HELSINKI UNIVERSITY OF TECHNOLOGY
Department of Civil and
Environmental Engineering

Gerald Krebs

DEVELOPMENT OF LAND-USE WITHIN THE URBANIZING KYLMÄOJA WATERSHED

A Master of Science Thesis submitted
for inspection in Espoo 24.8.2009

Supervisor: Professor Ari Jolma, TKK

Instructors: Outi Salminen, PhD, TKK

Ulla-Maija Rimpiläinen, M.Sc., City of Vantaa

HELSINKI UNIVERSITY OF TECHNOLOGY **ABSTRACT OF THE MASTER'S THESIS**

FACULTY OF ENGINEERING AND ARCHITECTURE

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Author:	Gerald Krebs		
Thesis:	Development of land-use within the urbanizing Kylmäoja watershed		
Date:	24.8.2009	**Number of pages:**	184
Professorship:	Environmental planning and management information technology	**Code:**	Yhd-102
Supervisor:	Professor Ari Jolma, TKK		
Instructor:	Outi Salminen, PhD, TKK		
Instructor:	Ulla-Maija Rimpiläinen, M.Sc., City of Vantaa		

In this Master's thesis land-use changes within the catchment of the Kylmäoja urban stream were investigated. The catchment of the Kylmäoja stream has a total size of 20.84 km², of which circa 75% or 15.72 km² is located in the city of Vantaa and 25% or 5.12 km² is located in the municipality of Tuusula. Development within the catchment is dominated by suburban residential land-use with scattered small industrial areas. Furthermore, also a part of the Helsinki-Vantaa airport is located within the borders of the basin.

Spatial analysis was carried out with the focus on the development of impervious surfaces in the catchment. The investigation of impervious surfaces contributing to changes in run-off quantity and quality considered roofs, roads and condition of yard areas. Roofs were accounted for as surface area whereas roads and yards were assessed as well in terms of surface area as also quality of the surfaces. The development of the extent of imperviousness within the catchment was investigated for a time span over five decades assessed through individual years, which were selected either due to the availability of data or significant development changes. The years of spatial land-use assessment were 1977, 1982, 1992, 2007 and 2030, the latter representing a projection of current urban planning. To allow a realistic estimation for imperviousness in 2030, a relation between the floor area – which is defined in the plot-ratio in urban planning today – and the run-off relevant components, the roof area and the yard area, was established during this work. Novel roof-to-floor area and yard-to-floor area coefficients were established based on the spatial analysis of the present situation and were implemented for determination of imperviousness in 2030. It was found that no existing database, neither in the city of Vantaa nor in the municipality of Tuusula contains any information on the impervious yard area size, or quality of the yard surface materials. Both qualities were therefore investigated from orthophotos and *in-situ* and a new dataset including that very important information for run-off estimation, and hence the influence of the land-use on the stream was created as a part of this research.

The effects of land-use change on the Kylmäoja stream were evaluated by carrying out an analysis of the determined ultimate imperviousness within the entire Kylmäoja catchment and for the defined eleven subcatchments. A constant increase of imperviousness was found from the beginning year of investigation, 1977, until 2030 – leading to an ultimate imperviousness of 26% in the Kylmäoja catchment in 2030. The development of imperviousness was investigated in further detail for the three transboundary subcatchments defined in this work to investigate the effects of urban planning differences within the involved authorities, the city of Vantaa and the municipality of Tuusula. In 2030, the subcatchment of the western branch will have a higher level of imperviousness in Tuusula (25%) than in the southern and downstream Vantaa part of the subcatchment (23%), in which also parts of the Helsinki-Vantaa airport with its vast asphalt surfaces reside. The Tuusula areas of the central branch catchment will reach 43% of imperviousness in 2030, whereas in the Vantaa part of this subcatchment, the imperviousness level will not exceed 22% by 2030. Furthermore the rough run-off estimation conducted during this work, based on the rational method, followed the trends of the spatial imperviousness analysis results in the Kylmäoja catchment. This estimation also proved the importance of the design, dimensioning, and surface material choices for yard areas in urban planning and site planning for optimal run-off management and stream health. In 2030, 34% of the generated run-off in the Kylmäoja catchment will derive from impervious yard areas, more than from any other origin including the airport runways, which in 2030 will account for 19% of the generated run-off.

Keywords: urban planning, land-use, land-use planning, spatial analysis, imperviousness, stormwater run-off, GIS-software, airport run-off, ratios

Language: English

TEKNILLINEN KORKEAKOULU
INSINÖÖRITIETEIDEN JA ARKKITEHTUURIN TIEDEKUNTA
YHDYSKUNTA- JA YMPÄRISTÖTEKNIIKAN LAITOS

DIPLOMITYÖN TIIVISTELMÄ

Tekijä:	Gerald Krebs		
Diplomityö:	Maankäytön kehitys kaupungistuvalla Kylmäojan valuma-alueella		
Päivämäärä:	24.8.2009	**Sivumäärä:**	184
Professuuri:	Ympäristönsuunnitelun tietotekniikka	**Koodi:**	Yhd-102
Valvoja:	Professori Ari Jolma, TKK		
Ohjaaja:	Johtava tutkija, PhD Outi Salminen, TKK		
Ohjaaja:	Suunnitteluinsinööri, DI Ulla-Maija Rimpiläinen, Vantaan kaupunki		

Tässä diplomityössä tarkastellaan maankäytön muutoksia kaupungistuvalla Kylmäojan valuma-alueella. Kylmäojan valuma-alueen koko on 20.84 km^2, josta noin 75% eli 15.72m^2 sijaitsee Vantaan kaupungin alueella ja noin 25% eli 5.12 km^2 Tuusulan kunnan alueella. Merkittävin tekijä alueen kehittämisessä on asuinalueiden rakentaminen yhdessä hajanaisten, pienten teollisuusalueitten kanssa. Lisäksi osa Helsinki-Vantaan lentokenttästä sijaitsee valuma-alueella.

Työssä tehtiin paikkatietoanalyysi, joka keskittyi vettä läpäisemättömien pintojen esiintymisen kehittymiseen valuma-alueella. Veden määrää ja laatua muuttavien läpäisemättömien pintojen tarkastelussa huomioitiin katot, tiet sekä piha-alueiden tila. Katot sisällytettiin suoraan tutkimusalueen pinta-alaan, kun taas teiden ja pihojen osalta analyysiin sisältyi sekä niiden pinta-ala että päällysteen materiaali. Valuma-alueen vettä läpäisemättömien pintojen kehittymistä tutkittiin yksittäisten vuosien osalta viiden vuosikymmenen aikana. Tutkimusvuodet valittiin joko saatavilla olevan tiedon tai merkittävien maankäytön muutosten perusteella. Analyysiin käytetyt vuodet olivat 1977, 1982, 1992, 2007 ja 2030, joista viimeisin on tämän hetkisen yhdyskuntasuunnittelun perusteella tehty ennuste. Jotta valuma-alueen vettä läpäisemattömän alueen pinta-ala vuonna 2030 voitiin arvioida mahdollisimman luotettavasti, työssä luotiin suhdeluvut kerrospinta-alan – joka määritellään nykyisen yhdyskuntasuunnittelun tonttisuhteessa – sekä valunnan kannalta merkittävien muuttujien eli katon ja pihojen pinta-alojen välille. Työssä luotiin täten paikkatietoanalyysin avulla uudet kertoimet kattojen pinta-alan ja kerrosalojen sekä pihojen pinta-alan ja kerrosalojen välille, ja näitä kertoimia käytettiin määrittelemään tutkimusalueen läpäisemättömyys vuonna 2030. Tutkimusta tehdessä huomattiin, että yhdessäkään Vantaan tai Tuusulan tietokannassa ei ole tietoa vettä läpäisemättömien pihojen pinta-alasta tai pihojen pintamateriaalista. Tämän vuoksi nämä ominaisuudet määriteltiin ilmakuvien avulla sekä paikan päällä. Tutkimuksessa siis luotiin kokonaan uusi tietokanta ja kertoimet tälle valunnan arvioinnissa tarvittavalle tärkeälle tiedolle, joka mahdollistaa maankäytön vaikutusten arvioinnin.

Maankäytön muutosten vaikutukset Kylmäojaan arvioitiin analysoimalla veden läpäisemättömyys koko Kylmäojan valuma-alueelle sekä 11 osavaluma-alueelle. Läpäisemättömyyden tasainen kasvu oli näkyvissä tutkimuksen aloitusvuodesta (1977) aina vuoteen 2030 saakka, jonka seurauksena Kylmäojan valuma-alueen lopullinen veden läpäisemättömyys vuonna 2030 arvioitiin olevan 26%. Läpäisemättömyyden kasvua arvioitiin yksityiskohtaisemmin kolmella osavaluma-alueella, jotka ulottuvat kaikki sekä Tuusulan että Vantaan alueelle. Tämä mahdollisti myös Vantaan kaupungin ja Tuusulan kunnan yhdyskuntasuunnittelun erojen välisen tarkastelun. Vuonna 2030, läntisen osavaluma-alueen läpäisemättömyys on suurempi Tuusulan (25%) kuin Vantaan (23%) puolella, vaikka siellä sijaitsee myös osia Helsinki-Vantaan lentokentästä ja sen kiitoradoista. Keskimmäisen osavaluma-alueen läpäisemättömyys Tuusulan alueella tulee olemaan vuonna 2030 arviolta 43%, kun taas alavirtaan Vantaan alueella läpäisemättömyys jää noin 22 prosenttiin. Työssä valuntakertoimien avulla laskettu valuntamäärien kehitys oli samansuuntaisia kuin Kylmäojan valuma-alueelle arvioitu läpäisemättömien alueiden osuuden muutos. Arvio osoittaa, että optimaalisen valunnan hallinnan sekä vesistön tilan kannalta yhdyskunta- ja kaupunkisuunnittelussa on tärkeä huomioida piha-alueiden suunnittelu, mitoitus ja pintamateriaalien valinta. Tulosten mukaan 34% Kylmäojan valuma-alueen valunnasta tulee vuonna 2030 vettä läpäisemättömiltä piha-alueilta; tämä osuus on suurempi kuin miltään muulta alueelta, mukaan lukien lentokentän kiitoradat joilta vuonna 2030 tulee arviolta 19% kaikesta valunnasta.

Avainsanat:	yhdyskuntasuunnittelu, maankäyttö, maankäytön suunnittelu, paikkatietoanalyysi, veden läpäisemättömyys, hulevesien valunta, GIS-ohjelmisto, lentokenttien valunta, suhdeluku
Kieli:	Englanti

TECHNISCHE UNIVERSITÄT HELSINKI
FAKULTÄT FÜR INGENIEURWESEN UND ARCHITEKTUR
FACHBEREICH FÜR BAUINGENIEURWESEN

KURZFASSUNG DER DIPLOMARBEIT

Verfasser:	Gerald Krebs		
Titel:	Entwicklung der Landnutzung im Einzugsgebiet des Stadtbaches Kylmäoja		
Datum:	24.8.2009	**Seiten:**	184
Lehrstuhl:	Umweltinformatik und angewandte Geoinformatik	**Kennzahl:**	Yhd-102
Begutachter:	Professor Ari Jolma, TKK		
Betreuer:	Outi Salminen, PhD, TKK		
Betreuer:	DI Ulla-Maija Rimpiläinen, Stadt Vantaa		

In dieser Diplomarbeit wurde die Entwicklung der Landnutzung im Einzugsgebiet des Stadtbaches Kylmäoja untersucht. Das Einzugsgebiet Kylmäoja hat eine Gesamtausdehnung von 20.84 km^2, wovon circa 75% oder 15.72 km^2 im Stadtgebiet von Vantaa und 25% oder 5.12 km^2 im Gemeindegebiet von Tuusula liegen. Die Landnutzung im Einzugsgebiet ist vorwiegend durch Wohngebiete, unterbrochen von kleinen Industriegebieten, gekennzeichnet.

Der Schwerpunkt der räumlichen Auswertung lag auf der Entwicklung versiegelter Oberflächen. Die Evaluierung undurchlässiger Oberflächen, die den Abfluss sowohl hinsichtlich Qualität als auch Quantität beeinflussen, beschäftigte sich mit Dachflächen, Straßenflächen und im speziellen mit dem Zustand der Grundstücksflächen und ihrer Versiegelung. Während bei Dächern nur das Ausmaß der Fläche ermittelt wurde, wurden bei Straßen- und Grundstücksflächen sowohl das Ausmaß als auch die Beschaffenheit der Fläche bewertet. Die Entwicklung der Impermeabilität im Einzugsgebiet wurde über einen Zeitraum von fünf Jahrzehnten untersucht, definiert durch einzelne Jahre, die entweder wegen der Verfügbarkeit von Daten oder wichtigen Entwicklungsschritten bedeutend sind – es sind dies die Jahre 1977, 1982, 1992, 2007 und 2030, letzteres als Vorhersage basierend auf gegenwärtiger Stadtplanung. Um eine realistische Vorhersage zum Ausmaß der Versiegelung im Jahr 2030 treffen zu können, mußte eine Beziehung zwischen der Grundfläche eines Gebäudes – in der Stadtplanung bestimmt durch die Bebauungsdichte – und den für den Abfluss relevanten Komponenten, der Dachfläche und der versiegelten Grundstücksfläche, hergestellt werden. Neue Koeffizienten, sowohl für die Beziehung zwischen Dach- und Grundfläche, als auch für die Beziehung zwischen versiegelter Grundstücksfläche und Grundfläche wurden im Zuge dieser Arbeit, basierend auf der gegenwärtigen Situation, entwickelt, und in der Vorhersage für 2030 implementiert. Da gegenwärtig weder die Datenbanken der Stadt Vantaa noch die der Gemeinde Tuusula Informationen zum Zustand versiegelter Flächen enthalten, wurden sowhohl Beschaffenheit als auch Ausmaß dieser, für die Abflußberechnung wichtigen Oberflächen durch Auswertung von Orthophotos und *in-situ* Besichtigungen evaluiert und deren Einfluß auf das Gewässer untersucht.

Die Auswirkungen der Raumnutzung und ihrer Veränderungen auf das Gewässer Kylmäoja wurden durch Bestimmung der Gesamtversiegelung für das Gesamteinzugsgebiet und elf Teileinzungsgebiete evaluiert. Die Untersuchung zeigte einen konstanten Anstieg der Versiegelung seit dem ersten Jahr der Untersuchung, 1977, und wird im Einzugsgebiet Kylmäoja im Jahr 2030 26% betragen. Um die Auswirkungen unterschiedlicher Planungsansätze und Ziele, die durch Einfluss verschiedener Planungsstellen bedingt werden, zu untersuchen, wurde die Versiegelung in den drei grenzüberschreitenden Teileinzugsgebieten, die sich sowohl auf Vantaa als auch auf Tuusula erstrecken, im Detail ermittelt. Im Jahr 2030 wird die Gesamtversiegelung im Einzugsgebiet des westlichen Bachlaufes in Tuusula (25%) einen höheren Wert erreicht haben als in Vantaa (23%), obwohl dieser Teil von den großen Asphaltflächen des Flughafens dominiert wird. Im mittleren Zulauf wird die Versiegelung in Tuusula 2030 einen Wert von 43% erreichen, während der Wert in Vantaa (22%) unter dem, für den Flußlauf kritischen Wert von 25% bleibt. Die Abschätzung des Oberflächenabflusses, die auf Basis von Abflussbeiwerten durchgeführt wurde, folgt in der Logik der Versiegelungsentwicklung im Einzugsgebiet. Die Ergebnisse der Abschätzung unterstreichen die Bedeuteung von Planung und Bemessung von Einfahrten und Parkplätzen, im Besonderen in Bezug auf die Wahl des Deckmaterials, für Abflußmanagement und Qualität der städtischen Gewässer. Im Jahr 2030 werden 34% des Oberflächenabflusses im Einzugsgebiet wird von versiegelten Grundstücksflächen generiert, mehr als von jeder anderen Oberfläche, auch der Start- und Landbahnen des Flughafens, die einen Anteil von 19% am Oberflächenabfluß in Kylmäoja haben werden.

Stichwörter:	Stadtplanung, Landnutzung, Raumplanung, Raumanalyse, Versiegelung, Oberflächenabfluss, GIS-software, Flughafenabfluss, Beiwerte
Sprache:	Englisch

FOREWORD

This Master's thesis research was carried out at the City of Vantaa and the Helsinki University of Technology Lahti Center. Compliments to the City of Vantaa for providing the opportunity and major funding for this research. The conducted research is part of and partially supported through two TKK Lahti Center EU projects: the STORMWATER project (grant A30116) and the HYDROSYS project (grant 224416, DG INFSO). Furthermore, Maa- ja Vesitekniikan Tuki ry has provided support to this project through participation in the STORMWATER project. I would like to thank all the parties participating in funding this research.

The supervisor of this study was Professor Ari Jolma and the instructors were Outi Salminen, PhD (TKK) and M.Sc. (Tech.) Ulla-Maija Rimpiläinen (City of Vantaa). I wish to thank them for advice and support during this work. I would also like to thank Professor Pertti Vakkilainen for initial inspiring conversations leading to this conducted research.

Furthermore I would like to thank the whole personal of the Vantaa public works department (Vantaan kaupunki rakennusvirasto). Special compliments to Anne Mäkynen, Tomi Henriksson and Anna-Karin Kyrönviita for providing mapdata and an introduction to urban planning. Special thanks also to Keijo Ikonen and Reeta Paukku, who provided data on the stormwater sewer network within the catchment. Compliments to the municipality of Tuusula for mapdata and support. Thanks also to Teemu Kokkonen from the Helsinki University of Technology, for software introduction and valuable advice.

Map material is published with the permission of the City of Vantaa and the municipality of Tuusula.

Special thanks and hugs to my lovely family, Tuuli, Moona, and Annika, who have supported with their love and believed in me during this work. Thanks also to my great friends, especially to Anna Heusgen, Yves Sara, and Ville Heinonen, for their support and encouragement. Very special thanks to Marko Keskinen for his support and the translation of the abstract into Finnish.

"Live as if you were to die tomorrow. Learn as if you were to live forever."
- Mohandas Gandhi (1869 – 1948)

Espoo, 24 August 2009

Gerald Krebs

TABLE OF CONTENTS

REFERENCES

APPENDICES

FIGURES

TABLES

1 Introduction

The level of urbanization in developed countries is still rising and is expected to reach 80.6% in 2030 (United Nations 2007). In Finland the percentage of population living in urban conditions was 62.4% in 2005 and is expected to reach 71.8% in 2030 (United Nations 2007).

The city of Vantaa is at the moment (2009) one of the fastest growing municipalities in Finland, with a present growth rate of 1% per year (Vantaan kaupunki – Ref. 1). This growth, involving both residential and commercial development and the associated land-use change, causes interferences with the city's urban streams and wetlands. Higher levels of impervious surfaces result in higher volume of run-off with higher peak discharge, associated with shorter travel time and more severe pollutant loads (Lee 2003). The determination of imperviousness in urban watersheds is therefore an important indicator to manage urban watersheds and the related water environment. A study conducted in the city of Helsinki in 2003 focused on the effects of de-icing in urban streams and concluded, that 35 – 50% of the salt used on roads in Helsinki passes into natural streams (Ruth 2003).

The aim of this thesis was to investigate the development of land-use in the Kylmäoja watershed and associated effects of land-use changes on the Kylmäoja urban stream, located in the eastern part of the city's area with its headwaters within the borders of the northern neighbouring municipality of Tuusula. The focus was to investigate and quantify the development of land-use and associated imperviousness. The timeline covered in this study was the time until the present day as well as an estimation of the land-use for a possible situation in the future. The specific investigated years 1977/1975, 1982, 1992/1993, 2007 and 2030 were chosen based on rationale explained later.

Land-area needed for retention of stormwater, like forests, marshlands and grasslands, are more and more displaced by the impervious surfaces of streets, driveways and roofs, intensifying the surface run-off and reducing groundwater recharge. Determining the extent of this imperviousness and the effects on the stream are key objectives of this work. Common methods of land-use analysis associate a percentage of imperviousness with each represented land-use type. However, there are no standardized methods for deriving these estimates and there may be a high variation in the amount of imperviousness within the same land-use class (Canters 2006). During the spatial analysis conducted during this work, three types of imperviousness were chosen for investigation and quantified based on available and created data. Whereas the impervious area consisting of rooftops and roads are the base of any run-off estimation, in this case also a third component, which proved during this work of major importance, was investigated: the yard areas. Driveways and parking lots are, along with the road network, the major parts of the traffic component of land-use. However, unlike streets and roads, these parts are mainly reserved for individual transportation. According to Freund (1993) in the last century the automobile has become the dominant means of transport for people in mature industrialized countries. The development of automobile domination in transportation, and its impact on society, economy and ecology, also in terms of land-use, has been the focus also in many other publications (Holtz 1998 or Nye 1999).

It was found that no existing database neither in the city of Vantaa nor in the municipality of Tuusula contains any information about the impervious yard area size, or quality of the yard surface materials. Both criteria were therefore investigated from orthophotos and *in-situ* and a new dataset including this very important information for run-off estimation and hence, the influence of the land-use on the stream was created as a part of this research.

During this work the catchment of the Kylmäoja stream was divided into eleven subcatchments. Five subcatchments covered the drainage areas of the six branches joining the main stream during its course and five subcatchments covered the drainage area of the main stream sections between the junctions. The subcatchments of the three headwaters of the stream are transboundary, as their northern areas are located in the municipality of Tuusula and the southern areas are located in the city of Vantaa. Specialities of transboundary catchments, such as the availability of material and data or varying focus in urban planning within the involved authorities and thus strongly varying development in different areas, were dealt with during this work.

In the hydrological interpretation the development of imperviousness in the Kylmäoja catchment and the eleven subcatchments is presented, used as an indicator for the effects of land-use on a stream (Schueler 1994). Furthermore also run-off estimates were calculated for the years in observation. Finally, approaches are presented to mitigate the impact of urban development in the Kylmäoja catchment.

This work consists of six chapters, starting with an introduction to the catchment area and the Kylmäoja stream. Chapter 2 deals with the investigation of available and suitable data for the analysis, in chapter 3 the delineation of the catchment and the stream is carried out, and chapter 4 concentrates on the spatial analysis carried out. The effects of the land-use on the Kylmäoja stream are concluded in chapter 5, the hydrological interpretation of the spatial analysis carried out. Results are presented in the chapters 3, 4 and 5. Chapter 6 contains the discussion, including approaches for improvement and mitigation of the expected development and concluding remarks.

1.1 *The city of Vantaa*

Figure 1.1 The coat of arms shows the salmon inhabiting Vantaanjoki (Vantaan kaupunki).

1.1.1 Some figures about Vantaa

The city of Vantaa is situated in the southern Finnish county Uusimaa, not far from the coast of the Gulf of Finland (figure 1.2). The neighbouring cities and municipalities are Kerava and Tuusula in the north, Sipoo in the east, Helsinki in the south, Espoo in the west and Nurmijärvi in the northwest. The agglomeration of the cities of Vantaa, Espoo, Kauniainen and Helsinki is commonly referred to as the "capital region" of Finland.

192567 inhabitants in 2007 make Vantaa the fourth biggest city by population in Finland after Helsinki, Espoo and Tampere (Väestörekisterikekus 2007). The upward trend of the population development in Vantaa is strong. Whereas the country community Helsinki (see History) counted a population of 6253 in 1870, the population doubled to the threshold of the twentieth century and reached 30000 in 1940. After structural changes and the union of large areas with the city of Helsinki, the number of inhabitants was reduced just to a half in 1950. Nevertheless the city experienced its most rapid population growth between the 50's and the 80's of the twentieth century reaching 130000 in 1980. After this period the growth rate flattened a little, but the population still grows with an average 1% per year (Vantaan kaupunki – Ref. 1). According to current forecasts the population will reach 200000 inhabitants in 2012 and reach 234000 in the year 2030, which is also the target year of the Master Plan introduced by the city in 2007 (Vantaan kaupunki – Ref. 2).

The city of Vantaa covers a surface area of 242.62 km². The total surface of 1.99km² of inland waters is relatively poor for Finnish conditions (Maanmittauslaitos – National Land Survey of Finland 2008). Nevertheless the city is pervaded by a number of rivers and streams. The river Vantaanjoki, from which the city has derived its name, is located in the western part of the city and the river Keravanjoki crosses the eastern part including the administrative centre of Vantaa, Tikkurila.

The city is currently divided into seven urban districts (Myyrmäki, Kivistö, Aviapolis, Tikkurila, Koivukylä, Korso and Hakunila) and further subdivided into a total of 61 subdistricts.

The high-density areas of the city are mainly restricted to the southwest and the east of the municipality, including Myyrmäki and Tikkurila. Even though Vantaa has developed to a major city in Finland over the last decades, large areas are still characterised as rural. Approximately 10000 hectares of the city's area is covered with forest, almost 40% of the city's total territory (Vantaan kaupunki – Ref. 3). Furthermore 4000 hectares or around 16% of the total area are in agricultural use (Vantaan kaupunki – Ref. 4).

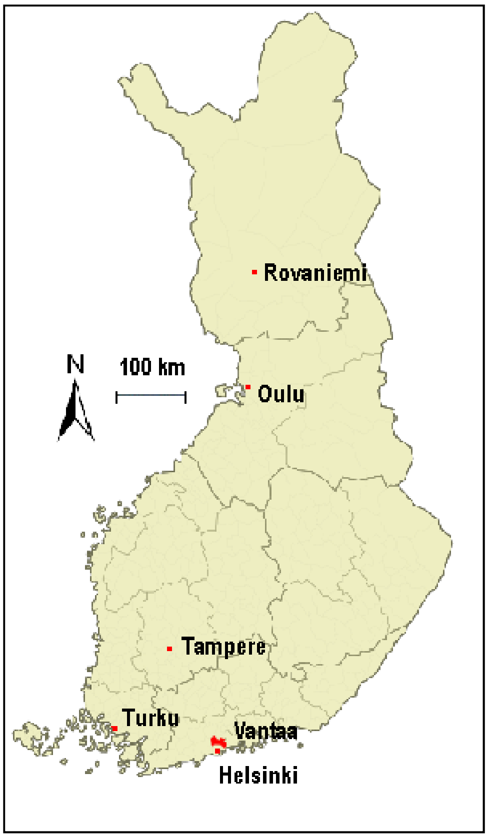


Figure 1.2 The municipal area of the city of Vantaa is located in southern Finland.

Without doubt the city of Vantaa has a good infrastructure. Due to its location north of the city of Helsinki, six of the eight main arterial roads leading north from the capital cross the city's area, namely the road to Vihti (Vihdintie), the highways to Hämeenlinna (Hämeenlinnanväylä), Tuusula (Tuusulanväylä), Lahti (Lahdenväylä) and Porvoo (Porvoonväylä) and the eastern arterial highway (Itäväylä). These traffic ways are connected by the Ring Road III (Kehä III), which describes a semi-circle around the city of Helsinki.

The international airport Helsinki-Vantaa is situated in Vantaa. The airport was opened in 1952 for the Olympic Summer Games taking place in Helsinki. 13.1 million Passengers and 180.000 take-offs and landings in 2007 (Helsinki-Vantaa Airport – Ref. 1) make it the biggest airport in Finland (Finavia). Currently the airport operates with three runways and two terminals (Helsinki-Vantaa Airport – Ref. 2). The Helsinki-Vantaa airport is located in the centre of the city's area, north of the Ring Road III (Kehä III), reaching to the borders of Tuusula in the north. The airport is of special interest in this research, since fractions of the operational runways and other infrastructure are situated within the borders of the Kylmäoja catchment.

Two rail tracks leading north from Helsinki cross Vantaa. The main line (Päärata) through Tikkurila in the eastern part of the city carrying long-distance trains and commuter traffic has been opened as early as 1862 (Vantaan kaupunki – Ref. 5). In the western part of the city, the rail line to Vantaankoski is used for commuter traffic between Helsinki and Vantaa.

In the year 2009 construction will start for the new ring rail line (figure 1.3), connecting the Vantaankoski line with the main line via the airport. The design involves an 18 km long new track, of which 7 km will be underground in two separate tunnels below the Aviapolis and the airport area. The new line will have a total of five stations (three of them at ground level and two underground) and an additional option for five more stations (four on ground level and one underground). Traffic on the line is scheduled for 2014 at the latest (Kehärata).

Figure 1.3 The ring rail line will be open for traffic in the year 2014 and connect the eastern and western centres of the city, Tikkurila and Myyrmäki, via the Helsinki-Vantaa airport. The border of the Kylmäoja catchment is also shown (modified map, original Kehärata).

1.1.2 History

This chapter is based on information published on the homepage of the city of Vantaa which is available online (Vantaan kaupunki – Ref. 5) and shall give a short overview of the development of the city of Vantaa and shall help the reader to see the background of variation in land-use within the city's border as well as within the Kylmäoja watershed – from urban and suburban to typically rural. The history of the city of Vantaa reaches back to medieval times, even though the city's name Vantaa was not introduced until 1972. The river Vantaanjoki was first mentioned under the name Helsingaa in 1351, when the Swedish king Magnus II entitled the manhood of the Estonian convent Padise to fish for salmon in the river (the salmon inhabiting Vantaanjoki is shown in the coat of arms of the city of Vantaa, see figure 1.1). The parish Helsinki (Helsingin pitäjänkirkko), founded at the end of the 14th century and deriving its name from the river, was first mentioned in records in 1428. Construction of the stone built Saint Laurentius church was finalised in 1460.

In the year 1550 King Gustav I Wasa founded the city of Helsinki (Swedish Helsingfors) at the mouth of the river Vantaanjoki to compete with the harbour of Tallinn (back then named Reval), located on the Estonian shore of the Gulf of Finland. Later the city was relocated to the peninsula of Vironniemi, also the present city centre location, and even though Helsinki did not gain significant importance during the first centuries of its existence, it outshined the parish Helsinki leading to affiliation of the parish to the church of Helsinki in 1652.

During the 30's of the 18th century water powered saw mills were established along the rivers Vantaanjoki and Keravanjoki, making the parish Helsinki one of the most important centres of early industrialisation in Finland. The foundation of the iron work Wanda Bruk, construction of a paint manufactory at the riffle Tikurilankoski, and further ironwork at the riffle Vantaankoski are examples of the industrial development of the time.

After defeat in the Swedish-Russian war Sweden had to assign the land of present Finland to Russia in 1809. Three years later Tsar Alexander I decided to move the capital of the newly formed princedom Finland from Turku to Helsinki. This transfer caused a rapid growth in the city of Helsinki and dwarfed the parish. Whereas in 1805 the parish with its 4840 inhabitants still outsized the city of Helsinki with 4337 inhabitants, in the year 1865 the city of Helsinki counted 23.000 inhabitants compared to 7.000 in the parish Helsinki. The same year, 1865, the municipal administration of Finland was reorganized and political municipalities replaced the former parishes. The parish Helsinki changed to the country community Helsinki with its administrative centre located in Malmi.

In 1862 the first rail line in Finland connecting Helsinki with Hämeenlinna was taken into use causing a growth spurt for the settlements along the new line, included was Tikkurila. The old station building in Tikkurila is shown in figure 1.4.

Figure 1.4 The old station building from 1862, today home to the city museum, stands for early development in the city (Vantaan kaupunki).

In the course of the 20th century areas of the country community Helsinki were consistently integrated into the city of Helsinki. As examples may be mentioned Meilahti, Käpylä and Kumpula in 1906, Pasila in 1912, and Ruskeasuo in 1926. A large annexation took place in 1946, also causing structural changes in the country community. The city of Helsinki incorporated one third of the area of the country community, including its administrative centre Malmi and two third of the community's inhabitants. After these changes Tikkurila was established as the administrative centre of the community.

In the years 1954 and 1959 the area of the community grew again by incorporation of Rekola, Korso and Koivulylä from the neighbouring communities Tuusula and Kerava. The latest change has been the annexation of Vuosaari to Helsinki in 1966. With the recently discussed incorporation of areas of Sipoo to Helsinki, the city of Vantaa would also assign its south-eastern area and the small access to the sea (Helsingin sanomat – Ref. 1).

In 1972 the status of the country community Helsinki was changed to a market town and was, in 1974, given the status of a city with the name Vantaa. (Vantaan kaupunki – Ref. 5)

1.1.3 Future and the Master Plan 2007

In the year 2001 a decision was made to revise the Master Plan of Vantaa. Previous Master Plans existed from the years 1968, 1983 and 1992. Each of them symbolised a different period for the city of Vantaa as well as for planning principles.

The Master Plan in 1968, designed during the most rapid population growth of the city (then still country community Helsinki), intended to create the key characteristics of the urban structure. The year of 1983 and the according Master Plan favoured low-rise housing.

The Master Plan of 1992 divided the city into two main areas of growth: Marja-Vantaa west of the airport and Tammisto-Pakkala in south of it. The decision to revise this Master Plan made in 2001 had different reasons. The metropolitan area was growing faster than predicted, the entire region was developing in new directions and Vantaa itself was changing from a suburban town to a city with its central characteristics and an international business city at the same time.

Main principal of the plan 2007 was to achieve spatial cohesion by steering growth to infill and renewal of existing areas. The Master Plan is designed until 2030 and dimensioned for a population of 240.000 inhabitants by then. Since the city of Vantaa has developed, unlike the usual pattern would be from one centre, from multiple centres at the same time, increased spatial cohesion of the urban structure was attempted in the new Master Plan. The new Aviapolis area, emerging around the airport, will be connected with Tikkurila, the administrative downtown of Vantaa, by a boulevard, to provide not only a traffic way, but a feel of urban ambience. Also the improvement of public transportation connections as well as pedestrian and bicycle traffic utilities, both being classical features of a well developed urban environment, are key factors in this current Master Plan. As a counterpart to the urban structure, great emphasis is put on the protection of nature and natural resources, and recreational areas (Vantaan kaupunki – Master Plan).

The land-use map of the city of Vantaa’s 2007 Master Plan is shown in figure 1.5 and the corresponding legend is shown in figure 1.6.

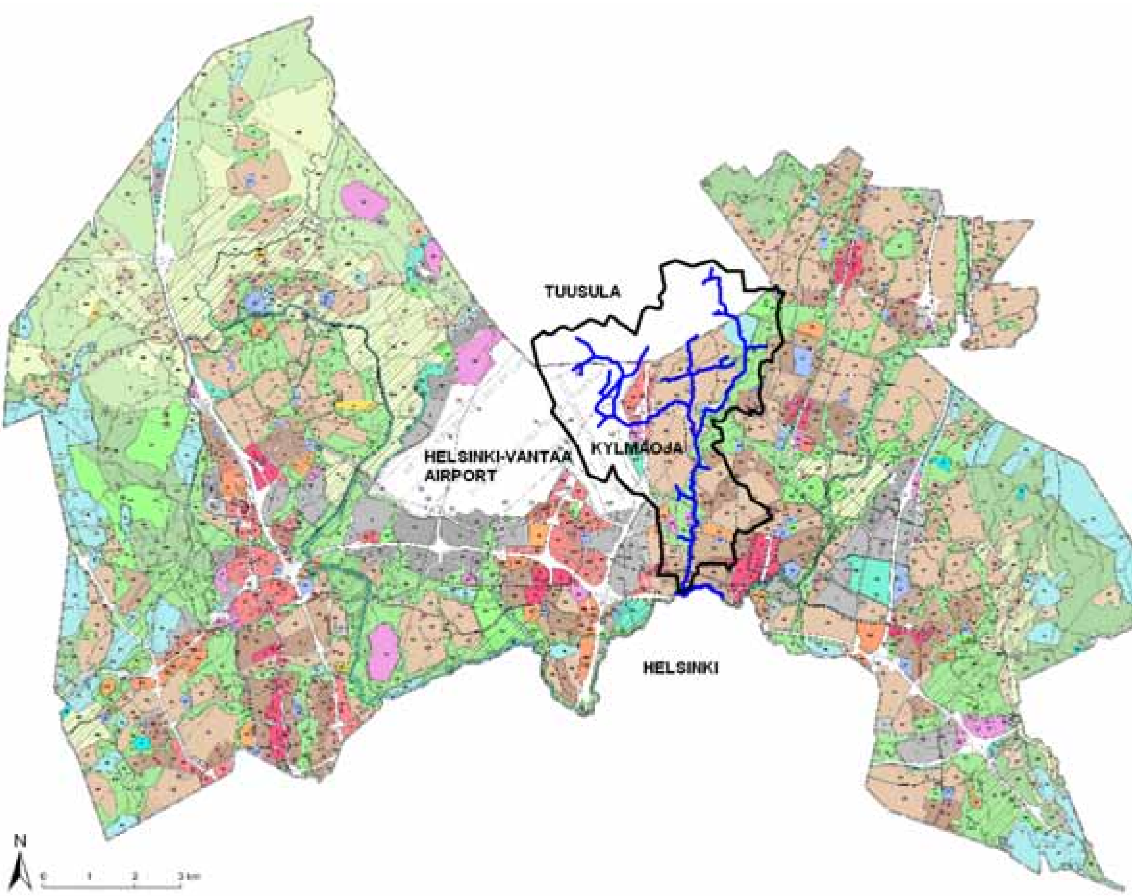


Figure 1.5 Land-use map of the Master Plan 2007. The borders of the Kylmäoja catchment are also shown (modified land-use map, original Vantaan kaupunki).

