

# **Environmental impact from the use of recycled materials in road construction**

– Method for decision-making in Norway

✉ Gordana Petkovic, Dr.Ing. [Norwegian Public Roads Administration]  
Christian J. Engelsen, M.Sc. [Norwegian Building Research Institute/  
/University of Oslo]  
Arnt-Olav Håøya, M.Sc. [Rambøll]  
Gijs D. Breedveld, Ph.D. [Norwegian Geotechnical Institute]

A method is presented for the assessment of environmental impact from recycled materials in road structures - the approach chosen by the Norwegian Public Roads Administration as a way of obtaining more practical acceptance criteria for recycled materials in road construction. The approach is based on a combination of the European standard for characterization of waste, ENV 12920, and Guidelines for evaluating impact on health and ecosystem; SFT 99:01, issued by the Norwegian Pollution Control Authority. The possibility of using generalized default assumptions contrary to site-specific data is the key issue.

As an introduction, Norwegian conditions concerning natural resources and waste are described with the aim of pointing out major differences from European countries that have achieved high recycling levels. Traditionally, Norway is not a typical “recycling country”, especially in regards to the recycling of construction and demolition waste. Nationally the level of recycling for this type of waste is roughly estimated to be 10-20%. One reason for the low level of recycling in this area is the abundance of high quality and relatively low cost natural aggregates. Another reason is that ambitious environmental policy sets high standards for pollution control and raises concern regarding potential damage caused by long-term leaching.

---

**Keywords:**

recycling, road construction, environmental impact, risk assessment, leaching, acceptance criteria, Norway

## **1. Introduction**

In Europe, the processing and recycling of demolition waste have made large progress since the start in the Netherlands at the beginning of 1980s. For many countries (e.g. the Netherlands, Germany and Denmark) the major driving forces have been, and still are, the limited landfill capacity and reduction of adequate mineral resources (Tränkler et al., 1996, Hjelmar, 1996). In contrast, Norway is not a typical “recycling country”, especially in regards to the recycling of construction and demolition waste. Nationally the level of recycling for this type of waste is roughly estimated to be 10-20%, which is well below the EU average of 25 % (Mehus et al., 2003). In order to overcome some of the obstacles for the use of construction and demolition waste, the Norwegian Public Roads Administration initiated the “Recycled Materials Research and Development Program” in 2002 ([www.gjenbruksprosjektet.net](http://www.gjenbruksprosjektet.net)). In addition to the recycled materials produced from construction and demolition waste, the program also focuses on shredded tires and cellular glass utilized as lightweight fill materials. In the program objective, environmental issues are given high priority.

This paper will present a method for assessing environmental impact of recycled materials in road structures. As an introduction, the Norwegian situation concerning natural resources and volume of waste is shown, with the aim of pointing out major differences from European countries that have been processing and recycling demolition waste for more than 20 years. Over these years a large amount of data concerning environmental properties of various materials has been gained worldwide. This information is partly not assessable due to the widespread of methods used when generating the data, as stated by van der Sloot (2002). The method in this paper is therefore based on a compilation of the European standard for characterization of waste, ENV 12920, and Norwegian “Guidelines for the risk assessment of contaminated sites” (Vik et al. 1999). A strategy based on connecting two standard procedures of this type for the purpose of generating acceptance criteria for recycled materials applied in road structures, has not been reported in literature. To the authors’ best knowledge, a comparable approach combining ENV 12920, as a way of description of the recycled material, with environmental monitoring rules has been reported in France only (Domas et al., 2003). There are, however, differences concerning risk evaluation.

## **2. Background**

### **2.1. Natural setting - Norway**

Norway is located on the North Sea side of the Scandinavian Peninsula. The total surface area of 324,000 km<sup>2</sup> is inhabited by 4,3 mill people. Population density in Norwegian districts (19 in total) ranges from 1-1000 people per km<sup>2</sup>. Rock, as a natural resource, is relatively abundant. The yearly production of gravel and crushed rock is approximately 50 mill tons, or 11,6 tons / inhabitant. Easy access to good rock material has also resulted in relatively strict technical specifications for aggregates in construction works.

Roads in Norway are typically constructed on marine deposits (clay, requiring lightweight fill materials), glacial deposits (sand and gravel) and rock or shallow soil. The climate is characterized by relatively abundant precipitation and low average temperatures. Due to easy access to fresh water from rivers and lakes, barely 15% of the population uses ground water as drinking water. In contrast, drinking water in Denmark is produced exclusively from ground water (Henriksen and Stockmarr, 2000). Run-off from waste deposits in Norway has therefore not been a problem that has received much attention.

In terms of available space, natural resources and quality of ground water, land filling still presents a plausible solution for construction and demolition waste in Norway. This is the main difference between Norway and the European countries that have achieved high recycling levels, e.g. the Netherlands and Denmark. That is also the reason why Norway could not simply use criteria for recycled materials established in other countries such as Germany, Switzerland, Austria and the Netherlands (Engelsen et al., 2002).

## 2.2 Primary waste generated

The approximate amount of construction and demolition waste generated yearly is 1,5 mill tons, of which 1,1 mill tons is estimated to consist of concrete and masonry rubble. The estimated recycling percentage for construction and demolition waste in Norway (10-20 %) represents approximately 0,4 % of the annual production of gravel and crushed rock. This indicates that the utilization of available recycled construction and demolition waste does not significantly affect the consumption of natural aggregate. However, various applications of recycled concrete aggregate have been tested and guidelines have been formulated (Engelsen et al., 2003, Mehus et al., 2002, Lahus et al., 2002). A quality certification system has also been developed (Karlsen et al., 2002).

