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Supporting decision making under uncertainty for river basin management – Guidance for HarmoniRiB case studies

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Supporting decision making under uncertainty for river basin management – Guidance for HarmoniRiB case studies*

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Content

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1 Introduction

1.1 Focus of this guidance

The focus of this guidance document is decision making under uncertainty in river basin management. Our purpose is to give hints for the analysis of decision situations in the HarmoniRiB case studies.

The background of HarmoniRiB and thus of the case studies is the implementation of the EU-Water Framework Directive. The directive states the goal that all waters[3] in the EU should reach a good status[4] by 2015[5]. In order to achieve this goal the member states need to set up river basin districts, each one having a management plan that includes a programme of measures which will achieve good status in the most cost-effective manner. We conceptualize this management problem as a decision problem: Which measures should be selected for the programme of measures?

The HarmoniRiB case studies are not able to cover all problems of the implementation of the EU-Water Framework Directive in all their complexity. They only investigate certain aspects of this problem. Therefore, we concentrate in this guidance document on a certain type of decision, the **selection of management measures** to reach a certain goal (this would usually be good status) for the case study river basins. Thereby we put a special focus on uncertainties.

1.2 Overview

The decision making process is structured in three phases:

1. *Framing the decision making problem* including the problem identification, a first analysis of pressures and impacts, the identifications of potential measures and alternatives actions, and the identification of evaluation criteria.
2. *Impact analysis* where the effects of the different measures and alternatives on the considered criteria are estimated and assessed.
3. *Final evaluation, decision support and decision making* where the information of the impact analysis is analysed, interpreted and utilised for supporting the decision makers and finally influences the actual decision making.

The following structure might be used as a structure for the documentation of the case studies. Pending on the focus and intention of the case study the complete treatment of

[3] Waters are defined as rivers, lakes, transitional waters (estuaries) and coastal waters.

[4] There are five status classes, high, good, moderate, poor and bad. Each is defined by ecological, physico-chemical and morphological criteria deviating from a reference condition (which is high status)

[5] The Directive does allow certain reasons why this criterion and deadline may not be met, briefly:

- Where certain uses prevent good status but deliver over-riding economic benefit (the heavily modified designation)
- Where achievement of the objective would incur disproportionate costs (derogation), this may involve extending the deadline to a later one
- Arising from natural disasters.

a decision making process might be too ambitious. It is indicated in the text where some short cuts are possible. But it should be kept in mind that a well-founded policy advice needs a thorough consideration of all phases and the involved complexities.

2 Framing the decision making problem

2.1 Identifying the problem

2.1.1 Good status reached or failed?

Each case study should start with an analysis of the status quo: are the water bodies in the river basin at (or above) good status? If not, then action must be taken to achieve good status. Also, does the prolongation of the status quo, i.e. the baseline scenario, indicate that the good status will be failed in the future? This first analysis of the river basin needs a thorough knowledge of the river basin. It might be supported by modelling.

2.1.2 Concentration on one or two problem fields

The WFD demands to reach the good status simultaneously in all respects. Good status is defined as two equally important elements, good ecological status and good chemical status. The former is defined based on biological quality elements, together with supporting hydro-morphological (hydrological and morphological), physico-chemical (e.g. temperature, salinity) and chemical elements. Groundwater status is defined in terms of water balance and chemical status.

In theory, for the case studies to follow the Directive, each should make explicit reference to biological quality elements. However as general understanding of the links between physical and chemical pressures is likely to be low, this may not be possible, at least in a quantitative manner. We recommend for the case studies to concentrate on one or two aspects, where the good status is failed (e.g. hydrological alteration, eutrophication (nutrient concentration), morphology, ground water balance). Possible pressures are (see UBA 2004, 29):

- Point sources / sewage treatment
- Point sources / precipitation
- Diffuse sources
- Water abstraction
- Run off regulation
- Morphology

2.1.3 Identifying the decision maker(s)

In many member states the institutional arrangements for the implementation of the WFD are not completed by now. Particularly the responsibility for setting up the river basin management plan and the programme of measures is not clarified, yet. However, a prerequisite for the analysis of a decision making problem is that the decision maker (or group of decision makers) with his authorities and responsibilities is identified. The decision maker will normally be a competent authority, designated by central government and given delegated powers. For example in the UK, there is a competent authority for England and Wales, the Environment Agency. In some instances, central or regional government itself could be the decision maker.

The decision maker receives the decision support. He is also the final instance for all evaluations, preliminary decisions and (of course) final decisions. The scientists and/or consultants provide services to the decision maker.[6]

2.1.4 Identifying the problem and uncertainty

The identification of the problem is the basic step of any analysis. The investigation of uncertainties builds on this. An explicit analysis of the uncertainty of this first and fundamental step is rather difficult.

2.2 Objectives and criteria

2.2.1 Objectives

The most prominent objective of the Directive is the good status of the waters. The definitions of the good status of ground and surface water are laid down in Appendix V of the Directive. The practical definitions of the objectives have not yet been stated by the European Commission, so they has not been available for the HarmoniRiB case studies, yet. (See guidance of ECOSTAT working group.)

The good status is not the sole source for evaluation criteria in the WFD. The text provides many more norms and objectives:

- *General objectives*. Article 1 contains a list of general objectives including “promotion of sustainable water use based on long-term protection of available water resources” or “mitigating the effects of floods and droughts”. However, how these general objectives link to good status is not defined further.
- *Cost-effectiveness*. The WFD asks in Article 11 and Appendix III for taking into account the cost effectiveness of the alternatives. The WATECO guidance document gives special emphasis to cost-effectiveness (more than one would expect after a reading of the legal text of the WFD). Therefore, it can be foreseen that cost-effectiveness will be of high importance for the selection of measures to be included in the programme of measures.
- *Weightings, (dis-)proportionality and exceptions*. The WFD leaves space for the river basin authorities, the member states and the European Commission to interprete the objectives and to assess how a river basin district performs with respect to the objectives. Furthermore the WFD foresees in Article 4 and elsewhere exceptions from the good status under certain circumstances (e.g.

[6] Since the implementation of the WFD is an obligation of the member states, the decision maker acts in behave of the public not in behave of himself. He is responsible to the public. Taking this into account the scientist and/or consultant have simultaneously the role of an informed citizen who controls the decision maker.

disproportionality of costs, use of rivers for shipping). Although these weightings and exceptions will not be in the centre of the HarmoniRiB case studies, they should be kept in mind when interpreting the results of an cost-effectiveness or multicriteria analysis and particular when discussion the results with the decision makers.

2.2.2 Criteria

For a formal decision analysis and decision support the objectives need to be transferred and operationalized to evaluation criteria. A criterion is understood as an instruction for measuring the degree of reaching the related objective. The measuring might be on a numerical scale but it might be on a linguistic scale (e.g. ‘good’, ‘medium’, ‘bad’), too.

For reasons of practicability we recommend to concentrate in the case studies on the following three coarse categories of criteria for the evaluation of management measures: Effectiveness (with respect to reaching the good status), costs, and supplementary criteria (like practicability, acceptance, and impacts on tourism/regional economy). Examples for criteria might be:

Effectiveness

- Concentration of nitrate, phosphate or other substances at certain gauges (mg/litre)
- Total load of phosphate or other substances at certain gauges (kg)
- Numerical indicator for morphology (no unit)
- Saprobeian index (no unit)
- Number of fish species (no unit)

Costs

- Total costs (€)
- Direct implementation costs (€)
- Indirect costs (€)

Supplementary criteria

- Social welfare (€)
- Employment (no unit)
- Practicability (‘good’, ‘medium’, ‘bad’)
- Acceptance (‘good’, ‘medium’, ‘bad’)

The criteria should be selected in a way that double counting of effects is avoided or at least made transparent. An example of double counting would be a simultaneous use of environment and resource costs on the one hand and total costs on the other hand because the total cost includes the former cost category.

2.2.3 Uncertainty about objectives and criteria

The statement of objectives is more or less precise. A political statement that the government “wants to do anything to foster a sustainable development of the water resources” leaves much space for interpretation. The good status of the WFD is much more accurate and controllable. At the moment the exact formulation and operationalization has not been worked out by the European Commission, yet. However, any attempt for exact definitions and operationalizations will nevertheless not reduce the space for weighting and interpretations to zero.

2.3 Preliminary list of potential measures

2.3.1 Definitions

The notion "measure" is crucial for the WFD but is not clearly defined. A measure is an action directed toward a certain objective.[7] The description of a measure should include the actor, the purpose of the action and the action itself.

