2.2 The Delphi study

In order to meet the last requirement in the list shown above, it was decided to use the Delphi approach for seeking consensus among a panel of experts. This approach was used in the Phosphate Report to obtain relative impact scores for 39 chemical substances identified as emissions in the life cycles of the three builders up to and including the production stage. The Delphi technique was developed by the Rand Corporation in America in the late 1950s for applications in the area of technological forecasting. It was designed to overcome a number of problems in group dynamics which arise when experts meet face-to-face to search for consensus to a problem. The technique gives each member of the panel equal status and complete anonymity, which allows them to express their personal points of view, independent of the organisation for which they work and the prevailing orthodoxy in the application area. A feedback mechanism, which may be repeated for a number of rounds, or 'iterations', allows them to compare their answers with their peers and, where they disagree with a majority of the others, either to modify their own views or seek to change those of the others. The technique has been used very widely in business for new product development, in education and in social/cultural studies. It is also being used in policy making, such as the Foresight programme being run by the Department of Trade and Industry in the UK[2]. Since the early 1970s it has been used increasingly in environmental impact assessment.[3,4,5,6] A key finding by Richey (ref 4) was that reliable valuations could be obtained from panels consisting of 8 experts, since higher numbers of experts did not necessarily yield significantly different answers, and diminishing returns quickly applied. It is important to note here that panel size is not subject to the statistical laws for sampling from finite populations. Differences between panellists do not reflect random variations, they rather reflect the inadequate scientific knowledge of the phenomena under evaluation.

2.2.1 Panel selection

Ideally a panel would be selected using a random sampling method of some sort. Here a sampling frame - a list of all possible members - is utilised and the panel is selected using randomly drawn numbers or similar methods. In the Phosphate Report this method was used, using a directory of members of British universities. This was possible because the experts sought were generalists with a broad experience of environmental problems, and these could be readily identified in the appropriate university departments. While such directories exist for universities in other countries it was not considered a suitable basis for the current research, because experts were sought who were fully conversant with the environmental problems created by wastewaters and sludges leaving wastewater treatment plants, particularly with respect to detergent builders. At the start of the project no such sampling frame was available, so an alternative, less 'scientifically-based', but nevertheless appropriate method was used. This might be called the 'snowball' method, whereby one expert in the field is identified and visited to discuss the range of questions to be answered. The contact is asked whether he or she knows other experts with the necessary experience to answer the questions. Any potential experts thus identified are either visited or contacted by mail or telephone, and asked if they are able to provide the estimates requested and if they know who could also do so, perhaps in another country. In this way a list of 18 experts from the four Nordic countries was compiled, and each was sent an initial questionnaire and an invitation to participate. The acceptance rate in shown in Table 2.2.1.

Table 2.2.1 Invitations and acceptances to the Nordic panel

Country	Invitations	Acceptances
Denmark	2	1
Finland	5	3
Norway	2	1
Sweden	9	5
Total	**18**	**10**

Four of the panel were in academic establishments (all professors), the other six worked in environmental research agencies (2), regulatory bodies (2) or as scientists for water treatment authorities (2).

It was recognised that the Nordic experience of water treatment, particularly where nutrients are concerned, is quite different, historically, from that of most other European countries. It was therefore considered most useful to have a second panel made up of scientists from the other west European countries. This panel was run independently of the 'Nordic' panel, which allowed comparisons to be made between the results of the two panels. Where results are similar they are judged to be applicable to the whole of western Europe - and perhaps the rest of the world, since water is water and phosphorus is phosphorus, etc. wherever they occur. Where the results are different - after giving due consideration to the sizes of the panels and the variations within them - it is possible to seek reasons for such differences and evaluate their significance for the environmental problems to which they apply. A 'Rest of Europe' panel was therefore identified and sent invitations. Initially a list of seventeen experts from 8 EU countries was produced using the same 'snowball' method as the Nordic panel. These were invited to participate, but the response this time was rather disappointing - only five experts agreed to join the panel. To make up the shortfall a further ten names were identified from the 1993 directory of the International Association for Water Quality.[7] This directory would have made an excellent sampling frame for the whole study had we been aware of it earlier in the project. The directory lists members' interests and areas of expertise in the water quality area under a number of headings. The ten experts were picked for their expertise in eutrophication, sludge use or toxicity of chemicals. Two acceptances were received from this group, which gave a total of seven for the 'non-Nordic' hereafter referred to, for the sake of convenience, as the 'European' panel. Table 2.2.2 shows the composition of the panel by country.

