Water use (domestic + other)			
l/p/d	As-is	All-P	P-free
142	166	105	231
283	**78**	**55**	**80**
566	41	31	45
Rainfall (as % of domestic + other)			
15	88	61	103
30	**78**	**55**	**80**
60	59	46	66
Water hardness mg/l $CaCO_3$			
54	78	56	78
107	**78**	**55**	**80**
214	78	54	98

The indices are fairly sensitive to the levels of rainfall assumed, but the range examined is very large. Water hardness seems to have little effect, although it is perhaps worth a reminder that as hardness rises, so will the amount of builder required. No allowance for this is made here, however.

The table below shows the effects of varying the inputs with regard to permitted phosphorus concentrations in the effluent from tertiary treatment.

Treatment systems			
Maximum P allowed in effluent			
mg/l	As-is	All-P	P-free
1.0	78	55	80
0.5	**78**	**55**	**80**
0.3	73	51	75
0.1	64	45	65
0	60	42	60
Tertiary treatment %			
84.4	**78**	**55**	**80**
100	55	39	56

The table shows that as the statutory limit is reduced, the benefits seem fairly modest. A greater fall in the indices would be achieved by having 100% tertiary treatment rather than by allowing no phosphorus to be discharged from plants with tertiary treatment, if either were possible.

The table below shows the effects of varying the input value for total solids in wastewater. The index is fairly sensitive to the assumed level, particularly at the lower levels, where the indices increase as the level is lowered. Since a constant value has been assumed for all countries this should not affect the relative levels of the indices. Of course if the levels are very different between countries this could change their relative positions, but this is thought unlikely.

Total solids in wastewater			
mg/l	As-is	All-P	P-free
125	114	77	153
250	**78**	**55**	**80**
500	62	45	68

In order to assess the sensitivity of the assumptions about sludge disposal routes, the model was run on the assumption that each route accounted for the whole of the sludge produced. Thus the row in the table overleaf labelled agriculture gives the indices which would arise if all the sludges were disposed of by that route.

The implication of the table is that for Sweden, at any rate, the model indicates that landfill is the preferred option, with agriculture slightly ahead of incineration in second place. Sea disposal incurs a substantial penalty and is a long way last.

Finally in this part of the sensitivity analysis the assumptions about dilution

Sludge disposal route	As-is	All-P	P-free
Agriculture	86	59	99
Landfill	70	51	63
Incineration	88	62	95
Sea	1082	233	1097

rates in receiving waters are examined. The table shows that for the most part the levels assumed for dilution rates have little effect on the overall indices. The exception, perhaps, is the rate assumed for inland waterways, which was set at a much lower dilution than the other watercourses. A higher dilution rate would significantly reduce the overall levels of the indices, but not, once again, the relative levels between scenarios. The dilution rates have been held constant for each country thus far. The table below shows how the overall indices would vary for each country if the dilution rates change. 'Medium' means the levels used in the previous analysis, 'Low' means those levels multiplied by 2 and 'High' means those levels divided by 5.

The table shows that if high dilution rates are used, Sweden will show the lowest indices. High dilution rates, however, do not transform the Danish or UK indices to anything near those pertaining to Norway at medium dilution levels.

Dilution rates (Sweden)		As-is	All-P	P-free
Lowland	0.01	87	61	89
lake	**0.005**	**78**	**55**	**80**
	0.001	71	51	72
Upland	0.01	78	55	80
lake	**0.005**	**78**	**55**	**80**
	0.001	78	55	80

Dilution rates (Sweden)		As-is	All-P	P-free
Inland	0.01	102	70	105
waterway	**0.005**	**78**	**55**	**80**
	0.001	48	35	49
Estuary	0.01	80	56	82
	0.005	**78**	**55**	**80**
	0.001	77	54	78
Coast	0.01	88	62	91
N:P > 7	**0.005**	**78**	**55**	**80**
	0.001	70	50	71
Coast	0.01	82	58	84
N:P < 7	**0.005**	**78**	**55**	**80**
	0.001	77	54	78

