Chesapeake Bay National Estuarine Research Reserve in Virginia

GUIDELINES

WATER QUALITY MONITORING

GUIDELINES ON THE APPLICATION OF ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY AS A DECISION-MAKING TOOL TO IMPROVE DATA QUALITY

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CHESAPEAKE BAY
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GUIDELINES ON THE APPLICATION OF ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY AS A DECISION-MAKING TOOL TO IMPROVE DATA QUALITY

By Eduardo J. Miles

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PREFACE

There has been a continuous degradation of the environment due to human activity in the production of goods and services. Recognition of this fact has caused international agencies, such as the World Bank and the United Nations Environment Programme, as well as almost every government in the world, to enact laws or regulations on the application of environmental impact assessment (EIA).

Environmental impact assessment is a decision-making planning tool used to systematically identify, predict, evaluate, and mitigate potential impacts of a current or proposed project on the environment and on society (Senecal *et al*., 1999). The main purpose of environmental impact assessment is to provide information to planners and decision-makers so they can determine the best solution that minimize biophysical, social and other significant effects of the project prior to major decisions being taken and commitments made (European Commission Environment; International Association of Impact Assessment, 1999; Natural Resources Conservation Authority, 1997).

Even though impact analysis is a widely used tool, there is a whole segment of professionals and academia who work on water quality monitoring that do not take advantage of this tool during project planning, design, and execution. Mainly, there are two reasons for this. First, a lack of knowledge of what entails impact analysis, and second, a misunderstanding of the application scope of the tool.

This document has a twofold purpose. First, to bring the basic concepts of impact analysis to the attention of the water quality monitoring community. Second, to show the benefits that could be obtained from the application of this process as an information gathering and decision-making tool. Mainly the benefits obtained from anticipating and avoiding impacts that could jeopardize the monitoring objectives, and ensuring that these impacts are considered and incorporated in the development decision-making process. In particular, the document aims to provide practical guidance on how impact analysis could be employed as a standard operating procedure to systematically and comprehensively evaluate negative impacts on water quality monitoring projects.

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INTRODUCTION

Water quality monitoring projects are executed to answer a variety of questions, or address concerns, that managers, researchers, policy makers, and other stakeholders have with regard to biological or physical interactions, water usage, recreation and aesthetics, or status of water bodies among many other water issues or concerns.

As any other type of monitoring project, there are some critical success factors that must be properly addressed for a water quality-monitoring project to be successful. A clear understanding of the negative impacts on the monitoring project by the monitoring team is one of these critical factors (*i.e.*, what are the different human actions that take place in the monitoring influence area that can negatively impact the monitoring project?). It is crucial to realize that the entire water quality monitoring effort may be unsuccessful if all the different variables that can negatively affect the monitoring objectives are not clearly defined, or understood by those conducting the project.

It is common practice in a water quality monitoring project, especially in academia, that negative impacts on the project are almost never considered during the project's design phase and generally are addressed after the fact. Thus, a reactive decision-making process is applied. This approach has a number of disadvantages, primarily that addressing negative impacts after the fact can be very costly and can jeopardize the fulfillment of the monitoring and data quality objectives. In order to ensure achieving the project's objectives, it would be beneficial to have a protocol to follow that evaluates and predicts the different impacts' significance on the project's objectives. Managing, controlling, or only understanding the effect of these impacts in a timely manner is necessary for the proper project execution, and critical for ensuring quality data.

The impact analysis process (process that it is used in environmental impact assessment) is an information-gathering and decision-making tool that can be used for this purpose. Impact assessment can be employed in a water quality monitoring project to identify, understand, and evaluate these impacts in a timely manner and address their effects by applying correction or mitigation measurements to minimize their effect on the project's objectives.

This manual discusses the great benefits that the 'impact analysis process' (process that it is used in environmental impact assessment) has to offer to the water quality monitoring community as the protocol to be used to evaluate and predict the negative impacts on the monitoring project.

The document provides a very brief insight into the impact analysis process and outlines very concisely how this process could be applied in a water quality monitoring project, mainly targeted for those professionals and academia that are unfamiliar with this procedure.

Even though the document focuses on the application of impact assessment in water quality monitoring, it can also be employed in other environmental monitoring projects: for example, erosion control by living shorelines, sea level rise studies, wetlands restoration. Any type of endeavor where the understanding and mitigation of human and environmental negative impacts on the project is important to ensure the fulfillment of the project's objectives would benefit from the application of the impact assessment process.

i. REFERENCE

European Commission. 2000. **Environmental Integration Manual: Good Practice in EIA/SEA - Evaluation of the significance of environmental impacts**. Towards Sustainable Economic and Development Co-operation. Version 1.0.

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CHAPTER 1

ENVIRONMENTAL IMPACT ASSESSMENT IN WATER QUALITY MONITORING PROJECTS

This chapter is intended to provide a general overview of the steps of environmental impact assessment and how can be used in a water quality monitoring project.

1.1 ENVIRONMENTAL IMPACT ASSESSMENT: A BRIEF OVERVIEW

There are many definitions of what constitutes environmental impact assessment (EIA) (Glasson *et. al*, 1999), but in essence the main objective of an environmental impact assessment is to assess, predict, and evaluate whether the execution of a project, a policy, or a program, or the production and marketing of a product or a service is likely to cause significant impacts on the environment (biological, physical, or socioeconomic) and then develop measurements to avoid, minimize, mitigate, or compensate these impacts (Senécal *et al*., 1999; Sadler and McCabe, 2002).

In other words, environmental impact assessment is a series of processes through which information is collected to determine, assess, predict, and communicate the impacts of a proposed project, program or policy on the environment and society. For example, one definition of environmental impact assessment given by the United Nations Department of Economic and Social Affairs, Division of Sustainable Development is:

> *"A structured approach for obtaining and evaluating environmental information prior to its use in decision-making in the planning and development process. EIA includes predictions of how the environment is expected to change if certain alternative actions are implemented and advice on how best to manage environmental changes if one alternative is selected and implemented. As used here environment includes the physical, biological, economic, health, and socio-cultural context of human activities. The relevant concepts are well developed and are described in a variety of publications on the subject".*

The main processes or stages found on most EIAs are (Carroll *et al*., 2002; Morris, 2009; Sadler and McCabe, 2002):

Screening: is the process to determine whether or not an EIA is required. In addition, it is intended to determine the level of detail that must be accomplished.

Scoping: is the process to identify the key issues and impacts to be addressed during the EIA and eliminate those that are of little concern. In addition, during scoping, the time and space boundaries of the EIA are defined and feasible alternatives are identified.

Baseline Studies: is the process to collect background information to describe the actual conditions of those elements of the environment and society that are likely to be affected by the proposed project; to characterize the pre-project state.

Impact Analysis: is the process to identify and analyze the main impacts and predict their significance. This process entails a detailed analysis of the impacts and their effects. It is carried out in three phases: identification, prediction, and evaluation.

Mitigation and Impact Management: is the process to determine the measures necessary to prevent, minimize or offset, or remedy significant adverse impacts. These measures are incorporated into a management plan or management system.

Presentation of Findings and Proposals in the Environmental Impact Statement: the environmental impact statement is a document that provides all the necessary information obtained from the EIA for decision-making. It compiles information regarding the project's purpose, the need for the proposal, impacts, mitigation measures and management, environmental effects that cannot be avoided, and description of alternatives to the proposed project.

Implementation and Follow-up: this process is comprised of all the management activities to monitor the changes in the environment and societal elements during the implementation and operational phases of the project. Activities performed in this stage include: identification of impacts, verification that the effects are within the predicted levels, assessment of the mitigation measurements, implementation of corrective actions, and implementation of feedback systems to improve future actions.

A generalized environmental impact assessment process flow chart is shown in Figure 1.

For illustration purposes, a brief example of a typical environmental impact assessment application follows.

In order to get financial aid from the European Bank for Reconstruction and Development (EBRD) to construct an outer ring road, the Municipality of Tirana, in Albania, had to complete a full EIA of the by-pass route project. The project is a 4-to-6 lane road around Tirana's main urban area for completion by 2020. The EIA had to address the impacts that the route would have on the socio-economic environment (*e.g.* structures affected, loss of land, air quality, noise, *etc*.); the impacts on the biological environment (*e.g.* loss of habitats for animals and plants, pollution of animal habitats, noise (birds, bats), *etc*.); and the impacts on the physical environment (*e.g.* surface and ground water) (Bernard and Brenner, 2009).

Once the impacts were identified and evaluated, mitigation measurements were developed. For example, it was determined that noise would be one of the impacts associated with both the construction and operation phases of the outer ring road. The measures to be implemented to avoid, minimize, mitigate or compensate the noise are:

- During the construction phase: prohibition of night work

- During the operational phase: supply of sound-proof, double-sided windows in those areas where the noise must be reduced to acceptable night time noise levels.

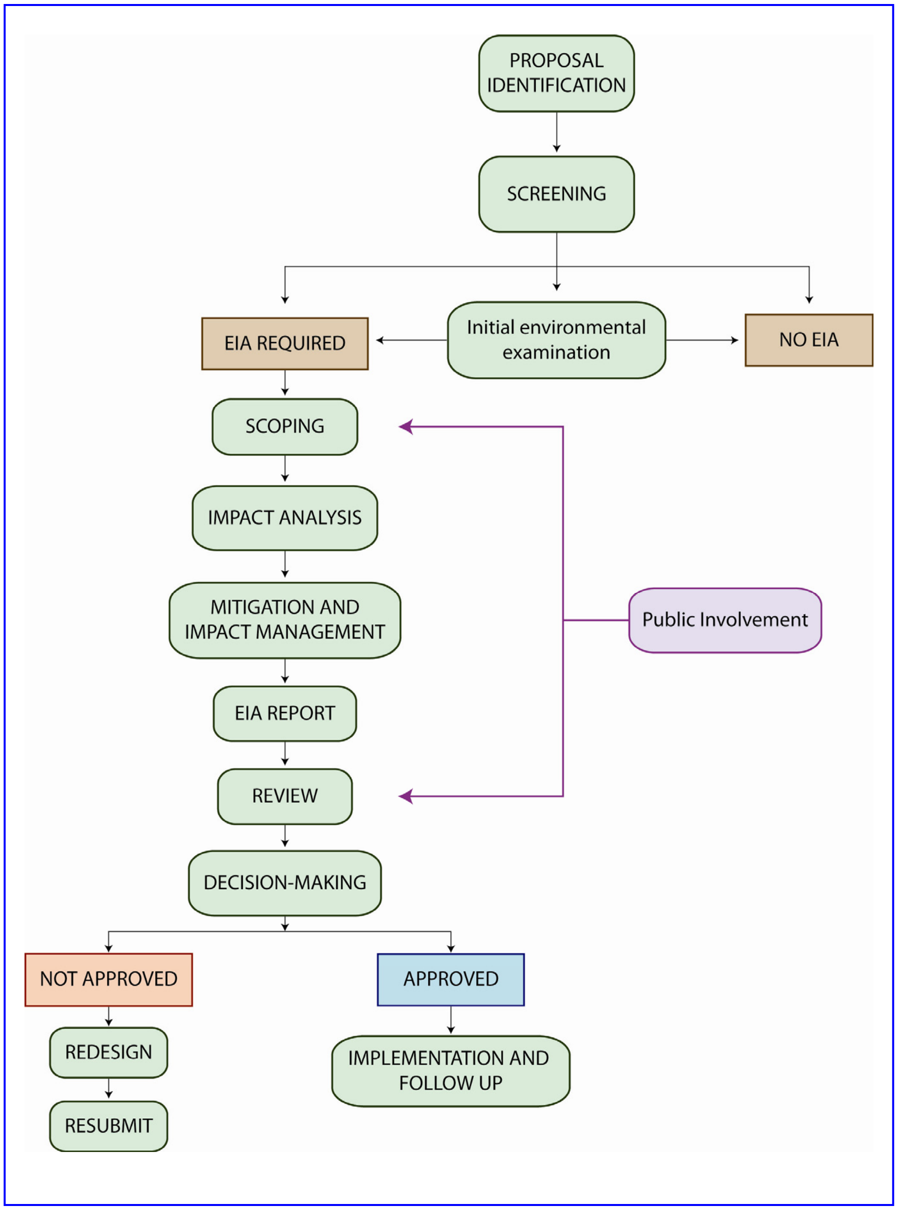

Figure 1. Generalized EIA process flow chart (Source: Sadler and McCabe, 2002)

Figure 2. Impacts produced by the construction of the by-pass route

Another impact identified was the fragmentation of animal habitat and barriers (*i.e.* for turtles and otters). To mitigate this impact, a plan was devised for bridge corridors for wildlife to be constructed at three locations.

By applying impact analysis to a project, all the different activities that produce a negative impact on the environment and society can be easily identified, predicted, and assessed (Modak and Biswas, 1999). In addition, environmental impact assessment is an information gathering (Sikoyo, 1999) and decision-making tool (USEPA, 1998) that provides the management team with the necessary data to understand:

- All possible environmental implications of the proposed project and to set priorities that will benefit the environment at an early stage of the project development (UNEP, 1990).

- Major strengths and weaknesses of the different activities that will be performed in terms of their positive and negative effects on the environment (DOC, 2008).

Among the different processes that make the structure of the EIA, impact analysis, and mitigation and impact management are considered to be critical processes, and sometimes referred as the technical heart of the EIA (Sadler and McCabe, 2002). Impact analysis is the process employed to identify the main impacts on the environment of a proposed action, project, or program, predict their main characteristics, and evaluate their significance. Mitigation and impact management is the process to develop measures to avoid, eliminate, minimize, mitigate, or compensate these impacts (USEPA, 1998).

1.2 APPLICATION OF IMPACT ASSESSMENT ON WATER QUALITY MONITORING PROJECTS

Environmental impact assessment is commonly employed in projects where there are likely environmental consequences of the proposed activity, such as development projects (*e.g.* construction of a dam or a waste water treatment plant) or projects that intervene in the natural resources, surroundings and landscape (*e.g.* extraction of mineral resources, disposal of waste into a stream, projects that have adverse impacts on endangered plant, animal species, or critical environments) (OECD, 1992). However, this tool has hardly ever been used in projects that are not likely to have negative impacts on the environment or society; for example, in monitoring (*e.g*. water quality monitoring) or environmental enhancement (*e.g.* living shorelines) programs. In particular, in water quality monitoring projects, there has been no need or interest in applying impact analysis during project planning and execution, mainly due to the fact that this type of projects are designed to collect information in a passive way, and during their execution they do not generate impacts on the environment or society.

Nevertheless, it is a well known fact the many advantages that can be obtained by the adaptation or application of models or concepts that have worked in one environment, and applying them in another domain (Sloane, 2003). This is the case for impact analysis in water quality monitoring (WQM) projects; the tool can be adopted and adapted to improve the project management process, especially in terms of information gathering and decision-making actions. In order to adopt this tool in water quality monitoring projects, the cause and effect relationship of the impacts to be analyzed must be modified as shown in Figure 3.

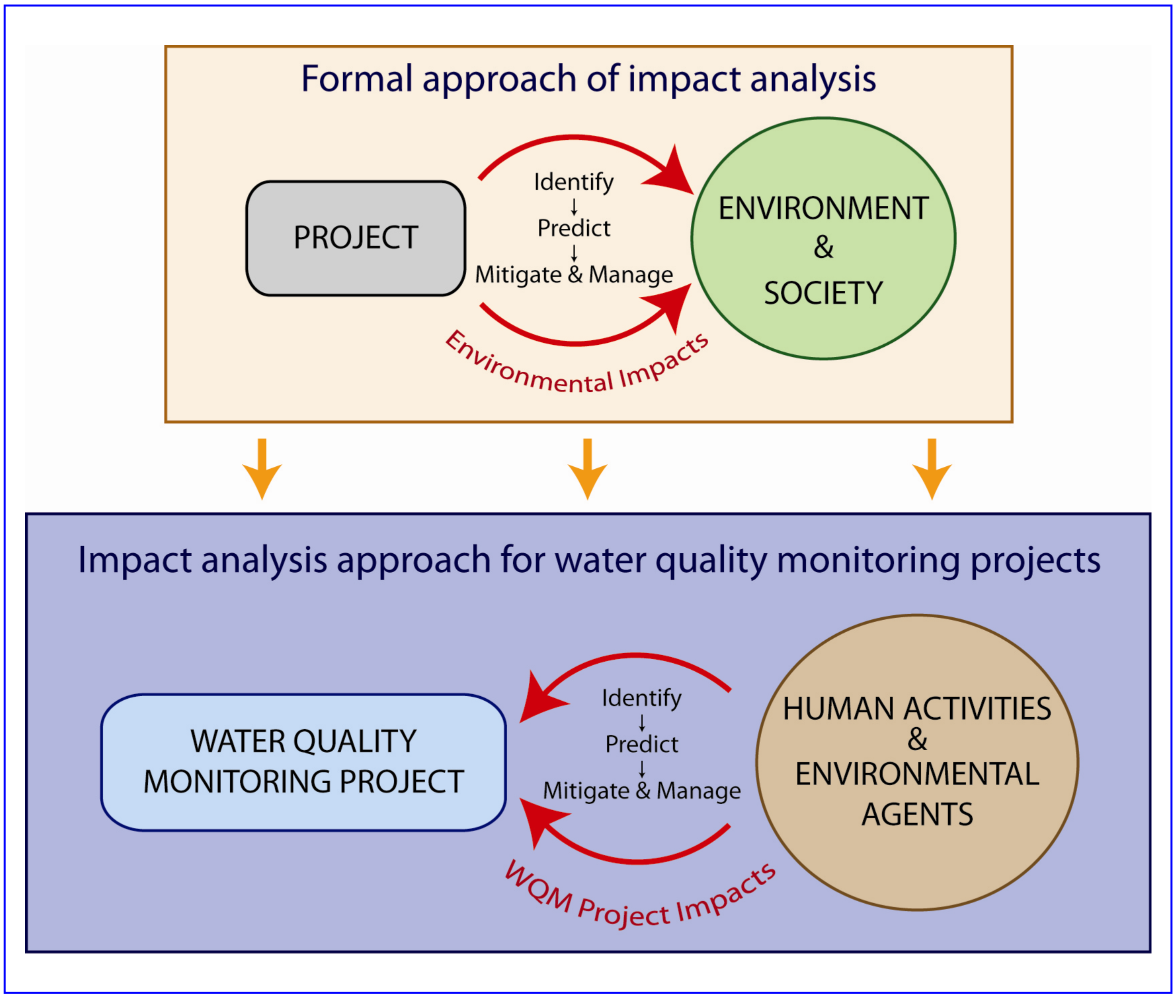

Figure 3. Impact analysis approach for water quality monitoring projects.

Water quality monitoring projects are executed to answer a variety of questions that managers, researchers, policy makers and other stakeholders have with regard to:

- the status of water bodies
- the water usage
- biological or physical interactions
- recreation and aesthetics

among many other water issues or concerns.

