CHALMERS

Material Flow Analysis of Aggregates

Case Studies of Two Municipalities in the Göteborg Region

Master of Science Thesis

EVA JOHANSSON

Department of Energy and Environment
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2006
Report: 2006:5

MASTER OF SCIENCE THESIS

Material Flow Analysis of Aggregates

Case Studies of Two Municipalities in the Göteborg Region

EVA JOHANSSON

Environmental Systems Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2006

Material Flow Analysis of Aggregates
Case Studies of Two Municipalities in the Göteborg Region

Report 2006:5
ISSN 1404-8167

Environmental System Analysis
Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Göteborg, Sweden

http://www.esa.chalmers.se

Telephone + 46 (0)31 772 1000
http://www.chalmers.se

Chalmers Reproservice
Göteborg, Sweden 2006

Abstract

The construction industry is a sector where resource demand is large. Some of the required resources are renewable and some are not. One resource which is without a doubt necessary in the construction industry is aggregates. Aggregates is a common name for sand, gravel, crushed rock and other bulk materials used by the construction industry. Out of the above mentioned materials sand and gravel are very limited and crushed bedrock is more abundant. Therefore it is better, from a resource point of view, to use crushed bedrock instead of sand and gravel for construction. Although, this substitution is complicated in some usage areas because of the better technical properties of sand and gravel.

Sweden has an environmental quality objective limiting the extraction of gravel. This objective has inspired Göteborgsregionens kommunalförbund (GR) to develop a regional gravel policy. A first step in this development is to understand the present situation. To get a better understanding of the aggregate situation GR decided that an investigation of the material flow of aggregates was needed. This report is the result of this investigation. The central questions of the investigation were: What does the material flow for aggregates look like in two different municipalities in the Göteborg region? What types of aggregates are extracted where? Where are the different aggregates used and what are they used for?

To answer the questions above and to meet the aim of this study, the framework of Material Flow Analysis (MFA) was used. Two municipalities with completely different aggregate resource conditions were used to represent the Göteborg region. Consequently, the MFA tool was used in two case studies.

One important result of this thesis work is a conceptual model which describes the different processes of the aggregate flow. With the help of this model some conclusions could be drawn about the aggregate flow in the municipalities. One conclusion is that there are large differences between the municipalities in the study, especially in the per capita consumption of aggregates. Another conclusion is that camouflaged flows of aggregates in the form of concrete and asphalt are not to be overlooked since they represent an important part of the total aggregate consumption.

Keywords: material flow analysis (MFA), aggregates, gravel, crushed bedrock, usage areas

Sammanfattning

Byggindustrin är en bransch med stor resursanvändning. En del av de använda resurserna är förnybara medan andra inte är det. En resurs som utan tvekan behövs i byggindustrin är ballast. Ballast är ett samlingsnamn för sand, grus, krossberg och andra bulkmaterial som används i byggindustrin. Sand och grus är exempel på begränsade naturliga resurser som behövs för att bygga vår infrastruktur och våra bostäder. En liknande resurs som inte är lika begränsad är krossberg. Därför är det bättre att ur ett resursperspektiv använda krossberg istället för sand och grus. Denna substitution försvåras dock inom vissa användningsområden av det faktum att sand och grus helt enkelt har bättre tekniska egenskaper.

Sverige har ett miljömål som begränsar uttaget av grus. Detta miljömål har inspirerat Göteborgsregionens kommunalförbund (GR) till att ta fram en regional gruspolicy. Ett första steg i utvecklandet av denna policy är att skaffa sig kunskap om dagens situation. Förståelse för nuläget anses vara en viktig grund för den framtida policyutvecklingen. I syfte att skapa denna förståelse beslutade GR att materialflödet för ballast skulle undersökas. Denna rapport är resultatet av denna undersökning. De centrala frågorna för arbetet har varit: Hur ser materialflödet ut för olika typer av ballast i två olika kommuner i Göteborgsregionen? Var produceras olika typer av ballast? Var används de olika typerna av ballast och vad används de till?

Metodverktyget Materialflödesanalys (MFA) har använts för att besvara ovanstående frågor och uppfylla studiens syfte. MFA-verktyget har använts för att undersöka situationen i två kommuner inom regionen med helt olika ballastsituation.

Ett viktigt resultat av arbetet är en konceptuell modell som beskriver ballastflödets olika processer. Med hjälp av denna modell har sedan slutsatser kring ballastflödet i kommunerna dragits. En slutsats är att det är stor skillnad mellan de två undersökta kommunerna, framförallt vad gäller ballastkonsumtionen per capita. En annan slutsats är att de kamouflerade ballastflöden, i form av betong och asfalt, står för en betydande del av den totala ballastkonsumtionen.

Nyckelord: materialflödesanalys (MFA), ballast, grus, krossberg, användningsområden

Acknowledgements

I have come to owe many thanks to several persons during my thesis work. Thanks to my supervisor Sverker Molander for challenging me to think a step further and “open more boxes”. Thanks to my second supervisor Joanna Friberg at GR for helping me with lots of practical work. Thanks to Pär Johnning at NCC Roads AB, Marianne Nilsson at Ucklums Grus AB and Åsmund Seglem at Vikans Kross AB for helping me gathering data. Thanks to Peder Falck, Gustaf Magnusson, Elisabet Porse, Fredrik Svensson and Göran Tobiasson for acting as a reference group and giving me regular feedback. Thanks to Jonas Tornberg for introducing me to GIS. Finally, thanks to David for supporting me in everything I do.

Göteborg, January 2006

Eva Johansson

Glossary

The following terms and abbreviations are used in this thesis.

Aggregates	Sand, gravel, crushed rock and other bulk materials used by the construction industry
Crushed bedrock	Bedrock that have been blown up and crushed into different size fractions
GR	Göteborgsregionens kommunalförbund, is a co-operative organisation uniting thirteen municipalities in western Sweden
Gravel	Naturally formed and sorted soil that mainly consists of the fraction 2-20 mm
Gravel pit	Production site for gravel
Macadam	Crushed bedrock of certain size. Macadam has minimum and maximum grain sizes, often designated as minimum/maximum size in millimetres, i.e. 16/32 which is macadam with minimum grain size of 16 mm and maximum grain size of 32 mm
MFA	Material Flow Analysis
Quarry	Production site for crushed bedrock.

Table of Content

1 Introduction

Almost all human activities are dependent on natural resources. Construction and industrial processes account for a large part of the total resource use in the world. The resources needed are sometimes renewable but more often they are not. A common way of classifying natural resources is dependent on how renewable they are, e.g. how long natural circulation time they have. Based on this reasoning the natural resources can be divided into three categories; flows, funds and stocks. Flows are constantly flowing resources, such as sunlight and the hydrologic circulation. They are more or less independent of human activity and flows continuously. However, the rate at which they flow may vary, for instance the amount of rain, which may vary both in time and space. Funds are resources that at a sensible usage can give yield for an indefinite time period. They are driven by solar energy and can therefore be endless if they are not over exploited. Only the interest may be used since using more than the surplus will eventually eliminate the resource. Examples of funds are biological resources like animals, plants and ecosystems and state-resources like air, water and land. Stocks are natural resources where each extraction means a reduction of the resource amount. The regeneration time for these resources is very long from a human perspective. (Månsson 1993, pp. 47-51)

The limitation of resources has been an important aspect in the development of the sustainability concept. Sustainable development is defined by The World Commission on Environment and Development (the Brundtland Commission) as: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (1987, p. 43). Considering this, it is important to manage the world's resources. Today using and managing a stock resource in a sustainable way often means to use less of it. This is done by not using unnecessarily large quantities of the resources and when needed using the resources efficiently. Since people generally find it difficult to change their way of living, the most effort is put into making resource use more effective rather than actually consuming less. However, there is definitely a limit to which extent this strategy is practicable, e.g. it is not plausible to completely make people stop using natural resources. To get output, some input will always be needed. In order to reach a sustainable society it would be good if all input consisted of renewable resources, e.g. flows and funds. This is not the case today; stock resources are still a necessity to maintain our society. Since it is impossible to stop using limited resources, the second best alternative is to use the least limited resources.

Sand and gravel are examples of limited natural resources, so called stock resources, which are needed for our infrastructure and our housing. A similar resource that is less limited is crushed bedrock. Therefore it is better, from a resource point of view, to use crushed bedrock instead of sand and gravel for construction. Although, the better technical properties of sand and gravel impede this substitution in some use areas. In Sweden, the government has noticed the problem and work in order to slow down the extraction of sand and gravel. An environmental quality objective, limiting the extraction of sand and gravel, has been developed. The strategies to reach this objective have so far been to put taxes on the material and to be restrictive with prolongation of gravel pit permits and with issuing new gravel pit permits.

1.1 Problem Description

The Swedish environmental quality objective limiting the extraction of sand and gravel has inspired Göteborgsregionens kommunalförbund (GR) to develop a regional policy concerning these types of aggregates. A first step in this development is to understand the present situation. The comprehension of the present will be the basis of future policy making. With the intention of better understanding the present situation it was decided to investigate the material flow of aggregates. This report is the result of this investigation. The central questions of the investigation were: What does the material flow for different types of aggregates look like in two different municipalities in the Göteborg region? What types of aggregates are extracted where? Where are the different aggregates used and what are they used for?

1.2 Methodology

The framework of Material Flow Analysis (MFA) has been used to answer the above questions and meet the aim of the study. However, looking at the entire Göteborg region would have been too extensive for this thesis work. To represent the region, two municipalities with different aggregate resource conditions were used in this study. Consequently, the MFA tool was used in two case studies. The method of MFA is further described in chapter 2.4 and the more detailed working procedures for the current study is described in each case study chapter respectively, chapter 5 and 6.

1.3 Report Outline

Chapter 2 starts with a theoretical background of aggregates and continues with an introduction to the Swedish environmental objectives. A presentation of previous work done by GR in this area is also included in this chapter. The chapter ends with a description of the general MFA procedure and adjustments made in this theoretical framework in order to fit the current study.

Chapter 3 presents a conceptual model of general aggregate flow. The general aggregate flow defines the system by determining goods and processes.

Chapter 4 deals with the choice of case study municipalities. This choice defines the system by setting geographical system boundaries.

Chapter 5 and 6 contain the case studies of Öckerö and Stenungsund municipalities respectively. The specific working procedure of each case study is described. The results are presented and an analysis is made.

Chapter 7 discusses the results of the case studies performed, both by comparing them with each other and by comparing them with a county average. The chapter ends with a discussion about uncertainties of the current study and recommendations for further work in this study area.

Chapter 8 summarizes the conclusions of this study.

2 Background

This chapter serves as a general background to different areas related to this study. It answers the questions why this study is made, what is included in it and how it is performed.

2.1 Theoretical Background of Aggregates

Aggregates are often defined as *"Sand, gravel, crushed rock and other bulk materials used by the construction industry"* (Planning portal 2005). This is also the definition used in this report. There are two main types of aggregates, those made by nature and those made by man. Sand, gravel and crushed bedrock are all so called stock resources. Sand and gravel were produced naturally during the last ice age and since production stopped more than 10.000 years ago these resources are so called stock resources. Bedrock that is possible to crush and use as crushed bedrock is more abundant than the naturally produced sand and gravel. Therefore the man made aggregate, crushed bedrock could be considered less limited than sand and gravel. The quantity of sand and gravel that was produced by the ice varies a lot between different regions. This difference has to do with the conditions associated with the ice melting in the area. The supply of sand and gravel in the Göteborg region is classified as scarce (Grånäs 1994 see GR 2003, p. 63).

A central term connected with stock resources is reserves. Reserves are defined as the part of the resource that is discovered, technically possible and economically profitable to extract at the current market price. The reserve is not a fixed amount but can grow or shrink in size depending on resource discoveries, technical development and changing market demand. (Månsson 1993, pp. 52-53)

Aggregate material is necessary for construction of infrastructure and housing. It is used for road and railway construction and for production of concrete and asphalt. The aggregate consumption per capita in Sweden is slightly over 8 tonnes per year (Berg et al. 2005, p. 6). The amount of aggregates used and the many usage areas makes aggregates very transport-intensive. The main part of these transports are by truck which results in that approximately half of all goods transported by truck in Sweden are aggregates (SBMI 2005)

There are several properties determining what usage a specific type of aggregate material is suitable for. The most important ones are the distribution of grain sizes and the shape, durability and strength of the single grains. Further on these properties also determine if one type of material is possible to substitute with another. For example if it is possible to substitute gravel with crushed bedrock. Different usage areas are more or less sensitive to substitution. Concrete production is today considered the area where it is the most difficult to substitute gravel with bedrock. (SBMI 2005)

Sand and gravel have traditionally been the dominating raw materials in the aggregate industry. This is because they have good properties and are easy to extract. However, there is a conflict of interests when it comes to extracting sand and gravel for construction uses. The natural sand and gravel formations are good groundwater aquifers. These formations filter and clean the water and are therefore valuable as drinking water producers. Half of the Swedish municipalities' drinking water comes from groundwater aquifers (Berg et al. 2004, p 46). This means that by extracting too much gravel, future drinking water production may be threatened.

2.2 Sweden's Environmental Quality Objectives

Sweden has developed sixteen environmental quality objectives in order to reach sustainable development. These objectives are designed to:

- promote human health
- safeguard biodiversity and the natural environment
- preserve the cultural environment and cultural heritage
- maintain long-term ecosystem productivity and
- ensure wise management of natural resources. (Andrén 2005)

In order to make the objectives more tangible several interim targets have been set. The progress towards the goals is measured through different indicators. The result of these measurements is evaluated on a regular basis. (Andrén 2005)

Environmental quality objective number fifteen is called 'A Good Built Environment'. The interim target number four of this objective limits extraction of natural gravel.

"By 2010 extraction of natural gravel in the country will not exceed 12 million tonnes per year and reused materials will represent at least 15% of the aggregates used." (Andrén 2005)

The gravel extraction trend for 1993-2003 is visualized in Figure 1. The extraction has generally decreased over the years but the trend is not constant, some years there has been an increase of extracted gravel. The gravel extraction is closely related with the total aggregate demand and changes in this demand are visible in Figure 1.

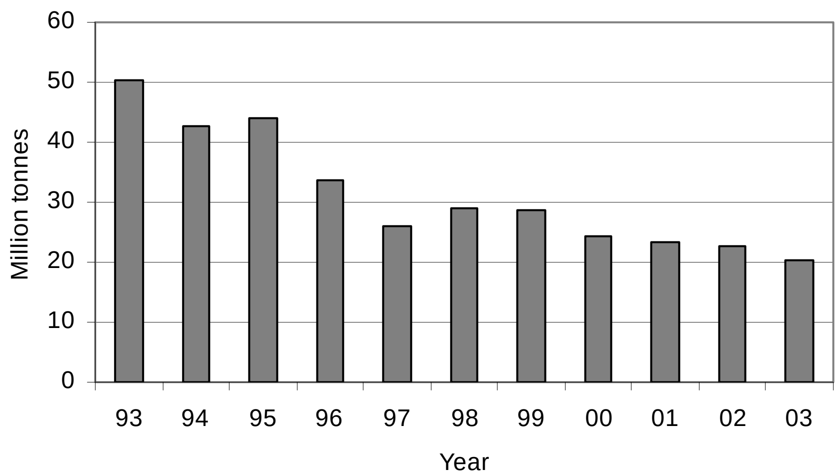


Figure 1: Gravel extraction in Sweden 1993 - 2003 (Boverket 2005)

In order to get a fairer view of the gravel extraction trend, the gravel share of the total aggregates use is often used (Berg et al. 2005, p 53). This share is now about 30 % and has been constantly decreasing since the mid 80's. (Arell 2003, pp. 5-9) Due to this decrease the environmental objective for 2010 is considered to be within reach.