Table 2.2.2 Invitations and acceptances for the 'European' panel

Country	Invitations	Acceptances
Belgium	1	-
Denmark	1	1
France	3	-
Germany	7	2
Italy	2	1
Netherlands	5	2
Spain	1	-
Switzerland	2	-
UK	5	1
Total	**27**	**7**

* As Denmark was the only Nordic country in the EU (until january 19950, it also qualified for the European panel.

Five of the panel had professorial status, three working predominantly in universities, the other two in water research institutes. The two other panel members, both holders of Ph.Ds, also worked in water research institutes.

2.2.2 The task

In the specialist disposal study which was conducted as part of the original Phosphate Report, the experts were asked to compare the environmental impact of two effluent discharges from a wastewater treatment plant. Although they were given details of the type of treatment used in the plant and a description of the receiving watercourse, they had to make assumptions about dilution rates, ambient concentration levels of the substances involved and the contribution made by other sources to that ambient rate. The same was true of the sludges: details were given of the type of treatment and the disposal method or use to which the sludge was put, but no information was given concerning concentrations of the substances in the sludge. Perhaps the biggest drawback of the approach used in the earlier study was in making the link between the valuations given for the wastewater discharges, compared with those for sludges. A linking question was asked, comparing the impact of $1m^3$ of sludge disposed of at sea compared with $1m^3$ of wastewater discharged to a class 2 river, but it proved very difficult to answer, and resulted in very large variations between the experts. To overcome these problems, the concept of a 'basic scenario' was introduced, which describes a typical wastewater treatment plant as a whole. This scenario, shown in Figure 2.2.1, sets levels for all the substances in the water effluent and in the sludges arising from wastewater treatment.

An important feature of the concentrations given for water effluents is that they are stated as concentrations in the receiving water, rather than in the effluent itself. This means that the experts, hereafter referred to as 'judges', did not need to consider dilution rates and background levels. They were able to assess the likely environmental impact directly from the concentration in the receiving water. This approach would also have been useful for sludges, but the problems it raises in describing resultant concentrations on the land, or in landfill or incineration proved to be difficult.

The basic scenario - the wastewater treatment plant as a whole - was given an index of 1000 to represent its environmental impact. The parameters describing the treatment plant were then changed in a systematic way, each small change in effect describing a 'new' treatment plant. The task of the judges was to estimate an index for the 'new' plant which reflected its environmental impact when compared to the basic scenario plant, which scored 1000. Initially, for instance, the judges were asked to consider a treatment works identical in every way to the basic plant, except that phosphorus content in the receiving waters is 0.025 mg/l, rather than 0.05 mg/l. Everything else - the location, zeolite and polycarboxylate concentrations, BOD, COD, etc., and sludge concentrations and use remain the same as in the basic scenario. The task given to the judges was to estimate an index for the environmental impact of this plant, compared with the 1000 for the basic plant. If a judge assigned an index of 500, say, this would mean that he considered the slightly changed plant to have half the impact of the basic scenario plant, whereas a index of 2000 would imply it had twice the impact. The judges were given no guidance as to the parameters they use to assess impact - it was left entirely to them to bring their own value sytems to the question. Further changes in the phosphorus concentrations were then made, the judge giving a new index for each changed situation. Next the phosphorus concentration was returned to that of the basic scenario value of 0.05 mg/l but the plant was 'moved' to a new location beside an upland lake, and a new index estimated.