One problem facing the water monitoring community is the lack of consensus among the different agencies, institutions and organizations on the definition of the different types and terminology of water quality monitoring (Ward *et al*., 1990). In this manual the definition of water quality monitoring employed by the Intergovernmental Task Force on Monitoring Water Quality (ITFM, 1995) is adopted:

an integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses", and identifies five major monitoring purposes:

1. Characterize waters and identify changes or trends in water quality over time.
2. Identify specific existing or emerging water quality problems.
3. Gather information to design specific pollution prevention or remediation programs
4. Determine whether program goals, such as compliance with pollution regulations or implementation of effective pollution control actions, are being met
5. Respond to emergencies, such as spills and floods

These major monitoring purposes are not mutually exclusive and some monitoring endeavors can meet more than one of these purposes at the same time

Any type of water quality monitoring project, as well as other kinds of environmental monitoring endeavors (*e.g.* living shorelines projects, sea level rise studies, wetlands restoration, *etc*.) interact during their execution, directly or indirectly, with different agents of the environment (biological or physical) and with various types of human activities. Some of these agents and activities can produce negative impacts on the project that could jeopardize the fulfillment of the project's objectives. For example, some of the environment agents and human activities (direct or outcome) that could produce negative impacts on a water quality monitoring are shown in Figure 4.

In order to ensure achieving the project objectives, it would be beneficial to have a protocol or a management decision process to follow that evaluates and predicts the different impacts' significance on the project's objectives. Managing, controlling, or only understanding the effect of these impacts is necessary for the proper project execution, and critical for ensuring quality data. Environmental impact assessment is an information-gathering and decision-making tool that can be used for this purpose. EIA methodology can be used in a water quality monitoring project to identify, understand, and evaluate these impacts in a timely manner and address their effects by applying correction or mitigation measurements to minimize their effect on the project's objectives.

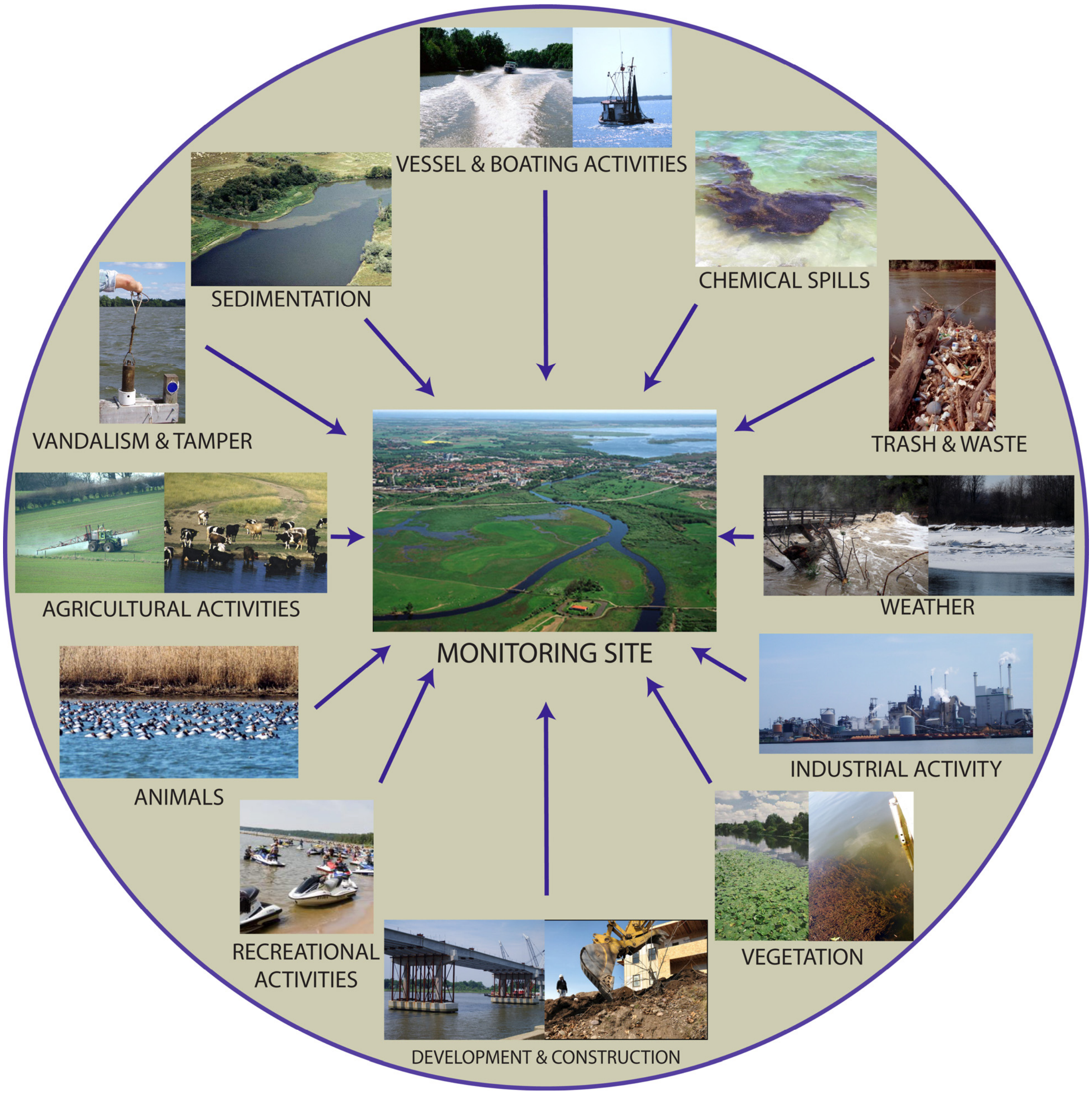

Figure 4. Possible human activities and environmental agents impacts on a water quality monitoring project

Benefits that can be obtained from the application of the environmental impact assessment methodology in a water quality monitoring project are:

- Ensure that a standard operating procedure is applied to systematically and comprehensively evaluate negative impacts on the project.
- Generate the necessary conditions in the monitoring team to create awareness on the environmental and human impacts and their effects on the monitoring objectives.
- Ensure that a comprehensive overview of the monitoring area and its surroundings is undertaken at the early stages of the decision-making process.
- Ensure that possible negative impacts are explicitly addressed and incorporated into the decision making process.
- Provide a good method to consider contingency plans in terms of impact significance.
- Provide the means to anticipate, avoid, minimize, neutralize, or take into consideration, the possible outcomes of the impacts on the data quality.
- Categorize different impacts that affect or interact with the success of the project's objectives (scientific, environmental, financial and other practical issues) in terms of their significance.
- Provide means of standardization in a subjective topic.
- Provide a good method of gathering and documenting information.
- Provide alternative to reduce cost and time of the project implementation.
- Establish a good method to decide, compare, and evaluate monitoring alternatives.

This document will focus only on the stage **Impact Analysis** of the environmental impact assessment process. These guidelines are intended to provide a general idea on the terminology and flow of activities needed to perform an impact assessment in a water quality monitoring project. The guidelines do not attempt to present information on the other components of the EIA. The reader should consult the selected references to obtain a more detailed discussion on the additional stages found on most EIAs.

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CHAPTER 2

KEY CONCEPTS AND DEFINITIONS

2.0 KEY CONCEPTS AND DEFINITIONS

The following terminology is employed in impact analysis:

Activity: An activity can be defined as an event or a particular action taken to produce or attain some specific outcome. An activity has an expected duration, cost, and resource requirements (UNEP, 2009). An activity may consist of several sub-activities or actions, as is defined in ISO IEC 90003 as "*a set of related tasks*."

Environmental Aspect: Element of an organization's activities, products or services that can interact with the environment (ISO, 1996). There are two types of environmental aspects (Brady, 2005):

(i) **Direct environmental aspects**: aspects caused as a direct result of the project implementation or operation. The organization has a direct influence and control over the effects of this type of aspects, for example, emissions to the air or disposal of waste on land.

(ii) **Indirect environmental aspects**: activities over which the organization can have influence, but no control. For example, supply chain controlled aspects (*e.g.* mode of transportation).

Impact: the United Nations Development Programme defines impact as (UNCDF, 2003):

> "*The overall and long-term effect of an intervention. Results from a programme or project that are assessed with reference to the development objectives or long-term goals of that programme or project; changes in a situation, whether planned or unplanned, positive or negative, that a programme or project helps to bring about. Impact is the longer term or ultimate result attributable to a development intervention, in contrast with output and outcome, which reflect more immediate results from the intervention. The concept of impact is close to development effectiveness*".

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CHAPTER 3

WATER QUALITY MONITORING PROJECT IMPACT ANALYSIS

3.1 INTRODUCTION

Water quality monitoring projects go through a series of stages during their life cycle, starting with initial planning, following with implementation, operation and oversight and ending with assessment (Stevens, 2002). To ensure the all these stages can achieve their intended results in relation to the quality objectives, performance criteria, and decision-making requirements, organizations must have an adequate quality management system to assure that (USEPA, 2006):

- **During the planning phase** all the project's assumptions and requirements, sampling methods and procedures, resources and constraints are identified, considered, and evaluated, and the appropriate water quality monitoring plan is established that ensures the data to be collected are of the appropriate type and quality for their intended use.
- **During the implementation, operation, and oversight phase**, the quality assurance plan and the necessary standard operating procedures are established in order to ensure the requirements for collecting the data are met.
- **During the assessment phase** the necessary methods and procedures are in place to verify and validate the data and the data quality assessment process is established to ensure the data are of appropriate quality to achieve their intended use.

Research has shown that most of the project's life-cycle quality and cost are committed by the decisions taken by the end of the planning and design stages (Gibson *et al*., 2007). The planning phase is a critical success activity given that during this stage the following elements are indentified and defined: project's requirements, performance criteria, sampling methods and analyses, data type, quality and quantity, spatial and temporal scope of the project, and schedule and resources (USEPA, 2006).

An important step in the planning process is the identification of practical constraints, limitations, and interferences that could complicate the sampling activities and possibly affect the quality of the data (Cavanagh *et al*., 1997). Some of these negative impacts are relatively easy to address and the necessary corrective or control measurements to minimize their effects are straightforward; for example, accessibility and safety issues. Some practical constraints may be: permission to access the site is not granted; authorization to sample in one of the sampling site can not be obtained; or a sampling site can not be accessed by boat, foot, truck, or car. Corrective actions that can be taken to minimize or eliminate the negative effect of these constraints could be to find another sampling site that complies with the monitoring objectives.

However, there are many impacts for which their assessment is not so straightforward and they require a proper evaluation and analysis procedure to adequately identify them and understand their full effects on the project.

It is a well-known fact that environment agents and human activities that negatively impact the project must be addressed during the planning phase. Project managers and monitoring teams employ different approaches to address these impacts, with expert knowledge possibly being one of the most commonly used approach. Nevertheless, monitoring teams generally do not use standard operating procedures (SOP) that ensure a systematically and comprehensive evaluation of these environment agents and human activities. This accounts for the fact that these impacts are overlooked, misinterpreted, or even the best practice to manage them are not known, or not even properly addressed, causing several problems in the capability to optimally fulfill the monitoring and data quality objectives (Miles, 2008).

Implementation of a SOP to address the significant negative impacts on the water quality monitoring project will assure the quality and consistency of the assessment and the implementation of good monitoring practices to address and manage these impacts. The impact analysis process is an excellent tool to be used as the guideline to develop the SOP.

Furthermore, it a good practice to use a systematic approach to planning water quality monitoring programs (Ward *et al*., 1990). For example, US EPA describes a systematic planning process as follows:

> *A systematic planning process "uses a common-sense approach to ensure that the level of documentation and rigor of effort in planning is commensurate with the intended use of the information and the available resources. The systematic planning approach includes well-established management and scientific elements that result in a project's logical development, efficient use of scarce resources, transparency of intent and direction, soundness of project conclusions, and proper documentation to allow determination of appropriate level of peer review (USEPA, 2006)".*

A systematic process commonly employed to perform the planning phase of a monitoring activity is the 'quality objectives process (DQO)' (Spooner and Mallard, 2003) developed by the U.S. Environmental Protection Agency.

The DQO process consists of seven iterative steps (Figure 5) (US EPA, 2006):

Step 1. State the Problem: concisely describe the problem to be studied.

Step 2. Identify the Decision: identify what questions the study will attempt to resolve, and what actions may result.

Step 3. Identify the Inputs to the Decision: identify the information that needs to be obtained and the measurements that need to be taken to resolve the decision statement.

Step 4. Define the Study Boundaries: specify the time periods and spatial area to which decisions will apply. Determine when and where data should be collected.

Step 5. Develop a Decision Rule: define the statistical parameter of interest, specify the action level, and integrate the previous DQO outputs into a single statement that describes the logical basis for choosing among alternative actions.

Step 6. Specify Tolerable Limits on Decision Errors: define the decision maker's tolerable decision error rates1 based on a consideration of the consequences of making an incorrect decision.

Step 7. Optimize the Design: evaluate information from the previous steps and generate alternative data collection designs. Choose the most resource-effective design that meets all DQOs.

The first six steps of the DQO process are used to develop the data collection design. The seventh step of the process combines all the information gathered in the previous six steps and uses this information to decide what design solution would be most effective; here the most resource-effective data collection design is identified.

Having a sound planning process will contribute to the understanding of how the project's assumptions and proposed analyses will be conducted and will ensure that the data to be collected is of the appropriate type and quality for their intended use.

An important step in the planning process is the identification of practical constraints, limitations, and interferences that could complicate the sampling activities and possible affect the quality of the data. Therefore, during the spatial and temporal boundaries definition (Step 4), all possible activities and agents across the geographic area (within the specified project time frame) that could generate negative impacts must be properly identified, predicted, and evaluated (USEPA, 2006).

The impact assessment process can be used in a water quality monitoring project as an information-gathering and decision-making tool to identify and evaluate significant impacts which humans or environmental agents have, or could have, on the monitoring project objectives and/or data quality.

As previously mentioned, it is a good practice to have a standard operation procedure (SOP) to evaluate the environment agents and human activities that can negatively impact a water quality monitoring project. Environmental impact assessment is an excellent management tool to be used for this purpose. In particular, the impact analysis process of the EIA methodology can be employed in water quality monitoring projects as the SOP to identify, understand, and evaluate environment agents and human activities in a timely manner and address their impacts by applying correction or mitigation measurements to minimize their effects on the project's objectives.

Applying impact analysis when conducting Stage 4 (*Define the Boundaries of the Study*) of the DQO process will ensure the output of this step contemplates:

- The necessary corrective actions that must be taken to ensure the negative impacts do not hinder the monitoring objectives.
- The necessary monitoring actions that must be taken to manage the effects of those impacts that cannot be avoided during the project's life cycle.

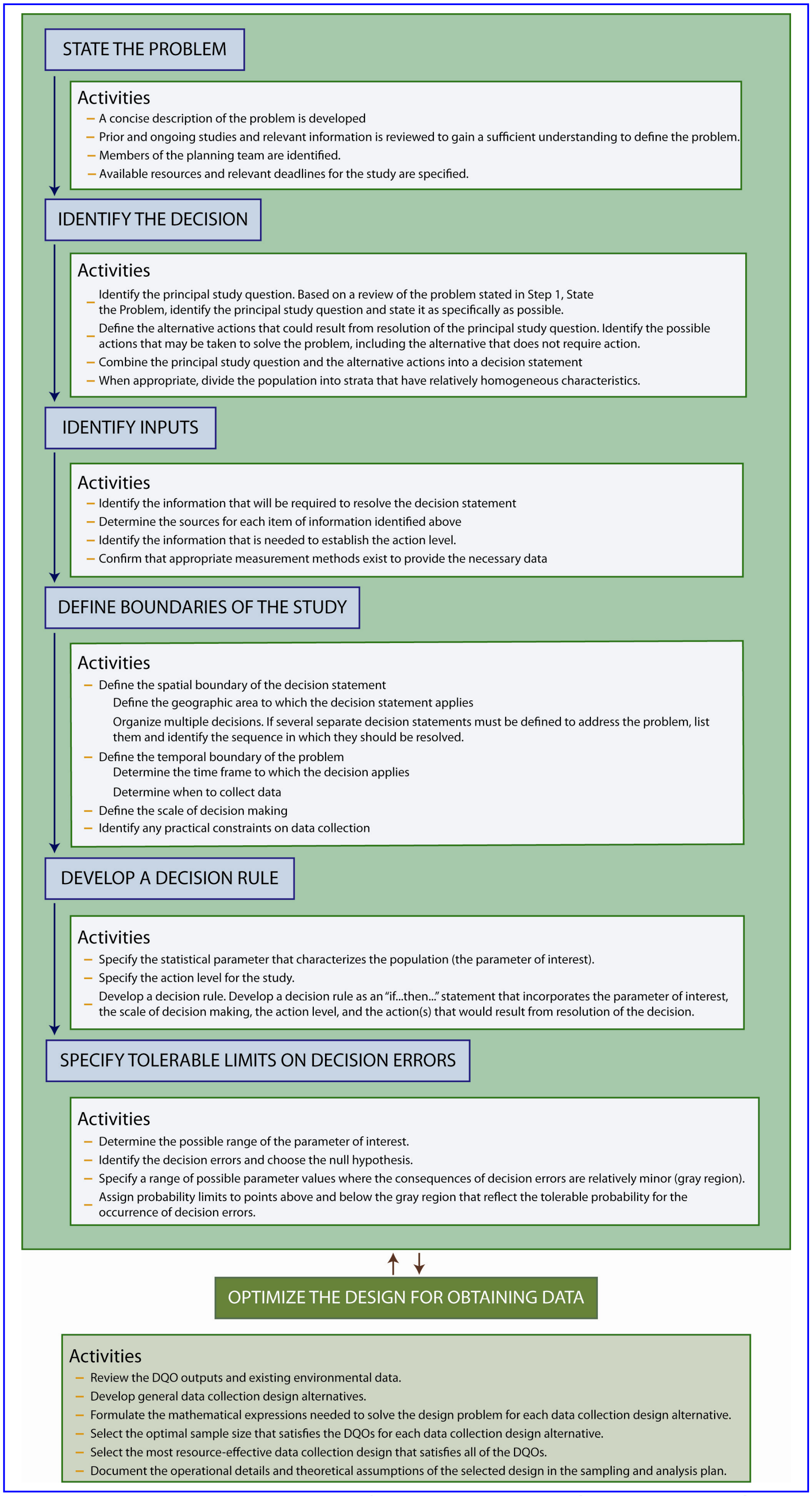


Figure 5. Data quality objectives process (US EPA, 2006)

Basically the process of impact analysis has three phases (Sadler and McCabe, 2002):

I. Identification of the impacts to be assessed,
II. Prediction of the main characteristics of these impacts, and
III. Evaluation of the implications of the impacts that cannot be mitigated.

To accommodate these phases to a water quality monitoring project, four specific activities must be performed:

1) List all relevant human activates and environmental agents that can have a negative impact on the WQM project;

2) Identify WQM project aspects for each relevant human activity and environmental agent;

3) Identify the WQM project impacts; and

4) Decision making; identify what type of measures, if any, will be applied to monitor, control, reduce, avoid, or offset the potential adverse effects of the impacts on the monitoring project.

