ERROR PROPAGATION ANALYSIS OF XPS 31-133 AND CRTN TO HELP DEVELOP A NOISE MAPPING DATA STANDARD

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SUMMARY

In support of the WG-AEN, DEFRA have recently commissioned a research project to study the accuracy implications of using the WG-AEN Good Practice Guide Toolkits. This research included carried out a series of error propagation and sensitivity tests on the XPS 31-133 and CRTN methodologies using two forms of analysis. A series of Monte Carlo simulations were used to investigate error propagation in the non-geometric aspects of the methods, alongside spatial noise model based sensitivity tests for the geometric aspects. This paper sets out a description of the two testing procedures undertaken, and presents some of the results of the produced. The paper will focus on how the results of this research can be used in practice to help develop a quality audit of available datasets for noise mapping purposes, and to help inform development of specifications for future data capture exercises.

BACKGROUND

In its capacity of support for the chair of the European Working Group – Assessment of Exposure to Noise (WG-AEN), the UK Governments' Department for Environment Food, and Rural affairs (DEFRA) has let a research project to determine the likely effects, on the acoustic accuracy of calculated noise levels, of following the advice contained within the Working Groups' Position Paper (GPG) [1]

The GPG provides a series of Toolkits designed to assist EU Member States (MS), and their designated competent authorities, fulfill their obligations under the Environmental Noise Directive (END) [2]. The GPG Toolkits provide guidance on possible steps to be taken, or assumptions to be made, when all of the data that MS need in order to undertake the large scale wide area noise mapping required by the END is lacking either in coverage or in detail.

The research project, presented in [3], brought the authors of this paper to the question how the results of such an accuracy study could be used for drawing up requirements for noise mapping input data, depending on the required level of acoustic accuracy. In fact, it is the antitheses of the GPG accuracy study: *What level of input dataset accuracy is required in order to achieve a sufficiently accurate noise map?* Answers to this question could well inform data suppliers in their process of capturing and processing datasets so that they provide the suitable input for noise mapping.

SOURCES OF UNCERTAINTY IN NOISE MAPPING

The accuracy study focused on how the uncertainty in the calculated result in decibels may be related to uncertainty, errors, or assumptions in the input parameters. A study of this nature is generally referred to as an "error propagation" analysis.

To understand how this form of study is useful in noise mapping, and also how it may help to build up an understanding of the complete picture, it is instructive to consider the work by Isukapalli and Georgopoulos [4] who stated that there are normally 4 stages involved in the uncertainty analysis of a model:

- estimation of uncertainties in model inputs and parameters (*characterisation of input uncertainties*);
- estimation of the uncertainty in model outputs resulting from the uncertainty in model inputs and model parameters (*uncertainty propagation* or *sensitivity*);
- characterisation of uncertainties associated with different model structures and model formulations (*characterisation of model uncertainty*);
- characterisation of the uncertainties in model predictions resulting from uncertainties in the evaluation data (*uncertainty of evaluation data*).

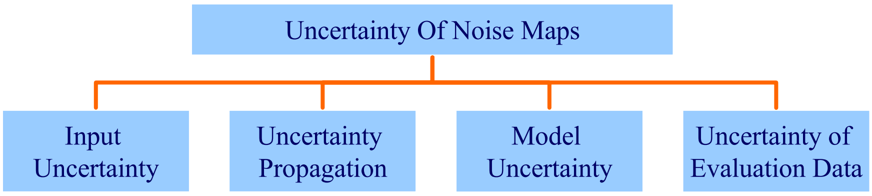

Figure 1: Four components determining the uncertainty of noise maps

It is important to understand that the project has only investigated uncertainty propagation through the CRTN and XPS 31-133 calculation methods, via two different sets of step changes, (1) in line with the GPG Toolkit steps, both individually and in combination; and (2) as individual input parameter variations across the range of probable input values, both for individual parameters, and in combination.

The input uncertainty is both determined by uncertainties in static input such as the position of the sources, building geometry, ground altitude variations and by the quality of time-varying attributes such as the traffic flow, and -especially for the interim method- meteorological data (figure 2).

