civil engineering organizations must guarantee a sequential coordination among all the processes involved in a project. Specifically, the following processes are critical:

- involvement of stakeholders (both internal and external to the organization) in development of the project, as provided in the

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Aahrus Convention (Silva, 2003; United Nations Economic Commission for Europe, 2004);

- development of methods for obtaining information and providing such information to decision makers, as established by quality engineering principles (Juran, 1992);
- updating of information; and
- promotion of continuous process improvement, as outlined in the Deming cycle (see **Exhibit 1**).

This article specifically addresses organizations that provide services on civil engineering projects, particularly hydrologic and hydraulic projects. However, the discussion will likely be of interest to any business or professional organization that becomes involved in such projects. The methodology discussed here is based on procedures used by Globalvia, S.A., under the QEMS that has been implemented by the company.

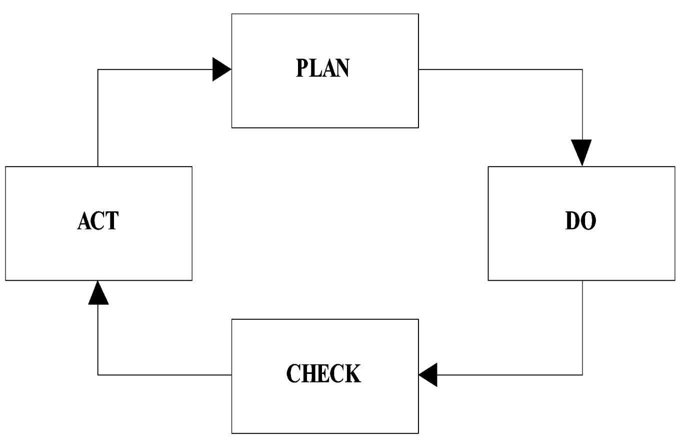
Methodology: An Integrated Design Process

The methodology proposed here involves an integrated procedure for developing hydrologic and hydraulic design processes within watersheds in a manner that conforms to the technical requirements of both ISO 9001:2000 (a quality management system) and ISO 14001:2004 (an environmental management system).

The QEMS procedure is designed to allow continuous monitoring of processes in order to adjust and correct possible nonconformities during process implementation. The QEMS approach allows for prevention of problems, as well as for implementation of continuous improvement programs (see **Exhibit 2**).

The QEMS procedure utilizes information about quality and environmental issues drawn from recognized literature (e.g., Aguayo, 1990; Deming, 1982; Juran, 1992; Scherkenbach, 1991) and from experienced organizations such as the United States Environmental Protection Agency (EPA, 2002).

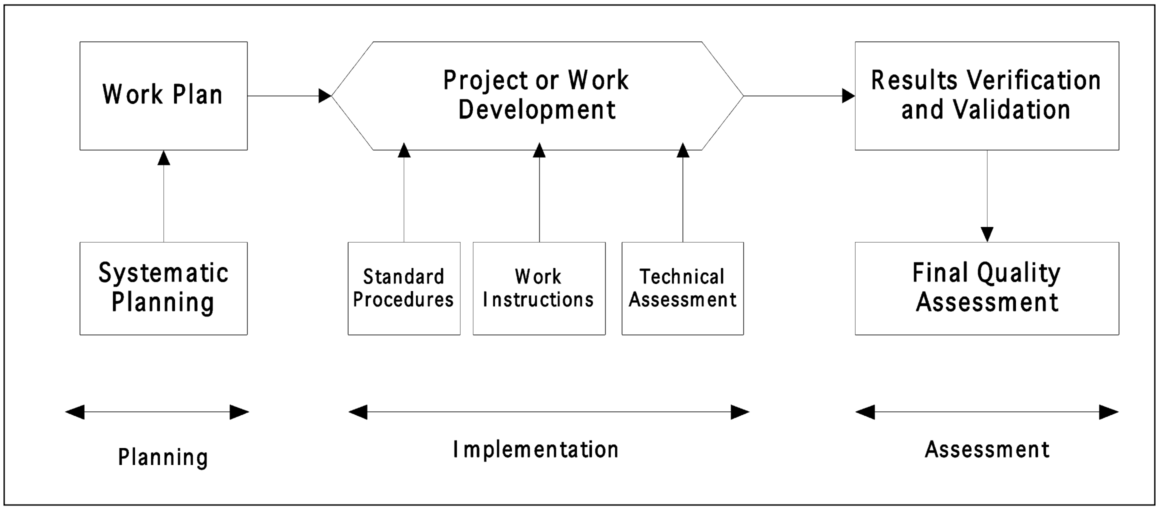
Exhibit 1. Deming Cycle for Continuous Improvement



- **PLAN**: Design or revise process components to improve results.
- **DO**: Implement the plan and measure its performance.
- **CHECK**: Assess the measurements and report the results to decision makers.
- **ACT**: Decide on changes needed to improve the process.