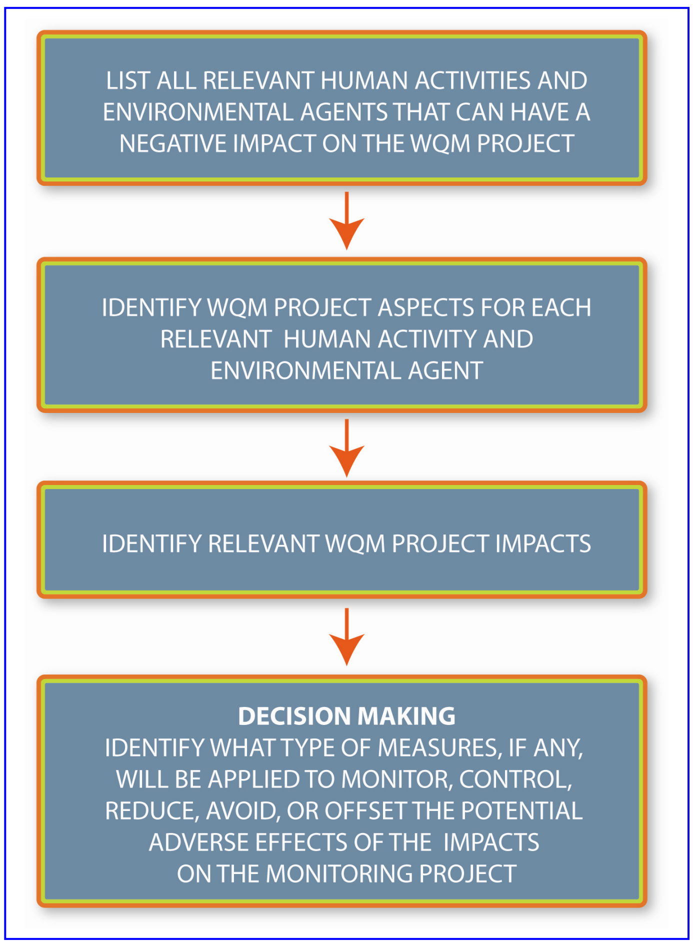


Figure 6. WQM impact analysis flow of activities

In order to facilitate reading and understanding, the description of these activities were written in a straightforward manner.

3.2 LIST ALL RELEVANT HUMAN ACTIVATES AND ENVIRONMENTAL AGENTS THAT CAN HAVE A NEGATIVE IMPACT ON THE WQM PROJECT.

Human activities can be defined as a particular action or actions taken by people to produce or attain some specific outcome or to fulfill a need (Houben, 2010). The human activities to be considered are not limited to field activities or activities that take place in the monitoring influence area (*e.g.* aerial application of pesticides). It can be related to any part of the monitoring project, for example, training. An environmental agent is any biological (*e.g. hydrilla verticillata*) or physical (*e.g.* an unpredictable weather event, *e.g.* hurricane) component of the environment.

In order to identify, understand, or evaluate possible impacts on the WQM project, the first task is to identify major human activities and environmental agents that may interact with the monitoring process so as to cause an impact. There are several management or problem solving tools that can be used to ensure the major activities and environmental agents are considered during the assessment. The most commonly used management tools are: brainstorming, checklists, matrices, cause and effect diagrams, dimensional analysis, flowcharts, and mind-mapping (Sadler and McCabe, 2002; Canter, 2008; Morris and Therivel, 2009).

Commonly, these tools are applied in the specific information management procedure. The tools are designed by the impact assessment team to aid and facilitate information gathering, synthesis and analysis for the particular project. The procedure provides a protocol or a framework by which the information-gathering activities must be performed. How the information is gathered and organized, and what management tools are used for this purpose will depend on user needs and preferences.

As a basic guideline on how this activity can be approached, a procedure to facilitate the identification of major human activities and environmental agents is presented. The procedure is intended to be used as a framework for information-gathering. Depending on the complexity of the monitoring project, the procedure will be modified; additional information-gathering activities will be included, or the degree to which an activity is performed will be adjusted to meet user needs.

1. Describe the project.

   Prepare an overview of the nature and objectives of the project. Information from the first three stages of the Data Quality Objective process can be used for this purpose (*i.e.* conceptual model of the problem; type of data needed and how it will be used, *etc*.).

   Specify the requirements that each monitoring site must fulfill:

   - The "Musts": Necessary and specific requirements; those key things that the site must have in order to accomplish the program objectives. Failure of any of these requirements is likely to cause problems meeting the program objectives.
   - The "Better if": Second tier of requirements that are better if they are achieved, but if they are not met, the monitoring objectives are not affected. For example, given budget constraints, it will be better if the monitoring station is placed on a pier rather than constructing an off-shore station. This option eliminates the need of a monitoring vessel.

2. Obtain maps or satellite images from the area of operation and its surroundings.

   Maps or satellite images are an excellent visual aid to determine sources of human activity, or areas where environmental agents can impact during the time frame the study will take place. There is a range of web information sources that can be easily accessed to assist in the mapping process (*e.g.* Google Earth).

3. Gather relevant information regarding the human activities and the characteristics of the environmental agents both in the immediate and adjacent area around the project site.

   Multiple information sources can be used for this purpose, *e.g.* previous studies, state and local government offices or websites, universities, *etc*.

   The site-specific characteristic cycle (SSC cycle) (Miles, 2008) can be used as a tool to guide the information seeking process. The SSC cycle is a management decision support tool designed to address the different site-specific characteristics that can influence water quality monitoring program objectives and data quality. The site-specific characteristics are organized into five major subject areas: environmental factors, accessibility and safety, community issues, station characteristics, funding and budget considerations. By employing the SSC cycle, the site-specific characteristics can be systematically and properly assessed and thus prevent the negative consequences of overlooking or misinterpretation of important factors.

   For example, the type of information that can be gathered during this stage can be of the following nature:

   - Monitoring site # 5 is located in the proximity to a nesting area of migratory geese.

   - Two of the stations are located in a tributary that its water level and flow are affected every time a near by dam is opened.

- The flow meter # 2 will be located in the littoral zone where *hydrilla verticillata* is abundant during summer.

- The telemetry station is located in an area where high winds are typical during the first weeks of fall.

- Two big housing development plans were identified through the Department of Housing and community development of the county office. Possible alteration of water course and drainage patterns.

4. Perform a site assessment (if possible).

   A site or field assessment is a very useful practice to collect information. Observation and expert knowledge will help to identify and assess relevant human activities and environmental agents that could have a negative impact on the project. In addition, a site assessment will help to determine if the decisions made during the initial planning phase are viable, or if certain points must be modified due to unpredicted factors (Miles, 2009).

   During the site assessment, worst case scenarios must be considered. If possible, the site assessment must be conducted during the time period considered to have the greatest negative impacts on data quality. However, not always this is possible. Therefore, the assessment team must be alert in order to identify any variables of concern that could have a future effect on data quality.

   It is a good practice to prepare a checklist of questions to be asked or items to be evaluated during the site assessment. For example, items of the checklist can be of the following nature:

   - What are the present uses of the water body within, or in near proximity, to the project site? (*e.g.* bathing, washing, fishing, recreation, commercial navigation, *etc*.)
   - If boat traffic is seasonal in a narrow river, it is important to understand high peaks of traffic to assess possible impacts, *i.e.* where is the best place to set the station?
   - Are there any big construction projects in the near future that could affect the water quality?
   - Identify land use and land use practices of the watershed.
   - Identify the location of existing and proposed public and private storm drainage facilities including catch basins and other inlet/outlet structures.

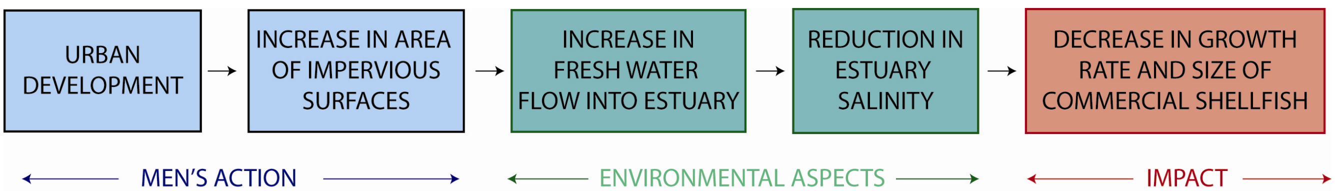
5. Analyze and evaluate the information.

   Analyze, evaluate, and organize the data into main topics with supporting details. Discriminate between relevant and irrelevant information.

3.3 IDENTIFY WQM PROJECT ASPECTS FOR EACH RELEVANT HUMAN ACTIVITY AND ENVIRONMENTAL AGENT

Once the relevant human activities and environmental agents are determined, the WQM project aspects of each activity or agent must be identified. A WQM project aspect is any type of human activity or any environmental agent that can interact with the water quality monitoring project (based on the definition of environmental aspect (ISO, 1996)).

Two examples of project aspects are given in the following figure.



(a)

(b)

Figure 7. Activity – Aspects - Impact examples
(Source: Figure (a) Sorensen, 1971; Figure (b) USEPA, 2000)

WQM project aspects can be thought of as the causes of the impacts; they are the elements of the human activities or environmental agents that can interact with the project and produce impacts. The relationship between aspects and impacts is largely one of cause and effect. Impacts are the effects or outcomes produced on the project by the aspects. For example, a WQM project aspect could be an increase in fresh water in the monitoring area by urban development or by farm activity due to shoreline habitat destruction.

The relationship between aspect and impact is largely one of cause and effect

To further illustrate the "aspect" concept, the following example is given:

Suppose the monitoring project will have two monitoring stations in a small creek located on a large farm. The following farm activities were found to be relevant in their interaction with the monitoring project: spray field management, waste management and shoreline habitat destruction. These activities have different elements that can be seen as the cause of possible impacts with the project; for example, one aspect for each activity is given next:

Activity ↓	spray field management	Activity ↓	waste management	Activity ↓	shoreline habitat destruction
Aspect	Supplemental nutrients release to surface water	Aspect	Increase BOD inputs to surface water	Aspect	Increase runoff

To identify project aspects, one of the easiest ways is to employ a process flow approach (Block, 1999). This procedure breaks down the process or activity into its main parts (sub-processes and support activities) and display the interconnection and sequence of these parts on a flow diagram. A process flow diagram is graphical representation of a process that delineates where each activity begins, transformation(s) that occur as part of the activity, and where the activity ends. Once the flow diagram is competed, each process and activity is examined to identify associated aspects (Block, 1999). For example, a process flow diagram for a wastewater treatment facility is displayed in Figure 8.

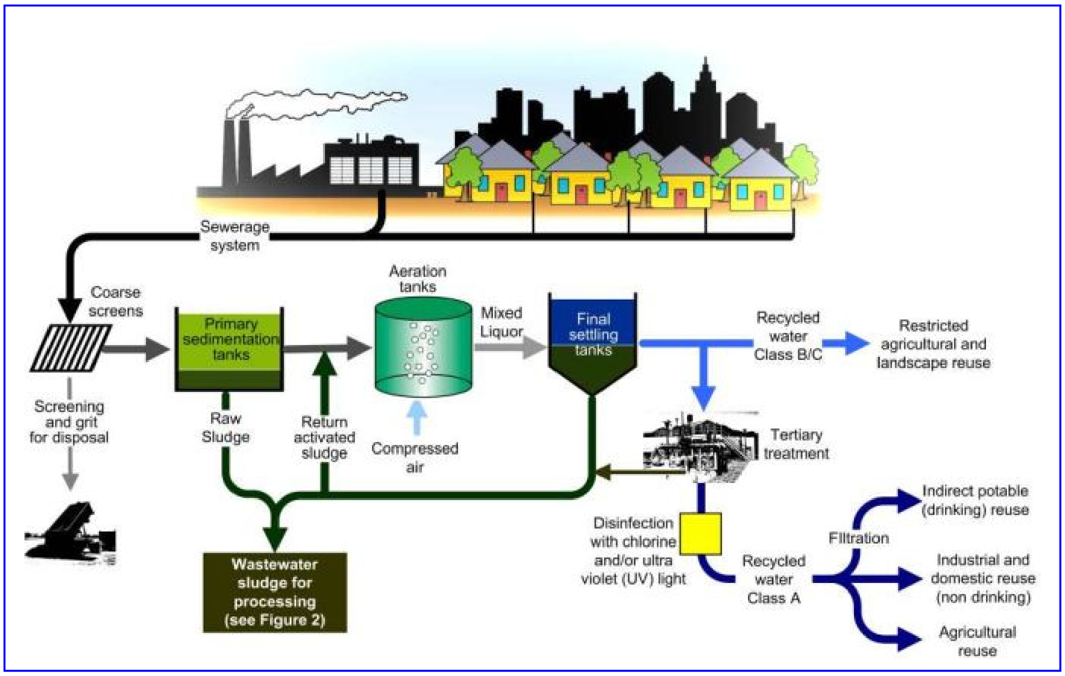


Figure 8. Wastewater treatment process flow diagram
(Source: www.biosolids.com.au)

The terms process and activity are often used interchangeably; for example, the waste management in a farm can be seen as a process or as an activity. Regardless of the term used, a process flow diagram or an activity diagram are constructed in similar manner (USEPA, 2000):

1) Divide the activity or process into its core sub-activities, unit processes, areas, or steps.

   The main purpose of the categorization is to break down the activity or process into smaller units of operation, or simpler steps, in order to enable a more detailed and simpler analysis. For example, a company can be subdivided into departments; or an agriculture activity (*e.g.* harvesting) can be subdivided into steps or sub-activities, etc. Each sub-activity or step is further analyzed to determine if individual flow diagrams are needed. Figure 9 shows a two-fold sub-categorization of a core activity of the main process.

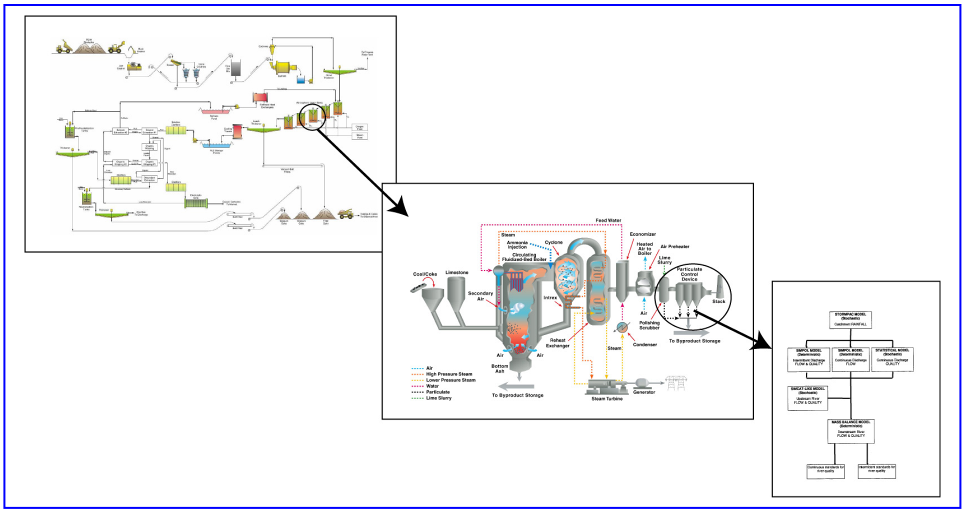
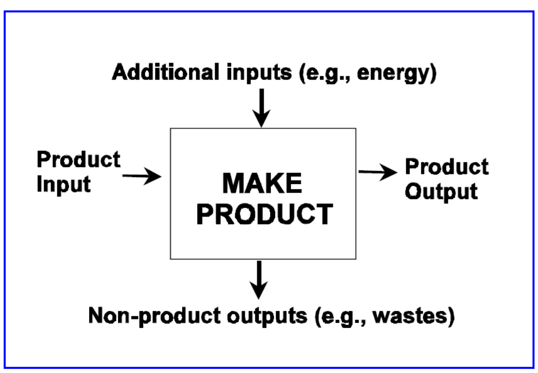


Figure 9. Process flow diagram: sub-categorization of a core activity

2) Analyze the inputs and outputs of each activity



An activity transforms inputs into outputs. Inputs may be products, materials, labor, energy, etc. Outputs may be a physical product (may be an input to another activity), a service, waste, or another process (*e.g.* runoff, erosion).

Figure 10. Basic diagram of inputs and outputs of an activity
(Source: USEPA, 2000)

3) Identify project aspects of each activity

   Each activity is analyzed to determine if the outputs can interact with the project.

The Food and Agriculture Organization of the United Nations (FAO) diagram of the parameters that are likely to be addressed in the site description of an EIA is a useful tool, first, for reviewing the project aspect information gathered, and secondly, for determining if additional aspects not considered initially must be addressed (Figure 11). Using the diagram is straightforward: first, the human activity to be evaluated is placed at the project site box; secondly, the different parameters of the diagram are analyzed to evaluate if they can produce a project aspect.

To enhance the process flow approach, a questionnaire may be useful to guide the team through the evaluation process of the flow diagrams. The questions are aimed at identifying how the activities or agents interact with the project. For example, possible questions that can be helpful to include in the questionnaire to assess each activity or agent are of the following nature:

General questions

- Are chemicals used?
- Can chemicals spill or flow into surface water?
- Are natural resources used or destroyed?
- Is runoff increased?
- Does the water freeze in the winter?

Or site specific questions

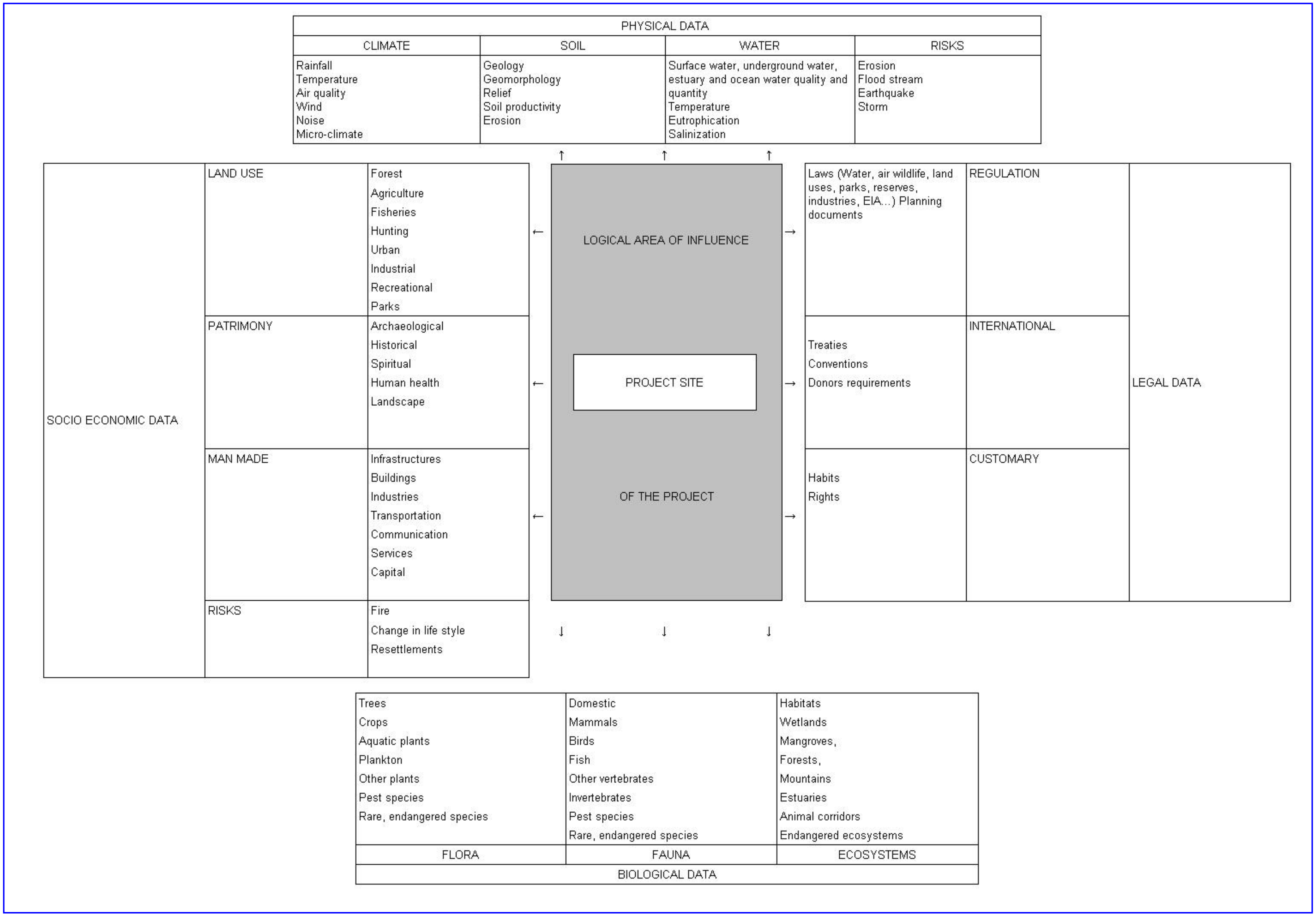
- Does fauna (i.e. cows) cross the creek at low water?
- Is water withdrawn from the creek for irrigation purposes?