LEGEND OF THE MASTER PLAN MAP

AK	Housing area dominated by apartment buildings
AP	Housing area dominated by small houses
AP-1	Housing area dominated by small houses
AT	Village area
C	Area for central functions
P	Area for services and administration
PY	Area for public services and administration
PK	Employment area dominated by offices
PE	Area for special commercial services
TY	Employment area for functions without adverse environmental impact
T	Employment area
TE	Employment area for special functions
ET	Area for public utilities
et	Area for public utilities for a fixed duration
ET	Public utility plant
V	Water supply tunnel
J	Waste water tunnel
K	Natural gas main
Z	Power line
EK	Waste disposal site
ek	Protection area for waste disposal site
EM	Area for motor-race track
EV	Protection green area
EP	Garden and research area
RA	Area for holiday houses
VU	Area for sports and recreation facilities
VL	Area for local outdoor recreation
VR	Area for outdoor recreation and leisure
M	Area for agriculture and forestry
MV	Area for agriculture
SL1	Nature reserve
SL2	Nature reserve
sl	Valuable natural environment
//////	Valuable area with regard to culture and history
W	Water area
pv	Important ground-water basin
LM	Road traffic area
LR	Rail traffic area
tu	Road traffic tunnel
LJ	Public transport terminal
LL	Air traffic area
ev	Protection green area for airport
kt	Runway
m1	Air traffic noise exposure area 1
m2	Air traffic noise exposure area 2
m3	Air traffic noise exposure area 3
— · —	City boundary
··· —	Boundary of the Master Plan area
——	Area boundary
– – –	Advisory area boundary
— · —	Boundary between sub-areas subject to different Master Plan regulations
– – –	Advisory boundary between sub-areas subject to different Master Plan regulations
	Boundary of the Master Plan area ratified by the Ministry of Environment, on January 26, 1995

Translation: Jukka Kullberg / Olga Wiljakkala / Aila Hanley

Additional information:

The City of Vantaa, Master Planning Department
Kielotie 28, 01300 Vantaa, tel 358 9 839 2712

The Master Plan map and report are on sale in the customer service
Kielotie 28, 01300 Vantaa, tel 358 9 839 2242

G:\YLEISK\TIEDOTE\KANSENG.PM4
18.11.1996

Figure 1.6 Legend of the 2007 Master Plan map (Vantaan kaupunki).

1.2 The stream and its catchment

The target site of this study was the Kylmäoja urban stream and its catchment located in the eastern part of the city of Vantaa. The catchment reaches from areas residing in the neighbouring municipality of Tuusula in the north to the border between the cities of Vantaa and Helsinki in the south. There the stream discharges into Keravanjoki, leading further to the sea. The total size of the Kylmäoja catchment is 20.84 km², of which 15.72 km² or approximately 75% are located in the territory of the city of Vantaa and 5.12 km² or 25% are located in the municipality of Tuusula (see figure 1.8).

The stream can be subsided into three main branches, the eastern, the central and the western branch, uniting to the main stream south of Ilola, approximately in the centre of the catchment area. For the analysis of the land-use, the total catchment of the stream was divided into eleven subcatchments. The following short description deals with the catchments of the three main branches and the catchment of the main stream

The northern area of the total catchment, draining into all three main branches of the Kylmäoja stream, is addressed separately due to the following reasons: First this area of the catchment belongs to the neighbouring municipality of Tuusula, facing the analysis with distinct kind of material available, and second, the development over the last decade, as well as the land-use of the area are unique in respect to the rest.

Generally may be said, that the land-cover in the Kylmäoja catchment area offers a great variety of different land-uses (figure 1.7).

Figure 1.7 The land-use in the northern part of the Kylmäoja catchment shows great differences (picture taken June 2008).

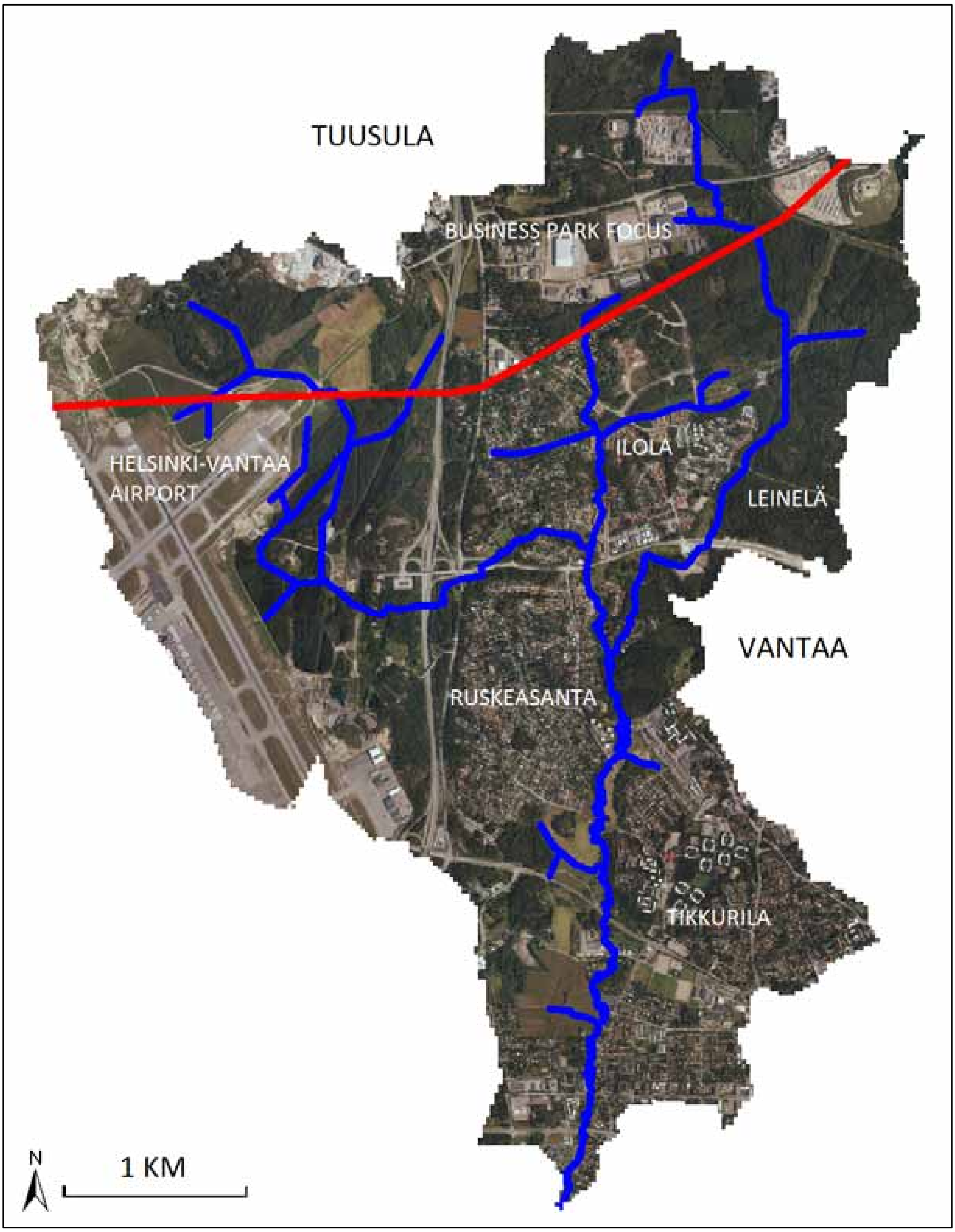


Figure 1.8 An orthophoto of the catchment to show the distribution of land-use within the Kylmäoja catchment. In the northwest the airport, the protected green area in the northeast and the urban areas in the centre and the south of the catchment (Ilola, Ruskeasanta and Tikkurila). The residential development Leinelä and the business development FOCUS are also marked (modified Orthophoto, original Vantaan kaupunki 2007).

1.2.1 The northern areas – forest versus industry in Tuusula

The northern part of the catchment area is located in Tuusula, the northern neighbouring municipality to the city of Vantaa. This area discharges into the three main branches and is therefore not handled as a subcatchment on its own, but shared among the subcatchments of the main branches of Kylmäoja. The land-cover remains still mainly undisturbed but is undergoing a rapid change, partly originating from the relocation of the container terminal of the city of Helsinki from its current location in Ruoholahti – south-western Helsinki – to Vuosaari in the East. Simultaneously a new train connection is planned from Vuosaari northwards connecting to the main train track in Korso, northeast of the Kylmäoja catchment area (Vuosaari harbour 2009). Due to this relocation the southern areas of Tuusula with their good traffic connections offer a favourable location for logistical centres especially, and industry in general. The land-use in this Tuusula area is undergoing changes accordingly with the expected increase in stormwater run-off discharges and higher stormwater peaks affecting the Kylmäoja stream.

Figure 1.9 Logistical centres in Tuusula are surrounded by forest (picture taken June 2008).

1.2.2 The western branch – the influence of the airport

The western section of the catchment is dominated by the Helsinki-Vantaa Airport and discharges into the western branch of the stream. Whereas this subcatchment is otherwise rather thin populated, most of the surface areas of the 2nd runway and smaller areas of the 1st runway are part of the Kylmäoja catchment and run-off drains into the Kylmäoja stream. The effects on the stream are significant, as well in terms of quality but also in terms of discharge (see figure 1.8).

Figure 1.10 Southern part of the Helsinki-Vantaa airport, part of which discharges into the Kylmäoja stream (picture taken September 2008).

1.2.3 The central branch – suburban residential housing

The areas of Ilola (see figure 1.8) and Kylmäoja are dominated by row- and detached houses. The 2007 Master Plan defines most of the area to be zoning type A2 – A4, which is between dense low-rise housing areas and low-rise housing areas (Vantaa Master Plan 2007). An interesting aspect of this area is the development of the plot-ratio. Due to the significantly rising apartment and estate prices in the capital area (Helsingin sanomat – Ref. 2), the goal of estate owners is naturally to reach the allowed plot-ratio with construction, in order not to waste valuable living area or to optimize profit. This development is common in the whole capital area, but of crucial importance in areas, which are dominated by one family houses. Dividing estates with earlier one building into two plots, or erecting detached houses is a common practice and naturally influences the discharges of stormwater due to the increased share of impermeable land-cover.

Figure 1.11 The central branch of Kylmäoja northeast of Ilola (picture taken June 2008).

Figure 1.12 The central branch of Kylmäoja south of Ilola (picture taken September 2008).

1.2.4 The eastern branch – industry and nature

The subcatchment of the eastern branch of Kylmäoja houses the probably widest variation of land-use within the entire catchment. Whereas the 2007 Master Plan of the city of Vantaa declares the area within Vantaa to be partly sustained in its natural condition just south of the border to Tuusula, used for recreation of inhabitants as well as for retention of stormwater, the south eastern part of the subcatchment in Vantaa is the location of the residential development Leinelä (see figure 1.8).

The subcatchment area within the borders of the municipality of Tuusula is the destination of industrial development, mainly influenced by a business park named FOCUS (see figure 1.8), planned to be erected until 2030. The area of Kulomäki is dominated by logistical centres already today and will stay a major focus of industrial development for the municipality of Tuusula also in the future. Even though agreements between the municipalities are on the table, the different intentions on the development of the land-use are obvious.

1.2.5 The main stream – the highest urbanization within the catchment

The land-use in the catchment of the main stream reaches from dense-low rise housing areas in Ruskeasanta, mainly detached houses and row houses, to dense housing, industrial and workplace areas in Tikkurila, the eastern centre of the city. The above-described change of the plot-ratio is also valid for the area of Ruskeasanta, showing a quite similar land-use as Ilola or Kylmäoja.

Figure 1.13 Kylmäoja at the junction of the eastern branch and the main stream (picture taken September 2008).

Figure 1.14 Kylmäoja stream short before the outlet of the basin to Keravanjoki (picture taken September 2008).

2 Methodology

2.1 Availability of information

After getting familiar with the catchment of the stream in detail, an important step was, to check and sort the available material. This action had to be taken, as well for the material on the stream itself, meaning taken flow measurements or construction concerning the stream, like regulations or bridges, as well as for the map material the city of Vantaa has produced on the catchment over the time.

During survey of the map data of the city, it turned out fast, that the availability of map material will not be a limiting factor. The city was able to provide a wide range of datasets, allowing focus on preferences concerning the choice of data.

Regarding the data of the stream the situation proved to be different though. For later validation of a hydrological model, flow measurements are of major importance, carried out in the years of land-use analysis. Due to the limited existence – discharge measurements in the Kylmäoja stream were carried out in 1977 and 1982 – these years mark important time steps for the spatial analysis.

2.2 What to use?

Maps had to be identified, to show the development of construction in the catchment, useful for the past as well as for future scenarios. Analysis was conducted for 1977 and 1982 and further for the years 1992 and 2007, which mark crucial time steps for the development of the city, since in each year, a new Master Plan was implemented overruling previous plans. The investigated years and the reason behind the selection are shown in table 2.1.

Table 2.1 The years in focus during this investigation and the rationale why these years were chosen.

Years in focus	Reason
1977	In 1977 the discharge in the Kylmäoja stream was measured
1982	In 1982 the discharge in the Kylmäoja stream was measured
1992	Introduction of a new Master Plan in the city of Vantaa
2007	Introduction of a new Master Plan in the city of Vantaa
2030	Target year of the City of Vantaa Master Plan 2007

2.2.1 Vantaa

Base for the analysis of these past years was a building data set, kept up to date by the city of Vantaa, containing information, among others, about the date of construction, the gross and net area of the building and the building type, and was available as vector data. The information of the building type was relevant to determine the additional impervious area on the plot, like driveways and parking lots, which correspond with the size of the building as well as with its the type. The share of parking area for an apartment block is naturally higher than for detached houses, but also two family houses require more parking lots, than a detached one family house of similar size.

Furthermore a digital database about the road networks was investigated. The data set contained information about the exact dimension of impervious area for each section of road within the catchment. The availability of the date of construction was incomplete, and required estimation for certain areas.

For the prediction of the future scenario in 2030, the land-use map implemented with the Master Plan 2007 was the base of analysis. The data existed in vector format, containing information such as the land-use category, the corresponding maximum plot-ratio and the dimensions of the relevant areas. Furthermore a dataset was analysed, which contained a comparison between the maximum plot-ratio allowed for an estate and the already used area. This dataset was created for housing and work place areas by the city of Vantaa and used as an estimation of the impervious area for 2030.

The map data and databases used during different process steps of the spatial analysis conducted are presented in table 2.2 (for Vantaa) and table 2.3 (for Tuusula).

Table 2.2 The map data and databases used for the analysis within the city of Vantaa's part of Kylmäoja catchment.

ANALYSIS	MAP / DATABASE	PROCESSING
DELINEATION OF THE WATERSHED	Digital elevation model (DEM)	Delineation of the Kylmäoja watershed
	Stormwater sewage system map	Manipulation of the catchment and subcatchment boundaries
	Orthophotos 2007 (city of Vantaa)	Identification of the exact location of Kylmäoja stream
ROOFAGE	Building database (Rakennukset and Rakennukset alueina)	Analysis of rooftops
ROADS	Road network database (digikadut)	Analysis of road network
	General map (opaskartta)	Analysis of construction years for road sections
YARD AREAS	Orthophotos 2007 (city of Vantaa)	Determination of the dimension and the surface type of yard areas
FORECAST 2030	City of Vantaa Master Plan 2007 land-use map	Land-use analysis for 2030
	Database of building potential for residential and workplace areas	Land-use analysis for 2030

2.2.2 Tuusula

The situation for the areas in Tuusula differed from Vantaa in two ways: Tuusula has, with 36000 inhabitants (Väestörekisterikekus 2007) and 225.49 km² (Maanmittauslaitos – National Land Survey of Finland 2008) a population density of 160 inhabitants/km², which is only 20% of the figure in Vantaa (793 inhabitants/km²). Documentation of the municipality's land-use and future development was therefore not as widely available in a digital format. The status of the areas of the catchment in Tuusula was furthermore in different scales at the time of investigation, which caused variation in the base for the forecast.

The data for 1975, 1993 and 2007 was created based on orthophotos and historical city maps, indicating already developed areas in these years. The dataset for the road network was created in an equal way. Since the data was based on orthophotos from 2007, the output was an estimation of the situation in earlier years and undocumented changes could not be considered.

The analysed data for the forecast – the target year is 2030 – consisted of various maps of city planning in different scales, reaching from detailed plots with related plot-ratios to general plans, with a land-use related efficiency.

Table 2.3 The map data and databases used for the analysis within the municipality of Tuusula's part of Kylmäoja catchment.

ANALYSIS	MAP / DATABASE	PROCESSING
DELINEATION OF THE WATERSHED	Digital elevation model (DEM)	Delineation of the Kylmäoja watershed
	Orthophotos 2007 (city of Vantaa)	Identification of the exact location of Kylmäoja stream
ROOFAGE	Orthophotos 2007 (city of Vantaa)	Analysis of rooftops
ROADS	Orthophotos 2007 (city of Vantaa)	Analysis of road network
	General map (opaskartta)	Analysis of construction years for road sections
YARD AREAS	Orthophotos 2007 (city of Vantaa)	Determination of the dimension and the surface type of yard areas
FORECAST 2030	Urban planning maps in different scales	Land-use analysis for 2030

2.3 The approach – development of new coefficients

The spatial analysis was conducted to investigate the distribution of impervious surfaces within the catchment in detail. This chosen approach exceeds the common way of considering land-use types, efficiencies and plot-ratios for run-off estimation, used in urban planning today.

Besides imperviousness created by rooftops and road surfaces, also the yard areas (driveways, parking lots, and so on) have to be taken into account to allow for realistic run-off estimation even though the importance of the latter is still widely neglected. Nearly all zoning codes in urban planning set a maximum density of an area, based either on dwelling units or roofage. The commonly used plot-ratio (table 2.4), sets the maximum floor area allowed to be constructed on a plot, without any correspondence to the roof area created (the possible limitation of storeys to be constructed sets some limit on the roof area) and totally neglecting the increase of imperviousness of the yard area associated with the constructed building.

Hence in this work it became obvious that, besides the existing plot-ratios, other relevant relationships based on the analysis carried out on impervious areas had to be created and implemented in the forecast of development in the year 2030.

The ratios developed during this work are the

- relationship between floor area and roof area (Vantaa)

$$\frac{ROOF\ AREA}{FLOOR\ AREA} = ROOFAGE\ COEFFICIENT\ (VANTAA)$$

- relationship between floor area and impervious yard area (Vantaa)

$$\frac{YARD\ AREA}{FLOOR\ AREA} = YARD\ COEFFICIENT\ (VANTAA)$$

- relationship between roof area and impervious yard area (Tuusula)

$$\frac{YARD\ AREA}{ROOF\ AREA} = YARD\ COEFFICIENT\ (TUUSULA)$$

and are based on the spatial analysis carried out for the time line before 2007.

Due to the fact, that the available data provided by the municipality of Tuusula contained no information of the floor area of buildings, and therefore the roof area was derived directly from orthophotos as a part of this project, the base for the coefficient in Tuusula is the roof area unlike in Vantaa, where the floor area was used.

Table 2.4 The important ratios in urban planning and run-off estimation are shown in the table. The terms of efficiency and plot-ratio are widely used in urban planning and zoning, but not directly relevant for run-off estimation. The coefficients for the relation between the floor area (hence the plot-ratio) and roof and yard area and the relation between roof area and yard area developed during this work, have better relevance for run-off estimation.

Efficiency	Used	This term efficiency estimates the constructed area for a zoning type, including minor roads. In Vantaa the value varies from 0.15 – 0.5 for residential land-use, from 0.6 – 0.8 for workplace areas and is 0.4 concerning industrial areas.
Plot-ratio	Used	This value defines the relation between floor area and gross area on a defined plot and depends on the land-use type.
Roofage coefficient (Vantaa)	Developed	This value defines the relation between floor area, hence the plot-ratio on a plot and the roof area, which is relevant for run-off estimation.
Yard coefficient (Vantaa)	Developed	This value defines the relation between floor area, hence the plot-ratio on a plot and the yard area, which is relevant for run-off estimation.
Yard coefficient (Tuusula)	Developed	This value defines the relation between roof area on a plot and the yard area, which is relevant for run-off estimation.

The determination of impervious surfaces follows the rationale explained below (table 2.5). For the timeline before 2007, the extension and quality of surfaces were determined using databases and orthophotos.

Since a forecast of imperviousness in 2030 was only feasible based on plot-ratios and efficiencies given for potential areas, the increase of roof area and yard area, both relevant for run-off estimation, was calculated utilizing the coefficients defined during this work.

Table 2.5 The table shows the process of determining the proportion of each imperviousness component in the Kylmäoja catchment for the time before 2007 and the calculation approach used for the forecast.

	COMPONENT	UNTIL 2007	FORECAST 2030
VANTAA	Roofage	Roofage in the catchment according to the manipulated database	Increase of roofage based on maximum floor area built $ADDITONAL\ FLOOR\ AREA\ (2030) * ROOFAGE\ COEFFICIENT\ (VANTAA) = ADDITIONAL\ ROOFAGE (2030)$
	Yard area	Yard area in the catchment based on the analysis of orthophotos	Increase of yard area based on maximum floor area built $ADDITIONAL\ FLOOR\ AREA\ (2030) * YARD\ COEFFICIENT\ (VANTAA) = ADDITIONAL\ YARD\ AREA (2030)$
	Roads	Road surface in the catchment according to the manipulated database	Road surface based on forecast data of the city of Vantaa
TUUSULA	Roofage	Roofage in the catchment based on the analysis of orthophotos	Increase of roofage based on maximum floor area built $ADDITONAL\ FLOOR\ AREA\ (2030) * ROOFAGE\ COEFFICIENT\ (VANTAA) = ADDITIONAL\ ROOFAGE (2030)$
	Yard area	Yard area in the catchment based on the analysis of orthophotos	Increase of yard area based on maximum floor area built $ADDITIONAL\ FLOOR\ AREA\ (2030) * YARD\ COEFFICIENT\ (TUUSULA) = ADDITIONAL\ YARD\ AREA (2030)$
	Roads	Road surface in the catchment based on the analysis of orthophotos	Road surface based on forecast data of the municipality of Tuusula

3 Delineation of the catchment

3.1 Introduction

For the spatial analysis of the basin, the commercial software MapInfo, used by the city of Vantaa and the software stack Geoinformatica, developed by Professor Ari Jolma at the Helsinki University of Technology were used in combination. The relevant file data for the analysis existed in MapInfo file format, which is compatible in use also with Geoinformatica.

Delineation of the stream network and the catchment area was conducted based on a digital elevation model (DEM), with a grid cell size of twenty-five meters. The raster contained elevation information for each grid cell.

3.2 Background

One of the simplest and most commonly used ways to delineate a stream network and a basin based on a DEM assumes the direction of the flow to be identical with the direction of the steepest slope. The method used in Geoinformatica is commonly known as the D8 method, which defines eight possible flow directions of a cell, the four orthogonal directions and the four diagonal directions of a square (figure 3.1).

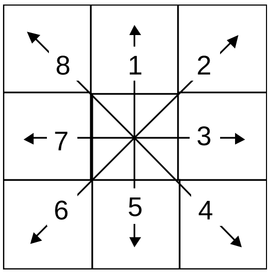


Figure 3.1 Possible flow directions in the D8 method (Teemu Kokkonen, TKK).

The steepest slope between a cell and its surrounding is chosen to be the flow direction and a new raster grid is created, with numbers from one to eight as characteristic values.

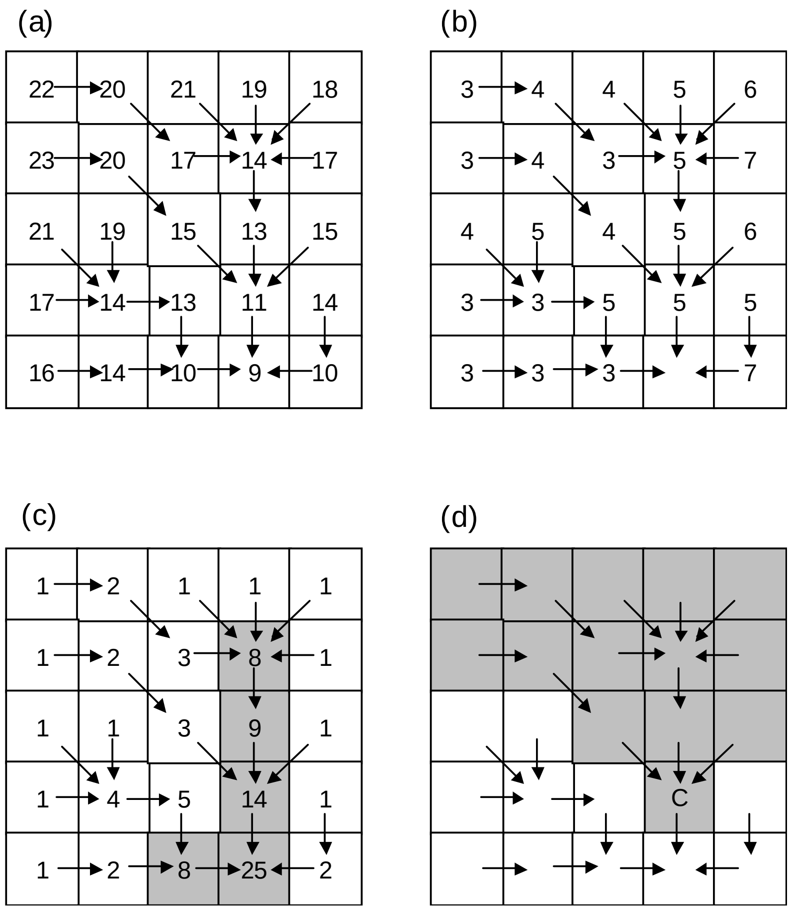


Figure 3.2 Derivation of flow directions with the D8 method, elevations of grid cells (a), flow direction codes given according to the convention shown in figure 3.1 (b), flow accumulation values, stream cells (grey) with a threshold > 7 shown (c) and an example of the catchment for the cell marked with C (d) (Teemu Kokkonen, TKK).

The catchment area is defined, by identification of all cells whose waters drain into a given cell, based on the flow directions (figure 3.2).

To define a stream network, flow accumulation values indicating how large upslope area a cell has, can be used. All cells accumulating the flow of an amount of cells larger than a given threshold value are defined to be stream cells. The threshold value is chosen in a way to define a reasonable stream network, as close as possible to the actual stream network, which is modelled.

An important factor while delineating a catchment from a digital elevation model is the fact, that DEMs contain usually flat areas and depressions. In these areas the determination of the flow direction is complicated. In the case of flat areas, they may be either indicating an error in the DEM or represent the reality, the flow is redirected to the closest cell having a resolved flow direction. That may cause unrealistic flow scenarios. Depressions, or pits, are cells, which are completely surrounded by cells with a greater elevation, which makes it impossible to define the flow direction of the cell, since the depression is accumulating the flow of all surrounding cells, but not draining anywhere itself. Before the delineation of the watershed, depressions in the DEM have to be identified and filled; commonly meaning the elevation of the cell is raised to the height of the lowest cell surrounding it.

3.3 Manipulation of the digital elevation model (DEM)

The basin and the stream network delineated with the methods explained shortly above were then compared with the actual position of the stream, derived from maps and orthophotos. Due to the issue with flat areas and depressions in the DEM and regulation and construction on the stream and its catchment in reality, the output and the delineation have to be checked for variations. These differences have to be evaluated upon their relevance on the result of the analysis. A junction being in a different location has a naturally greater effect on the analysis, than the misplacement of the stream, even over a longer distance, within a reasonable range.

Figure 3.3 shows the differences between the first output and the actual position of the stream, derived from orthophotos. The misplacement of the junctions between the northern three branches, as well as the wrong location of two branches entering the stream from the west, can be seen. These variations have a large influence on the model output of the subcatchment and, therefore had to be corrected.

The elevation data of the DEM in crucial points was manipulated, to force the software to assume the stream in its actual position.

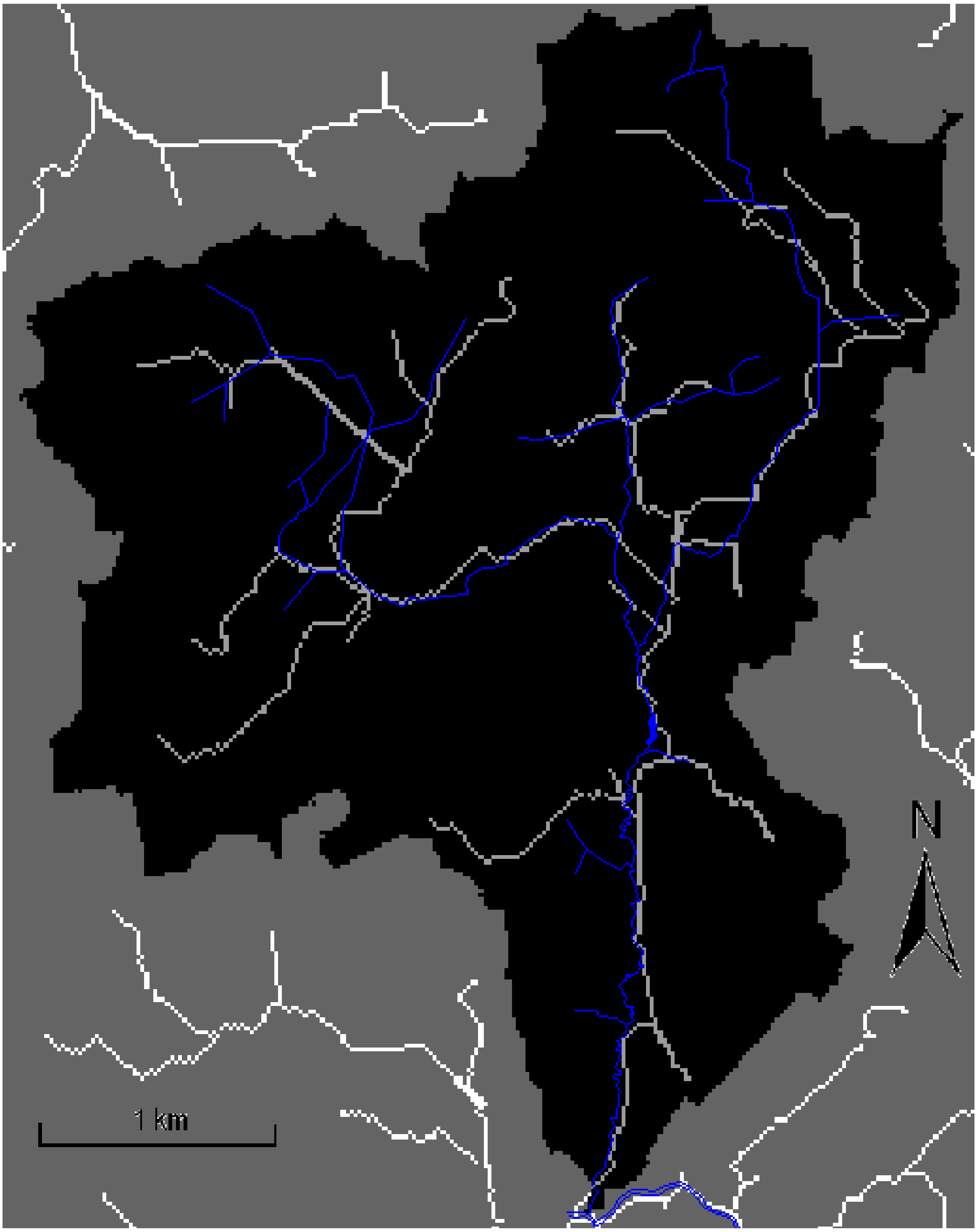


Figure 3.3 The difference between the stream delineated from the original DEM (light grey) in contrast to the actual location of the stream (blue), catchment before manipulation (black) is also shown.

3.4 Modification of the catchment and its subcatchments

The delineation of a catchment based on a DEM results in catchments based on topography, hence engineering works such as storm water sewers are not considered in the output. Since the catchment of Kylmäoja covers mostly urban and suburban areas, investigation of the storm water sewer network was necessary to delineate the real catchment. Comparison of the catchment with the storm water sewer maps, provided by the city of Vantaa, showed that the influence of the storm water sewer network on the shape of the catchment is significant and has to be considered.

The changes affected especially the airport and the most urban areas in the southern part of the catchment. Whereas based on the DEM both terminals of the airport, most other facilities, the entire 2^{nd} runway and parts of the 1^{st} and 3^{rd} runway of the airport contributed to the discharge of Kylmäoja, that is not the case when taking the sewer systems in the city of Vantaa into account. The storm water from the terminals, most other buildings and parts of the 2^{nd} runway is directed to Kirkonkylänoja, a stream south of the airport. The stormwater of parts of the 3^{rd} runway, due to topography also draining into Kylmäoja, is directed to Krakanoja, also located south of the airport, leaving the majority of the 2^{nd} runway and parts of the 1^{st} runway as contributors for the run-off to Kylmäoja.

In the southern and most urban areas of the basin, the changes mainly affected the borders between the subcatchments, which were modified accordingly. The results of the modifications conducted during the process are visualized in figure 3.4.

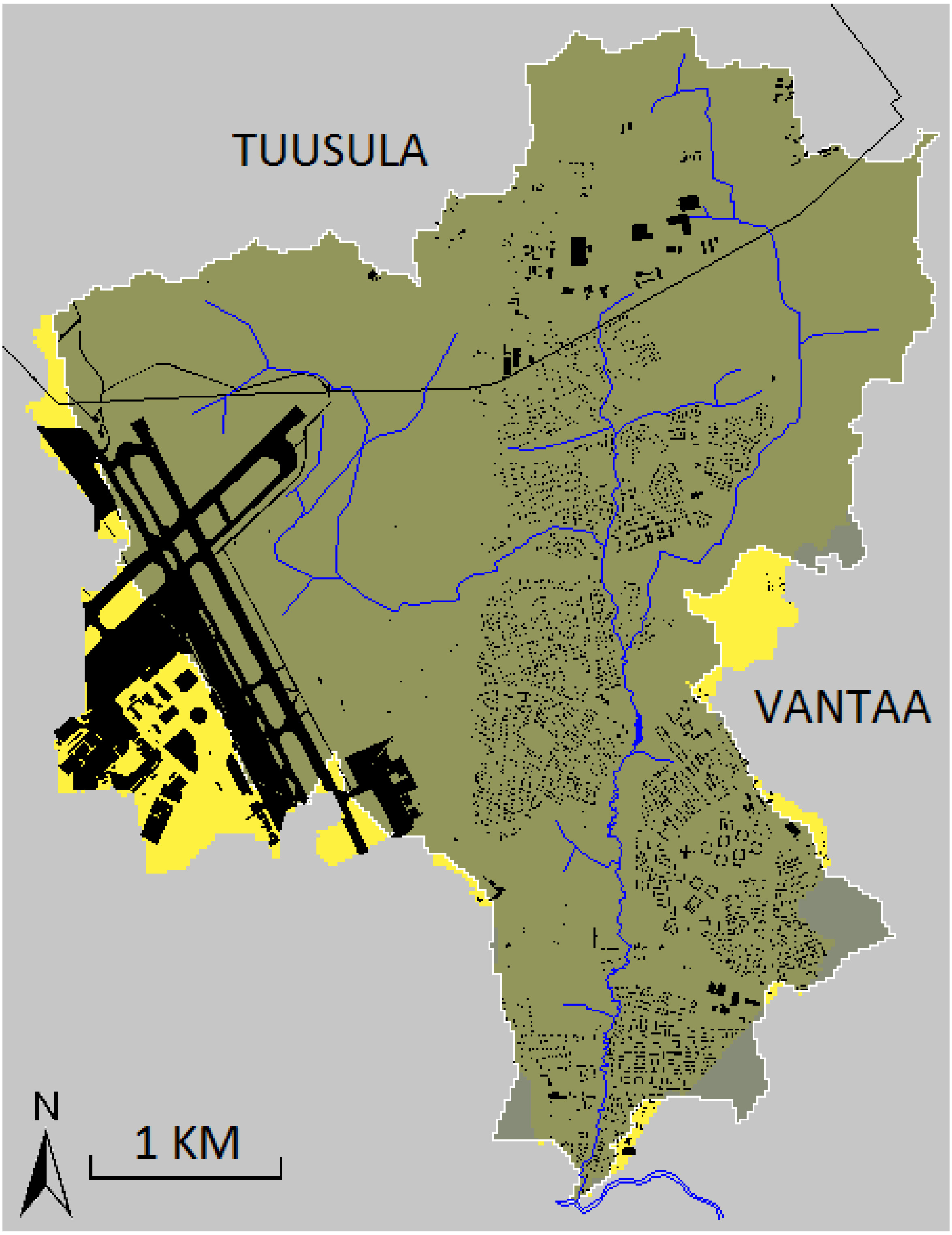


Figure 3.4 The figure shows the perimeter of the final modified catchment (white), olive green indicates areas where the final catchment and the DEM output are identical, yellow indicates areas belonging to the catchment based on the DEM and grey areas indicate areas not belonging to the catchment based on the DEM. Shown are also the airport and existing buildings in the catchment. The stream is shown based on the investigation of orthophotos.

3.5 The subcatchments

The total catchment of Kylmäoja was subsided into eleven subcatchments in this work, five subcatchments indicating the five branches joining the stream over its length and six subcatchments to cover the sections of the main stream between these junctions.

The subcatchments were numbered from one to eleven. Further in this text and the belonging charts and maps, the subcatchments will be addressed as C1, C2, ….., C11. For the three subcatchments, which are partly located in Tuusula and partly in Vantaa, namely the subcatchments 1, 2 and 6, the address subcatchment 1-Vantaa or subcatchment 1-Tuusula, respectively C1-Vantaa or C1-Tuusula will be used if not told differently.

The subcatchment sizes vary from 7.574 km^2 for subcatchment 2 (western branch), 4.738 km^2 for subcatchment 6 (eastern branch) and 2.109 km^2 for subcatchment 1 (central branch) to 0.361 km^2 for subcatchment 4 and 0.258 km^2 for subcatchment 8.

Table 3.1 The size of the eleven subcatchments defined in this study. Furthermore the distribution of the area between Vantaa and Tuusula and the fraction of the total Kylmäoja catchment are shown for each subcatchment.