The amount of asphalt waste generated in 2002 was reported to be 470 000 tons. Only 8000 tons of this was land filled, while the rest was recycled. The recycling percentage for 2002, however, was 105.6%. This is attributed to a large amount of stored asphalt waste from previous years now being recycled in current construction projects (Institute of asphalt Technology, 2002). As the recycling percentage of asphalt is no longer an issue, focus is being placed on improving the technology necessary for more feasible warm recycling of asphalt. The real challenge, however, seems to be improving the management of asphalt waste so that high quality material is not used in low quality applications.

The number of vehicle tires collected annually in Norway is approximately 4 million, which corresponds to 32 000 tons. In 2002, approximately 30% of this material was used in construction applications, 10% was combusted in cement production and 50% accumulated at storage, while the remaining 10% was reused in a number of various applications (Johnsen, 2003). European Council Directive 1999/31/EC on the landfill of waste prohibits the placement of whole tires in landfills, effective July 1<sup>st</sup> 2003. The placement of processed (shredded) tires in landfills will also be prohibited, effective January 1<sup>st</sup> 2006. Norwegian legislation prohibited the placement of tires in landfills already in 1995 for tires from private cars, vans, busses, trucks, motorcycles and

trailers of these vehicle categories, and since 2002 for all tire types excluding bicycle tires (Norwegian Pollution Control Authority, 1994). As a result, new applications need to be found for the use of this type of material. The Norwegian Pollution Control Authority, however, is very restrictive in approving the use of shredded tires and requires more documentation prior to approval.

Compared to the Netherlands, Denmark and Sweden (van der Sloot, 1996, Hjelmar, 1996, Hartlén 1996) the waste volumes in Norway are small, especially with respect to the surface area of the country.

## 2.3 Current Norwegian environmental policy

The Norwegian Ministry of Local Government and Regional Development, the ministry responsible for building and housing, published a first generation action plan for 2001-2004 (Ministry of the Environment, 2001-2002). The plan acknowledges the current low level of recycling of building materials in Norway and specifically states that this level must increase in the years to come.

Recognizing the need for increased effort and improvement in construction and demolition waste management, the Norwegian building and construction industry published a national action plan. The plan identifies increased recycling, in addition to the increased use of prefabrication and module-based production as important methods of reducing the construction and demolition waste problem.

Thus, environmental policy, combined with growing public awareness regarding the use of natural resources, are promoting the increased use of recycled materials. However, as shown in the previous section, an abundance of natural resources, available space, quality ground water and small waste volumes tend to undermine the discussion around the development of recycling. These circumstances create a situation that has a tendency to focus more on possible problematic aspects, especially the pollution generated from recycled materials, as opposed to the potential benefits.

## 2.4 The Norwegian Roads Recycled Materials Research & Development Program

### 2.4.1 Overview

The Norwegian Public Roads Administration initiated a four-year R&D program, “The Norwegian Roads Recycled Materials R&D Program” in 2002. The main objective of this program is to facilitate more frequent and environmentally safe application of recycled materials in road construction. The primary aims of the program are:

- To increase the general level of knowledge of recycled materials and, more specifically, the characteristics of recycled materials available in Norway,
- To revise rules and building processes such that recycled building materials can be readily included.

This is the first time road authority puts organized effort in incorporating recycled materials in design codes and building practice. Materials that are of special interest in

Norway are recycled concrete aggregate, asphalt, and light-weight fill materials: shredded tires and cellular glass. Industrial waste consisting of coal combustion residues, steel and iron slag has limited volume in Norway. Municipal solid waste incinerator ash is not included in program due to potential labeling as hazardous waste in Norway.

Potential use for each of these materials in road construction applications is evaluated on the material's technical and environmental properties, both in the laboratory and in the field. The program also deals with handling of waste and the administrative work necessary for recycling, such as legislation, taxes, and relations regarding responsibility. Finally, a separate work package is dedicated to studying the environmental impact of recycled materials in road structures.

#### *2.4.2 Environmental impact of recycled materials*

For the purposes of this project, the focus is on the possible environmental effects from recycled materials in road structures during service life, thus excluding environmental effect of production and processing, construction phase, and disposal. The objective is to develop and apply a national decision-making strategy that would ensure that the potential environmental risk related to the use of recycled materials in road construction remains within acceptable limits.

In areas with sensitive land use, such as housing developments, playgrounds and schools, soil quality criteria are applied for acceptance of recycled materials. Applying recycled materials in areas with less sensitive land use requires, according to the regulations, case-to-case evaluations, which are both time consuming and expensive. In view of these facts, replacement of the case-to-case approach with general acceptance criteria for recycled materials for the most common applications in road construction will be beneficial. This is the main aim of the work package "Environmental impact".

Practical benefits from the application of this strategy are to be obtained by the end of 2005, in the form of acceptance criteria for recycled materials. Acceptance criteria may include specific screening criteria for recycled materials that could be applied in production control, or restrictions on ways of application of recycled materials. It is imperative that these criteria be implemented in the Norwegian Public Road Administration's standard documentation for road construction.