See Scherkenbach (1991).

Exhibit 2. Simplified Model of the QEMS Process Applied to Project Development



Initiating Hydrologic and Hydraulic Design Processes

Obtaining Data and Information

At the beginning of a hydrologic design process, watershed hydrological studies are conducted in order to obtain data on peak discharge, create a runoff hydrograph for different recurrence intervals, and gather information needed to design hydraulic structures. **Exhibit 3** illustrates how hydrological studies are conducted with the GLOBALVIA system.

Determining Time of Concentration

"Time of concentration" refers to the period of time needed for maximum or peak runoff to accumulate in the watershed. Determining time of concentration is a key component of hydrologic design.

It is important to stress that the time of concentration should not be determined solely by empirical methods, which may not reflect actual land use in the watershed. Process-based methods allow the practitioner to take into account the watershed's use and occupation characteristics.

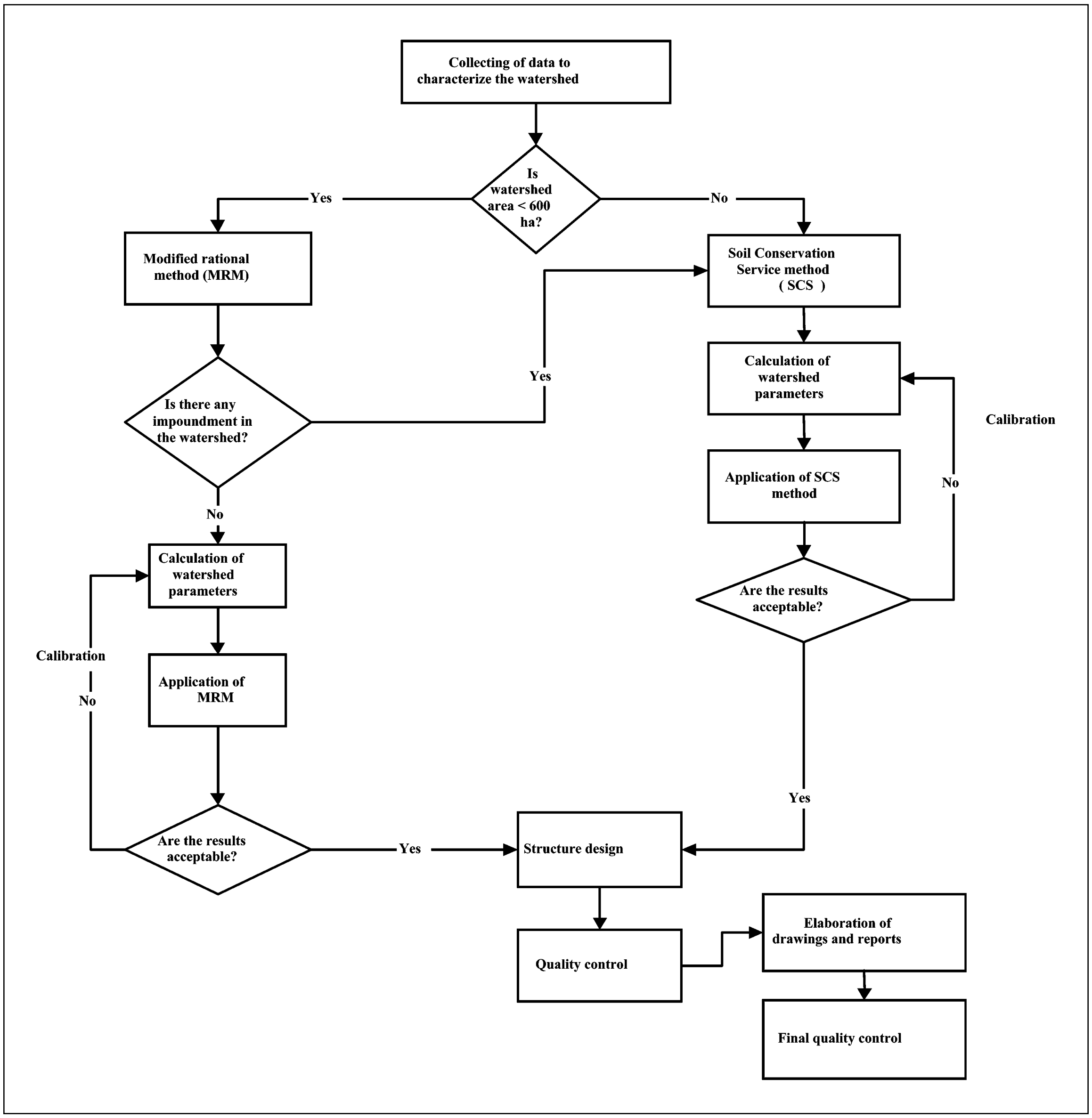
Available methods include those used by the U.S. Natural Resources Conservation Service (formerly the Soil Conservation Service) (see Natural Resources Conservation Service, 1997; Soil Conservation Service, 1972, 1973, 1986) and the Federal Aviation Administration (see Chow et al., 1988), as well as the method outlined by Hathaway (1945), and the kinematic wave method (Overton & Meadows, 1976; Ragan, 1971). See **Exhibit 4.**