	Size [km^2]	Vantaa [km^2]	Tuusula [km^2]	Fraction of the total catchment [%]
C1	2.109	1.619	0.490	10.1
C2	7.574	4.924	2.650	36.4
C3	1.332	1.332		6.4
C4	0.361	0.361		1.7
C5	0.532	0.532		2.6
C6	4.738	2.757	1.981	22.7
C7	0.765	0.765		3.7
C8	0.258	0.258		1.2
C9	0.432	0.432		2.1
C10	1.702	1.702		8.2
C11	1.031	1.031		4.9
C TOT	20.835	15.714	5.121	100

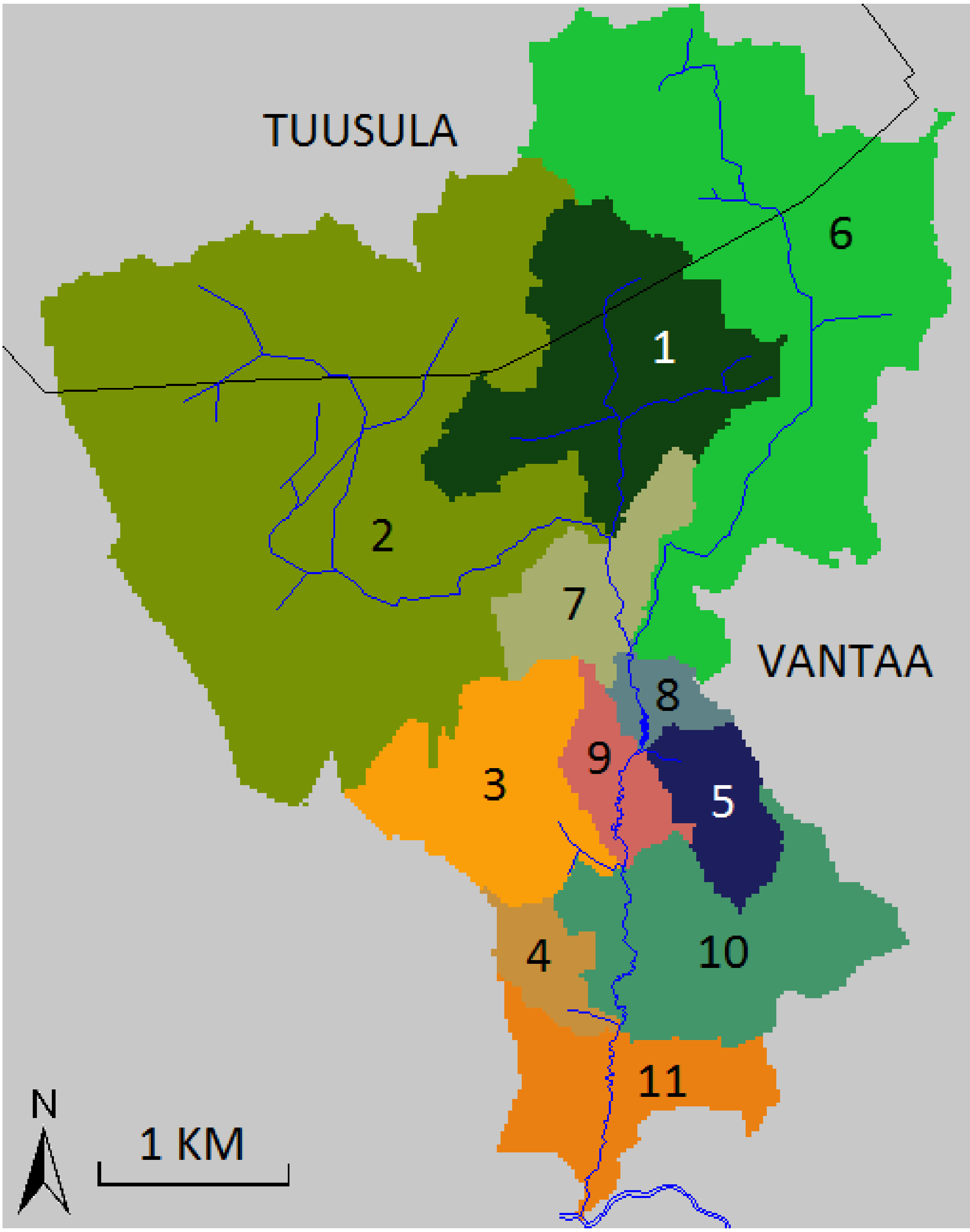


Figure 3.5 The eleven subcatchments C1 – C11 marked with their reference number which will be used further in the text.

4 Spatial analysis

4.1 Introduction

The target of the spatial analysis was the identification of surfaces contributing to the stormwater run-off draining into the Kylmäoja stream, as well in terms of quantity as in terms of quality of these surfaces. Three main structure components were in the focus of the analysis carried out: First the development of building rooftops in the catchment, second the road network and third, the contribution of impervious areas on estates, like driveways and parking lots.

Whereas the development of the roofage and the road network are critical mainly in terms of quantity, the situation on private and public yards is a little more complicated. Not only the scale of constructed surfaces, but, with not minor importance, also the condition of these areas has to be investigated carefully. Whereas the variation of run-off coefficients for roofs and roads are rather uniform, reaching from 0.80 to 1.00 in common literature (Kibler 1982, RIL 2004 or ATV-DVWK-REGELWERK 2000), with all roads having either asphalt or concrete covering, as it is the case in the catchment, the range of possible surface materials in use for yard construction reaches from loose gravel, with a factor of 0.30, to brick, with a factor between 0.75 and 0.85 to asphalt, with a possible coefficient up to 1.00.

Since there was no detailed register existing, which would have contained information about the size and condition of these surfaces, the fundament of the survey was aerial photography.

4.2 Analysis of building roofs

Figure 4.1 A typical detached house in the Kylmäoja catchment (picture taken September 2008).

Figure 4.2 A typical row house in the Kylmäoja catchment (picture taken September 2008).

Figure 4.3 An apartment block in the most urban areas of the Kylmäoja catchment (picture taken September 2008).

4.2.1 Vantaa

4.2.1.1 Before the year 2007

Base of the analysis of building structures in the catchment, was existing vector data, kept updated by the city of Vantaa. The dataset consists of two files, Rakennukset (buildings) and Rakennukset alueina (buildings as shape).

The file Rakennukset contains data about every building in Vantaa, reaching from the floor area, the type of building and year of construction or the number of floors to the connection with the municipal canalization or the fresh water supply. The relevant data used from this file were the floor area, the year of construction and the building type.

The most relevant data for the estimation of the run-off, the roof area of the building, was derived from the database Rakennukset alueina. The file contains similar information as the Rakennukset data, though not as detailed and updated, but the shape of the building is defined as polygon, allowing the analysis of the roof area. Since the polygons shape is based on the perimeter of the outer walls and not on the actual roof of the building, the study showed that corrections were necessary to estimate the actual roof areas.

The total number of buildings within the catchment and the borders of the city of Vantaa are 4.198. This large number made a correction of the roof area for every building impossible within the limits of this work, and therefore a general approach was necessary.

In general, the missing roof area in the database found compensation in the definition of yard areas. Roofs which were reaching over driveways or covering terraces were listed as yard area, which made the total impervious area of a building, the combination of the roof and the yard correct. In cases of larger inaccuracies, correction of the polygons was carried out, to achieve an exact result for the roofage.

4.2.1.2 The target year 2030

The forecast of land-use in the city of Vantaa in the year 2030 was subsided into two parts. The first part of the analysis concerned areas which were already considered in the detailed city plan and were therefore classified with exact maximum plot-ratios and building types.

The second part dealt with regions which were yet only considered in the 2007 Master Plan. These areas were classified with efficiencies and land-use types and whereas the forecast in the city plan is specific, data for these areas was generalized and implied greater uncertainties.

The analysis of city planned areas used the defined maximum plot-ratio of an estate, to get the maximum constructed floor space possible in comparison with the already constructed floor space, to identify the increase of floor area possible. The consequence of the combination of limited space and constant growth of population in the capital metropolitan region (Helsinki, Espoo and Vantaa) are high costs for living and construction also in the city of Vantaa (Helsingin sanomat – Ref. 2). It is therefore logical that it is desirable to achieve the optimal use of the maximum plot-ratio, and built the floor area possible on an estate. This is valid as well for private housing as also for work places. A noticeable process is the replacement of older houses with one or more houses on the same estate, causing not necessarily always significant increases in the roofage, but remarkable changes in the yard condition, caused e.g. by the higher demand of car parking places.

The data in the land-use map for areas unbuilt today, deals with efficiency and density, as mentioned above. The city of Vantaa defines five different types of residential land-use. They reach from A4 and A3, with an estimated density of up to 0.15, A2 with a density of 0.15 – 0.30 and A1, estimated from 0.30 – 0.50 to C, for areas marked as centres, where the estimation for the factor between floor area and estate reach from 0.80 to even 1.10.

The categories for industrial and work place areas are manifold, but in the catchment only the definition of TP, marking work place areas and TY, industrial areas where the environment puts special requirements on the functions are represented and therefore of importance. Density factors for TP reach from 0.60 to 0.80 and the estimation for TY is 0.40.

Other categories in the land-use map, which include structures, were neglected, because there is no change predicted. That concerned namely areas reserved for services, e.g. schools, daycares, nursing homes, health stations or hospitals.

The analysis of the development limited itself, for the reasons explained above, to the increase of roofage for housing and work place areas. The categories, which are important for the use of different factors and therefore used, were A0 for areas with mainly detached- and row houses, AK for areas meant for apartment blocks, A3, marking low-rise housing areas, A2, dense low-rise housing areas, A1, reserved for dense housing and T, describing all areas reserved for work places.

The data for the forecast also contained estimations about the realisation date of different areas. Whereas residential buildings are assumed to be mostly constructed or extended by the year 2030, the progress in industrial and work place areas depends on the economical situation. As a result, the business park planned at the intersection of Tuusulanväylä and the new ring rail line (Kehärata), marked in the 2007 Master Plan as TP is not assumed to be constructed before 2030 anymore, due to the current economical developments (see figure 1.8 and 4.4). The designated area offers, with a plot-ratio of 0.50, building permission for a floor area of approx. 307.000 m². Using a factor of 0.80 between the floor area and the roof area, the accumulation of additional impervious area contributing to the run-off into Kylmäoja would be 245.000 m². This area is not directly considered in the analysis, but is marked as optional, first parts of the area might still be constructed within 2030 and second, if not, might be constructed not long beyond the target year of this analysis.

The largest residential development area in the catchment is Leinelä (see figure 1.8 and 4.4). The total planning area is 33 ha, of which approx. 19 ha or 57 % are within the Kylmäoja catchment. The total floor area of the project will be 110.480 m². Construction of apartment buildings started in 2008 and the project will be finished in 2015 according to the plan (Vantaan kaupunki – Ref. 6). In the Master Plan the area is defined as A1, a dense housing area, containing mainly apartment blocks. The factor between floor area and roof area for these kinds of buildings in catchment 6, where the area is located, is 0.52 in 2007. That results in roof area of 57.500 m².

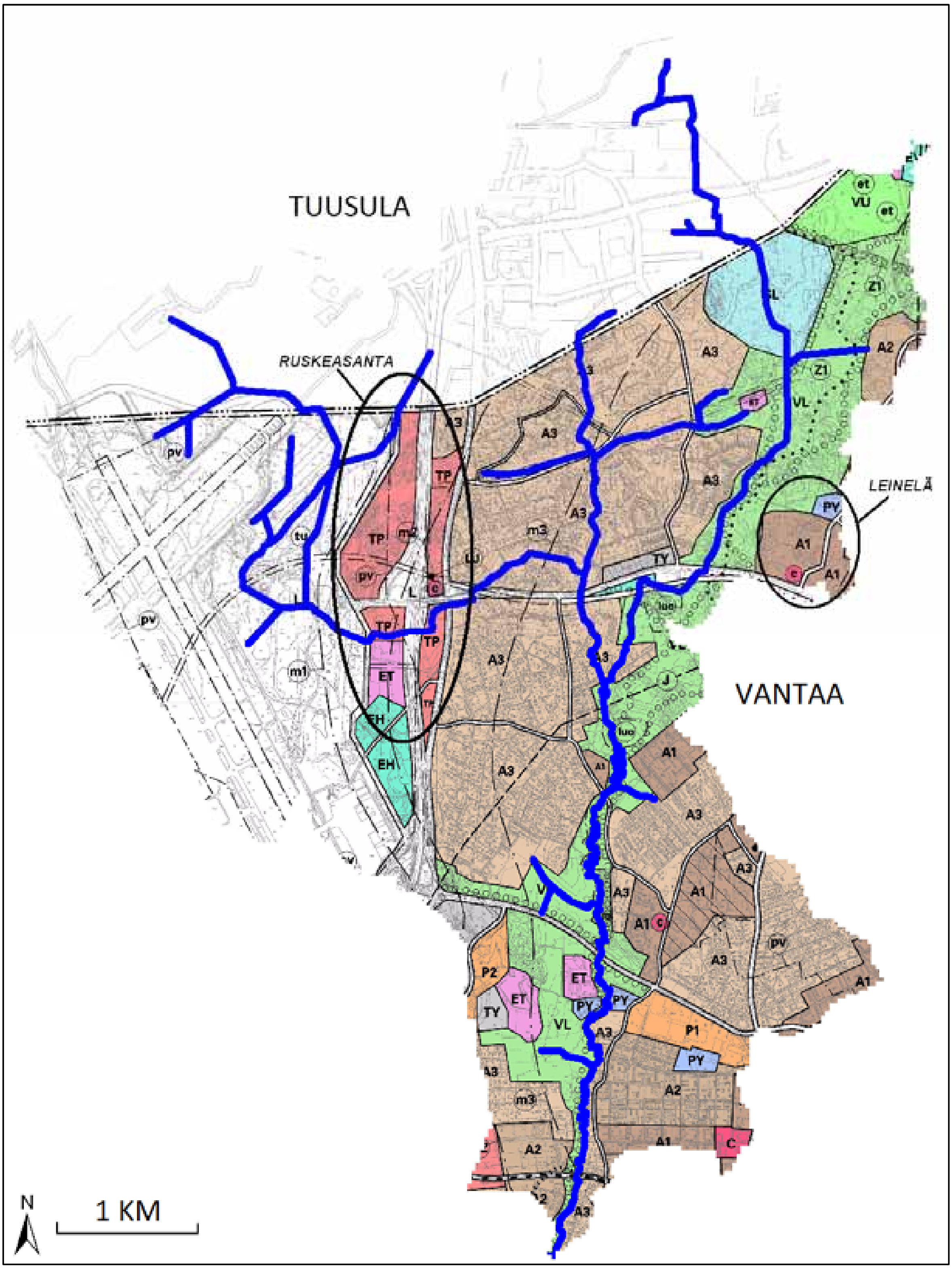


Figure 4.4 The 2007 Vantaa Master Plan land-use map. It is notable, that the catchment will also be dominated by residential areas (different shades of brown, from low density – light, to high density, dark) in 2030. The work place area in Ruskeasanta east of the airport and the residential area in Leinelä are tagged. The key for the zoning types used can be found from figure 1.6 (modified land-use map, original Vantaan kaupunki).

Since both the maximum plot-ratio and the density deal with the floor area, a relation with the roof area needed to be established. That was done with the help of the results from the analysis of the development before 2007. The investigation of both the floor area and the roof area for each building in the catchment allowed the creation of factors for each building type in each subcatchment for the considered time period. The factors reach from 0.80 – 1.00 for detached houses and 0.50 – 0.90 for row houses to values as low as 0.30 for apartment blocks. The relation between floor area and roof area for industrial and office buildings, combined as work places reaches from 0.70 to even 1.90 for some industrial storage and production buildings.

4.2.2 Tuusula

4.2.2.1 Before the year 2007

As already mentioned above, the digital database provided by the municipality of Tuusula, was less detailed then the one available from the city of Vantaa. Exact data about buildings and roads did not exist in digital format and therefore, the approach of the analysis had to be revised. The result was, to create a new database, suitable for the needs of the analysis.

As the base of the analysis, it was chosen to use general maps, showing the development of the municipality, in combination with aerial photography. Maps were available for the years 1975, 1993 and 2007. These general maps do not show building structures in detail, but indicate areas developed at the time of publication.

The database was created with the software MapInfo, which allowed the creation of polygons and the assignment of attributes, in this case the area, the year of construction, the building type, and the location of the building. The polygons were, in difference to the database from the city of Vantaa, based on the actual roof area of the building in question, visible from the related orthophoto.

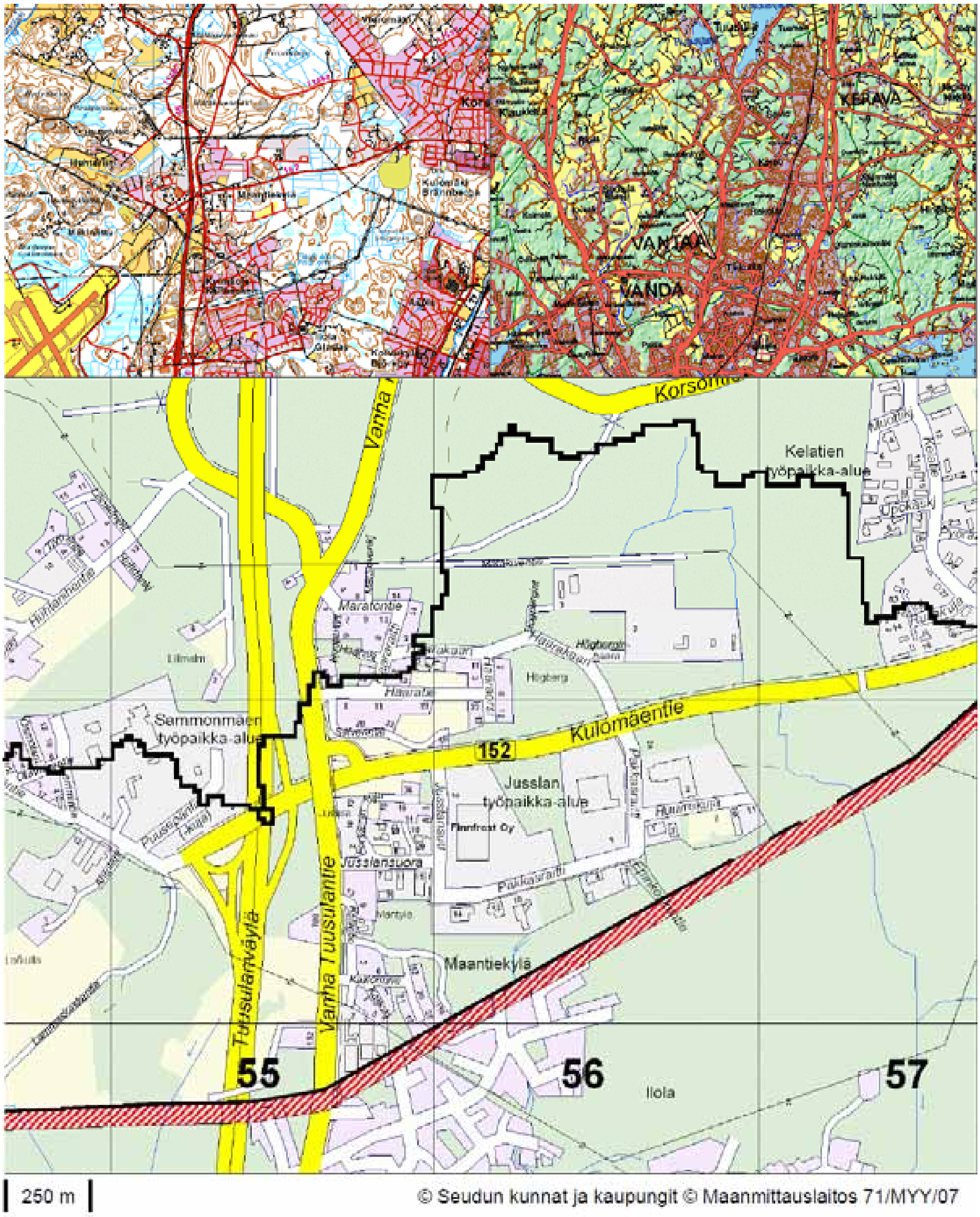


Figure 4.5 The municipality of Tuusula's general map showing the area north of the city of Vantaa, belonging mainly to subcatchment 1 (http://kartta.kuuma.fi/kuuma/map.php). The northern border of the Kylmäoja catchment is also shown (modified map, original Vantaan kaupunki).

Since the created dataset was based on orthophotos taken in 2007 by the city of Vantaa, it was not possible to interpret changes done on buildings over the years. It had to be assumed that a building shown on photos from 2007 already existed in the current shape in 1975 and 1993. This assumption was possible due to the land-use structure of the area in question and the fact that industrial buildings are clearly indicated in general maps even with their shape. The assumption was therefore only necessary for private housing, marked only as areas on the maps.

The location north of the airport, in the approach path of the 1st runway, makes the area mostly unsuitable for private housing, favouring industry and office buildings. Since the airport was taken into use in 1952, it can be assumed, that houses meant for living were constructed before 1975. That is also indicated by land-use plans of the municipality, which declare the area to be meant for industrial use and show only little possibility for construction of residential buildings.

4.2.2.2 The target year 2030

The subcatchments in Tuusula will be dominated by the business park named FOCUS, covering an area of over ten square kilometres. The development of the area is planned between the years 2005 and 2010. The area is located directly north of the airport and its eastern part will cover almost the entire catchment of Kylmäoja within Tuusula.

The material used for the forecast of the number of buildings in Tuusula may be separated into two different areas with land-use plans in different scales.

The current status of plans for areas belonging to the catchments 1 and 6, located in the north eastern part of the Kylmäoja basin, was on the level of city planning. Maximum plot-ratios and land-use types were assigned to small areas.

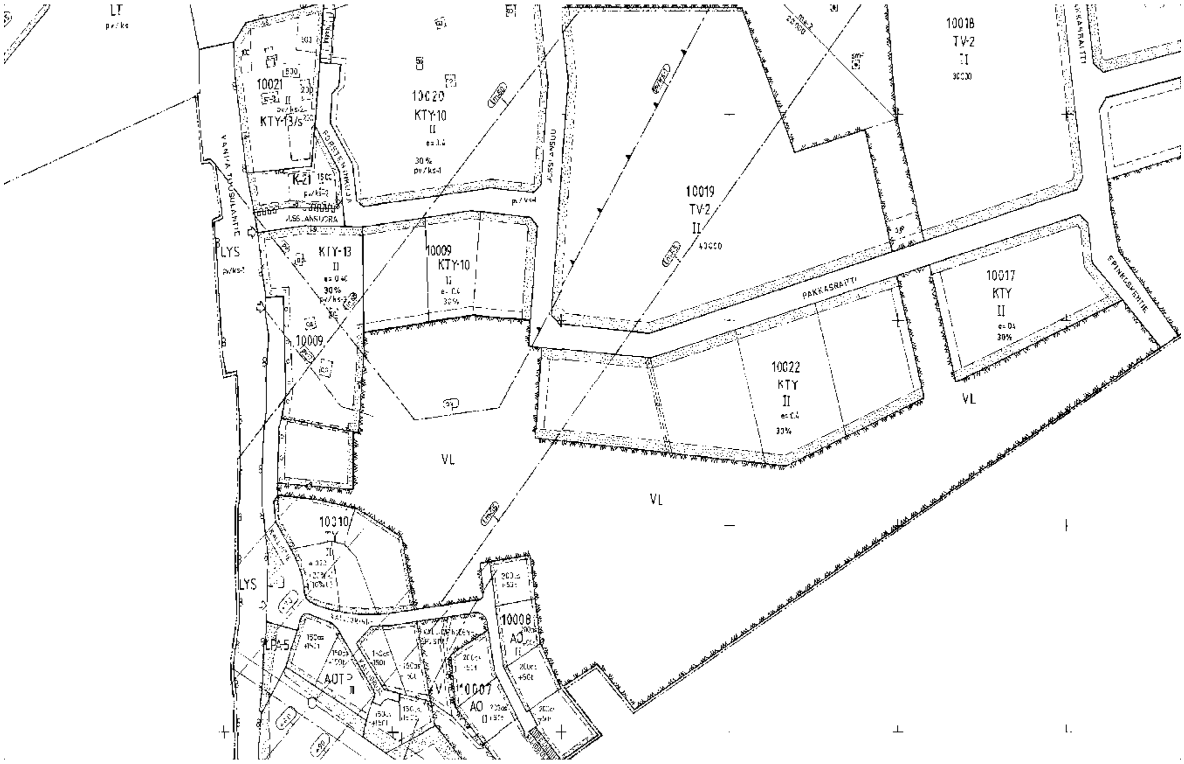


Figure 4.6 Detailed plan for parts of the subcatchments 1 and 6 located in Tuusula (Tuusulan kunta).

The planning status of the western areas of the catchment in Tuusula, north of the airport differed from the eastern areas. Parts are planned detailed already whereas others are referred to only in general plan. Detailed land-use plans exist namely for the area north of Kulomäentie, at the moment ending at Tuusulanväylä coming from the East, and west of Tuusulanväylä. In the general plan, the area between Tuusulanväylä and Tuusulantie is defined as a future work place area. Same goes for a smaller area west of Tuusulanväylä.

Figure 4.7 Location and extension of the Tuusula business park named FOCUS, developed north of the Helsinki-Vantaa airport. The borders of the Kylmäoja catchment are also shown (modified map, original Tuusulan kunta).

4.2.3 Results

The results of the spatial analysis of building roofs in the Kylmäoja catchment are handled separately for the city of Vantaa and the municipality of Tuusula in this chapter. Since the analysis was done for each subcatchment, this restriction only concerns the subcatchments 1, 2 and 6, whose extension reaches over the border between the two municipalities. In the following text and charts, these three subcatchments will be addressed separately as C1, C2 and C6 Vantaa or C1, C2 and C6 Tuusula.

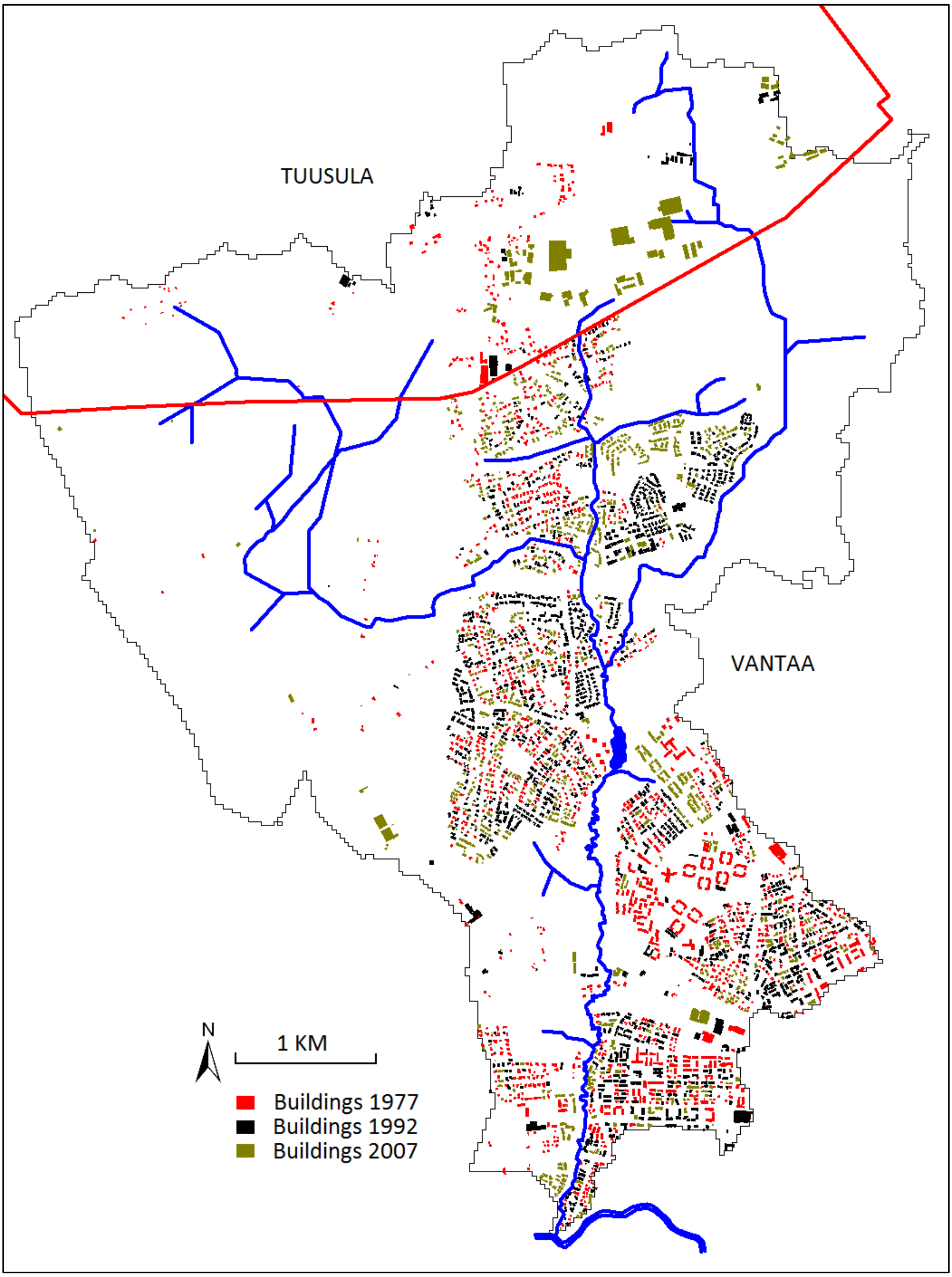


Figure 4.8 The map shows the development of buildings and respectively roof area in the Kylmäoja catchment over the time span investigated. Buildings in red colour were constructed before the year 1977, black indicates structures completed before 1992 and olive shows buildings completed most recently, before the year 2007.

A combined summary covering the whole catchment and combining the results as well for the subcatchments as also for Tuusula and Vantaa are given later in this document (chapter 4.5) and charts showing the development of roofage in the entire Kylmäoja catchment are presented in appendix E.

The findings of the investigation of the building database consist of two main parts; first the development of the roof area in the catchment, directly derived from the database for the years before 2007, and the relation factors between the roof area and the living area, used for the estimation of the roofage in the year 2030. The factors were determined for each building type in the catchment for every year in observation and each subcatchment. Nevertheless, only the factors for the time span between 1992 and 2007 were used for the estimation of the roof area in 2030, assuming that the empty plots will be filled up with similar structures, as at the moment state of the art, until the target year.

The development of roof area showed – similar to the other categories of impervious areas investigated – the fast growth in the southern part of Tuusula over the last 30 years. In 1975, only less than 9 % of the roof area in the Kylmäoja catchment was located in Tuusula. Due to fast growth in Vantaa in the 1980's, the fragment of built roof area in Tuusula even reduced to 7 % in 1993. With the beginning of emphasis on the industrial character of southern Tuusula in the 1990's, the share grew to almost 16 % in 2007 and will reach almost 25 % in the year 2030.

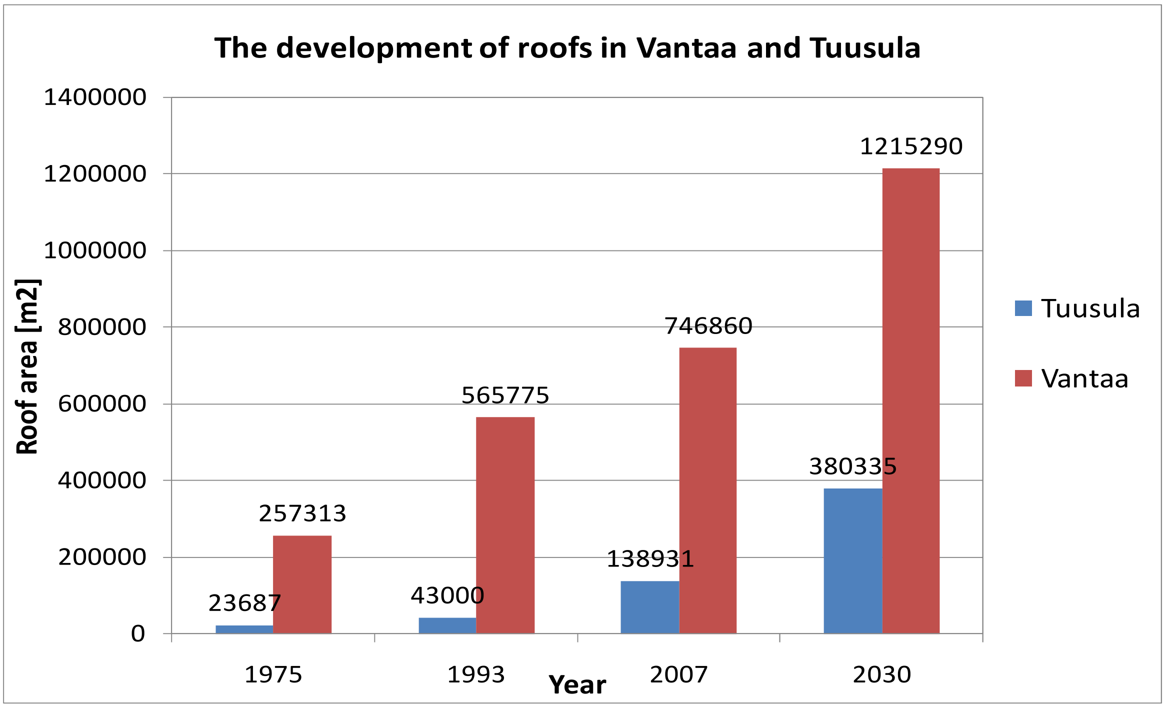


Figure 4.9 Development of the roof area within the Kylmäoja catchment in Tuusula and Vantaa between 1975 and 2030.

4.2.3.1 Vantaa

The relation between roof area and floor area, for low-rise residential areas in Vantaa, containing mainly detached and row houses for buildings constructed between 1992 and 2007, reaches 0.69 in subcatchment 8 and 0.72 in subcatchment 11 to 0.91 in subcatchment 6 and 0.92 in subcatchment 2. The average relation found was 0.80, for buildings constructed between 1993 and 2007.

Values for apartment blocks and high-rise residential areas, presented here only for subcatchments with a potential of growth for this land-use type, reach from 0.37 in the subcatchments 10 and 11, the most urbanized areas of the catchment to 0.52 in the subcatchments 1 and 6. The weighted average numbers at 0.39.

The factor defining the relation in areas for services, including facilities like schools, kindergartens, old people's homes or churches as well as sport facilities, like swimming or icing halls, is given only for subcatchment 10 with a value of 0.37. None of the other subcatchments have a potential for service facilities in the 2007 Master Plan. Also the potential in subcatchment 10 is of minor importance, since the possible increase of roof area makes only 365 m^2.
The existing relation for industrial and work place areas is stable around 0.80 for all subcatchments beside subcatchment 2, where the value numbers to 0.62. The slightly lower value is most likely caused by the proximity of the industrial areas to the airport, and therefore denser and consequently higher construction.

Table 4.1 The coefficients between roof area and floor area for the eleven subcatchments in Vantaa determined for the time span 1992 - 2007 and used initially for the year 2030. Factors for not represented land-use categories were not determined. See the map for subcatchments (figure 3.5)

	A0 Detached house / row house / low-rise residential area	**Ak** Apartment blocks / high-rise residential area	**P** Area for services	**T** Industrial buildings / office buildings / work place area
Catchment 1-Vantaa	0.82	0.52		0.80
Catchment 2-Vantaa	0.92			0.62
Catchment 3	0.78			0.81
Catchment 4	0.78			0.80
Catchment 5	0.72	0.39		0.80
Catchment 6-Vantaa	0.91	0.52		0.80
Catchment 7	0.84			0.80
Catchment 8	0.69			0.80
Catchment 9	0.79			
Catchment 10	0.77	0.37	0.37	0.80
Catchment 11	0.72	0.37		0.80

The development of roof area was investigated for each different building type defined by the city of Vantaa and represented in the Kylmäoja catchment – thirty in the most urban subcatchment 10, which also contains the largest variety of service facilities. Due to the fact that this kind of detailed description of the potential land-use in 2030 is not possible, the categories for the overall analysis were reduced to the four main categories, already explained earlier and also shown in table 4.1 displaying the floor-to-roof area relation.

Nevertheless two tables, namely for the subcatchments 1 and 2 are also shown to display the result and to illustrate the potential of the detailed database. Charts for all subcatchments can be found from appendix A.

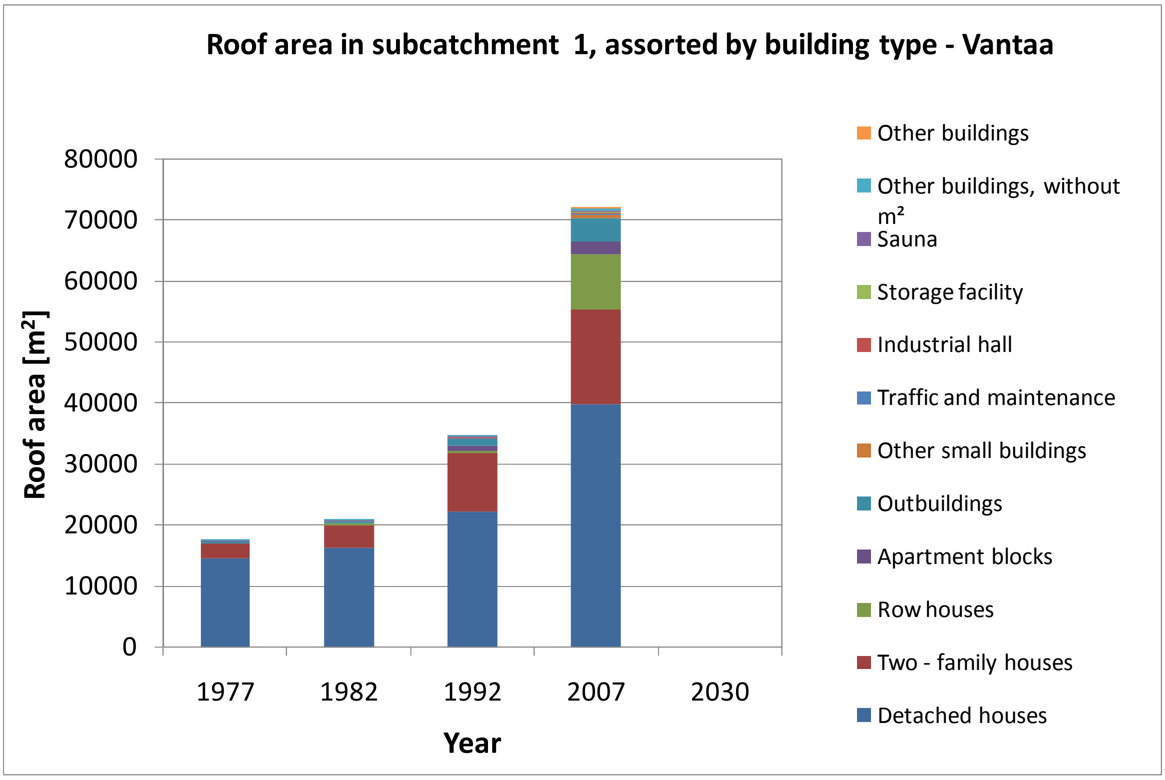


Figure 4.10 Roof area in subcatchment 1 – Vantaa assorted by building type 1977 – 2007.