### **3. Method**

#### **3.1 General description**

The method chosen in this project is based on the combination of the European standard for the characterization of waste (ENV 12920, 1996), and the Norwegian guidelines for evaluating the impact of contaminated soil on health and ecosystem (Vik et al. 1999). ENV 12920 focuses on the management procedures in the testing and evaluation of leaching behavior for waste materials. By applying these procedures to different scenarios in road structures, relevant release estimates for the waste materials can be determined. These release estimates can further on be used as the input data for health and ecosystem risk evaluation, following the previously mentioned Norwegian

guidelines for risk assessment of contaminated sites. The general idea of this approach is that the coupling of waste characterization and risk assessment guidelines can be used by systematically varying the key parameters in chosen application scenarios. This leads to an iterative process between quantification of leaching and evaluation of risk. Consequently, the environmentally tolerable doses can be directly linked to the chosen scenarios for which the maximum leachable content can be determined. This forms the basis for acceptance criteria for recycled materials with respect to leaching behavior and type of application. It is important to study possibilities for using generalized scenarios and parameter estimates contrary to site-specific data as part of this iterative method. In this project cement- and glass-based materials, shredded tires and recycled asphalt will be the main focus. However, the method should be applicable to other materials as well.

In the following, this paper will describe all the elements of this approach and how the authors believe it can be used for obtaining practical acceptance criteria for recycled materials in road construction. Generation of result from applying this approach is currently in progress.

### 3.2 Environmental impact assessment – coupled procedure

ENV 12920 is carried out in seven steps (1 to 7), with the aim of determining the scenario-specific leachability for the given recycled material within the specified time frame. However, the standard does not consider the migration of constituents from the utilization scenario into the surrounding environment and the toxicity to humans or ecological impacts on flora and fauna. The methodology in ENV 12920 is, therefore, extended on to these aspects, by adding a step 8 – risk assessment for the given combination of material, scenario and land use. This extended, coupled procedure of characterization of waste material under specified conditions followed up by the assessment of corresponding risk, is a method for assessing environmental impact of the recycled material in a road structure during the service life of the road. The coupled procedure will be scenario-specific if a set of parameters in a given scenario is applied. If, however, a wider range of scenario parameters is applied, including the most conservative conditions, the effect of more generalized default parameters can be evaluated and judged.

Environmental impact during service life is only a part of the *total* environmental impact. The environmental impact assessment of a product or activity is defined as the analysis and evaluation of all possible factors likely to have a significant effect on the environment, from the production of the product to its disposal. The left column in Figure 1 illustrates the steps of an environmental declaration, each step representing a stage in the life cycle and the corresponding effect on the environment. Declaration systems, which exist in Norway and a number of other countries, currently lack relevant long-term data concerning the service life of recycled materials in road structures. The right column in Figure 1 illustrates the steps of the coupled procedure for environmental impact assessment in service life. By performing the coupled procedure for secondary materials in a certain application, e.g. a road structure, the declaration system is supplied with relevant input data concerning service life. This relation is illustrated in Figure 1 in the connection between the right and left column.

In the following sections, the coupled procedure for environmental risk assessment in service life will be described step by step.