For a well-defined selection problem the measures should fulfil the following prerequisites:

- *The decision maker should be the actor*. The decision maker should have the power to realize the action if he wants to do so.
  E.g. the actor of "reduction of fertilizer" is a farmer. Therefore, it is not a potential measure of a river basin authority because the latter does not have the power to directly reduce the fertilizer. But the authority may try to influence the behaviour of the farmer by taking a different kind of measure. Example for a measure by the river basin authority that subsequently leads to a reduction of the fertilizer are a nitrate tax, a regulation that establishes an upper bound for fertilizer or a programme that gives incentives for organic farming.
- *The actions should be alternatives*. Taking one action should be independent form taking another one. If one action cannot be taken without taking the other one, too, they should be regarded as one action.
- *The actions should be comparable*. The actions should be described in the same level of detail.

To reach a complex goal like the good status of waters in a river basin there are in general many chains of single measures needed, that are linked and hierarchically build on each other.

In the context of the WFD we define a measure as an action of the decision maker (i.e. the member states or the authority responsible for the implementation) that is purposely undertaken towards achieving objectives of the WFD. Only in a few cases the decision maker will be able to act in a way that the status of the waters is directly improved. Most of the time they rather will issue orders, regulations, or prohibitions, put economic

[7] The incomplete list of principle and supplementary measures in Appendix VI of the WFD gives hints, what categories of measures that are in principle suitable for inclusion in the programme of measures. However, the WFD does not answer the question what degree of concreteness is requested, what spatial scale and what administrative level is corresponding to the measures. Appendix VI contains, for instance, the Bathing Water Directive (76/160/EEC), the Drinking Water Directive (80/778/EEC) as amended by Directive (98/83/EC), the Sewage Sludge Directive (86/278/EEC) (4), the Urban Waste-water Treatment Directive (91/271/EEC), the Nitrates Directive (91/676/EEC) as „basic measures". Furthermore so-called "supplementary measures" are mentioned in an "incomplete list": legislative instruments, administrative instruments, economic or fiscal instruments, negotiated environmental agreements, codes of good practice, recreation and restoration of wetlands areas, abstraction controls, demand management measures, inter alia, promotion of adapted agricultural production such as low water requiring crops in areas affected by drought, construction projects, educational projects, and research.

incentives, reach voluntary agreements with polluters or take other measures that influence the behaviour of private households, farmers, companies etc. We call the measures that try to influence the behaviour of other persons so that they e.g. refrain from polluting water or from abstracting water **actor-related actions**. We define on the contrary **environment-related actions** as actions that directed by their actors directly towards improving the state of the waters. Examples for environmental-related actions are riparian buffer strips, reduction the density of cattle on meadows, removal of dams and weirs.

In order to evaluate the impacts of an actor-related measure, one needs to consider the environment-related actions that are initiated by the former, too. That is, if the case studies aim at decision support of water authorities they **need to consider combinations of actor- and environment-related measures**.

2.3.2 Incomplete list of actor-related measures

Actor-related measures are undertaken by the decision maker (WFD competent authority for river basin management). The measures try to influence the behaviour of persons who in turn affect (directly or indirectly) the status of the waters. The intensity of the intervention of the decision maker can vary between orders and prohibitions that prescribe a certain mode of behaviour and advisory instruments that maybe only offer the necessary information for a change of behaviour. As a general the rule of thumb holds that a higher intensity of intervention brings about a higher degree of certainty that the intended effect will be realized.[8] However, the impact of a measure greatly depends on the concrete design (UBA 2004, 43-44). Examples of actor-related measures are:

Legal instruments

Legal instruments are characterised by a very high level of intervention intensity, in that they prescribe or prohibit certain modes of behaviour.

- Orders, prohibitions.

Charges, taxes and other financial incentives

Charges, taxes, subsidies and the like try to influence (economic) behaviour by changing prices for goods. Higher prices generally lead to a decline of the demand for the good and vice versa. The intervention intensity is lower than that of legal instruments but still high.

- Charges on fertilizer.
- Programme to foster organic farming.

Co-operative instruments and voluntary agreements

Co-operations need a good will of all involved parties. The intervention intensity is rather low because the agreements are voluntary. However, the practice shows that voluntary agreements are easier to reach if there is a ‘threat potential’ e.g. by threatening to issue an order or a prohibition.

- Contracts between river basin authorities and farmers, industries, etc. The content of the contracts can vary greatly.

[8] Higher degree of certainty that the intended effect will be realized is not identical with a higher degree of effectiveness (as suggested by UBA 2004, 44).

- Unilateral promises of polluters, e.g. industry codes of practice.

Advisory instruments

Advisory instruments work by offering information necessary to modify behaviour and by referring the benefits of a changed behaviour. The level of intervention intensity is the lowest compared to the categories above. Their effectiveness often relies on demonstrating a financial benefit to the actor (e.g. lower costs because of reduced but more effective fertilisation).

- Offer of advice and consultancy, providing information material on a web page.

Direct action

In some cases the distinction between actor-related and environment-related measures is not necessary because the decision maker is at the same time the actor of an environment-related measure. This could be for example:

- Removal of dams and weirs (if they are owned by the river basin authority)
- Purchase of land (e.g. for afforestration, riparian buffer strips, reduction of farm land)

Development of new actor-related measures

The listed actor-related measures may be combined to new and more comprehensive measures. It is e.g. necessary to accompany an organic farming programme by advisory instruments to guarantee that the know-how for environmentally sound farming is available.

2.3.3 Short cut for case studies

The analysis of actor-related measures is crucial for the analysis on a decision making problem because the focus is directed towards the possibilities of the decision maker to take action. However, the prediction of behaviour of third persons is extremely difficult and uncertain. Moreover most of the expertise in HarmomiRiB is in natural sciences not in social sciences. For these reasons we would advise if resources are limited to concentrate in the case studies on the analysis of environment-related measures. The cost of this concentration would be that comprehensive decision support is not possible any more. Evaluation techniques like cost-effectiveness analysis and multicriteria analysis cannot be applied. Only parts of the impact analysis can be conducted. Important proportions of costs will probably be neglected because they are related to actor-related measures. To summarize: The (intermediate) results must be interpreted very carefully.

2.3.4 Examples of environmental-related measures

The following examples of environmental-related measures are taken from the problem areas point and diffuse sources. A more extensive discussion of these measures can be found in UBA (1999, 2004, 104-245).

Point sources

- *Upgrading of a sewage treatment plant with regard to the parameters BOD_S, COD, NH_4-N, N_{total} or P_{total}*

  - *Brief description*. The listed substances negatively affect the aquatic system. Improving the treatment technique lowers the discharge of these substances into the surface water.
  - *Actors*. Associations and independent organisations that run a sewage treatment plant, local authorities, companies.
  - *Possible actor-related measure*. Orders that tighten up the environmental and technical standards, subsidies for investments in better techniques.
- *Reducing the discharge of substances from chemical production and application via membrane filtration*
  - *Brief description*. Many substances produced by the chemical industry harm the status of the water. Changes in the production techniques can lower the discharge of the harmful substances to the aquatic system.
  - *Actors*. Companies, small private enterprises
  - *Possible actor-related measure*. Orders that tighten up the environmental and technical standards, voluntary agreements, subsidies for investments in better techniques, money for R&D activities (supporting, long-run measure).
- *Qualified dehydration in the combined and separation process*
  - *Brief description*. Separate collection and discharge of rainfall and sewage if economically reasonable. Discharge of heavily contaminated rainfall only after prior treatment.
  - *Actors*. Associations and independent organisations that run a sewage treatment plant, local authorities, companies, private households
  - *Possible actor-related measure*. Development programme, subsidies

Diffuse sources

- *Reduction of nutrient and pesticide discharges via the creation of riparian buffer strips*
  - *Brief description*. Riparian buffer strips reduce the erosion of particles directly into the surface water. Therefore, the discharge of nutrients and pesticides that mainly transported by particles (e.g. phosphorus) will be reduced. Furthermore, the strips function as a buffer for dissolved substances. By that the transport time is lengthened and break down processes within the soil have more time to operate.
  - *Actors*. Land owners, farmers
  - *Possible actor-related measure*. Purchasing land, compensation payments, orders, measure could be integrated in a programme for organic farming.
- *Reduction of nitrogen discharges into surface water and groundwater by*
  a) determination of a requirement-oriented quantity of fertiliser, preparation of land and farm gate balances,
  b) applying organic fertiliser in a manner which will conserve rivers, and ensuring adequate storage capacities,
  c) conversion of selected agricultural land into extensively used grassland or land use based on principles of organic farming in accordance with EEC Regulation 2092/91 (reduction of overall fertiliser requirements)

  - *Brief description*. All parts of the (composed) measure aim at a compliance or improvement of the 'good agricultural practice'. They positively affect the aquatic system by reducing the amount of fertiliser per hectare, reducing the area where fertilizer is applied, improve the exploitation of nitrate by the plants, prevent the leakage of nitrate etc.
  - *Actors*. Farmers
  - *Possible actor-related measure*. Compensation payments, orders, measure could be integrated in a programme for organic farming. Combine and tighten up the requirements of other agriculture supporting programmes.
- *Reducing of phosphate discharges into surface waters by*
  a) erosion-minimising soil cultivation (such as contour cultivation, direct sowing, mulch sowing with existing or new equipment, cultivation primarily at right-angles to the slope)
  b) Erosion-minimising soil management: full soil coverage all year round (field planting with intermediate crops), conversion of selected arable land into extensively used grassland or land use which follows the basic principles of organic farming in accordance with EEC Regulation 2092/91.
  - *Brief description*. Phosphate comes into the surface waters mainly by particles because its dissolvation properties are poor. Therefore an important strategy to prevent phosphate discharges is to reduce erosion.
  - *Actors*. Farmers
  - *Possible actor-related measure*. Measure integrated in a programme for organic farming. Combine and tighten up the requirements of other agriculture supporting programmes.