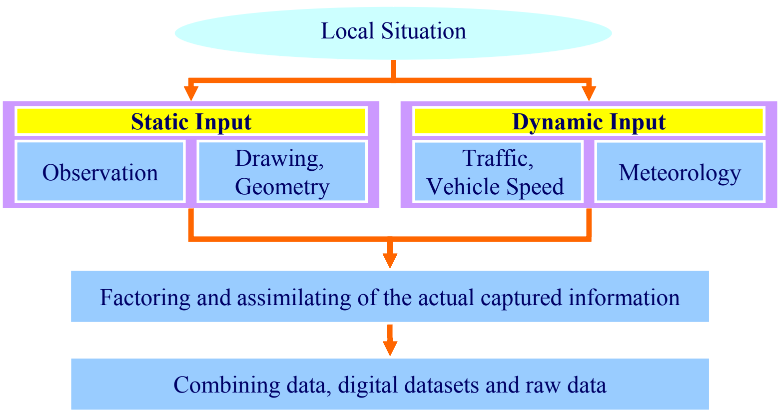

Figure 2: Input uncertainty scheme

This raw data, which is often captured primarily for other purposes than noise studies, needs to be processed, combined with other datasets and/or digitized before it can be used in a noise calculation model.

Model uncertainties are the issue of how well the prescribed calculation standard represents the real world situation, and what uncertainties it introduces due to the (necessary) simplifications made in order to present a solution which is relatively simple to implement.

The secondary issue of how the documented standard is transposed from a paper document into a 3D noise calculation tool, and how the tools additional simplifications, efficiency techniques and assumptions introduce further uncertainties into an uncertain methodology in order to create usable real world calculation times (figure 3).

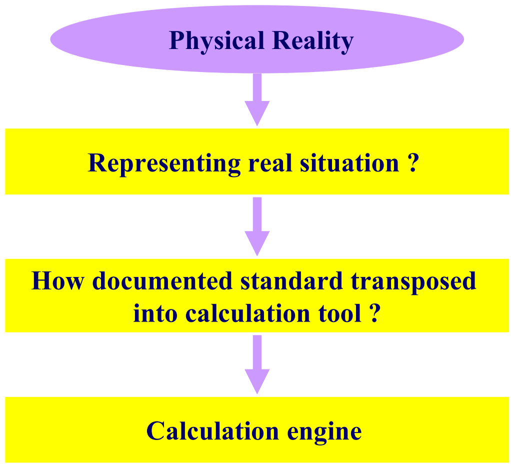

Figure 3: Model uncertainty scheme

The sources of uncertainty do not end where the noise levels are calculated. The final result of a noise mapping project is the number of residents and dwellings within noise level bands for reporting to the EC. For this purpose, noise contours will be generated by using (different) interpolation techniques and combined with population data, introducing further sources of uncertainty.

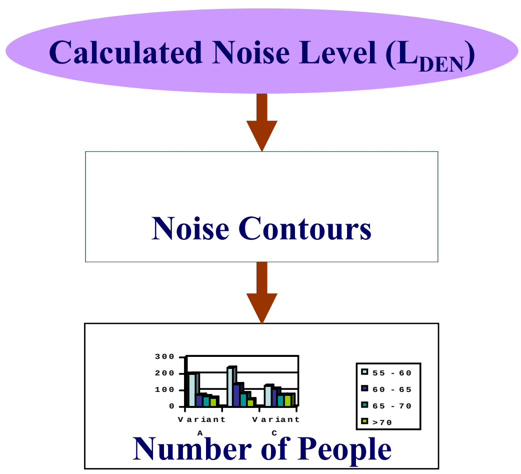

Figure 4: Uncertainty propagation

The evaluation data that is used to confirm the accuracy of the calculated noise level, is in itself open to uncertainty due to its means of capture. In relation to this Kragh [5] made a statement presenting the fundamental nature of this issue:

"The uncertainty of a predicted noise level is an interval in which the true value lies. It is difficult to quantify the uncertainty of a calculated noise level because the true value is unknowable……..A measured noise level may deviate from the calculation result due to the influence of weather, variation in source operating conditions, background noise etc. during the measurement."

Figure 5 shows the interaction between uncertainties in the source operating conditions, the meteorological factors and the noise measurement itself. Corrections to the directly measured noise levels are necessary in order to compare them with the calculated, long-term noise levels.