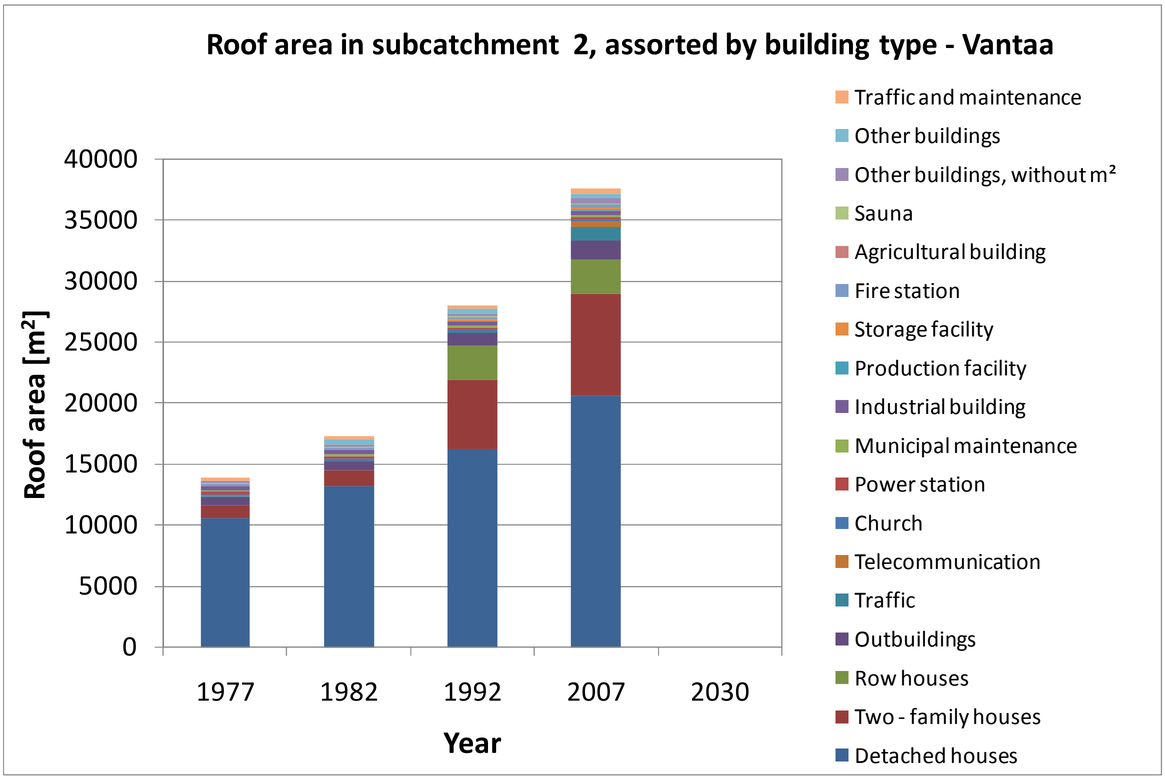


Figure 4.11 Roof area in subcatchment 2 – Vantaa assorted by building type 1977 – 2007.

The largest increase in roof area until the year 2030 in Vantaa, as well in relation to 2007 as also in absolute figures will happen in the subcatchment 6, the basin of the eastern branch of the Kylmäoja catchment. The roof area in this subcatchment in 2007 was 31033 m^2 and will reach in 2030 a number of 161690 m^2, an increase of 420%.

The catchment is dominated by green areas at the moment, partly under protection, and is, because of the vast unbuilt areas, target of several development sites, both in Vantaa and Tuusula – like the residential area of Leinelä in Vantaa, named earlier. The increase of roofage for apartment blocks in the catchment, almost 49000 m^2 mainly derives from the project in Leinelä.

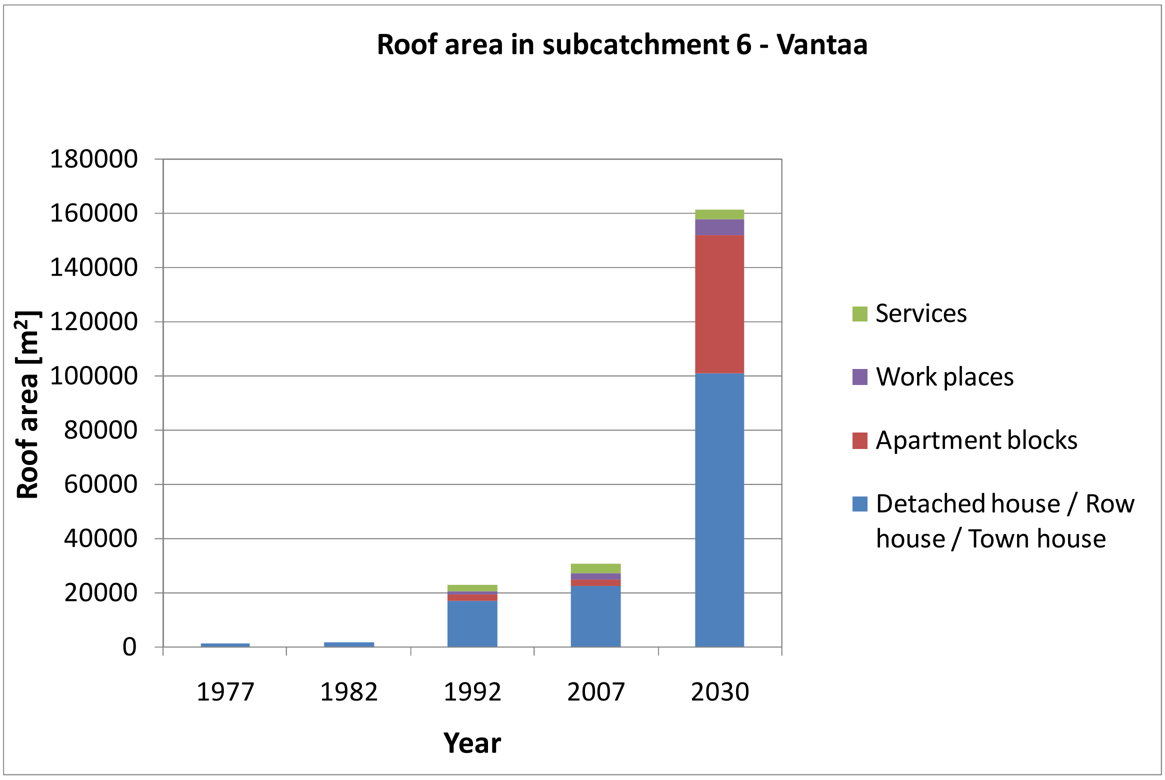


Figure 4.12 Roof area in subcatchment 6 – Vantaa 1977 – 2030.

Beside the subcatchment 6, the subcatchments 1, contributing to the discharge of the central branch of the stream, and 11, representing one of the most urban areas of the catchment, will experience the largest increment in roof area in 2030. The roof area in subcatchment 11 will number in 199300 m^2, an increase of 73200 m^2 compared to the year 2007. Whereas the growth in subcatchment 1 ranks with 70194 m^2 only little behind subcatchment 11, the relative increment of 97 % is significantly higher than in the already densely built subcatchment 11, where this value reaches 58 %.

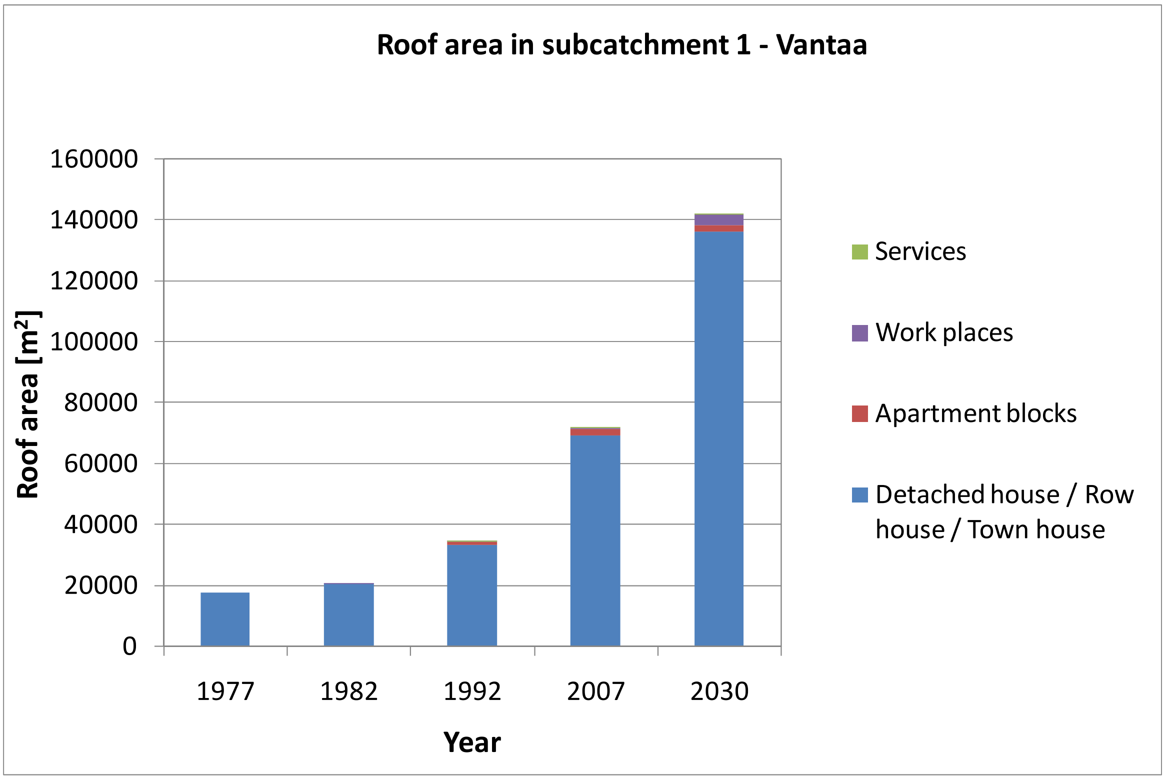


Figure 4.13 Roof area in subcatchment 1 – Vantaa 1977 – 2030.

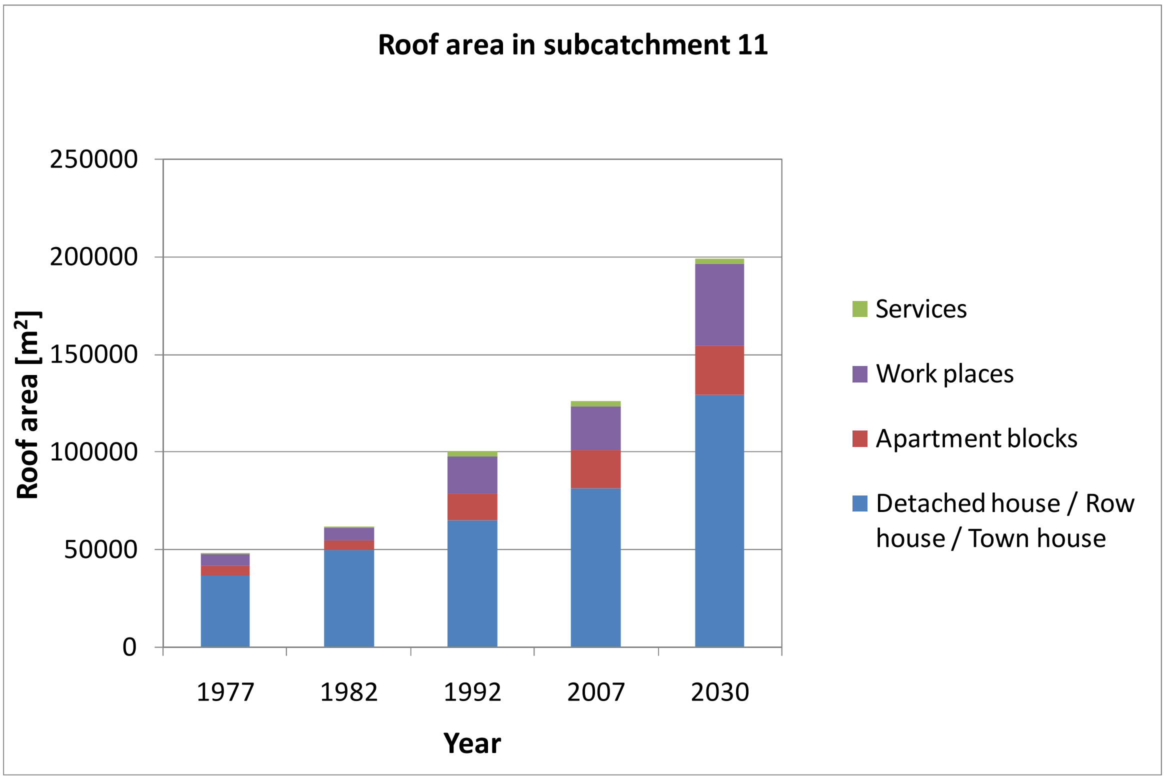


Figure 4.14 Roof area in subcatchment 11 1977 – 2030.

An interesting case is the subcatchment 2, creating the run-off for the western branch of the Kylmäoja stream and containing parts of the airport. As explained above, the matter when the business park planned east of the Helsinki-Vantaa airport will be effectively realized has a significant influence on the stormwater discharge in the Kylmäoja stream.

The business park planned to be erected around the potential station of the new ring rail line in Ruskeasanta, is, due to the current economic situation not likely to be realized before the year 2030 anymore, and has therefore no direct influence on the result of this analysis. Nevertheless it should be mentioned, that the construction of the work place area, reserved in the Master Plan 2007, will add roof area of approx. 160000 m^2 to subcatchment 2, whereas the forecasted growth of roofage is only 18500 m^2 in the subcatchment, without it.

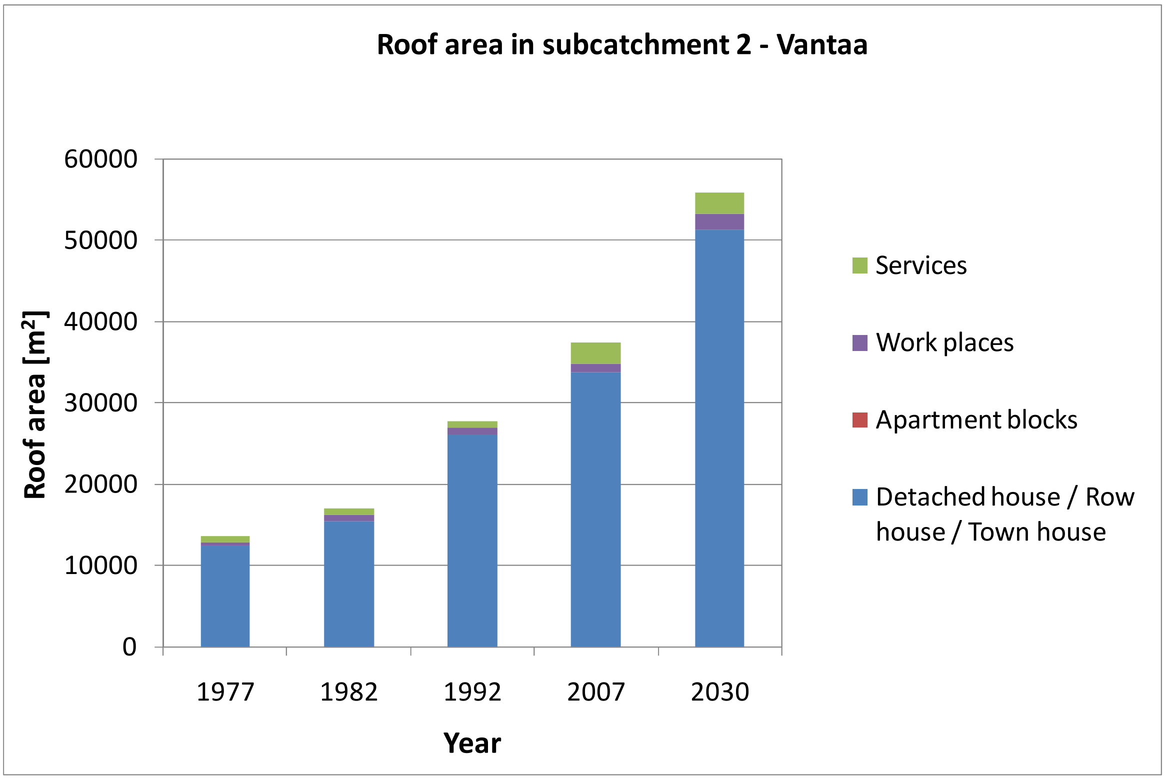


Figure 4.15 Roof area in subcatchment 2 – Vantaa 1977 – 2030.

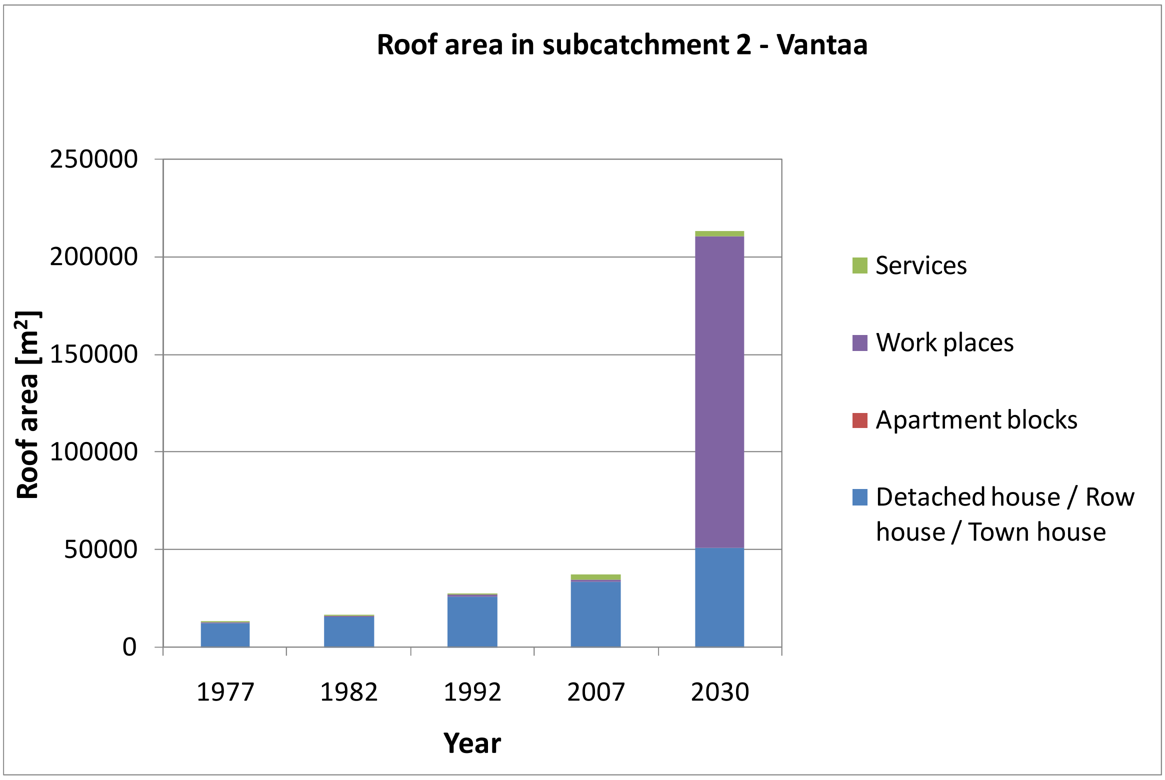


Figure 4.16 Roof area in subcatchment 2 – Vantaa 1977 – 2030 with the business park development around Ruskeasanta.

If we look at the section of the Kylmäoja catchment located within the borders of the city of Vantaa, the following development is notable. The extension of roofage is expected to grow from 746860 m^2 in the year 2007 to 1215290 m^2 in the target year 2030, an absolute growth of 468430 m^2, describing a relative increase of almost 63 %.

When looking at a similar time span of 23 years – as from 2007 to 2030 – in earlier time periods, e.g. the period from 1984 till 2007, the increment numbered in 401721 m^2, a plus of 116 % to the value of 345139 m^2 in 1984. In the same time period one step earlier, between 1961 and 1984, the roof area increased by 281881 m^2, plus 440 % from 64258 m^2 in 1961. Even earlier, between the late 1930's and 1961, the roof area increased by 53296 m^2 or plus 486%.

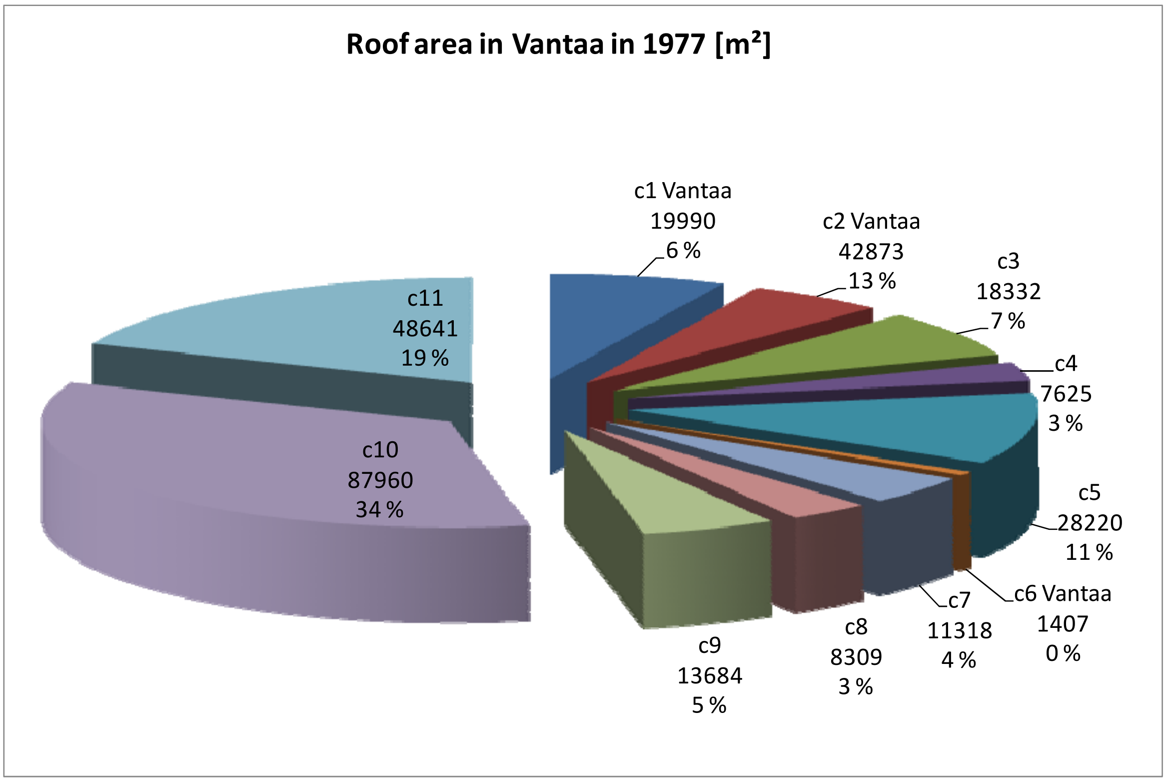


Figure 4.17 Roof area within Vantaa's part of the catchment assorted by subcatchments 1977.

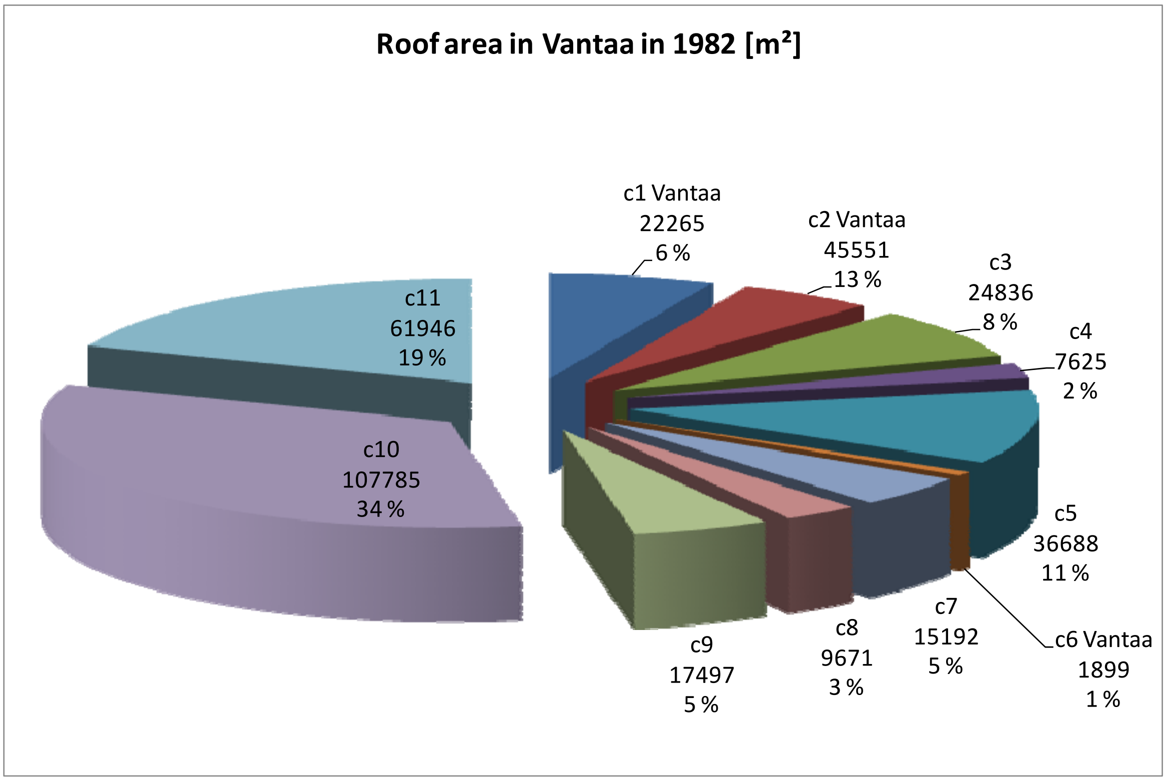


Figure 4.18 Roof area within Vantaa's part of the catchment assorted by subcatchments 1982.

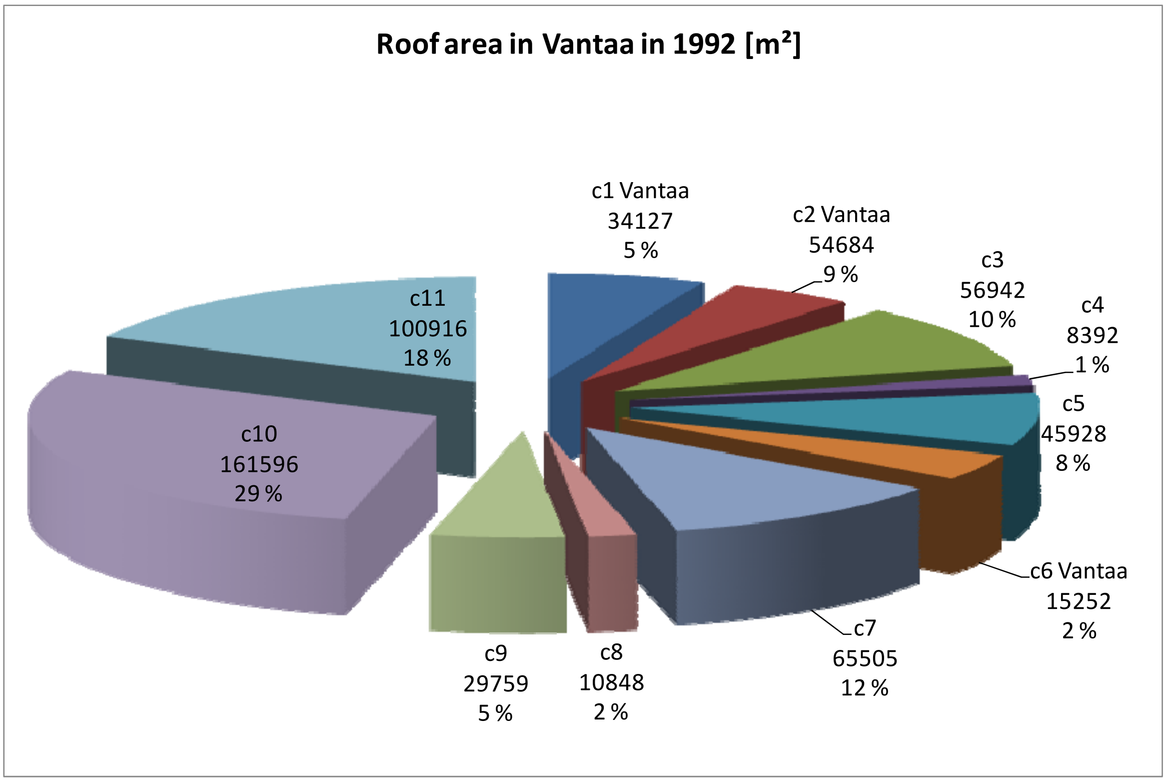


Figure 4.19 Roof area within Vantaa's part of the catchment assorted by subcatchments 1992.

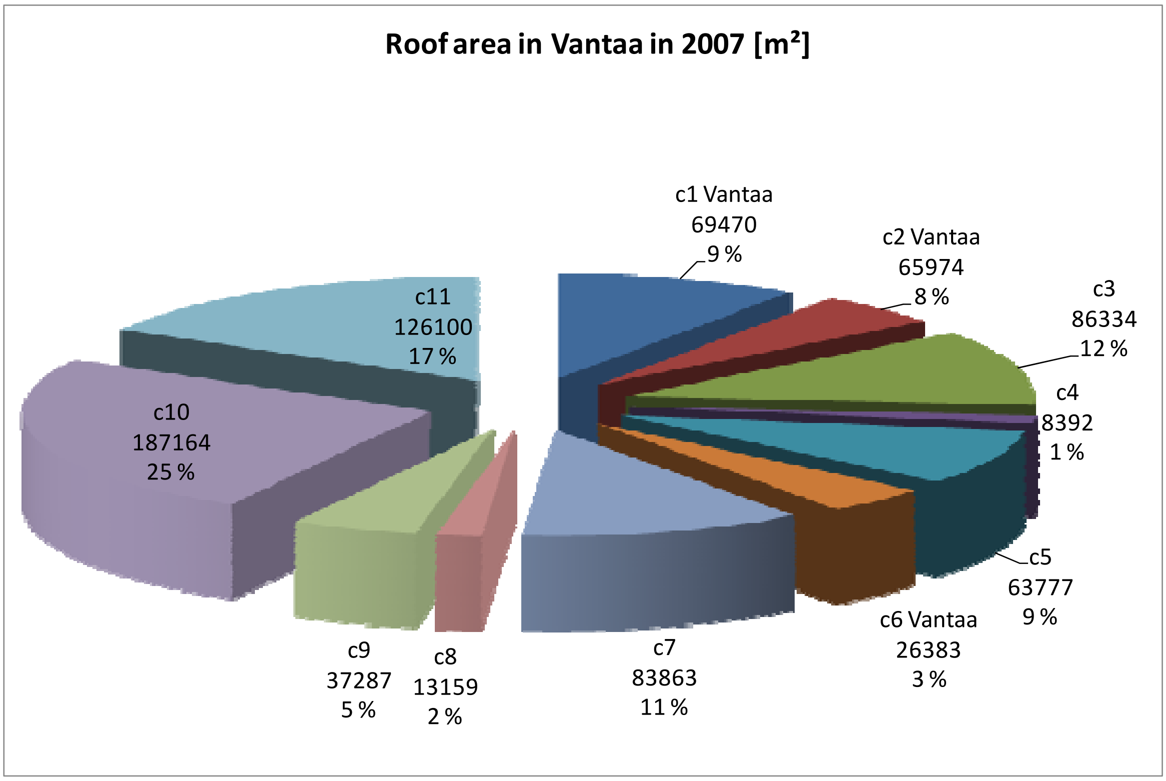


Figure 4.20 Roof area within Vantaa's part of the catchment assorted by subcatchments 2007.

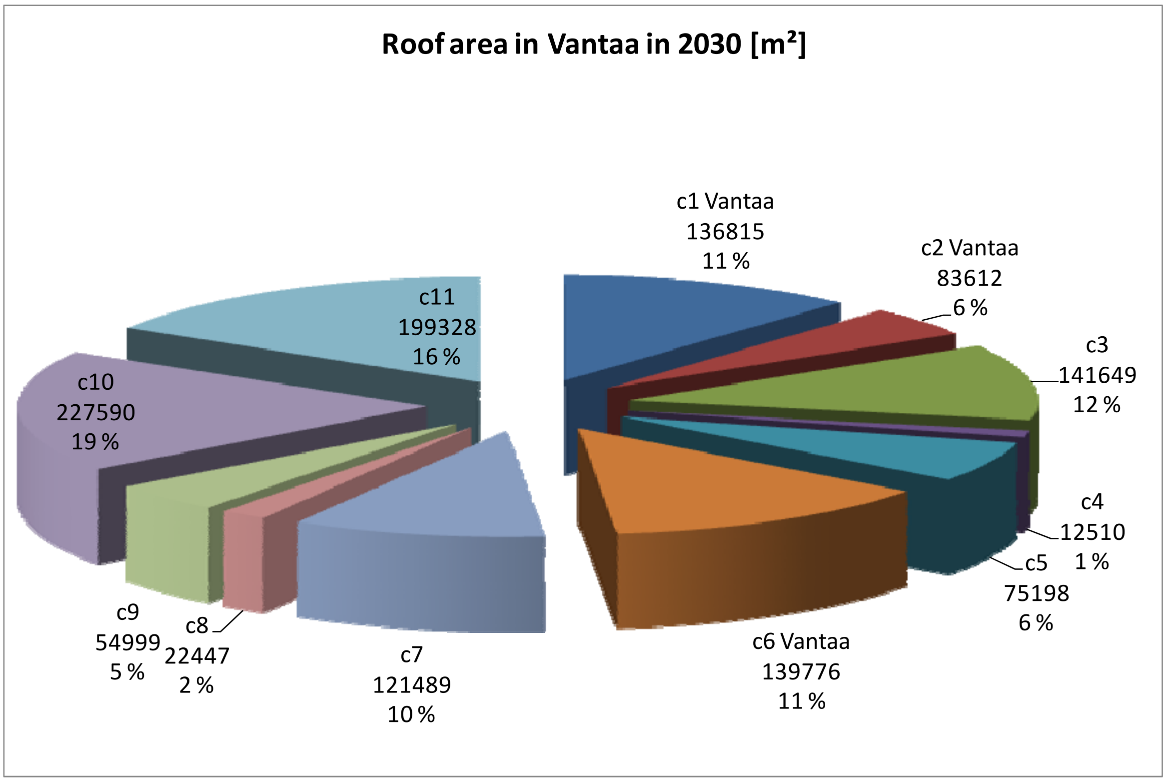


Figure 4.21 Roof area within Vantaa's part of the catchment assorted by subcatchments 2030.

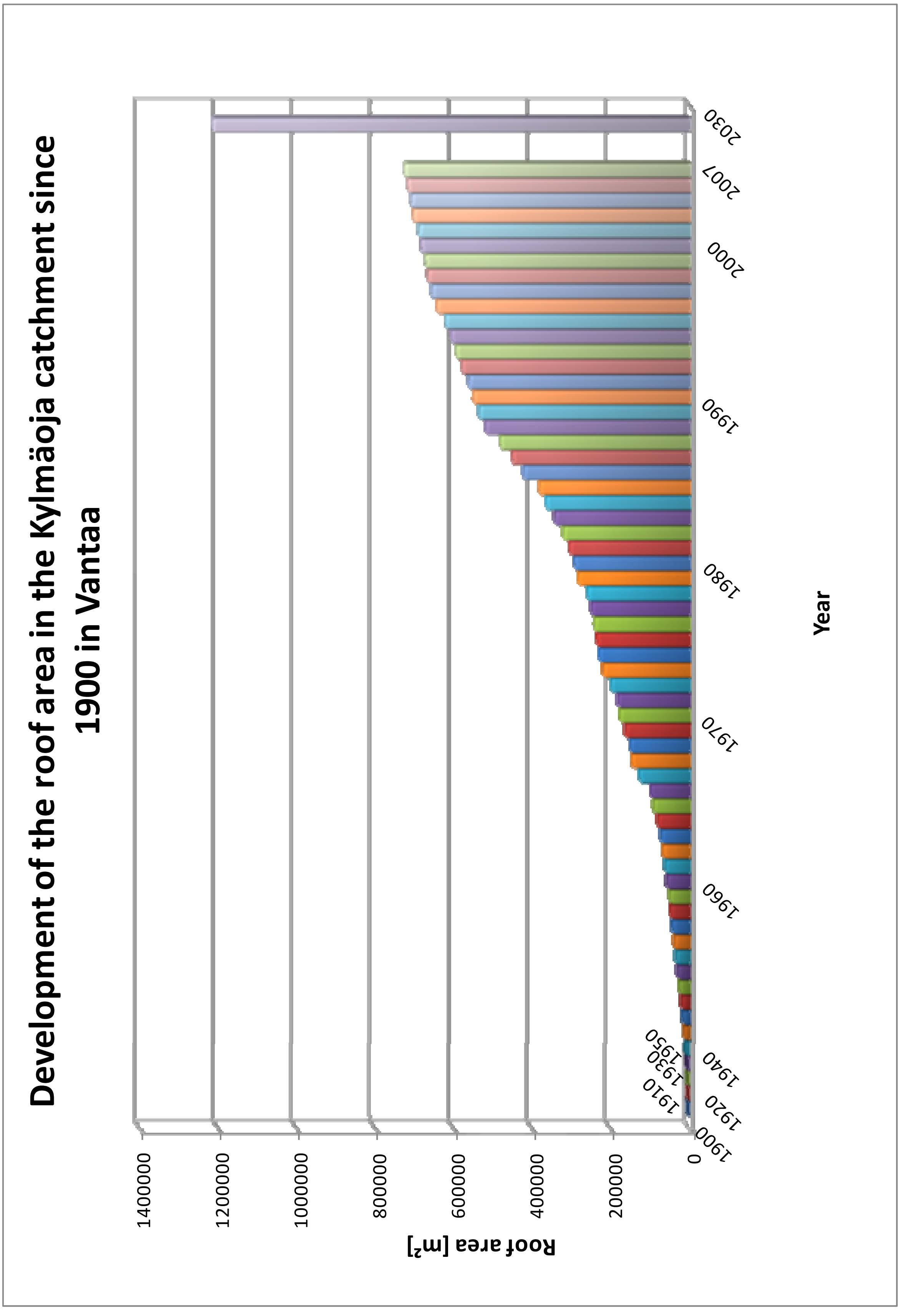


Figure 4.22 The development of roof area in the Vantaa part of the Kylmäoja basin 1900 – 2030, based on the available building database from the city of Vantaa.