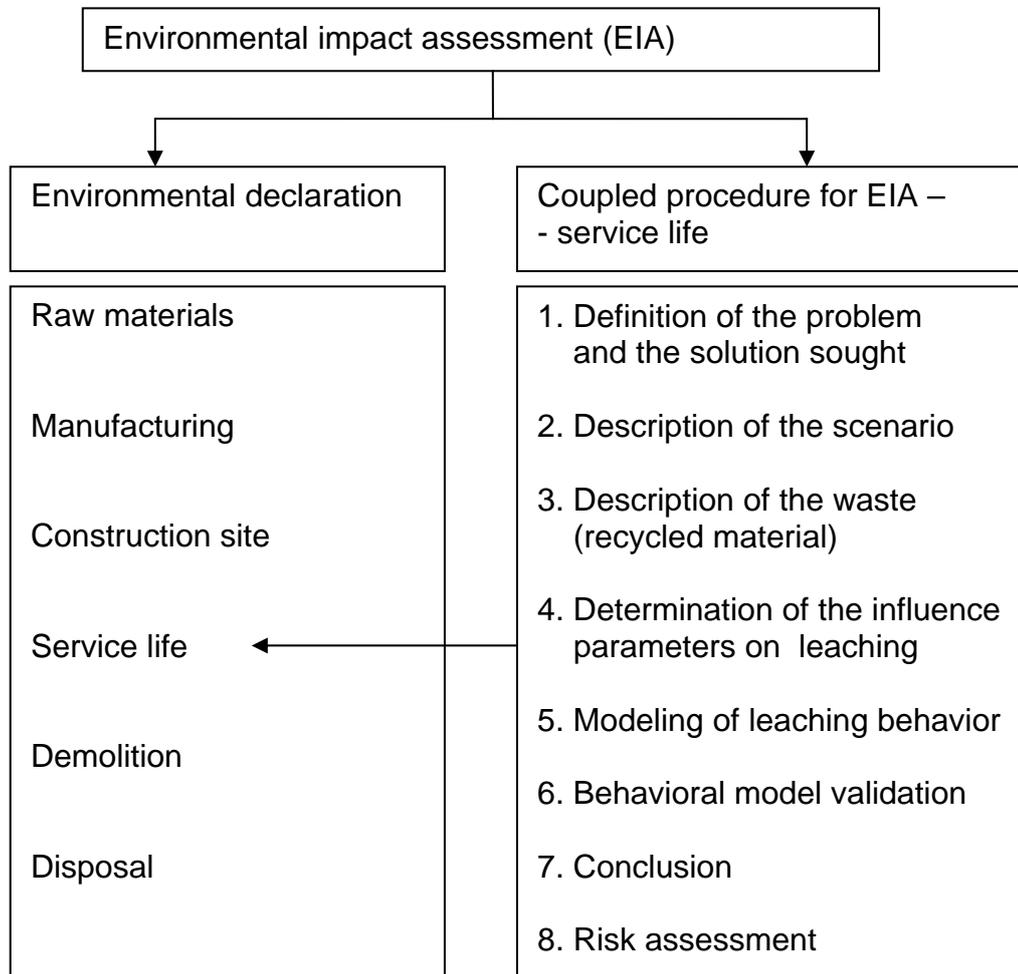


Figure 1. The relationship between the coupled procedure for environmental impact assessment in service life and environmental declaration

### 3.2.1 Step 1 - Definition of the problem and the solution sought

This step focuses the search for facts and documentation. The main concern regards the effects resulting from the application of the material in particular parts of the road structure. In the present project, all parts of a standard road structure are considered potential applications for a recycled material (see Figure 2).

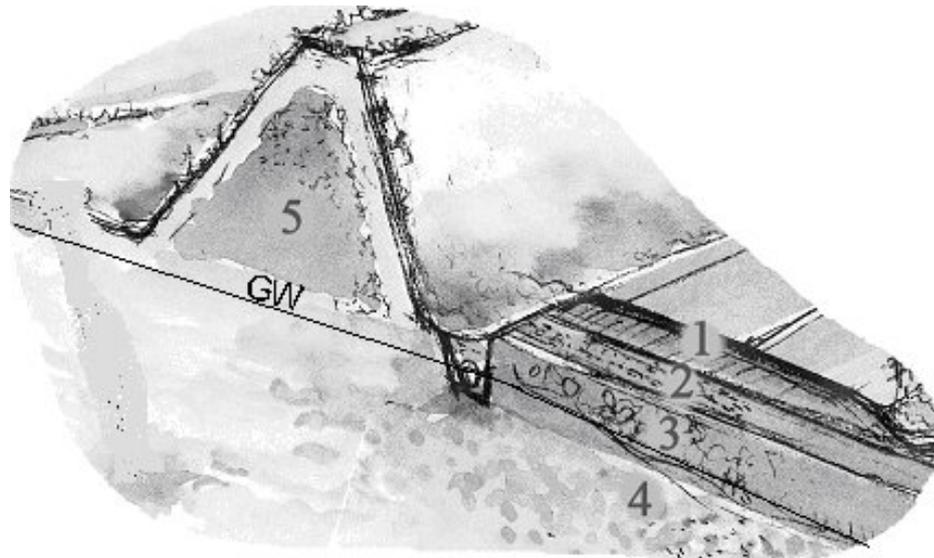


Figure 2. Chosen applications of recycled materials: (1) pavement, (2) top structure, (3) and (4) support structure - above and below ground water level (GW), and (5) noise barrier.

Both salt and fresh water exposure are considered, as well as varying climatic conditions. In addition, runoff to sensitive recipients such as lakes and rivers is considered. The potential applications and ground water level variations are combined into scenarios for the calculation of environmental impact (see Table 1).

Table 1. Scenarios (I – VI), which are of interest for the calculation of environmental impact, consisting of combinations of chosen applications and variations of ground water level.

Scenario elements	Scenarios					
	I	II	III	IV	V	VI
1 Application in pavement	Yes	Yes	No	No	No	No
2 Application in top structure (100 cm)	Yes	No	Yes	No	No	No
3 Application in support structure (500 cm)	Yes	No	No	Yes	No	No
4 Application in support structure below groundwater level (GW) (100 cm below road surface)	Yes	No	No	No	Yes	No
5 Application in embankment or noise barrier	Yes	No	No	No	No	Yes

Possible effects on the environment from the use of recycled materials are evaluated with regard to the exposure of organisms and humans to soil, sediment, surface water and ground water. In searching for a solution, priority pollutants that can leach from the waste are addressed, as well as the potential to spread into the surrounding areas within a time frame of 100 years. The development of geo-chemical gradients from the construction to the surrounding soil should also be addressed.

### 3.2.2 Step 2 - Description of the scenario

Natural setting and the specific exposure scenario define the general conditions for the environmental impact assessment during service life of the road structure. The scenario is defined by quantitative and qualitative parameters relevant for applying laboratory results to a general natural setting. The scenario includes: technical setting, climatic conditions, biological conditions, and land use.

The natural setting and exposure conditions for a general road/highway environment as defined in this project are:

- *Precipitation*: Background concentrations are clean coastal precipitation including salt applied to the applied road. Precipitation is 1000 mm/year.
- *Biological and chemical conditions*: Microorganisms exist as in soil with low organic content (<1%). Soil conditions such as content of carbon dioxide, pH, Eh and moisture transport are also similar.
- *Base (source)*: Sorted fraction of gravel or rock. Size 25 m wide, 1 m thick and 1000 m long.
- *Sub base (source)*: Unsorted fractions. Size 35 m wide, 5 m thick and 1000 m long. Clean groundwater pass with a speed of 60 m/year.
- *Infiltration (transport source)*: Precipitation on the pavement and side of the road infiltrate the base and sub-base. 30% through the pavement (asphalt) and 70% over the side, based on Bendz et al. (2003).
- *Land use (exposure)*: Well or surface water as a drinking water are > 50 m from the road. Water quality in surface waters is within Norwegian class 2 or better (“Moderately polluted”).