Meeting the national environmental objectives is a shared responsibility. To facilitate the work on a regional level these environmental quality objectives have been elaborated by county administrative boards and regional environmental quality objectives have been created. The regional interim target for natural gravel in the County of Västra Götaland read:

"By 2010 extraction of natural gravel in the County of Västra Götaland will not exceed 1.4 million tonnes per year and reused materials will represent at least 15 % of the aggregates used."(Länsstyrelsen 2005)

The amount of extracted gravel in Västra Götaland has decreased since 1990, but during the latest years the reduction has stagnated and is now approximately 2 million tonnes per year. It is regarded as doubtful that the environmental objective for 2010 will be met. The share of gravel of the total aggregates used has also decreased the latest years and is currently around 20 %. This is one of the lowest figures in the country. Västra Götaland also has a low gravel use per capita compared to the rest of Sweden, 1.5 tonnes per year compared to 2.6 tonnes per year for all of Sweden. (Arell 2003, p. 9 and Länsstyrelsen 2005)

2.3 Previous Work by Göteborgsregionens kommunalförbund (GR)

The limitation of gravel resources is not at all a newly discovered problem. It has been known for quite a while and as early as 1969 an inventory of gravel resources and aggregate consumption in the Göteborg area was made by the regional planning association (regionplaneförbundet för Göteborg med omgivningar). This inventory also included a classification of the gravel deposits from a geological nature protection point of view and a description of possible substitution materials for gravel. The inventory showed that the resources of till in the Göteborg area were scarce. Since sand- and gravel deposits usually are formed through water working on till, these kind of deposits are consequently scarce as well (Knutsson 1969, p. 26). One of the results of this inventory was an estimation of the extractable gravel amount in the Göteborg area. It was estimated that the Göteborg area had 250 million tonnes of extractable gravel (Knutsson 1969, p. 75). Another outcome of the study was that the total aggregate consumption in the Göteborg area was estimated to be 410 million tonnes until the year 2000. If the division between gravel, 45 %, and crushed bedrock, 55 %, was going to be the same through the years it was concluded that by the year 2000, there would only be 60 million tonnes gravel left in the Göteborg area. Knutsson (1969, p. 83) suggested an immediate start of discussion about measures for saving gravel.

The scarcity of gravel in the Göteborg area, pointed out by the inventory in 1969, encouraged GR to develop a plan for gravel pits and quarries (Grus- och bergtäktsplan) in 1975. In this plan the figure for extractable gravel amount in the Göteborg area was updated into 130 million tonnes. The difference compared to the amount that had been estimated in 1969 was explained by the fact that the gravel consumption between 1969 and 1975 had been quite high, environmental care restrictions had changed and the size of the gravel deposits had been over estimated in 1969. (Jonsson & Åkerström 1975, p. 12) Some of the gravel available in the Göteborg area will most likely be consumed in the areas surrounding the Göteborg area. Out of the total extractable amount, 90 million tonnes were estimated available for consumption within the Göteborg area (Jonsson & Åkerström 1975, p. 12). The yearly consumption of aggregates was by this time 7-8 million tonnes, and the division between gravel and crushed bedrock, 35-40 % and 60-65 % respectively. The crushed bedrock share was assumed to increase and be 80-85 % by the year 2000. Under this estimation the gravel demand for 40-50 years would be covered (Jonsson & Åkerström 1975, p. 37). The conclusion of this study was that reduction of gravel consumption would be extremely important. The recommendation was that reduction should primarily be achieved through substitution with crushed bedrock and therefore location of new quarries was seen as crucial (Jonsson & Åkerström 1975, p. 38).

In the inventories so far, the discussion about the importance of gravel deposits for drinking water supply had been left out. Therefore GR developed a plan for gravel supply considering drinking water supply in 2003 (Grusförsörjningsplan för Göteborgsregionen). The result of this work is that when drinking water supply is considered (e.g. when gravel deposits are reserved as drinking water reservoirs) the extractable gravel in the Göteborg area is practically already used up. The extractable gravel amount left in 2003 was 1-17 million tonnes. The figure varies depending on which conflicting interests that are taken into account (GR 2003, p. 5).

All this previous work by GR gives background for this thesis work. This study focuses on usage areas for different types of aggregates and also looks further into the geographical distribution of the aggregates.

2.4 Material Flow Analysis

A Material Flow Analysis (MFA) presents physical flows. It illustrates the usage of resources and gives at the same time an indirect estimation of the environmental impact. There are several different ways and levels to perform analyses of material flows. (Moberg et al. 1999, p 15) This report uses the framework described in "Practical Handbook of Material Flow Analysis" by Brunner & Rechberger (2004). Brunner and Rechberger defines MFA as a *"systematic assessment of the flows and stocks of materials within a system defined in space and time"* (2004, p. 3). The MFA connects the sources, the pathways and the sinks of a material. The result of an MFA can be controlled by a material balance comparing all inputs, stocks and outputs of a process. This distinct characteristic of MFA has made the method attractive as a decision-support tool in resource management, waste management and environmental management. (Brunner & Rechberger 2004, p. 3)

2.4.1 Terms and definitions

In order to understand the MFA procedure there are several terms that need to be defined.

Substance – any chemical element or compound with a homogeneous constitution. Examples of substances are: carbon, nitrogen and carbon dioxide. (Brunner & Rechberger 2004, p. 35)

Goods – units with an economic value. They consist of one or several substances and the economic value can be either positive or negative. Examples of goods are: wood, drinking water, concrete and sewage sludge. (Brunner & Rechberger 2004, p. 36)

Material – a joint term for substances and goods (Brunner & Rechberger 2004, p. 37).

Process – transformation, transport, or storage of materials. Examples of processes are: the human body, wastewater treatment plants and quarries. (Brunner & Rechberger 2004, p. 37)

Flow – the rate at which mass flows between processes. The unit used for flow can be kg/sec or t/year. (Brunner & Rechberger 2004, p. 39)

System – a group of physical components that are connected or related in such a way that they form an entire unit. A system is limited in space and time by specified boundaries. In MFA the components are called processes and those processes interact with each other since they are connected by the flows. The MFA system is often a so called open system that interacts with its surroundings through material and/or energy imports and exports. (Brunner & Rechberger 2004, p. 43)

Bulk-MFA – an MFA that treats mass balances of goods without considering substances. Consequently, in this kind of MFA the term material is no longer a joint term but equals goods. (Brunner & Rechberger 2004, p. 51)

2.4.2 MFA Procedures

Performing an MFA requires several steps, illustrated in Figure 2. Firstly the problem is defined and goals are set. Then the system is defined by selecting substances, system boundaries, processes and goods. Next, flow and stocks are determined by assessing mass flows of goods and substance concentrations in these flows. Finally the results are interpreted and illustrated so that conclusions are visualized. (Brunner & Rechberger 2004, p. 53)

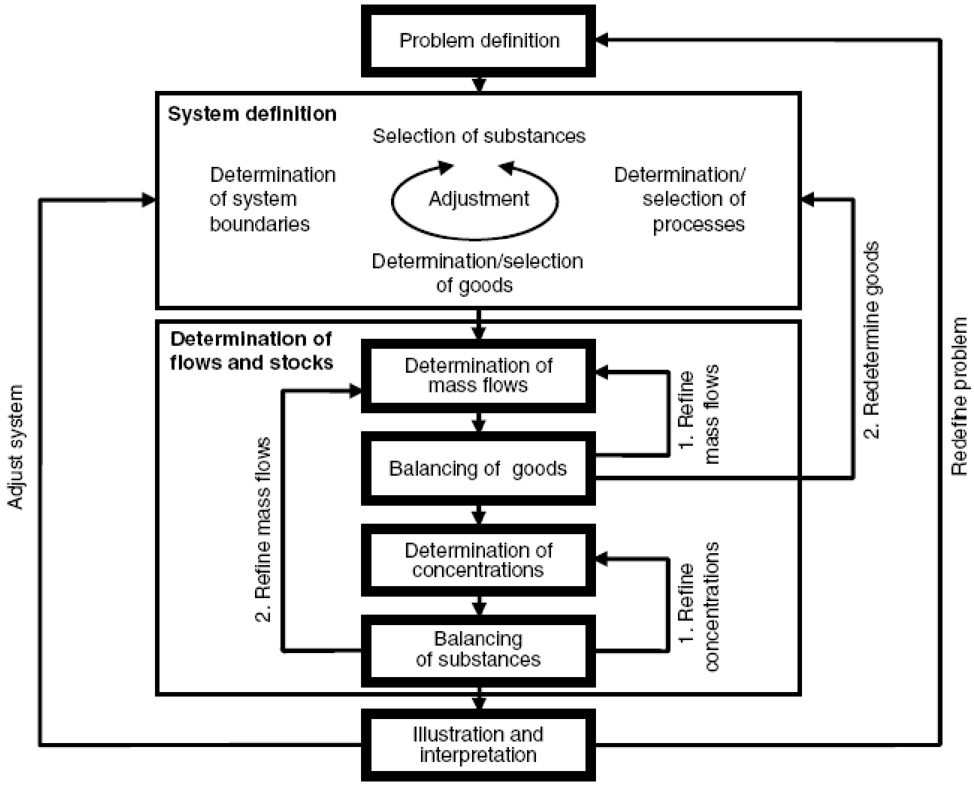


Figure 2: Procedures for MFA (Brunner & Rechberger 2004, p. 54)

As indicated in Figure 2 MFA is an iterative process. During the work with an MFA it is important to keep the goal in mind. This goal is crucial for setting boundaries for the system and making the right simplifications in the model. The accuracy of the obtained data has to be checked so that it complies with the predefined goal. Regardless of the accuracy, the type of data that is obtained does not always fully correspond to the goal of the study. If this is the case the data needs to be modified in order to better comply with the study. (Brunner & Rechberger 2004, p. 54)

The current study can be classified as a bulk-MFA. As mentioned previously this implies that single substances are not taken into account. The focus then lies on the goods which in this case is aggregate material. This results in a simplification of Figure 2 above since the steps of determining concentrations and balancing substances can be removed.

3 Conceptual Model of Aggregate Flow

In the current study the first step of MFA, problem definition, was done in chapter 1.1. The next step according to the MFA framework is to define the system. This is partially done since the goods to be studied have been selected. When the case study municipalities are chosen the system boundaries will be defined by the physical borders of these municipalities. What is left of the system definition is then to determine processes and flows. This is done in this chapter and the result is put together into a conceptual model of aggregate flow. The conceptual model is presented in Figure 3 below.

The flow starts with raw material production in the left part of the figure. The raw material may origin from different types of production sites. For crushed bedrock (krossberg) the production site is called a quarry (bergtäkt) and for gravel (grus) the source is simply called gravel pit (grustäkt). A third type of production site is also possible and that is when the first two types are located in the same place, which in this model is called combination of gravel pit/quarry (kombinationstäkt). This MFA describes an open system with geographical system boundaries; which means that aggregates can be imported and exported over these system boundaries. The imported aggregates can origin from any part of the conceptual model, 'Production of raw material', 'By-products from construction work', 'Aggregate handling' and 'Usage', see Figure 3. The common feature for all of them is that they origin from outside the geographical area. The exported aggregates, on the other hand, are split into 'Usage' and 'Aggregate handling'.

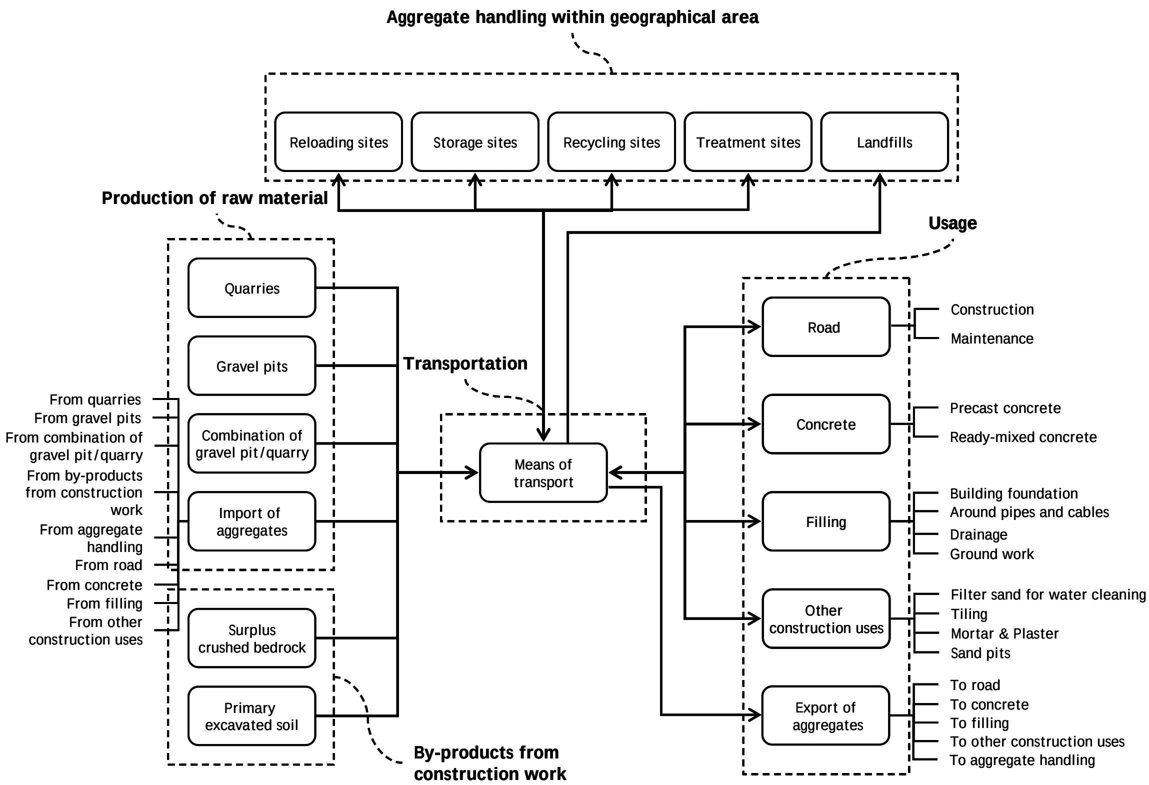


Figure 3: Conceptual model of aggregate flow

Other inputs of aggregates to the material flow are the by-products from construction work. In this model those are divided into two groups, surplus crushed bedrock (entreprenadberg) and primary excavated soil (nya schaktmassor). Surplus crushed bedrock is crushed bedrock that arises when a construction requires removal of bedrock. Primary excavated soil is soil that needs to be removed at the initial phase of a construction work. The word 'primary' indicates that the soil has not been placed there by humans, but rather by nature. This is to distinguish from soil that has been used for example as filling material and which may also be excavated due to new construction work. This type of soil might have been called secondary excavated soil and would have formed another type of by-product. However, a group like this would have caused problems in the model since this kind of soil can also be seen as old filling materials, leaving two possible placement options in the model. To avoid this, the secondary excavated soil, in this model will be included in the recycling flow from 'Filling'.