4.2.3.2 Tuusula

Since the database used for the spatial analysis of the areas of the Kylmäoja catchment located in Tuusula, namely parts of the subcatchments 1, 2 and 6, was created during this project, according to the specific needs of this research, instead of detailed differentiation of building types, land-use categories were used. The existing structures were sorted by the use of building and the database contains the categories detached housing, office buildings, industrial buildings and outbuildings – the last one separated because an utilisation of the related yard either does not exist or is included in the later chapter with the corresponding main building.

The produced database contains no information about the floor area of buildings for the years before 2007, due to the lack of digitized information. The relation between floor area and roofage needed for the forecast in 2030, because of the fact that land-use plans deal either with efficiency or a plot-ratio, both related to the floor area, was established with the factors evaluated for similar areas in Vantaa. The factors for housing derive from Vantaa's part of subcatchment 1, factors for industrial buildings were used from subcatchment 7, containing a similar, though smaller, industrial structure as represented in Tuusula. The coefficients are shown in table 4.2.

Table 4.2 The table shows the factors between roof area and floor area for the three subcatchments in Tuusula. The numbers derive from the results of the investigation in Vantaa for similar areas.

	Residential areas	**Industrial areas**
Catchment 1 – Tuusula	0.82	0.80
Catchment 2 – Tuusula	0.82	0.80
Catchment 6 – Tuusula	0.82	0.80

To be able to implement the forecast year 2030 to the same output, these four categories were combined, resulting in the separation into buildings with residential use and structures with either industrial purpose or used for work places as office buildings.

This reduction had two main reasons. In first place, the housing areas in the catchment in Tuusula consist only of detached houses, most of them built before 1975, making a distinction, as made for the city of Vantaa for detached, two-family and row houses or apartment blocks, not necessary. And second, the result of the analysis in Vantaa showed, that the relation between roofage and impervious yard area for buildings of almost any commercial purpose, present in the catchment, remains approximately the same.

Unlike the analysis in Vantaa, the analysis in Tuusula focused on different years for observation. Since the base of the created data were general maps, produced earlier in longer time intervals, the output has to concentrate on the years, from which maps are available. Those were the year 1975 - the closest to 1977, the year 1993 – for 1992 used in Vantaa, 2007 and 2030. The year 1982 had to be neglected because of missing data.

The largest unbuilt areas left for construction and considered in the various plans of the municipality belong to the subcatchment 2, the basin of the western branch of the Kylmäoja stream, located north of the Helsinki-Vantaa airport. Together with the existing roof area of 34491 m^2 the predicted increment of 164187 m^2 will add up to a total roofage of 198678 m^2, a relative growth by 475 %. Of the total increase of roofage in the Tuusula catchment from 2007 till 2030, 246417 m^2, almost 67 % will happen in the subcatchment 2. The main contributors to this increase are two large work place areas located west of the highway Tuusulanväylä, creating a roofage of approx. 103000 m^2, when using an efficiency of 0.70, similar to the one used in Vantaa for similar areas.

The catchment in Tuusula is mostly defined as an industrial and work place area. Besides existing private housing, no areas are defined as residential areas in the general plans of the municipality. This development can be seen from the charts of the three subcatchments partly located in Tuusula shown below.

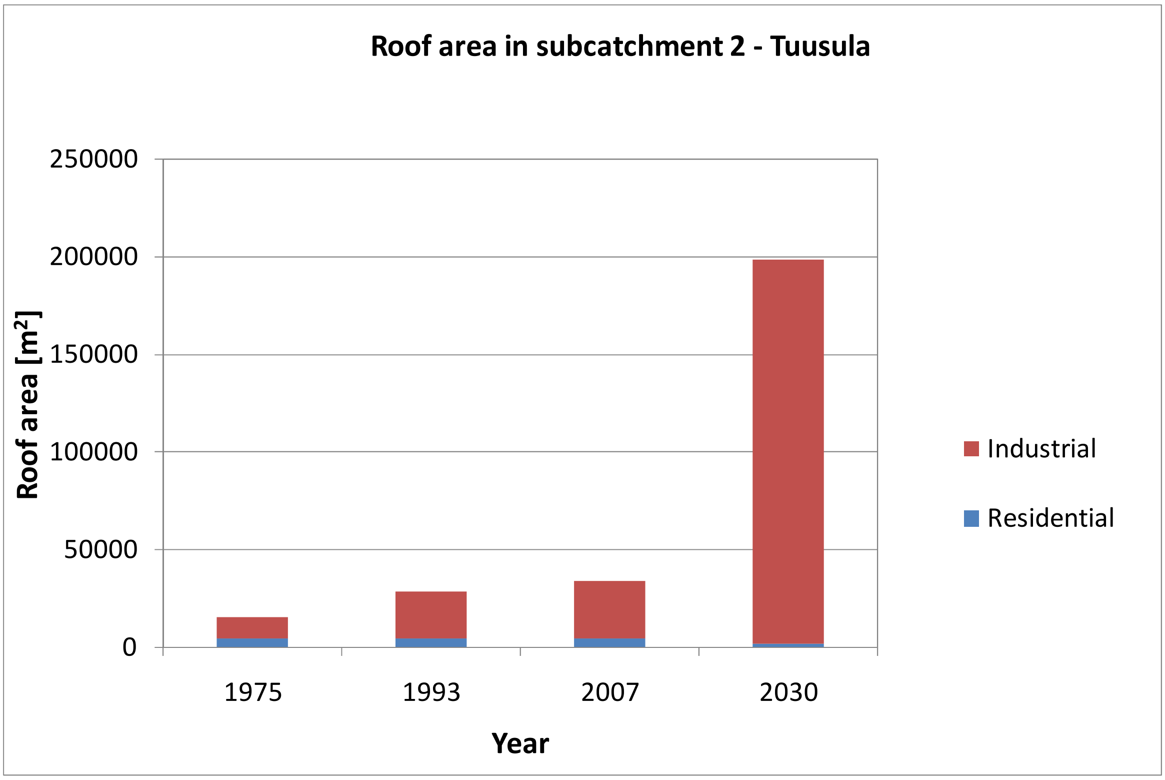


Figure 4.23 Roof area in subcatchment 2 – Tuusula 1975 – 2030.

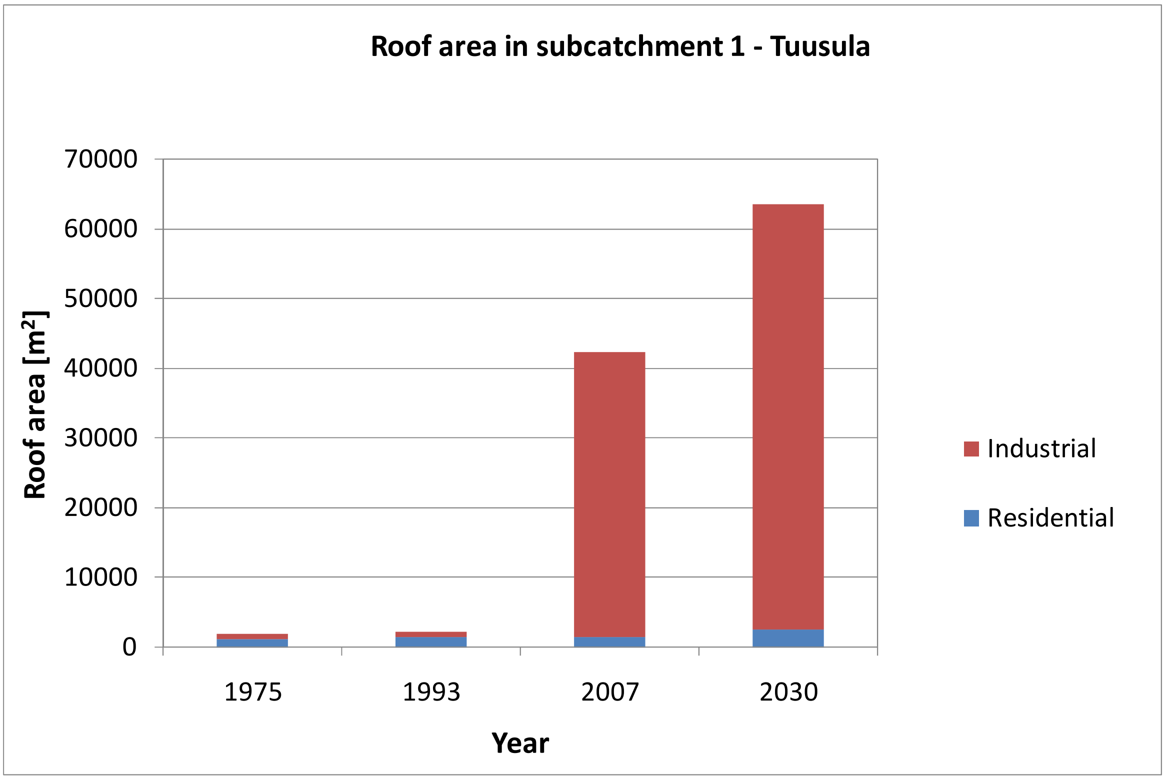


Figure 4.24 Roof area in subcatchment 1 – Tuusula 1975 – 2030.

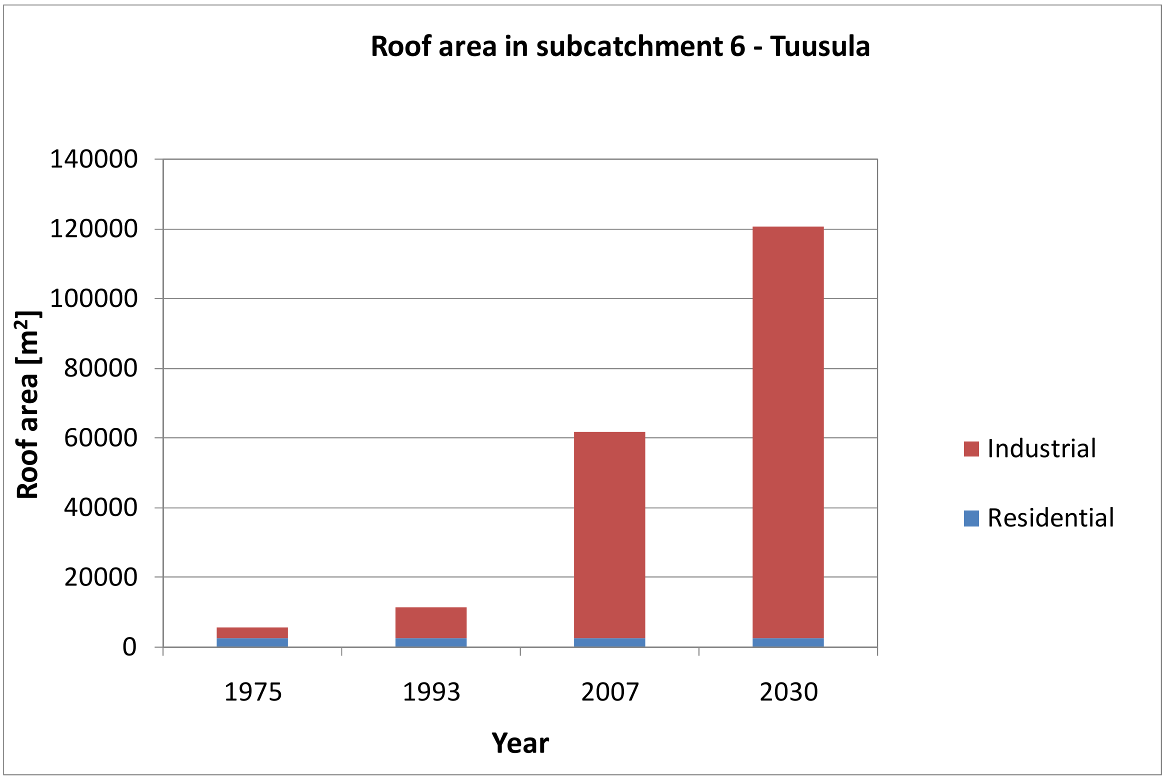


Figure 4.25 Roof area in subcatchment 6 – Tuusula 1975 – 2030.

The development of the roofage in the entire watershed located in Tuusula can be seen from figure 4.26. According to the analysed data, the roof area in Tuusula will reach a total of 375444 m^2, which means that in 2030 almost 25 % of the entire roof area within the Kylmäoja catchment will be located in Tuusula. In other words, in 2030, the constructed roof area in Tuusula and Vantaa will be equal in proportion to each municipality's share of the total catchment.

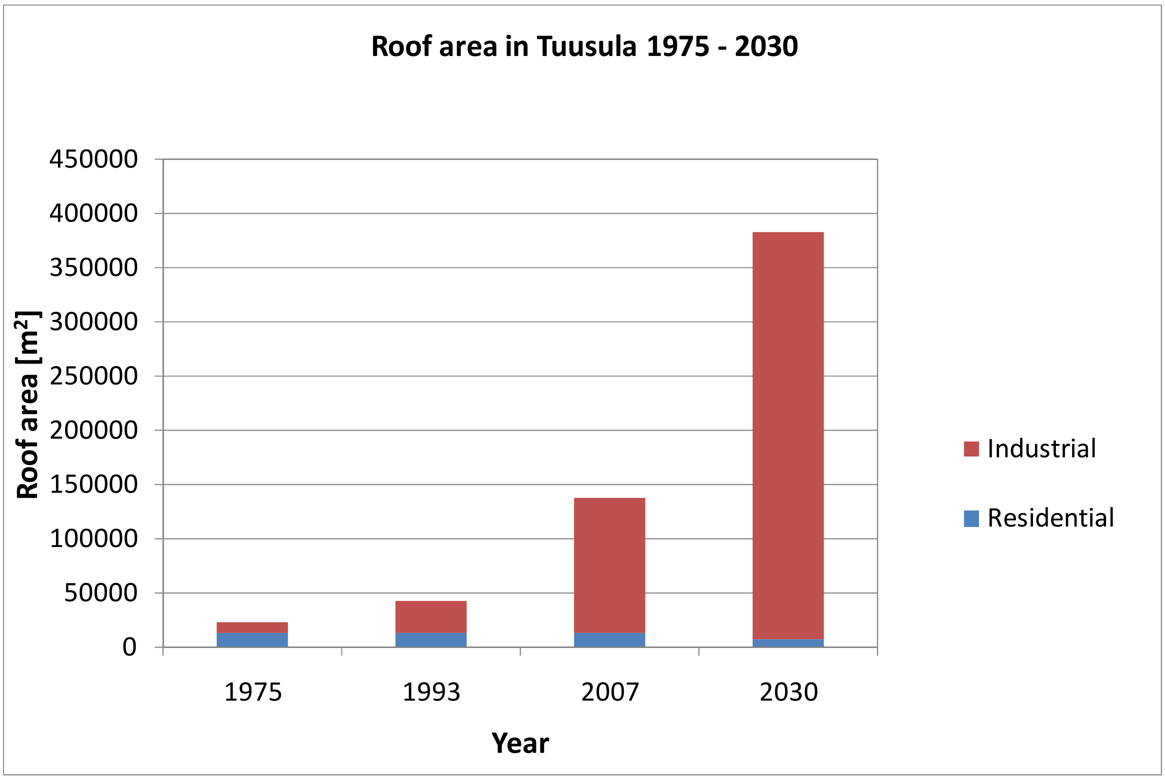


Figure 4.26 The development of roofs in Tuusula's part of the catchment 1975 – 2030.

4.3 Analysis of roads

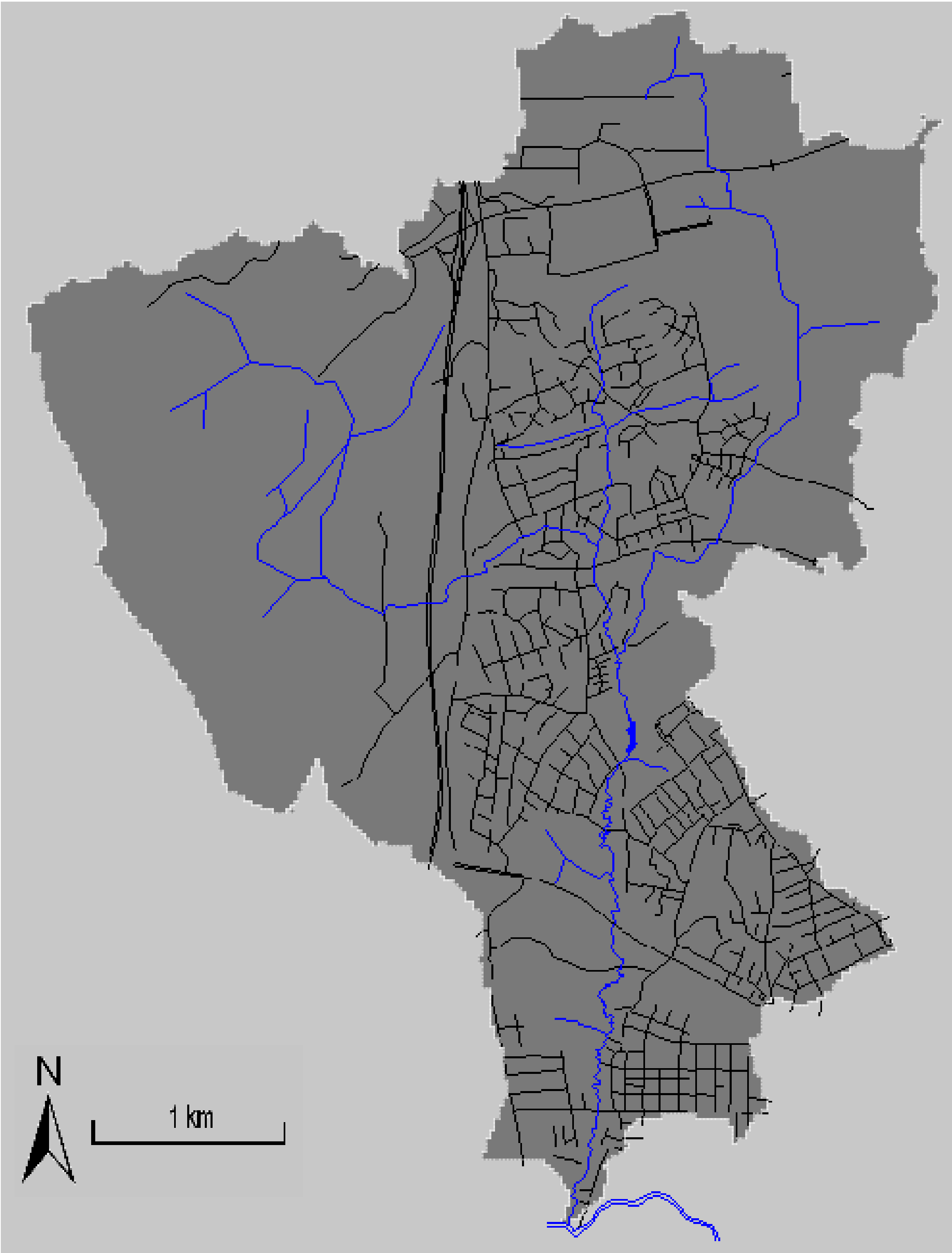


Figure 4.27 The map shows the network of streets and roads (black) in the Kylmäoja catchment. The blue line represents the stream and the dark grey area defines the Kylmäoja catchment.

Figure 4.28 Different types of roads found within the Kylmäoja catchment. The highway Tuusulanväylä east of the Helsinki-Vantaa airport (picture taken September 2008).

Figure 4.29 A typical small street in a low-rise residential area (picture taken September 2008).

4.3.1 Vantaa

The investigation of road surface in the city of Vantaa contributing to the stormwater run-off in the Kylmäoja catchment was based on a dataset about the road network within the city's borders, sustained by the city of Vantaa.

The data contains such information as the dimension of the section (width and length), type of road surface – according to the road administration of the city, all major and most minor roads are constructed with either asphalt or bituminous surface – and the time of construction. The data of the time of construction is inchoate, especially for roads built before the 1980's. Since the time of construction is crucial to get the actual contributing surfaces for the years in observation, the road data was compared with the development of building structures. The assumption, that roads in settlements, and to interconnect them, are build short before or along with development of first houses, affirmed also by conversations with local residents and members of the building authority of the city of Vantaa, allowed to narrow the point of construction down to a time period of a few years. For the time steps considered in the analysis, 1977, 1982, 1992 and 2007, this definition is accurate enough.

The result of the comparison was an exact, for the roads sections with a given date of construction, or approximate date of construction for every section of road in the Kylmäoja catchment in Vantaa.

The estimation of the road situation in 2030 in the city of Vantaa is difficult to make. City planned areas already have a sufficient road network, making bigger construction of new roads unlikely. The renovation and eventual extension of existing roads could not be considered, since there is not enough data existing for the long time span looked at.

Areas defined in the Master Plan, which are not city planned yet, include minor internal roads. Due to the fact that their extension is small compared to the rest of impervious surfaces in the catchment, these minor road networks were also not considered. Smaller connection roads and pathways between e.g. buildings and parking places are considered in the impervious yard area of the building complex in question, with the derived factor between floor area and yard area.

The biggest infrastructure project in the basin of Kylmäoja is the planned ring rail line. The Government and the City of Vantaa have agreed to implement the Ring Rail Line project. Construction starts in 2009 and traffic on the Ring Rail Line is scheduled to start in 2014 at the latest. The 18 km long rail track will connect the centre of eastern Vantaa, Tikkurila, with Myyrmäki, the centre of western Vantaa, via the Helsinki-Vantaa airport. The track will cross the Kylmäoja catchment from east to west. The reserved area for rail traffic in the catchment is 40.876 m^2.

The influence of the new railway on the discharge in Kylmäoja derives not only from the rail track itself, but also from facilities constructed along with it, besides stations and bridges, mainly parking places.

The catchment contains two stations for the ring rail line, the station in Leinelä, a residential development area of Vantaa and the optional station in Ruskeasanta. Whereas construction of apartment buildings in Leinelä started already in 2008 and shall be finished by the year 2015 (Vantaan kaupunki – Ref. 6), realisation of the office park planned around the intersection of Tuusulanväylä and the ring rail line was postponed and is not considered to happen before 2030 anymore. The earlier planned station in Ruskeasanta was therefore reduced to a station reservation for an option later (Kehärata). The location of the planned railway and the stations in Leinelä and Ruskeasanta are shown in figure 4.30.

Figure 4.30 A general map of the catchment showing the Ring Rail Line (black), with the station Leinelä and the station reservation in Ruskeasanta (red). Tagged are the potential work place area around the station in Ruskeasanta and the residential development in Leinelä. The rail track leads to the main rail track to the east and continues to the Helsinki-Vantaa airport and further to Myyrmäki to the west (modified map, original Vantaan kaupunki).

4.3.2 Tuusula

The procedure of analysis of the road network in Tuusula was similar to the investigation of building structures in the same area. Base were again general maps of the years 1975, 1993 and 2007 in combination with aerial photography.

Since the dates of construction for roads were unknown, the estimation of those was concluded via the status of development of different areas, assuming, that the construction of buildings and roads in the area went more or less parallel. Since the span between the years in observation was more than a decade an inaccuracy of a couple of years was also here, as for the analysis in Vantaa, negligible.

In difference to the city of Vantaa, the road network in Tuusula does still contain some sections with gravel cover, making the differentiation of the surface important. Nevertheless the share of gravel-covered roads is not too large in influence. In 2007, more than 85% of the roads in the catchment belonging to Tuusula had either asphalt or a bituminous cover, in total an area of 138000 m². The share of gravel roads was below 15%, in total 18000 m².

In the land-use plan shown in figure 4.31, the L and LT represent areas for road traffic and LL stands for areas reserved for aviation. Whereas the road marked with LT represents Tuusulanväylä which already exists at the moment, the objects referred to as L represent the planned extension of Kulomäentie leading from the highway to the west, planned to be the 4th arterial road in the metropolitan region, the Ring Road IV (Kehä IV). This road is, beside the new ring rail line, the biggest infrastructure project in the catchment and will be brought to realisation within the next two decades (Tuusulan kunta).

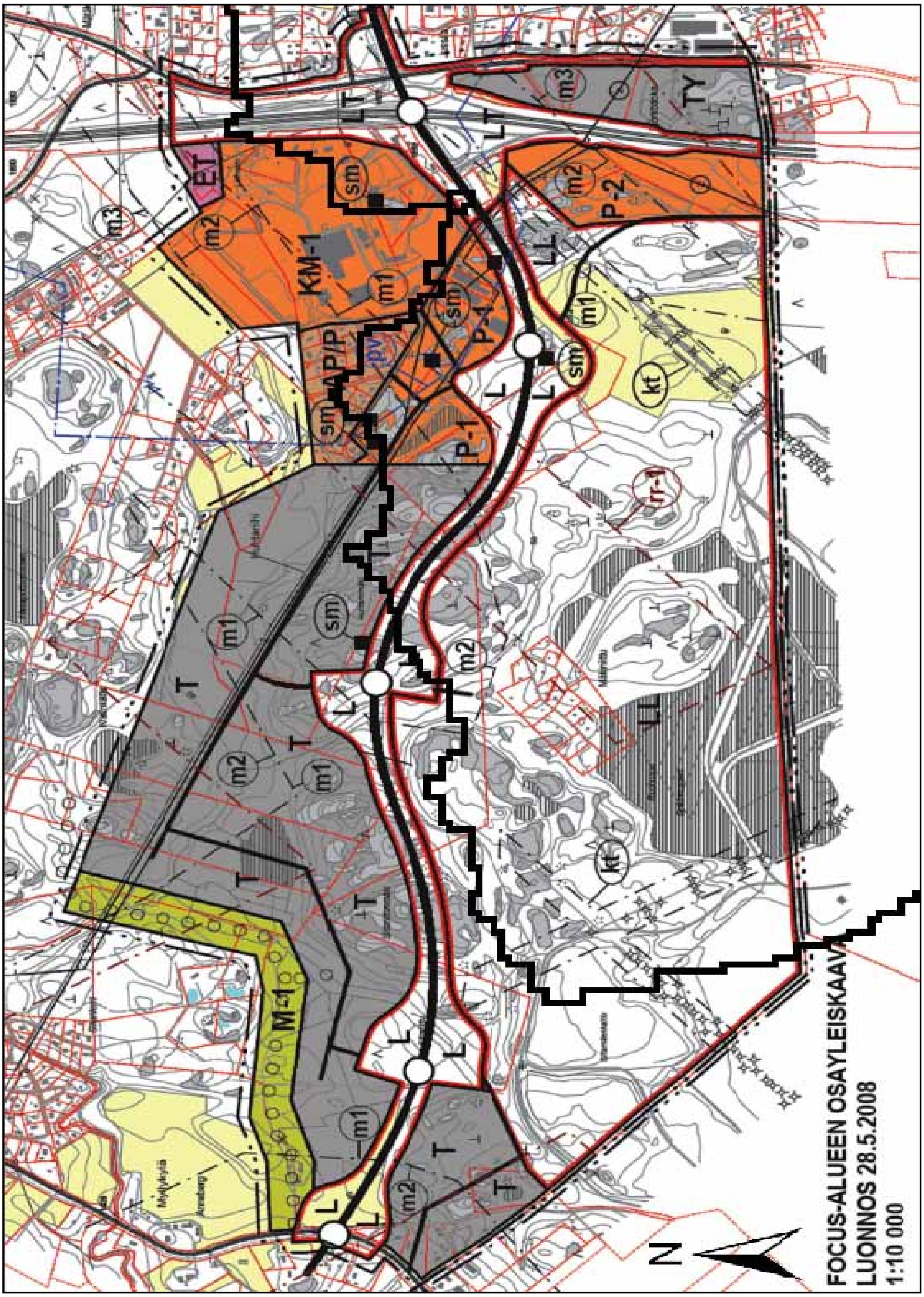


Figure 4.31 General land-use plan for parts of subcatchment 2 located in Tuusula. The map shows the south western part of the planned business park FOCUS. The northern border of the Kylmäoja catchment is also shown (modified map, original Tuusulan kunta).

4.3.3 Results

Since the analysed data is of the same kind both for Vantaa and Tuusula, even though latter one was created during this project, no separation is done between the two municipalities for the report of the results.

The only noticeable increase in impervious area caused by roads until 2030 is happening in the subcatchments 2 and 6, both times in Tuusula's part of the catchment. The addition of approx. 13200 m² of asphalt area in the subcatchment 2 derives from the construction of the extension of Kulomäentie – or Ring IV from the highway Tuusulanväylä westwards (the road traffic area reserved for this project can be seen from the map in figure 4.31). The construction of a traffic area, without clearly defined purpose, but represented in the land-use plan of the municipality of Tuusula, will add a little less than 3000 m² of impervious area to the subcatchment 6.

The road and street network in the city of Vantaa is well established already today, and will, according to the data available, not be significantly extended within the upcoming decades.

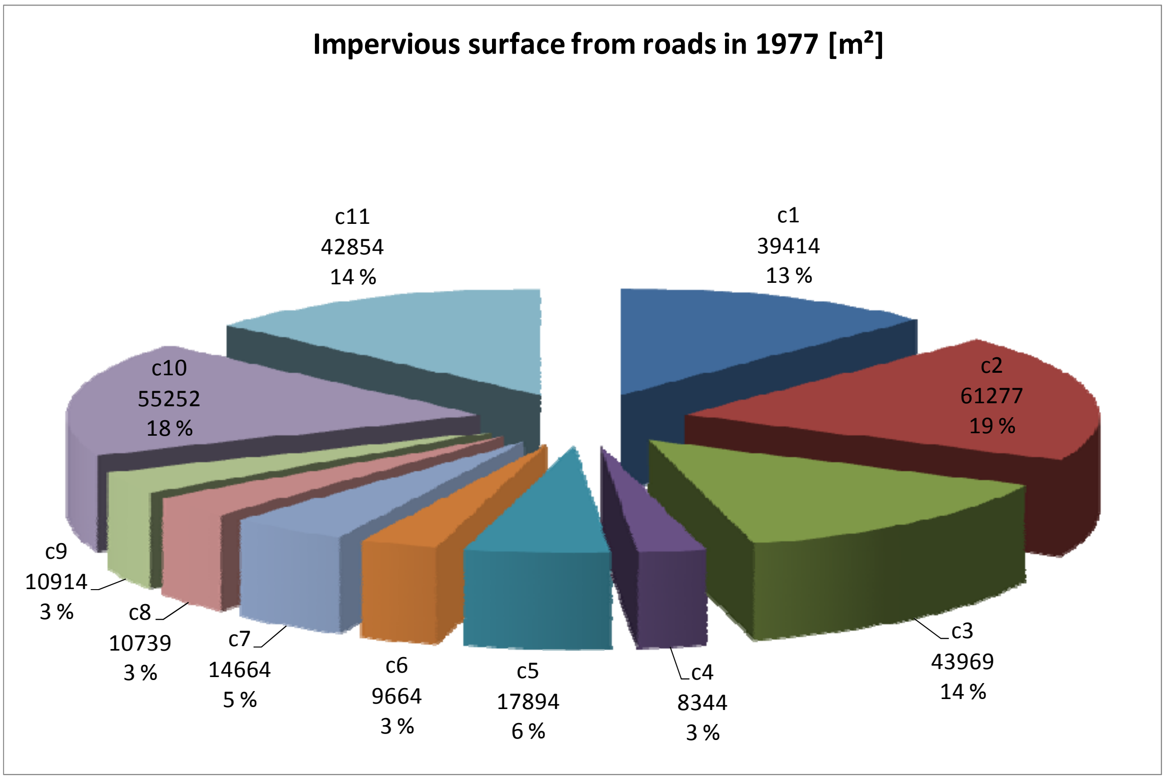


Figure 4.32 Road surface in the catchment 1977.

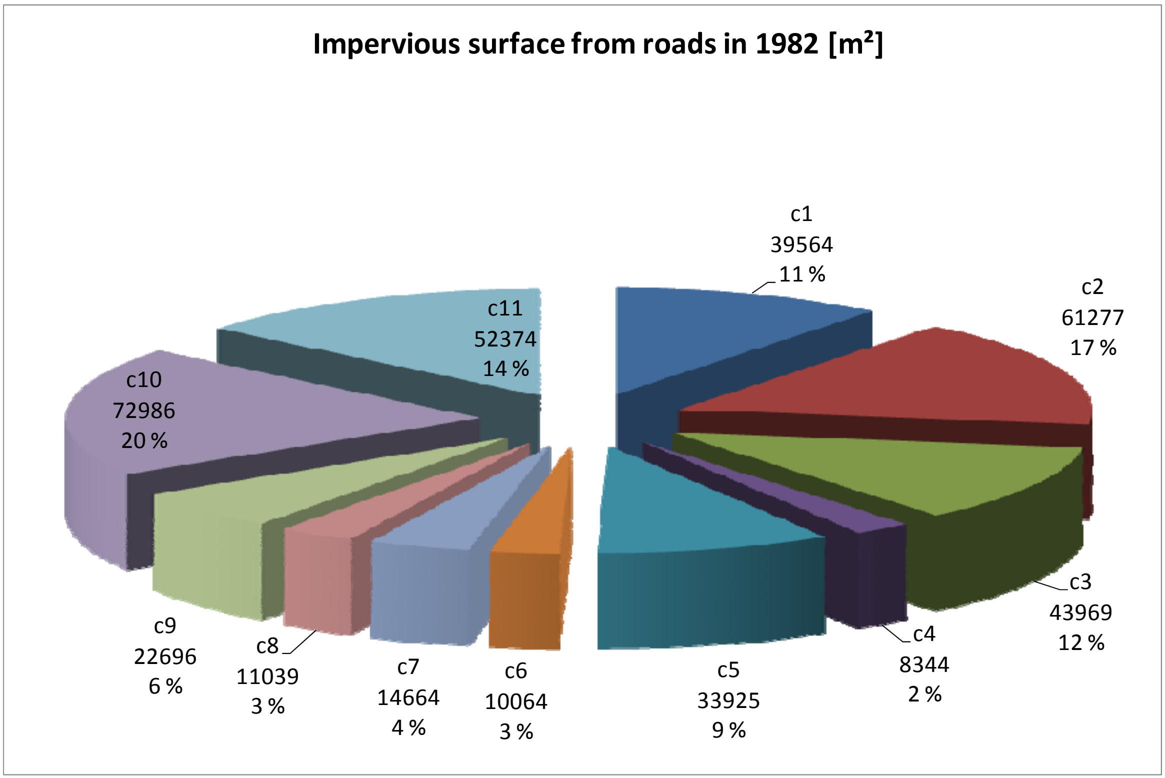


Figure 4.33 Road surface in the catchment 1982.

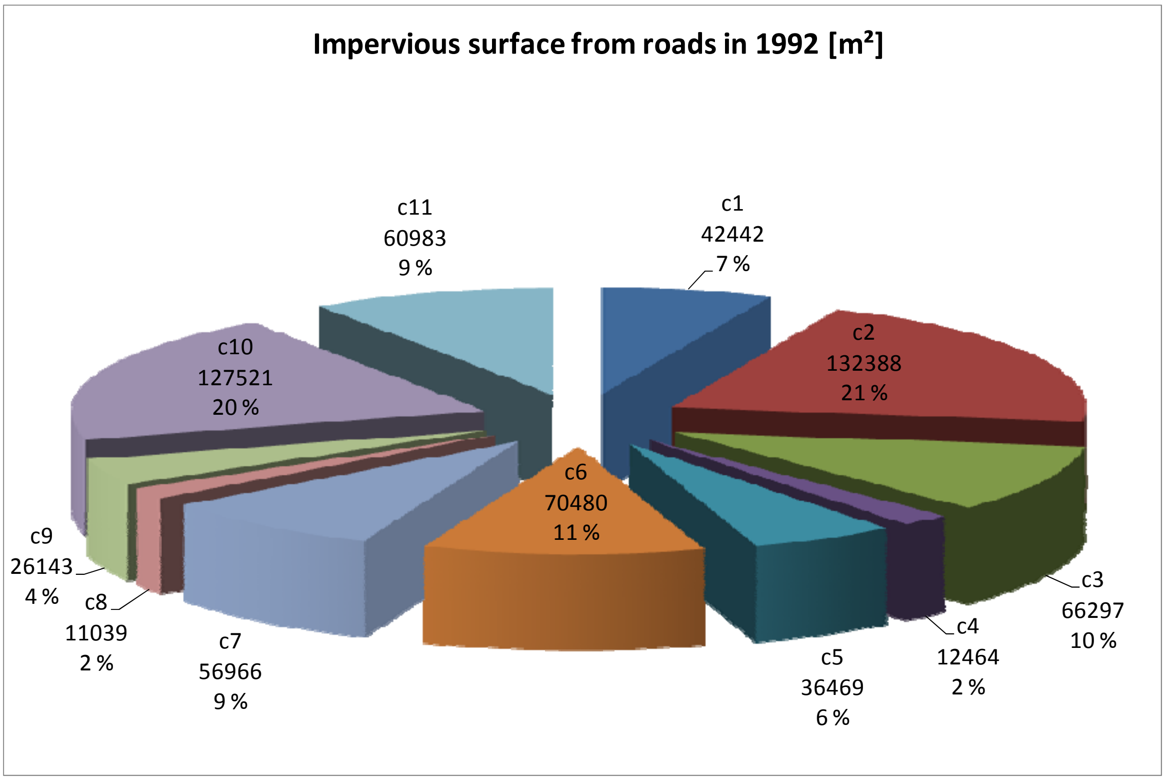


Figure 4.34 Road surface in the catchment 1992.