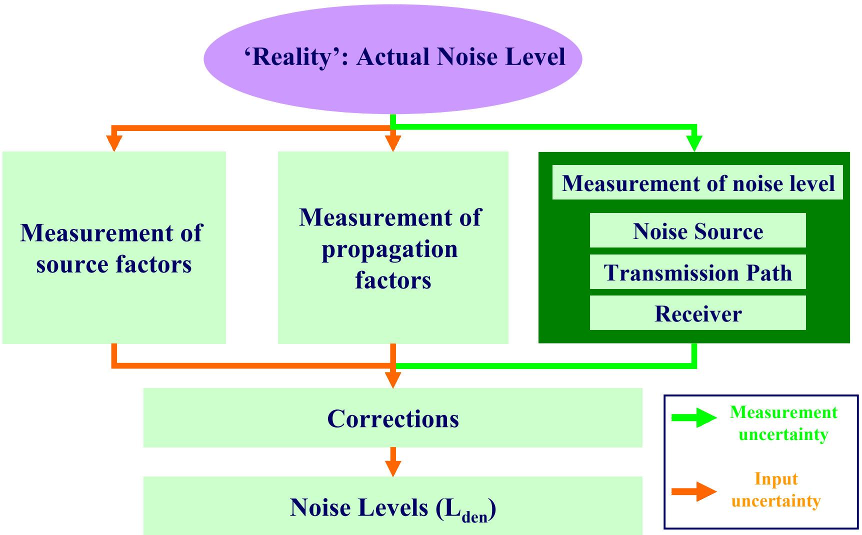

Figure 5: Uncertainty of Evaluation Data

The issue of measurement uncertainty has also been researched in detail by Craven and Kerry [6] whose work suggested that you were doing well if repeated measurements were within 5dB(A) at the same site, for the same source, on different days.

Having said that, it is also possible, as an alternative approach, to assess the uncertainty of the calculated noise level against the true value of the calculation. If one considers the situation where all the relevant input data is known with certainty and precision, this can be said to provide a true calculated result, even if it differs from a measured result. De Muer and Botteldooren [7] suggested that:

"A lack of quality and imperfection of models and input data can either be caused by uncertainty or imprecision. Uncertain information can be characterised by the partial knowledge of the true value of a statement. Imprecise information is linked to approximate information or not exact information."

The work within this project was centered on assessing the means by which uncertainties, error or assumptions within the input datasets of noise maps propagate through the calculation tools to produce uncertainties or errors in the decibel results obtained. The analysis was undertaken in two forms to provide results to inform two types of guidance.

- Using step changes to the input data type and quality in accordance with the guidance set out in the GPG Toolkits;
- An analysis of sensitivity to variation in the input attributes for both XPS 31-133 and CRTN, in order to assess a ranking order for input data quality, and develop a practical specification for noise mapping datasets.

TESTING METHODOLOGY FOR NON-GEOMETRIC ASPECTS

In the context of uncertainty analysis, Monte Carlo Simulation have proved to be a practical tool, computing the outcome of a model repeatedly using input variables which have been randomly sampled from a series of possible input values according to its associated distribution.

The output of such simulations can then be displayed in histograms which describe the probability distribution of the output allowing for the calculation of statistical parameters such as standard deviation, and variance. The method also allows probabilistic determinations such as upper quartiles and inter-quartile ranges. In addition to viewing the tendencies of the model with respect to errors, the method allows for stepped transitions in calculation methodology.

Overall, Monte Carlo Simulation is essentially easy to implement and gives a high level of accuracy as long as the correct input distributions are known. The method uses the model as function of inputs which gives more focus on the output and not the under lying function. Monte Carlo suits itself to software and coding therefore opening the possibility to including the method within software. The downside of the method in this respect is the required computation load.

In order to carry out Monte Carlo analysis on the emission functions for CRTN and XPS 31-133, it was necessary to develop a software tool to automate the process of running the analysis.

It is important to note that the function under investigation is the complete development of the emission sound power, or basic noise level. This way the decibel uncertainty result has a linear relationship to the receptor noise level. Since there is currently no information regarding the distribution of the input parameters, a normal distribution has been assumed for all the input attributes.

The Monte Carlo Simulation has been straightforward to implement utilising Matlab and Fortran, obtaining a high level of accuracy provided the input datasets actually do have a normally distributed uncertainty and a large sample size is taken.

Figure 6 shows the analysis workflow through the tools developed to carry out the Monte Carlo analysis.