Other elements that can produce interactions with the monitoring project and must be addressed during the evaluation process are:

Table 1. Elements that can produce interaction with water quality monitoring projects

Wastewater discharges	Human interest & economy	Consumption of resources
Storm water discharges, run-offs	Community activities	Generation of energy
Release of soils, dust	Laws and Regulations	Generation of waste
Habitat (fauna & vegetation)	Access; Land condition	Land use adjacent to monitoring sites
Financial Resources	Personnel & Training	Natural environment: Weather

The output of this step is a list of project aspects that will be assessed to determine the type of impact (effect) that each one can have on the project objectives and data quality.


PHYSICAL DATA
CLIMATE
SOIL
WATER
RISKS
Rainfall
Temperature
Air quality
Wind
Noise
Micro-climate
Geology
Geomorphology
Relief
Soil productivity
Erosion
Surface water, underground water, estuary and ocean water quality and quantity
Temperature
Eutrophication
Salinization
Erosion
Flood stream
Earthquake
Storm
SOCIO ECONOMIC DATA
LAND USE
Forest
Agriculture
Fisheries
Hunting
Urban
Industrial
Recreational
Parks
PATRIMONY
Archaeological
Historical
Spiritual
Human health
Landscape
MAN MADE
Infrastructures
Buildings
Industries
Transportation
Communication
Services
Capital
RISKS
Fire
Change in life style
Resettlements
LOGICAL AREA OF INFLUENCE
PROJECT SITE
OF THE PROJECT
Laws (Water, air wildlife, land uses, parks, reserves, industries, EIA...) Planning documents
REGULATION
Treaties
Conventions
Donors requirements
INTERNATIONAL
Habits
Rights
CUSTOMARY
LEGAL DATA
Trees
Crops
Aquatic plants
Plankton
Other plants
Pest species
Rare, endangered species
Domestic
Mammals
Birds
Fish
Other vertebrates
Invertebrates
Pest species
Rare, endangered species
Habitats
Wetlands
Mangroves,
Forests,
Mountains
Estuaries
Animal corridors
Endangered ecosystems
FLORA
FAUNA
ECOSYSTEMS
BIOLOGICAL DATA

3.4 IDENTIFY THE WQM PROJECT IMPACTS

A WQM project impact is any change to the project, wholly or partially, resulting from a human activity or an environment agent (based on the definition of environmental impact (ISO, 1996)). The WQM project impacts can be seen as the effects produced by the project aspects (the causes).

> The WQM project impacts can be seen as the effects produced by the WQM project aspects (the causes).

In order to identify WQM project impacts, all changes in the project produced by a set of project aspects must be categorized. This task requires that evaluators be able to determine and understand cause-effect relationships between the aspects and the project (COMNAP, 1999). It is very likely that most of the people involved in designing the monitoring project, site selection, and/or executing the site assessment, have expertise in a number of areas, but not in every area needed to identified and categorized impacts in a reliable and proficient way. In this matter, we can say that they are non-experts in the impact assessment area. Therefore, it is necessary to provide them with tools to standardize what can be a very subjective process, and also, to support their assessment and decision making efforts as well.

Table 2. Examples of Activities-Aspects-Impacts

ACTIVITY ⇨	ASPECT ⇨	IMPACT
Clean land close to water body for farm land	Potential for run-off	Increase water turbidity
Vessels refueling	Potential gas spillage	Contamination
Budgeting	Stations resource allocation	Constrain in station designs
Boating-PWC	Generation of waves	Increase water turbidity
Construction of bridge	Vegetation clearing during construction	Exposure of soil to wind and water erosion; sedimentation

Impact analysis requires a systematic approach. In particular, in the United States, the USA National Environmental Policy Act (NEPA) mandates the undertaking of a systematic approach in the assessment of environmental impacts, and requires the development of methods and procedures to guide the analysis (Lein, 2003). The systematic approach applies also when impact analysis is applied in a WQM project. In response to NEPA, a large range of management tools, methodologies, and techniques (general and specific) were developed to enable a systematic approach to impact analysis and to support decision-making. Some of these tools are: checklists, models, matrices, expert systems, following guidelines, among many others (Canter, 1997b). These tools do not provide specific answers to impact analysis; their objective is to organize, to synthesize, and to provide certain structure for handling the huge amount of information that sometimes the evaluators must deal with (Lohani *et al.*, 1997).

In general, impact identification in a water quality monitoring project is a complex task given the lack of knowledge the evaluator has on the nature and extend of the impacts, specially taking into consideration that impacts may be different in different environmental settings (Goncalves, 1998). It is mainly for these reasons that there is no universal method that can be applied for project impact identification in all environmental settings (Canter, 1997). Therefore, the methods outlined in this section must be used as guidelines only; they provide a good systematic approach to asking questions, and to ensuring that most relevant issues are addressed and not overlooked.

In addition, during the implementation of these methods, it must be taken into consideration that they were developed to identify impacts on the environment, not to identify impacts on water quality monitoring projects. Therefore, some of these tools can be used without modifications to determine possible human and environmental negative impacts on the project; others might need varying degrees of modification; while others will only be able to be used as guidelines for development of similar management tools, methodologies, and techniques for WQM project impact identification.

WQM impact analysis can be broken down into three overlapping phases (Sadler and McCabe, 2002):

1. **Identification**: identify impacts
2. **Prediction**: define characteristics of impacts
3. **Evaluation**: determine the significance

3.4.1 Identification of WQM Project Impacts

Commonly, a management tool is applied to aid impact identification and to ensure the undertaking of a systematic approach (Morgan, 1998; Sadler and McCabe, 2002). Among these tools, checklists, Leopold matrix, and cause and effect diagram are frequently used in the environmental impact assessment, and likewise, they can be employed in WQM projects. Therefore, these management tools are briefly introduced in this section.

> ***Note**: It must be taken into consideration that these tools were developed to identify impacts produced by a project on the environment. Nevertheless, they can be directly applied or easily transformed for project impact identification.*

3.4.1.1 CHECKLISTS

Checklists are lists of:

- potential impacts
- items or features that may be affected
- questions or salient point that must be assessed

The checklist display important points, factors, or concepts to be considered by the evaluator. Commonly, checklists are used as an assurance framework so all the important issues are considered; in addition to bringing to attention and to awareness potential impacts that maybe otherwise wouldn't be addressed (Lohani *et al.*, 1997; United Nations, 1997).

Checklists can be based in standard lists or they can be specially formulated to accomplish the particular needs of the project. In general, checklists may include instructions for impact identification and evaluation; however, direct cause-effect links are commonly not included. In the literature there are a variety of standard checklists for various sectors of activities (*e.g.,* industries, agriculture), or for specific affected areas (*e.g*., wetlands, costal zones). In addition, checklists are sometimes combined with agency's environmental guidelines to improve the effectiveness of impact assessment (FAO, 1996).

There are five types of checklists commonly used for impact identification:

1. **Simple Checklist**

These checklists contain only a list of parameters or components to be considered. They focus the attention only on those factors that have to be considered. They do not provide any guidance on how impacts are to be assessed, measured, or interpreted. They do not advise on the type of predictive technique to be used and the type of data required (USAID/SARI/E).

Two examples of simple checklists are shown next:

	Potential Impact from Bridge Construction				
Resource	Site Clearance	Earth Moving	Lay foundation	Import Materials	Cumulative impacts
Air quality	x	x			x
Water quality	x	x			
Landscape	x	x		x	x
Ecology	x	x			
Noise	x	x	x	x	x
Archaeology	x	x			
Traffic	x	x	x	x	x

Simple checklist developed for the Huasai-Thale Noi Road Project (Source: Lohani *et al.*, 1997)

	Nature of Likely Impacts									
	Adverse						Beneficial			
Items	ST	LT	R	IR	L	W	ST	LT	SI	N
Aquatic Ecosystems		x		x	x					
Fisheries		x		x	x					
Forests		x		x	x					
Terrestrial Wildlife		x		x		x				
Rare & Endangered Species		x		x		x				
Surface Water Hydrology		x		x		x				
Surface Water Quality		x								
Groundwater	*	*	*	*	*	*	*	*	*	*
Soils										
Air Quality	x				x					
Navigation		x			x					
Land Transportation								x	x	
Agriculture							x			x
Socioeconomic								x		x
Aesthetic		x			x					

Legend
x indicates potential for type of impact; ST denotes Short Term; LT denotes Long Term
R denotes Reversible; IR denotes Irreversible; L denotes Local
W denotes Wide; SI denotes Significant; N denotes Normal

2. **Questionnaire Checklist**

These checklists are based on directed questions that are posed relative to different aspects of the project (WHO, 1983).

Three examples of questionnaire checklists are given next:

PARAMETERS	ANSWER		Specify and quantify direct area/s that will be affected
	YES	NO	
Will the project cross, traverse or affect any bodies of water?			
Will the project affect any national parks, forested or watershed areas, sanctuaries or similar areas?			
Will the project affect any mangrove areas, swamps, wetlands or similar areas?			
Is the project located in a flood prone areas or areas vulnerable to storm surges?			
Is the project located in an erosion prone area?			
Will the project traverse or is near an area with indigenous community/s?			
Is the project located in an area with critical/steep slope?			
Will the project traverse or is near any sites with cultural/historical significance?			
Source: Environmental Management Bureau, Philippines			

PARAMETERS	Impact		Notes/ Comments
	Yes	No	
Effects on humans, buildings and man-made features Change in population arising from the development, and consequential environmental effects.			
Visual effects of the development on the surrounding area and landscape.			
Levels and effects of emissions from the development during normal operation.			
Effects of the development on local roads and transport.			
Effects of the development on buildings, the architectural and historic heritage, archaeological features, and other human artifacts, e.g. direct loss or damage, or indirect impacts through pollutants, visual intrusion, vibration.			
Effects on flora, fauna and geology. Loss of, and damage or disruption to, habitats, species, geological palaeontological and physiographic features.			
Effects on land. Physical effects of the development, e.g. change in local topography, soil erosion etc.			
Effects of chemical emissions and deposits on soil of site and surrounding land.			
Land use/resource effects: - quality and quantity of agricultural land to be taken			
- sterilization of mineral resources			
- other alternative uses of the site, including the 'do nothing' option			
- effect on surrounding land uses including agriculture			
- waste disposal.			
Source: Scottish Executive, 1999.			

Impacts on fauna, flora and ecosystems	YES	NO
Are there people or studies which can describe the local ecosystems? Knowledge can be held locally (i.e., university, inhabitants,) or very far from the site (i.e., international research centers…).		
Is the list of the species living inside the site known ?		
Are there threatened species ?		
Are the ecosystems mapped ?		
Is it possible to localize sensitive areas ?		
Are the species or the ecosystems present on site, rare ?		
Are there local, national or international regulations (laws, treaties, conventions…) on nature protection which can be applied in these areas ?		
With the actual level of knowledge, is it possible to predict the impact on fauna, flora and ecosystems with sufficient accuracy ?		
Is it necessary to implement particular studies to complete the knowledge to date?		
Are there particular factors of the operations likely to affect the fauna, flora or ecosystems ?		
Are these repercussions reversible or not ?		
Does the project include a restoration plan ?		
ource: FAO, 1996		

3. **Descriptive Checklist**

These checklists provide some guidance on impact assessment. Information is provided on how to approach impact prediction, and how to perform the measurements. For example, guidance of which specific variables must be measured to categorize each component can be provided (Lohani *et al.*, 1997).

Two examples of descriptive checklists are given next:

Data Required	Information Source, Predictive Techniques
Nuisance	
Change in occurrence of odor, smoke, haze, etc. and number of people affected	Expected industrial processes and traffic volumes, citizen surveys.
Water Quality	
For each body of water, changes in water use, and number of people affected	Current water quality, current and expected effluent
Noise	
Changes in noise levels, frequency of occurrence, and number of people bothered.	Current noise levels, change in traffic or other noise sources, changes in noise mitigation measures, noise propagation model, citizen surveys.
	Source: adapted from Schaenman, 1976

Environmental Factor and concerns	Basis of estimation
1. Air Quality **Health** Changes in dust level, number of people at risk **Noise** Changes in noise levels, number of people bothered	Current dust levels, estimates based on experience/expert judgment, populations maps. Changes in traffic type and number, other noise sources, current noise levels, experiences elsewhere, typical calculations for noise
2. Forest and Wildlife Changes in size and condition of forest, impacts on plant and animal	Observation of the forest, interview, experiences in similar circumstances, professional judgment.
3. Landslides and slope stability Chances of slope failures, landslides and erosion; effects on resources, infrastructures and people.	Field observation, surface geology and soil, past incidents in locality, expert judgment
	Source: DISC, 2008

4. **Scaling Checklist**

These checklists include information to assess the importance or significance of each impact. Algebraic or numeric scales are used to establish qualitative (subjective) ratings of the parameters. The checklist incorporates the criteria under which the relative rating are assigned (WHO, 1983).

An example of a scaling checklist is given next:

Environmental Issues	Construction	Operation	Decommissioning
Greenhouse / Energy	0	+2	0
Landscape and visual	-1	-2	+1
Noise	-1	-1	-1
Air quality	0	+2	0
Soil, drainage and geology	-1	0	-1
Flora and Fauna	-1	-1	+1
Heritage	0	0	0
Infrastructure and utilities	+2	+2	0
Bushfire	0	0	0
Social	-1	-1	+2
Economic	+2	+2	+2
Cumulative	-1	+1	+1
Score	**-2**	**+4**	**+5**

Key	Value
Major positive impact	+2
Minor positive impact	+1
No appreciable impact	0
Minor negative impact	-1
Major negative impact	-2

5. **Scaling Weighting Checklist**

The scaling weighting checklists are similar to scaling checklists with additional information for the subjective evaluation of each parameter with respect to all the other parameters (Thomas and Elliot, 2005).

One of the most known scaling weighting checklists for impact assessment is the Environmental Evaluation System (EES) developed at Battelle Columbus Laboratories. The EES is based on a classification consisting of four levels, arranged from general information to specific: categories, components, parameters, and measurements. There are four categories (ecology, pollution, aesthetics, and human interest) and each category is further subdivided into thematic data or components (Figures 13 through 16). Further, each component is divided into several parameters, and each parameter into one or more measurements. The number of measurements will depend on the necessary data needed to obtain a representative parameter estimate.

The EES was first designed for water resource development including a total of seventy-eight parameters. Since then, the system has been employed in a variety of projects. For each project, a set of parameters is selected that best meets the description of each component. For example, in the pulp and paper industry, the component water pollution could be represented by: BOD, dissolved oxygen, fecal coliforms, inorganic carbon, pH, temperature, total dissolved solids, turbidity, *etc*. (FAO, 1996).

Once the parameters and measurements are chosen, three steps must be followed to complete the checklist (Dee *et al*., 1973; FAO, 1996; Ponce, 2009). The first step is to set up environmental quality values for each parameter scaled between 0 (very bad) to 1 (very good). Commonly, environmental quality is expressed on physical, chemical, or biological characteristics of the environment. These characteristics will have some upper limits, or maximum ranges, that will be acceptable to maintain some desired quality (Dee *et al.*, 1973). Each of these characteristics' value could be normalized to obtain an environmental quality value number between 0 and 1. The graph or equation to do this transformation is called value function. For example, the value function for dissolved oxygen is displayed on Figure 12; high values of DO are desired to maintain a healthy environment (values close to 1).

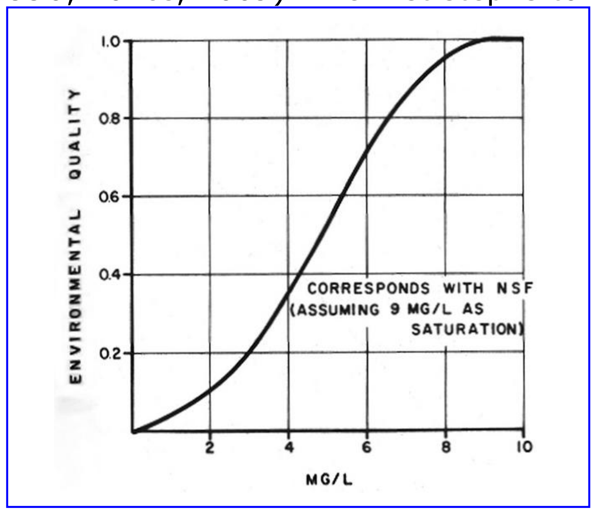


Figure 12. Dissolved oxygen value function
(Source: Dee *et al*., 1973)

The second step is to determine the relative importance of each parameter. To perform this task, a number of points or parameter important units (PIU) are distributed among the different parameters. The amount of points assigned to each parameter will be based on its relative importance within the overall system. The allocation process is based on value judgments; for example, the Delphi technique can be used to determine relative importance. In the table displayed in Figures 13 to 16, for example, a total of 1000 PIU's were distributed among the parameters.

The third step is to combine the results of the previous two steps; for this purpose a new unit is defined, the environmental impact unit (EIU). The EIU is determined by the sum of all the products of the assigned PIU of each parameter (relative weight of importance) and the corresponding environmental quality value. The EIU is used to compare between two scenarios: with and without the project.