### 3.2.3 Step 3 - Description of the waste (recycled material)

In order to identify the parameters that can influence the leaching mechanism, the chemical, physical, and mechanical properties of the materials should be described. The properties chosen must be relevant for the scenario under consideration. The relevant material parameters requiring documentation, chosen in this project, are given in Table 2. In the case of cement-based materials, full characterization of commercially produced recycled concrete aggregates and laboratory cast concrete samples is being carried out experimentally. For asphalt, shredded tires and cellular glass, available laboratory data are used.

Table 2 Parameters identifying different material properties

Parameter	Material type			
	Cement-based	Shredded tires	Asphalt	Cellular glass
Nature and origin	X	X	X	X
Compressive strength	X		X	X
Porosity	X		X	
Texture	X	X		X
Permeability	X	X	X	
Density	X	X	X	X
Grain size distribution	X			X
Inorganic element content	X	X	X	X
Organic constituents	X	X	X	
Total organic carbon	X			
ANC <sup>1</sup>	X		X	

<sup>1</sup>Acid Neutralization Capacity

#### 3.2.4 Step 4 - Determination of the influence of parameters on leaching behavior

A number of factors or parameters affect the degree of leachability from the material. These factors are material parameters, i.e. material properties outlined in the previous section, and parameters dependent of the field scenario (Connor, 1990). Parameters classified under the latter include field pH, exposure time, DOC, degree and rate of infiltration, chemical reactions, etc. Some of the field parameters are clearly related to material properties, e.g. chemical reactions will take place in a given material only if it is brought in contact with a given type of water. Hence, the potential for leaching is determined by the combination of the two sets of parameters. Furthermore, the release of contaminants from the material in the considered scenario, including specified time frame, will be more dependent on some material properties and scenario conditions than others. On this basis, the fundamental parameters for assessing the leaching potential resulting from the given scenario and given material are listed in Table 3.

Table 3 Scenario-specific parameters affecting the leachability.

Parameter	Material type			
	Cement-based	Shredded tires	Asphalt	Cellular glass
Field pH	X	X	X	X
Redox potential	X		X	
CO <sub>2</sub>	X			
Salinity	X			
DOC	X	X	X	
Degree and rate of infiltration	X	X	X	
Compaction	X			
Biological factors <sup>1</sup>		X	X	

<sup>1</sup>Biodegradation, transformation and gas formation

Determining how and to what extent the scenario-specific parameters affect leachability is an extensive and time-consuming procedure. Such an evaluation requires full-scale demonstration projects for each material concerned, which is beyond the scope of this project. In order to address this concern, fundamental intrinsic leaching characteristics are determined by laboratory leaching tests. In addition, mass

transfer models (percolation or diffusion) are applied in order to extend the results to 100-year release estimates. By taking this approach, the interpretation of leaching data will be facilitated (see next section for modeling). This is also the most versatile approach in terms of the comparability of materials and scenarios (Kosson et al., 2002).

To cover the main chemical and physical features of the materials, the following main types of parameter-specific laboratory leaching tests are applied:

- Tests based on equilibrium as function of pH and L/S,
- Mass transfer rates tests,
- Availability tests.

For the purpose of the iterative calculations (see Section 3.2), the numerical values of parameters in Table 3 will be varied in a broad range, simulating both realistic and conservative scenarios. The actual values of the parameters in Table 3 will be measured in the field for the calculation of site-specific cumulative release.

### *3.2.5 Step 5 - Modeling of leaching behavior*

The aim is to formulate a model allowing the application of short-time characterization test results to the relevant lifetime of the construction (100 years). The model should consider interactions between the various compounds and the surrounding matrix, as well as changing conditions over time. Hence, the model applies the parameter-specific tests data identified in Section 3.2.4. Current long-term assessment models, however, differ in their individual degree of sophistication (Sanchez et al., 2002, van der Sloot et al., 2001, Baker and Bishop, 1997). These models can consist of simple release models to more sophisticated ones, depending on the level of leaching characterization. Both types of models are typically based on percolation/equilibrium or diffusion data. However, more sophisticated models can be designed to account for the chemistry between solid and liquid phases, wash off effects, intermittent wetting and ageing processes (both chemical and physical).

Kosson et al. (2002) showed simplified equations of how cumulative release can be estimated in a specified time frame for both, percolation and mass transfer-controlled scenarios. In the percolation scenario, for which local equilibrium is assumed, the cumulative release is based on equilibrium tests as function of pH and L/S ratio. The calculation for transferring L/S ratio applied in laboratory into the actual field scenario is also shown. For mass transfer-controlled scenario, based on the solution of Fick's second law, the cumulative release is calculated from the tank leaching tests. For both types of leaching scenarios, the simplified models need input data from the scenario including density and volume of the fill, infiltration and field pH, which is recognized in Sections 3.2.2 and 3.2.4.