From raw material production the flow continues with transportation. There are several means of transportation possible e.g. truck, railway or boat. Today, the main part of aggregates is transported by truck (SBMI 2005).

The usage areas of aggregates have been grouped in four main groups that are represented in the conceptual model, Figure 3. The first group is 'Road' which is divided into 'Construction' and 'Maintenance'. Examples of materials that are included in 'Maintenance' are asphalt (since it is often part of the wearing course (slitlager) and therefore is replaced from time to time) and macadam/gravel used to grit slippery roads. Secondly, there is the group 'Concrete', which may be split into 'Precast concrete' and 'Ready-mixed concrete'. The third group is 'Filling', which is a collective term including aggregates used for 'Building foundation', 'Around pipes and cables', for 'Drainage' and for other 'Ground work'. Examples of 'Ground work' are construction of parking spaces and earthworks done in areas that need to be prepared for future construction work. The group 'Other construction uses' gathers usages that have not been covered by the former three groups. These areas are: 'Filter sand for water cleaning', 'Tiling', 'Mortar & Plaster' and 'Sand pits'. Worth noticing here is that 'Sandpits' include sand for sandpits as well as sand used for horse training paddocks. 'Tiling' includes the sand under the tiles but also aggregates used for garden footpaths and cobble stones.

In addition to 'Production of raw material', 'By-products from construction work' and 'Usage' there is a group of processes called 'Aggregate handling' in the model. This group consists of 'Reloading sites', 'Storage sites', 'Recycling sites', 'Treatment sites' and 'Landfills'. Reloading sites are places were means of transport may be changed, e.g. from boat to truck. Storage sites are, just as the name implies, sites were aggregates are stored for future usage. Recycling sites are used for storage of used aggregates that may be reused in the future. On treatment sites polluted aggregates may be decontaminated by different cleaning methods. Landfills are used for terminal storage of unusable aggregates. The materials that are placed in landfills can be either new or used.

It is worth noticing that there are many possible ways for aggregate material to move in the model. This is mainly because in the model there are several double arrows, meaning that the material can go both ways. The backward arrows from 'Usage' represent a recycling flow; see also the section about excavated soils above.

Furthermore, it is also important to be aware that the model in Figure 3 does not illustrate the geographical situation. It is often the case that aggregate handling is located in the same place as raw material production. The consequence of this could be that there is no need for transportation in between those activities.

One type of groundwork, within the filling usage area, is 'construction of ground'. This activity is often quite closely related to landfill activity. The reason for this is permit applications; it is easier to get a permission to build ground than to open a landfill[1]. One of the

[1] Elisabet Porse, Kretsloppskontoret Göteborg, Referensgruppsmöte, 2005-10-03

outcomes of this is that it is cheaper to dispose surplus aggregate material at a ground-building project than to leave it in a landfill.

The aggregates in already made asphalt and concrete that may be imported from other geographical areas are not included in this initial model. To map these flows was considered beyond the current system boundaries.

3.1 Actors in the Aggregate Flow

To maintain a flow of aggregates, a number of actors with roles of various kinds are needed. Identification of these actors is crucial for knowing who to ask and where to look for data further on. The roles of the actors are connected with the different activities in the aggregate flow. This is illustrated in Figure 4 below. In addition to the original activity groups of the material flow, a new group of activities has been added in this figure to cover the roles of 'Supervision & Planning'. Note that one actor can have more than one role in the aggregate flow, e.g. the same company can be both landowner, possessor of the permit and exploiter of a quarry.

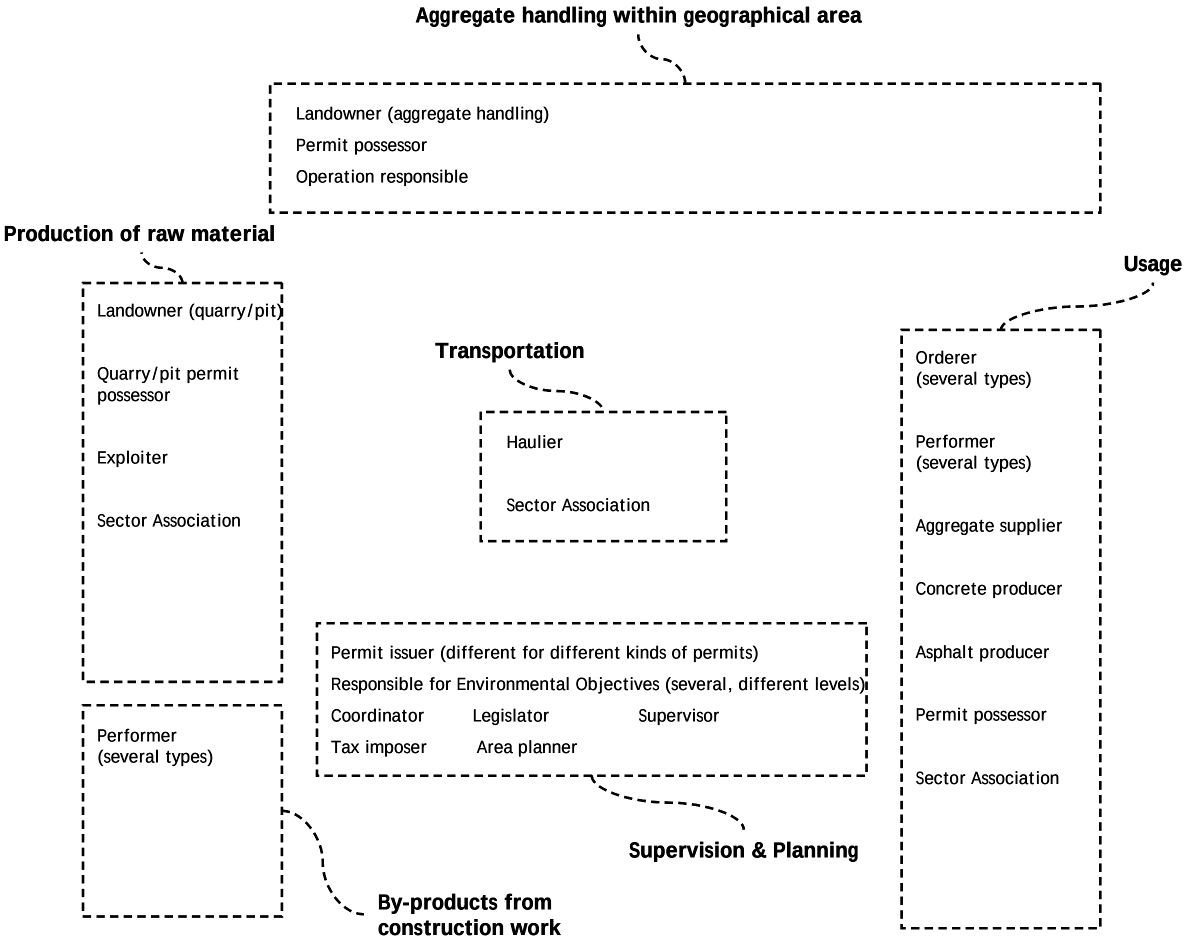


Figure 4: Actor roles in the aggregate flow.

There are different kinds of permits, e.g. permit to run a quarry, permit to run a concrete factory, and so on. Because of this there are also different permit issuers, see Figure 4. Usually it is either the municipality or the county administration board that issue permits. The environmental objectives are divided in groups depending on geographical coverage; there are local, regional and national objectives. This means that there are several actors responsible for the different environmental objectives. Depending on the type of construction, road, house, etc. there are also different types of both commissioners and performers, see also Figure 4.

4 Choice of Case Study Municipalities

Looking at the aggregate material flow within the whole Göteborg area was considered to be too difficult and time consuming for a thesis work. Therefore it was decided that the work was to be delimited to case studies. The number of case studies was discussed together with GR and it was agreed to do two case studies, one on a municipality with scarce supply of gravel and one on a municipality with good supply of gravel. To find a municipality with scarce supply was quite easy, Öckerö municipality does not have any such resources and was therefore chosen to represent the scarce supply case. For the opposite case, abundance of natural gravel, three different municipalities were suggested, Härryda, Lerum and Stenungsund. In order to select the most representative of those three municipalities, a pre study was made. The method used for this study was searching for information in the map services of the SGU (Geological Survey of Sweden) website (SGU 2005) and to make telephone interviews with people involved in the aggregate flow of each municipality.

In Härryda there were three quarries and five gravel pits (SGU 2005). However, there was an ongoing discussion whether one of the quarries really should be classified as a quarry or not. This site could instead be classified as ground preparing for future industrial area. Other characteristics of Härryda were that there was a permit for recycling of asphalt in one of the quarries and that there was a topsoil producer in the north part of the municipality where excavated soil was handled.[2]

In Lerum there were no quarries and three gravel pits (SGU 2005). Although, talking to people involved with aggregates in Lerum it turned out that there was no longer a valid permit for one of the gravel pits[3] [4]. Another thing was that out of the two remaining pits one was going to close down within a few months, leaving only one pit left in Lerum[4].

In Stenungsund there were two quarries, five gravel pits and one site that was a combination of gravel pit and quarry (SGU 2005). There was a concrete plant within the municipality and a permit for recycling of asphalt in one of the quarries. In addition to this there was also a seaport with aggregate trade in Stenungsund[5].

Out of the pre study it could be seen that Lerum did not have that good supply of aggregates that was thought when it was proposed for case study. This led to the conclusion that Lerum was not a good representative of a municipality with abundance of gravel. Left were then Härryda and Stenungsund, both with apparently good supply of gravel. The difference between them was mainly that Stenungsund had a concrete plant and Härryda had not. The presence of a concrete producer was considered as an important aspect since concrete production is a usage area where it is difficult to substitute gravel with crushed bedrock. Furthermore, the total number of aggregate production sites was larger in Stenungsund than in Härryda. Summarizing this, the concrete plant and the number of sites plead for Stenungsund.

The conclusion of the pre study was that Öckerö and Stenungsund were the municipalities that are the most suitable for case studies. By choosing these municipalities the exact geographical system boundaries were set.

[2] Göran Tobiasson, Härryda kommun, telephone interview, 2005-09-06
[3] Lennart Dahlberg, Lerums kommun, telephone interview, 2005-09-06
[4] Katarina van Berlekom, Länsstyrelsen Västra Götaland, telephone interview, 2005-09-29
[5] Pär Johnning, NCC Roads AB, telephone interview, 2005-10-12

5 Case Study – Öckerö Municipality

Öckerö municipality consists of ten islands, Öckerö, Hönö, Fotö, Grötö, Björkö, Kalvsund, Hälsö, Knippla, Hyppeln and Rörö (Öckerö kommun 2005). The land area of Öckerö municipality is quite small, 26 km^2 and the number of inhabitants is 12,000, which gives a population density of 469 inhabitants/km^2 (SCB 2005).

5.1 Method

In order to obtain data to put in the model, information was gathered in several ways. As Öckerö did not have any aggregate production within the municipality, all aggregates needed to be imported. According to Peder Falck at Öckerö municipality practically all aggregates used in Öckerö municipality came from Vikans Kross AB in Torslanda. This seemed quite reasonable since Vikans Kross AB was the quarry closest to Öckerö municipality. If aggregates were to be taken from another quarry/gravel pit the transport length would double (SGU 2005). All deliveries from Vikans Kross AB were stored in a delivery note database. This database included information like; delivery note number, date, time, car number, car type, type of good, delivery information and delivered amount. Delivery information was either a project number for larger constructions sites or an address. By searching for each island in Öckerö municipality, in the database, delivery information was obtained. This information was given in tonnes of particular goods delivered to specific places. The data have been listed in a table which may be found in Appendix A.

The information from the delivery note database did not fully correspond to the information asked for in the problem description of this study, see chapter 1.1. It answered the question about where the aggregates were transported but not what they were used for. Since Vikans Kross AB did not keep a record of what their sold products were used for another way of finding this information was needed. One way of doing it would have been to contact all aggregate users in the municipality and ask them what they used their aggregates for. However, there were very many users and it was soon realised that it would have been impossible to contact them all. Since there was information about the different products it seemed logical to try to find a connection between products and usage areas. Therefore, four different persons involved in aggregate industry were contacted and interviewed about what different kinds of materials are usually used for. The persons interviewed were; one quarry exploiter, one gravel pit exploiter, one haulage firm and one contractor. Their answers are shown in Table 1

Table 1: Products and usage areas according to four interviewed persons

Product	1	2	3	4
Quarry fines (stenmjöl) (0/2, 0/5, 0/8, 0/10)	Around cables & pipes	Asphalt production, around pipes & tiling	Horse paddocks	Around cables & pipes & for horse paddocks
Crushed bedrock (0/12, 0/16, 0/18)	Road gravel	Roads, wearing course (slitlager)	Road gravel	Roads, wearing course (slitlager)
Crushed bedrock (0/32, 0/35, 0/40)	Road gravel	Roads, base course (bärlager) & ground work	Roads	Roads, base course (bärlager) & ground work
Crushed bedrock (0/80, 0/90, 0/150)	New roads & ground work	Roads, sub-base course (förstärk-ningslager) & ground work	New roads & filling	Roads, sub-base course (förstärkningslager)
Macadam 2/5	Gritting & tiling	Asphalt, gritting & tiling	Filter sand & tiling	Tiling
Macadam 5/8		Asphalt & garden footpaths	Drainage & garden footpaths	
Macadam (8/16, 11/16)	Drainage & building foundation	Asphalt, concrete & drainage	House building & drainage	
Macadam (16/22, 16/25, 16/32)	Drainage & building foundation	Asphalt, concrete & drainage	Building foundation & drainage	Building foundation & drainage
Sand 0/4	Mortar & Plaster	Sandpits, around pipes & mortar	Mortar, plaster, around cables & sandpits	Mortar
Sand 0/8	Concrete, filter sand & gritting	Concrete	Concrete, gritting & horse paddocks	Filter sand & horse paddocks
Coarse gravel 8/16	Garden footpaths & drainage		Garden footpaths & drainage	

As shown in Table 1 the correlation between the answers is quite good. Unfortunately, there are a few products that have several usage areas and therefore it will be more difficult to combine these products with the right process in the conceptual model. In order to reduce the uncertainty the delivery information found in the delivery note database was compared to construction permits within the municipality. When putting data into the model the first choice has been to use combined information from construction permits and delivery note database. When the information was not sufficient, the connection between product and usage area as indicated by the interviewed persons has been used.

5.2 Results & Analysis

Figure 5 presents the aggregate flow in Öckerö municipality during one year, December 2004 – November 2005. The model in Chapter 3 has been simplified and adjusted in order to fit the obtained data. The division of gravel and crushed bedrock for the different usage areas is not visible in Figure 5. It is difficult to know how many tonnes that were gravel out of the 14822.5 tonnes that were used for filling. This information was lost when the materials were partitioned between different usage areas. However, on an aggregative level it is known how many percent that is gravel and how many that is crushed bedrock. The reason for this is that the delivery note database which was the source of information contained all the information about the origin of the materials, see Appendix A (Vikans Kross AB 2005).