Categories, components, and parameters of the Battelle EES.					
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Categories	**Components**	**Parameters**	**Parameter Importance Unit (PIU)**		
			Parameter	**Component**	**Category**
Ecology	Species and populations	1. Terrestrial browsers and grazers	14	140	240
		2. Terrestrial crops	14		
		3. Terrestrial natural vegetation	14		
		4. Terrestrial pest species	14		
		5. Terrestrial upland game birds	14		
		6. Aquatic commercial fisheries	14		
		7. Aquatic natural vegetation	14		
		8. Aquatic pest species	14		
		9. Sport fish	14		
		10. Waterfowl	14		
	Habitats and communities	11. Terrestrial food web index	12	100	
		12. Land use	12		
		13. Terrestrial rare and endangered species	12		
		14. Terrestrial species diversity	14		
		15. Aquatic food web index	12		
		16. Aquatic rare and endangered species	12		
		17. River characteristics	12		
		18. Aquatic species diversity	14		
	Ecosystems	Descriptive only	-	-	

Figure 13. The Battelle Environmental Evaluation System – Category Ecology
(Source: V. M. Ponce, 2009)

Category	Component	Parameter	Weight	Component total	Category total
Pollution	Water	19. Basin hydrologic loss	20	318	402
		20. BOD	25		
		21. Dissolved Oxygen	31		
		22. Fecal coliforms	18		
		23. Inorganic carbon	22		
		24. Inorganic nitrogen	25		
		25. Inorganic phosphate	28		
		26. Pesticides	16		
		27. pH	18		
		28. Stream flow variation	28		
		29. Temperature	28		
		30. TDS	25		
		31. Toxic substances	14		
		32. Turbidity	20		
	Air	33. Carbon monoxide	5	52	
		34. Hydrocarbons	5		
		35. Nitrogen oxides	10		
		36. Particulate matter	12		
		37. Photochemical oxidants	5		
		38. Sulfur dioxide	10		
		39. Other	5		
	Land	40. Land use	14	28	
		41. Soil erosion	14		
	Noise	42. Noise	4	4	

Figure 14. The Battelle Environmental Evaluation System – Category Pollution
(Source: V. M. Ponce, 2009)

Category	Component	Parameter	Weight	Component total	Category total
Aesthetics	Land	43. Geologic surface material	6	32	153
		44. Relief and topographic character	16		
		45. Width and alignment	10		
	Air	46. Odor and visual	3	5	
		47. Sounds	2		
	Water	48. Appearance	10	52	
		49. Land and water interface	16		
		50. Odor and floating materials	6		
		51. Water surface area	10		
		52. Wooded and geologic shoreline	10		
	Biota	53. Animals - domestic	5	24	
		54. Animals - wild	5		
		55. Diversity of vegetation types	9		
		56. Variety within vegetation types	5		
	Manmade objects	57. Manmade objects	10	10	
	Composition	58. Composite effect	15	30	
		59. Unique composition	15		

Figure 15. The Battelle Environmental Evaluation System – Category Aesthetics
(Source: V. M. Ponce, 2009)

Human interest	Educational/scientific packages	60. Archaeological	13	48	205
		61. Ecological	13		
		62. Geological	11		
		63. Hydrological	11		
	Historical packages	64. Architecture and styles	11	55	
		65. Events	11		
		66. Persons	11		
		67. Religions and cultures	11		
		68. Western frontier	11		
	Cultures	69. Indians	14	28	
		70. Other ethnic groups	7		
		71. Religious groups	7		
	Mood/atmosphere	72. Awe-inspiration	11	37	
		73. Isolation/solitude	11		
		74. Mystery	4		
		75. Oneness with nature	11		
	Life patterns	76. Employment opportunities	13	37	
		77. Housing	13		
		78. Social interactions	11		
Sum total of parameter importance units (PIU)					1000

Figure 16. The Battelle Environmental Evaluation System – Category Human Interest
(Source: V. M. Ponce, 2009)

There are several sources to obtain environmental impact checklists for specific projects or general applications; for example, websites, environmental impact assessment reports, international agencies documents, *etc*. As an example, some websites that provide specific checklists are shown next:

- The Norwegian Agency for Development Cooperation has a series of initial environmental assessment, covering different industries. In each series, there is a checklist that includes aspects and impact in each type of industry. For example;
  - Mining and extraction of sand and gravel; checklist

    http://www.nzdl.org/fast-cgi-bin/library?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=CL2.2&d=HASH016ee52901909f9724b6c56b.6
  - Forestry projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASH5b212bc8ad8276c460b9fc.6
  - Urban development projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASH0156d234412490540bfb0bf8.6
  - Agriculture projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASH0124b6d5bcce182fe6d874e7.6
  - Transport projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASHaebe58d6925e4e7410f31e.6
  - Water Supply: Water Supply, Wastewater, Irrigation projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASH4375c0fd13740cc1db4a6e.6
  - Waste management projects; checklist

    http://nzdl.sadl.uleth.ca/cgi-bin/library.cgi?e=d-00000-00---off-0envl--00-0----0-10-0---0---0direct-10---4-----stt--0-1l--11-en-50---20-about-checklist+descriptive--00-0-1-00-0-0-11-1-0utfZz-8-00&a=d&cl=search&d=HASH6217e702f44a3c069fe448.6
- U.S. Environmental Protection Agency: this agency has several environmental impact checklists. As an example, the link for a pollution prevention and environmental impact reduction is given next,

  http://www.epa.gov/compliance/resources/policies/nepa/pollution-prevention-checklist-nepa-pg.pdf
- Nevada Division of State and Lands: an initial environmental impacts checklist is provided with the intention to help fully understand the potential environmental impacts of a project.

  http://lands.nv.gov/Question1/Q1%20Forms/Attachment%20Q1-E,%20Initial%20Environmental%20Impacts%20Checklist%2001-27-04.pdf
- N.C. Department of Environment and Natural Resources (DENR): the guidance document to assist in completing the Environmental Management System manual for pork producers "Pork Environmental Management System Toolkit" provides a good list of aspect and impact. http://www.p2pays.org/iso/pork/producer.asp#AB

3.4.1.2 LEOPOLD MATRIX

The Leopold matrix is the best known matrix for impact assessment associated with almost any type of construction project. The matrix was formulated by the U.S. Geological Survey during the 1970s.

The matrix consists of (SCOPE, 1979; FAO 1996):

- **Causative actions:** 100 columns representing examples of activities linked to the project that could have an impact, *i.e.* water supply, erosion. (Figure 17).
- **Environmental components and characteristics:** 88 rows representing environmental and social conditions that could be affected. These are divided in three major groups: physical (*e.g.,* soil, water), biological (*e.g.,* fauna, flora), and social and cultural (*e.g.,* land use, economy)) (Figure 18).

A three-step process is used to estimate the impacts (FAO, 1996):

1. All interactions considered important are marked in the matrix with a diagonal line.
2. The magnitude of the interaction is evaluated applying a score of 1 to 10 (1 being minimum and 10 maximum) and it is registered at the upper left hand corner of the box.
3. The importance of the impact is evaluated assigning a score from 1 to 10 and registering in the lower right hand corner.

The Leopold matrix has a number of limitations. For example, there are 8800 possible interactions (88 $\times$ 100), and two entries per interaction, these gives 176000 items that must be taken into account in a decision process where aggregate indices are not possible. In addition, it accommodates both quantitative and qualitative data, but it does not provide a means for discriminating between them (SCOPE, 1979).

Although the original matrix is still occasionally used, its importance is based on fact that the matrix provides a helpful guidance for designing other matrices that better meet particular project needs (Edwards-Jones *et al*., 2000). The matrix can be easily customized, adapted and amended to suit the needs of individual projects. For example, for some projects the causative actions are so broad that they are of relatively little diagnostic value. Therefore, in most projects it is a good practice to construct matrices that are specific rather than generic (Treweek, 1999). For example, individual actions may be itemized and similar actions can be separated into different ones; the environmental characteristic "water quality" could be subdivided into, *i.e.*, total dissolved phosphorus, total dissolved nitrogen, total suspended solids, and chlorophyll concentration. In addition, environmental components or characteristics, not included in the matrix, can be added as appropriate to make it more specific for a certain kind of application.

SCOPE (1979) suggests creating a series of matrices:

- A set for environmental effects and for impact indicators
- A set for each of two or three future times of interest
- A set for each of two or three alternatives

A total of 8 to 12 matrices may be created to start an assessment.

Project Actions (Columns in the Matrix)

MODIFICATION OF REGIME

Exotic flora or fauna introduction
Biological Controls
Modification of habitat
Alteration of ground cover
Alteration of ground-water hydrology
Alteration of drainage
River control and flow codification
Canalization
Irrigation
Weather modification
Burning
Surface or paving
Noise and vibration

LAND TRANSFORMATION AND CONSTRUCTION

Urbanization
Industrial sites and buildings
Airports
Highways and bridges
Roads and trails
Railroads
Cables and lifts
Transmission lines, pipelines and corridors
Barriers, including fencing
Channel dredging and straightening
Channel revetments
Canals
Dams and impoundments
Piers, seawalls, marinas, & sea terminals
Offshore structures
Recreational structures
Blasting and drilling
Cut and fill
Tunnels and underground structures

RESOURCE EXTRACTION

Blasting and drilling
Surface excavation
Sub-surface excavation and retorting

PROCESSING

Farming
Ranching and grazing
Feed lots
Dairying
Energy generation
Mineral processing
Metallurgical industry
Chemical industry
Textile industry
Automobile and aircraft
Oil refining
Food
Lumbering
Pulp and paper

Product storage

LAND ALTERATION

Erosion control and terracing
Mine sealing and waste control
Strip mining rehabilitation
Landscaping
Harbor dredging
Marsh fill and drainage

RESOURCE RENEWAL

Reforestation
Wildlife stocking and management
Ground-water recharge
Fertilization application
Waste recycling

CHANGES IN TRAFFIC

Railway
Automobile
Trucking

Shipping
Aircraft
River and Canal traffic
Pleasure boating

WASTE EMPLACEMENT AND TREATMENT

Ocean dumping
Landfill
Emplacement of tailings, spoil and overburden
Underground storage
Junk disposal
Oil-well flooding
Deep-well emplacement
Cooling-water discharge
Municipal waste discharge including spray irrigation
Liquid effluent discharge
Stabilization and oxidation ponds
Septic tanks, commercial &. Domestic
Stack and exhaust emission
Spent lubricants

CHEMICAL TREATMENT

Fertilization
Chemical deicing of highways, etc.
Chemical stabilization of soil
Weed control
Insect control (pesticides)

ACCIDENTS

Explosions
Spills and leaks
Operational failure

OTHERS

Figure 17. Leopold matrix - project actions (Source: SCOPE, 1979)

Environmental 'Characteristics' and 'Conditions' (Rows in the matrix)

PHYSICAL AND CHEMICAL CHARACTERISTICS

EARTH

Mineral resources
Construction material
Soils
Landform
Force fields & background radiation
Unique physica1 features

ATMOSPHERE

Quality (gases, particulates)
Climate (micro, macro)
Temperature

WATER

Surface
Ocean
Underground
Quality
Temperature
Snow, Ice, & permafrost

PROCESSES

Floods
Erosion
Deposition (sedimentation, precipitation)
Solution
Sorption (ion exchange, complexing)
Compaction and settling
Stability (slides, slumps)
Stress-strain (earthquake)
Recharge
Air movements

BIOLOGICAL CONDITIONS

FLORA

Trees
Shrubs
Grass
Crops
Microflora
Aquatic plants
Endangered species
Barriers
Corridors

FAUNA

Birds
Land animals including reptiles
Fish & shellfish
Benthic organisms
Insects
Microfauna
Endangered species
Barriers
Corridors

CULTURAL FACTORS

LAND USE

Wideness & open spaces
Wetlands
Forestry
Grazing
Agriculture
Residential
Commercial
Industrial
Mining & quarrying

RECREATION

Hunting
Fishing
Boating
Swimming
Camping & hiking
Picnicking
Resorts

AESTHETICS & HUMAN INTEREST

Scenic views and vistas
Wilderness qualities
Open space qualities
Landscape design
Unique physical features
Parks & reserves
Monuments
Rare & unique species or ecosystems
Historical or archaeological sites and objects
Presence of misfits

CULTURAL STATUS

Cultural patterns (life style)
Health and safety
Employment
Population density

MAN-MADE FACILITIES AND ACTIVITIES

Structures
Transportation network (movement, access)
Utility networks
Waste disposal
Barriers
Corridors

ECOLOGICAL RELATIONSHIPS SUCH AS:

Salinization of water resources
Eutrophication
Disease-insect vectors
Food chains
Salinization of surficial material
Brush encroachment
Other

OTHERS

Figure 18. Leopold matrix – environmental characteristics and conditions (Source: SCOPE, 1979)

Two examples of customized Leopold matrices are given next: the first matrix corresponds to a road project, and the second one to a pulp and paper industry.

Customized Leopold matrix for a road project (USAID, 2002)

Environmental Components	Physical environment									Biological environment									Social Environment							
	Agricultural lands	Soil erosion	Slope stability	Energy resources	Surface water quality	Ground water quality	Air quality	Noise	Aquatic eco-system	Wetland eco-systems	Terrestrial eco-systems	Endangered species	Migratory species	Beneficial plants	Beneficial animals	Pest plants	Pest animals	Disease vectors	Public health	Resources/land use	Distribution system	Employment	At-risk population	Migrant populations	Community stability	Cultural values
Project Components																										
I. Project Planning & Design																										
Obtain geo-mechanical investigations																										
Obtain ground water investigations																										
Design basic road route																										
Determine excavated road material locations																										
Determine borrow pits quarries – where?																										
Planning of disposal site locations																										
Planning of drainage systems																										
Land surveying																										
II. Construction																										
Clearing of top soil																										
Disposal of removed vegetation																										
Excavation of embankments																										
Rock blasting																										
Road camp management																										
Putting gown base material																										
Mining, crushing and transport																										
Construction of concrete drainage systems																										
Construction of erosion control																										
Land survey																										
Bridge construction																										
III. Operation & Maintenance																										
Preventive soil erosion measures																										
Winter maintenance activity: salt applications																										
Maintenance of drainage systems																										
Fence maintenance																										
Road patching																										
Maintenance of road signage																										
Pay toll facilities & management																										
Commercial facilities impact																										
IV. Decommissioning																										
Old road sections																										
Reclamation of quarries and excess material landfills																										
Abandonment of excavated road materials																										
Abandonment of old asphalt and concrete materials																										

The matrix should be filled in with symbols which indicate:
1) the size or extent of any impact, and 2) whether it is adverse or beneficial

Adverse impact		Beneficial impacts
× (small)	Negligible or non-existent	• (small)
× (medium)	Moderate	● (medium)
× (large)	Large	● (large)

- Customized Leopold matrix in a paper & mill project (FAO, 1996)

Evaluation method (Magnitude / Importance)				ACTIONS						
				BUILDING OPERATIONS	WATER SUPPLY	RAW MATERIAL PREPARATION	INDUSTRIAL PROCESSES	LIQUID EFFLUENTS	SOLID WASTES TREATMENT	TOTAL
ENVIRONMENTAL / SOCIAL CONDITIONS	PHYSICAL	SOIL	SOIL QUALITY							
			EROSION							
			GEOMORPHOLOGY							
		WATER	RIVERS							
			COASTAL ZONE							
			SUBSURFACE WATER							
			SEA QUALITY							
		AIR	AIR QUALITY							
			ODOURS							
			NOISE							
	BIOLOGICAL	FLORA	FORESTS							
			CROPS							
			WETLANDS							
			SEA-GRASSES							
			RIVER FLORA							
		FAUNA	MAMMALS							
			BIRDS							
			FISH							
			OTHERS VERTEBRATES							
			INVERTEBRATES							
		ECOSYSTEMS	ECOSYSTEMS QUALITY							
			ECOSYSTEMS DESTRUCTION							
	SOCIAL	LAND USES	RURAL							
			FISHERIES							
			URBAN							
			INDUSTRIAL							
			RECREATIONAL USES							
		PATRIMONY	LANDSCAPE							
			HISTORICAL/CULTURAL							
			HERITAGE							
			WILDERNESS QUALITY							
		SOCIAL	POPULATION DENSITY							
			EMPLOYMENT							
			HAZARDS							
	TOTAL									

3.4.1.3 CAUSE AND EFFECT DIAGRAM

A cause and effect analysis is a graphic management tool used to identify the relationship between effects and its causes. The analysis employs diagramming techniques to summarize large amounts of information of the possible causes of a given effect, and to identify how each of these causes contributes to the effect, either directly or indirectly, and which ones appear to have the major significance (ReVelle, 2004).

One of the most common graphic techniques employed in cause and effect analysis is the Ishikawa or fishbone diagram. The basic layout of the diagram is a fishbone like configuration (a fish skeleton; Figure 19), where the effect or problem to be investigated is placed at the end of the backbone or spine, and the main causes are placed on what would be the ribs, or branches angle-off of the backbone. Each of the main causes is further broken down into sub-causes, and each of the sub-causes, in turn, is further broken down into root causes (the smaller bones represent causes of the larger bones they are attached to).

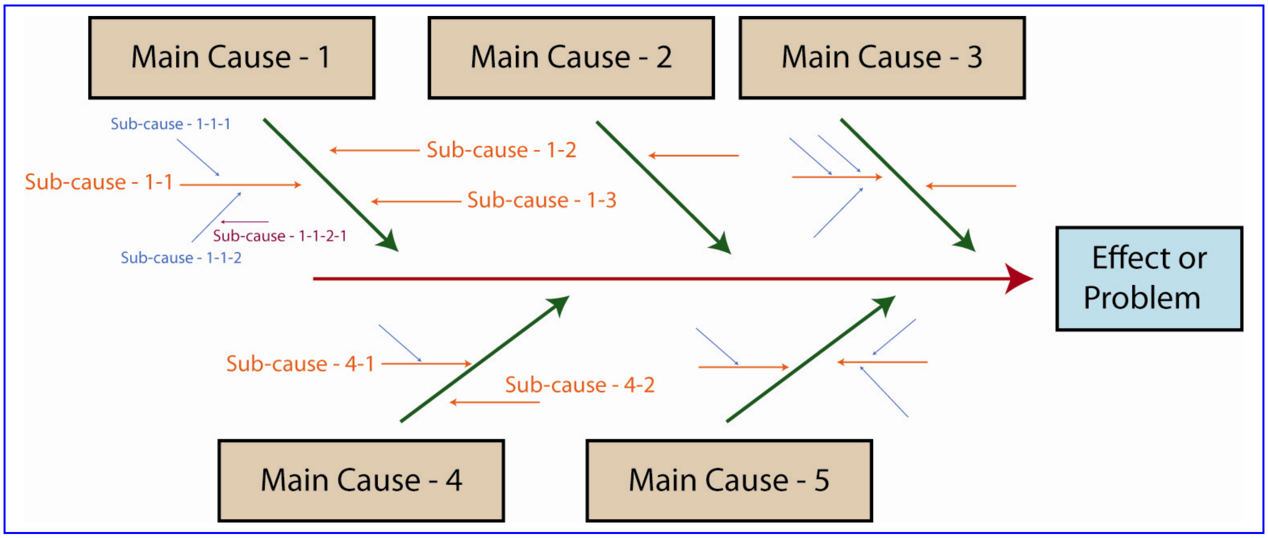


Figure 19. Cause and effect diagram – general layout

Commonly, the steps to construct a cause and effect diagram are (Kerzner, 2009):

Step 1: Determine the effect to be addressed (*i.e.* aspect) or the problem to be solved. The statement must be specific (not large or too vague). For example, which are the most significant impacts that can negatively influence the data collection on James River Station IV.