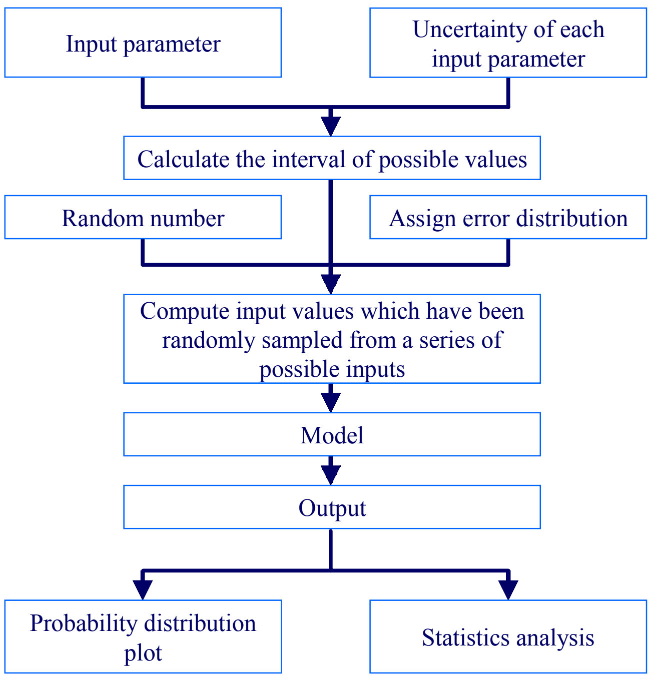

Figure 6: Process flow of the Monte Carlo tools

TESTING METHODOLOGY FOR GEOMETRIC ASPECTS

Analytical analysis techniques can be used to assess uncertainty propagation where there is a direct relationship between the input data and the result produced from the calculation method used. However, when the accuracy of results depends upon a number of variables which include location information, and hence depend upon the actual geometry, an analytical approach becomes much more complicated and is not an option within the confines of this research project. As an example, the uncertainty propagation due to building height change will vary with change in building height, but also in a second dimension as the location of that change in building height varies within the geometry of the model.

For this reason an alternative approach has been used to test the input data with a geometrical aspect. The accuracy implications of such datasets have been examined by the use of a series of test maps, starting with a situation where input data is very detailed; this is known as the *crisp model*. Subsequently, the level of certainty is decreased stepwise, according to the tools in the GPG Toolkits to produce a series of metamodels. Each metamodel is a copy of the crisp model for which the detailed data within the crisp model, for a particular dataset or attribute, has been reduced in quality, or simplified, in line with the likely effects of using a particular option provided in a GPG Toolkit.

The crisp model and metamodels were then calculated using noise mapping software packages (Predictor and LimA were used), to produce a series of grid results. The results sets have then been analysed to assess the uncertainty in the results from the metamodels, compared to those from the crisp model.

For each input parameter under investigation a number of metamodels were produced in order to create a spread of uncertainty. Each was then calculated to produce a series of uncertainty propagations and finally the series of results were analysed together against the crisp model results to estimate the impact upon the accuracy which has been introduced.

This method is conceptually quite simple, and by utilising GIS tools to manage the step changes in input parameter data it was a straightforward exercise to develop the necessary metamodels. However, a significant downside was the time taken to run each series of grid calculations required to achieve a spread of results for each input uncertainty. For this reason it was only possible to carry out between 3 and 18 scenarios for any one input parameter under investigation. The number of scenarios tested has varied due to the design of the specific tests required for each aspect under consideration. It is considered that this has not lead to definitive results. However, it is thought that it has provided an understanding of the uncertainty propagation suitable to inform the use of the GPG Toolkits. A description of the development and content of the test cases is presented in [3].

TECHNICAL SPECIFICATIONS FOR INPUT DATASETS

Following on from the work on single and multi-parameter input testing of the CRTN and XPS 31-133 calculation methods, quantifying the implications for acoustic accuracy of the selection steps within the GPG Toolkits, a proposal was drawn up for a dataset specification, suitable for the purpose of noise mapping in support of developing the END results and subsequent noise action plans. The concept is to assign a “Group” reference to the supplied dataset, such that the potential error in calculations is understood.