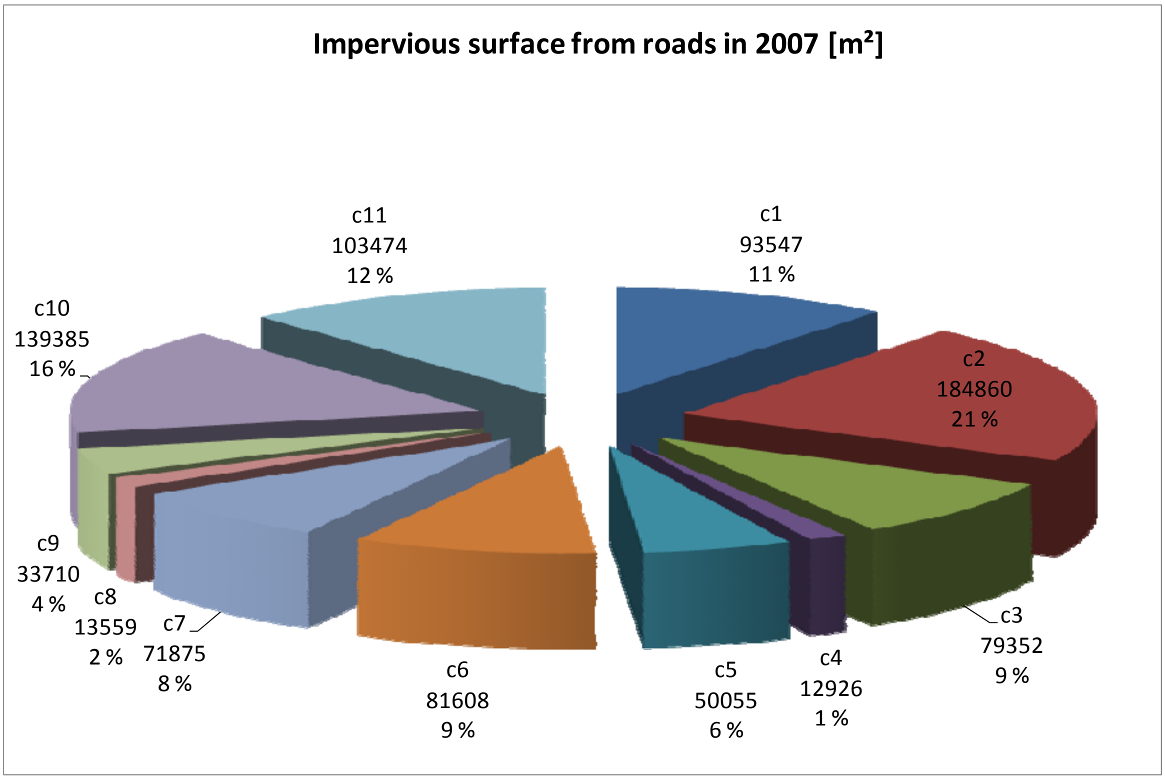


Figure 4.35 Road surface in the catchment 2007.

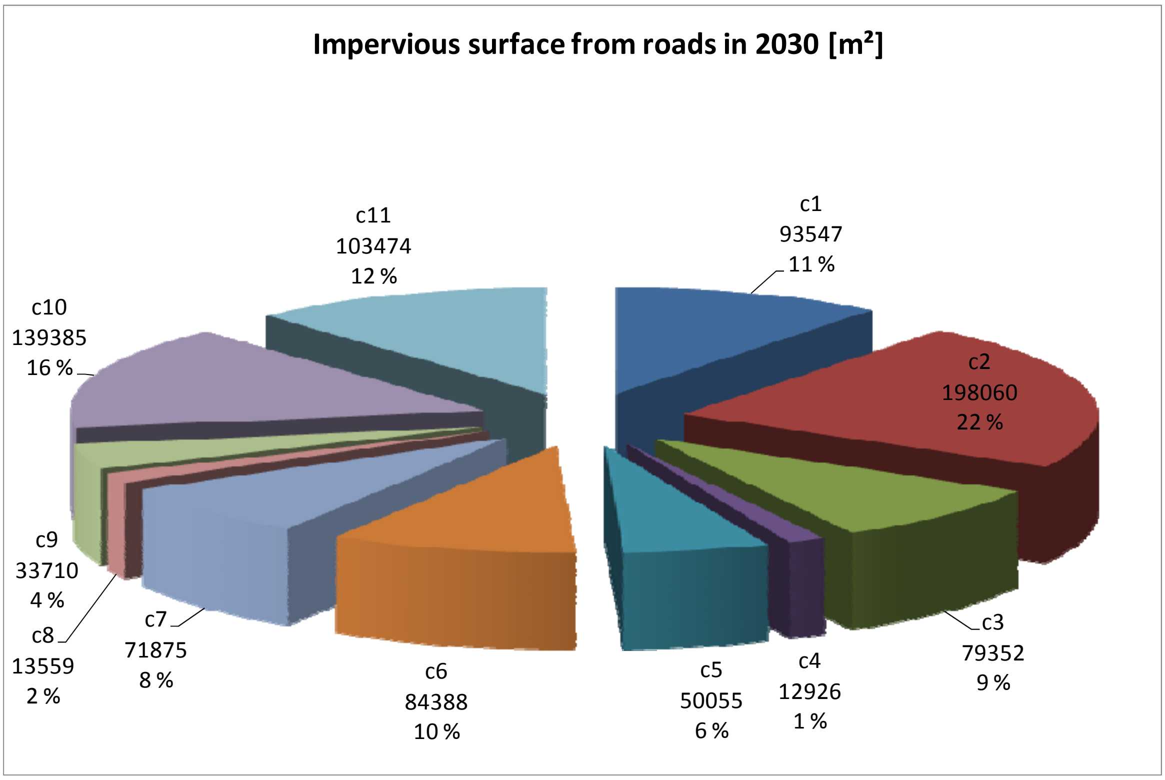


Figure 4.36 Road surface in the catchment 2030.

Since the only significant changes between the years 2007 and 2030 will happen in the subcatchments 2 and 6, the total road surface in the Kylmäoja catchment will not change much until the target year (figure 4.37). The construction in Tuusula will increase the impervious road surface in the catchment by approx. 16000 m² from 864350 m² in 2007 to 880331 m² in the year 2030.

As mentioned earlier, since the 1970's all roads in Vantaa are covered either with an asphalt or bituminous surface. The investigation of the area in Tuusula showed, based on orthophotos produced in 2007, that approx. 18000 m² or 10 % of the total road network in the catchment still have a gravel surface.

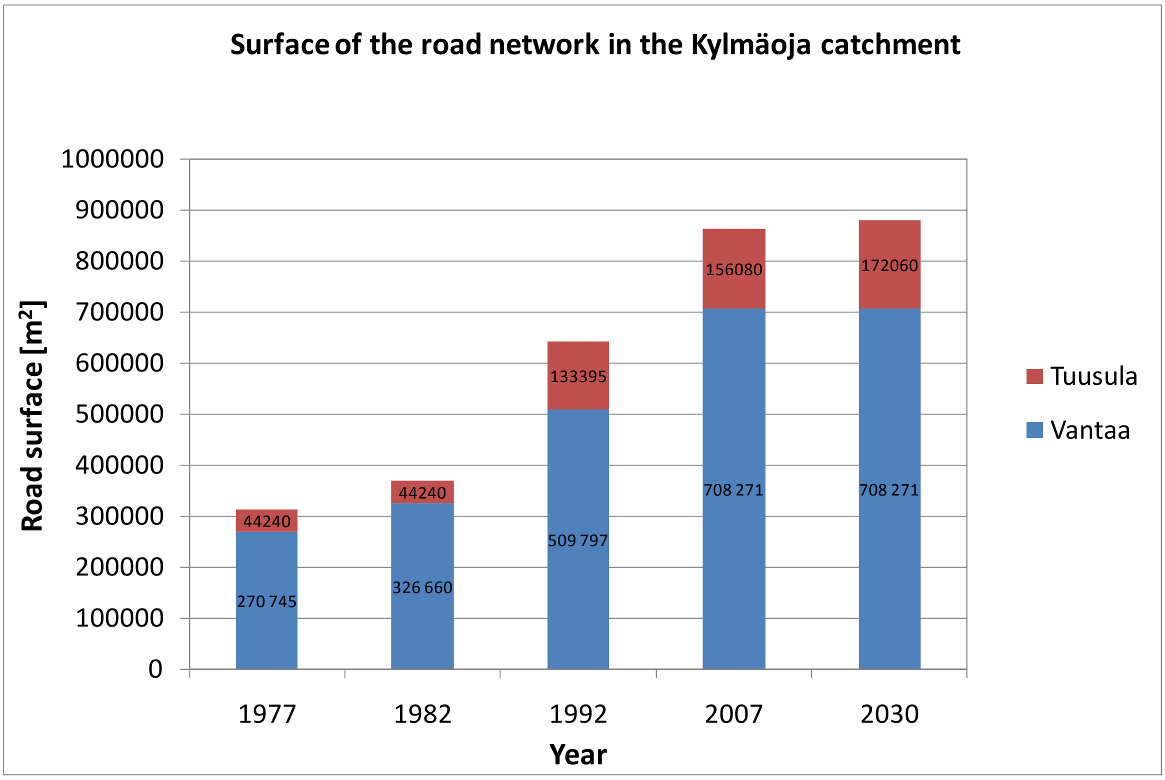


Figure 4.37 Road surface in the catchment Tuusula – Vantaa 1977 – 2030.

4.4 Analysis of the yard areas

4.4.1 Introduction and methodology

How does the layout of the yard of a detached house look like? How large is the area used for parking, pathways and other facilities? And which kind of surface was chosen to use? Gravel, sand, bricks or asphalt?

These questions and especially the answers to them are of significant interest for the estimation and calculation of run-off in urban and rural areas. Even though building permissions are required also for the design and layout of yards, as well as for the building itself, little data exists about their actual condition. The practice, to finish construction on the building itself, to move in and reduce the pressure of expenses as early as possible, and to postpone the design and construction on the yard to the next summer is common, especially for privately built detached houses. As a result, the inspection of the yard cannot be done at the same time with the house, making later checks time consuming and expensive and therefore often neglected. Changes on the yard may also be done after longer time without big efforts. These factors might be reasons for the lack of existing data on the yards.

Consequently, as already mentioned above in this document, the investigation of the condition of yards concerning impervious areas, differed significantly from the rest of the spatial analysis carried out.

A dataset had to be created, based on the existing building data and aerial photography. Since the area contains more than four thousand buildings, analysis of every yard was not possible within the limits of this work. The approach chosen was to investigate a reasonable number (between 5 and 50 yards for each building type, each subcatchment and each time step observed) of typical estates in detail for each existing building type, depending on the total number of the building type in the subcatchment, during the chosen time steps in each of the eleven subcatchments. With this procedure average values of impervious areas for yards were calculated and then used for all buildings of the type in question for the subcatchment and the time.

Table 4.3 Example for the calculation of the contributing yard area. Numbers derive from catchment 1 for the year 1977.

Building type	Number of buildings total	Number measured [-]	Area measured [m²]	Yard area average [m²]	Yard area total [m²]
	According to the municipal database		Measured from ortho-photos	Area measured / Number measured	Average area * Total number
Detached house	117	20	2979	149	17427
Two family house	15	8	1367	171	2563

Since orthophotos did not allow an exact identification of the kind of surface, the investigation of the surfaces was carried out partly *in-situ*. The inspection of yards of different building types in the catchment resulted in the conclusion, that the larger the building complex the higher the probability of the use of asphalt as the surfacing material. The approach was to even the effect of the material used for covered areas with the run-off coefficient. The total covered area in a yard is measured, independent from the surface type and the result of eventually too large areas then mitigated with the definition of the coefficient.

For detached and two-family houses, the assumption used was, that the distribution between asphalt and gravel used is even. Whereas for fifty percent of the covered yard area asphalt is in use, for the other fifty percent the material is gravel. This assumption goes as well for the yard areas in total as also for some yards in detail.

For row houses the relation of 80% of asphalt to 20% of gravel was determined as a useful estimate. The increase in comparison to detached houses mainly derives from the bigger amount of parking areas, which are mainly covered imperviously, contributing 80% to the area. The share of 20% derives from connecting pathways, which are mainly gravel covered. For apartment blocks and commercial as well as industrial buildings, the relation of parking area compared to gravel area reaches a proportion, allowing to neglect the gravel surfaces leading to a contributing asphalt area of 100%.

Special cases in terms of yard areas were also considered in the analysis, even though their contribution to the run-off may be negligible. Schools and kindergartens have, besides parking areas also playgrounds and sport fields. These yard areas were considered as a combination of playgrounds and asphalt covered parking lots. Another minor house type available in the catchment is the summer cottage, which was found to have normally only gravel used for parking spaces.

A special yard type in the catchment is the cemetery located in Ruskeasanta, east of the Helsinki – Vantaa airport. For this building the run-off coefficient will be determined as a combination between parking lots and common literature values for cemeteries.

Figure 4.38 A typical asphalt yard in the Kylmäoja catchment (picture taken June 2008).

Figure 4.39 A driveway covered with gravel (picture taken June 2008).

4.4.2 Vantaa

The analysis for the city of Vantaa and the municipality of Tuusula were conducted in an equal way, due to the lack of data for both areas, following the description given in chapter 4.4.1 and table 4.3. The software used for the analysis was MapInfo, a GIS-software used in the city of Vantaa. The software allows the definition of polygons on top of aerial photography and gives the possibility to distinguish buildings according to given attributes.

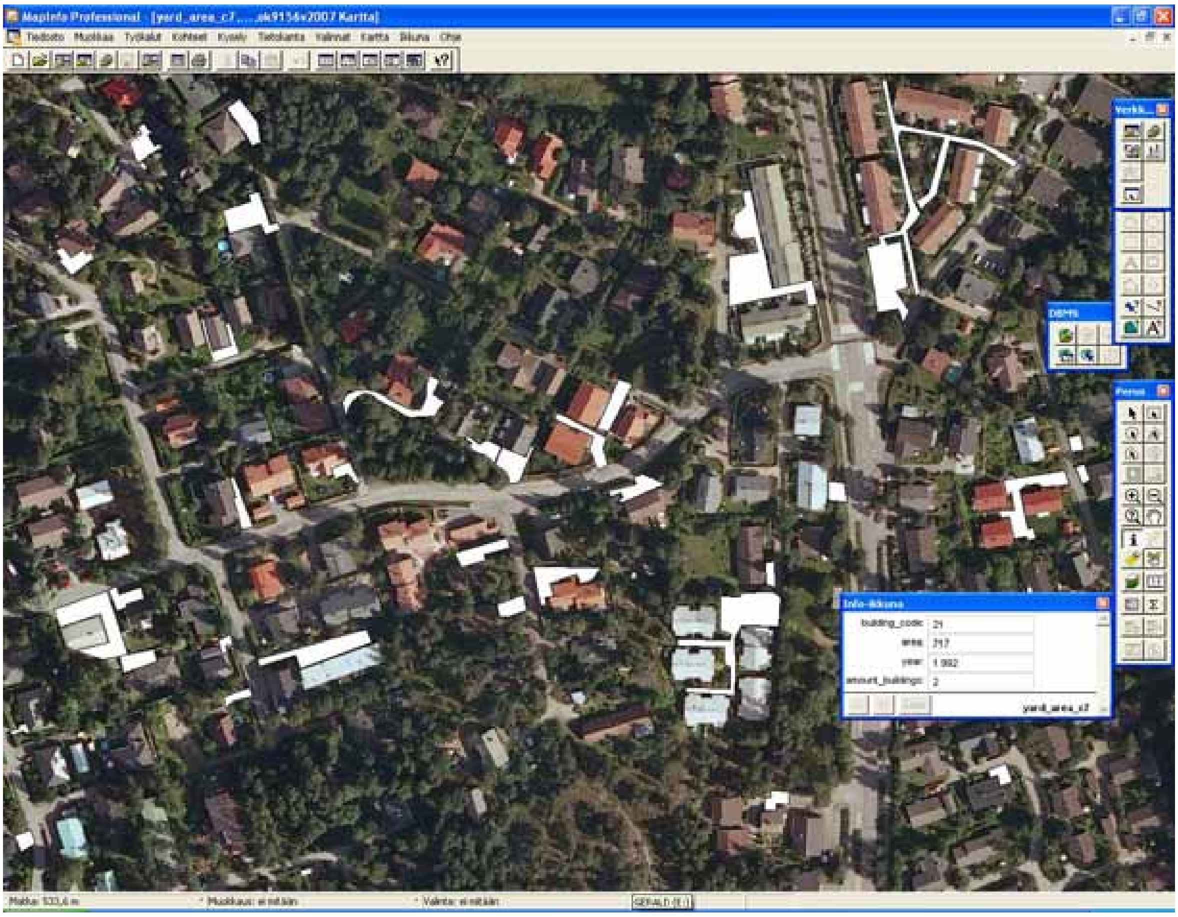


Figure 4.40 The figure shows a screenshot of the procedure for defining yard areas. This example shows a residential area located within the subcatchment 7 in the city of Vantaa.

4.4.3 Tuusula

In difference to the analysis of buildings and roads, the analysis of the yard area condition was conducted the same way for Tuusula as for Vantaa. An interesting aspect of the investigation is the high level of industrialisation in the catchment in Tuusula in terms of the relation of area consumption to number of buildings (details are explained under results).

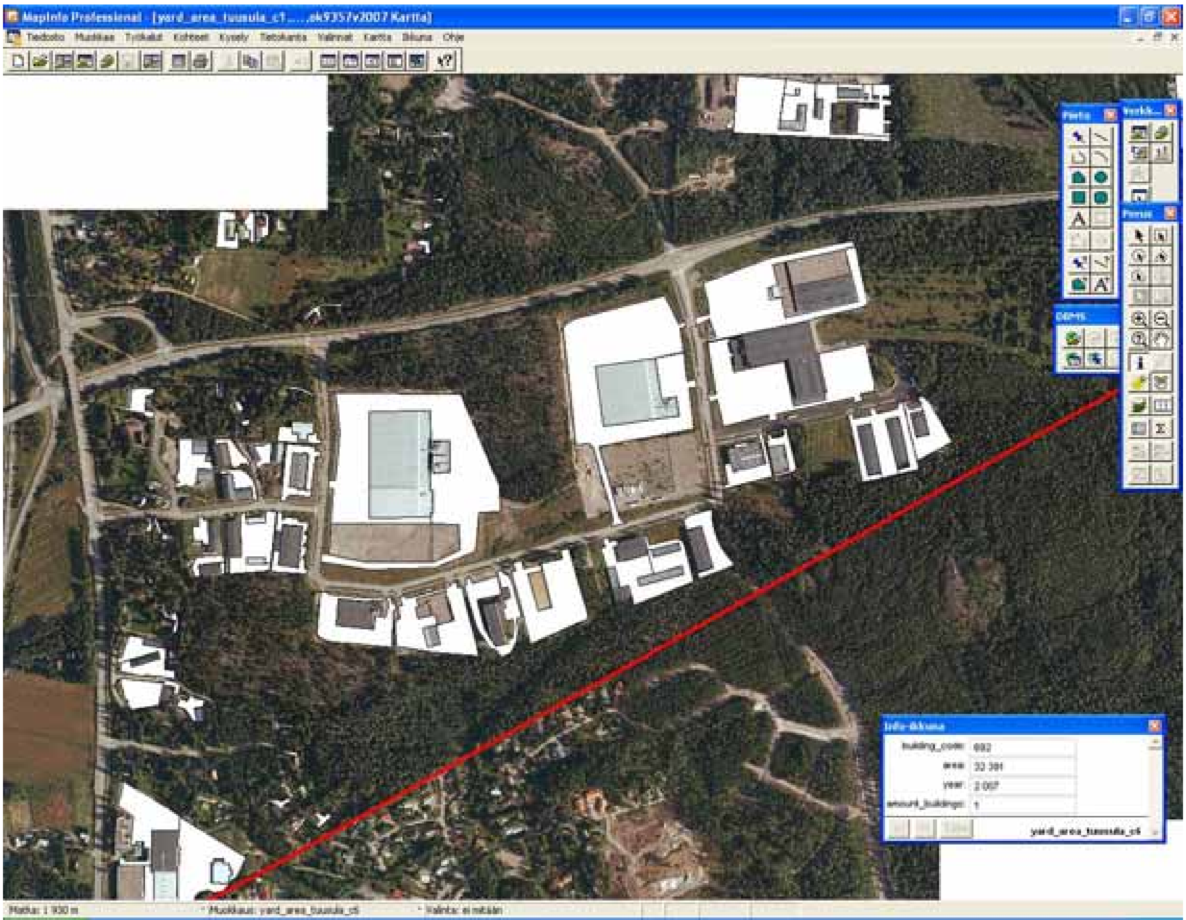


Figure 4.41 The figure shows a screenshot of the procedure used for defing yard areas. The example shows the industrial area located in the subcatchment 1 in the municipality of Tuusula (part of the development FOCUS). It is possible to see the dimension of industrial buildings (several logistic centres in the centre of the picture) in comparison to private housing (the small white spots in the left top of the picture). Possible to see is also the contrast between residential areas in Vantaa, just south of the border (red line) and the industry just north of it.

4.4.4 Results

As done for the output of the investigation of the roofage in the Kylmäoja catchment, the results of the spatial analysis of the yard condition are separated for the areas located in Vantaa and Tuusula.

Charts showing the development of impervious yard surface in the entire Kylmäoja catchment are presented in appendix I.

4.4.4.1 Vantaa

The relation between floor area and yard area in the eleven subcatchments in Vantaa was determined for the same categories of land-use as already conducted for the roofage.

For low-rise housing areas, detached, two-family and row houses the coefficient for the proportion between yard area and floor area reached from 0.32 in subcatchment 6 and 0.33 in subcatchment 8, to 0.95 in the subcatchment 9. The average value for the relation yard area – floor area in Vantaa for 2007, taking into account the distribution of the total number of 715 among the subcatchments, was found to be 0.74 for houses constructed between 1993 and 2007. In other words, in average for a building with a living area of 100 m², 74 m² have to be taken into account for the impervious area constructed in the yard. Since not 100% of these areas are asphalt – the distribution found reached from fifty-fifty between asphalt and gravel for detached houses, to 80% asphalt and 20% gravel for row and terraced houses, these areas are considered with evaluated run-off coefficients in the later hydrological interpretation.

For apartment blocks and high-rise residential areas, proportion values reached from the maximum of 0.88 in subcatchment 1 to 0.52 in the southern subcatchment 11. The average relation found for this land-use is 0.61. Service areas represented in the catchment have an average factor of 0.61.

Whereas the factors for the above described categories show a relatively small range, the relation between yard and floor area varies significantly for industrial buildings. For single objects factors of even 7.74 for a petrol station and 4.38 for a green house with shop, in this case only with gravel surface, were found. The smallest contributing yard area was only 60% of the floor area in the case of a storage facility belonging to a shop in subcatchment 7. To avoid unrealistic and especially too large yard area factors for the forecast, these singular objects were not considered when defining the average relation.

Table 4.4 The table shows the factors between floor area and run-off relevant yard area for the eleven subcatchments in Vantaa determined for the time span 1992 - 2007 and used initially for the year 2030. Factors for not represented land-use categories were not determined.

	A0 Detached house / row house / low - rise residential area	**Ak** Apartment blocks / high - rise resi-dential area	**P** Area for services	**T** Industrial buildings / office buildings / work place area
Catchment 1 - Vantaa	0.78	0.88		0.87
Catchment 2 - Vantaa	0.92			0.62
Catchment 3	0.71			2.52
Catchment 4	0.71			0.87
Catchment 5	0.68	0.67		0.87
Catchment 6 - Vantaa	0.32	0.88		0.87
Catchment 7	0.79			0.87
Catchment 8	0.33	0.88		
Catchment 9	0.95			
Catchment 10	0.72	0.69	0.69	0.87
Catchment 11	0.68	0.52	0.52	0.87

Since the development of impervious yard area and roofage in the catchment are related, the same conclusions as made earlier are also valid here. The largest increase in surface is expected to take place in the subcatchment 6. The number of 26383 m² in the year 2007 will be increased by 113400 m² and reach a total of almost 140000 m² in the year 2030.

As found for the roofage already, subcatchment 6 will be followed in terms of impervious yard areas by the subcatchments 1 and 11. The impervious yard surface in subcatchment 1 will almost double to 137000 m². The increase in the urban subcatchment 11 is expected to be 74500 m² or 45 %, summing up to a value of 241700 m² in 2030.

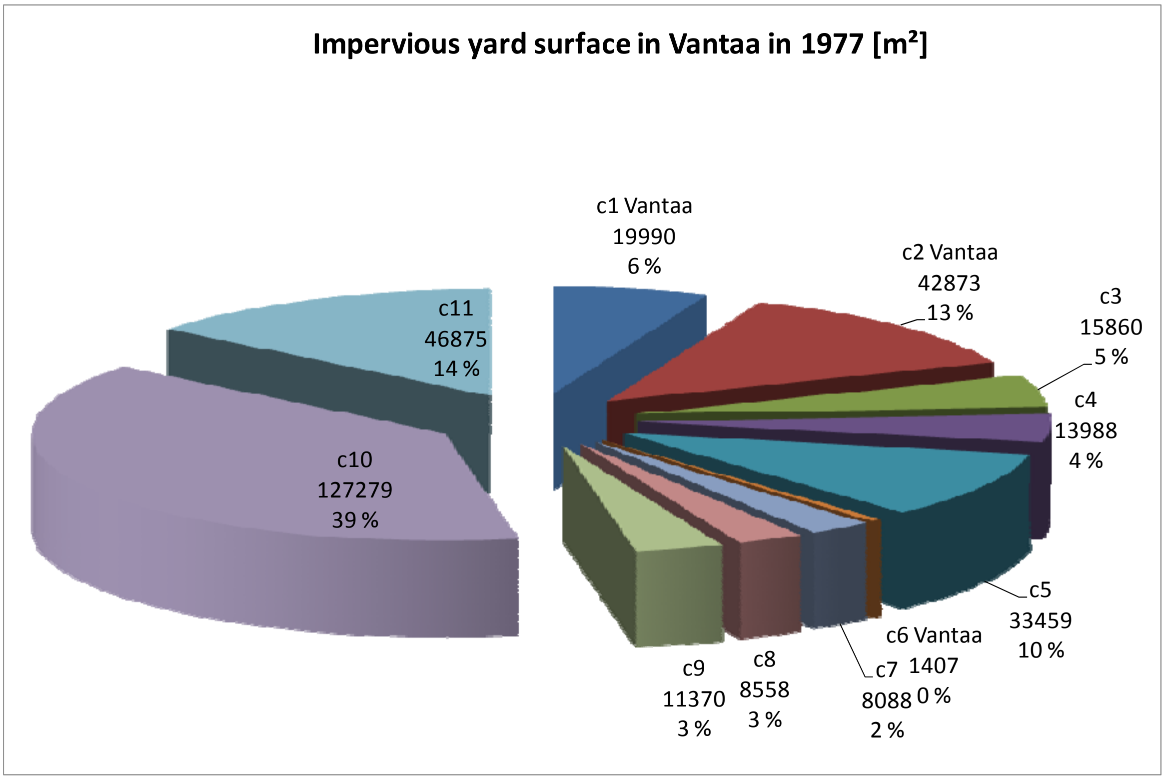


Figure 4.42 Impervious yard surface within Vantaa's part of the catchment assorted by subcatchments 1977.

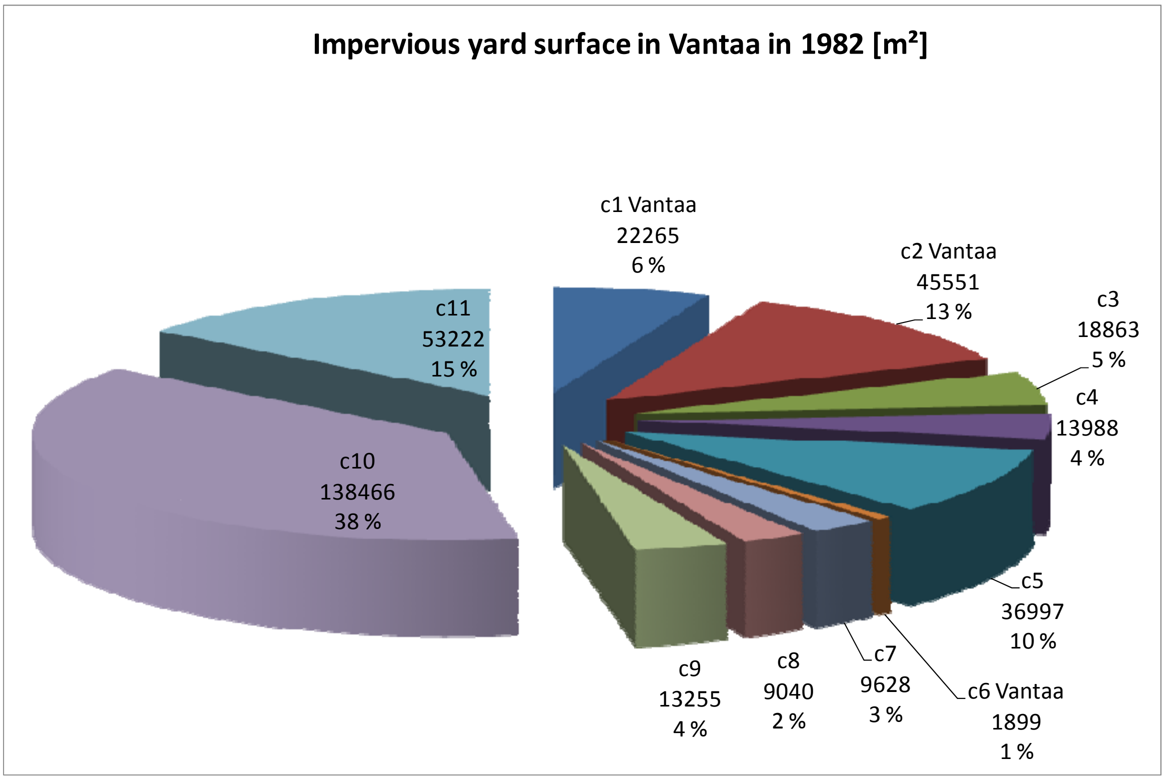


Figure 4.43 Impervious yard surface within Vantaa's part of the catchment assorted by subcatchments 1982.

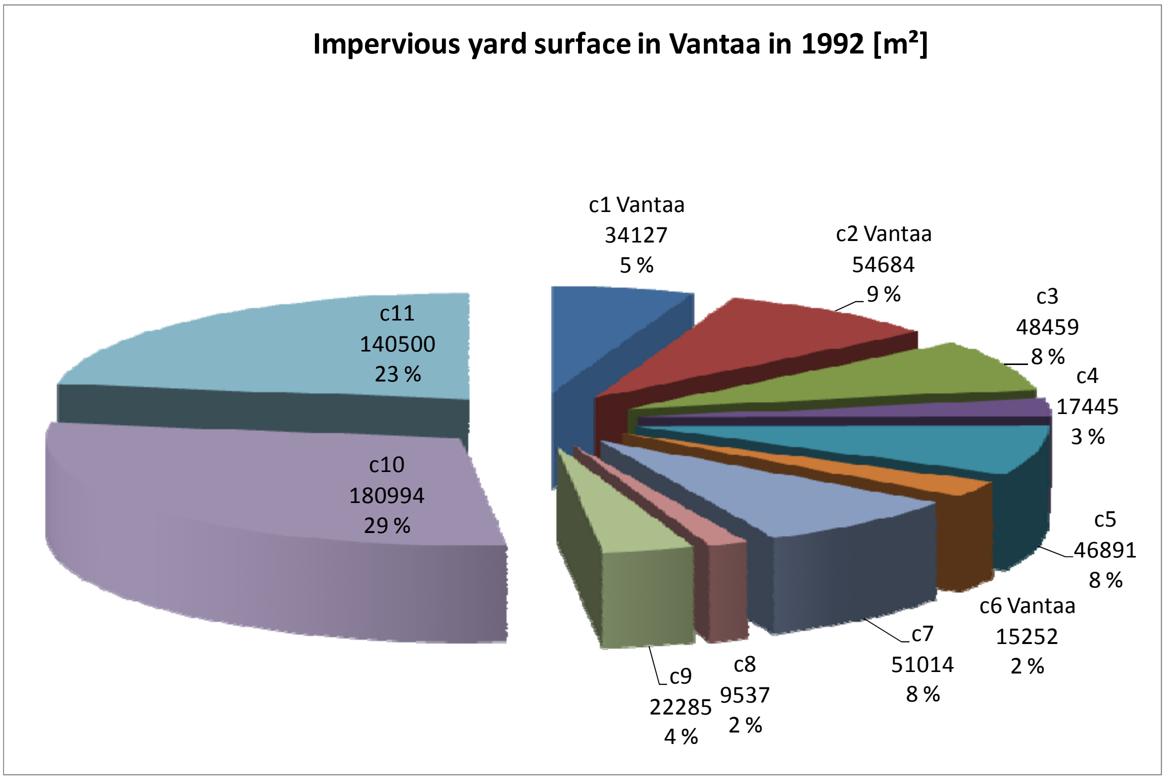


Figure 4.44 Impervious yard surface within Vantaa's part of the catchment assorted by subcatchments 1992.

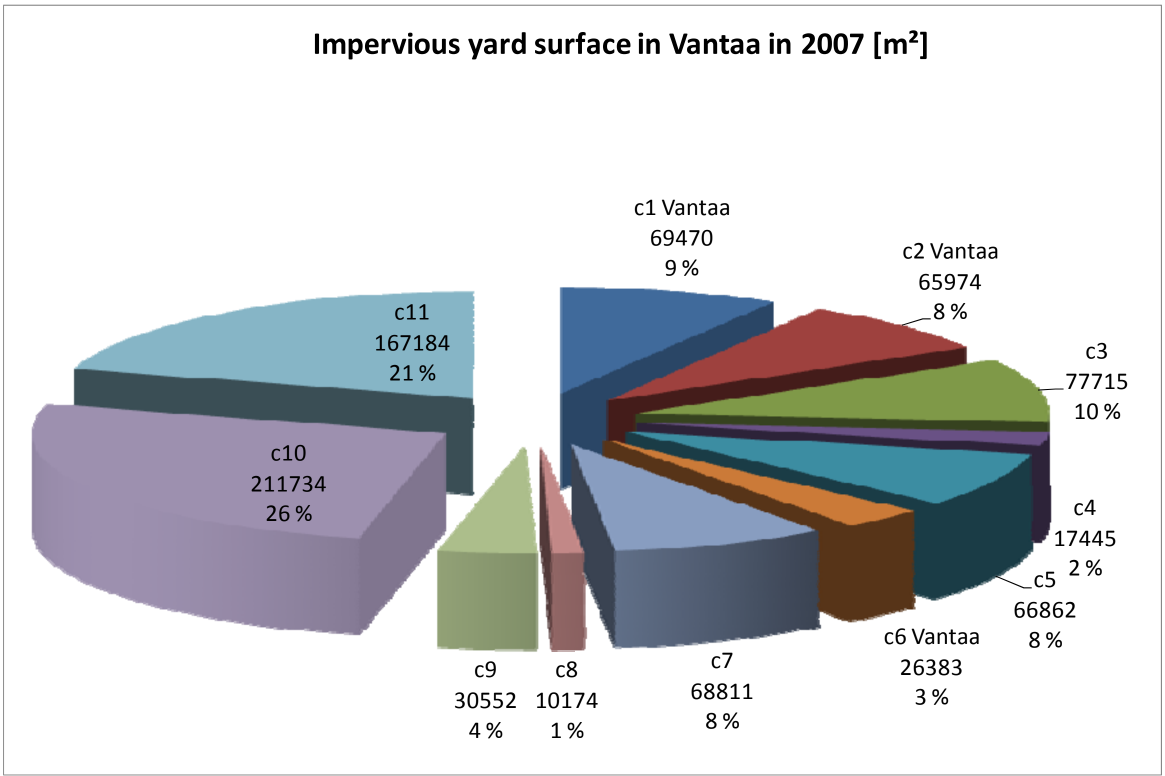


Figure 4.45 Impervious yard surface within Vantaa's part of the catchment assorted by subcatchments 2007.

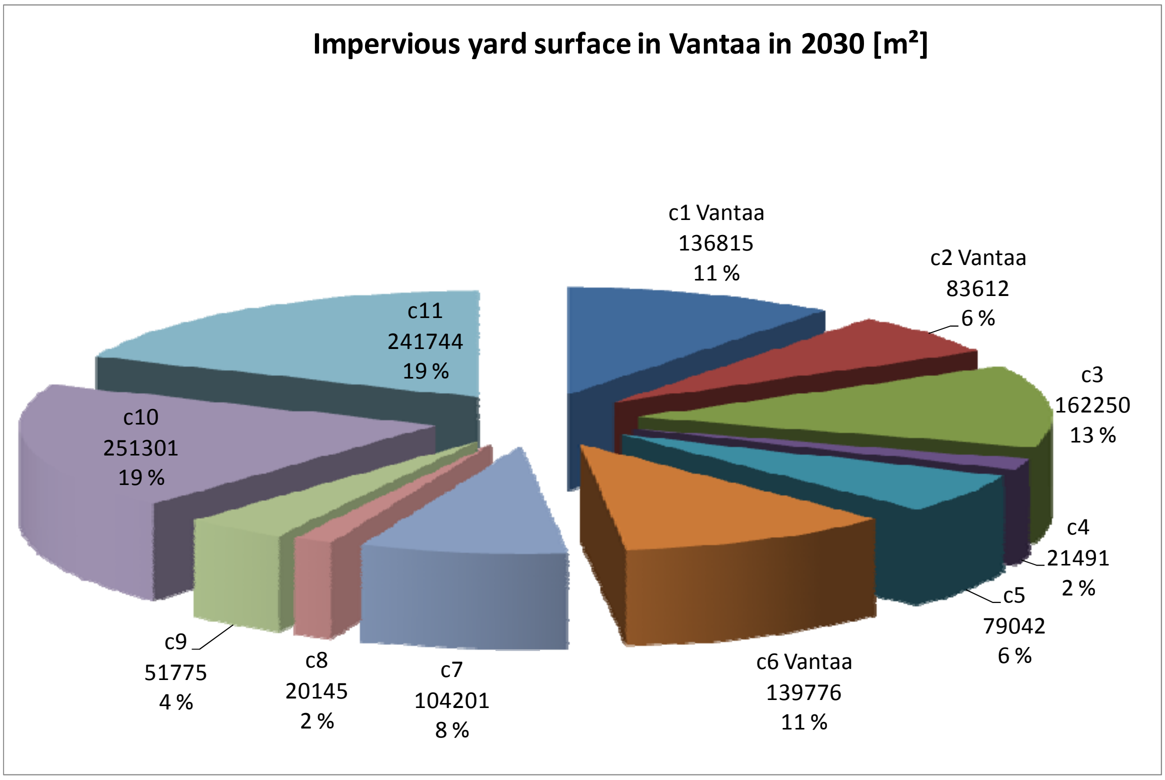


Figure 4.46 Impervious yard surface within Vantaa's part of the catchment assorted by subcatchments 2030.