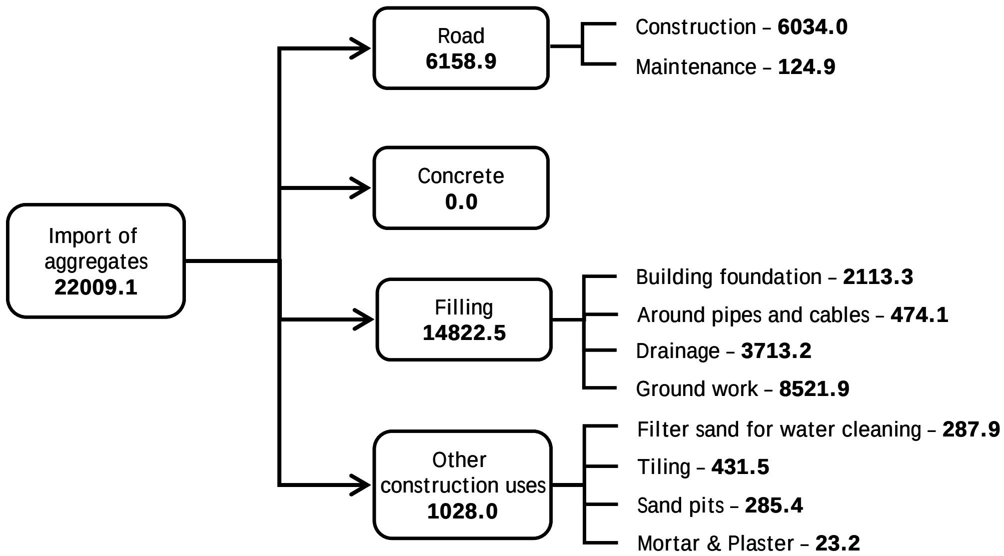


Figure 5: Aggregate flow in Öckerö municipality (all amounts are in tonnes), December 2004 – November 2005

Since there are no quarries or gravel pits in Öckerö municipality all aggregates used there have been imported. The total amount of consumed aggregates in Öckerö municipality between December 2004 and November 2005 was 22009.1 tonnes. 115.1 tonnes of these were gravel and this corresponds to 0.5 % of the total aggregate use in Öckerö municipality (Vikans Kross AB 2005).

5.2.1 The usage of aggregates distributed on different usage areas

The usage of aggregates distributed on different usage areas in Öckerö municipality is visualized in Figure 6.

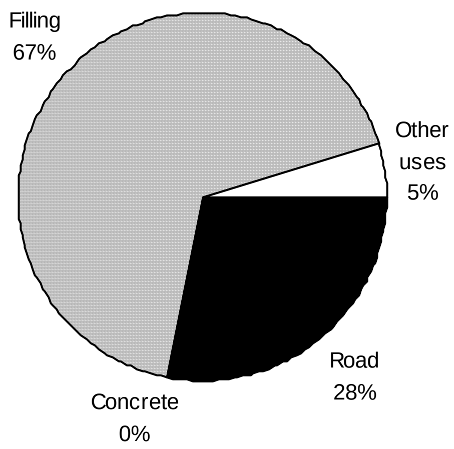


Figure 6: Aggregates distributed on different usage areas in Öckerö.

In Öckerö the dominating part is filling which represents two thirds of the total use. Approximately 30 % goes to road and only a small fraction goes to other uses. There is no concrete production in Öckerö municipality why this sector is not represented. The absence of a concrete factory naturally makes the other three sectors larger.

Öckerö municipality is geographically small and has a high population density. The small land area makes distances short which in turn affect the amount of material needed for road construction. Öckerö attracts many people and is therefore a growing municipality. The houses that are built for the new inhabitants are almost without exception single houses and terrace houses. This way of housing is quite land consuming and therefore requires a lot of ground work. As can be seen in Figure 5 filling consists of building foundation, filling around pipes and cables, drainage and ground work. Since housing construction includes all theses usage areas it is easy to see why filling account for such a great part of the aggregate usage in Öckerö.

5.2.2 Aggregates per capita

The total amount of aggregates used within Öckerö municipality in a year is 22009.1 tonnes, see Figure 5. The number of inhabitants is as mentioned earlier in this chapter 12000, which gives an aggregate consumption per capita of 1.8 tonnes per year. This is much lower than the mean consumption for both Västra Götaland and Sweden which is 8.6 tonnes per capita and year (Berg et al. 2005, p. 30).

One reason for the low per capita consumption in Öckerö can be that when aggregates are scarce they are used more carefully. Much effort is put into balancing the masses so the surplus material from one place can be used in another place where it is better needed. Furthermore the amount of reused aggregates is probably large in a municipality like Öckerö.

Another reason for low per capita use is the type of society that Öckerö represents, a society just for housing and almost without industrial production. The scarcity of natural resources has impeded for industries to settle in Öckerö. People that want to live on the islands often find their jobs in the neighbouring municipalities. As a consequence of the absence of industrial production, offices, parking areas and even shops are less abundant. The above mentioned factors all contribute to the low per capita usage of aggregates in Öckerö municipality.

The gravel per capita consumption for Öckerö municipality is 0.009 tonnes per year (Vikans Kross AB 2005). This is remarkably low compared to the per capita consumption in Västra Götaland and in Sweden, which are 1.7 and 2.3 tonnes per year respectively (Berg et al. 2005, p. 30). However, it might not be that strange since, as mentioned earlier, there is no concrete production in Öckerö and that is what would have raised the gravel per capita consumption normally.

6 Case Study – Stenungsund Municipality

Stenungsund municipality is located approximately 50 km north of Göteborg city along the coast of Bohuslän. The land area of Stenungsund municipality is larger than Öckerö, 254 km^2, and the population density is lower than in Öckerö, 88 inhabitants/km^2. The total number of inhabitants in Stenungsund municipality is 22,000 (SCB 2005). Being situated at the coast Stenungsund became an important trading port early on. This location has also contributed to the abundance of industries that Stenungsund has nowadays. (Jansson 2004)

6.1 Method

Since Stenungsund is a municipality with abundance of aggregates, the first step was to locate theses resources. The locations of the quarries/gravel pits can easily be found with the help of SGU map services (SGU 2005). Through these maps it is also possible to see, what type of production site it is, who the exploiter of a specific site is, how long the permit is valid and the size of the site. The information at the SGU website is based on production data from 2003. To check that this data was still valid the County Administration Board (Länsstyrelsen) was contacted and asked about which current permits there were in Stenungsund municipality at the time of this study[6]. The information from these two sources was put together and the result may be seen in Table 2.

Table 2: Aggregate production sites in Stenungsund municipality

Production site	Name	Type of site
1	Huveröd 1:7, 2:3 & Stubberöd 1:2	Gravel
2	Sköllunga 2:6	Gravel
3	Sköllunga 2:6	Crushed bedrock
4	Sköllunga 3:2, 3:3, 4:31	Gravel
5	Sköllunga 10:1, 11:1, 5:1	Gravel
6	Tosteröd 1:2	Gravel
7	Grössbyn 2:2	Gravel
8	Stora Gategård 1:1	Crushed bedrock

To find out more detailed information about the produced aggregates in Stenungsund municipality it seemed logical to start with contacting the exploiters of the production sites. Exploiter information was available for all but two production sites, Tosteröd and Grössbyn (SGU 2005). The most probable reason for this is that those sites are run by persons instead of companies and that SGU therefore is not allowed to publish their names online. However, Tosteröd and Grössbyn only account for 1.5 % of the remaining permitted aggregate extraction (Stenungsunds kommun 2005, p.58).

For production sites 1-5, the data source consisted of paper copies of invoices collected in files. The invoices included information about delivery address, invoice address, date, type of product and amount. This information was put together so that it shows how many tonnes of a specific product that were delivered to a specific place. In some cases delivery address was missing and the invoice address was then used as substitution. This adds some uncertainty to the study but most of the times when delivery address was missing the customer was a person and then the delivery- and invoice addresses are the same.

For production site 8, the data source was a sales database. This database provided information like; time period, customer name, type of product and amount. Only the 75

[6] Anne Catherine Anehammar, Länsstyrelsen Västra Götaland, telephone interview, 2005-11-15

biggest customers (in tonnes) were used as they accounted for 97.5 % of the total delivered tonnes. The total produced aggregates in Stenungsund municipality has been put together in a table which may be found in Appendix B. The table shows how many tonnes of different goods that were extracted and where they were delivered.

The same data problem as was experienced in the Öckerö case also occurred in Stenungsund; the data did not fully correspond to the information asked for in the problem description of this study, see chapter 1.1. Therefore the same method, connection between products and usage areas, was implemented here.

The information about construction related usage areas which was needed in the model was taken from the most accurate source possible. The available sources were; first hand information from the users, information provided by the producers about their customers and finally the relationship between products and usage areas. Information from the user is considered the most accurate. When the information was from the producer, it was checked with the product-usage relationship and these two sources of information were combined. If no information was available the product-usage relationship was applied.

When determining if the aggregates were used within the municipality or if they were exported, the delivery addresses were primarily used. If delivery information was missing producer information about were the different customers were active was used. When a customer was active in more than one municipality the amounts of aggregates were divided in proportion to the number of inhabitants in the municipalities concerned. Partitioning aggregates by the number of inhabitants in different municipalities had to be done for 12.6 % of the total produced tonnes of aggregates.

6.2 Results & Analysis

Figure 7 presents the aggregate flow in Stenungsund municipality during one year, November 2004 – October 2005. The model in Chapter 3 has been simplified and adjusted in order to fit the obtained data. It is not possible to see the division of gravel and crushed bedrock for the different usage areas in Figure 7. For the same reason as in the Öckerö case it is difficult to divide the used aggregates into gravel and crushed bedrock.

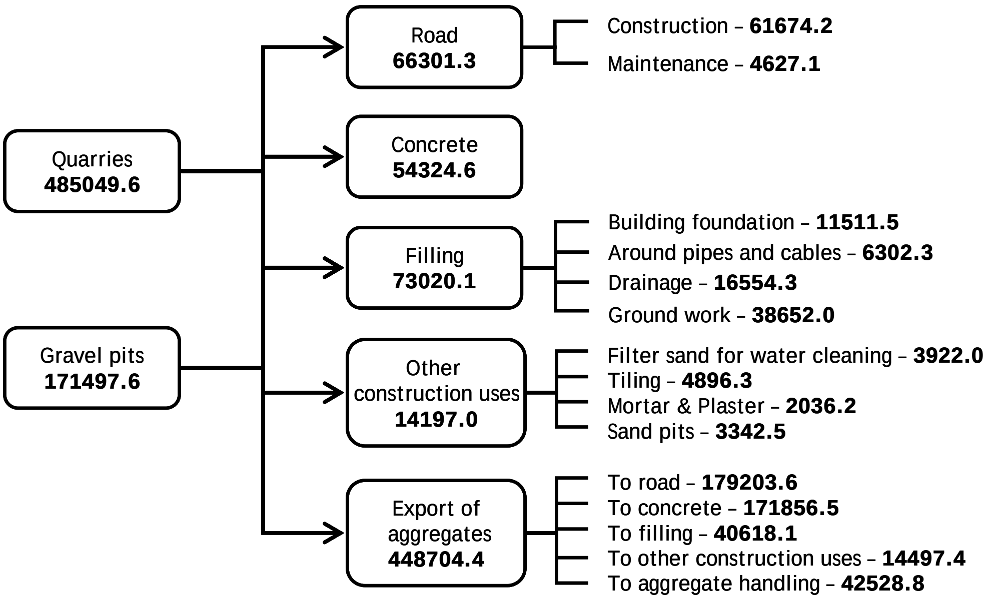


Figure 7: Aggregate flow in Stenungsund municipality (all amounts are in tonnes), November 2004 – October 2005

The total produced aggregate amount in Stenungsund municipality between November 2004 and October 2005 was 656547.2 tonnes. During the last ten years the production in Stenungsund has varied between 437142 tonnes and 644465 tonnes (Berg et al 2004, p. 39). The amount of produced gravel (171497.2 tonnes) corresponds to 26.1 % of the total produced aggregate amount. The total amount of consumed aggregates in Stenungsund municipality between November 2004 and October 2005 was 207843.0 tonnes. Out of this amount, 41644.6 tonnes were gravel which corresponds to 20.0 % of the total consumed amount of aggregates (Ucklums Grus AB 2005)

68.3 % of the produced aggregates are exported. This is unusual since aggregates are often considered one of the products with the shortest mean transportation length. Stenungsund has a special condition as it is located close to the sea and is able to export a lot of its aggregates through the harbour. 28.5 % of the total produced aggregate amount is exported to Denmark (NCC Roads AB 2005). This export is possible because it is so much cheaper to transport aggregates by boat. The cost of transporting one ton of aggregates to Denmark by boat is the same as transporting it 30 km in Sweden by truck.[7]

6.2.1 The usage of aggregates distributed on different usage areas

The usage of aggregates distributed on different usage areas in Stenungsund municipality is visualized in Figure 8.

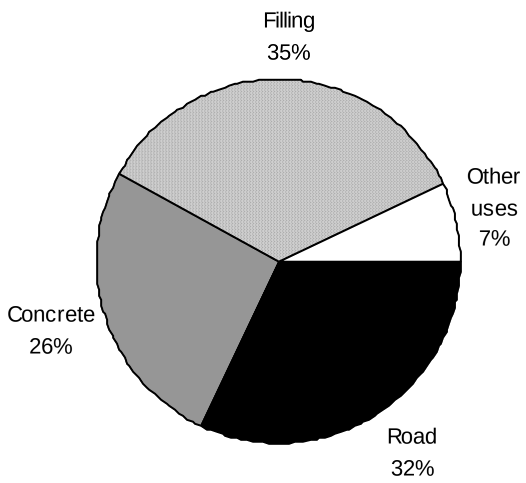


Figure 8: Aggregates distributed on different usage areas in Stenungsund

The large part of aggregates used for concrete in Stenungsund has its explanation in the abundance of gravel in this municipality. It is quite natural that production of goods is located where there is a good supply of raw material. Just like in the Öckerö case the road sector accounts for approximately 30 %. However, in Stenungsund this cannot be explained by small land area and short distances but rather by the fact that Stenungsund has not had any road construction works going on during the time period studied.

6.2.2 Aggregates per capita

The total amount of aggregates used within Stenungsund municipality in a year is 207843 tonnes, see Figure 7. The number of inhabitants is as mentioned earlier in this chapter 22000, which gives an aggregate consumption per capita of 9.4 tonnes per year. This is a bit higher than the mean consumption for both Västra Götaland and Sweden which is 8.6 tonnes per

[7] Pär Johnning, NCC Roads AB, telephone interview, 2005-10-12

capita and year (Berg et al. 2005, p.30). However as said before concrete production is quite abundant in Stenungsund and this might affect aggregate consumption to be larger per capita here than it is for the rest of the country. If the aggregates used for concrete production in Stenungsund are excluded the consumed amount of aggregates drops down to 153518.4 tonnes and the per capita consumption drops to 7.0 tonnes per year.

The per capita consumption of gravel for Stenungsund municipality is 1.9 tonnes per year (NCC Roads AB 2005 & Ucklums Grus AB 2005). The same figure for Västra Götaland is 1.7 tonnes per capita and year and for Sweden 2.3 tonnes per capita and year (Berg et al. 2005, p. 30). Compared to this figures Stenungsund municipality has a quite normal gravel per capita consumption.