- Group A is aimed to have very detailed input data. This group should be used for detailed calculations, and for validation;
- Group B is aimed to manage uncertainty in the input attributes to within limits which each produce less than a 1dB error, this is considered a “best standard” for END noise maps;

- Group C is aimed to manage the input specifications such that potential errors in each element produce less than 2dB of error, this is considered a “good standard” for END noise maps;
- Group D is aimed to manage the input specifications such that potential errors in each aspect produce less than 5dB of error, this is considered a “pass standard” for END noise maps; and
- Group E is assigned when requested limits desired for Groups A, B or C cannot be met with confidence, in this case it is recommended that data quality is improved where possibly by new data capture, or by using the guidance within the GPG, in preference to the data available.

The multi-parameter sensitivity testing carried out has indicated that the compound effect of a number of parameters each in error, will be a combined error of higher magnitude. For example, managing to contain each input dataset to fit within Group C, less than 2dB per parameter variation, could lead to an overall calculated level with an uncertainty in the order of 5dB.

The input datasets presented at the commencement of a noise mapping project not only need to be analysed in order to determine their quality, but also to enable them to best serve the purpose of noise mapping calculations. Input datasets are frequently presented at a level of precision which is quite unnecessarily detailed for noise mapping calculations. The technical specifications for input datasets may then act as a guide to the extent to which incoming datasets may be simplified, before being passed into the noise calculation software, without this simplification detracting from the overall quality objectives of the project.

RECOMMENDATIONS FOR DATASETS TO BE USED IN CONJUNCTION WITH XPS 31-133

Figure 7 below sets out the recommendations for the uncertainty values to be used in order to assess the quality of an input dataset for noise mapping purposes, or where a data capture exercise is to be commissioned with respect to the road traffic data.

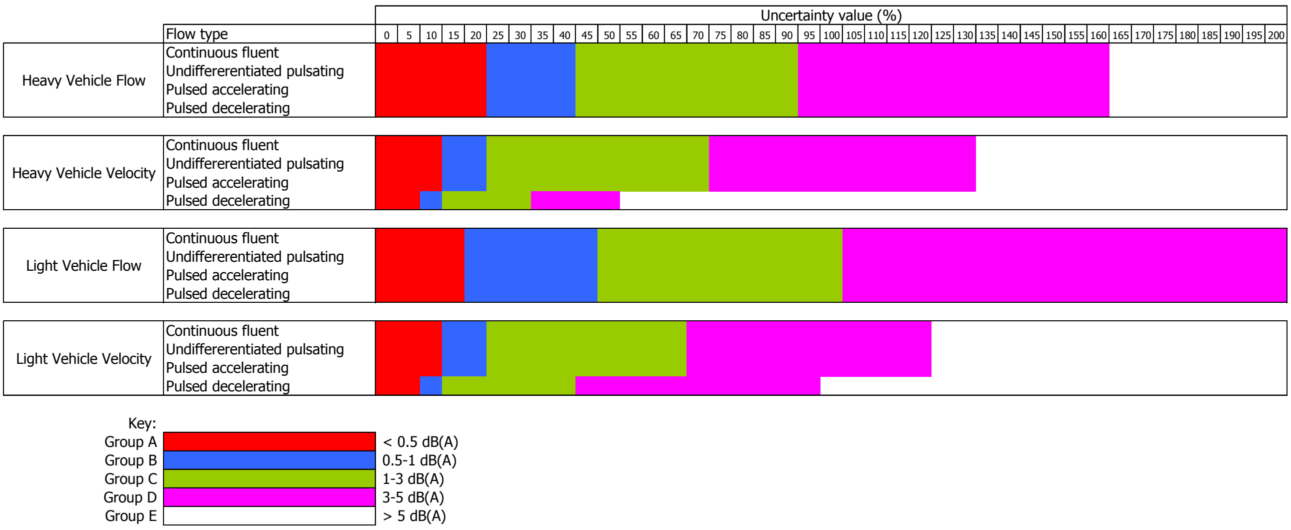

Figure 7: Group reference and associated uncertainty values for XPS 31-133 road traffic data

Further requirements for input datasets to XPS 31-133 calculations are presented in tables 1 and 2 below. A similar set of requirements was drawn for CRTN, not presented in this paper.