In this project the modeling in Kosson et al. (2002) is currently being applied as a basis, however as a conservative first approximation. Recent papers deal with ways of providing more exact release estimates (Sanchez et al., 2003, Garrabrants et al., 2002). The modeling in these works is conducted for waste stabilized with Portland cement and accounts for intermittent wetting, varying relative humidity, and release based on a coupled dissolution-diffusion model. Furthermore, Dijkstra et al. (2002) have applied

geochemical modeling to column leaching data from MSWI bottom ash. These, more sophisticated, model approaches require more extensive information, and will therefore be limited to cement-based materials, which are the main focus of this project. Modeling of long-term release of pollutants from asphalt, shredded tires and glass-based materials will be performed using simple models based on conservative solubility and partitioning coefficients.

### *3.2.6 Step 6 - Behavioral model validation*

Model predictions of leaching shall mimic the natural leaching processes. Validation of the material leaching characteristics model can be done in one of the following ways:

- laboratory verification of the modeled effect for each factor in the description of leaching characteristics,
- field verification of the predicted leaching behavior,
- verification in comparison with natural materials.

Each of these approaches has its limitations with respect to time span that can be validated or compared to full-scale applications.

Interesting and extensive work concerning the relation between laboratory and field site leaching from MSWI bottom ash and coal fly ash has been carried out by Schreurs et al. (2000). In this work leaching of different inorganic constituents at field site was determined in different ways including the concentration decrease in the material, possible constituent accumulations in the underlying soil and difference in leaching between fresh and field aged material. Furthermore, the results were compared to release calculations according to the Dutch building Materials Decree for both percolation and diffusion controlled scenarios, and reasonable agreement was reported. The work of Schreurs et al. (2000) will be useful in the process of field verification for cement-based materials, in terms of ways of determining actual leaching and how field data can be linked to laboratory data.

For the purposes of this project, laboratory verification is being carried out on cement-based materials only. In addition, field site verifications, in terms of full scale demonstration projects with cement-based materials, are currently under planning. For shredded tires a monitoring program of the field leachate is already established on a noise barrier structure and will be used for field site verification. For glass-based materials, which are relatively inert regarding leaching characteristics, comparison with natural aggregates (e.g. granite) may be relevant.

### *3.2.7 Step 7 - Conclusions concerning long term leaching*

Generally this step is the concluding step of the ENV 12920 and will accordingly consist of determining whether the defined problem is solved or whether the information is insufficient. In the latter case it may be necessary to repeat previous steps e.g. modify the model, change the scenario conditions etc.

The present coupled procedure, however, includes risk assessment, as pointed out in the introduction of Section 3.2. The evaluation of the results from the process of characterization of the recycled material (step 1 through step 6) must include a

verification of the significance of these data for risk assessment to be performed in step 8. The relevant criteria for this evaluation will be to control that all the necessary input parameters for the assessment of risk are available and representative.

### 3.2.8 Step 8 - Risk assessment for given scenarios

In steps 1 – 7, the main focus is on calculating the cumulative released amount of constituents of concern. A definition of the *acceptable* level of leaching, however, is not addressed. This is the task of the risk assessment procedure, which includes all of the following: source identification, transport pathway evaluation and exposure assessment of target organisms. Dose response and hazard identification is based on available data concerning maximum tolerable daily intake for human exposure and PNEC (predicted no-effect concentration) for exposure of the ecosystem. The Norwegian "Guidelines for the risk assessment of contaminated sites", recognize three tiers:

- Tier 1 – Screening: the material composition is compared with soil quality criteria (SQC) for areas with sensitive land use. If the composition of the material exceeds the SQC, assessment according to Tier 2 should be performed.
- Tier 2 – Generic Quantitative Risk Assessment – quality criteria for the actual exposure scenario are determined and compared with the material composition. This tier takes into consideration local conditions and land use (present or future). Scenario-specific transport and exposure conditions are modeled using an equilibrium partition approach, implying that the focus is on concentration of contaminants, not the total load. Exceeding these criteria requires remedial action or performing a more detailed, Tier 3, risk assessment.
- Tier 3 – Tailored Quantitative Risk Assessment - actual environmental effect on site, obtained by field observations/monitoring and advanced study. Additional factors, such as bio-availability of contaminants, degradability and immobilization, have to be considered. The time-release function from leaching test as well as total load will be important parameters here. Long-term effects are included in Tiers 2 and 3.

Traditional risk assessment approaches are based on estimating concentrations in water or soil, forming the basis for exposure of humans/organisms. In the case of a road structure, however, the total amount released to the environment will be more relevant than concentrations in the various matrices. In the first phase after construction, a high concentration pulse is expected. However, this concentration pulse will rapidly reduce. On a long-term basis, the low concentration range will contribute more substantially to the overall environmental load than the early peak concentrations.

The selected scenarios (see Section 3.2.1 and Table 1) are assumed to cover the most common combinations of technical, climatic, biological and exposure conditions in road structures. It is also assumed that the material properties used as input values are based on regular testing employing test methods reflecting the actual application of the recycled material (see Section 3.2.3). Thus, by performing the coupled procedure for environmental impact assessment, steps 1 through 8, a basis for the acceptance of a recycled material for the intended application will be obtained.

### 3.3. Formulating acceptance criteria for recycled material

In common applications of recycled materials, the constructors need to know the maximum acceptable contents of pollutants in the recycled material, alternatively acceptable level of leaching from the recycled material, assigned for a certain application.