Designing Detention Basins

When postdevelopment conditions are expected to increase the peak discharge (Q_p) considerably, proper runoff management requires inclusion of a detention basin in the stormwater drainage system. A detention basin often will be needed in order to allow water flows to be discharged at a controlled rate, thus reducing Q_p to a level that does not exceed the capacity of the available drainage structures.

There are several empirical methods that can be used in feasibility studies to estimate the required volume of the detention basin. In detailed design projects, however, the practitioner should use a process-based method, such as level pool routing, to balance the inflow and outflow. See **Exhibit 5.**

Exhibit 3. GLOBALVIA's Procedure for Hydrological Studies and Drainage System Design



Channel Routing

In selecting channel routing techniques, it is recommended that the practitioner use the procedure suggested by the U.S. Army Corps of Engineers (1994), as shown in **Exhibit 6.**

Subsurface Drainage

The relationship between subsurface water levels and surface runoff tends to be straightforward. In some situations it is necessary to decrease the water table level—for example, in order to improve the stability of infrastructure.

The methods used to reduce water table levels depend on soil characteristics and depth of impervious barriers. Among the existing methods is the ellipse equation developed for parallel drains (see Natural Resources Conservation Service, 1997),

$$S_d = \sqrt{4K_w \frac{(m^2 + 2am)}{q}}, \text{ with } m = d - c$$

Exhibit 4. Empirical and Process-Based Methods for Determining Time of Concentration

Method		Equation	Terms of Equation	Reference
Empirical	Kirpich	$t_c = 0.0195L^{0.77}S^{-0.385}$	t_c is time of concentration (in minutes); L is the length of main channel (in meters); and S is the average watershed slope (in meters/meter). Recommended for rural basins of up to 45 hectares (ha).	Kirpich (1940) Chow et al. (1988)
Process-based	SCS Lag Formula	$t_c = \dfrac{1.552L^{0.8}\left(\dfrac{1000}{CN} - 9\right)^{0.7}}{1900\sqrt{S}}$	t_c is the time of concentration (in hours), L is the watershed length (in meters), CN is the curve number (–), which is a function of watershed use and occupation, and S is the average watershed slope (in %). Recommended for nonurban watersheds of up to 810 ha.	Soil Conservation Service (1972) Soil Conservation Service (1986) U.S. Army Corps of Engineers (1994)