2.3.5 Combining measures to alternatives

Most likely it will be impossible or at least not efficient to reach the good status with a single measure. One reason for this is that the good status is a multidimensional objective. It comprises thresholds and development targets for nutrients (nitrate, phosphate), other pollutants (see list of prioritised substances), morphology, macrophytes, fish etc. Many measures aim at only one of these (sub-)objectives. Therefore, several single measures should be combined to a bundle of measures. We will call such a bundle an *alternative*. The task for the decision maker is to select the alternative that is most suitable with respect to the objectives and criteria determined before.

The combination of measures to alternatives is an important step – preliminary decision – in the process of decision making. It makes sense to combine complementary measures because the performance of the combination not of each single measure is decisive. One has to take into account the (positive and negative) cross effects of the single measures.

If a case study concentrates only on a single (sub-)objective like nitrate concentration the issue of combining measures may be of minor importance.

2.3.6 *Uncertainty about alternatives*

The identification of potential measures for river basin management is a creative process. Many measures are known and already tested elsewhere, but new measures could be created. The list of potential measures can never be complete. There is (only partly reducible) ignorance about the complete set of potential measures.

The determination of a set of measures that will be closer investigated, assessed and compared means at the same time to cut off other potential measures. It is important to have an attitude of openness when determining this set of potential measures and to reflect the possibility that the most appropriate measure for some reasons might be excluded in this preliminary selection.

2.4 Set up a draft of a multicriteria matrix

Problem identification and determination of objectives lead to a list of evaluation criteria. Considerations about potential actor- and environment-related measures and combinations of different measures to alternatives bring out a list of alternatives. The result of the problem framing can be summarized by the frame of a multicriteria matrix where the head row contains the different criteria and the head column contains the different alternatives.

Criteria **Alternative**	C_1	C_2	…	C_n
A_1	???	???	…	???
A_2	???	???	…	???
…	…	…	…	…
A_m	???	???	…	???

The next two steps are

1. to fill out the matrix, that is, to assess how each alternative performs with respect to the listed criteria. This impact analysis can be supported by modelling and can include an uncertainty analysis of the assessments (see Chapter 3)
2. to evaluate the completed multicriteria matrix by cost-effectiveness or multicriteria matrix taking into consideration the information on uncertainties (see Chapter 4).

2.4.1 *Short cut for case studies*

If for a case study the short cut of neglecting actor-related measures is chosen, a matrix of the design as shown in the figure below might be helpful to summarise the results of an impact analysis.

Criteria Environ.-related measure	C_1	C_2	…	C_n
M_1	???	???	…	???
M_2	???	???	…	???
…	…	…	…	…
M_m	???	???	…	???

Be careful with the interpretation of such a matrix. A direct comparison of different measures is not possible. Further considerations about

- possible combinations of the measures
- the cross effects of the measures
- the possibilities to enforce the measures

are necessary.

3 Impact analysis

The purpose of the impact analysis is to predict the consequences of an alternative with respect to the different criteria. This can be done by formal methods (modelling) or by expert assessments on the basis of their experience and knowledge or a mixture of both.

3.1 Analysis of physical impacts of environment-related measures and related uncertainties

Environment-related measures are actions that directly aim at a change of the state of the environment. The prediction of their impacts is – in general – the purpose of hydrological and other models. It is important that the models are able to make statements about the performance of the measures under consideration with respect to the identified evaluation criteria (see Sec. 2.2.2).

It is an important task to estimate the uncertainty related to the physical impact assessment. An analysis of these uncertainties my include sensitivity analysis, scenario analysis, model adequacy, model validation and calibration etc. The information about the uncertainty can be given in different formats: description of model adequacy, probability distribution, intervals, 95% percentiles etc.

3.2 Costs of environment-related measures and related uncertainties

The definition of the term ‘costs’ is not simple. However, for the purpose of the HarmoniRiB case studies it might be sufficient to define the costs of an action as the amount of money that is necessary to compensate the negative (and positive) effects of the action. Benefits are nothing else than negative costs.

Cost-benefit analysis monetarises all effects of an alternative. An alternative is preferred to the status quo if the (sum of the) benefits exceed the (sum of the) costs. In contrast to this, in cost-effectiveness analysis the benefits of reaching the intended objectives are not monetarised. Like in cost-benefit analysis, costs in cost-effectiveness analysis are expressed in monetary units.

For the case studies the first step is to identify the most important cost categories. For the measure “building a sewage treatment plant” the main costs are the construction costs, the operating costs and (if necessary) the construction costs of the sewage network. Other cost categories may be important in special cases like planning costs, the transaction costs of institutional stetting

Depending on the method of cost evaluation an assessment of the related uncertainties should take place. In most cases the uncertainty assessment will be an expert judgement that yields a qualitative assessment of the uncertainties of costs.

3.3 Other impacts

As discussed in Section 2.2 on objectives other consequences of a measure besides the impacts on the good status and costs may matter. The methods to assess the performance of the alternatives with respect to these additional criteria vary greatly depending on the character of the criteria. For instance welfare could be measured by a cost-benefit analysis, employment could be assessed by a macro-economic model and acceptance could be estimated on the basis of a survey.

3.4 Impacts of actor-related measures

Predictions of the impacts of actor-related measures are a major source of uncertainty, particular if the impact of ‘soft instruments’ like voluntary agreements, financial incentives, and information instruments cannot be predicted precisely and need to be coarsely estimated. But there is even an implementation deficit of ‘hard instruments’ like regulations of technical standards of sewage treatment plants or upper limits for fertilizer application. Furthermore, if monitoring is neglected there are incentives to secretly exceed the limits.

The assessment of the impact of actor-related measures is extremely difficult for many cases. No general advice can be given on how to proceed. Each actor-related measure needs to be carefully investigated. Some (costly) economic methods and models exist for the prediction of the impact of financial incentives on the behaviour of economic actors like farmers (e.g. calculations of compensation payments by calculating the loss of income caused by a certain renunciation of fertilizer).

The impact of an alternative is composed by the impacts of the different single measures and the cross-impacts of the single measures. The impact of each measure comprises the impact of its actor-related measure on the actors (particularly with respect to the environment-related measures) and the impacts of the environment-related measures.

Example

One measure might be a programme to foster organic farming: farmers who take part receive subsidies and are obliged to undertake certain environment-related actions (no artificial fertilizer, upper bounds of cattle per hectare, soil conserving cultivation etc.).

The measure is accompanied with consulting measures by the authorities with the aim to provide the know how of organic farming to the farmers.

To assess the impact of the programme one has to estimate (among other issues):

- What is the loss of income of the partaking farmers? (this may not be straightforward as organic produce can demand a price premium, depending on demand for it).
- How much subsidies need to be paid?
- How many farmers participate?
- What is the structure of their farms (cattle, arable land, meadows, rotation of crops, etc.)?
- Where are the partaking farms located including information on the soils and typography?
- How large is the implementation deficit (farmers who receive the subsidies but get around the obligations)?

4 Evaluation

4.1 Cost-effectiveness analysis

The idea of cost-effectiveness is rather simple. It is to choose the alternative out of the set of alternatives reaching the given objectives – a threshold, in case of the WFD the good status – that costs the least.

In case studies where only a few alternatives are considered the application of cost-effectiveness as a selection rule may be straightforward and unproblematic.