Table 1: Group reference and associated requirements for source factors (XPS 31-133)

Factor	**Group A**	**Group B**	**Group C**	**Group D**	**Group E**
Gradient type (-2% < flat < +2%)	No error, sections <50m	No error, sections <100m	No error, sections <200m	Flat by default	Flat as a default
Traffic flow type	No error	Within 1 class	Within 1 class	Continuous by default	Continuous by default
Surface type	No error, sections <50m	No error, use classes	≤ 1 class away	≤ 2 classes away	Dense asphalt by default
Road centerline (vertically)	<0.5m	>0.5m - <1.0m	>1.0m - <2.0m	>2.0m - <5.0m	Flat as a default
Road centerline (horizontal)	<1.5m	>1.5m - <4.0m	>4.0m - <8.0m	>8.0m - <15m	>15m

Table 2: Group reference and associated requirements for propagation factors (XPS 31-133)

Item	**Aspect**	**Group A**	**Group B**	**Group C**	**Group D**	**Group E**
Ground model	**Ground height, contours, TINs etc (Vertical)**	<0.5m	>0.5m-<1.2m	>1.2m-<2.5m	>2.5m-<5.0m	>5.0m
	Ground height, contours, TINs etc (Horizontal)	<1.5m	>1.5m-<4.0m	>4.0m-<8.0m	>8.0m-<15m	>15m
	Profile edges (Vertical)	<0.5m	>0.5m-<1.2m	>1.2m-<2.5m	>2.5m-<5.0m	>5.0m
	Profile edges (Horizontal)	<1.5m	>1.5m-<4.0m	>4.0m-<8.0m	>8.0m-<15m	>15m
	Equal height contour spacing (Vertical)	<1.0m	>1.0m-<3.0m	>3.0m-<8.0m	>8.0m-<15m	>15m
Buildings	**Vertical**	<1.5m	>1.5m-<4.0m	>4.0m-<8.0m	>8.0m-<15m	>15m
	Horizontal	<1.5m	>1.5m-<4.0m	>4.0m-<8.0m	>8.0m-<15m	>15m
	Minimum Size (m^2)	$<5m^2$	$>5m^2$-$<15m^2$	$>15m^2$-$<30m^2$	$>30m^2$-$<50m^2$	$>50m^2$
	Absorption coefficient	within 10%	Use absorption classes	Use absorption classes	Reflective by default	Reflective by default
Barriers	**Vertical (re road surface)**	<0.5m	>0.5m-<1.0m	>1.0m-<2.0m	>2.0m-<5.0m	>5.0m
	Horizontal (re road surface)	<1.5m	>1.5m-<4.0m	>4.0m-<8.0m	>8.0m-<15m	>15m
	Minimum Height (m)	<1.0m	>0.5m-<1.0m	>1.0m-<2.0m	>2.0m-<5.0m	>5.0m
	Minimum Length (m)	<10m	>10m-<25m	>25m-<40m	>40m-<100m	>100m
	Absorption coefficient	within 10%	Use absorption classes	Use absorption classes	Reflective by default	Reflective by default
Ground cover	**Ground factor (%)**	<5%	>5%-<10%	>10%-<25%	>25%-<50%	>50%
	Surface minimum size (m^2)	$<5m^2$	$>5m^2$-$<15m^2$	$>15m^2$-$<30m^2$	$>30m^2$-$<50m^2$	$>50m^2$

CONCLUSION

This research project has carried out an investigation into input data accuracy requirements in the context of environmental noise mapping. The results of the single parameter, and multi-parameter error propagation testing have helped to gain an understanding of the effect upon the receptor decibel result levels calculated due to errors or uncertainties within the input datasets.

The results of the technical investigations were used to help draw up an interpretation of the END in the context of data requirements. The results were presented in a series of equal noise error bands to help illustrate the order of merit of the datasets, and the potential for resultant error connected with uncertainty in each. These tables can be used to help equalise effort across the various input datasets in an effort to maximise value, and minimise error. The multi-parameter testing showed that even if each individual dataset uncertainty was constrained within a certain error band, then the total resultant uncertainty of the final result is most likely to be in the next uncertainty band above.

Finally, the research has shown that the level of error within the calculated result can be significant in the context of the 5dB bands of results required for the EU END noise mapping in 2007. The level of accuracy required for some input datasets may well challenge the best information currently available across the EU, and should be seen as an indication towards how data capture and management organisations need to be worked with proactively by the acoustics community if the results in 2012 are to be of a higher degree of accuracy.

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