Exhibit 5. Some Empirical and Process-Based Methods for Detention Basin Design

Method		Equation	Terms of Equation	Reference
Empirical	Simplified Triangular Hydrograph	$V_s = \dfrac{1}{2}t_b(Q_i - Q_o)$	V_s is the storage volume (in cubic meters, or m^3); Q_i is the peak discharge for post-development conditions (inflow) (m^3 per second, s); Q_o is the peak discharge for pre-development conditions (outflow) (m^3/s); and t_b is the duration of basin inflow (per second).	Washington State Department of Transportation (1997) Integrated Science & Engineering (2000) Virginia Department of Transportation (2001)
	Wycoff & Singh	$\dfrac{V_s}{V_r} = \dfrac{1.291\left(1 - \dfrac{Q_o}{Q_i}\right)^{0.753}}{\left(\dfrac{t_p}{t_b}\right)^{0.411}}$	V_s and V_r are the basin and runoff volume, respectively; Q_i and Q_o have the same meaning as noted above; t_b is the duration of basin inflow, and t_p is time to peak (in hours).	Wycoff & Singh (1976)
	Pagan	$V_s = 35.3107S_pQ_i$ The Pagan curve to obtain S_p can be approximated by the following equation: $S_p = -2883Ln\left(\dfrac{Q_o}{Q_i}\right) + 13408$	S_p is the storage parameter. The other terms have the same meaning as referenced in the Wycoff & Singh method, above.	Virginia Department of Transportation (2001)
Process-based	Continuity Equation: Level Pool Routing	$\dfrac{\delta V(t)}{\delta t} = I(t) - O(t)$ $\dfrac{2V_{i+1}}{\Delta t} + O_{i+1} = I_i + I_{i+1} + \dfrac{2V_i}{\Delta t} - O_i$	V is the storage volume; I is the inflow hydrograph; and O is the outflow hydrograph.	U.S. Army Corps of Engineers (1994) Ramírez (2000)

Note: Other empirical methods are also available, such as those proposed by Debo and Reese (1995) and Tucci (1998).

where:

S_d is the parallel drain spacing (in feet),

K_w is the weighted hydraulic conductivity above the restrictive layer (in inches per hour),

m is the vertical distance (after drawdown) of the water table above drain and at midpoint between drains (in feet),

d is the depth to drain from surface (in feet),

Exhibit 6. Selecting the Appropriate Channel Routing Technique

Factors to Consider in Selection of Routing Technique	Methods That Are Appropriate for This Specific Factor	Methods That Are Not Appropriate for This Factor
No observed hydrograph data available for calibration.	• Full Dynamic Wave • Diffusion Wave • Kinematic Wave • Muskingum-Cunge	• Modified Puls • Muskingum • Working R&D
Significant backwater that will influence discharge hydrograph.	• Full Dynamic Wave • Diffusion Wave • Modified Puls • Working R&D	• Kinematic Wave • Muskingum • Muskingum-Cunge
Flood wave will go out of bank into the floodplains.	All hydraulic and hydrologic methods that calculate hydraulic properties of main channel separate from overbanks.	• Muskingum
Channel slope > 10 ft/mile and $\frac{TS_o u_o}{d_o} \geq 171$	All methods presented	• None
Channel slopes from 10 to 2 ft/mile and $\frac{TS_o u_o}{d_o} < 171$	• Full Dynamic Wave • Diffusion Wave • Muskingum-Cunge • Modified Puls • Muskingum • Working R&D	• Kinematic Wave
Channel slope < 2 ft/mile and $TS_o\left(\frac{g}{d_o}\right)^{1/2} \geq 30$	• Full Dynamic Wave • Diffusion Wave • Muskingum-Cunge	• Kinematic Wave • Modified Puls • Muskingum • Working R&D
Channel slope < 2 ft/mile and $TS_o\left(\frac{g}{d_o}\right)^{1/2} < 30$	• Full Dynamic Wave	• All others

Legend: T is hydrograph duration; S_o is friction slope or bed slope; u_o is reference mean velocity; d_o is reference flow depth; g is acceleration of gravity.

c is the depth to water table drawdown after the evaluation period (in feet),
a is the depth of barrier (impervious layer) below drains (in feet), and
q is the drainage rate (in inches per hour).

Another approach is the Hooghoudt "drainage spacing" equation (see Hooghoudt, 1940; Rimidis & Dierickx, 2003),

$$q_s = \frac{4Kh_t^2}{L^2} + \frac{8Kd_e h_t}{L^2}$$

where:
q_s is the specific discharge (in meters per day);
K is the hydraulic conductivity of the soil (in meters per day);
L is the drain spacing (in meters);
h_t is the total head loss (in meters); and
d_e is the equivalent depth of the impervious layer (in meters).

This method is recommended for nonstratified soils and for two-layered soils that have drains located in the transition zone between layers.

When stepped spillways are considered as part of a project, it is recommended that the design criteria guarantee the skimming flow, since this leads to better energy dissipation (see Chanson, 1993). The conditions for skimming flow are determined by

$$h_c \geq 1.195 h_d - 0.595 \frac{h_d^2}{L_d}$$

where:

h_c is the critical flow depth;

h_d is the height of the step; and

L_d is the length of the step.

