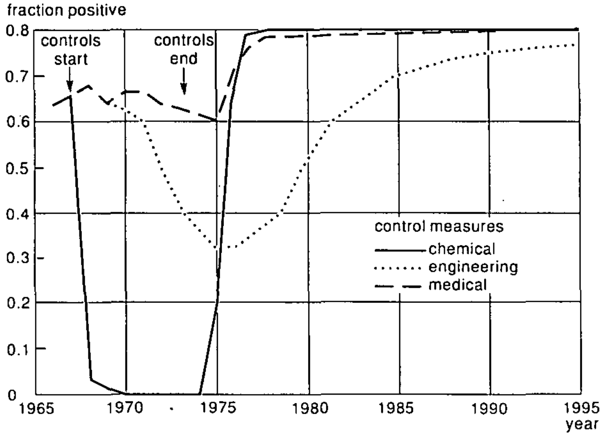

Figure 25.3 Predicted bilharzia prevalence in the Dez Irrigation Scheme, Iran (after Oomen et al. 1988)

Besides the positive impact that drainage has on public health, it can also have negative impacts (e.g. the leaching of high concentrations of toxic trace elements; Section 25.4.9). High concentrations of these elements can pollute the receiving water and be a health hazard. The maximum acceptable levels as recommended by the U.S. Environmental Protection Agency are given by Hornsby (1990).

Example 25.10
In the Dez Pilot Irrigation Project in Khuzestan Province, western Iran, irrigation in a 20 000 ha area started in 1965. Recognizing that any expansion in irrigation would also increase the prevalence of bilharzia, the authorities set up a bilharzia-control program in 1967 (Oomen et al. 1988). The program consisted of three types of measures: engineering, chemical, and medical. The engineering measures were to drain or fill borrow-pits, small ponds, and swampy areas around villages; the banks of canals were repaired; canals were dredged, and the land-levelling program was expanded. Chemicals were used to kill the snails. Finally, if the prevalence of bilharzia remained above 10%, drugs were used. Within eight years of the start of the control program, the prevalence of urinary bilharzia had been brought down to the 2% level. A stability analysis involving computer simulations showed that, if the control program were to be terminated, the impact of the engineering methods is superior to that of drugs and chemicals, particularly in the first decade (Figure 25.3).

25.5 Downstream Side-Effects

25.5.1 Disposal of Drainage Effluent

General
Drainage water has to be disposed of, either by gravity flow or by pumping, via a canal or directly into a river leading to the sea, or, more rarely, into an inland lake without an outlet, which generally consists of a specially created evaporation pond or series of ponds, or into an underground sink. On the way to its destination, the

drainage water can influence its surroundings in various ways. The problems associated with the disposal of drainage water are not the same everywhere. Here, we make a distinction between disposal in humid temperate areas, in humid tropical areas, and in arid or semi-arid areas.

Humid Temperate Areas

Technically speaking, drainage in many countries in the humid temperate zone is no longer a problem. The new, as yet unsolved, problem that has cropped up in the last 25 years is the pollution of surface water and groundwater as a result of the leaching of excessive amounts of fertilizers, liquid manure, pesticides, and herbicides. In principle, these problems are the result of intensified cropping practices and are not caused by drainage. When applied in quantities in excess of what is used by the crop or retained by the soil, fertilizers, manure, pesticides, and herbicides are partly leached out of the soil (Example 25.9). Subsequently, the leaching water either joins the groundwater or, if the land is drained, it appears as drainage effluent in the surface water. In both cases, considerable environmental problems can develop.

Nitrogen and phosphate that are leached out of intensively fertilized soils are major elements that cause the eutrophication of surface waters. Because more nutrients are available, the eutrophication leads to higher productivity that to some extent can be appreciated in a positive way. Nevertheless, the higher productivity includes excessive algae growth, and the subsequent turbidity causes many creatures to perish. Further, pesticides and herbicides leached from agricultural land and added to the drainage effluent can have toxic effects (Example 25.15).

Humid Tropical Areas

In the coastal plains of many countries in the humid tropics, large areas of peat and acid sulphate soils are found. If peat soils are drained, irreversible subsidence results, and if acid sulphate soils are reclaimed, the quality of the drainage water deteriorates as a result of the acidification. The negative effects often extend outside the reclaimed areas, because of the loss of functions and the change in the quality of the drainage effluent (Section 25.4.6).