The description of the problem should therefore be reversed. Performing the coupled procedure for environmental impact assessment, steps 1 through 8, for combinations of chosen scenarios and chosen materials will form the basis for *adjustment* of the initial conditions in order to maintain acceptable risk. This adjustment is an iterative calculation, giving feedback from step 8 to step 3. In this way, threshold values for material input data are determined for each specific scenario. This iterative assessment process leads to criteria for the acceptance or refusal of the recycled material for the given application. A useful reference is a simplified reverse calculation from risk based soil quality criteria to a designed concrete pavement shown by Hilary et al. (2003), although the assumptions are different from the scenario descriptions made in this project.

The threshold values obtained in such a way should be compared to the realistic values for materials available on the market. Acceptance criteria can then be formulated either by defining the limitations of the composition or leaching quantity of the material, or by defining where and how the material may be used (see Section 3.2.1 and 3.2.2). Acceptance criteria for recycled materials in road construction can be modified by taking into consideration social aims and political decisions, market situation etc.

Acceptance criteria formulated as described here are planned to be integrated in the Norwegian Public Roads Administration guidelines for the use of recycled materials in road structures. Limiting values for composition or leaching quantity should be defined as a quality criteria for the recycled material and preferably integrated in a quality certification scheme for recycled materials.

## 4. Conclusion

National waste policy requires solutions that reduce the amount of waste delegated to landfills, and increases the use of secondary materials. Natural settings, abundance of natural resources and small waste volumes, however, do not provide the same incentive to contractors in Norway, despite substantial taxing of waste delivered to landfills. Therefore, it is in the interest of the State that the Norwegian Public Roads Administration develops functional guidelines for the application of recycled materials in road structures. One of the key success factors in the Norwegian Roads Recycled Materials R&D Program is the establishment of a nationally recognized method and a set of acceptance criteria, which can be applied to future guidelines for road construction.

The acceptance criteria for recycled materials for road construction can be formulated by performing the suggested coupled procedure for environmental impact assessment for typical road scenarios and, for each combination of material and scenario, calculating the threshold values for material input so that acceptable environmental

impact is maintained. This calculation is iterative and results in a set of values defining the acceptable composition of a recycled material or the leaching characteristics. The Norwegian Roads recycled Materials R&D Program will conclude its work by establishing environmental quality guidelines for selected recycled materials applied in road construction.

## **5. Acknowledgement**

During the process of defining ways for handling the environmental impact of recycled materials constructive and valuable input was received during discussions with the Swedish National Road Administration, Dr. Åsa Lindgren et al., with the research group of Dr. Jan Hartlén at the University of Lund in Sweden, and with Dr. Hans A. van der Sloot at Energy Research Center of the Netherlands.

The authors are also grateful to the Recycled Materials Resource Center at the University of New Hampshire and Dr. Taylor Eighmy, for their encouragement and kind cooperation in connection with the TRB Summer Workshop in Portsmouth in June 2003.

## **6. References**

Baker, P.G. and Bishop, P.L., 1997. Prediction of metal leaching rates from solidified/stabilized wastes using the shrinking unreacted core leaching procedure, *Journal of Hazardous Materials*, 52: 311-333.

Bendz, D., Flyhammar, P., Hartlen, J., 2003. In: *Environmental Impact Assessment of Recycled Hazardous Waste Materials on Surface and Ground Waters* Chemodynamics, Toxicology, Modeling and Information System Leaching from residues used in road constructions- a system analysis, Aboul-Kassim, T.A.T., Williamson, K (Eds.), *Water Pollut. Series, Vol. 5*, Springer Verlag, Heidelberg, (in press).

Conner J.R., 1990. *Chemical Fixation and Solidification of Hazardous Waste*. Van Nostrand Reinhold, New York.

Dijkstra, J.J., van der Sloot, H.A., Comans, R.N.J., 2002. Process identification and model development of contaminant transport in MSWI bottom ash. *Waste Management*, 22: 531-541.

Domas, J., Chateau, L., Pepin, G., 2003. The French innovative methodology for determining the acceptability of waste in public works. In: G. Ortiz de Urbina and H. Goumans (Editors), *WASCON 2003 Progress on the Road to Sustainability*. 5<sup>th</sup> International Conference on the Environmental and Technical Implications of Construction with Alternative Materials, 4-6 June 2003, San Sebastian, Spain. INASMET, San Sebastian, pp. 763-769.

Engelsen C. J., Lund O. J., Breedveld G. D., Mehus J., Petkovic G., Håøya A. O., 2003. Leaching characteristic of unbound recycled aggregates: Preliminary study and

ongoing research. In: G. Ortiz de Urbina and H. Goumans (Editors), WASCON 2003 Progress on the Road to Sustainability. 5<sup>th</sup> International Conference on the Environmental and Technical Implications of Construction with Alternative Materials, 4-6 June 200, San Sebastian, Spain. INASMET, San Sebastian, pp. 177-187.

Engelsen, C. J., Lund, O. J., Hansen, E., Hansesveen, H., 2002. Leaching of harmful substances from recycled aggregates in laboratory and field site. In: Proceedings (CD), Sustainable Building 2002, 3<sup>rd</sup> International Conference on Sustainable Building, 23-25 September 2002, Oslo Norway.

European Standardisation: ENV 12920 “Characterisation of waste - Methodology guideline for the determination of the leaching behavior of waste under specified conditions” (1996)

Garrabrants, A.C., Sanchez, F., Gervais, C., Moszkowicz, P., Kosson, D.S., 2002. The effect of storage in an inert atmosphere on the release of inorganic constituents during intermittent wetting of a cement-based material, Journal of Hazardous Materials, B91: 159-185.