Ensuring Public Participation

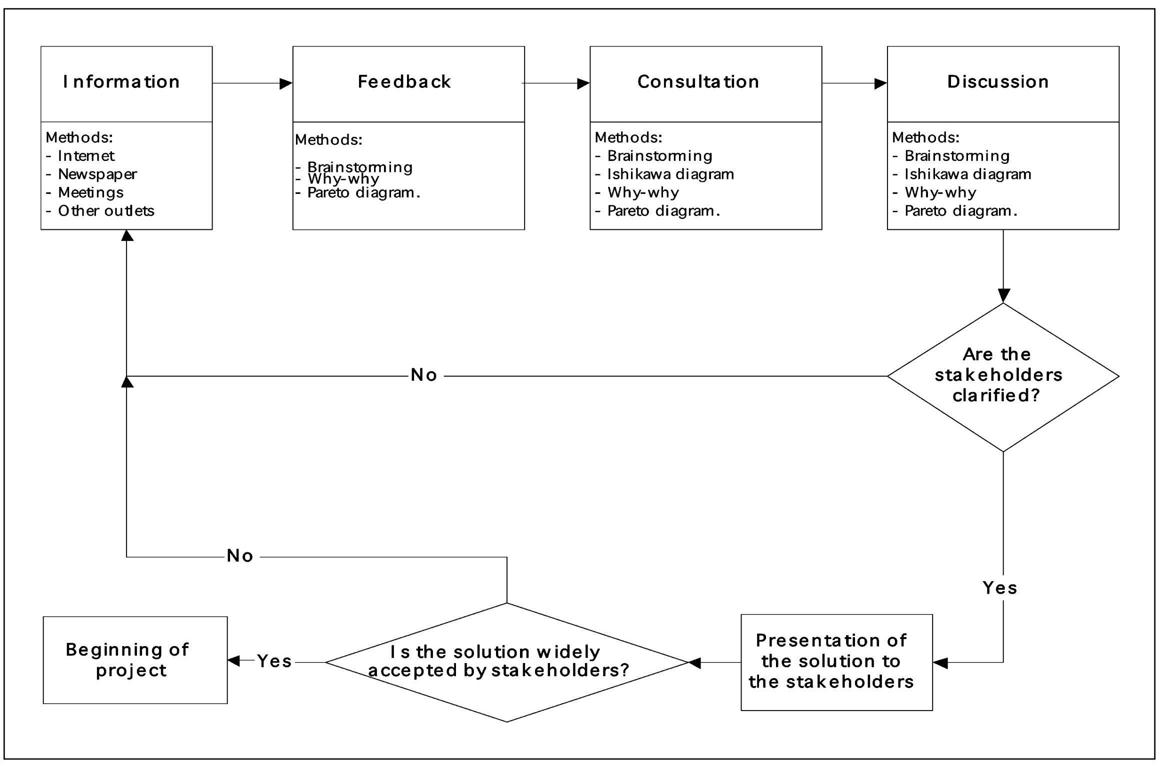
Public involvement can considerably improve the outcome of most major engineering projects. Participation by a wide range of stakeholder groups can provide valuable information that allows project sponsors to adjust their objectives to local interests.

For example, where a detention/retention basin must be placed in an urbanized watershed area, numerous stakeholders may have an interest in the project. Interested stakeholders may include project sponsors, potential purchasers and users of the finished project, and people who live and work in the area. The stakeholders may want to discuss, and obtain information about, the type of detention/retention basin being considered (e.g., dry or wet basin) and its planned location.

Exhibit 7 illustrates a method for developing public participation in decision-making processes related to engineering projects.

It is important to stress that integrated environmental assessment requires the practitioner to systematically combine information and knowledge gained from conventional science, experience with past environmental problems, management principles, and stakeholders who represent the various social sectors affected (Kasemir et al., 2002). Problems related to public involvement and stakeholder participation are discussed ex-

Exhibit 7. GLOBALVIA's Procedure for Public Participation



tensively in the literature (e.g., Federal Highway Administration, 2002; Joss, 1998; Kass, 2001; Petts, 1995).