Arid and Semi-Arid Areas

The main purpose of drainage in arid and semi-arid areas is salinity control (i.e. by leaching out the salts that would become harmful to irrigated production if they remained in the soil; Chapter 14). More often than not, the disposal of the effluent is a costly affair, and an appropriate disposal (i.e. without considerable environmental side-effects) can be prohibitively expensive. For reasons of costs, many irrigation schemes in arid and semi-arid areas have no drainage system at all, or, if they do, the saline drainage water is often disposed of (i.e. dumped) into a river whose water has to be used for irrigation or other purposes downstream. Because the drainage of irrigated lands is – with few exceptions – essential for sustainable irrigated production, the problem of a cost-effective and environmentally-safe disposal of drainage effluent is one of the most urgent items to be tackled. The challenge of solving this problem, even in rich countries, is enormous. If no action is taken, many irrigated areas will be ruined and lost forever through salinization and sodification.

Because of limited rainfall, most soils in arid and semi-arid regions contain large quantities of soluble material below the rootzone. When these soils are irrigated, harmful salt concentrations can develop in the rootzone because of the addition of the salts brought in with the irrigation water (which is transpired by the plants), and because of the upward movement of salts by capillary rise from below the rootzone (Chapter 11). By over-irrigating (for leaching), accompanied by drainage, these harmful salt concentrations in the rootzone will not develop (Chapter 15). The consequence of this process is that the drainage effluent contains a relatively high concentration of salts. The salt concentration, or the composition of the salt, can be such that the water is an environmental hazard, by being an unsuitable habitat for aquatic creatures, by being unsafe for drinking, and by being unsuitable for irrigation.

Reducing the problem either by using large quantities of water for leaching or by mixing the drainage effluent with water that has a low salt concentration to reduce the salinity of the drainage water to acceptable levels is generally impossible because the water is simply not available.

25.5.2 Disposal Options

Options to minimize the disposal problem can be either to reduce the quantity of drainage water by preventive measures or to solve or reduce the effects of the disposal of drainage water. Preventive measures should aim at improving irrigation and drainage efficiencies. Measures to reduce the downstream effects of the disposal of drainage effluent are:

- The re-use of the drainage water;
- Discharge to surface water;
- Evaporation ponds;
- Desalination;
- Deep-well injection.

The two preventive methods and the first three disposal options will be discussed in this section. The last two options, well-known treatments in the oil and gas industry, are at present not used to dispose of drainage water and will not be further elaborated, although reference is made to Tanji (1990).

Improving Irrigation Efficiency

The question of whether or not to increase irrigation efficiency was discussed in Chapter 14. Wolters (1992), in a study covering about 5% of the total irrigated area in the world, reported irrigation efficiencies varying between 10 and 80%. Sometimes, low efficiencies are acceptable or unavoidable, but in other circumstances it may be necessary to increase already high effiencies. If irrigation efficiency can be increased, the amount of water percolating to the groundwater will be reduced, thereby increasing the drainage efficiency.

The technical measures to solve irrigation-induced water-disposal problems can seldom be considered on their own. They need to be underpinned by charges, subsidies, a legal framework, and other supporting measures.

Charges and subsidies are effective incentives to encourage people to perform certain activities, or to discourage them from doing so. Charges can be an effective tool to control water consumption or disposal. In many countries, actual water charges are far below the cost of water development, which means that there is little or no incentive to economize on irrigation water. By making water available to irrigators at cost price, which is usually much higher than the price charged, an incentive for water saving can be introduced.

Improving Drainage Efficiency

Sometimes, drainage efficiency can be improved by installing a shallower drainage system or maintaining a higher watertable during part of the year as was discussed in Section 25.4.3. This not only reduces water shortages but can also prevent the drainage of deeper saline aquifers, which can deteriorate the quality of the drainage water (Grismer 1989).

Waste water, which is often polluted in one way or another, cannot generally be disposed of free of charge. Urban councils, responsible for waste-water treatment, charge households and industrial customers under the banner of 'The polluter pays'. In many countries, agricultural waste water, including drainage water from irrigated lands, can be dumped free of any charge. By instituting a waste-water-disposal charge that is related to the quality and quantity of the released effluent, the agricultural polluters could pay for preventing or cleaning up the environmental damage they cause.