Dilution rates by country	As-is	All-P	P-free
Denmark			
High	506	258	945
Medium	**327**	**183**	**570**
Low	109	69	167
Finland			
High	144	98	138
Medium	**117**	**82**	**113**
Low	86	61	82
Norway			
High	98	69	98
Medium	**87**	**59**	**87**
Low	74	52	74
Sweden			
High	128	86	134
Medium	**78**	**55**	**80**
Low	36	27	36
United Kingdom			
High	597	172	942
Medium	**536**	**164**	**848**
Low	335	115	506

2.5.4.2 Judges

The second area in which sensitivity is examined is in the judges' individual responses. This is to check whether the processes used in amalgamating the judges' scores and fitting curves to them could have been responsible for the relative values of the indices, particularly those for 'All-P' against 'P-free'. An analysis was therefore done which calculated the three indices based on each judge's individual ratings. It was not feasible here to fit curves for every judge. Instead, for any given concentration of a substance a value was interpolated from the judge's scores, by assuming a straight line in the range within which the concentration lies. This will introduce a bias into the data compared with curve-fitting, so that the overall averages will not coincide precisely with those previously calculated. The results of this analysis are shown in the table below.

The table is arranged in two parts: firstly, those (10) judges who were considered to have properly understood the question are listed, followed by those (6) who had two or more zeros in their responses for concentrations of zero. One judge, N5, was not considered here because he did not give any values for zeolite and PCA concentrations in receiving waters, and declined an offer to be placed at the median values. It was therefore not possible to run the model for this judge. Some other judges had small gaps, which were filled by using median values. The actual values of the indices for each judge are shown together with those values normalised to the 'As-is' value. Although there is considerable variation between judges in their actual indices, the table shows a consistent pattern where the normalised data is concerned. Only two judges - N8 and E6 - score the 'All-P' scenario higher than the 'As-is', and only one - E6 - rates the 'P-free' scenario higher than the 'All-P'. This suggests that the overall values for all judges are not an artefact of the aggregation method.

	Actual indices			Relative to 'As-is'		
Judge	As-is	All-P	P-free	As-is	All-P	P-free
'Full' scorers						
N1	22	10	23	100	45	104
N3	245	133	317	100	55	129
N4	38	25	50	100	66	134
N6	13	9	15	100	73	115
N8	337	410	497	100	122	147
N9	1710	1682	1748	100	98	102
N10	24	17	29	100	72	124
E1	84	57	102	100	68	121
E6	305	338	266	100	111	87
E7	33	16	45	100	48	135
'Zero' scorers						
N2	0.3	0.0	1.0	100	11	299
N7	7	1	19	100	9	281
E2	0.1	0	0.5	100	0	649
E3	2.3	1.0	3.9	100	45	168
E4	0.4	0	1.4	100	0	372
E5	0.2	0.1	0.4	100	45	164

2.5.5 A comparison with the original Phosphate Report

In the original Phosphate Report five judges evaluated the impacts of the following two wastewaters:-

Concentrations in mg/l	Wastewater A	Wastewater B
Phosphorus	20	15
Zeolite A	0	25
Polycarboxylates	0	3

Wastewater A was designed to represent the 'All-P' situation and wastewater B the 'P-free'. Although the number of experts used was small, there was a uniformity of view which suggested that, in general, wastewater A had an impact around 6% higher than B for water discharges and 1% higher impact for sludges.

A comparison can be made of the values obtained in the original report and the current study. One important difference between the two studies was that, although, the type of treatment and type of receiving watercourse were specified in the original report, the experts had to judge treatment removal rates, effluent dilution rates and background values themselves, in order to mentally calculate a concentration in the receiving water. In the current study the judges were given the concentrations directly. This problem was overcome by applying the same dilution rates and initial concentrations used in the current report to the original.