However, two main problems may arise when applying this idea:

- *There are large uncertainties in the prediction of the costs*: The assessment of costs for one alternative takes some time and needs resources. In real world decision problems normally the number of alternatives is not given. In many cases it might be huge – even infinite[9] – so that the costs of all alternatives cannot be determined with reasonable effort.[10]
- *There are large uncertainties in the prediction of the effects*: In this case the set of alternatives that reach the threshold cannot be determined. The set is fuzzy. The uncertainty of reaching the threshold needs to be assessed and evaluated. The easy selection rule 'choose the cheapest' cannot be applied because cost and probability of reaching the objectives are two (possibly competing) criteria for the selection.[11]

[9] Take as a simple example the alternatives 'reducing the area of arable land by *x* %'. One can choose for *x* any real number between 0 and 100. That is, the number of alternatives is indefinite.

[10] Normally information on costs is – if at all – only available for specific quantities as they could be observed on markets. In general cost-function, i.e. the function that relates the quantity of a good to its costs, is non-linear.

[11] The decision to be made depends on the risk strategy and risk acceptability of the decision maker. How much certainty is required for the decision? What is the risk of not achieving the desired effect of the measure?

A widespread strategy to reduce the complexity of a cost-effectiveness analysis is to consider separate cost-effectiveness *relations*. In some cases it might be reasonable to assume a linear quantity-cost relationship for a certain range of values. In the WATECO guidance document, for example, linearity is assumed in the discussion of cost-effectiveness. In case of linearity an optimization procedure may be applied to calculate the cost-efficient alternative even if the number of alternatives is infinite.

Example: Assume the reduction nitrate costs 100 € per kg by technique *A* and 150 € per kg by technique *B*. Technique *A* may be applied to up to 500 kg and technique *B* without limits. If the reduction goal is 800 kg the cost-effective solution would be to apply technique *A* for 500 kg (which costs 50.000 €) and technique *B* for the rest of the required reduction, i.e. 300 kg (which costs 45.000 €). So the aimed reduction of 800 kg can be optimally reached at total costs of 95.000 €.

However, several problems may come up:

- The assumption of linearity of the cost-effectiveness relation is in most cases valid only in narrow boundaries.
- Many measures have an impact on more than one objective. If technique *B* in the example above (which is cheaper than technique *A*) reduces additionally 0.7 kg phosphate it might be more effective than technique *A* (even neglecting the upper bound of the application of technique *A*). In such a case the separation of the cost-effectiveness problem in a nitrate and a phosphate problem does not work.

4.2 Multicriteria analysis

If cost-effectiveness considerations cannot easily be undertaken because there are large uncertainties in the prediction of costs or effects or both, multicriteria analysis may be a way out.

- *Scoring*

  There is a large number of multicriteria methods available (see e.g. Vincke 1992). The simplest one is ‘scoring’: Each criterion is measured in scores (e.g. school grades or 1, 2, 3 standing for ‘good’, ‘medium’, ‘bad’). Each criterion gets a weight according to its importance. The final score of an alternative is the weighted sum of its scores in the different criteria.

  The scoring method can also be applied to probability distributions of scores. The outcome is again a probability distribution.

- *MAUT*

  Similar to scoring is the class of methods called ‘MAUT’ (multi attribute utility theory). Instead of scores each criterion is measured by a utility function (a real-valued function that measures the attainment of the related objective). The final evaluation is again calculated as the weighted sum of the performance in the different criteria. The different methods of MAUT can be distinguished mainly by the way how the utility function is determined. One has to keep in mind that the determination of the utility function and the determination of the weights are interrelated.

  Similar to scoring MAUT is able to handle probability distribution functions.

- *PROMETHEE*

  PROMETHEE is one of many so-called outranking methods. In outranking methods alternatives are always valued relative to other alternatives (using pair-wise preferences). This method as well as its extension for probability distributions is in detail described and explained in Klauer et al. (2004). For an excerpt see the appendix.

4.3 Interpretation of results from cost-effectiveness and multicriteria analysis

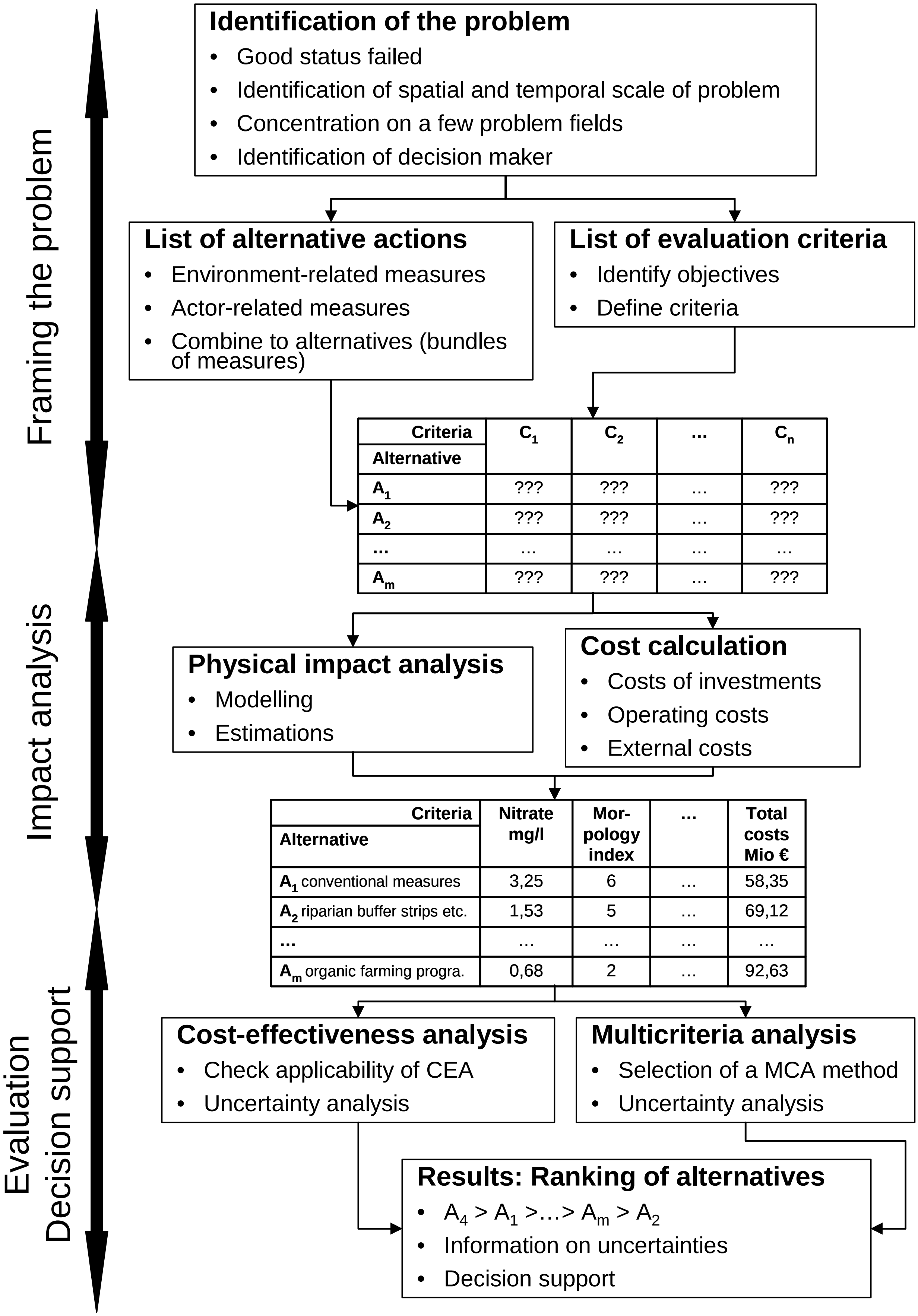
The outcome of a cost-effectiveness or a multicriteria analysis is (if uncertainty is neglected) a ranking of the alternatives. Despite of the clearness and plainness of such a result the analyst must be careful in interpreting. He should always keep in mind that the ranking was produced under a large number of explicit and implicit assumptions and preliminary decisions. Many aspects of the real world problem are excluded in any formal decision analysis. The result of a decision support methods ought to help the decision maker but cannot replace his decisions. He is responsible for the decision and so for the consequences of his decision.

The limitations of the decision support need to be reflected by the analyst as well as by the decision maker. The analyst takes responsibility for his advice, too.

If a formal uncertainty analysis is undertaken at the decision support the result is not a plain ranking but probability distributions of rankings or the like. The interpretation of such results is more complex. Decision makers have in general no strong experience in interpreting so that support by the analyst is necessary.

5 Summary

Our structuring of the decision making process for the selection of river basin management measures is summaries in the following figure.



Criteria / Alternative	C_1	C_2	…	C_n
A_1	???	???	…	???
A_2	???	???	…	???
…	…	…	…	…
A_m	???	???	…	???