4.4.4.2 Tuusula

Data on the floor area of buildings in Tuusula for the time before 2007 was not available and therefore, the establishment of a relation between impervious yard area and floor area, as conducted for the part of the catchment located in Vantaa, was not accomplishable. Instead, the relation was established between the yard area and the evaluated roof area, defined in the created database, to be able to use a factor for the year 2030.

The factors were defined for two different categories, private housing and industrial buildings, since a significant difference between office buildings and productive industry could not be found.

Table 4.5 The table shows the factors between yard area and roof area for the three subcatchments in Tuusula. The figures derive from the investigation of buildings constructed between the years 1993 and 2007.

	Residential areas	Industrial areas
Catchment 1 – Tuusula	0.78	2.15
Catchment 2 – Tuusula	0.78	1.72
Catchment 6 – Tuusula		2.14

The investigation showed that the factors in residential areas in Tuusula – in total a number of 68 detached houses were identified on the existing orthophoto material from the year 2007 – are slightly higher than the values found for Vantaa – a direct comparison was possible using the product of roof and yard factors in Vantaa.

The values found for industrial areas on the other hand, are significantly higher than the output for Vantaa. This development is caused by the type of industry represented in Tuusula. Logistical centres, as one example, consist, beside the already large dimension of the buildings themselves, of large asphalt areas used for parking and manoeuvring of trucks and other means of goods transportation.

The yard area in the catchment for residential and industrial construction develops similar to the roofage in Tuusula. Whereas the constructed yard area of residential buildings will even reduce according to the available data, the impervious yard area coming along with industrial construction, will grow by 130% to reach a total of 721836 m² in 2030.

Considering the run-off generated from roofs, dependency is only given on the dimension of the area. Hence 100 m² of roof of a detached house cause the same run-off, as the same area covering a structure used for industrial storage.

When looking at the yard area, as shortly explained earlier, the run-off depends, besides the dimension of the area of course, highly on the material used for the surface. For detached houses the materials found in use as surface cover were gravel, for half of the houses and yards and asphalt for the other 50%. For industrial and work place construction the material in use is asphalt in 100% of the cases.

Consequently, the influence of the constant industrialisation of the catchment on the run-off produced is disproportionate to the actual increase of impervious area, due to the higher run-off coefficient for asphalt – commonly between 0.80 and 1.00, compared to the value 0.63 used for the yards of detached houses.

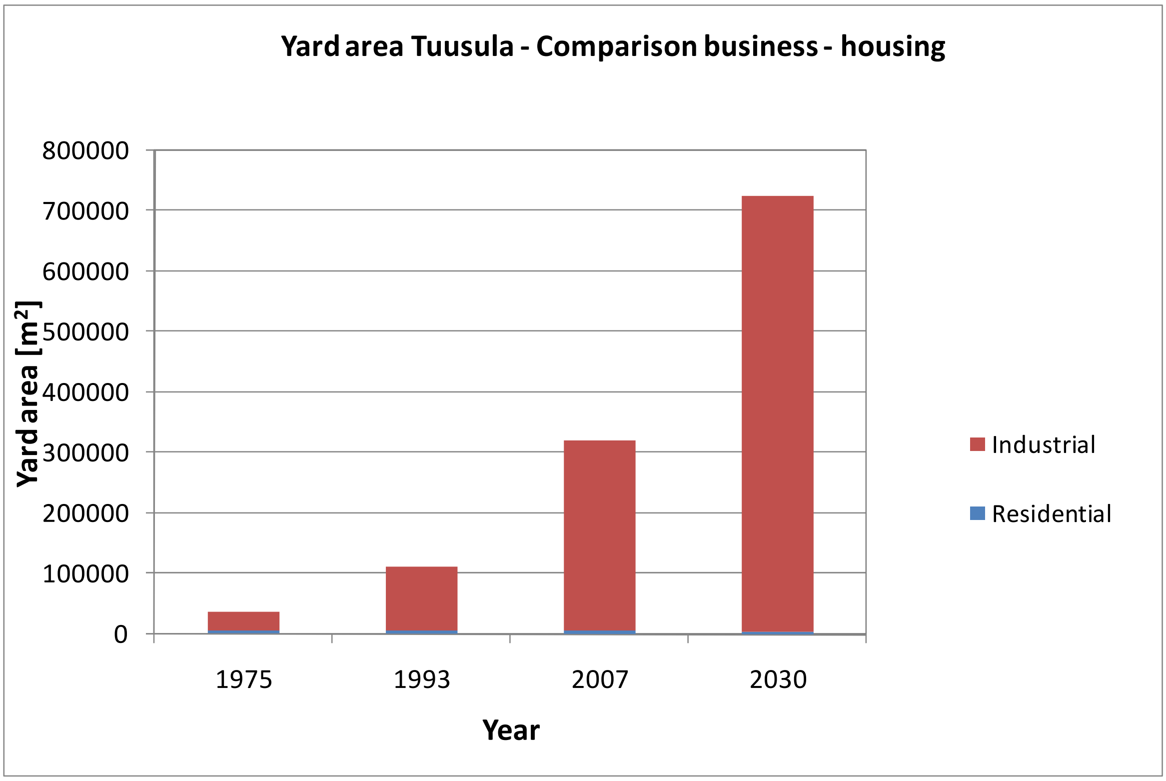


Figure 4.47 Impervious yard area in Tuusula's part of the catchment 1975 – 2030.

The subcatchment with the largest increase expected in yard area is the subcatchment 2, as also for the increase of roofage. The Tuusula part represents the northern part of this subcatchment generating discharge for the western branch of the Kylmäoja stream. The impervious area is expected to grow from almost 85000 m² in 2007 by more than 255000 m² to a total of more than 340000 m² in 2030.

The smallest development can be seen from the subcatchment 1. This area is expected to grow by 21000 m² to reach 63600 m² in 2030. The relatively small growth can be explained by the large share of already finished construction by 2007 in this subcatchment. The absolutely smaller number compared to the subcatchment 2 and 6 is caused mainly by the smaller extension of this subcatchment.

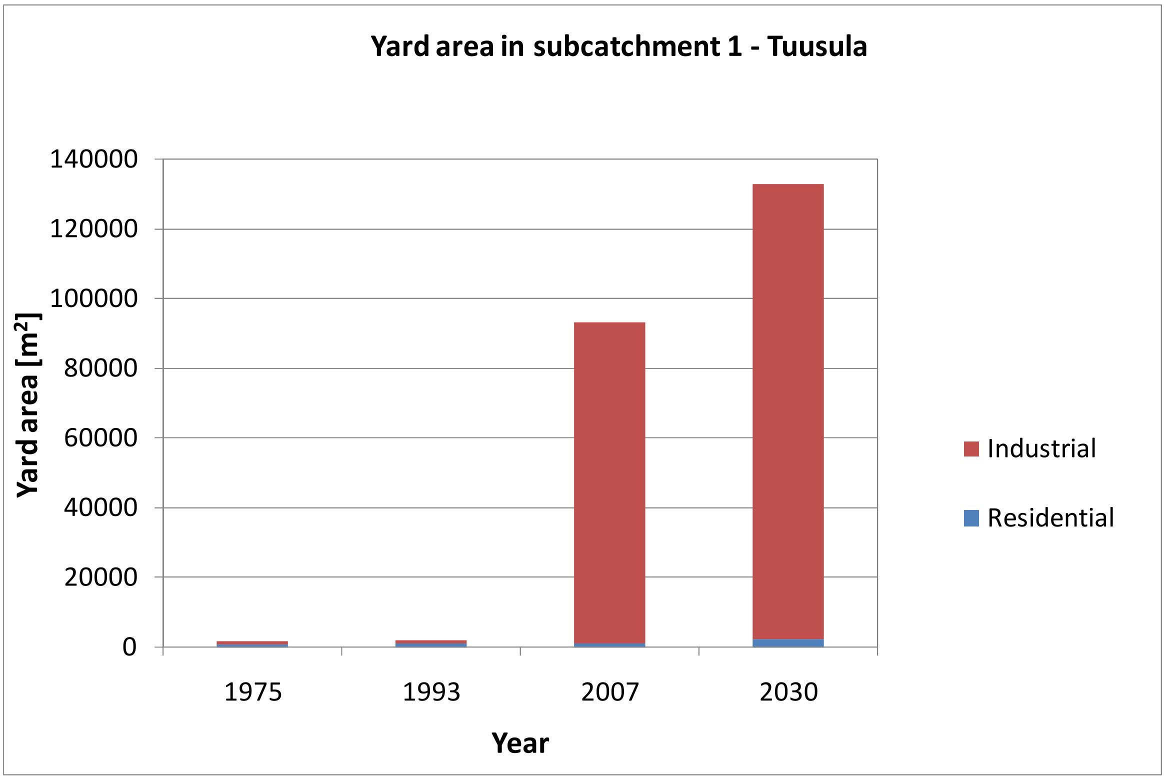


Figure 4.48 Impervious yard area in subcatchment 1 – Tuusula 1975 – 2030.

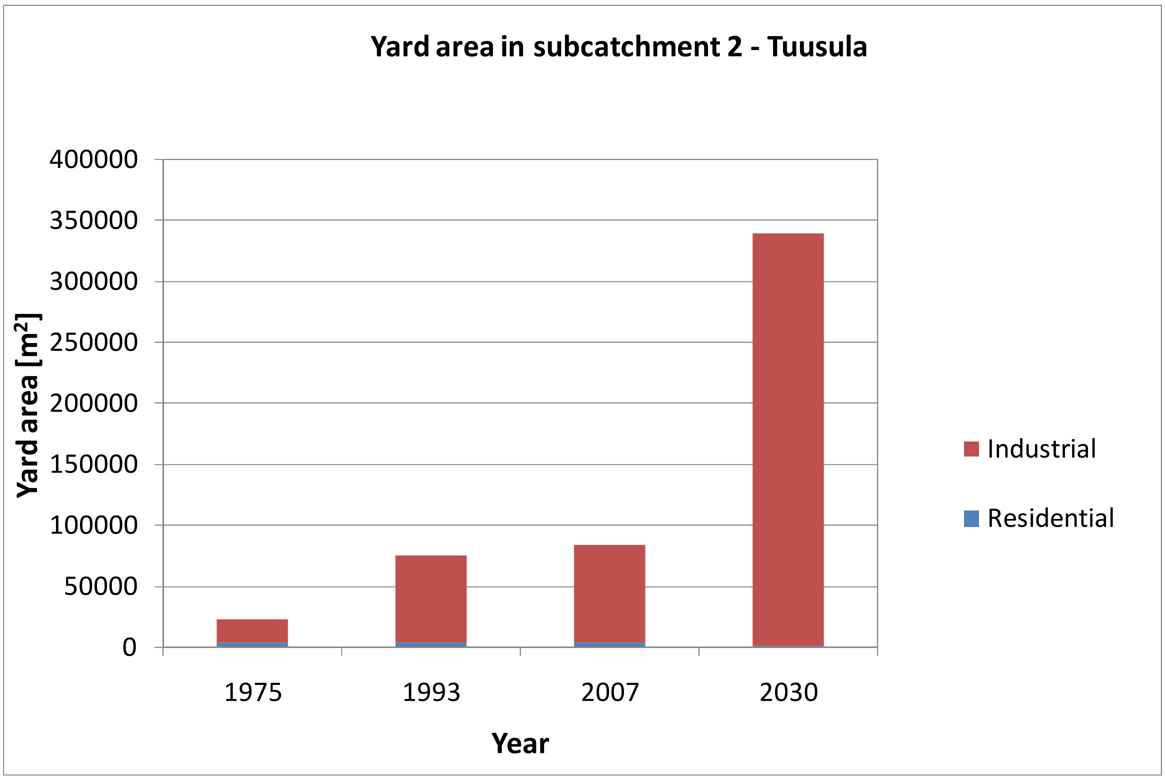


Figure 4.49 Impervious yard area in subcatchment 2 – Tuusula 1975 – 2030.

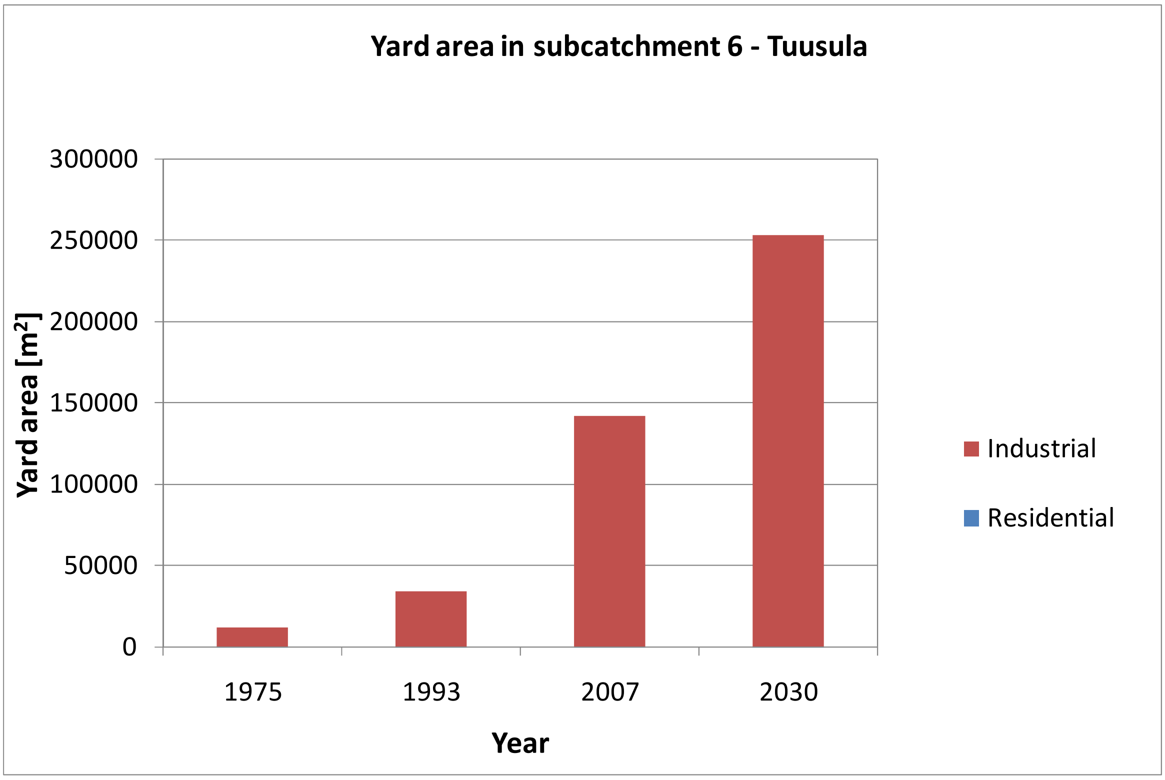


Figure 4.50 Impervious yard area in subcatchment 6 – Tuusula 1975 – 2030.

4.4.4.3 Helsinki-Vantaa airport

The international airport Helsinki-Vantaa is situated in Vantaa. The airport has been opened in 1952 for the Olympic Summer Games taking place in Helsinki. 13.1 million Passengers and 180.000 take-offs and landings in 2007 (Helsinki-Vantaa Airport – Ref. 1) make it the biggest airport in Finland (Finavia).

Figure 4.51 The picture shows the Helsinki-Vantaa airport seen from the East. The runway in the front belongs to the Kylmäoja catchment. The terminal facilities in the background do not generate run-off for Kylmäoja (picture taken September 2008).

Part of the runways as well as other infrastructure drain into the Kylmäoja catchment, the majority into the western branch via the subcatchment 2 and a smaller area, located in the subcatchment 3. Even though the contributing asphalt surface of the airport is huge in relation to the other factors discussed earlier, the airport infrastructure cannot increase anymore, considering the fraction important for the Kylmäoja stream, and also did not anymore after the first observation year 1977, except smaller extensions in the subcatchment 3 between 1993 and 2007.

The Helsinki-Vantaa airport accounts for an asphalt surface of one million square meters in 2007, mainly constructed already before the opening in the year 1952 (Helsinki-Vantaa Airport – Ref. 1). The extension done between 1993 and 2007 concerned logistical facilities in the southeast of the airport's territory. The construction added a little less than 100000 m² to the existing surface, 10% of the total surface in 2007.

4.5 Summary and discussion of the spatial analysis

As a summary of the spatial analysis, several points are of significant importance and are described below.

The impervious area within Vantaa's part of the catchment is expected to grow from 3.25 million square meters in 2007 to 4.1 million square meters in 2030 showing a 26% increase in impervious surfaces. The impervious area in the Tuusula areas of the catchment will more than double until the year 2030, from a little less than 600000 m² to 1.24 million square meters in the forecast year. The total impervious area caused by roofs, roads and yards (including the Helsinki-Vantaa airport) will be 5.34 million square meters in 2030, a relative increase of 38%.

Table 4.6 The table shows the impervious area contributing from the listed categories separated for Vantaa and Tuusula. Other area represents the difference between the impervious area in the Kylmäoja catchment and the gross area of the Kylmäoja catchment.

	1975 [m²]	**1993 [m²]**	**2007 [m²]**	**2030 [m²]**
Roofage Vantaa	257313	565775	746860	1215290
Roofage Tuusula	23687	43000	138931	380335
Impervious yards Vantaa	329747	611323	812306	1174909
Impervious yards Tuusula	37783	112251	320562	725656
Helsinki-Vantaa airport	900918	900918	997561	997561
Roads Vantaa	270745	509797	708271	708271
Roads Tuusula	44240	133395	156080	172060
Other area	18970975	17958949	16954836	15461325

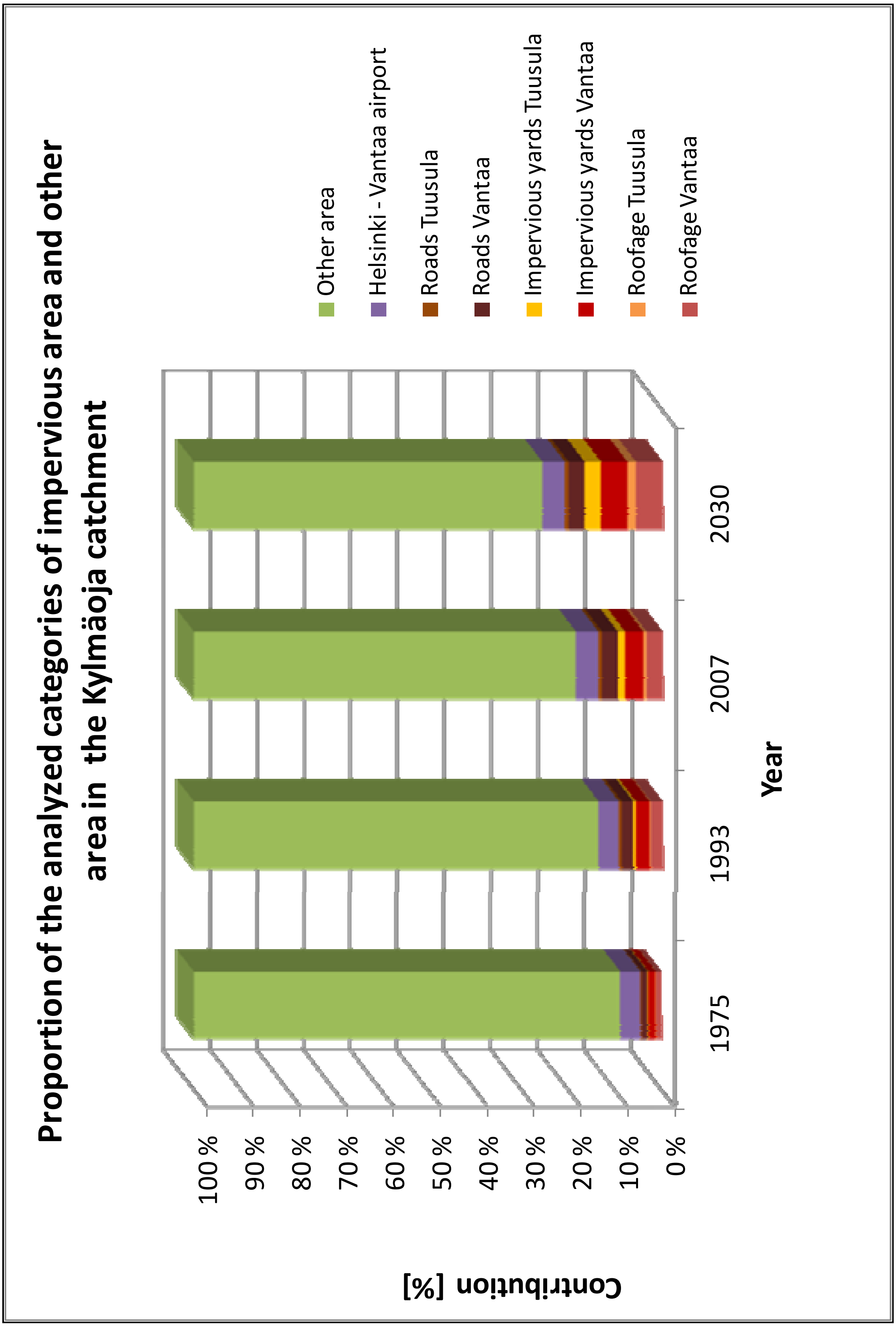


Figure 4.52 Categories of built impervious areas within the Kylmäoja catchment between 1975 and 2030. The "other area" category comprises both the built areas excluding roads, impervious yard surfaces, and roofs, as well as natural areas.

The extension of the impervious yard areas, especially the relation to the roofage, was found of severe significance. The proportion of the impervious yard area to the total impervious area in the Kylmäoja catchment developed from 20% in 1977 up to 29% in 2007 and is expected to reach 36% in 2030, as shown in figures 4.53 – 4.56.

Whereas in 1975 the municipality of Tuusula accounted for only 5% of the impervious surface in the Kylmäoja catchment, the value reached 10% in 1993 and 16% in 2007. In the year 2030, according to the analysed information, 24% of the impervious surface in the catchment will be located in Tuusula, by then mirroring the distribution of land-area within the Kylmäoja catchment between the city of Vantaa and Tuusula, which is 75% (Vantaa) to 25% (Tuusula). Further significance of the Tuusula imperviousness areas to the stream result from the location of the Tuusula areas at the Kylmäoja headwaters region. Imperviousness brought about changes in hydrology and water quality including temperature thus effect the entire length of the downstream sections.

Beside the large dimension of the impervious yard areas caused by the industrial definition of the catchment in Tuusula also another effect of the development is noticeable. Since the number of buildings compared to the roof area is much smaller in Tuusula than in Vantaa, the road network is less tight. As an effect, in comparison with the roofage and the yards, the influence of the road surface in Tuusula on the total catchment is even decreasing until 2030.

The influence of the Helsinki-Vantaa airport on the catchment gradually decreases, simply because the airport will not extend anymore and all the other investigated surfaces grow until 2030.

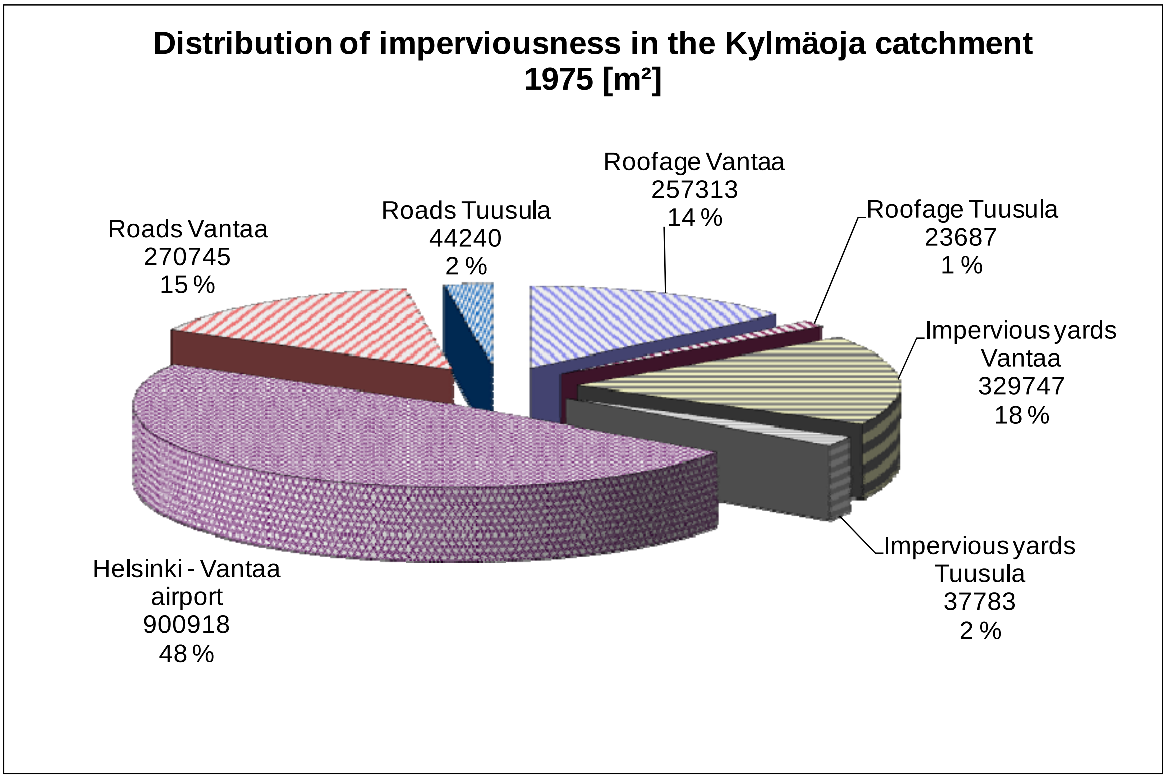


Figure 4.53 Distribution of impervious area in the catchment 1977.

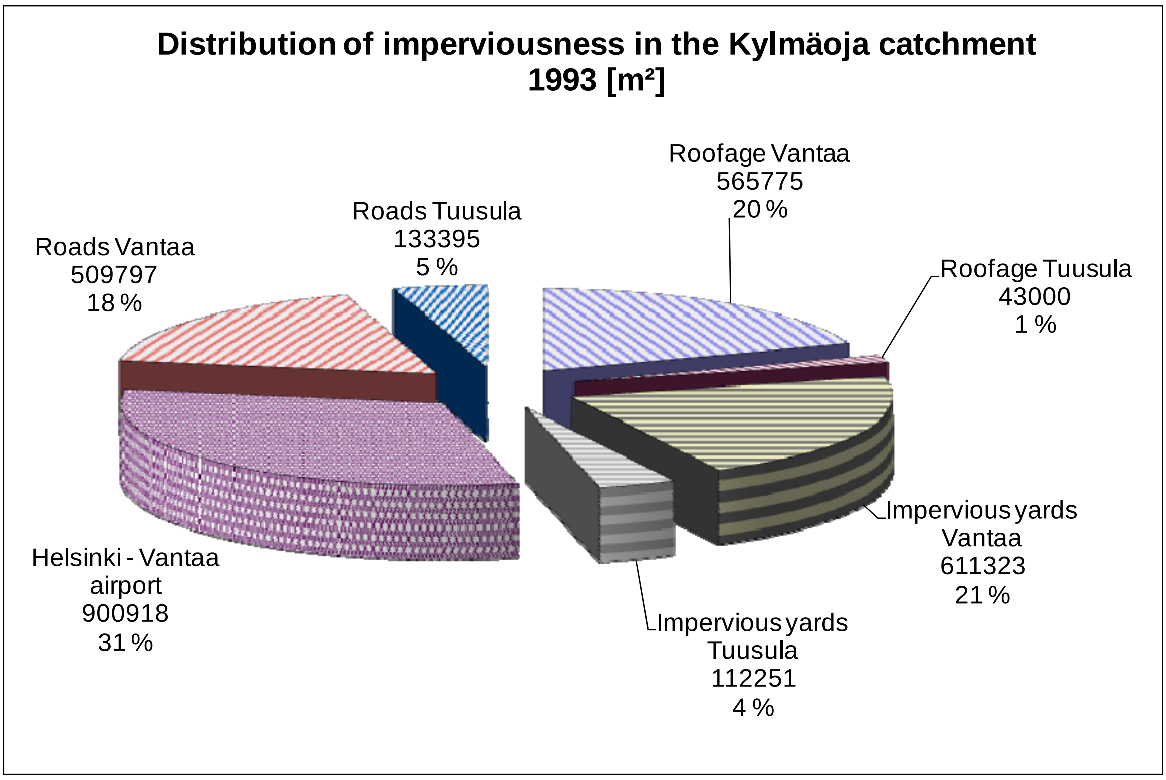


Figure 4.54 Distribution of impervious area in the catchment 1993.

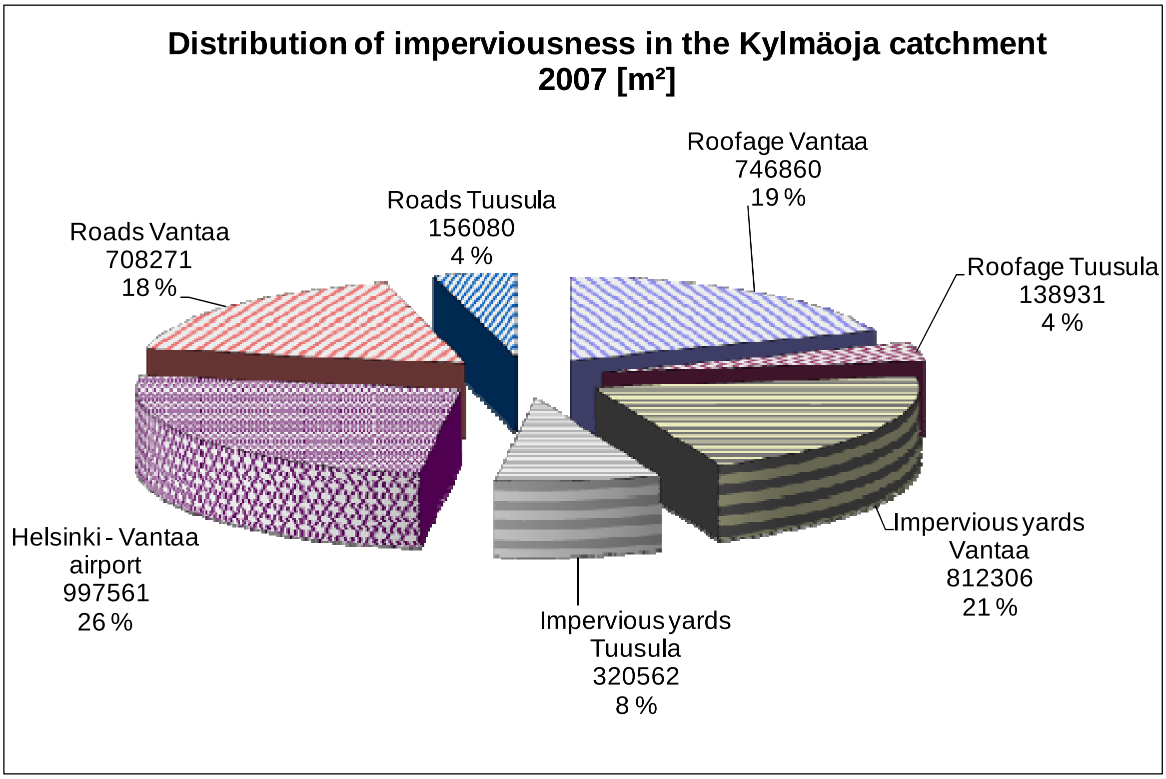


Figure 4.55 Distribution of impervious area in the catchment 2007.

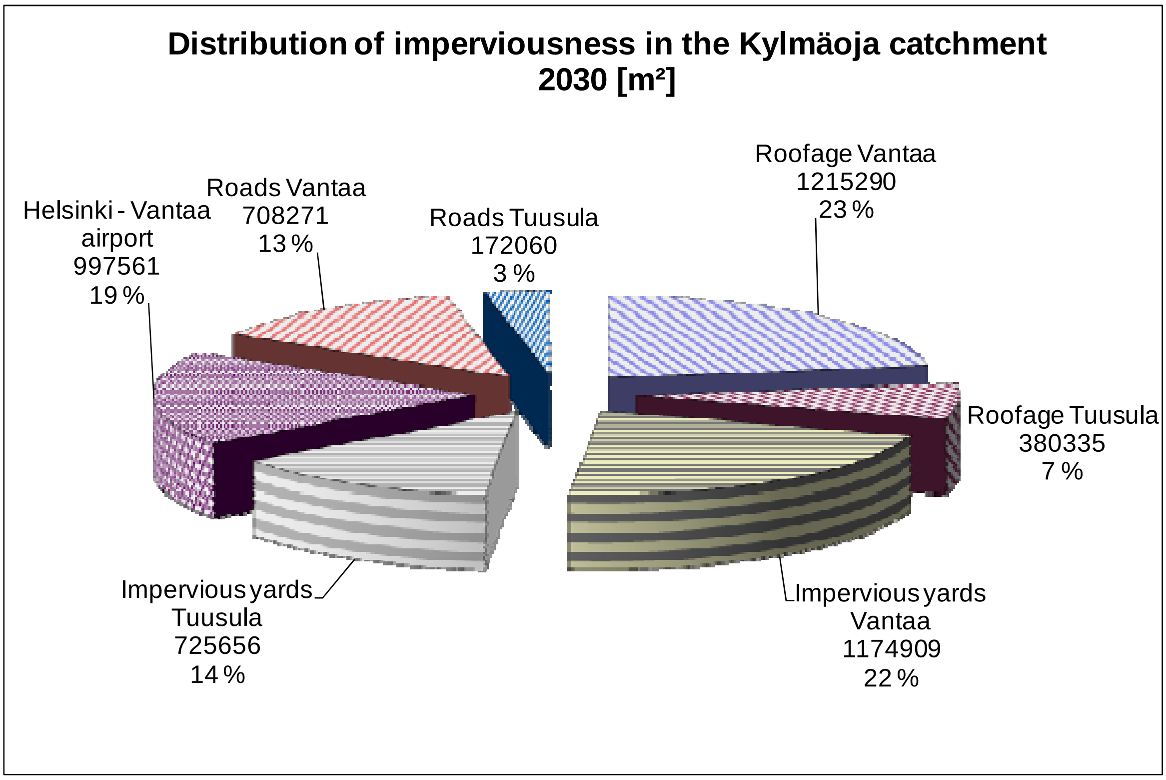


Figure 4.56 Distribution of impervious area in the catchment 2030.

5 The hydrological interpretation of catchment land-use

5.1 Introduction

The illustration of the results of the spatial analysis conducted and the effects on the Kylmäoja stream consists of two parts. The first way chosen for visualisation is the imperviousness of the catchment and the subcatchments and the development over the years in observation.

For the second part, the run-off generated from the surfaces defined, was estimated using the rational method.

5.2 Imperviousness of the catchment and its subcatchments

The level of imperviousness in a basin is an indicator for the effects of land-use on the stream itself. The value is given as the percentage of total impervious area within the catchment in relation to the total area of the catchment and is one of the few variables in a watershed that can be quantified, simply as the percentage of the area that is not “green” (Schueler 1994). In his work Schueler (1994) proved the term of imperviousness to be a valid indicator for the effects of land-use in a watershed on the changes in the affected stream network.

In his urban stream classification, he considered, among others, such variables as channel stability, water quality and stream biodiversity, to depend on the ultimate imperviousness of the basin (table 5.1).

The three categories of streams are defined as

- Sensitive streams (one to 10% imperviousness)
- Impacted streams (11 to 25% imperviousness) and
- Non-supporting streams (26 – 100% imperviousness).

In Schueler’s classification, sensitive streams represent the most protective category, in which strict zoning, site impervious restrictions, stream buffers and best stormwater practices are applied. Impacted streams can be expected to experience some degradation and the key resource objective is to mitigate the impacts to the greatest possible extent, using effective stormwater management practices. The last category of non-supporting streams recognizes that channel stability and stream biodiversity cannot be fully maintained at this level of existing catchment imperviousness, even when stormwater practices are fully applied. The main objective for streams in this category is to protect downstream water quality by removing urban pollutants. (Schueler 1994)

No such classification exists for catchments in Finland whereas the Schuler's classification is based on a large number (18) of catchment-stream relationship studies carried out across the USA (mainly for catchments located in the northern states) for various catchment types and scales. The biological parameters used in the investigation reviewed by Schueler reach from wetland plants and aquatic insects to fish in general and salmon and trout, which were in focus in two studies conducted (presented by Schueler 1994 and listed with the key findings of the studies). Since trout and salmon inhabit Kylmäoja and Keravanjoki the classification was applied also in this work.