Re-Use

The re-use of drainage water is practised worldwide, mostly in arid or semi-arid regions where irrigation water is in short supply, but also in temperate regions, where re-use is practised during the dry summer months. Re-use can be practised at farm level, project level, and regional level. Drainage water can never be completely re-used, however, because the salts that are imported with the irrigation water have to be exported out of the area. It is therefore always necessary to make a water and salt balance to calculate the long-term effects of the re-use of drainage water on soil salinity (Chapters 15 and 16).

Re-use at farm level can be practised when the drainage water is of good quality. Farmers can pump irrigation water directly from the open drains (Example 25.11) or use shallow wells to pump groundwater.

Re-use at project and regional level is practised when drainage water is pumped back into the irrigation system (Example 25.12). With this type of re-use, the drainage water is automatically mixed with better-quality irrigation water. The quantity and quality of both the irrigation and drainage water determine how much drainage water can be re-used. Because this type of re-use requires high investment costs (i.e. the construction of pumping stations) and because the effects on soil salinity are difficult to predict, careful planning is a prerequisite. Computer simulations can help to predict future changes, as will be illustrated in Example 25.11.

Example 25.11

In the Nile Delta in Egypt, farmers re-use drainage water by pumping it for irrigation directly from the drains. On the basis of a measuring program and simulations with the SIWARE integrated water-management model (Abdel Gawad et al. 1991), it is estimated that, in the eastern part of the Nile Delta, 15% of the crop water is supplied from groundwater and on-farm re-use. A major disadvantage of this type of re-use is that, because the salinity of the re-used water is often high, it contributes more than proportionally to the total salt supply to the crop. For the Eastern Nile Delta, the chloride contribution of the 15% re-used water is about 46% of the total crop chloride supply through irrigation.

Example 25.12
Since 1930, 21 pumping stations have been built in the Nile Delta in Egypt to pump part of the drainage water back into the irrigation system (El Quosy 1989). In the 1980's approximately 2.9×10^9 m^3/year of drainage water with an average salinity of 1.45 dS/m was pumped back into the irrigation system, totalling approximately 15% of the crop water supply.

Discharge to Surface Waters
In general, drainage water is discharged to rivers or lakes. If this water is used again for irrigation in downstream reaches, it can also be regarded as re-use. The natural flow in the river, both quantitatively and qualitatively, determines how much drainage water can be discharged into it (Example 25.13). Models can be used to simulate the effect of the disposal of re-used water on the river regime (e.g. Smedema et al. 1992).

Example 25.13
Once more, Egypt serves as an example. Agriculture in Egypt depends almost entirely on irrigation from the Nile. Of the amount of water passing the Aswan High Dam (approximately 55×10^9 m^3/year), part is used to irrigate the Nile Valley between Aswan and Cairo (approximately 0.9×10^6 ha). Because all the drainage water is discharged back into the River Nile, the salinity of the Nile water increases in downstream direction (Table 25.2). The increase in the total salt load between Cairo and the Mediterranean Sea is due to the leaching of deeper (saline) soil layers and the seepage of saline groundwater.

If the receiving water cannot cope with the amount of drainage water, a separate facility to a safe outlet, usually the sea, has to be constructed. Two of the best known outfall drains, especially created for the disposal of highly saline drainage water, are the Left Bank Outfall Drain in Pakistan (Example 25.14) and the Third River in Iraq.

Table 25.2 Discharge, salinity, and salt load in the River Nile (after El Quosy 1989)

Location	Discharge ($\times 10^9$ m^3/yr)	Salinity (dS/m)	Total salts ($\times 10^9$ kg)
Aswan High Dam	55	0.31	11.0
Delta Barrage (Cairo)	35	0.47	10.5
Mediterranean Sea	14	3.59	32.0

The Third River, which was completed in 1993, acts as an outfall drain for the area between the Euphrates and the Tigris.

But even the disposal to such a 'safe' outlet (the sea) can have environmental effects. An example is the eutrophication of the North Sea caused by the leaching of minerals from agricultural land as a result of the excessive use of manure, fertilizers, and pesticides.

Example 25.14
The Left Bank Outfall Drain has been constructed to drain approximately 0.5 million ha in the Sind Province of Pakistan (McCready 1987). The disposal of the drainage effluent to the River Indus or one of its branches is unacceptable because of the high salinity levels: the effluent from subsurface drainage can vary from 4.7 to 15 dS/m and that from tubewells can be twice as saline. Disposal into the river would result in too high salinity levels and would make downstream use for irrigation impossible.