Criteria / Alternative	Nitrate mg/l	Mor-pology index	…	Total costs Mio €
A_1 conventional measures	3,25	6	…	58,35
A_2 riparian buffer strips etc.	1,53	5	…	69,12
…	…	…	…	…
A_m organic farming progra.	0,68	2	…	92,63

6 Example: the upper River Kennet case study

Mike Dunbar

6.1 Introduction

Here we will present some of the above guidance in the context of the upper Kennet. There are several good reasons for choosing the upper Kennet as an example, principally that there are considerable historical data available for the Kennet, not just on the environment, but some economic data too. This is because there has been ongoing discussion between Thames Water, the Environment Agency and other stakeholders over the ecological state of the river, and the costs to reduce any environmental impact (see below). This also means that there are generally two opposing viewpoints to each aspect of the study, which can be useful in highlighting uncertainties and how to deal with them.

However there are also some caveats which the reader needs to know about:

- Uncertainty was highlighted in the original studies on which we have based this assessment (usually to criticise the opposing party), but was not given any formal consideration.
- The framework for the previous assessments was principally cost-benefit analysis, not cost-effectiveness or multicriteria.
- There is still no clear agreement over whether the Kennet is at Good Status or not, and if not, what pressures are causing this.

This discussion is solely based on readily available data and aside from some consideration of uncertainty in economic data, no further analysis has been undertaken. This distinguishes this document from the WP7 case study, which involves additional data, and a more comprehensive uncertainty analysis in data and models.

General Background

Since 1989, water supply and sewerage in England and Wales has been the responsibility of publicly listed companies (i.e. not state-controlled enterprises). They are regulated by various government bodies, but particularly by the Environment Agency with regard to how their activities affect the environment, and by OFWAT (Office of Water Services) with regard to their monopoly position, their requirement to supply water and the prices they can charge. In some cases there are relatively small companies supplying water (but not sewerage), but the majority of the population are supplied by large companies organised on a catchment basis. Thames Water is one such company.

6.1.1 Identifying the problem

6.1.1.1 Good Status reached or failed?

Thames Water, or their predecessors have been taking groundwater from a site at Axford, very close to the River Kennet, since 1965. Although the abstraction is from groundwater, it is in a zone of high permeability, and it is agreed that for the purposes of impact assessment, the water can be considered to come from the river. Increasing quantities of water have been taken since then, with a temporary licence being granted for this. Increased abstraction was only allowed when the flows at a nearby gauge were above 61.4 Ml/d. Much of the water is transported outside the catchment to the rapidly growing town of Swindon, so is a net loss. Thames Water applied for the temporary licence to be renewed in 1994, and the Environment Agency deemed that further restrictions on abstraction were necessary to protect the river.

Thames Water disputed this, so a public inquiry, completed in 1997, discussed the case for more stringent controls on water abstraction. This highlighted ongoing uncertainties in the links between pressures and ecological status, even for a well-studied catchment like the Kennet. In addition it highlighted differences in approaches for estimating the economic value of water remaining in the river vs water used for public supply. Since then further investigations have been completed, although no firm conclusions have been reached.

The Environment Agency has a duty to take account of likely costs and benefits of their decisions, hence the need for an economic analysis. Recipients of those costs and benefits are defined broadly. There are no specific criteria such as benefits outweigh costs, only that they must be considered. In the case of the Kennet, there would be economic costs to Thames Water in having to move water from other existing sources and/or develop new sources, in order to meet this demand.

The main indicator used is the ecological status of the river (in this case the words ecological status are used in general terms as the background information pre-dates the WFD by several years). In this document we will not go into details as to how the ecological status is defined, suffice to say that ideally, the overall status will integrate the status of the fish, macrophyte and macroinvertebrate components of the river community. The Kennet is nationally recognised as of high ecological importance, for its diverse macrophyte and macroinvertebrate communities. Much of the river is designated as a site of special scientific interest (SSSI). Although the upper Kennet is not designated under the European Habitats Directive, it could be argued that the Kennet does warrant an objective of "high" status. The Environment Agency used the status of the river as the main reason to justify restricting water abstraction, but because of the cost-benefit framework adopted, and the fact that there is no direct link between Good Status and economic valuation, the economic valuation took into account indirect factors such as fishing, house prices, leisure activities, and "non-use" values.

6.1.1.2 Concentration on one or two problem fields

On the Kennet, the main problem field is the reduced flows in the river (due to abstraction) and its consequent detrimental impact on the ecology. Subsidiary problem fields are the morphology of the river (since habitat is a function both of river flow and channel structure) and nutrient enrichment (eutrophication).

6.1.1.3 Identifying the decision maker(s)

In this case, the Decision Maker is the Environment Agency. They are the regulatory agency and have the regulatory power to give abstraction licences, but are also accountable for their decisions. In other cases, for example when considering diffuse nutrient input to rivers, or historical river channel alterations, the EA still have overall river management responsibility but have far fewer powers to take direct action.

6.1.1.4 Identifying the problem and uncertainty

The problem is water abstraction, causing reduced river flow within the Kennet and thus any consequent impact on the ecology of the river. There is uncertainty as to the meaning of Good Status, this is quite important, but as part of this project, only basic assumptions can be made about this uncertainty. There is uncertainty as to the extent of the impact and whether there is a risk of not achieving Good Status. In addition there will be uncertainty is how much the abstraction needs to be reduced in order to not have a detrimental impact. In this example it will be difficult to encompass both these sources of uncertainty so it is necessary to make the assumption that the abstraction, combined with other impacts arising from nutrient enrichment and physical habitat degradation, does cause the river to fail to achieve Good Status. In this case, the problem then becomes one of identifying the most cost-effective measures for the achievement of Good Status.

6.1.2 Preliminary list of objectives

6.1.2.1 Objectives

General objectives. This example can be considered to come within the overall WFD objective of “promotion of sustainable water use based on long-term protection of available water resources”. The objective to mitigate the effects of droughts is also relevant.

Cost-effectiveness. Cost-effectiveness provides the overall context for all the case studies, however it needs to be remembered that most of the information available is based on previous cost-benefit analyses.

Good Status. In addition to overall Good Status of surface water bodies, competent authorities are required to achieve Good Status in groundwaters as well.

Weightings, (dis-)proportionality and exceptions. Two issues could arise here. Firstly the Kennet could be designated as a Heavily Modified Water Body under the WFD. This would require that there are modifications to the physical character of the river which continue to provide economic benefit which outweighs their negative effects. In the case of the Kennet it has had a long history of modification, partly for land drainage and flood defence (through bed lowering and channel widening) and partly for navigation (the river provides water to the Kennet and Avon canal and the canal and river run together in the mid to lower stretches). However the upper parts of the Kennet which are the focus for the study are not really subject to these impacts.

The second of these objectives concerns timing. If we assume that the river fails to achieve Good Status, it could be determined that it is most cost-effective to restore the river over a period of time which is longer than that initially required by the directive. In this case, the river would initially fail its objectives, but there would be derogation. We will not consider this further here.

6.1.2.2 Criteria

Within the Kennet a number of methodologies can be used to assess whether the river will achieve ‘Good Status’. Previous work on the Kennet used a model (PHABSIM – physical habitat simulation) to derive a flow value where the reduction in habitat caused by the abstraction was no more than 10%. This figure was derived partly with uncertainty in mind, as it was deemed that chance variation would mask any figure less than 10%.

Since the relationships between river hydrology and ecology are often poorly understood, hydrological criteria are often used as a surrogate to define acceptable flow alteration. The Environment Agency now has a Framework (RAM – Resource Assessment and Management) which it uses for this, this uses pre-defined allowable "takes" of water at a number of points on the natural flow duration curve. RAM also uses ecological criteria, notably the LIFE (Lotic Invertebrate Index for Flow Evaluation). The HarmoniRib WP7 case study has examined the uncertainties surrounding these criteria in more detail. The Environment Agency is currently developing a framework for setting River Habitat Objectives, but this is not yet widely available. Because of the wide variation in river habitat quality within a catchment such as the Kennet, river-specific criteria based on the habitat quality associated with good/high status can be developed.

Costs

Thames Water would directly bear the costs of any reduction in abstraction from the Kennet. They evaluated the costs of several different options which would be needed if this occurred, these are discussed in the next section. Additional costs would be associated with holding a public inquiry and with monitoring the status of the river. Improvements to river habitat require either capital works (ie incurring capital costs), or cessation of management, and may lead to adjacent agricultural land becoming less productive (i.e. incurring ongoing, recurrent costs).

Because the original work on the Kennet centred around cost-benefit analysis, benefits assessments were undertaken. These centred around Use and Non-use benefits.