6.2.3 Geographical distribution of different materials

The geographical distribution of the aggregates produced in Stenungsund municipality has also been studied. Figure 9 and Figure 10 and present distribution maps of two selected material groups, crushed bedrock 0/32, 0/35, 0/35 and sand 0/8. Distribution maps of quarry fines, crushed bedrock 0/12, 0/16, 0/18, crushed bedrock 0/80, 0/90, 0/150, macadam 2/5, macadam 8/11, 8/16, 11/16, macadam 16/22, 16/25, 16/32, sand 0/4 and coarse gravel 8/16 may be found in Appendix C. The aggregate materials exported to Denmark have been excluded in this part of the study. The main reason for this is that these aggregates are transported by boat instead of truck. It would be misleading to mix these two means of transport and then analyse the distribution patterns.

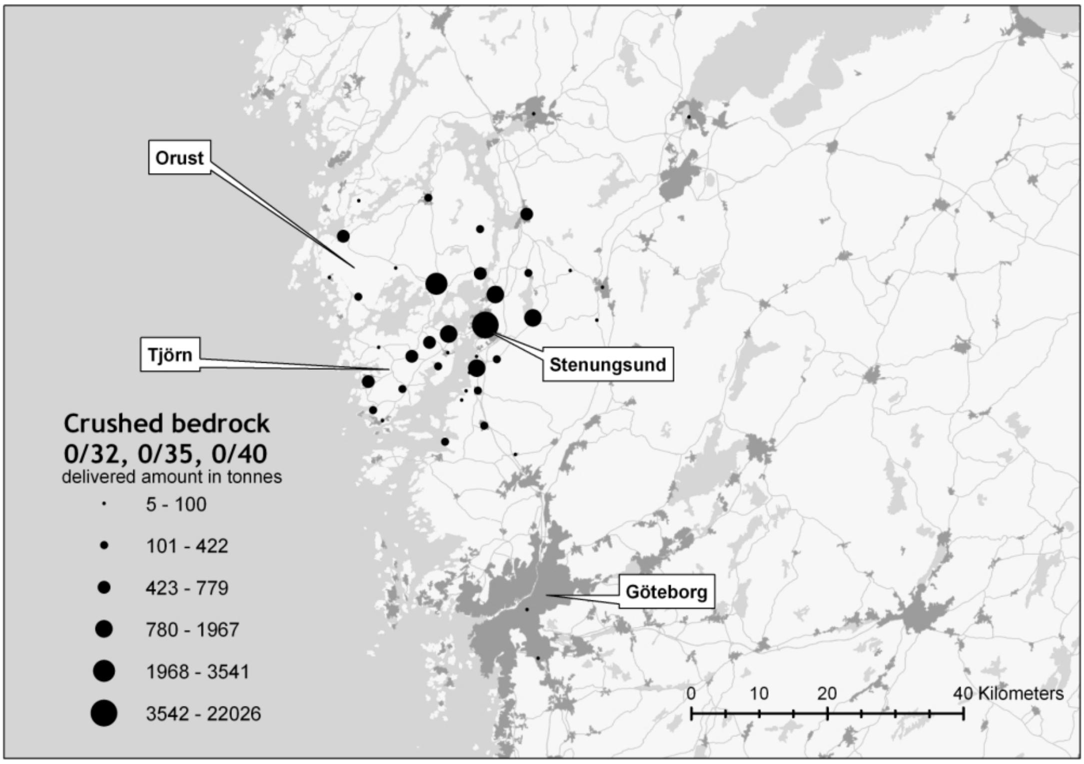


Figure 9: Geographical distribution of crushed bedrock 0-32, 0-35 and 0-40 mm produced in Stenungsund municipality between November 2004 and October 2005

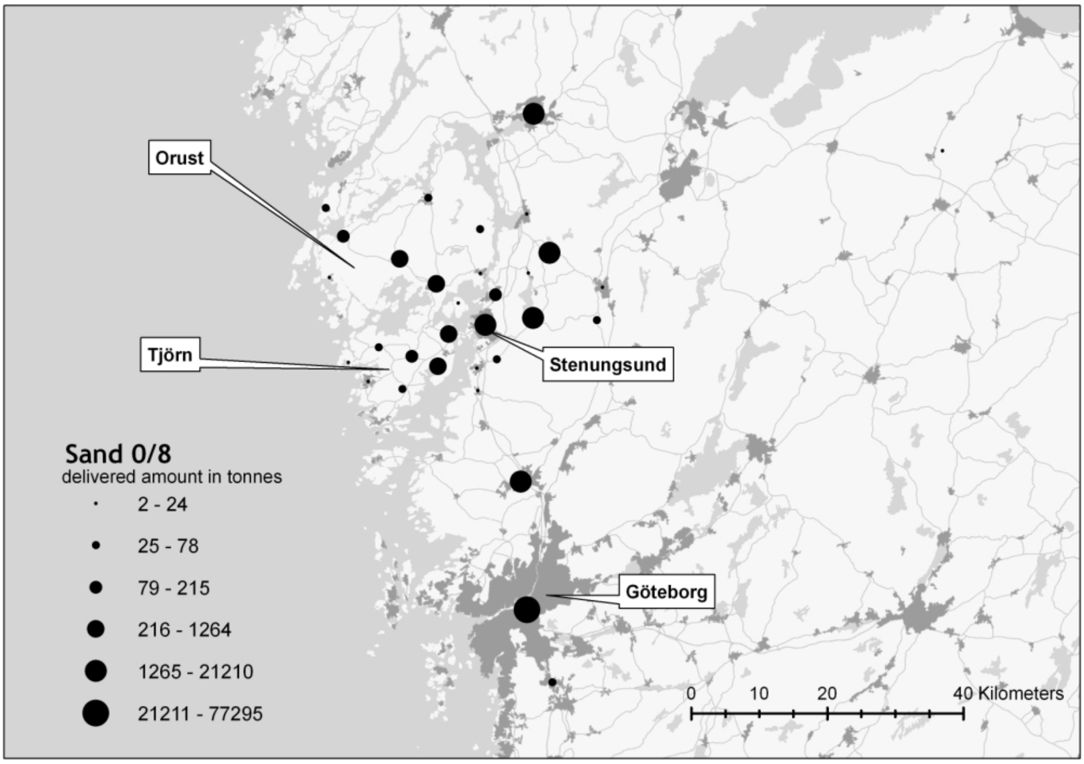


Figure 10: Geographical distribution of sand 0-8 mm produced in Stenungsund municipality between November 2004 and October 2005

It is clear that the aggregate distribution patterns in Figure 9 and Figure 10 differ. However, before analyzing the different patterns it is important to be aware of some other differences between the maps. The different sized dots represent different amounts of material delivered to specific places. Generally, the larger the dots are the larger the delivered amounts of aggregates are. On the other hand, the total delivered amount of sand 0/8 and crushed bedrock 0/32, 0/35, 0/40 differs and therefore dot sizes may not be compared between the maps, e.g. the same dot size represent different amounts of sand and crushed bedrock. The differing total delivered amount also affects the dot classes. There are six classes in each map and the total amount of sand 0/8 is larger than the total amount of crushed bedrock 0/32, 0/35, 0/40. Consequently, the difference in tonnes between the smallest and largest dots is larger as well. Another thing worth noticing is that smallest dot class does not start at zero but at the smallest delivered amount of the specific materials. The reason for this is that the zero values have been excluded from the database to avoid confusing small dots at places where no material has been delivered.

For crushed bedrock 0/32, 0/35, 0/40 all large dots are concentrated around Stenungsund see Figure 9. The interpretation may be that this material is consumed close to where it is produced. The large dots of sand 0/8 are spread within a larger geographical area, see Figure 10. The largest dot of sand 0/8 is found in Göteborg which is about 50 km from where the sand was produced. This indicates that the mean transportation length is longer for sand than for crushed bedrock.

6.2.4 Gravel extraction in Stenungsund compared to the environmental objectives

Stenungsund municipality account for 5.87 % of the gravel produced in the county of Västra Götaland (Berg et al. 2005, p. 35). If Stenungsund is assumed to keep its production share, the regional target for gravel extraction, see chapter 2.2, limits the production in Stenungsund to maximum 82180 tonnes per year by the year 2010. This corresponds to a halving of the amount produced today, see Figure 7.

Since aggregate production follows the state of the construction market, produced amounts tend to vary from year to year. To get a fairer view of progress towards the environmental target, the extracted amount of gravel is often compared to total extracted amount of aggregates. In the county of Västra Götaland gravel extraction corresponds to 19.3% of the total aggregate extraction (Berg et al. 2005, p. 26). For Stenungsund the share of gravel extraction is 26.1 %, see Figure 7. The fact that the number for Stenungsund is higher than for the county in general is most likely depending on the large export share in Stenungsund. The gravel pits in Stenungsund do not only satisfy demand within the municipality but in the neighbourhood as well.

6.2.5 Gravel used in vain

Concrete production sites utilize 148620.8 tonnes of the gravel produced in Stenungsund municipality. Another 1048.0 tonnes are used for playgrounds and sandpits. Concrete and playgrounds are two usage areas where it is still difficult to substitute the natural material. When comparing this amounts to the total produced amount, it accounts for 87.3 %. Consequently the remaining 12.7 % is used in vain.

However, it should be emphasized that some of this gravel might have been used for mortar and plaster which is a usage area where gravel still is needed. The problem is to specify among these amounts since they have been consumed by a lot of different small users. Calculating the amount for mortar and plaster from Figure 7, 2036.2 tonnes, the percentage of gravel used in vain is reduced to 11.5 %.

In order to put the usage of gravel produced in Stenungsund in perspective it can be compared with figures for other geographical areas. 86.7 % of the gravel produced in Stenungsund is used for concrete production. In Västra Götaland this figure is 49 % and for Sweden in total it is 31 %. In the county of Västerbotten the gravel used for concrete is only 3 % of the total gravel production. 85 % of the gravel produced in Västerbotten is used for road construction! It is obivious that regions with abundance of gravel, like Västerbotten, tend to use the material less carefully than regions where gravel resources are scarce, like Västra Götaland. (Berg et al. 2005, p. 10)

7 Discussion

This chapter discusses the result of the case studies performed. Firstly, by comparing the two case study municipalities and secondly by comparing the case study results with the county average. The chapter ends with a discussion about uncertainties of the current study and recommendations for further work in this study area.

7.1 Comparison between Öckerö and Stenungsund

As was assumed, Öckerö and Stenungsund municipalities are very different in many aspects. The most striking is the difference in per capita consumption of aggregates. 1.8 tonnes per capita and year in Öckerö compared to 9.4 tonnes in Stenungsund. As mentioned in chapter 5.2.2, when a resource is scarce it is generally used more carefully. An example of this is the usage of gravel in different regions, discussed in chapter 6.2.5. It has been observed that gravel is used more careful in regions with scarce supply (Berg et al. 2005, p. 10). This is most likely the case with aggregates in general as well. When the supply is scarce, or as in the Öckerö case non-existing, the consumption of the resource is naturally limited.

The difference in gravel per capita consumption, 1.9 tonnes per year in Stenungsund and 0.009 tonnes per year in Öckerö, has a part of its explanation in size of resource supply. In addition to this, import and export of aggregates over municipality borders also affect the per capita consumption. In the current study incoming and outgoing aggregates camouflaged as concrete and asphalt are not considered. The consequence of this is that as mentioned in chapter 6.2.2, the gravel per capita consumption in Stenungsund is overly high. All concrete produced in Stenungsund is certainly not consumed in Stenungsund but rather exported to neighbouring municipalities. In Öckerö it is the other way around, concrete is produced outside the municipality and imported and this gravel is not visible in this study. Therefore gravel per capita consumption in Öckerö is extremely low but would increase a lot if these flows were included.

7.2 Comparison between the case studies and the county average

There has not been any study like this one for the Västra Götaland County as a whole. However, in the report by Berg and others (2005) the distribution on different usage areas has been estimated by aggregate producers. The aggregate producers were asked to estimate how their deliveries were distributed on different usage areas. The uncertainty of these estimations is clearly large and the uncertainty increases as the geographical area decreases (Berg et al 2005, p. 9). For this reason Berg and others do not report any distribution for aggregates at municipality level. The question about usage area was answered by 75 % of the asked producers (Berg et al 2005, p.9). The result of these estimations for Västra Götaland County and the current study results for Öckerö and Stenungsund municipalities are shown in Figure 11.

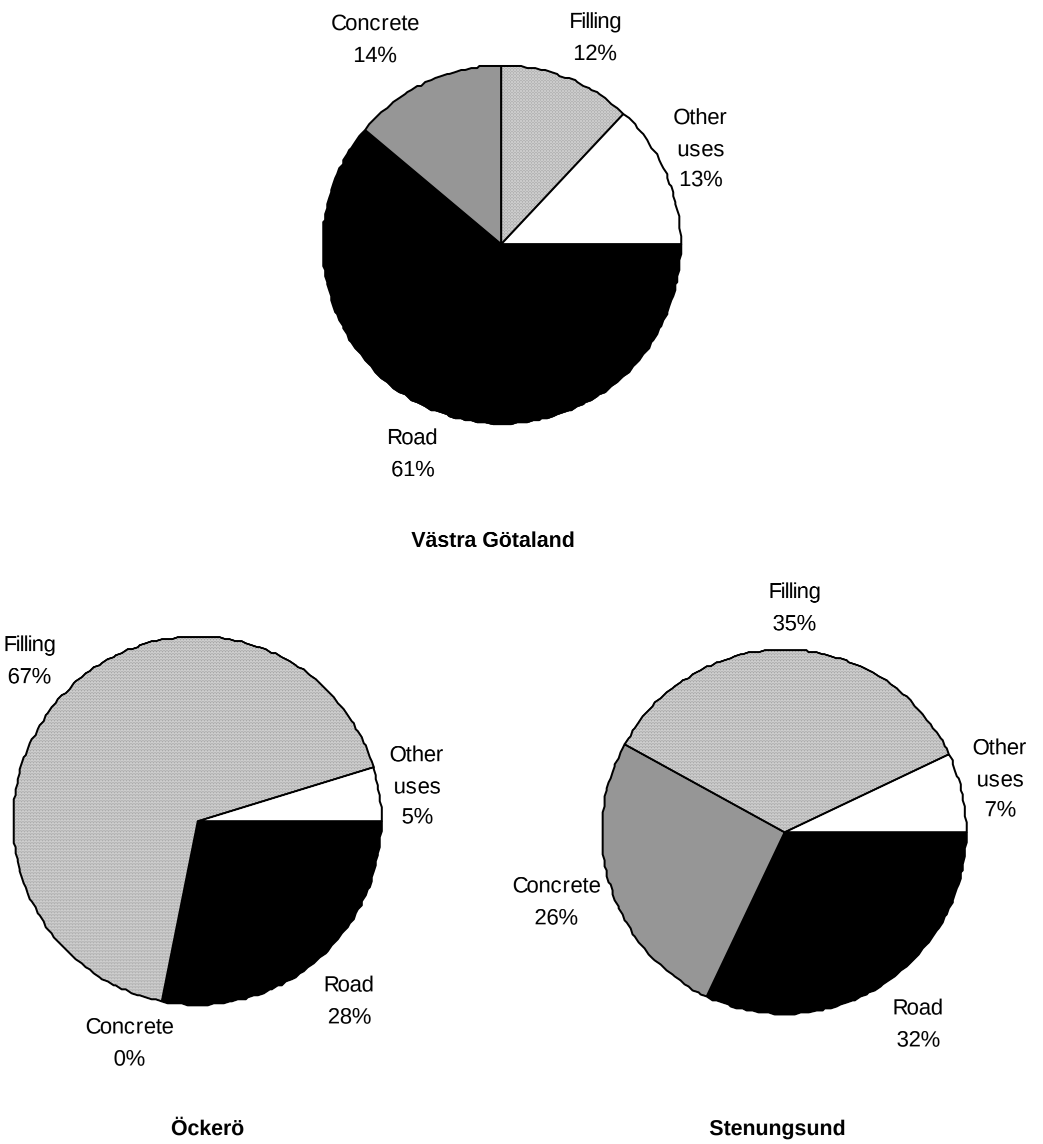


Figure 11: Aggregates distributed on different usage areas in Västra Götaland, Öckerö and Stenungsund

The distribution on usage areas looks quite different for the three geographical areas. The most striking difference is the size of the road sector, which is twice as big in the Västra Götaland case as in the two municipality cases. An explanation for the different appearances of the road sectors might be the method used to divide aggregates between different usage areas. The same type of aggregates that is used for road construction can also be used for different types of ground work. When producers in Västra Götaland made their estimations it is likely that all of this material ended up in road sector. In the municipality cases aggregates used for ground work was put into the filling usage area. Hereby material was virtually taken from road and put into filling. Consequently the filling sector in the municipality cases is larger than the filling sector in the Västra Götaland case.