Step 2: Draw the backbone and the effect or problem box.

Step 3: Brainstorm to find major causes, and organize these causes in categories. Commonly, six major categories are used: man, methods, materials, machinery, environment and anthropogenic activities. Causes can be arranged according to their level of importance or detail.

Step 4: Determine the main causes of each major category.

Step 5: Continue the analysis process to determine the root causes for each main cause in each major category.

This type of tool is useful to determine potential impacts that the environment and humans could have on the monitoring project, as it illustrates the relationship between cause and effect in a rational manner. Under each major category, the different aspects that could have an impact on the project are identified.

Brainstorming is used to explore all the potential or real aspects in each major category. The 5Why technique can be employed to identify the causes of the different aspects in order to fill each category. The 5 Whys method is an iterative process of asking question to determine root causes. The process starts by stating the problem and asking why the problem happens. If the answer to this question does not justify the root cause (a factor that cannot be explained by other causes), the answer becomes the new problem and why this new problem exists is asked; therefore, each question is based on the answer given for the previous one. The number of whys will depend on the complexity of the problem (*i.e.* 2 or 20); five whys is a good rule of thumb.

The cause and effect diagram is also an excellent technique to display the current level of understanding of how the system works, and to identify areas where additional insight might be required. One thing that must be kept in mind when using this diagram is that complex interaction between causes may be overlooked.

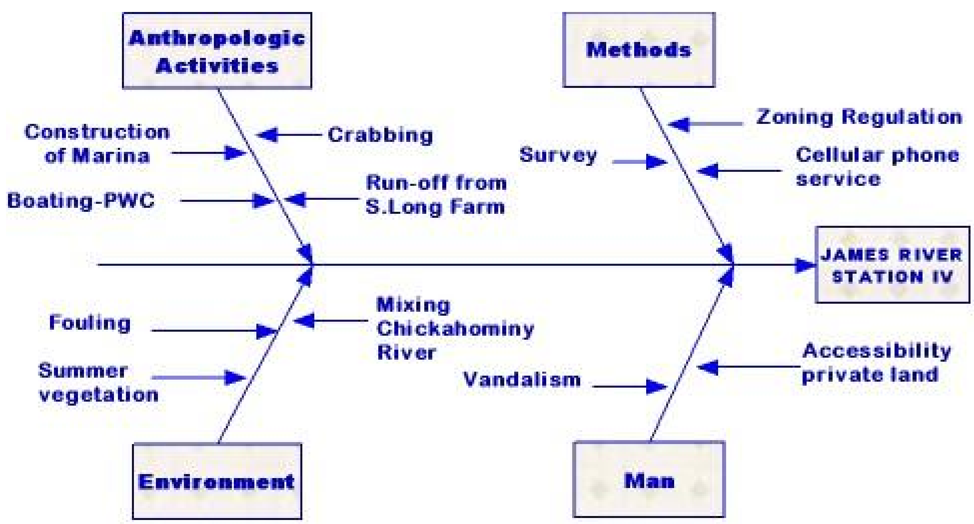


Figure 20. Example of a cause and effect diagram showing possible problems of sitting and data collection of James River Station IV.

3.4.2 Definition of WQM Project Impacts' Characteristics

Once all the impacts have been identified, their potential dimension and characteristics can be predicted or forecasted. This step provides the necessary information to facilitate impact categorization and significance evaluation. Identification of the potential dimension and forecast of the characteristics is a technical exercise that utilizes different type of data to estimate basic characteristics and parameters of the impacts. The most common characteristics and parameters considered during in impact prediction and decision-making include (UNEP, 2002):

CLASSES OF PROJECT IMPACTS: The impacts can be classified into different categories. The following classification is used by the U.S. Agency for International Development (2002):

- **Direct or Primary Impacts:** Direct impacts are those impacts that result from a direct interaction between an activity or aspect and the project. In general are obvious and quantifiable. An example can be icing of a monitoring station.
- **Secondary Impacts:** Secondary impacts are those impacts resultant from primary impacts as an outcome of subsequent interactions within the project. For example, effluent discharge can result in the enhancement of a special habitat, and this could affect a specific animal population, that in turn could affect the monitoring equipment.
- **Indirect Impacts:** Indirect impacts are those impacts that are triggered or promoted as a consequence of the original impact. For example, a new factory triggers a requirement for improved road access, which could cause runoff and affect water quality.

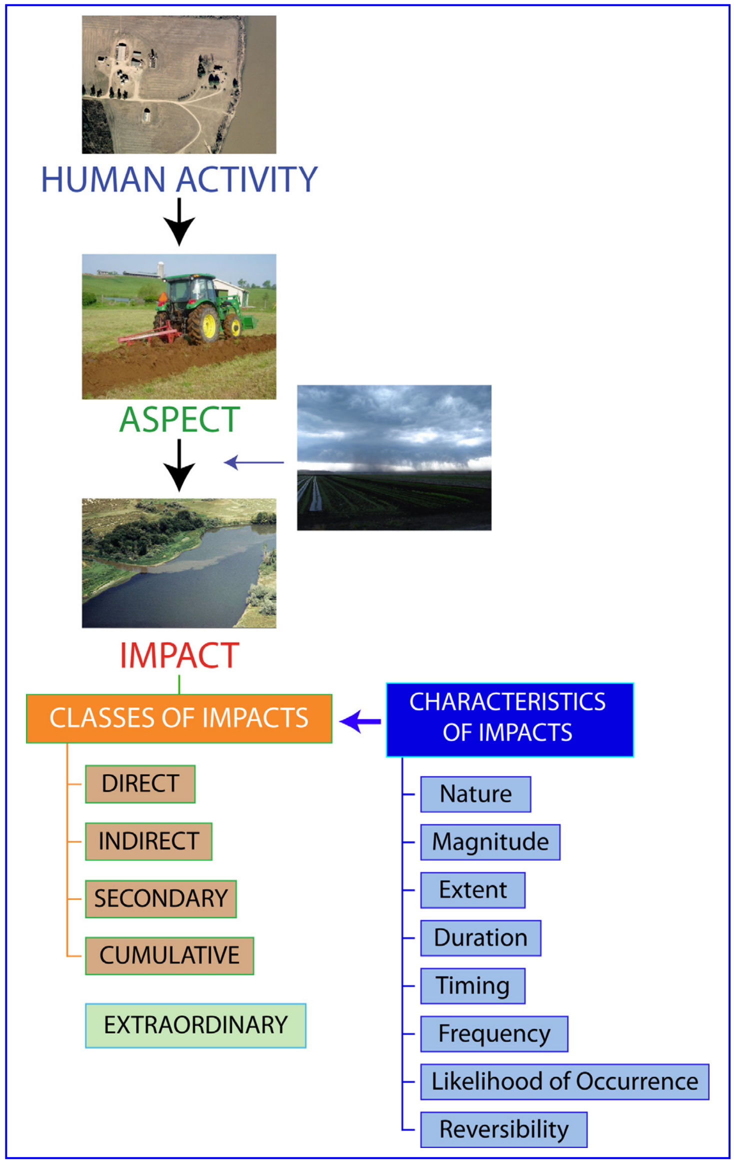


Figure 21. Project impact classes and characteristics

Cumulative Impacts: The notion of cumulative impacts acknowledge that impacts of human activities can combine, interact or trigger, other impact, producing effects that may be different in nature, or degree, from the effects of the individual activities. An example of cumulative impacts is the degradation of the water quality monitoring stations due to the weather, animals and boat traffic.

Project impacts, as environmental impacts, can accumulate in a variety of ways. Preston and Bedford (1988) utilize five categories to describe possible types of environmental cumulative impacts:

Time-crowded actions: An independent incident may have little effect in the project given its capacity to recover from the impacts. If an event is repeated before the environment can recover, the effects will accumulate. For example, a series of impacts that occur once a year, that in themselves are not important, but at a certain point of time, after years of occurring, they become significant (i.e. acid rain in water bodies).

Space-crowded actions: Some effects have a local consequence and do not affect outside a certain area of the place of impact. When several of these effects occur geographically close together, they can combine their impacts producing impacts that go beyond the original geographic area.

Synergisms: Where two impacts interact together to produce effects far in excess of the impact of a single action. This can also be seen as interactive impacts, when two different impacts that are not significant by themselves interact creating a new significant impact.

Indirect effects: An impact may trigger other impacts out of the impact area, or may produce effects at a certain time in the future. For example, the speculation of an activity considered desirable may encourage actions by people to take advantage of the consequences of the activity.

Nibbling: The impact, and other activities which have similar impacts, produces small changes in the environment, which after a certain time become significant.

Extraordinary Impacts: Extraordinary impacts are those impacts that result from unusual events produce by the environment. For example, floods, droughts, seismic activity, which can have a direct effect, or can cause other impacts.

CHARACTERISTICS OF PROJECT IMPACTS: Project impacts cannot be described in one or two words. Each impact has a number of characteristics, which collectively give a full description of the impact. The following characteristics are used by the USAID (2002) and UNEP (2002):

- **Nature:** Characteristic that indicates the type of change imposed on the project due to the aspect. The impact can have a positive or beneficial effect, or it can have a negative or adverse effect.

  It is possible that there is not enough information to determine if the impact will have a positive or negative effect. In this case, certain control variables must be chosen and monitored over time to determine the type of effect.

Magnitude: Characteristic that indicates the amount of change (absolute or relative change), in the size or value of a project feature. Different scales can be used to identify magnitude.

- **Extent:** Characteristic that indicates the spatial extent or zone affected by the impact. Different terminology can be used to indicate the extent.

  The extent can also be expressed in terms of the area affected. For example, in hectares of forest, kilometers of river, *etc*. Terms of localized or widespread can be used.

- **Timing:** Characteristic that indicates when the impact takes place. Time span between the moment the aspect took place and the moment the impact occurred. Some impacts may occur immediately after an activity is performed, while others may occur later on time, sometimes after many months or years. Terms of immediate or delay can be used.

- **Duration:** Characteristic that denotes the time period over which the impact will be felt. Commonly the duration is classified in categories; for example, commonly three categories are employed (Sakhalin Energy Investment Company):

  - **Short-term**: impacts that last only for a limited period. Some impacts are very short term. For example, turbidity during the construction phase of a bridge.

  - **Long-term**: impacts that last an extended period. For example, the land flooded by the construction of a reservoir.

  - **Permanent**: impacts that cause a permanent change in the affected receptor or resource. For example, destruction of an historic site as a result of the construction of a dam.

  Depending on the time frame considered, other categories could be added; for example, medium term, temporary, *etc*.

- **Frequency:** Characteristic that refers to the periodicity of occurrence. For example, some impacts can be seasonal. Different scales can be elaborated to define frequency. Frequency can be specified by intervals, 1 to 10 per month, 10 to 20 years, *etc*.

- **Likelihood of Occurrence:** Characteristic that denotes the possibility of a particular impact occurring as forecast. Different categories can be established.

Reversibility: Characteristic that denotes the possibility of the system to return to its original condition.

The estimation of these basic characteristics and parameters can be seen as predicting what would be the outcome of the aspect. There are many methods and techniques to predict and forecast the basic impacts' characteristics, ranging from simple techniques (*e.g.* intuition, comparisons with similar events and projects, checklists and matrices, among many others; in all of these techniques professional judgment must be employed) to experimental methods (physical models, field or laboratory experiments), mathematical models, and survey techniques (Munn, 1979; Canter, 1997).

One simple way to classify prediction methods is to divide them into (Therivel, 2006):

- <u>Quantitative methods</u>: commonly based on simulation models, statistical analysis, pilot models and experiments.
- <u>Qualitative methods</u>: are based on a unique combination of professional judgment, experience, training and intuitive reasoning.

For water quality monitoring projects, the project complexity, size and objectives, will determine which methodology may be the most effective and efficient to determine or estimate the impact's characteristics (quantitative, qualitative or a combination of both methods). There is an extensive literature that explains the advantages and drawbacks on the application of quantitative versus qualitative methods on different types of projects. Specifically, for most water quality monitoring projects, the forecast methods of choice are the qualitative methods given that:

  - professional or expert judgment, previous experience and scientific knowledge are commonly used in the decision-making process of water quality monitoring as well as to assess specific undesirable outcomes (Ongley, 2000; USEPA, 2002; Miles, 2009).

  - qualitative methods can be used when there is little quantitative information; and the time and effort to implement qualitative methods is relative small compared to computer based quantitative methods (Norton *et al*., 1988). In addition, professional judgment is generally employed when the data is conflicting and ambiguous or when assumptions must be developed to fill data gaps (USEPA, 1998).

One factor that the monitoring team must take into account when using qualitative classification is the highly subjective component inherent in these methods given they involve interpretation and application of judgment (Kassim and Simoneit, 2005). To make the decision-process more transparent, it is a good practice to describe how the judgments were made so they can be easily understood by any stakeholder, and/or the process can be followed or reproduced in the future. To this end, evaluation criteria are commonly employed. The criteria can be in terms of guidance (*e.g*., the CEA Agency Impact Criteria shown in FEARO (1994); see Box 1); and/or a system where implicitly or explicitly scores, ranks, or weights have to be assigned to each characteristic (*e.g.* qualitative ranking scales, *e.g.* from 1 to 10) (Lohani *et al*., 1997). For example, the monitoring team identified flooding in the catchment area as a possible impact given that it will produce peak discharges and elevated runoff in the river bed. The flooding was categorized as having a "semi-annually" frequency and assigned a score of 4 (*e.g.* using a scale that goes from 0=never to 10=continuously); a duration of "moderate" with a score of 5 (in a scale that goes 1=very short, less than one day to 5=very long, more than one month); and a magnitude of "very high" with a score of 5 (in a scale 1=minor to 5=very high).

Qualitative methods that are considerably simple to use and are accessible for almost any monitoring team are: Delphi method, brainstorming, or analogous studies (Liu and Liptak, 1997; USEPA, 1998).

Box 1. Canadian Environmental Assessment Agency (CEA Agency) provides the following guidance regarding impact criteria.

Magnitude of the Impact	Magnitude refers to the severity of the adverse environmental effects. Minor or inconsequential effects may not be significant. On the other hand, if the effects are major or catastrophic, the adverse environmental effects will be significant. When using this criterion, it is important to consider the extent to which the project could trigger or contribute to any cumulative environmental effects.
Geographic Extent	Localized adverse environmental effects may not be significant. Alternatively, widespread effects may be significant. When considering this criterion, it will be important to take into account the extent to which adverse environmental effects caused by the project may occur in areas far removed from it (e.g., acid rain and the long-range transportation of atmospheric pollutants), as well as contribute to any cumulative environmental effects
Duration and frequency	Long term and/or frequent adverse environmental effects may be significant. Future adverse environmental effects should also be taken into account. For example, many human cancers associated with exposure to ionizing radiation have long latency periods of up to 30 years. Obviously when considering future adverse environmental effects, the question of their likelihood becomes very important
Degree to which the effects are reversible or irreversible	Reversible adverse environmental effects may be less significant than adverse environmental effects that are irreversible. In practice, it can be difficult to know whether the adverse environmental effects of a project will be irreversible or not. It will be important to consider any planned decommissioning activities that may influence the degree to which the adverse environmental effects are reversible or irreversible

As mentioned before, dimension and characteristics of the different impacts are generally described using evaluation criteria. Commonly, checklists and matrices are used to organize and present the criteria information. For illustration purposes only, several examples of criteria used to categorize impacts are given next:

EXAMPLES OF FREQUENCY CATEGORIES

10	continuous event
5	50%
1	rarely
0	never

1.0	continuous
0.8	frequent
0.5	infrequent
0.2	occasional

1	Very low	Once a month
2	Low	Once in fifteen days
3	Moderate	Once a week
4	High	Once in tow days
5	Very high	Several times a day

10	continuously	4	semiannually
9	daily	3	annually
8	weekly	2	less than one time every 5 years
7	monthly	1	once in more than 5 years
5	trimester	0	never

EXAMPLES OF DURATION CATEGORIES

1	Negligible	Less than one day
2	Short	One to five days
3	Moderate	Five to 10 days
4	Long	Ten to thirty days
5	Very long	More than thirty days

10	High - Long term	Permanent, *i.e.* more than 20 years
5	Medium - Medium term	Reversible over time, *i.e.* 5 – 20 years
1	Low - Short term	Reversible, *i.e.* 0 – 5 years

1	Short term	0 – 12 months
2	Medium term	12 – 36 months
3	Long term	> 3 years

EXAMPLES OF EXTENT CATEGORIES

1	Low	Felt only at the source
2	Moderate	Extended to immediate adjacent area
3	High	Felt up to 100 meters from the source
4	Very High	Felt up to 1 kilometer from the source
5	Extremely High	Impact felt beyond 1 kilometer from the source

10	High	Widespread: far beyond site boundary
5	Medium	Local area: beyond site boundary
1	Low	Within site boundary

Major	Impact affects regional, national or global environment
Moderate	Impact affects the general vicinity of the input area
Minor	Impact limited to the immediate vicinity of the input activity
Negligible	Impact limited to a very small part of the input activity area

EXAMPLE OF MAGNITUDE CATEGORIES

1	Minor	Slight negligible impact noticeable
2	Low	Causes minimum discomfort to human health and global issues
3	Moderate	Impact on vegetation, soil, water and/or resource
4	High	Human health effect
5	Very High	Fatal- affecting heritage and/or archeological structures

1	Minor	Effluent within discharge limits. Rapid dilution in receiving waters.
3	Moderate	Effluent within discharge limits. Poor dilution capacity. Likely to produce degradation in some environmental quality standards inside influence area.
6	Major	Effluent outside discharge standards. Effluent produce degradation of environmental quality standards outside influence area.

Severity Scale	Human Impact	Animal/Plant Effect
10	Multiple deaths	Widespread permanent destruction
9	Single death	On-site permanent destruction
8	Disabling injury	Widespread genetic impact
7	Long term health effects	On-site genetic impact
6	Lost time injury/illness	Wide spread disfigurement
5	Restricted duty	On-site disfigurement
4	Medical only	Wide spread appearance
3	First aid treatment	Reduction of natural beauty
2	Discomfort	On-site appearance
1	None	None

(Source: USAID, 2002)

5 or 4	High - likely to result in severe/widespread damage to human health and the environment
3 or 2	Medium - moderate damage to human health and the environment
1 or 0	Low - minor damage to human health and the environment; little or no impact

EXAMPLE OF LIKELIHOOD OF OCCURRENCE CATEGORIES

Very Low	Impact has less than 1 or 2% likelihood of occurring
Low	Impact highly unlikely, between 2 to 20% likelihood of occurring
Medium	Impact could occur infrequently, between 20 t0 70% likelihood
High	Impact is likely to occur with more than 70% likelihood of occurrence

High or Certain	The impact is certain to occur (*i.e.* more than 90%) based in previous data and/or experience
Moderate or Probable	The impact may occur (*i.e.* between 70 and 90%) based in previous data and/or experience.
Low or Possible	The impact has a low probability of occurring (*i.e.* between 40 and 70%) based in previous data and/or experience.
Very Low	The impact has a very low probability of occurring (i.e. between 10 and 40%) and there is little uncertainty based in previous data and/or experience.
None or Nil	The impact has no probability of occurring based in previous data and/or experience.
Unknown or Unsure	There is insufficient data or experience to predict the likelihood of occurrence.