Evaporation Ponds
If there is no safe outlet available for the drainage effluent, evaporation ponds can be used. In such ponds, the drainage effluent evaporates from the open water surface, leaving the salts and other soluble trace elements behind. This results in large amounts of soluble salts and trace elements.

The size of an evaporation pond must satisfy the needs of the land area being drained, which means it must be based on the volume of drain water and the rate of evaporation for that region. Evaporation ponds can be natural depressions or artificial basins. Natural depressions have the advantage that the drainage effluent can be discharged by gravity flow, and the only construction work involved is to make earthen embankments and a spillway to regulate the water level in the pond. Artificial basins generally need pumping facilities to lift the drainage effluent.

The disadvantages of evaporation ponds are: loss of land, seepage, and the disposal of the remaining salts. Experience in California indicates that the area needed for evaporation ponds comes to 10 to 14% of the land area (Tanji 1990). Seepage from the pond to any underlying aquifer should be avoided because of the large quantities of soluble salts and trace elements involved. Especially in coarser soils, the ponds should be lined. Sometimes, evaporation ponds can be used to store salts during periods with low river flow, when the disposal of the drainage effluent would create unacceptable effects downstream. The ponds are then flushed during high river floods, discharging the salts safely to the sea. If no periodic flushing is possible, the removal of the salts is problematic, especially when the drainage water contains toxic trace elements.

To some extent, the environmental impact of dumping saline water in ponds is predictable. Nevertheless, the Kesterson experience in California, U.S.A., proves that there are unexpected and unpredictable dangers in evaporation ponds (Example 25.15).

Example 25.15
The San Joaquin River basin in California, U.S.A., has about 2 million hectares of irrigated agriculture. Salinity affects part of these lands and subsurface drainage was therefore installed. The quality of the drainage water was such that its disposal in

the San Joaquin River created problems for its downstream use for irrigation. A separate drainage canal, the San Luis Drain, was therefore planned to dispose of the drainage effluent in the San Francisco Bay. Because of environmental opposition and cost considerations, the San Luis Drain was only partly constructed. As a temporary solution awaiting the completion of the San Luis Drain, the drainage effluent was dumped into a series of evaporation ponds that became known as the Kesterson Reservoir (CIIWQP 1989).

The ponds, the only large water surfaces in the area, attracted great numbers of waterfowl and shorebirds, so that the area became known as the Kesterson Wildlife Refuge. Happiness about a newly created wildlife area was of short duration. Some years after the ponds began to be used, deformations in fish and birds appeared. A few years later, massive deaths occurred in birds as well as in fish. The cause of the mortality was found to be a too high concentration of the trace element, selenium, which occurs in various sediments that formed the soils of the San Joaquin Valley.

The environmental problems that gradually developed at the Kesterson Reservoir have received considerable attention and have resulted in an enormous number of publications (e.g. Summers and Anderson 1986; 1988; 1989). The events occurring at the Kesterson Reservoir appear to have been major instruments in making the U.S. aware of environmental problems associated with drainage (e.g. Summary, Highlights, and Future Trends and Prospects in: Pavelis 1987 and Tanji 1990).

25.5.3 Excess Surface Water

The installation of a subsurface drainage system can reduce surface runoff inside the project area (Example 25.8), but it can also lead to excessive surface water in downstream areas. On a small scale, this can happen when one farmer drains his land and evacuates his drainage water to the land of his downstream neighbour. On a large scale, downstream areas can suffer from excess water as a result of (surface) drainage upstream. The most common occurrence of this kind of problem is when infiltration is reduced upstream (e.g. by the felling/denudation of forests without the necessary precautions being taken to maintain the infiltration of intensive rainfall). This can cause enhanced runoff upstream and increased peak river flow and inundations in the downstream parts of river catchments. (How to calculate peak runoff rates was discussed in Chapter 4.)

25.5.4 Seepage from Drainage Canals

To reduce construction costs, main drains, which evacuate drainage effluent from upstream areas, often have water levels close to the soil surface in their downstream reach. Unless appropriate measures are taken, the productivity of land adjacent to drainage canals can be negatively affected by (saline) seepage (Example 25.16). As such seepage depends on the difference in hydraulic head and on permeability (Chapter 9), it can largely be prevented by (costly) lining or other methods which decrease embankment permeability. The magnitude of the seepage and eventual salinity resulting from it determines whether any preventive action needs to be taken.