For receiving waters the original report covered the five OECD types of receiving waters, four classes of river (NWC) scheme, estuaries and coasts. Each type of watercourse was assessed for five types of treatment systems. For the purposes of comparison it was not felt necessary to evaluate all these combinations. instead the oligotrophic and mesotrophic lakes were evaluated using tertiary treatment, eutrophic and hypertrophic lakes were assumed to have secondary treatment. Rivers were assumed to have secondary treatment, and estuaries and coasts primary treatment only. The results of the comparison of watercourse are shown in the table below. The cell entries represent the ratio of the impacts of wastewater A compared with wastewater B within each study, shown as an index of 100.

100 = same impact	Current study	Original study
Lakes		
Ultra-oligotrophic	110	106
Oligotrophic	103	113
Mesotrophic	97	107
Eutrophic	120	127
Hypertrophic	109	100
River	88	102
Estuary	114	100
Coast	115	111

The table shows that the results of the two studies are very broadly similar, although the value for rivers is a little low. It would seem reasonable, though, to assume no difference between the two sets of results.

In the original report five disposal routes were considered: the four used in the current study plus forestry, which cannot be analysed using our current study results. Each route was evaluated for four treatment systems. For the purposes of comparison the four disposal routes have been reduced to three by combining biological treatment with activated sludge.

The results of the comparisons are shown in the table overleaf. Here there seems to be a considerable difference between the two studies, in that the current study shows a much greater difference between the two wastewaters when it comes to sludge disposal. The difference between the two studies tends to be around 50% for agriculture, landfill and incineration, and around 25% for sea disposal. It is rather hard to explain why the two sets of figures, particularly for sea disposal, should be so different. It is assumed that the original panel significantly underestimated the relative impact of the sludges arising from the two types of wastewater.

100 = same impact	Current study	Original study	Current original %
Agriculture			
Primary	54	93	58
Secondary	32	88	36
Tertiary	35	88	40
Landfill			
Primary	59	100	59
Secondary	64	110	58
Tertiary	64	120	53
Incineration			
Primary	58	124	46
Secondary	60	134	44
Tertiary	60	120	50
Sea			
Primary	23	87	26
Secondary	19	89	22
Tertiary	19	98	20

This study did not set out to perform a full life cycle analysis of the relevant builder systems, but if an assumption is made that the impacts of the pre-disposal phases of the life cycle are similar in Sweden to those found in the UK, as calculated in the Phosphate Report, then it is possible to derive the following table:-

Impact 'scores'	**UK**	**Sweden**
STPP system		
STPP		
Amount used (kg)	0.70	0.79
Production	61	69
Disposal	29	9
Sodium carbonate	17	17
Total	**107**	**95**
Zeolite A/PCA	**110**	**110**

Thus whereas the impact scores for the two systems in the UK were broadly similar, the score for Sweden, given the rate at which it removes phosphorus from from wastewater, is somewhat lower, around 14%, for STPP than for the zeolite A/PCA systems. A large number of assumptions have been made here, however. It is probable that similar results would be obtained for Finalnd and Norway, but that the relative scores for Denmark would be nearer to the UK situation.

References

1. Wilson, R. and Jones, B. **The Phosphate Report.** Landbank Environmental Reserach and Consulting, London, 1994.
2. **The Foresight Programme.** Department of Trade and Industry, London, 1995.
3. O'Connor M.F.. **The application of multi-attribute scaling procedures to indices of value.** University of Michigan, Ann Arbor, 1972.
4. Lowe, J. and Atkins, M. **An alternative approach to cross-media evaluation.** Chapter 7 in *Total Environmental Control.* Pergamon Press Ltd., Oxford 1982
5. Richey, J.S. et al. **The Delphi technique in environmental assessment - implementation and effectiveness.** *Journal of Environmental Management* (1985) 21
6. Kriesel, W.E. **Representation of an environmental quality profile of a metropolitan area.** *Environmental Monitoring and Assessment* (1984) 4.
7. International Association for Water Quality (IAWQ) **Directory of members, 1993**