EXAMPLE OF LIKELIHOOD OF REVERSIBILITY

High	Highly reversible. Previous experience and data shows the environmental effects are reversible.
Medium	Probable reversibility. Previous experience and data shows the environmental effects are probable reversible
Low	Poor reversibility. Previous experience and data shows the environmental effects have a very low probability of being reversible.
None	Previous experience and data shows the environmental effects are not reversible
Unknown	There is not enough previous experience or data to assess reversibility

3.4.3 Evaluation of Impacts Significance

It can be said that the most critical element of impact analysis is to determine if the impacts will produce, or not, a significant effect on the monitoring project (Sadler, 1996). The degree of significance will determine the course of action to follow. Some impacts would be considered significant and certain control or corrective measures will be required; while others may cause minimal or no effect on the monitoring objects and it may be decided that no further action is needed.

To define significance in a WQM project, it must be taken into account: first, there is not a universally agreeable definition of significance (Lawrence, 2007), and second, scientists evaluate significance differently given that it depends on many factors, such as the intensity, expert judgment, context in which the impact would occur (significance determination is highly context-sensitive (relative to what), and context is composed of multiple elements, such as, economic, social, cultural, spatial, *etc.*) among many other things (Canter and Canty, 1992; Sadler, 1996).

The term "significant" used in the National Environmental Policy Act by the Council on Environmental Quality is associated to the context and intensity of the impact. It is defined that an impact must be analyzed in several contexts as society, affected region and locality. The intensity represents the severity of the impact and several issues must be considered in order to evaluate intensity, such as, degree to which the proposed action affects public health and safety, or whether the action is related to other actions. This view is shared by the Canadian Environmental Assessment Agency (1994) which describes significance as a concept that is tied up with two other concepts "adverse" and "likely".

Significance in most WQM projects can be interpreted following Haug et al. (1984) definition. First, significance in a WQM project would be ultimately based on professional and expert judgment.

Professional judgment plays an important role to determine impact significance. This is due to:

- The intricate and diverse nature of elements involved in the decision.
- Usually, not all the necessary information is available at the time of the decision-making.
- Professionals are accustomed to use their past experience to make decisions quickly, and sometimes almost automatically.
  "*Educated predictions and inferences, founded upon past* experiences *or knowledge are critical in significance evolution*" (Canter and Canty, 1992).

Second, the significance of a particular impact would depend on one or several thresholds (contingent upon the different project variables that the impact has an effect on), the degree of importance of each of these variables in the fulfillment of the project objectives, and the possibility that these thresholds are exceeded.

The evaluation of impact significance in WQM projects would be highly site and project-specific dependent. The project team would have to define significance thresholds and criteria to address the degree of significance for each relevant impact depending on the project's objectives. Decision-making would be based on decision rules that the team must define to apply the criteria. Giving the nature of most WQM projects, this process would be highly based on experience and professional judgment. To avoid a common critique regarding how significance is determined when using expert judgment (e.g. not clearly defined, limited justification or explanation (Lohani *et al*., 1997; Wood, 2008)); it would be beneficial to follow a methodology to determine significance. This will allow not only to make the process more efficient and effective, but also to provide the necessary transparency and clarity to communicate the evaluation criteria for further follow-ups, comparison with other studies, and most important, for future applications in other WQM projects.

Methodologies for impact significance determination within the EIA literature can be found in Thomson (1990), Saddler (1996), Lawrence (2007), Wood (2008), and Bevan (2009), among many other publications. For illustration purposes, one of these methodologies for impact significance determination, used by the Design for the Environment Program of the USEPA (1999), is described next. The methodology addresses project impact significance employing a three steps approach:

1. Choosing criteria for evaluating significance.
2. Evaluating your project aspects according to these criteria.
3. Determining which impacts are significant.

3.4.3.1 Choosing Criteria for Evaluating Significance

Criteria are needed to support judgments and to define a scale where the impacts can be evaluated. Criteria for evaluating impacts can vary considerable, some are standard and accepted by most people, and others are created to fulfill a particular need. For example, there are generic or specific criteria, cumulative effects potential criteria, quality criteria, performance or evaluation criteria, etc. In addition, criteria can be subdivided by disciplines (social or cultural) or aggregated. Common tools used to determine significance are environmental standards, guidelines or objectives (Canadian Environmental Assessment Agency, 1994).

Box 2. Examples of Significant Criteria

Significant Criteria for Soils

The significance of impacts on soils will be evaluated using professional judgment and recognized soils science techniques, taking account of the following factors:

- Magnitude of the impact: determined by its intensity, its extent in space, duration, and the likelihood of its occurrence;
- Vulnerability of the particular soil to the change caused by the impact;
- Methods planned for protection of soil resources during construction and their replacement during reinstatement; and
- Ability of the soil to recover from the impact.

Significance Criteria for Impacts to Surface Water Resources

Significance criteria for impacts to freshwater quality (and secondary impacts to water users) are therefore based largely on compliance with standards, together with the quality of the receiving water and its ability to dilute the effluent.

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The importance of having criteria to evaluate significance is due to the high probability of having different opinions in judging the same impact, and therefore, the significance of the same impact can vary between different professionals. In addition, criteria for impact significance are not fix or one hundred percent certain. Lawrence (2003) suggests that since knowledge is always incomplete, and attitudes and values vary, there is always uncertainty in significance determinations.

The significant criteria can be defined for each aspect of the project, or one criterion could be defined that includes different areas that are considered important for all the stakeholders.

The management team must define a scale of importance based on the project objectives and data quality, and in the damage the impact would cause on the project outcome if it occurs. It is recommended to base judgment on the severity and the likelihood of occurrence (EPA, 1999).

The best practice is to use, whenever is possible, widely agreed scientific criteria. For example, air and water quality standards, public health and safety standards, etc. If criteria must be developed, information about magnitude and likelihood of the impact is required. In addition, it is recommended to use guidelines or rules of thumb to design the criteria (Abaza *et al*., 2004).

Box 3. Environmental and Business factors to consider in significance evaluation:

⇒ Environmental considerations
⇒ Scale of the impact
⇒ Severity of the impact or potential impact
⇒ Probability of occurrence
⇒ Duration of the impact
⇒ Frequency of the impact or potential impact
⇒ Location of the facility (i.e. in a sensitive area)
⇒ Scope of the impact (local, regional, national, etc.)
⇒ Business considerations
⇒ Potential regulatory and legal exposure
⇒ Difficulty of changing the impact
⇒ Cost of mitigating the impact
⇒ Effect of change on other activities or processes
⇒ Concerns of interested parties
⇒ Effect on the organization's public image
⇒ Return on investment on the cost to mitigate the impact

Source: ISO 14004

Box 4. Rules of thumb of significant impacts:

- ⇒ extensive over space or time
- ⇒ intensive in relation to assimilative capacity
- ⇒ above or close to environmental standards or thresholds
- ⇒ non-compliant with environmental policies, land use plans, sustainability strategy
- ⇒ likely to threaten public health or safety
- ○ likely to limit agriculture, wood gathering or resource uses on which people rely for subsistence
- ⇒ likely to deplete or damage resources that are commercially exploited;
- ⇒ likely to affect protected or ecologically sensitive areas, rare or endangered species or heritage resources
- ⇒ likely to disrupt the lifestyle of large numbers of people or that of vulnerable minorities

Source: Ashe and Sadler, 1997.

Once the criteria are developed, the next step is to define the scale and weights that will be used to categorize the criteria (*e.g.*, low, medium, high or numerically, 1 to 10). Next, the rule to aggregate scores must be defined, and finally what is the significance threshold established.

Two examples of significance criteria are given next with the objective to provide an overview of two different approaches to create significance criteria.

➔ Example of Significance Criteria for Impacts to Biological Resources in an Offshore Platforms and Pipelines Project (Sakhalin Energy Investment Company).

Criteria of value and magnitude are used to evaluate significance. The significance of ecological impacts is a combination of the conservation value of the habitat/species affected and the magnitude of impact.

Criteria for the Evaluation of the Value and Sensitivity of Affected Habitats and Species

- The presence of any habitat, plant or animal species that is internationally, nationally, regionally or locally rare, especially species protected under Russian legislation.
- The presence of any habitat, plant or animal communities, which are internationally, nationally, regionally or locally uncommon or suffering serious reduction nationally or locally.
- The diversity of the habitats and their individual species richness are important. In general, the greater the total number of species recorded, the greater the conservation interest of the area.
- The presence of a nationally or locally important population of a particular species; an assessment of whether the habitat is a representative example of special interest or value.
- The 'naturalness' of the habitat. Naturalness and diversity can be strongly correlated and recreated habitats tend to be more species poor than their natural or semi-natural equivalents.
- The fragility and sensitivity of the habitat and its ability to recover (either naturally or with assistance) from disturbance. This criterion is linked also to size, naturalness and rarity but generally fragile sites are usually highly fragmented, decreasing rapidly in extent and number and are difficult to recreate.
- The recorded history of the site. The loss of an irreplaceable biological record would be particularly significant. Such records may also be of cultural and historical value.
- Whether at the local level the habitat is an ecological corridor between other isolated habitats of ecological importance.
- Whether a species has a seasonally variable vulnerability due, for example, to breeding, critical feeding times or migratory passage.
- Whether any species has cultural significance (for example, as a resource utilized by local settlements).
- The amenity value of the site.
- The research value and education potential of the site.

The Sakhalin Energy Investment Company suggests placing some sort of value (low, moderate, or high) on the resources that might potentially be affected. Even though this is to some extent subjective, expert judgment and stakeholder consultation will ensure a reasonable degree of consensus on the intrinsic value of a resource.

Criteria used to assess the magnitude of ecological impacts

A High Magnitude Impact: affects an entire population or species in sufficient magnitude to cause a decline in abundance and /or change in distribution beyond which natural recruitment (reproduction, immigration from unaffected areas) would not return that population or species, or any population or species dependent upon it, to its former level within several generations. A major impact may also affect a subsistence or commercial resource use to the degree that the well being of the user is affected over a long term. In the case of fish an impact over one season/generation would be significant.

A Medium Magnitude Impact: affects a portion of a population and may bring about a change in abundance and / or distribution over one or more generation*, but does not threaten the integrity of that population or any population dependent on it. Moderate Impacts to the same resource multiplied over a wide area would be regarded as a Major Impact. A short-term effect upon the well being of resource users may also constitute a moderate impact.

A Low Magnitude Impact: affects a specific group of localized individuals within a population over a short time period (one generation* or less), but does not affect other trophic levels or the population itself.

*These are generations of the animal/plant species under consideration not human generations. It should be noted that the reinstatement and recovery potential of an affected habitat also needs to be considered in applying the above criteria.

Overall Significance Criteria for Ecological Impacts			
	Low magnitude impact	Medium magnitude impact	High magnitude impact
Low value/sensitivity or locally important habitat or flora/fauna	Minor	Minor	Moderate
Moderate value/sensitivity or nationally important habitat or flora/fauna	Minor	Moderate	Major
High value/sensitivity or international important habitat or flora/fauna	Moderate	Major	Major

➔ Example of Significance Criteria used by the US Army Corps of Engineers (2003).

A simple numerical rating system is used to identify the significance of environmental impacts. The process has the following steps:

1. Identify the different characteristics to be used to describe the impacts
2. Define the numerical ratings for each characteristic
3. Define an algorithm to aggregate the characteristics
4. Calculate the significant score
5. Use combination of objective and subjective judgments to determine the significant impacts

For example, the characteristics and relative scores chosen to describe the impacts are:

Frequency or likelihood (F) scale		**Environmental Impact Severity (E) scale**	
5	Continuous-ongoing or daily	5	Severe-immediate threat likely to result in widespread damage to human health or the environment; requires great effort to remediate or correct
4	Frequent-more than once per month	4	Serious-no immediate health threat, but significantly damages the environment; difficult but possible to remediate.
3	Infrequent-more than once per year, less than once per month	3	Moderate-somewhat harmful, but correctable
2	Rare-impact may occur once every year or two	2	Mild-small potential for harm to environment, correctable
1	Never-never occurred or highly unlikely	1	Insignificant-trivial consequences, easily correctable or not impact
Mission Impact Severity (M) scale		**Regulatory Impact (R) scale**	
5	Loss of ability to accomplish critical mission or near mission failure	5	Regulated-noncompliance condition; actual or possible enforcement action
4	Severely degraded mission capability or serious mission restrictions	4	Regulated-generally in compliance, but not completely controlled or managed; some risk of noncompliance in future, or under scrutiny by regulators
3	Moderate mission restrictions	3	Regulated-in compliance, well controlled or managed; little regulator interest
2	Minor mission impacts or restrictions	2	Likely to be regulated in future by federal or sate
1	Insignificant mission impacts or restrictions; alternative courses of action are available	1	Best management practice applies
0	No mission impacts or restrictions	0	No requirements apply
Community Concern (C) scale			
4	Public outcry or lawsuits	1	Community is not currently concerned, but could become so
3	Serious community concern, political or activist inquires, intense negative media	0	Community is ambivalent or unconcerned
2	Moderate community concern, some media coverage		

The algorithm chosen to aggregate the different impacts and calculate the impact significant score is

SS = frequency × (environmental impact severity + mission impact severity) + regulatory status + community concern

The maximum possible rating for any given impact is 59.

Consider the following scenario: routine daily vehicle washing activities

The washing activities are performed daily and all wastewater is collected and processed to separate oil, grease, *etc*. No harmful wastes are disposed to the environment. Regulators do not have a special interest in the vehicle washing facility and there are no issues of concerns with the community. Restrictions would have little to no mission impact because vehicle washing is not a mission-critical activity in this case.

The scores assigned are: frequency (5), severity (1), mission impact (0), regulatory status (3), community concern (0), giving an SS = 8.

Once each impact is scored, significance must be determined. The only criterion established for significance is the regulatory. If an impact is regulated, the impact and associated aspect are considered significant. In addition, all regulated impacts can be sorted by their scores and ranked, for *i.e.* from high to low. Beyond the regulatory, there is a lot of flexibility, and generally standards, rules or customized methods are applied to define what is and what is not significant. For example, a SS numerical cut line can be applied (*i.e.* all impacts with scores higher than 35 are significant) or individual ratings can be used and considered, for example, the significance is determine by the individual score regardless of the SS score, *i.e.*, community concerns ratings of 3 or higher are considered significant.

3.4.3.2 Evaluating the Aspects or Impacts According to these Criteria

Each aspect or impact is evaluated according with the designed criteria.

3.4.3.3 Determining which Impacts are Significant

Given that there is no standard way to determine significance; two points to consider are:

- There is no one right method to determine significance; usually different types of systematic evaluation are used.
- Different factors participate in the determination of significance (*i.e.* severity and likelihood); thus, the designed criteria must have some kind of rule to determine the significant level of an impact.

A very common technique to determine significance is to use a numerical rating system employing some kind of equation, or an algorithm, to calculate a significant score (US Army Corps of Engineers, 2003).

For example, the following score is used to determine impact significance in Fort Lewis:

Frequency of impact	
1	continuous
0.8	frequent
0.5	infrequent
0.2	occasional

Impact severity	
5	high (serious; likely to result in severe/widespread damage to human health and the environment)
4 or 3	medium (moderate damage to human health and the environment)
2 or 1	low (minor damage to human health and the environment; little or no impact)

Impact probability	
5	high
4 or 3	medium
2 or 1	low

Legal risk	
5	high
4 or 3	medium
2 or 1	low

The impact significance score is calculated using the following equation:

Frequency x (Severity + Probability + Legal Risk) = Impact Significance

For example: an impact has the following values Severity = medium (4); Probability = medium (3); Legal Risk = low (1); the frequency of the impact is determined to be "frequent" (0.8). Applying the equation, the impact significance is 0.8 x (4 + 3 + 1) = 6.4.

A combination of objective and subjective judgments will assign different ranges of significant scores to the significance scale (*i.e.* between x and y it is very significant, between z and w it is moderate, *etc*.).

Weighting is another technique commonly used to simplify all assigned numerical impacts values into one single index. There are pros and cons of using weighting, for example, the aggregation may undermine a key impact within the arithmetic average. The Scottish Natural Heritage (2002) suggests that the criteria should clearly explain how the impact significance has been derived. It should set the basis of the judgment employed to assigned weights so others can understand the rationale behind the assessment.

SCOPE (1979) provides three guidelines to work with aggregation:

- Allocated values for each impact must be provided.
- The aggregations procedure must be clearly explained.
- There must be a procedure for rejecting or flagging an unacceptable impact, *i.e.* a construction in a cemetery ground.

The use of weights and scores is particularly useful in the assessment and comparison of alternatives, either by means of simple matrices, or using more formal methods such as Multi-Criteria Analysis (MCA).

Multi-criteria analysis has become a very valuable and increasingly widely-used tool to aid impact significance decision-making; in particular this technique is very useful when expert knowledge is employed for significance determination. For this reason, a very brief description of the technique is provided in the appendix section.

3.4 DECISION-MAKING

It can be said that the ultimate objective of the application of impact analysis on a WQM project is to obtain the necessary information with regard to each relevant impact for decision-making. The decision-making process involves making decisions on the type of control, correction, or mitigation measures, if any, that will be applied to monitor, control, avoid, reduce, or offset the potential adverse effects of the impacts on the monitoring project.

Fischhoff (1990) affirms that a good decision depends "*on a combination of good process and good outcomes*" and in environmental situations, judgment is commonly employed in the decision-making process. In order to support an effective decision-making process, tools to improve the quality of the judgment and appropriate methods of data presentation must be employed (Fischhoff, 1990; Conboy *et al*., 2009). It must be remembered that data is not information (Wang *et al*., 2001). In order for data to become information, Green and Petre (1996) state that it must be presented in a usable format, and to facilitate effective decision-making, the format must be selected in order to communicate the information meaningfully (Bhatia, 2005). Therefore, for an effective decision-making process, it is very important that an adequate methodology to organize and summarize the data is employed. Formats commonly used to present impact analysis data for decision-making are checklists and matrices (both in tabular formats) (Lohani *et al*., 1997).

Generally, the decision-making output can be subdivided in the following courses of action:

- **Do nothing**: This option is selected when the impact is considered positive or negligible; thus no further action is required.

- **Follow-up**: This option is selected when the impact is considered not to be significant enough to take direct mitigation measures, but it is possible the significance could change if certain conditions are present. Therefore, the aspect is monitored to ensure its impacts do not become significant.

- **Preventive measure**: Measures taken to prevent or eliminate potential significant impacts before occurring. It also includes any action taken to reduce these impacts to acceptable levels. Preventive refers to impacts that haven't yet occurred.

- **Corrective measure**: Measures taken to reduce or eliminate the adverse consequences of the impacts on the monitoring project.

- **Compensatory measure**: Actions taken to compensate unavoidable adverse effects on the monitoring project.