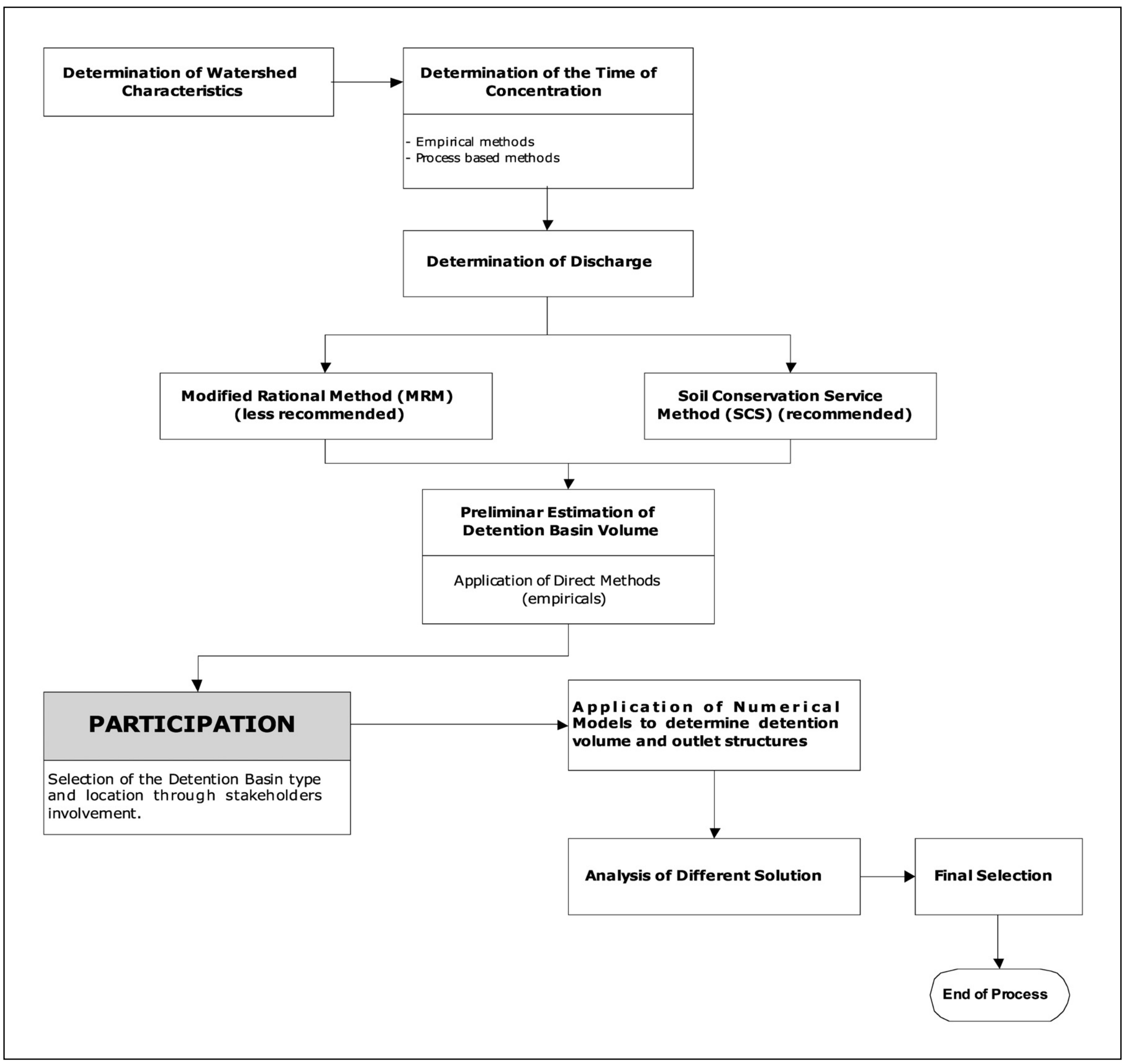
Exhibit 8 illustrates a set of procedures developed for a project involving the design and installation of a detention basin, with the public participation component highlighted. This procedure entails the use of both expert and nonexpert opinions as a way of optimizing the choice of a solution. Nonexpert opinions can be obtained from various sectors of the population via stakeholder participation.

Concluding Remarks

Environmental concerns are becoming increasingly important throughout society. All engineering disciplines must pay close attention to environmental issues as part of their work, and must strive to make engineering projects more acceptable in terms of their social and environmental impacts. This is particularly true in the case of projects involving hydrologic and hydraulic design.

This article suggests an approach that entails consideration of essential concerns related to environmental and social sustainability. It empha-

Exhibit 8. GLOBALVIA's Approach to Public Participation in a Project Involving Design and Installation of Detention Basins



sizes the use of public participation in project planning.

It is hoped that the ideas presented here will help engineering firms, and other interested parties, better incorporate environmental and social values into their design and installation projects.

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