7.3 Uncertainties of the results

This chapter starts with an examination of the method used in this study. It continues with identification of error sources, uncertainties, and also discusses about and estimates the effects that those uncertainties may have had on the results.

7.3.1 Uncertainties of the method

The conceptual model of this study did not take into account the incoming and outgoing aggregates in already made asphalt and concrete. This simplification has surely affected the results since much import and export over municipality borders come in this form. The main reason for this is that both asphalt and concrete are produced in special production sites and these are not evenly distributed geographically. The reason that these flows are not included in the model of the current study is that it would have been too time consuming to collect data for these flows.

Another cause of error in the results is due to the way aggregate fractions were used to determine usage areas. It is difficult to estimate how true the answers from the interviewed persons are. It could be that they mentioned the first usage area they thought of, or the just what they normally use the material for. It is not sure that their answers fully correspond to the real usage. A further problem with distributing aggregates between usage areas by fractions arises when a fraction has several usage areas. The difficulty is partitioning the amounts between the usage areas.

An error source for the geographical distribution is the way that aggregates were split between municipalities. When no exact geographical information was available population size was used to split the amounts between municipalities. This adds error to the result since aggregate utilization might not be directly proportional to population.

7.3.2 Uncertainties of the data sources

The material flow as it is described in the conceptual model has not been fully mapped, e.g. all included flows have not been traced. To collect data for all flows that is included in this model turned out to be too extensive for a thesis work. To understand the flow of aggregates even better, import of material, recycling loops and aggregate handling sites should be investigated further.

It was mentioned previously that the way aggregates were distributed on usage areas may have caused errors to the result. Even so there is direct usage information for some of the aggregates and for these amounts the usage can be considered as certain. In Stenungsund 60 % of the produced aggregate amounts have a known usage. In Öckerö 30 % of the consumed aggregate amounts have a known usage. The reason for the difference is that many tonnes of the produced aggregates in Stenungsund are used by large asphalt and concrete producers. In this case usage area is easily determined.

Apart from the common error sources for the two municipalities, there are some case specific error sources as well. For Öckerö municipality, data have only been taken from Vikans Kross AB. This means that if aggregates are imported to Öckerö from other quarries or gravel pits those have been left out. However, as mentioned in chapter 5.1, it is not likely that large amounts of aggregates have been imported from other sites since the transport length in this case would double. A problem with the delivery note database provided by Vikans Kross AB is that for 9.8 % of the delivered tonnes delivery information is missing (Vikans Kross AB 2005). This could be a source of error since the delivery information was used to track aggregate deliveries to Öckerö municipality. In most cases where delivery information is missing, the material has been bought by persons who have picked up their material by themselves. There is no reason to believe that this is more common in Öckerö municipality than in other areas, under this assumption the current study covers 90.2 % of the aggregate deliveries from Vikans Kross to Öckerö municipality.

The case specific error sources for Stenungsund municipality are the two production sites that have been left out and the way of determining whether the aggregates were used within or outside the municipality. The two production sites that were left out are Grössbyn 2:2 and Tosteröd 1:2. Not considering the aggregates produced at these sites naturally adds error to the result. Though, the size of this error is assumed to be minor since these sites are very small. It was mentioned earlier in chapter 6.1 that they only account for account 1.5 % of the remaining permitted aggregate extraction in Stenungsund municipality.

The result of Stenungsund municipality has also been affected by the way that aggregates were placed inside or outside the municipality. When delivery addresses were missing invoice addresses and information from the producers were weighted together to determine where the aggregates were used. The aggregates used by customers active in more than one municipality where split between the municipalities concerned proportional to their population sizes. Since aggregate use is not direct proportional to the number of inhabitants this could have affected the result.

7.4 Recommendations for further work

The results of the current study have indicated that there is an important issue to consider if further work in this area is to be made. The import and export of camouflaged aggregates, in concrete and asphalt, have been discovered to have large impact on the consumption of aggregates within a geographical area. A development of the conceptual model according to Figure 11 is therefore recommended.

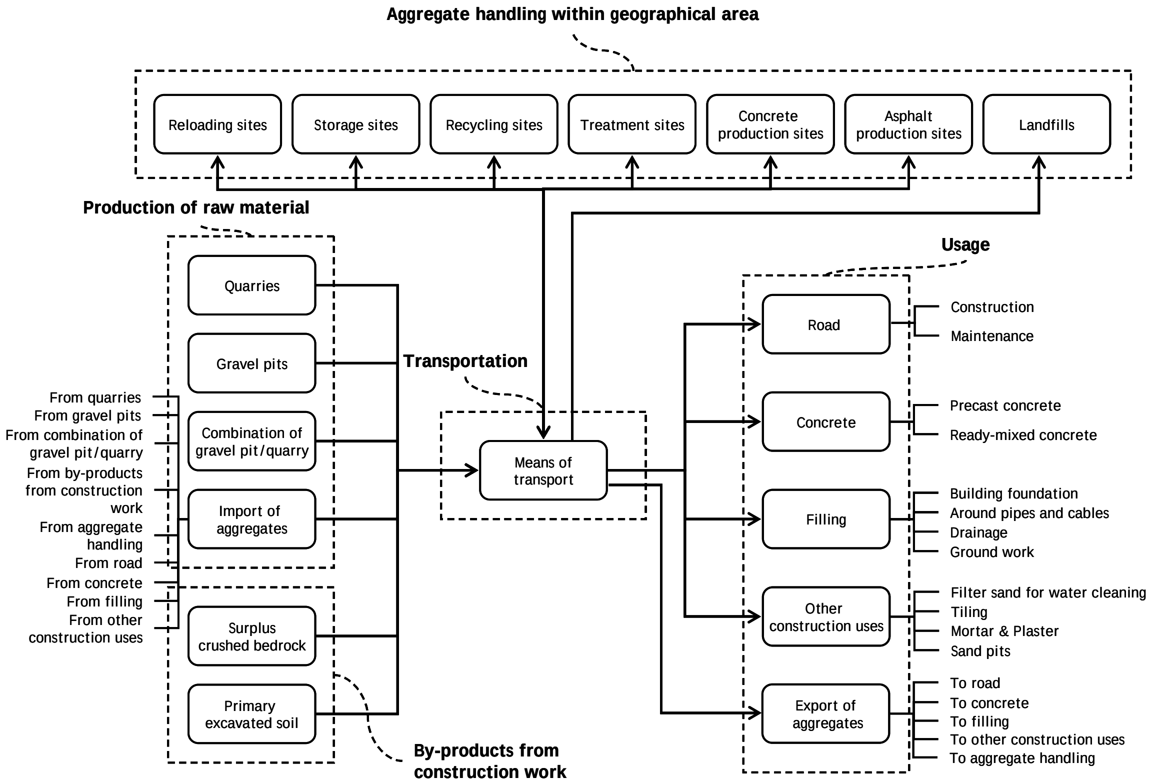


Figure 12: Developed conceptual model of aggregate flow

The development of the conceptual model is basically an expansion of the processes included in the ‘Aggregate handling within geographical area’. In this group two processes have been added, ‘Concrete production sites’ and ‘Asphalt production sites’. All aggregates used for concrete and asphalt production within the geographical area will herby go via the production sites in aggregate handling. This will in turn transform the ‘Concrete’ and ‘Road’ usage areas so that they just include the amount of aggregates used for concrete and asphalt within the geographical area. In this developed model, the produced concrete and asphalt which is not consumed within the geographical area will eventually end up in ‘Export of aggregates’. The exported camouflaged aggregates will therefore not burden the aggregate consumption within the geographical area.

8 Conclusions

- There are large differences between the municipalities studied. The most striking is the difference in per capita consumption of aggregates. 1.8 tonnes per capita and year in Öckerö compared to 9.4 tonnes in Stenungsund. The gravel consumption per capita differs as well, 1.9 tonnes per year in Stenungsund and 0.009 tonnes per year in Öckerö.
- There is a tendency that the mean transportation length is longer for gravel than for crushed bedrock.
- 12.7 % of the gravel produced in Stenungsund is used for purposes where the gravel may easily be substituted with crushed bedrock, this gravel could be said to be used in vain.
- If Stenungsund is assumed to keep its production share, the regional target for gravel extraction limits the production in Stenungsund to maximum 82180 tonnes per year by the year 2010. This corresponds to a halving of the amount produced today. Therefore the environmental quality objective seems difficult to reach on a municipality level.
- The camouflaged flows of aggregates in concrete and asphalt affect the result a lot. The main reason for this is that both asphalt and concrete are produced in special production sites and these are not evenly distributed geographically. Consequently, when looking at a specific geographical area import and export flows of these products has a large impact.

9 References

Andrén Robert, Envronmental Objectives Council (2005) *Sveriges miljömål, Officiell portal för våra 16 miljömål.* (Electronic) Available: < http://www.miljomal.nu/english/english.php > (2006-01-03)

Arell, Lars (2003) *Når vi naturgrusmålet?* SGU-report 2003:8, Uppsala: Sveriges Geologiska Undersökning, SGU

Berg, Åke, Arell, Lars, Fagerlind, Torbjörn, Sträng, Malin & Grånäs, Karin (2004) *Grus, sand och krossberg, produktion och tillgångar 2003*, per. publ 2004:3, Uppsala: Sveriges geologiska undersökning, SGU

Berg, Åke, Arell, Lars & Sträng, Malin (2005) *Grus, sand och krossberg, produktion och tillgångar 2004*, per. publ 2005:3, Uppsala: Sveriges geologiska undersökning, SGU

Brunner, Paul H & Rechberger Helmut (2004). *Practical Handbook of Material Flow Analysis*. USA: CRC Press LLC, Lewis Publishers

Boverket (2005) *Sveriges miljömål, Grusanvändning.* (Electronic) Available: < http://mmu.slu.se/Gus/Pub/Indikator.jsp?InkID=156:1&MmID=15&LocType=CC&LocID=SE&retur=/om_miljomalen/miljomalen/mal18.php > (2006-01-13)

GR (Göteborgsregionens kommunalförbund) (2003) *Grusförsörjningsplan för Göteborgsregionen.* Göteborg: GR

Grånäs, Karin (1994) *Hur länge räcker naturgruset? En sammanställning av kända tillgångar samt behov av framtida inventeringar*. In GR (Göteborgsregionens kommunalförbund) (2003) *Grusförsörjningsplan för Göteborgsregionen.* Göteborg: GR p. 63

Jansson, Lena (2004) *Stenungsundshistoria.* (Electronic) Available: < http://www.stenungsund.se/kommun/kommuninfo/historia.asp > (2005-11-04)

Jonsson, Karl-Erik & Åkerström, Rolf (1975) *Göteborgsregionen Grus- och Bergtäktsplan 1975.* Göteborg: Allfoto i Göteborg AB

Knutsson, Gert (1969) *Stor-Göteborg Grusförsörjning*. Göteborg: Typografia

Länsstyrelsen (2005) *Miljömålen, God bebyggd miljö.* (Electronic) Available: < http://www5.o.lst.se/miljomal > (2005-12-08)

Moberg, Åsa, Finnveden, Göran, Johansson, & Steen, Peter (1999). *Miljösystemanalytiska verktyg – en introduktion med koppling till beslutssituationer,* AFR-REPORT 251. Stockholm: Naturvårdsverket

Månsson, Bengt (1993). *Miljö för bärkraftighet. Perspektiv på naturresurser, deras begränsningar och deras roll i samhället*. Malmö: Liber-Hermods AB

NCC Roads AB (2005) *Sales data base, delivered material from Stora Gategård during one year, November 2004 - Oktober 2005* (Electronic)

Planning portal (2005) *Planning portal glossary: A.* (Electronic) Available: < http://www.planningportal.gov.uk/england/government/en/1115310681665.html > (2005-10-11)

SBMI (Sveriges Bergmaterialindustri) (2005) *Branschbeskrivning Bergmaterialindustrin.* (Electronic) Available: < http://www.sbmi.org/SIDOR/varbrans.htm > (2005-10-24)

SCB (Sveriges statistiska centralbyrå) (2005) *Kommunfaktablad* (Electronic) Available: < http://www.h.scb.se/kommunfakta/k_frame.htm > (2005-11-03)

SGU (Sveriges geologiska undersökning) (2005) *Karttjänster, Ballast och industrimineral* (Electronic) Available: < http://www.sgu.se/sgu/sv/service/karttjanst_start.htm#mineral > (autumn 2005)

Stenungsund kommun (2005) *Översiktsplan 2006* (Electronic) Available: < http://www.stenungsund.se/kommun/byggabo/OP-2006/OP2006Samrad/Hela_rapporten_med_kartor.pdf > (2005-10-27)

The World Commission on Environment and Development (1987) *Our common future*. Oxford: Oxford University Press

Vikans Kross AB (2005) *Delivery note database, delivered material from Vikans Kross during one year, December 2004 – November 2005* (Electronic)

Ucklums Grus AB (2005) *Paper copies of invoices of material delivered by Ucklums Grus AB during one year*, November 2004 - Oktober 2005

Öckerö kommun (2005) *Om kommunen* (Electronic) Available: < http://www.ockero.se/ > (2005-11-04)

Appendixes

Appendix A – **Aggregates delivered to Öckerö municipality**

Appendix B – **Aggregates produced in Stenungsund municipality**

Appendix C – **Geographical distribution of aggregates produced in Stenungsund municipality**