Example 25.16
At the Fourth Drainage Project in Pakistan, a subsurface pipe drainage system disposes of the drainage effluent by pumping it into a surface drainage network for conveyance to the Ravi River (Vlotman et al. 1993). Subsurface PVC interceptor drains were constructed along some sections of the surface drains to stabilize the deeply cut side slopes. Generally, the water level in the surface drainage system is higher than the watertable in the field, so the interceptor drains also intercept saline seepage water from the surface drains. Up to 40% of the discharge of one of the pumps of the subsurface drainage system comprised water from the interceptor drains.

It is expected that the water quality in the surface drainage system will deteriorate with time when more subsurface drainage units become operational. To protect the adjacent agricultural lands, the seepage from these surface drains has to be intercepted.

25.6 Upstream Side-Effects

Lowering the watertable in the project area usually leads to more seepage into the area and also to a lowering of the watertable in the area upstream of the project. In non-irrigated areas, such a lowering of the watertable can negatively affect plant growth because the contact between the (non-saline) groundwater and the rootzone is broken and this will lead to a decrease in yield. To prevent a fall in groundwater in the areas upstream of the reclaimed polders in the IJsselmeer in The Netherlands, border lakes have been maintained as a buffer.

25.7 Environmental Impact Assessment

In the previous sections, it has been shown that drainage can have many environmental impacts and that its relationship with the agricultural options can be complex. An Environmental Impact Assessment (EIA) is used as a tool for identifying alternative options during the reconnaissance and/or feasibility phase of the project cycle and to assess the environmental impacts of each of these options. It is merely a prediction of what may happen once a project is implemented. It is not the actual development, but only a scenario, which can make the decision-making process more clear. In this section, we shall briefly discuss the principles of an EIA. (For more details, see ODA 1992; Meister 1990; World Bank 1989; Biswas and Geping 1987; or Winpenny 1991.)

The purpose of an EIA is to ensure that the development options under consideration are environmentally sound and sustainable, and that any environmental consequences are recognized early in the project cycle and are taken into account in the project design. The EIA is characterized by the following steps (Figure 25.4):
- Defining the objectives of the project and selecting the evaluation criteria;
- Formulating alternative development options;
- Assessing the environmental effects;
- Selecting the evaluation method;
- The evaluation;
- Results of the evaluation/conclusions.

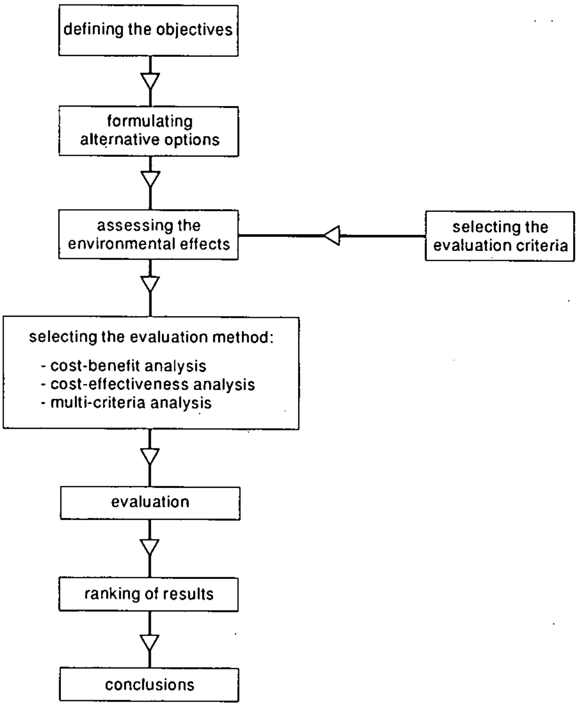

Figure 25.4 Steps in an Environmental Impact Assessment

Objectives and Criteria

In many countries, there is a legal obligation for an EIA before decisions can be made about the implementation of (major) projects. At this stage, it should be clear who is responsible for the EIA, what the scope of the study will be, how the results of the EIA will be presented, and who will use the results. It is important to realise that an EIA should focus on the main issues. Going into too much detail will make it extremely difficult to evaluate the alternative options. To make a good EIA, the objectives of the proposed project must be well defined, and the criteria, which will be used to compare the alternative options, must be clearly stated.