Figure 2.2.1 Basic scenario treatment plant

WATER EFFLUENT	**Location of treatment works:** beside a lowland lake or a waterway leading into it
	Phosphorus content: at a level which results in a concentration of **0.05 mg/l** (as P) in the receiving water
	Zeolite A content: at a level which results in a concentration of **0.1 mg/l** in the receiving water
	Polycarboxylate content: at a level which results in a concentration of **0.01 mg/l** in the receiving water
	Other substances: Suspended solids, BOD, COD etc., at a level 'typically' arising from a works treating the influent from domestic sources.
SLUDGES	**Sludges produced from secondary treatment -** activated sludge or trickling filter, digested and dewatered to give 25% of total dry matter.
	Phosphorus content: 2% of total dry solids
	Zeolite A content: 2% of total dry solids
	Polycarboxylate content: 0.2% of total dry solids
	Sludge use: Spreading on agricultural land at 1 tonne of dry solids per hectare
	Heavy metal content: within the following (EC) limits: (mg/kg dry solids) Zn 2500-4000 Cu 1000-1750 Pb 750-120 Cr 1000-1500 Ni 300-400 Cd 20-40 Hg 16-25
	Calorific value: 25 MJ/Kg
	Other substances: at a 'typical' level arising from such treatment

Then the phosphorus concentrations were changed as before and new indices estimated for each changed location. The whole process was repeated for a plant discharging into an inland waterway, an estuary, a coast where the N:P ratio is higher than 7 and finally a coast where the N:P ratio is less than 7. In this way, the judges were able to build up their estimates in the form of a recording table as shown in Figure 2.2.2, which was given the reference W1 to indicate that it was the first table in the water discharges part of the questionnaire. A full set of instructions for the task is shown in Appendix A1. It should perhaps be pointed out that although the task is quite a difficult one, only two parameters are ever changed at the same time, compared with the basic scenario.

The range of values for the phosphorus concentrations were chosen to reflect those which might be encountered in any type of watercourse. 0.01 mg/l is the generally accepted threshold below which eutrophication is unlikely to occur and is found in many lakes; 1 mg/l occurs in many rivers in the UK and elsewhere in Europe. It is probable, however, that not all the combinations of receiving waters and concentrations actually occur in practice, particularly in high dilution areas such as estuaries and coasts. The two categories were necessary for phosphorus because it was felt that impacts might be different for nitrogen-limited and phosphorus-limited waters.

Section W2 dealt with changes to the concentrations and generic locations relating to zeolite discharges. The phosphorus concentration reverted to the 0.05 mg/l of the basic scenario. The number of generic locations used was, however, reduced to 5 by combining the two coastal categories into, simply, coast.

Section W3 covers polycarboxylates using the same generic locations as zeolites. Sections S1 to S3 asked for the impacts associated with sludge disposal, covering phosphorus, zeolite A and polycarboxylates respectively. The four possible disposal routes used were: agriculture, landfill, incineration and sea disposal via a pipeline. It was felt that this list covered the four main disposal options in Europe. Section S4 examined the consequences of changes in the concentrations of heavy metals in the sludge, expressed as multiples of the concentration used in the basic scenario. Section S5 covered changes in the calorific value of the sludge, as it affects incineration with and without heat recovery. Finally Section S6 deals with the impacts of changes to the sludge volumes produced. A complete list of the parameters covered is given in Table 2.2.3, where the heavy typeface indicates the values used in the basic scenario.

Figure 2.2.2 Example of a recording table

SECTION W1: Phosphorus content by location of receiving water

	Phosphorus concentration in receiving watercourse (mg/l as P)							
Location	0	0.01	0.025	0.05	0.10	0.25	0.50	1.00
Lowland lake or feeder watercourse				1000				
Upland lake or feeder watercourse								
Inland waterway								
Estuary								
Coast with N:P ratio > 7								
Coast with N:P ratio < 7								