Use benefits were a combination of

- Local residents willingness to pay to visit the river (values from benefits transfer)
- The value of the Kennet fisheries
- Values of house prices near healthy rivers (using hedonic pricing)

Non-use benefits were valued as the willingness to pay for the preservation of a healthy river, again the WTP values per person were taken from other studies, and applied to the numbers of customers in Thames Water's area.

6.1.2.3 Uncertainty about objectives and criteria

For the River Kennet, uncertainty about objectives and criteria remains one of the largest sources of uncertainty. The original work on the Kennet was undertaken prior to the WFD (with its objective of Good Status and emphasis on hydromorphology as well as water quality), and prior to the development of the Environment Agency's RAM framework, which sets more transparent criteria for water resource management.

6.1.3 Preliminary list of potential measures

6.1.3.1 Definitions

The Environment Agency is the decision maker, and it is Thames Water who is actually abstracting water. Thus strictly speaking, the licensing of water abstraction is an actor-related action. However, in theory, there is very little uncertainty as to the adoption of such an action. The only uncertainty surrounds whether Thames Water will dispute the determination and take the matter to a public inquiry. This did indeed happen, there is good information on the costs of such an inquiry. Because of this lack of uncertainty, the situation bears some resemblance to the environment-related actions context.

With regard to any habitat improvement measures, actors would likely be landowners or manager, albeit with support from government or regulators. This bears more similarity with agricultural diffuse pollution where incentives are needed to adopt measures.

List of measures

Any measure or combination of measures will need to achieve the overall objective of Good Status in the Kennet.

Possible water resource measures include:

Thames Water reduce the amount of abstraction. The options may consider combinations of Hands Off Flows (abstraction must be substantially reduced once the flows in the river are reduced to the HOF) with a number of different licensed abstraction volumes.

This will require TW to obtain some water from elsewhere. The key options to achieve this are

- Import water from Farmoor reservoir (requires building a new pipeline from 40km away to Swindon)
- Provide nitrate removal at another source

Replacement of the water with water from elsewhere was the main option considered for the Kennet. Clearly these all require major capital works, for which there is a significant up-front capital cost.

Other potential measures include:

- Moving towards Good Status by restoring some of the morphology of the river channel.
- Reducing the amount of water needed by reducing leakage and encouraging customers to reduce water usage.

6.1.3.2 Incomplete list of actor-related measures

Any action to reduce abstraction would be a direct actor-related measure. In contrast, any efforts to restore the river channel would need to undertaken on a more voluntary basis. Measures such as reducing leakage and encouraging customers to reduce water usage lie somewhere in between.

6.1.3.3 Short cut for case studies

Consider above measures as being environment-related measures, there is no additional uncertainty over whether they are adopted or not.

6.1.3.4 Combining measures to alternatives

Under some circumstances, a single measure on its own could be enough. One example would be a major reduction in abstraction, and provision of water from the pipeline from Farmoor reservoir. This is a relatively costly single measure, so to justify it, a large reduction abstraction would have to be required.

There is also considerable scope to combine measures. This is particularly important if it is decided that an intermediate or small reduction in abstraction is required. For example, river restoration measures could be combined with leakage control and the upgrading of another source.

6.1.4 *Uncertainty about alternatives*

Many of the measures involve reduction of the abstraction, in which case there is uncertainty that the measures will achieve the aim of meeting 'Good Status'.

River restoration is also an inexact science, there is uncertainty as to whether restoring the river will have sufficient effects.

Concerning leakage control and reduction in consumption, other measures need to be taken to achieve these. This brings additional uncertainty.

Finally there is uncertainty in time. Good Status may be achievable, but sometime after 2015. For example, leakage control may be achievable, but such schemes take time to engineer and implement.

6.1.5 *Set up a draft of a multicriteria matrix*

Criteria		LIFE score	Proportion of flow at Q70	Physical habitat for fish	Leisure, Tourism
Flow requirement#	Measure				
Status quo Abst=13.1 HOF: 69 -> 9.3	Nitrate removal at alternate source				
Option 2 Abst=13.1 HOF: 104 -> 3	Import water via pipeline				
Option 3 Abst=13.1 HOF: 86 -> 6	Leakage control and water conservation, Plus habitat restoration				

All figures in thousand cubic metres per day

Abst = maximum amount of water abstracted when flow above hands off flow

HOF x -> y = hands off flow value and maximum amount of water abstracted when flow is below hands off flow.

For each option, there will be a set of (environment-related) measures aimed at achieving it).

When the matrix is completed a probability can be associated with

The stages in the Kennet case study can be stylised in the four diagrams below (figures 6.1 to 6.4). Figure 6.1 illustrates the uncertainty in the pressure-impact relationship, this is addressed in the HarmoniRib WP7 case study, but not considered further here. Figure 6.2 illustrates the uncertainty with the assessment of the impacts, and the relationship between impact and status. Figure 6.3 illustrates the uncertainties in the main economic assessment: what is the relationship between improvement in status and cost, for each option. Finally, Figure 6.4 illustrates how the individual measures which form the options could be achieved, along with uncertainty.

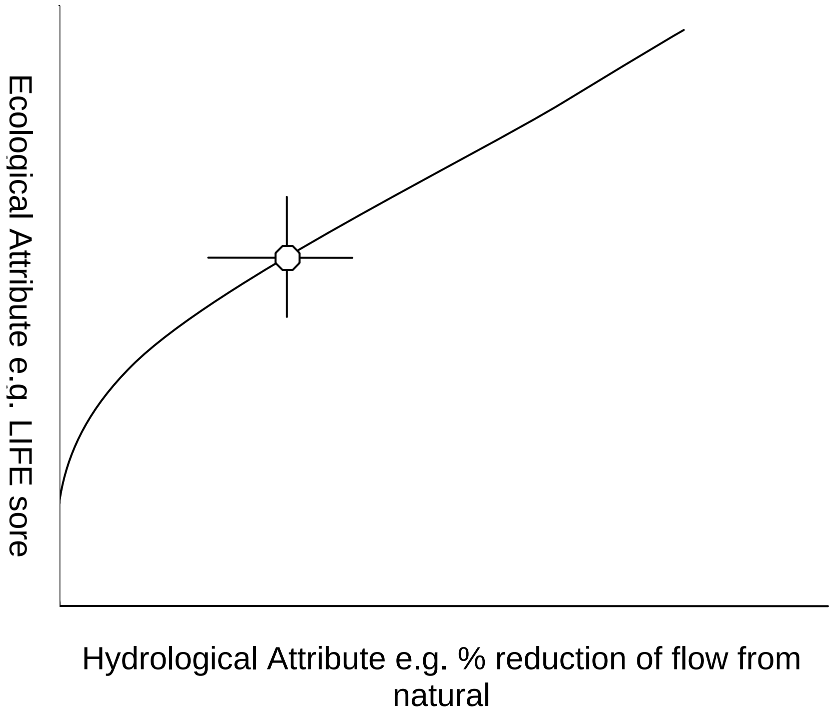


Figure 6.1. Stylised example of uncertainty in relationship between hydrological and ecological attribute.

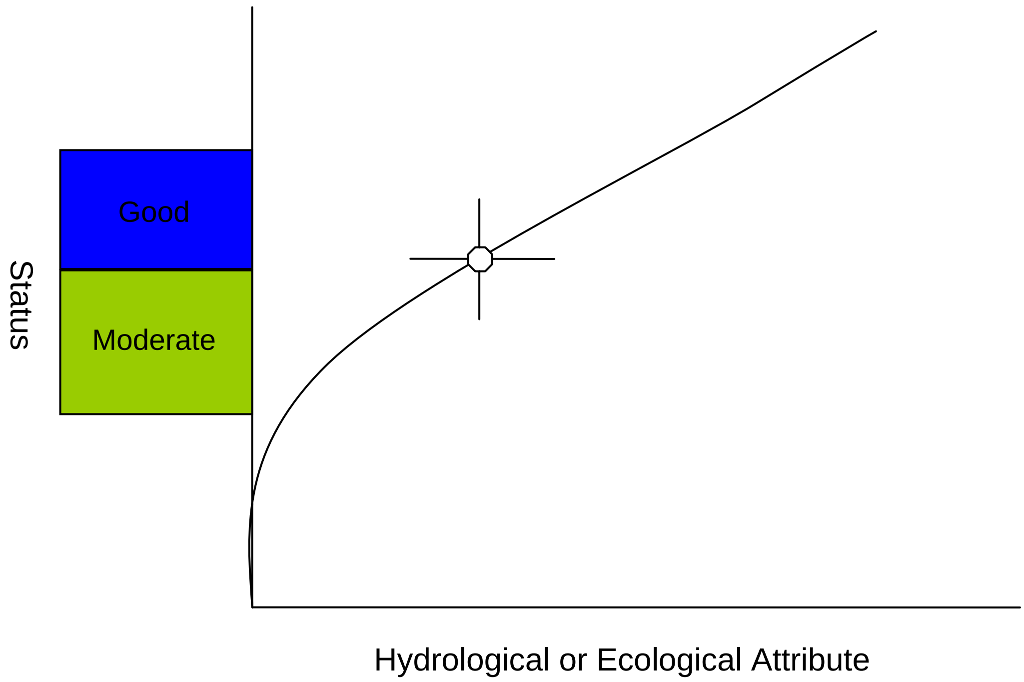


Figure 6.2. Stylised example of uncertainty in relationship between hydrological and ecological attributes and overall status.