Hartlen, J., 1996. Waste management in Sweden. Waste Management, 16: 385-388.

Henriksen, H.J. and Stockmarr, J., 2000. Ground water resources in Denmark: modeling and monitoring. Water Supply, 18: 550-557.

Hjelmar, O., 1996. Waste management in Denmark. Waste Management, 16: 389-394.

Institute of Asphalt Technology: “The Control Agreement for Reclaimed Asphalt – Annual Report 2002” (in Norwegian)

Inyang, H.I., Ogunro, V.O., Hooper, F., 2003. Simplified calculation of maximum allowable contaminant concentration in waste-amended construction materials. Resources, Conservation & Recycling, 39: 19-32.

Johnsen I., 2003. Kvernedede bildekk som gjenbruksmateriale i støyvoller (Shredded Tires as Light Fill Material for Noise Barriers). Norwegian Public Roads Administration, (in Norwegian)

Karlsen J., Petkovic G. and Lahus O., 2002. A Norwegian Certification Scheme for Recycled Aggregates (RCA). In: Proceedings (CD), Sustainable Building 2002, 3<sup>rd</sup> International Conference on Sustainable Building, 23-25 September 2002, Oslo Norway.

Kosson, D.S., van der Sloot, H.A., Sanchez, F., Garrabrants, A.C., 2002. An integrated framework for evaluating leaching in waste management and utilization of secondary materials. Environmental Engineering Science, 19: 159-204.

Lahus O., Lillestøl B. and Hauck C., 2002. Use of recycled concrete as aggregate in normal concrete in Norway. In: Proceedings (CD), Sustainable Building 2002, 3<sup>rd</sup> International Conference on Sustainable Building, 23-25 September 2002, Oslo Norway.

Mehus J., Lillestøl B., Petkovic G., Karlsen J., Skaare L. and Dønåsen E., 2002. The use of recycled concrete aggregates in the Norwegian building and construction industry. In: Proceedings (CD), Sustainable Building 2002, 3<sup>rd</sup> International Conference on Sustainable Building, 23-25 September 2002, Oslo Norway.

Mehus J., Petkovic G., Engelsen C. J., Karlsen J. and Lillestøl B., 2003. Recycled Aggregates a Viable Alternative for the Norwegian Building and Construction Industry. In: G. Ortiz de Urbina and H. Goumans (Editors), WASCON 2003 Progress on the Road to Sustainability. 5<sup>th</sup> International Conference on the Environmental and Technical Implications of Construction with Alternative Materials, 4-6 June 2003, San Sebastian, Spain. INASMET, San Sebastian, pp. 753-763.

Ministry of the Environment, 2000-2001. Summary in English: Report No. 24 to the Storting (2000-2001). The Government's Environmental Policy and the State of the Environment. <http://www.dep.no/md/engelsk/publ/stmeld/022001-040011/>

Norwegian Pollution Control Authority (SFT), 1994. Forskrift om innsamling og gjenvinning av kasserte dekk (Guidelines for collecting and recycling of disposed tires). <http://www.lovdatab.no/for/sf/md/td-19940325-0246-0.html> (in Norwegian)

Norwegian Public Roads Administration: "The Norwegian Roads Recycled Materials R&D Program", [www.gjenbruksprosjektet.net](http://www.gjenbruksprosjektet.net), project web site (in Norwegian)

Sanchez, F., Garrabrants, A.C., Vandecasteele, C., Moszkowicz, P., Kosson, D.S., 2003. Environmental assessment of waste matrices contaminated with arsenic, Journal of Hazardous Materials, B96: 229-257.

Sanchez, F., Mattus, C.H., Morris, M.I., Kosson, D.S., 2002. Use of a new leaching test framework for evaluating alternative treatment processes for mercury-contaminated soils, Environmental Engineering Science, 19: 251-269.

Schreurs, J.P.G.M., van der Sloot, H.A., Hendriks, Ch., 2000. Verification of laboratory-field leaching behavior of coal fly ash and MSWI bottom ash as a road base material. Waste Management, 20: 193-201.

The Federation of Norwegian Construction Industries, 2001. Nasjonal handlingsplan for bygg- og anleggsavfall (National Action Plan for Construction Waste). <http://www.grip.no/Okobygg/nasjonalhandlingsplan.htm> (in Norwegian).

Tränkler, J.O.V., Walker I. and Dohmann, M., 1996. Environmental impact of demolition waste - An overview on 10 years of research and experience. Waste Management, 16: 21-26.

van der Sloot, H.A., 2002. Developments in testing for environmental impact assessment. Waste Management, 22: 693-694.

van der Sloot, H.A., 1996. Present status of waste management in the Netherlands. Waste Management, 16: 375-383.

van der Sloot, H.A., Hoede, D., Cresswell, D.J.F. and Barton, J.R., 2001. Leaching behavior of synthetic aggregates. *Waste Management*, 21: 221-228.

Vik, E.A., G.D. Breedveld and T. Farestveit (1999). Guidelines for the risk assessment of contaminated sites. SFT report: TA-1691/1999, Norwegian Pollution Control Authority, Oslo <http://www.sft.no/publikasjoner/andre/1691/ta1691.pdf> (Norwegian text 1629/1999).