3.4.1 Work instructions to manage the impacts

In WQM projects, the monitoring team will need the impact decision-making information presented in a concise and easily accessible format. In particular, the different courses of action must be presented clearly and in a self explanatory manner, to enable and ensure an effective and efficient application of these actions during the project's life cycle. This is particularly important in those projects where the personnel involved in the monitoring activities are not the same as the design team. One of the best formats to present the courses of action is the "quality plan" template (ISO, 2005), commonly used in quality management systems.

A quality plan, by definition, is a document that specifies which procedures and associated resources shall be applied by whom and when to a specific process (ASQ, 2000). The document must specify all the activities of assurance and control necessary to ensure that the course of action for each relevant impact is performed meeting the design team requirements. The quality plan has generally a tabulated format with columns and column attributes. For example, the quality plan may include the following information: description of each relevant impact; type of actions to be taken (*e.g.* clean the *hydrilla* around the monitoring stations); who, when, and how the tasks will be performed; control points (to ensure effective execution); resources needed; measurements to take (to allow assessment of the effectiveness of these actions); responsibilities, *etc*. The information to be included will depend on the complexity of the monitoring project, and/or type of impacts.

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APPENDIX SECTION

APPENDIX : MULTI-ANALYSIS CRITERIA (MCA)

Why multi-analysis criteria?

When a project must deal with multidisciplinary factors, the project team has to cope with multiple sorts of decisions, for example,

- The information to be used includes both qualitative and quantitative data.
- The amount or nature of data available to support the analysis varies.
- There are multiple interest groups, stakeholders and experts. General consensus in a multidisciplinary team can be very difficult to achieve when members do not agree on the relative importance of each factor, elements, *etc*.
- There are multi exclusive issues to consider. Different alternatives or solutions to problems may exists, each one with its own advantages and disadvantages.
- There may be trade offs among the performance of certain factors
- Consensus imposes aggregation of different evaluations made by stakeholders and experts of the importance and influence of the different factors that affect the monitoring activity.
- Provides an analysis technique to arrive to the best solution possible, independent of particular perceptions.

When multi criteria problems arise, decision-making can be very complex. Multi-Criteria analysis can be very helpful to arrive to the best solution possible in this type of decision-making scenario (Belton and Stewart, 2002). In general, MCA provides a framework for complex decision-making by identifying the alternatives that are to be investigated, selecting a set of criteria by which to rank these alternatives, picking preferences or weights the stakeholders assign to the various criteria, and defining an aggregation algorithm by which the criteria are aggregated into a single index or rank order. Finally, a sensitivity and robustness analysis is done to explore how different preferences affect the outcome of the aggregation and how robust the index (or rank order) is with respect to deviations in the preferences (Proctor and Drechsler, 2003).

It is not the intention of this section to provide an in-depth approach to multi-criteria analysis; there is growing literature that discusses MCA techniques in detail. The goal is to provide some very basic MCA techniques that can be used during the evaluation of impact significance. It is recommended to review specialized literature to understand the MCA limitations, and the best technique to be applied to each particular case.

Box A1. Basic MCA glossary (Mendoza and Macoun, 1999):

Principle: A fundamental truth or law as the basis of reasoning or action.

Criterion: A principle or standard that a thing is judged by.

Indicator: An indicator is any variable or component of the ecosystem or management system used to infer the status of a particular Criterion.

Verifier: Data or information that enhance the specificity or the ease of assessment of an indicator.

Decision Element & Alternative: different elements or alternative that need to be analyzed in order to make complex decisions

Ranking: involves assigning each decision element a rank that reflects its perceived degree of importance relative to the decision being made.

Rating: similar to ranking, except that the decision elements are assigned scores between 0 and 100. The scores for all elements being compared must add up to 100. To score one element high means that a different element must be scored lower.

The Analytic Hierarchy Process (AHP): arrangement of the important components of a problem into a hierarchical structure similar to a family tree. The AHP method reduces complex decisions into a series of simple comparisons called Pair wise Comparisons. Pair wise Comparisons, involves a series of one on-one judgments regarding the significance of each indicator relative to the criterion that it describes. Each indicator under a criterion, then, is compared with every other indicator under that criterion to assess its relative importance.

The general MCA method has five steps (Calabuig, 1999):

1. Identify impacts to be analyzed or addressed.
2. Identify criteria by which these impacts or alternatives are going to be evaluated.
3. Apply criteria to each impact or alternative; identify the expected performance of each option against the criteria.
4. Apply the method to select or rank alternatives.
5. Analyzed results.

Note: The following references where consulted to describe the five steps: Calabuig, 1999; Department for Communities and Local Government, 2009; Dodgson *et al*., 2001; Mendoza and Macoun, 1999; Norris and Marshall, 1995; and OECD, 2005.

1. Identify impacts to be analyzed or addressed

The identification must be done as clearly as possible. In order to facilitate the understanding of the different features involved, alternatives, impacts, options or problems, each one can be defined or described by it selves, or by a set of factors or sub-factors (quantitative or qualitative) to form a hierarchy structure of one or more levels.

2. **Identify criteria by which these impacts or alternatives are going to be evaluated**

   There is not a standard method for defining criteria and there is no uniformly agreed methodology to weight individual indicators. One thing that can help is approaching the design by thinking what would differentiate between a good choice and a bad one, and how the criteria are going to be applied.

The criteria are defined by a certain number of criterions and each one will have some kind of indicators that would be used to evaluate the criterion against the decision element. These indicators are expressed in a variety of statistical units, ranges or scales.

Once the criterions are defined, some type of algorithm or another type of method (such as the Delphi method) must be identified to calculate the relative weight or importance of each decision element. Norris and Marshall (1995) describe fourteen methods of multi-criteria analysis ranging from very simple screening methods to sophisticated ranking and selection algorithms requiring computer-assisted computations. These methods can be subdivided into compensatory and non-compensatory methods. Non-compensatory methods do not permit tradeoffs between criterions. Comparisons are made on a criterion-by-criterion basis; a low performance value in one criterion cannot be offset by a high performance value in other criterion. Compensatory methods permit tradeoffs between criterions.

In general, whether a compensatory or non-compensatory method is applied, numerical multipliers or weights are used in the criteria to identify relative importance of each alternative or factor against each criterion.

The final result of the impacts, alternatives and/or factors and the criterions would be a **Decision Matrix**, which has as rows each impact being considered, and as columns each criterion.

Criterions can be ranked or scaled using one of the following methods:

RATING

The elements are valued by assigning a rate or a percentage score. The scores for all elements being compared must add up to 100. The advantage of rating is that provides both, an ordinal and cardinal measure of importance.

> Ordinal importance: refers to the order of importance
> Cardinal importance: refers to the difference in magnitude between the importance of two elements.

Comply with Criteria

Set a Y = impact or alternative complies with criteria; N = impact or alternative does not comply with criteria

		Criteria					
		C1	C2	C3	C4	C5	C6
Alternative	A1	Y	Y	Y	N	Y	Y
	A2	Y	Y	N	N	Y	Y
	A3	Y	Y	Y	Y	Y	Y
	A4	Y	Y	Y	Y	N	Y

RANKING

There are two different ways to rank: Regular and Ordinal Ranking.

Regular Ranking: the regular ranking assigns each element a specific rank depending on it's perceive importance. For example, ranks can be assigned using a scale like the following:

1	3	5	7	9
Weakly important	Less important	Moderately important	More important	Extremely Important

Ordinal Ranking: The elements must be arranged in order of importance in a hierarchy way. The impacts or alternatives are ordered with respect to the compliance or performance and with respect to each criterion Therefore, the elements cannot have the same ranking as could happen in regular ranking.

		Criterions					
		C1	C2	C3	C4	C5	C6
Alternative	A1	2	3	2	4	2	3
	A2	3	1	4	3	4	2
	A3	4	2	3	2	3	4
	A4	1	4	1	1	1	1

3. Apply criteria to each alternative or identify the expected performance of each option against the criteria.

In this step, scores are assigned to each impact or alternative in relation to each criterion.

4. Apply a method to select or rank alternatives or impacts.

There are several methods to rank the impacts, and the best method to apply will depend on the specific case. In this section, a brief description of some compensatory and non-compensatory methods is given with the objective to provide a basic understanding of these methods and to facilitate selection of a particular method.

NON-COMPENSATORY METHODS

Dominance: A discard process is used based on alternatives, or factors, that out performs other alternatives, or factors, with respect to one criterion while equally perform in the remaining criterions. There could be more than one solutions generated by this method. The comparison method can go like this: compare first two alternatives and if one is dominated by other, discard the dominated one; compare the undiscarded alternative with third alternative and discard any dominated alternative; the nondominated set is determined after (m-1) comparisons, where m is the number of criterions.

Maximin: This method is applicable only when criterion values are comparable with one another; either they are in commensurate units, or are normalized prior to performing the method. The process tries to avoid the worst possible performance by finding the weakest criterion value of each alternative and then ranking all alternatives by their weakest value. The alternative preferred is the one with the best or highest weakest criterion value.

Maxmax: Same as Maximin but this time the best performance criterion value is selected.

Disjunctive: This method is a screening method where an alternative is selected if it exceeds a threshold value for at least one criterion. For example, criterions are order in terms of importance and alternatives that fail to meet the threshold for the most important criterion are discarded.

Conjunctive: This method is a screening method where an alternative or impact is selected if exceeds a given performance threshold (*i.e.* water quality standard) for each criterion. Thus, if an alternative complies with all thresholds, then the alternative passes the screening process and is acceptable.

Lexicographic: The method is a rank-order method where the criterions are ranked by order of importance. Later the alternatives are ranked in order of importance of the most important criterion. The alternative with the highest values is selected. If there were a tide, the next important criterion value would select the alternative. This process continues until one alternative is selected.

COMPENSATORY METHODS

SIMPLE RANK VALUATION

Steps:

- Each alternative or factor is ranked in each criterion (the best performance in the criterion is assigned the number 1).
- The ranks are summed for each alternative.
- The alternative with the minimum total value is selected.

		Criterions							
		C1	C2	C3	C4	C5	C6	C7	Σ
Factors	f1	2	3	2	4	2	3	3	19
	f2	3	1	4	3	4	2	2	19
	f3	4	2	3	2	3	4	4	22
	f4	1	4	1	1	1	1	1	10

VALUATION BY PREFERENTIAL RANKING

Suppose the following scenario:

- There are **n** different impacts or factors, and **e** experts that are going to evaluate these factors to determine the most important factor.
- The factors are ranked against each criterion with an importance scale, *i.e.* 1 to 5, being 1 the worst.
- Each expert ranks the different factors with the selected scale.

After each rank is computed, the total score for each factor is calculated as:

$$TCf_j = \Sigma\ TCf_{ei}$$

Where:

TCf_j = sum of the e values given by the experts to factor j
TCf_{ej} = value that expert e assigned to factor j

Then a normalized weight value is $Ve = TCf_j / \Sigma TCf_j$ computed

The factor with the highest Ve is selected.

For example:

		Experts				
		i1	i2	i3	i4	
Factors	f1	2	1	3	3	9
	f2	1	2	1	2	6
	f3	5	4	4	3	16
	f4	3	5	2	1	11
	f5	4	2	5	5	16
					ΣTCf_j	58

		Ve
V1	9/58	0.155
V2	6/58	0.103
V3	16/58	0.276
V3	11/58	0.120
V4	16/58	0.276

SIMPLE VALUATION

Each alternative is scored in each criterion using the following scale of performance

2 = very positive	+1=positive	0=medium	−1=bad	−2=very bad

The scores for each alternative are summed and the alternative with the highest total value is selected.

		Criterions						
		C1	C2	C3	C4	C5	C6	Σ
Alternative	A1	+2	+1	0	+1	0	-1	3
	A2	+1	0	+1	0	0	0	2
	A3	+1	+2	+1	0	-1	-1	2
	A4	+2	+1	+2	+1	+1	+1	8

TOTAL AGGREGATION BY WEIGHTING

Probably the weighting methods are the most extensively used and best known in multi criteria analysis.

The general process involves:

- Scoring: Each alternative is assessed against the criteria. The alternatives are scored based on the criteria. The scores on each criterion are checked for consistency.

- Weighting: weights are assigned for each of the criterion to reflect their relative importance.

- Weighted scores: weights and scores are combined for each alternative to calculate the weighted score. All weighted scores are combined to obtain the overall weighted score.

Given that weights are value judgments, and sometimes indicators are of different nature, it is very important the method used to calculate the relative importance of each decision element be made extremely explicit and transparent.

Care must be taken so the criterion scales can be combined to obtain a meaningful weighted score. In order to compare indicators numerically, and to obtain aggregate value for each alternative (given that criteria scores can be quantitative and qualitative, and can be express in different measure scales, ordinal, interval or ratio) the criterion indicator scales must be in comparable units (SCOPE, 1979).

If normalization is not carried out, the results would not have a quantitative meaning. Various normalization techniques are available generally based on algebraic calculations. For example:

Normalization Technique: MIN-MAX

It performs a linear transformation on the original data normalizing the values between 0 and 1. Suppose that min_C and max_C are the minimum and maximum of feature C. The transformation would change the interval [min_C, max_C] into a new interval [new_min_C, new_max_C].

Every value of the old scale (V) would be normalized in the new scale (V_N) using the following formula:

$$V_N = \frac{V - \min_C}{\max_C - \min_C} \times (new\_\max_C - new\_\min_C) + new\_\min_C$$

For example, old scale (1 to 5), new scale (0 to 1). Normalize V = 3

$V_N = (3-1)/(5-1) \times (1-0) + 0 = 0.5$

The advantage of this method is that it preserves all relationships of the data values exactly.

Normalization Technique: DECIMAL SCALING

It normalizes data by a logarithmic transformation changing the decimal point of the values. For example, use if scales differ in range [0 to 1] and [0 to 1000].

$$V_N = \frac{V}{10^n}$$

Where n is the smallest integer such that makes $\max(|V_N|)<1$

For example, the V scale goes from –950 to 500. The maximum absolute value of V is 950, so n = next max integer ($\log_{10}950$) =next max integer (2.9777)=3

Normalization Technique: SUM

The normalization is obtained by dividing values by their sum.

Another way is by using the following formula $V_N = \dfrac{V - V\min}{\sum_1^n V - n \times V\min}$

Normalization Technique: VECTOR NORMALIZATION

Each row in decision matrix is divided by its norm. The elements of normalized matrix are calculated:

$$dij_N = \frac{dij}{\sum_{i=1}^{A} d_{i,j}^2}$$

Let A denote the total number of alternatives, and C the total number of criteria to be considered in a problem. The decision matrix is defined as

$D = (d_{i,j})$ for $1 \le i \le A$, $1 \le j \le C$

		Criterions				
		C_1	C_2	C_3	…	C_C
Alternatives	A_1	d_{11}	d_{12}	d_{13}	…	d_{1C}
	A_2	d_{21}	d_{22}	d_{23}	…	d_{2C}
	A_3	d_{31}	d_{32}	d_{33}	…	d_{3C}
	…	…	…	…	…	…
	A_A	d_{A1}	d_{A2}	d_{A3}	…	d_{AC}

WEIGHTED SUM

- Each alternative is scored for each criterion.
- Each alternative score is multiplied by the importance weight of the criterion.
- The weighted sum for each alternative is calculated.

$$Vi = \sum_{j=1}^{j=C} d_{ij} \times w_j$$

Simple method but limited when criteria have the same units of measurement.

WEIGHTED MEAN

Simple weighted averaging calculation is justified only if all the criteria is mutually preference independent; preference scores assigned to all alternatives on one criterion are unaffected by the preference scores on the other criteria (Dodgson *et al*., 2001).

The valuation process is as follows:

- Each alternative is scored for each criterion.
- Each alternative score is multiplied by the importance weight of the criterion.
- The weighted mean for each alternative is calculated.

$$Vi = \frac{\sum_{j=1}^{j=C} d_{i,j} \times w_j}{\sum_{j=1}^{j=C} w_j}$$

Where:

V_i= value for alternative i
d_{ij}= value assigned to alternative i criterion j
w_j = weight of criterion j

Example,

		Criterions								
		C1	C2	C3	C4	C5	C6	C7	C8	Vi
Weights		2	5	3	4	2	1	1	5	
Alternative	A1	9	8	8	6	7	4	5	10	7.8
	A2	8	10	6	7	5	5	6	7	7.3
	A3	7	9	7	8	6	3	3	8	6.9
	A4	10	7	9	9	8	6	7	9	8.3

V_4 = (10×2)+(7×5)+(9×3)+(9×4)+(8×2)+(6×1)+(7×1)+(9×1) = 192/23 = 8.3

PRODUCT OF NORMALIZED SCORE VALUES

- Select one alternative to be the "reference alternative".
- Normalize all alternatives with respect to the reference alternative.
- Calculate the product value of the normalized values.

$$Vi = \prod_{j=1}^{j=C} \frac{d_{i,j}}{d_{r,j}}$$

Where

Vi = weighted product value for alternative i
d_{ij} = value of criterion j for alternative i
drj = value of criterion j for reference alternative r

Example,

		Criterions								
		C1	C2	C3	C4	C5	C6	C7	C8	Vi
Alternative	A1	9	8	8	6	7	4	5	10	1
	A2	8	10	6	7	5	5	6	7	1.6
	A3	7	9	7	8	6	3	3	8	0.3
	A4	10	7	9	9	8	6	7	9	3.5

A1 is selected as reference,

$V_4 = (10/9)\times(7/8)\times(9/8)\times(9/6)\times(8/7)\times(6/4)\times(7/5)\times(9/10) = 3.5$

WEIGHTED PRODUCT OF NORMALIZED VALUES

- Select one alternative to be the "reference alternative".
- Normalize all alternatives with respect to the reference alternative.
- Calculate the weighted produces of the normalized values.

$$Vi = \prod_{j=1}^{j=C} \left(\frac{d_{i,j}}{d_{r,j}}\right)^{w_j}$$

Where

Vi = weighted product value for alternative i
d_{ij} = value of criterion j for alternative i
d_{rj} = value of criterion j for reference alternative r
w_j = weight of criterion j

Example,

		Criterions								
		C1	C2	C3	C4	C5	C6	C7	C8	Vi
Weights		2	5	3	4	2	1	1	5	
Alternative	A1	9	8	8	6	7	4	5	10	
	A2	8	10	6	7	5	5	6	7	
	A3	7	9	7	8	6	3	3	8	0.03
	A4	10	7	9	9	8	6	7	9	1

$V_{a3} = (7/10)^2\times(9/7)^5\times(7/9)^3\times(8/9)^4\times(6/8)^2\times(3/6)^1\times(3/7)^1\times(8/9)^5 = 0.03$

If the ratio is greater than or equal to one, then (in a maximization case) the alternative **i** is better than **r**. The best alternative is the one that has the highest value.

The weight product can also be approached as a pairwise comparison. When comparing an alternative s (A_s) to an alternative t (A_t), the product of the quotients (d_{sj} and d_{tj}) is calculated (raised or not to the weight). If $V_{(s/t)}$ is > 1 then alternative **s** is preferred to alternative **t**. Hence, to find the best alternative [A × (A-1)/2] pairwise comparisons needs to be conducted.

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