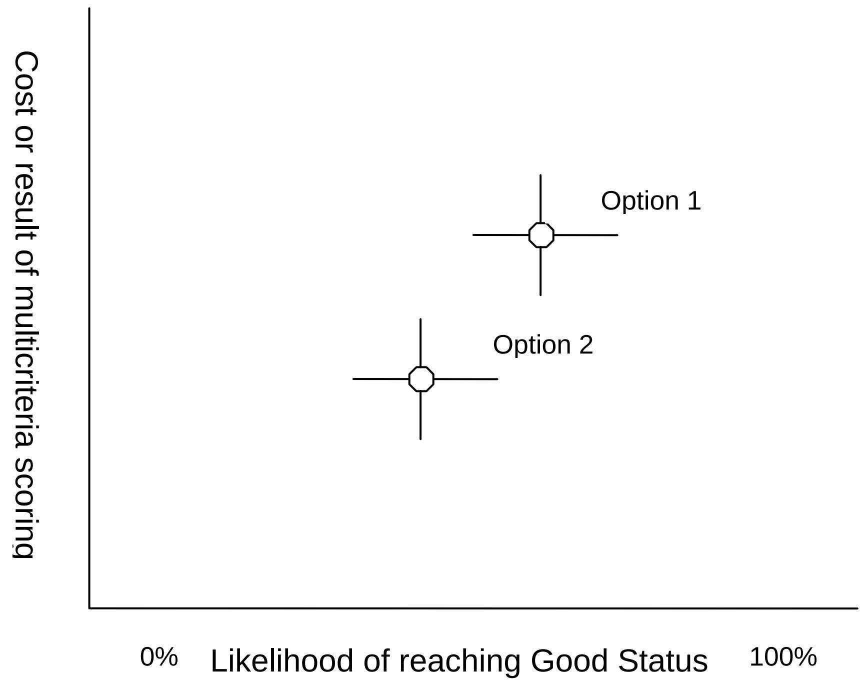


Figure 6.3. Illustration of uncertainty for overall options, both in terms of likelihood of achieving Good Status and costs.

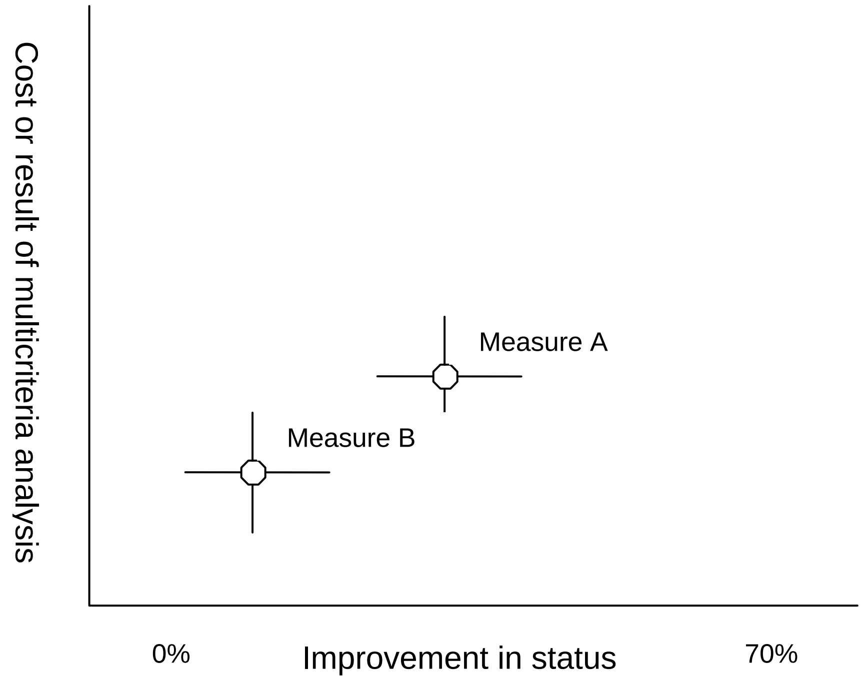


Figure 6.4. Illustration of uncertainty for each measure (which will be packaged together to achieve options), both in terms of improvement of status and costs.

6.2 Impact analysis

The purpose of the impact analysis is to predict the consequences of an alternative with respect to the different criteria. This can be done by formal methods (modelling) or by expert assessments on the basis of their experience and knowledge or a mixture of both.

6.2.1 Physical and ecological impacts of environment-related measures

It is well known that both changes in river flows and habitats affect the structure and nature of in-river communities. On the Kennet, there is the uncertainty associated with defining these relationships in a particular case. The main ecological measure used will be the LIFE score, this is designed to index the response of the macroinvertebrate community to flow variation. It also responds to habitat degradation. Clearly there is uncertainty in the extent to which water abstraction affects river flows, and whether this regulation can be detected in terms of its effects on the macroinvertebrate community. Macroinvertebrates are also affected by organic pollution, fortunately the Kennet is fairly clean. In the past, the river has been affected by eutrophication and there is ongoing debate as to the legacy of this. Eutrophication has an effect on instream plants and algae, which can provide both a habitat and food source for invertebrates, so ideally these links would be included.

6.2.2 Costs of environment-related measures

Previous work by Thames Water has looked into the various measures that would be required to achieve the Environment Agency's most stringent proposed restrictions on water abstraction (corresponding to Option 2 above).

As discussed above, these included:

- Measure A. Import water from Farmoor (requires building a new pipeline from 40km away to Swindon)
- Measure B. Provide nitrate removal at another source
- Measure C. Water conservation
- Measure D. River restoration, including dredging river to remove fine sediment, removal of weirs, channel narrowing and reinstatement of more diverse marginal habitat.

Indirect costs would include costs of monitoring the ecological status of the river in the future.

6.2.3 Other impacts

The following benefits could be associated with an improvement of the ecological status of the river.

- Leisure and tourism, including fishing and general recreation.
- House prices.

- Non-use benefits.

Sustainability could be assessed for the different measures: for example local solutions could be weighted more favourably than solutions with impacts over a wider area.

6.2.4 Impacts of actor-related measures

In terms of licensing water abstraction this is not a big issue: voluntary agreements and human behaviour are not so important. The main area where this would be an issue is if physical river restoration were identified as an appropriate measure. The river is owned by a multitude of different interests, and the Environment Agency does not have any permissive powers to compel river restoration works. There would need to be a combination of instruments and grants to encourage land owners to take action. Such schemes are already in existence in some European countries, for example in the UK the Entry Level Scheme provides a single payment in return for basic environmental measures. These schemes could be expanded to cover more water-related measures, and added to in terms of grants for the improvement of river habitats.

6.3 Evaluation

The following table illustrates the stages in the analysis. For the HarmoniRib project, Stages 2 and 5 are the most important as they are the ones within which some quantitative analytical work can be undertaken.

Stage	Uncertainty	Limitations
1. What is Good Status for the Kennet?	Some uncertainty in the objective can be considered	Difficulties in defining reference conditions. Probably need to assume that status (with respect to water resource pressure) in a series of “good” flow years is good.
2. What is the impact of water abstraction and physical habitat degradation on the ecology of the Kennet?	Several sources considered (hydrology and ecology). Central part of HarmoniRib WP7 study	Some sources of uncertainty can be justified quantitatively, others will need best judgement to assess quantitatively
3. What is the consequent current ecological status?	Focus is on whether the river is at Good Status or not	Not really worth spending much time evaluating this as many issues beyond our control.
4. What is the likelihood of various options (reductions in abstraction and increases	Scenario analysis. All hinges on what probability of achieving Good Status is	Need to assume river is not at Good Status.

Stage	Uncertainty	Limitations
in hands off flows) to change the ecology, and thus reach good ecological status.	acceptable.	
5. How can measures be packaged to achieve the desired options.	Assessed using cost-effectiveness analysis and multicriteria analysis.	

The overall question then, is what measures are required which give an acceptable probability of achieving Good Status.