Appendix A – Aggregates delivered to Öckerö municipality

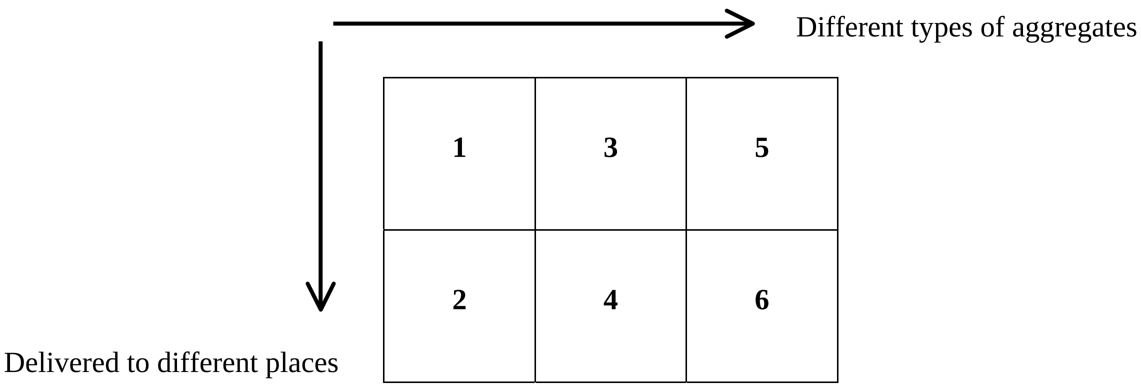
Delivered to	Secondary asphalt		Crushed bedrock												
	Milled asphalt	Crushed asphalt	Quarry fines	0/16	0/25	0/40	0/60	0/90	0/100	0/150	0/300	2/5	5/8	8/11	8/16
Björkö	16.0	41.3	56.3	234.5		299.6	337.7	27.8		555.0	10.7	93.2			
Fotö			509.0	331.3	5.3	92.0	320.9			21.1		57.6	2.5		
Hyppeln			15.0	4.3				90.5	7.4	8.0				23.4	
Hälsö			165.7	478.0	248.6	291.0	144.0	2225.3	17.3	239.4		14.4	2.5	69.8	
Hönö	21.4	55.0	43.7	764.7	12.5	343.0	591.3			835.3	14.2	164.2	5.9		
Knippla			64.7	61.1			29.8					3.3			11.8
Rörö						148.5	23.9								
Öckerö	16.0	41.3	35.4	716.5	12.5	1463.6	2365.4	66.6		819.8	10.7	351.8	47.5		

Delivered to	Gravel					Crushed bedrock							**Total amount**
	Plaster sand	Grinding sand	Cable sand	Mortar sand	FP-sand	12/16	16/22	16/32	32/60	40/120	90/150	100/350	
Björkö						44.4	387.1	432.6	10.5			5.5	**2552.2**
Fotö			22.4		4.7		423.9	134.3			5.1		**1930.1**
Hyppeln								3.9					**152.5**
Hälsö			5.6		4.7		106.0	111.1			5.1	0.0	**4128.4**
Hönö					10.9	8.3	550.4	853.3	14.0		11.9	7.3	**4307.2**
Knippla		32.7						26.4	12.6				**242.2**
Rörö													**172.4**
Öckerö	8.2			15.0	10.9	105.7	440.0	1808.4	38.0	133.7	11.9	5.5	**8524.3**

Note: All amounts are in tonnes. 0/16, 0/25, 0/40 etc. represent the minimum and maximum grain sizes in millimetres of a specific fraction.

Appendix B – Aggregates produced in Stenungsund municipality

The basis for this appendix was a table in Excel. The original table was too big to fit in this report format so it had to be split into six single tables. How the original table was split, is described in the below figure.



Note that:

All amounts in the tables are given in tonnes.

0/16, 0/25, 0/40 etc. represent the minimum and maximum grain sizes in millimetres of a specific fraction.

Appendix B – Aggregates produced in Stenungsund municipality

Delivered to	Crushed bedrock										
	Quarry fines	012, 0/16, 0/18	0/32, 0/35, 0/40	0/80, 0/90, 0/150	2/5	2/8	5/8	5/16	8/11, 8/16, 11/16	8/25	16/22,16/25, 16/32
Aröd			20.6	233.2							81.1
Backamo											
Bleket		195.0	317.6		8.0						
Brastad									106.4		
Denmark	32244.0				22203.5		45274.4	10931.0	70183.0		5142.8
Dingle											
Ellös	24.6	887.3	519.3	310.8	118.5		16.0		722.4		373.5
Fagerfjäll	237.1	134.5	257.9	493.0	240.0				2501.9		152.0
Flatön		105.8	18.9	356.2					10.2		
Färgelanda											
Getskär		157.6	35.5				14.2		69.5		
Grundsund											
Göteborg	31216.1	171.8	5.1	180.7	497.8						1517.8
Hakenäset	43.4	689.0	422.4	448.2	189.9				1109.0		166.4
Harestad					26.6				12.0		
Hasteröd		13.4	17.7								
Hedekas											14.5
Henån		881.9	382.7	650.3	25.3		56.1		506.5		490.7
Hisings Backa		29.0									
Hjälteby	537.6	622.4	468.6	139.2	67.6		52.7		77.5		263.5
Häljeröd											
Hälleviksstrand		98.6	79.7	196.9	21.2		10.1		97.0		116.0
Höviksnäs		227.1	18.6	118.6	14.6				32.4		23.9
Jörlanda	51.1	372.6	383.2	110.6	46.0		15.8		66.0		374.3
Kareby		7.8	7.4	382.8	11.0						209.2
Klövedal	28.7	1291.9	27.2		11.9				211.5		25.9
Kode		196.2	211.9	27.8	13.8		29.0		29.6		958.0
Kungälv					56.3		608.3		2220.0		
Kyrkesund	11.6	84.3			82.4				543.7		12.1
Kållekärr		438.5	745.1	152.1	83.4				6.9		9.3
Kållered									34.5		
Källsby			13.5								
Landvetter				203.0	12.0						98.0
Lilla Edet	15.8	137.6	48.6	30.3	6.0				3.0		76.5
Lindome		15.3									

Appendix B - Aggregates produced in Stenungsund municipality

Delivered to	Crushed bedrock										
	Quarry fines	012, 0/16, 0/18	0/32, 0/35, 0/40	0/80, 0/90, 0/150	2/5	2/8	5/8	5/16	8/11, 8/16, 11/16	8/25	16/22,16/25, 16/32
Ljungskile	24.7	1378.0	632.7	425.4	106.3		181.4	19.9	276.9	67.0	353.9
Lunneslätt			21.1								
Lökeberg											33.9
Myggenäs	529.2	1813.0	1850.2	4132.9	637.4		522.3	59.7	881.8	201.1	1856.7
Mölndal	36.9		35.5								
Nösund	4.2	155.1	286.9	186.6	39.0		51.6		636.9		143.2
Rönnäng		33.7	53.7	65.6	154.8		29.2		144.4		56.0
Rörtången		141.5	251.3	81.8					9.2		
Sjövik		8.3									
Skepplanda		11.0									
Skärhamn	552.6	427.4	778.9	139.3	106.7				138.1		173.7
Spekeröd	250.2	713.8	370.5	25.8	47.6		12.7		175.1		122.0
Stenungsund	9108.5	17913.5	22025.9	37131.0	3512.4	269.7	668.7		22199.2		12362.7
Stillingsön	63.2	506.1	180.8	1077.3	26.8		160.1		266.5		903.5
Stockevik					13.2						
Stora Askerön											16.3
Stora Höga	92.6	1009.8	1966.9	5492.9	237.1		64.7		317.4		1410.0
Stora Levene				32.5					15.0		
Strandkärr		65.0	31.3	812.5							18.0
Svanesund	74.3	532.9	467.1	4399.0	154.6		195.4		457.5		578.5
Svenshögen	139.4	149.2	256.2	794.6	52.3				10.0		243.3
Säffle		48.0	11.8								112.1
Särö											
Timmervik	51.1	134.8	91.6	174.9	1.2		2.6		43.6		149.9
Torslanda	395.6										101.2
Trollhättan		22.1		4.5	3061.4						
Ucklum	159.4	1251.7	1652.6	984.1	213.0		230.3		7561.9		1392.3
Uddevalla		29.2	6.0		6.5				5200.5		9.0
Vallhamn		65.2							2889.0	753.5	
Varekil	1232.8	2928.1	3541.2	6987.5	440.4		1204.3	119.5	2553.5	402.2	2306.8
Vänersborg		510.3	100.2		53.3		13.4		372.1		
Västerlanda		184.9	36.7	551.5	27.2		20.3				182.9
Ytterby											
Åmål											
Ödsmål	480.8	1169.7	1190.8	2830.1	213.5		238.6		1432.0		792.8

Appendix B - Aggregates produced in Stenungsund municipality

Delivered to	Crushed bedrock								Gravel				
	32/63	22/90	18/200	100/200	32/45	Blast stone	Waste	Crushed Asphalt	Sand 0/4	Sand 0/8	0/50	Drainage gravel	Cobble stone
Aröd									32.3				
Backamo										18627.9			
Bleket													
Brastad										1263.7			
Denmark	1085.0		20.6										
Dingle												58.3	
Ellös									120.3	214.6		392.2	11.5
Fagerfjäll		6.8					16.3		70.6	52.6			
Flatön													
Färgelanda												5.4	
Getskär									34.5				
Grundsund									53.6	77.8			
Göteborg									1463.9	77295.2		215.5	
Hakenäset		21.4							514.9	822.1		67.0	4.4
Harestad													13.7
Hasteröd													
Hedekas												46.3	
Henån								60.9	57.4	53.3		326.3	
Hisings Backa													
Hjälteby		1.2							103.4			14.9	
Häljeröd													
Hälleviksstrand										1.8		36.9	
Höviksnäs													
Jörlanda									121.6	11.3		77.0	
Kareby												43.5	
Klövedal		4.6							37.2	35.0		36.4	7.4
Kode									13.7			110.8	
Kungälv									882.4	8647.6		81.4	
Kyrkesund									10.7	12.5			40.0
Kållekärr								611.6	294.4	172.4			23.2
Kållered										35.1			
Källsby													
Landvetter													33.4
Lilla Edet									81.1	2.3		15.6	
Lindome													

Appendix B - Aggregates produced in Stenungsund municipality

Delivered to	Crushed bedrock								Gravel				
	32/63	22/90	18/200	100/200	32/45	Blast stone	Waste	Crushed Asphalt	Sand 0/4	Sand 0/8	0/50	Drainage gravel	Cobble stone
Ljungskile		1.1								14.0			
Lunneslätt									14.8				
Lökeberg												36.9	
Myggenäs		612.2	270.1		3.7		29.1	35.5	450.9	977.7	254.6	99.3	25.8
Mölndal													
Nösund		37.4							17.6				
Rönnäng												54.5	57.7
Rörtången													
Sjövik													
Skepplanda													
Skärhamn								676.0		8.4		35.2	91.6
Spekeröd									52.1	34.5		12.7	
Stenungsund	101.7	388.8	514.0	23.4	13.4	148.2	75.7	309.9	3310.9	21209.6	384.1	1250.1	224.9
Stillingsön		13.1							65.4	42.4			
Stockevik													
Stora Askerön										1.5			
Stora Höga									40.7	20.3			30.0
Stora Levene									14.7	22.8			
Strandkärr													
Svanesund		42.8	104.5						30.9	24.1		914.5	
Svenshögen									35.3	22.5		15.0	12.8
Säffle													
Särö													
Timmervik									64.1			105.7	
Torslanda													6.0
Trollhättan									2.0				
Ucklum									56.7	13743.3		201.0	
Uddevalla									476.6	8477.9			
Vallhamn													
Varekil		55.5	175.3		8.9		41.9	49.2	939.3	767.6	254.6	546.4	9.8
Vänersborg													
Västerlanda									14.5	40.2			
Ytterby													
Åmål									613.6				
Ödsmål									131.8	185.7	92.5	126.5	60.9

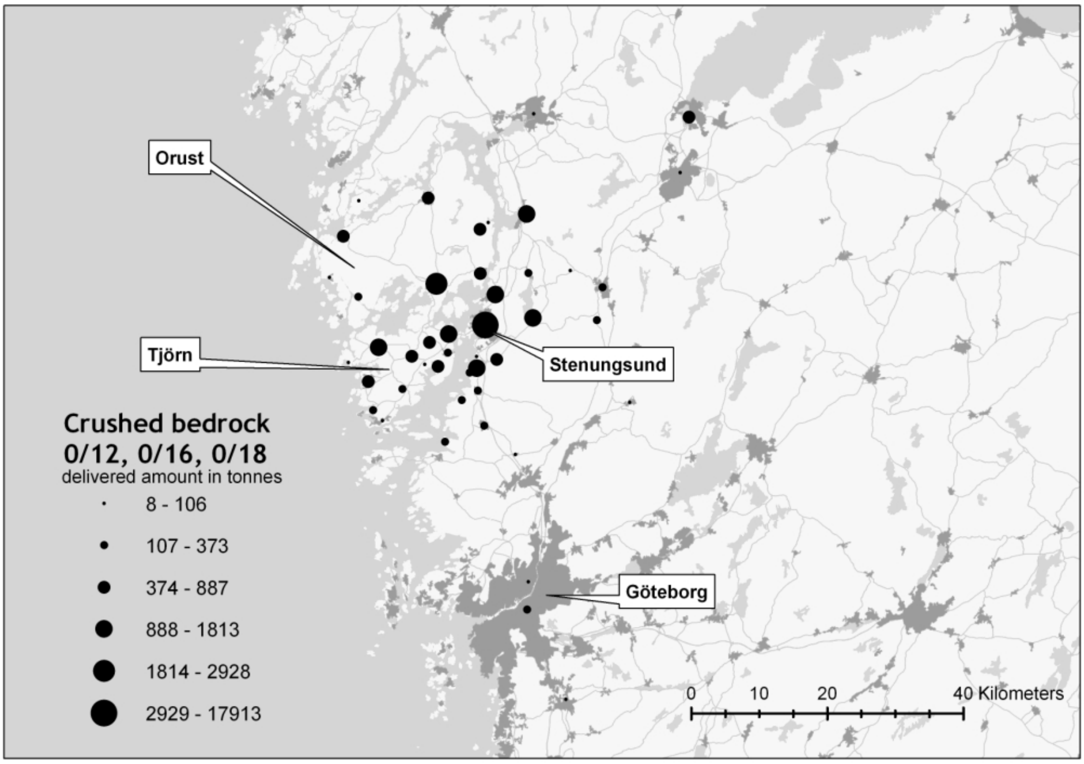
Appendix B – Aggregates produced in Stenungsund municipality