Alternative Options

Alternative options may include alternative sites, alternative technologies, or alternative phasing. It should be kept in mind that only the main issues are to be considered, so the selected options should not be too detailed. A difficult question is the number of options that should be considered. On the one hand, too many options make a comparison difficult, but, on the other hand, one should be careful not to exclude options that at first glance look unrealistic. Care should be also taken that the selected options are not biased. For example, an engineer, using his common 'technological' sense, tends to select the options that he favours, often excluding non-technical options. It is essential that the 'no project' option be included. The choice is rarely 'environment-versus-development', but rather a question of incorporating sensible environmental protection measures into the earliest stages of development projects.

Assessment of Effects

At this stage, the environmental effects of the project should be identified and quantified. The parameters that are used to quantify these effects can be technical (e.g. groundwater salinity, subsidence), but also socio-economic (e.g. farm income, health). Some impacts that may be difficult to quantify can only be assessed in a qualitative form. Checklists of possible environmental impacts have been prepared by the International Commission on Irrigation and Drainage (Mock and Bolton 1993) and the Overseas Development Administration (1992).

Baseline data on these parameters have to be collected and the changes that will result from the project activities have to be assessed. One of the reasons for including the 'no-project' option is that, with this option, the autonomous developments can be made visible.

Evaluation Methods

To select the best option, the combined effects of each option have to be compared. In an economic evaluation, this is done by translating these effects into monetary terms. When impacts cannot be monetized, however, they have to be retained in the analysis in a qualitative manner. Three evaluation methods will be briefly discussed: the Cost-Benefit Analysis, the Cost-Effectiveness Analysis, and the Multi-Criteria Analysis.

The Cost-Benefit Analysis (CBA) is an economic evaluation method in which the project's monetized benefits and costs are compared to verify its economic feasibility. The CBA includes three steps:

- All negative and positive effects are quantified in monetary values;
- For each effect, the present value is calculated;
- The best option is selected, using the Net Present Value (NPV), the Benefit-Cost Ratio (BCR), or the Internal Rate of Return (IRR).

The NPV and BCR methods use a pre-selected interest rate, which is called the Opportunity Cost of Capital (OCC). The IRR does not require a pre-selected interest rate, but the same judgement is needed to determine whether the project is economically attractive. The World Bank, for example, uses the IRR method, but usually requires the IRR to attain 10 to 12% for all projects.

Advantages of the CBA are that all effects are expressed in the same (monetary) dimension, which makes a straightforward comparison of the alternative options possible.

Limitations of the CBA are that:

- Effects have to be monetized, so effects that cannot be monetized are left out;
- The distribution of benefits and costs over the various parties involved is not taken into consideration unless 'social prices' are used;
- The long-term effects that are valued according to the process of discounting reduces the future net benefits.

Especially when long-term effects on the environment are uncertain or irreversible, the economic concept of discounting is controversial. In practice, measuring and evaluating problems have often impeded a comprehensive treatment of environmental effects in a CBA. If a function/value table is included, it is possible to incorporate environmental costs and benefits in the CBA. Alternative methods to overcome these limitations have been presented by Dixon et al. (1988)

The Cost-Effectiveness Analysis (CEA) investigates the best or cheapest way of achieving a desired objective by comparing the costs of possible interventions. The benefits are not expressed in monetary terms but in only one representative criterion that quantifies the effects of the project. Advantages of the CEA are that non-monetary effects can be included. Nevertheless, it is difficult to attribute all effects to one criterion, and often side-effects are not taken into consideration. Furthermore, because the benefits are not expressed in monetary terms, it is not possible to include the factor time and thus to compare effects which occur at different time steps.

The Multi-Criteria Analysis (MCA) is an example of a non-monetary evaluation method in which alternative options are compared using criteria of different dimensions. To account for the relative importance of each criterion, a weight can be attributed to it. MCA methods have been developed to overcome the limitations of the economic evaluation methods that all effects have to be expressed in monetary terms. As it is difficult to judge the importance of each criterion, however, and thus to select the correct weighting factor, the results of a MCA are often ambiguous. (For examples of MCA, see the United Nations Environmental Programme 1988.)

Results of Evaluation

The evaluation should result in a priority ranking of the selected options and, based on this classification, an option has to be selected. At this stage, it is important to know the degree of confidence of the EIA, the need for further data collection, analysis, etc.

In general, it can be said that an Environmental Impact Assessment makes it possible to assess environmental impacts and to compare alternative options systematically. Furthermore, the method requires that objectives and selection criteria be clearly stated and that the results are presented in a classified way. A major drawback is that the method suggests objectivity, but in reality each step requires subjective choices (selection of criteria, selection of options, selection of parameters, etc.).

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