For the Kennet case study, it makes sense to concentrate on a limited number of options and measures. In particular, a more extreme option, that major changes in the flow are required to achieve good ecological status, hence also major, costly measures (involving capital works) would also be required. Secondly, a more subtle scenario could be considered, where smaller alterations to the regime could be accompanied by other measures such as river restoration. This packaging of measures is interesting in itself, combining environment-related measures under more direct control (reducing abstraction) with actor-related measures such as incentives for habitat restoration. In the first case it is clear that cost-effectiveness analysis would be the most suitable tool. This is also to some extent true for the second case, which would involve more packaging of measures. However if multiple restoration measures were to be considered and weighted, an alternative would be to undertake a multicriteria analysis.

7 References

Klauer, B., Drechler, M., Messner, F. (2002): Multicriteria analysis under uncertainty with IANUS – methods and empirical results, UFZ-Diskussionspapier 2/2002, Leipzig (revised version accepted in Environment and Planing C)

UBA (Umweltbundesamt, Federal Environmental Agency) (ed.) (2004): Basic principles for selecting the most cost-effective combinations of measures for inclusion in the programme of measures as described in Article 11 of the Water Framework Directive – Handbook. UBA-Texte 02/04, Berlin.

UBA (Umweltbundesamt, Federal Environmental Agency) (ed.) (1999): Maßnahmenplan Nachhaltige Wasserwirtschaft – Handlungsschwerpunkte für einen zukunftsorientierten Umgang mit Wasser in Deutschland. UBA-Texte 25/99, Berlin

Vincke, Ph. (1992): Multicriteria Decision-aid. John Wiley & Sons, Chichester at al. 154 pp.

8 Appendix PROMETHEE

Excerpt from Klauer, B., Messner, F., Drechsler, M. (2004).

8.1 Preference function

Let A be the finite set of all alternative actions. The decision problem is to select the best action or – more extensively – to rank all alternatives. The performance of an alternative with respect to an objective of the decision-maker is measured by a criterion. Formally, a criterion i is a function $g_i : A \to \mathbf{R}$, taking its value in the totally ordered set $\mathbf{R}$, and representing the decision-maker's preferences according to some point of view (Vincke, 1992: 27). A central step in all outranking methods is the pairwise comparison of alternatives by a preference function. A (partial) preference function is a function $\Pi_i : A \times A \to [0,1]$. The quantity $\Pi_i(a,b) \equiv \Pi(s_i(a,b))$ is a function of the difference $s_i(a,b) = g_i(a) - g_i(b)$ between the performances of alternatives a and b in criterion i. A value of $\Pi_i(a,b) = 1$ represents strict preference of a over b in criterion i, a value of 0 represents indifference or a preference of b over a. Figure 1 shows two common forms of the (partial) preference function.

The form in solid lines is called 'normal preference function' and assumes that alternative a is strictly preferred (indifferent) to alternative b in criterion i if $g_i(a)$ is greater than (equal to) $g_i(b)$. The form in dashed lines acknowledges that people are not always willing or able to strictly decide whether alternative a is better than b in criterion i, even if $s_i(a,b) > 0$. In this case a is strictly preferred to b only if its performance g_i exceeds that of b by a quantity d_{Pi} which is called a preference threshold. There is indifference between two alternatives a and b if $s_i(a,b)$ is below an indifference threshold d_{qi}. If $s_i(a,b)$ lies between the two thresholds, $d_{qi} < s_i(a,b) < d_{pi}$, then there is hesitation between strict preference and indifference called weak preference (Vincke, 1992: 74).[12]

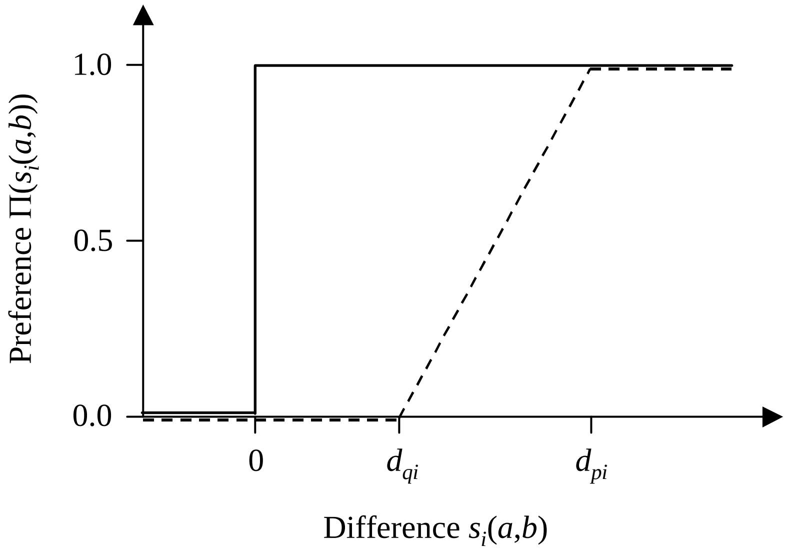
The total pairwise preference $\Pi(a,b)$ of an alternative a over an alternative b is the weighted sum[13] of partial pairwise preferences:

$$\Pi(a,b) = \sum_i w_i \Pi_i(a,b) \tag{1}$$

[12] Even if the consequences of the alternatives are certain, the decision makers might hesitate to decide between indifference and strict preference of one alternative with respect to a certain criterion if there are additional criteria. For instance a price difference of 100 Euro for a car seems to be irrelevant if the buyer is also concerned about the design, equipment, fuel consumption etc.

[13] The importance of the weights is discussed in detail in Sec. 5.4.

Figure 1: Preference of an alternative a over an alternative b in a criterion i as a function of the difference between the values ($s_i(a,b) = g_i(a) - g_i(b)$)



Solid line: normal preference;
Dashed line: preference with indifference and weak preference (indifference threshold d_{qi} and preference threshold d_{pi}: see text).

8.2 PROMETHEE

Several ways exist to deduce a rank order from the pairwise preferences Π, which lead to different outranking methods, such as ELECTRE (Roy, 1968), NAIADE (Munda, 1995) and PROMETHEE. In contrast to other outranking methods, PROMETHEE has the advantage that the concepts and parameters involved have some physical or economic interpretation easily understandable by the decision-makers (Vincke, 1992: 73). The simplicity of PROMETHEE makes it easy to integrate uncertainty. PROMETHEE is, due to the pairwise comparisons, restricted to discrete decisions, i.e. only a finite number of alternatives can be ranked.

One important common feature of all outranking methods is that the rank orders they produce are not necessarily complete but may be partial (pre)orders, meaning it is not always possible for all pairs of alternatives to decide whether the first alternative is ranked higher, lower or equal to that of the second alternative. This can be seen very simply in the PROMETHEE method, which acknowledges that there are (at least) two possible ways to create a complete rank order of alternatives in a set *A* of all alternative actions. The rank of an alternative $a \in A$ could be measured by the sum of the pairwise preferences of this alternative over all the alternatives in the set *A*:

$$\Phi^+(a) = \sum_{x \in A} \Pi(a, x) \qquad (2)$$

where a is preferred to b if $\Phi^+(a) > \Phi^+(b)$. Alternatively the rank of A could be measured by the sum of the preferences of the other alternatives in the set A over a:

$$\Phi^-(a) = \sum_{x \in A} \Pi(x, a) \qquad (3)$$

where a is preferred to b if $\Phi^-(a) < \Phi^-(b)$. If weak preference exists in some of the criteria, i.e. if some of the thresholds p_i and q_i are nonzero, then the sum $\Pi(a,b) + \Pi(b,a)$ is not a constant for all pairs of alternatives (a,b) and thus $\Phi^+(a) > \Phi^+(b)$ does not imply $\Phi^-(a) < \Phi^-(b)$.

Now PROMETHEE combines both measures and defines:

- a preferred to b if $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$;
- b preferred to a if $\Phi^+(a) < \Phi^+(b)$ and $\Phi^-(a) > \Phi^-(b)$;
- a and b are indifferent if $\Phi^+(a) = \Phi^+(b)$ and $\Phi^-(a) = \Phi^-(b)$;
- a and b are incomparable otherwise.[14]

Consequently, if there are weak preferences in one or more criteria incomparability can occur and lead to a partial rank order.[15]

[14] There exist different variations of PROMETHEE: The described definition of the preference, indifference and incomparability relations are called PROMETHEE I. In contrast to this version in PROMETHEE II it is $\Phi(a,b) = \Phi^+(a,b) - \Phi^-(a,b)$ and a is preferred to b iff $\Phi(a,b) > 0$. In PROMETHEE II the result is always a complete rank order of the alternatives.

[15] If only normal preferences are used in PROMETHEE the intensity of preferences have no impact on the ranking of the alternatives. This is – at least to a certain degree – not the case if weak preferences are applied.