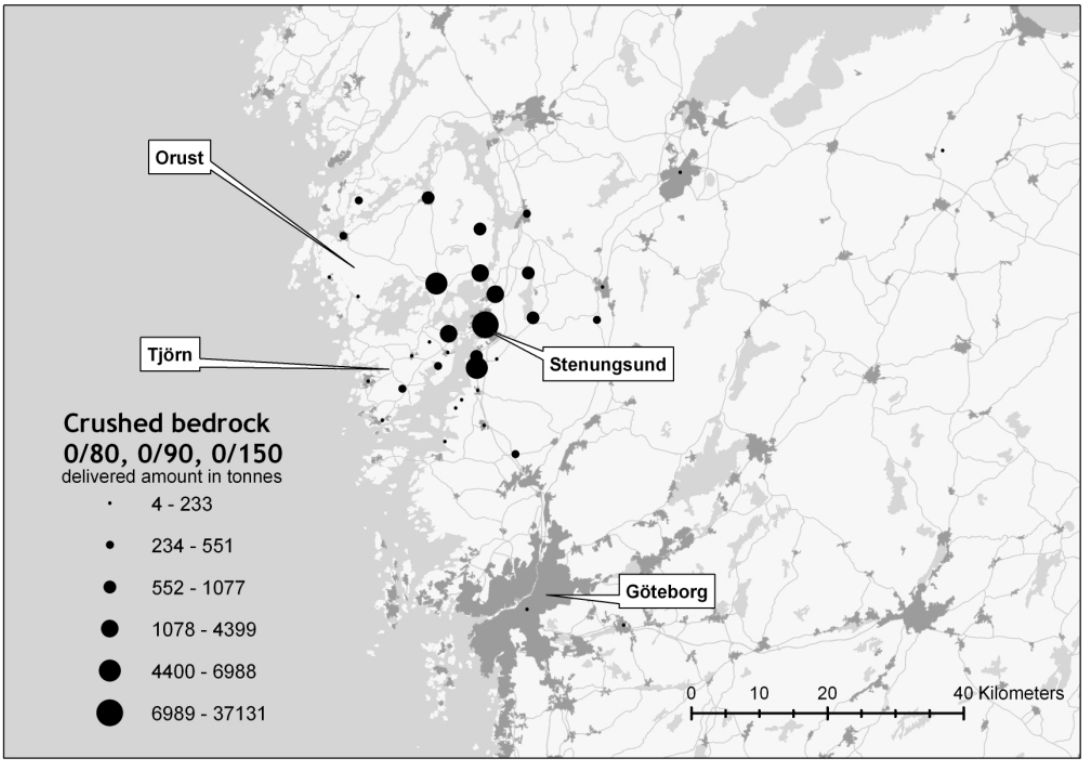
Delivered to	Gravel							
	Shingle 8/16	Shingle 8/18	Shingle 16/32	Infiltration sand	Filling sand	Stones	EU-sand	**Total amount**
Aröd								**367.2**
Backamo								**18627.9**
Bleket	31.5							**552.0**
Brastad								**1370.1**
Denmark								**187084.2**
Dingle								**58.3**
Ellös	153.5		14.0		22.4	5.4	18.6	**3925.0**
Fagerfjäll	86.4							**4249.0**
Flatön								**491.2**
Färgelanda								**5.4**
Getskär								**311.3**
Grundsund								**131.3**
Göteborg	7.7							**112571.6**
Hakenäset	28.9							**4527.0**
Harestad	56.9							**109.2**
Hasteröd								**31.1**
Hedekas								**60.8**
Henån	8.9							**3500.0**
Hisings Backa				181.5				**210.5**
Hjälteby	15.6						413.0	**2777.2**
Häljeröd				39.0				**39.0**
Hälleviksstrand								**658.1**
Höviksnäs								**435.2**
Jörlanda	41.1						44.7	**1715.4**
Kareby								**661.7**
Klövedal								**1717.7**
Kode	15.4							**1606.2**
Kungälv								**12495.9**
Kyrkesund	44.8							**842.1**
Kållekärr	12.8					5.4		**2554.9**
Kållered								**69.6**
Källsby								**13.5**
Landvetter								**346.4**
Lilla Edet								**416.7**
Lindome								**15.3**

Appendix B – Aggregates produced in Stenungsund municipality

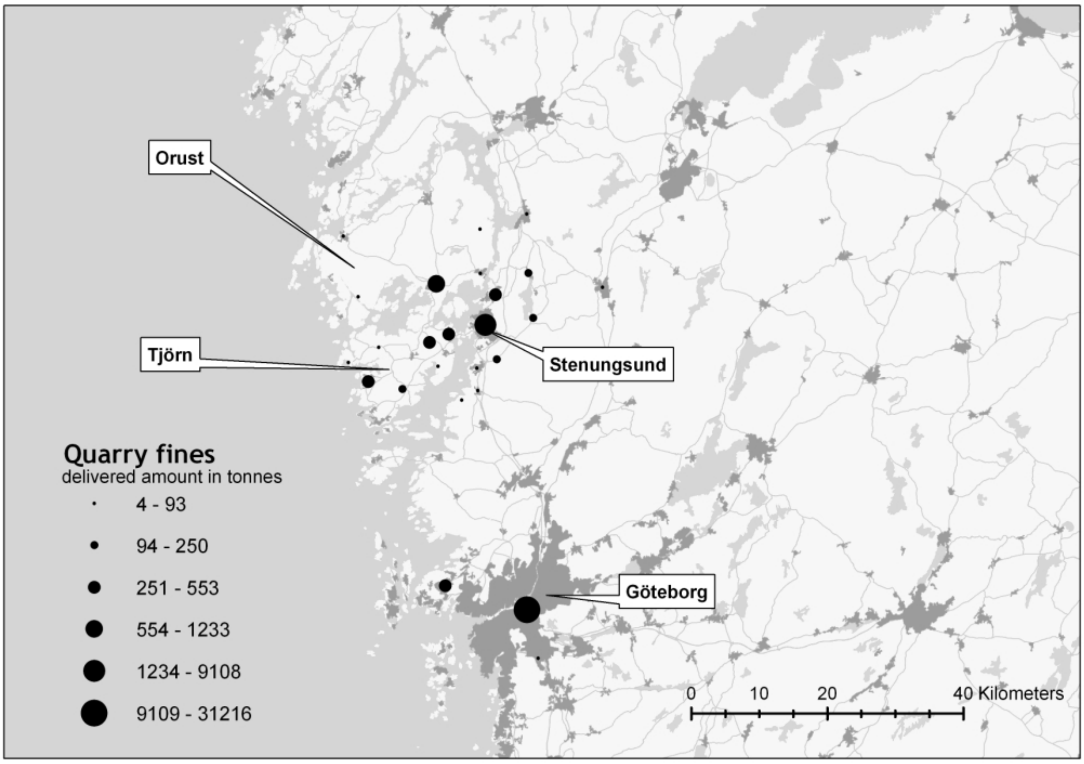
Delivered to	Gravel							
	Shingle 8/16	Shingle 8/18	Shingle 16/32	Infiltration sand	Filling sand	Stones	EU-sand	**Total amount**
Ljungskile								**3481.3**
Lunneslätt								**35.9**
Lökeberg								**70.8**
Myggenäs	15.0		8.6				18.2	**15284.9**
Mölndal							69.6	**142.0**
Nösund								**1558.4**
Rönnäng	13.4							**663.0**
Rörtången								**483.8**
Sjövik								**8.3**
Skepplanda								**11.0**
Skärhamn	13.0							**3140.8**
Spekeröd	27.8							**1844.5**
Stenungsund	348.6		65.0		33.6	8.1	178.3	**153780.1**
Stillingsön								**3305.2**
Stockevik								**13.2**
Stora Askerön	7.5							**25.3**
Stora Höga	118.2	13.1	16.6					**10830.3**
Stora Levene								**85.1**
Strandkärr								**926.9**
Svanesund								**7976.0**
Svenshögen	35.8		20.5					**1786.7**
Säffle					22.1			**193.9**
Särö	16.0							**16.0**
Timmervik	5.9						19.0	**844.5**
Torslanda								**502.8**
Trollhättan							13.6	**3103.5**
Ucklum	109.2		15.6					**27571.0**
Uddevalla	6.5							**14212.2**
Vallhamn								**3707.7**
Varekil	15.0		8.6		14.0		18.2	**24620.4**
Vänersborg								**1049.4**
Västerlanda	17.7							**1075.8**
Ytterby							16.8	**16.8**
Åmål								**613.6**
Ödsmål	73.4							**9019.0**

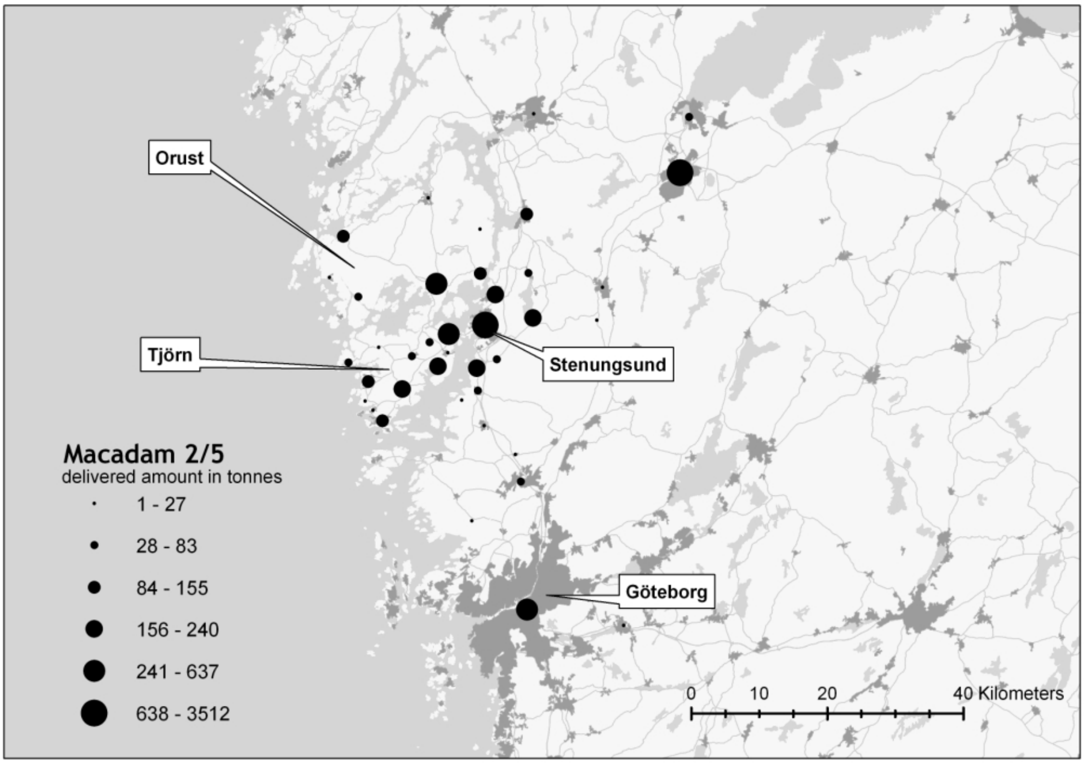
Appendix C - Geographical distribution of aggregates produced in Stenungsund municipality



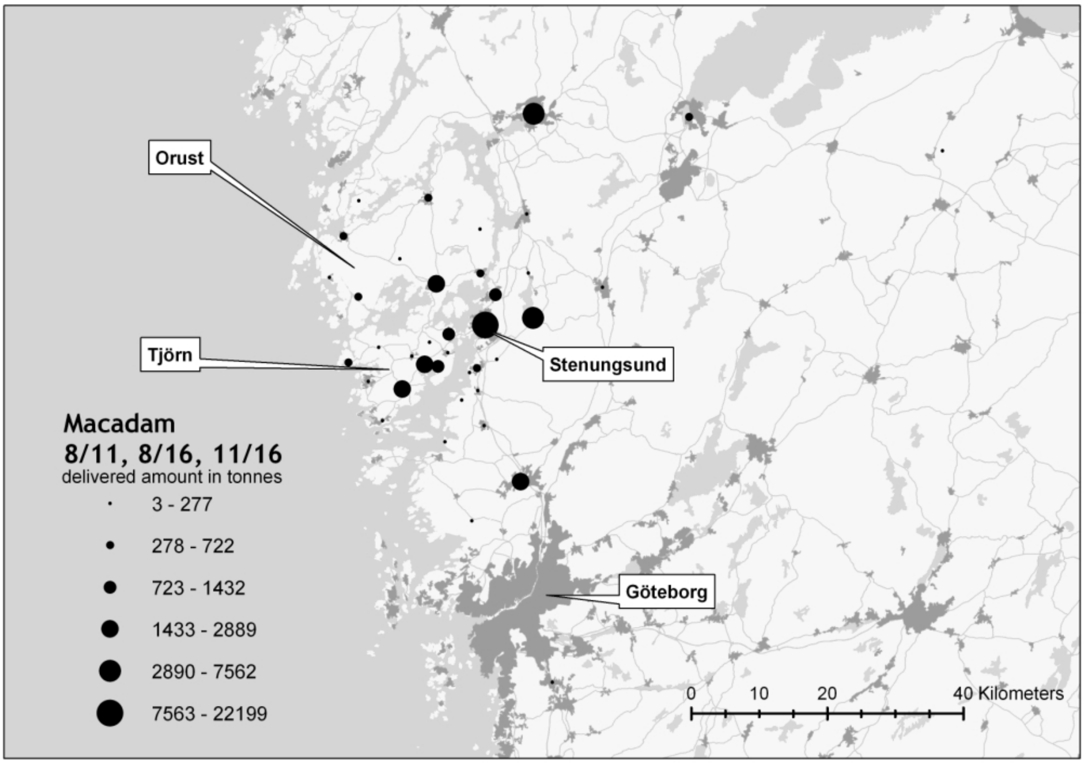


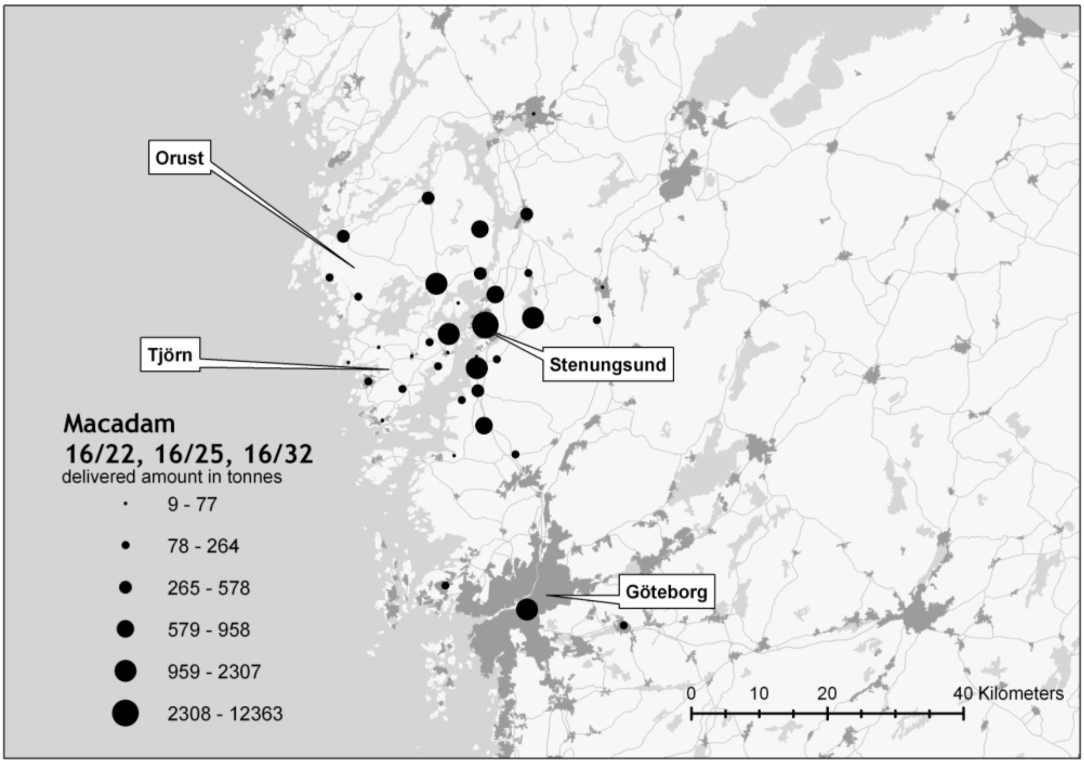
Appendix C - Geographical distribution of aggregates produced in Stenungsund municipality





Appendix C - Geographical distribution of aggregates produced in Stenungsund municipality





Appendix C - Geographical distribution of aggregates produced in Stenungsund municipality