Table 5.1 A possible scheme for classifying and managing for headwater urban streams based on ultimate imperviousness (Schueler 1994)

Urban Stream Classification	Sensitive (0-10% Imperv.)	Impacted (11-25% Imperv.)	Non-supporting (26-100% Imperv.)
Channel stability	Stable	Unstable	Highly Unstable
Water quality	Good	Fair	Fair-Poor
Stream biodiversity	Good-Excellent	Fair-Good	Poor
Resource objective	Protect biodiversity and channel stability	Maintain critical elements of stream quality	Minimize downstream pollutant loads
Water quality objectives	Sediment and temperature	Nutrient and metal loads	Control bacteria
Stormwater Practice Selection Factors	Secondary environmental impacts	Removal efficiency	Removal efficiency
Land Use Controls	Watershed-wide imp. cover limits (ICLs), site ICLs	Site imp. cover limits (ICLs)	Additional infill and redevelopment encouraged
Monitoring and enforcement	GIS monitoring of imp. cover, biomonitoring	Same as "Stressed"	Pollutant load modeling
Development rights	Transferred out	None	Transferred in
Riparian buffers	Widest buffer network	Average bufferwidth	Greenways

The percentage of imperviousness for each of the eleven subcatchments as well as for the whole Kylmäoja catchment was calculated during this work and is presented in table 5.1 and visualized on maps (figures 5.1 – 5.5).

The results show the development of imperviousness for the years in observation and classify the stream sections according to Schueler's findings. Whereas in 1977 still six out of eleven subcatchments could be classified as sensitive streams, five subcatchments were defined as impacted (all five at the lower end of the threshold) and no fraction of the catchment could be classified as non-supporting. The situation changed drastically until the year 2007 and will continue to degrade until 2030. In 2007 only the subcatchment 6 was below the threshold of 10% anymore, five subcatchments range between 11 and 26% of imperviousness and another five catchments are above the threshold of 26%. In 2030 four subcatchments are categorized as impacted streams and the other seven subcatchments are classified as non-supporting streams, none remain in the sensitive category.

The development of the gross Kylmäoja catchment follows the trend of the subcatchments. Until the year 1982, Kylmäoja stream was classifiable as a sensitive stream, with imperviousness of 9% (1977) and 10% (1982). In 1992 the proportion of imperviousness reached 14% and in 2007 the value reached 19%, defining Kylmäoja as an impacted stream according to the classification by Schueler (1994). In 2030, the imperviousness of the Kylmäoja catchment is expected to reach 26%, above the threshold of a non-supporting stream (table 5.2).

Table 5.2 The level of imperviousness for the eleven subcatchments and the total catchment for the years 1977, 1982, 1992, 2007 and 2030. Sections of the stream classified as sensitive (0-10% imperviousness) are marked green, impacted sections (11-25% imperviousness) are marked orange and non-supporting sections (26-100% imperviousness) are labeled red.

	1977 [%]	1982 [%]	1992 [%]	2007 [%]	2030 [%]
C1	4	4	5	18	27
C2	14	14	16	17	23
C3	6	7	13	26	36
C4	8	8	11	11	13
C5	15	20	24	34	38
C6	1	1	3	7	16
C7	4	5	23	29	39
C8	11	12	12	14	22
C9	8	12	18	23	32
C10	16	19	28	32	36
C11	13	16	29	38	53
C TOT	9	10	14	19	26

Besides the level of catchment imperviousness, another important indicator for the effects of land-use on the quality of streams is the distance of imperviousness from the aquatic system. This criterion has not been investigated during this work, but would be an important measure of stream health for further studies on this watershed.

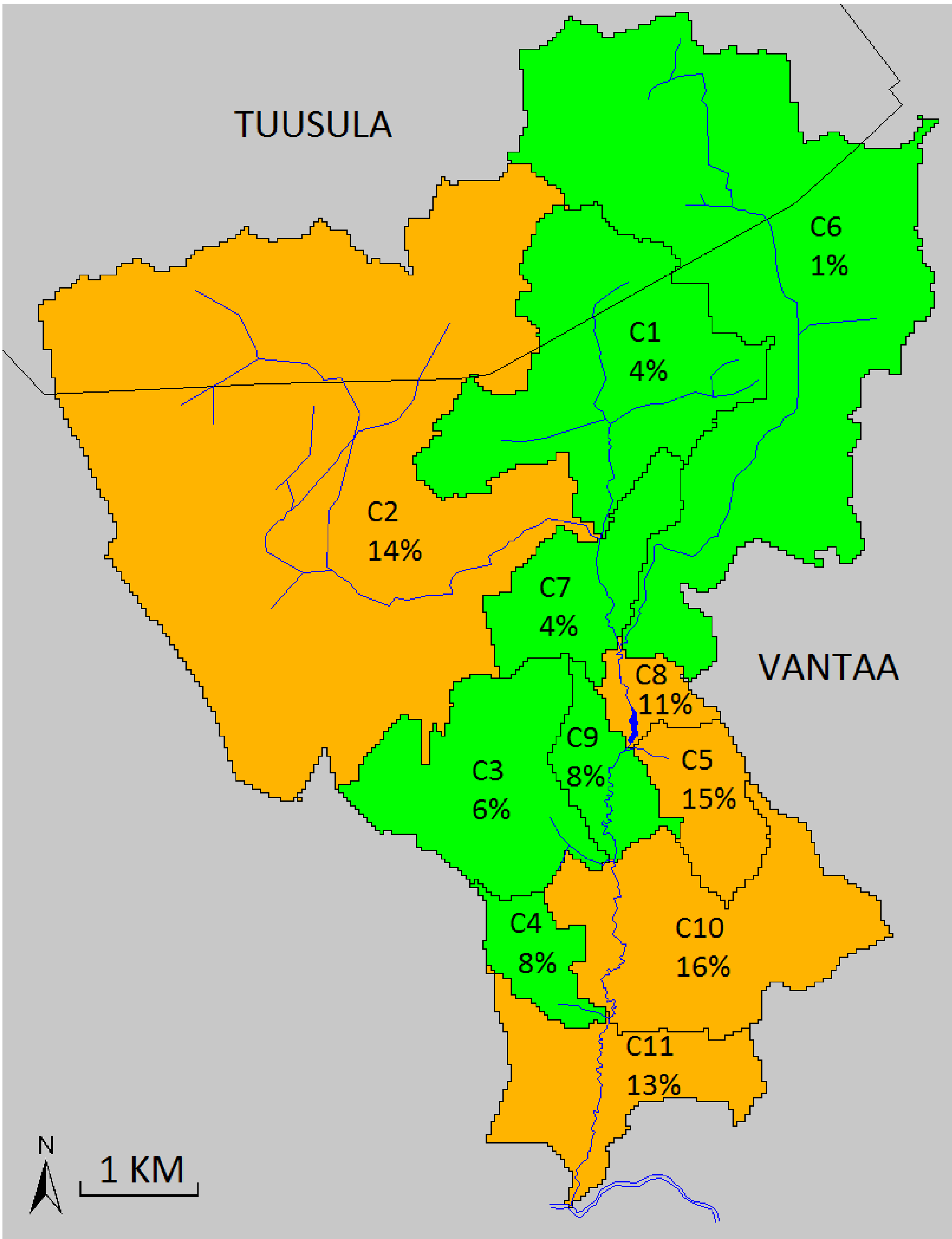


Figure 5.1 The level of imperviousness in the Kylmäoja catchment in 1977. Green subcatchments represent sensitive sections (6) of the stream whereas orange subcatchments (5) represent impacted sections of the stream. In 1977, no section of Kylmäoja is classified as non-supporting (red). The imperviousness of the total catchment in 1977 is 9%, defining Kylmäoja as a sensitive stream.

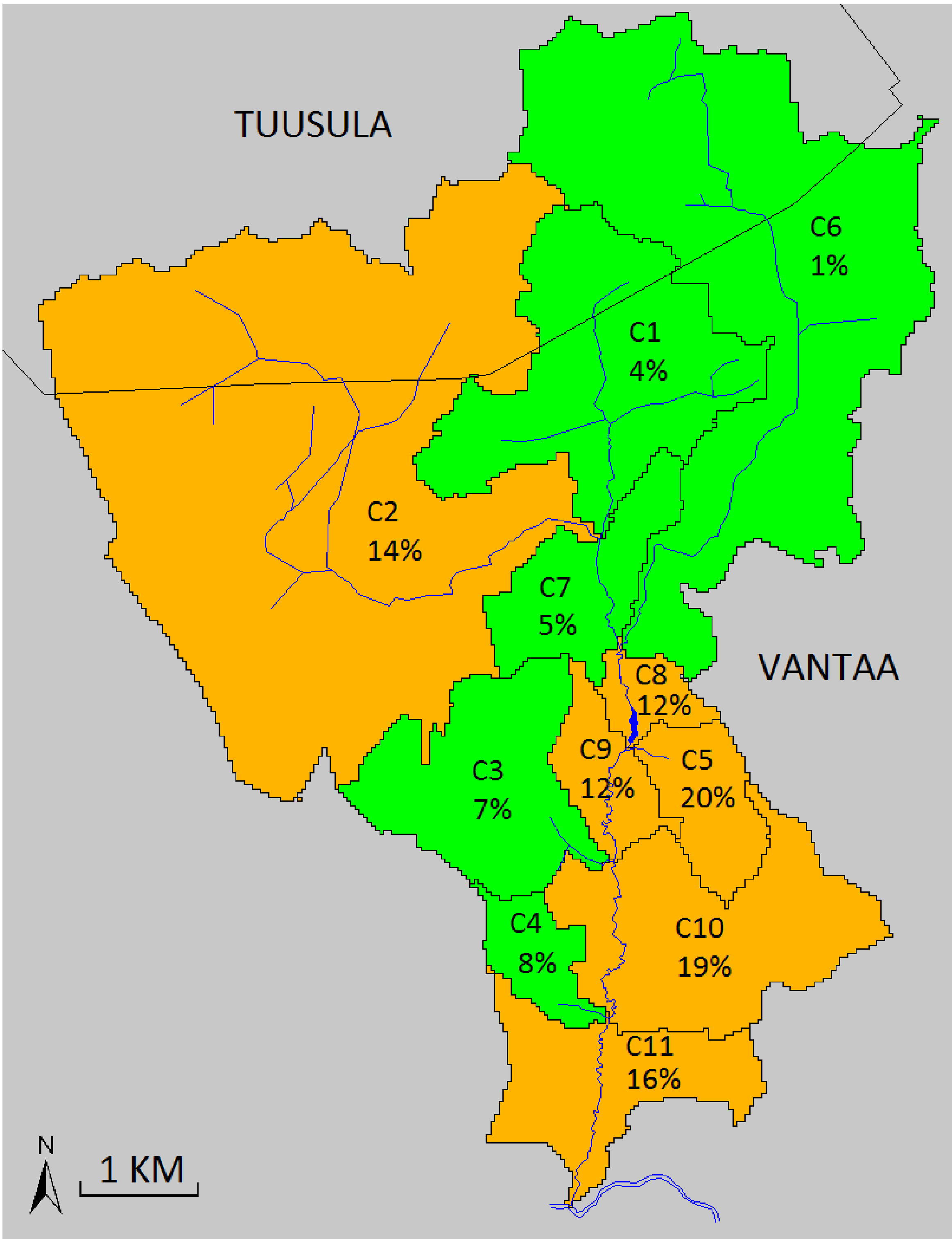


Figure 5.2 The level of imperviousness in the Kylmäoja catchment in 1982. Green subcatchments (5) represent sensitive sections of the stream whereas orange subcatchments (6) represent impacted sections of the stream. Still in 1982, no section of Kylmäoja is classified as non-supporting (red). The increase of imperviousness in subcatchment 9 caused the label for this section to change from sensitive to impacted. The imperviousness of the total catchment in 1982 is 10%, defining Kylmäoja still as sensitive stream.

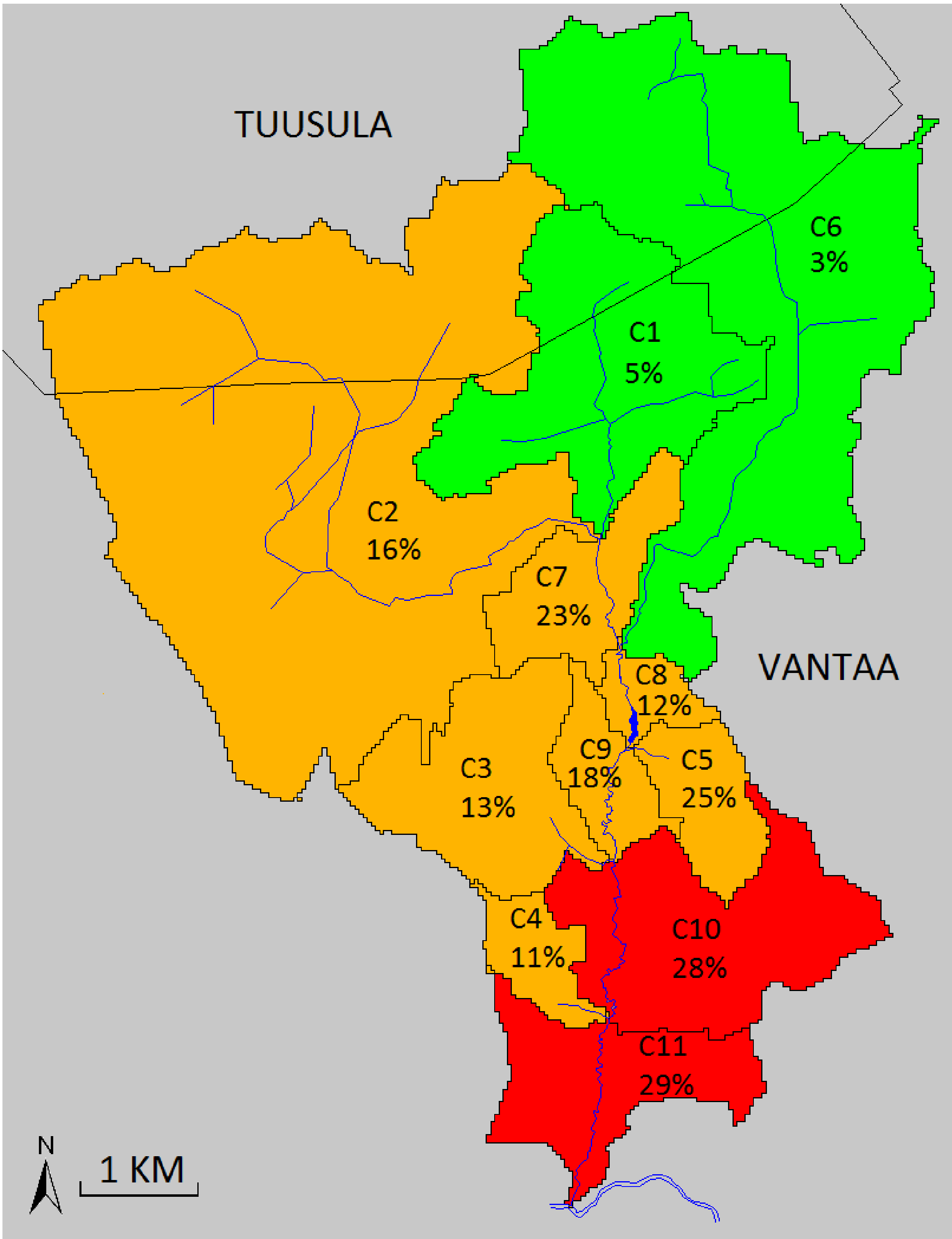


Figure 5.3 The level of imperviousness in the Kylmäoja catchment in 1992. Only 2 subcatchments (namely C1 and C6) range below the threshold value for an impacted stream. 7 subcatchments are categorized as impacted and the subcatchments 10 and 11 reach levels of imperviousness to be classified as non-supporting. The imperviousness of the total Kylmäoja catchment reaches 14%; hence Kylmäoja now becomes labeled as an impacted stream.

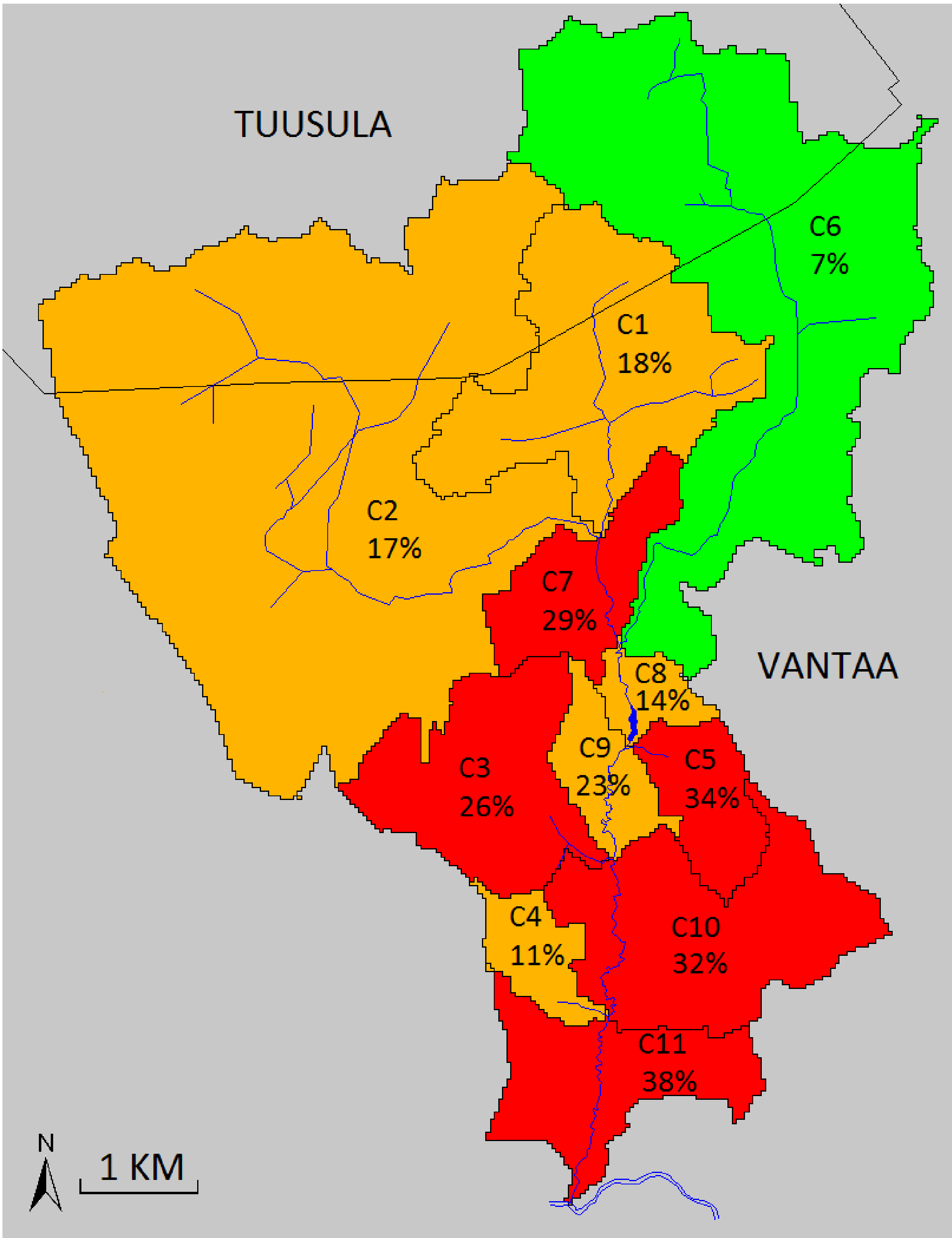


Figure 5.4 The level of imperviousness in the Kylmäoja catchment in 2007. Only subcatchment 6 ranges below the threshold value for an impacted stream. 5 subcatchments are categorized as impacted and 5 subcatchments (namely (C3, C5, C7 C10 and C11) reach levels of imperviousness to be categorized as non-supporting. The imperviousness of the total Kylmäoja catchment reaches 19%.

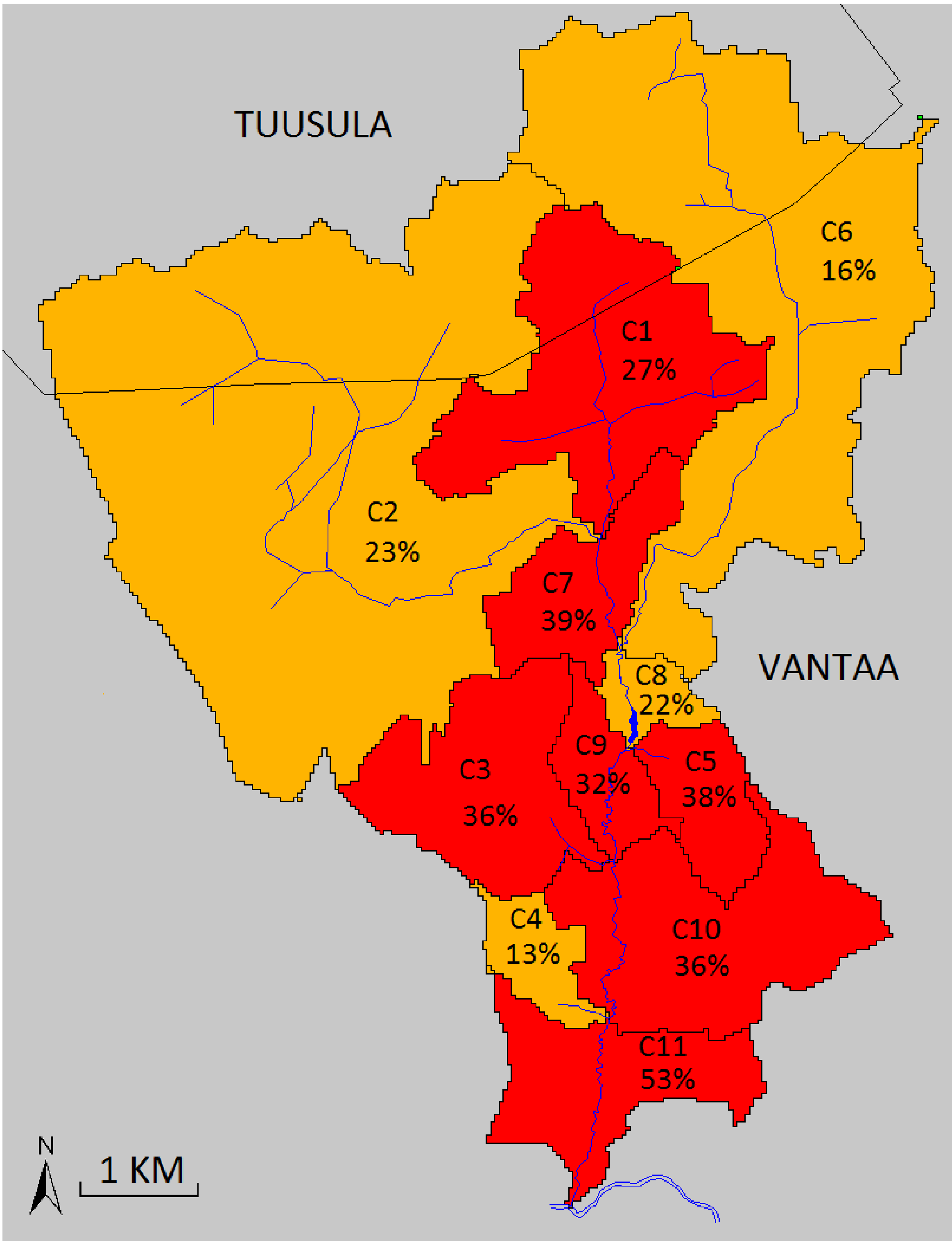


Figure 5.5 The level of imperviousness of the catchment expected in 2030. Whereas no section of Kylmäoja will be sensitive anymore, only 4 subcatchments can be categorized as impacted and the majority of the catchment (7 subcatchments) will have reached the label of a non-supporting stream. The imperviousness of the total catchment, which is expected to reach 26% in 2030, will make Kylmäoja as a whole a non-supporting stream.

5.2.1 Development of imperviousness within the transboundary subcatchments

The imperviousness within the three largest subcatchments, namely the subcatchments 1, 2 and 6 (see figure 3.5) was analyzed separately due to their size and their transboundary conditions. All three subcatchments are located partly in Vantaa and partly in Tuusula and the development of imperviousness within the subcatchment's borders as well as within the borders of the responsible authority are of importance for urban planning.

5.2.1.1 Subcatchment 1

The subcatchment of the central branch or headwater has a total size of 2.11 km^2, of which 1.62 km^2 or 77% are located within the city of Vantaa and 0.49 km^2 or 23% are located within the municipality of Tuusula.

The imperviousness in this subcatchment has been growing strongly within the past 15 years and is expected to increase still significantly until 2030. Whereas until 1992, both parts of the subcatchment were sensitive, by 2007 the imperviousness in Vantaa reached 14%, above the threshold value of an impacted stream and Tuusula's part reached even 30% – above the threshold of a non-supporting stream already. The trend is expected to continue until 2030, when the whole subcatchment will have an imperviousness of 27%, the areas within the borders of Tuusula will reach 43% whereas the area in Vantaa will have 22%, still below the threshold of a non-supporting stream. The development of imperviousness in this subcatchment is shown in figures 5.6 – 5.10.

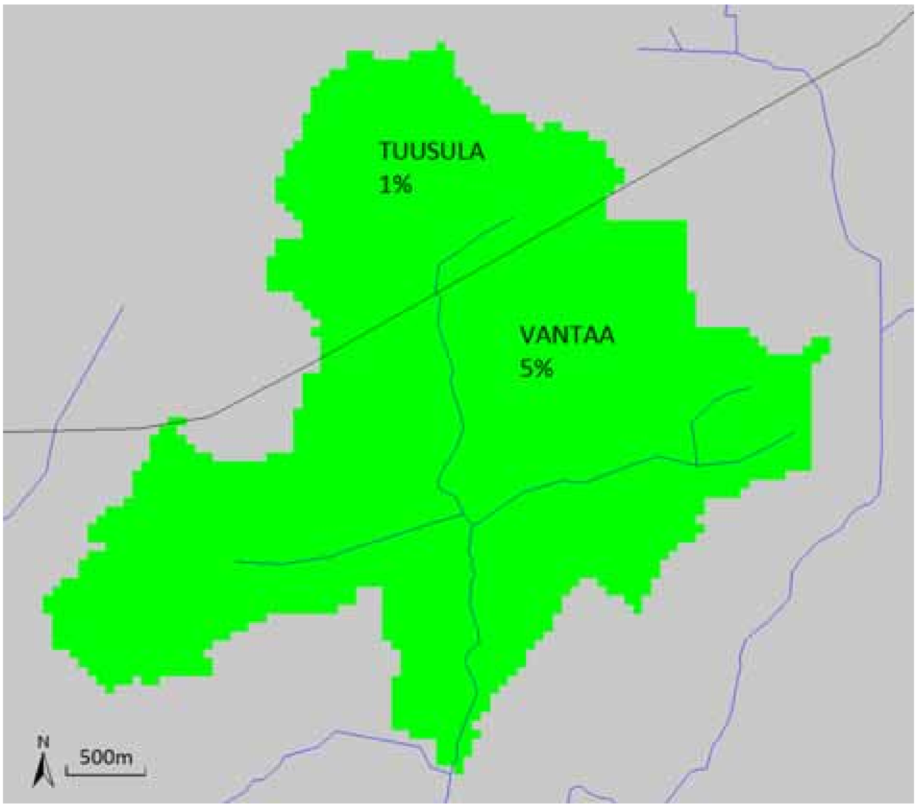


Figure 5.6 The level of imperviousness in subcatchment 1, separated for Vantaa and Tuusula in 1977.

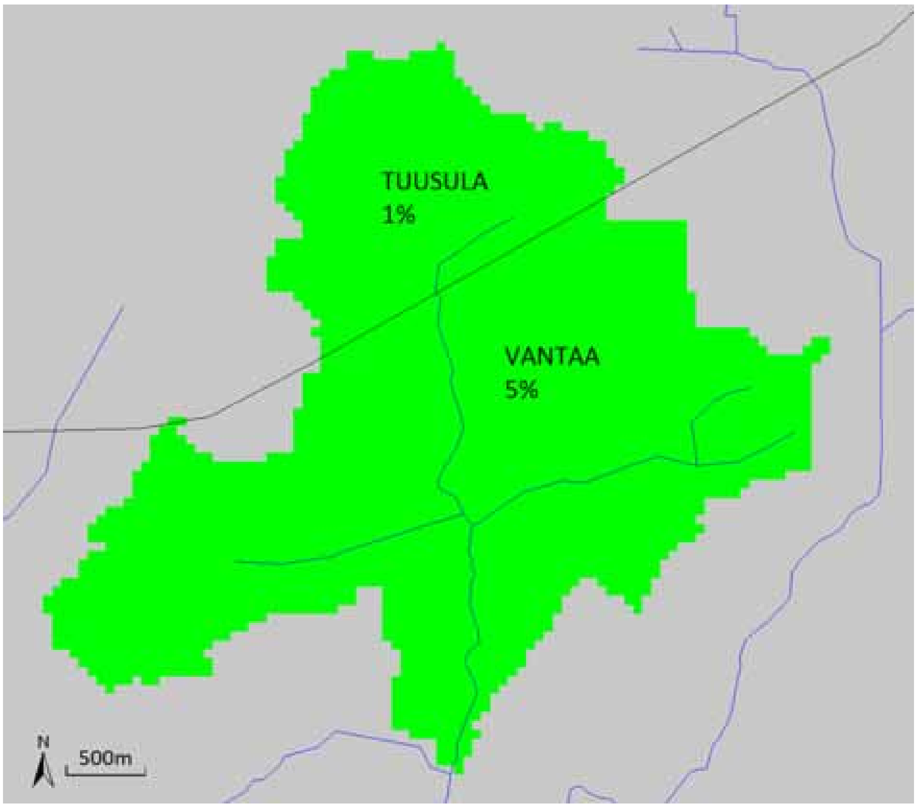


Figure 5.7 The level of imperviousness in subcatchment 1, separated for Vantaa and Tuusula in 1982.

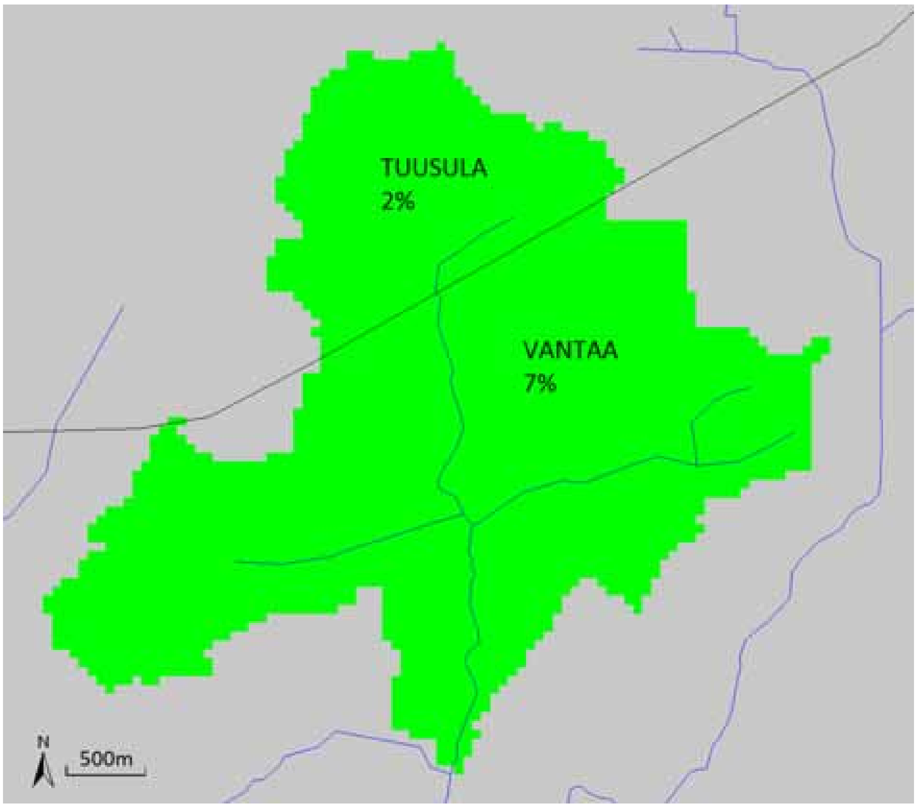


Figure 5.8 The level of imperviousness in subcatchment 1, separated for Vantaa and Tuusula in 1992.

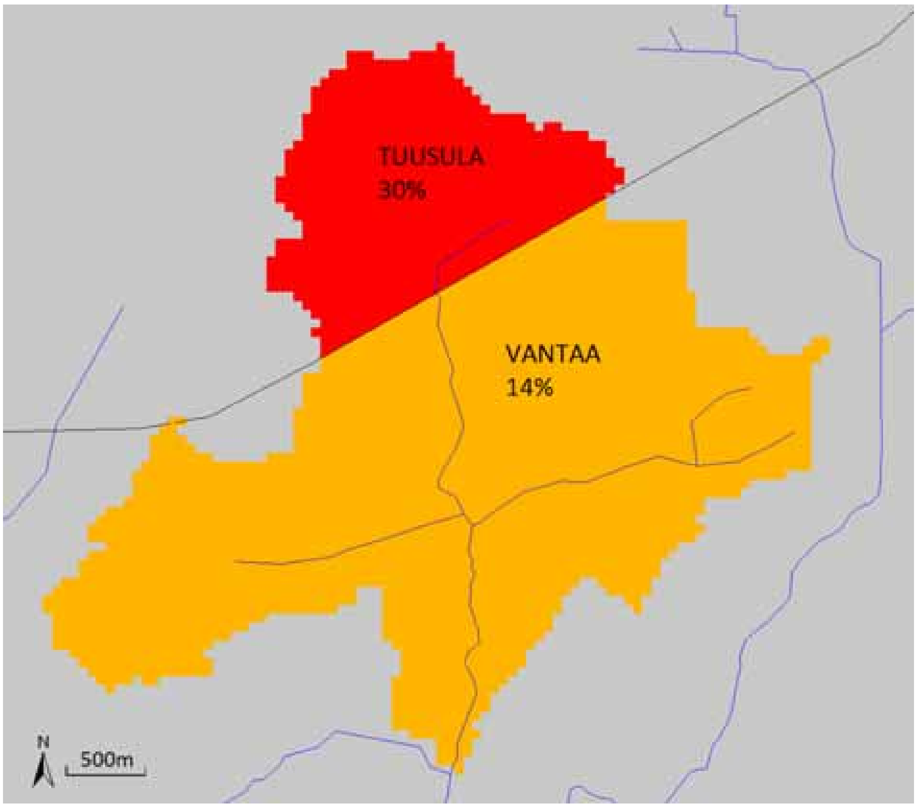


Figure 5.9 The level of imperviousness in subcatchment 1, separated for Vantaa and Tuusula in 2007.

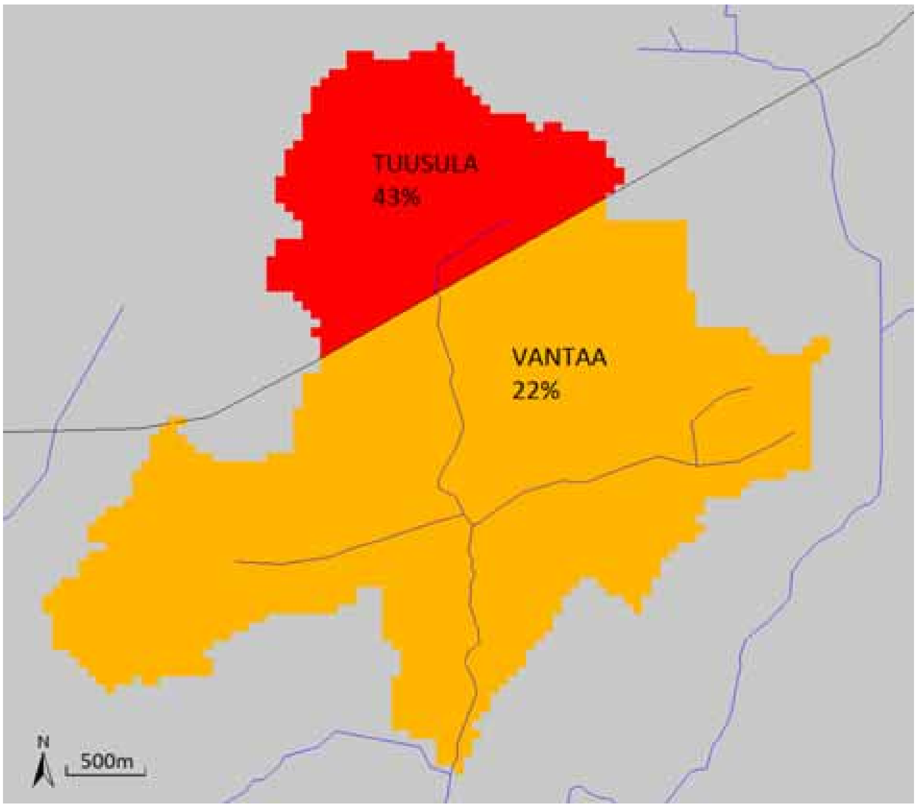


Figure 5.10 The level of imperviousness in subcatchment 1, separated for Vantaa and Tuusula in 2030.

5.2.1.2 Subcatchment 2

The subcatchment of the western branch has a total size of 7.57 km^2, of which 4.92 km^2 or 65% are located within the city of Vantaa and 2.65 km^2 or 35% are located within the municipality of Tuusula.

The subcatchment is dominated by the Helsinki-Vantaa airport, which opened in 1952 and hence is present since the starting year of the analysis conducted – 1977. The development of imperviousness within this subcatchment is therefore strongly influenced by the vast asphalt covered areas of the airport. The imperviousness in Vantaa's part of the subcatchment was 20% already in 1977 and grew only slightly to reach 22% in 2007. In 2030, the imperviousness in Vantaa's part is expected to reach 23%. Tuusula's part of the subcatchment, on the other hand, has been widely undeveloped, partly due to the close proximity to the airport and the associated flight paths, indicated by an imperviousness of 3% in 1977 and 8% in 2007. The industrial development in Tuusula within the last decade and the business park FOCUS planned to be erected will raise the imperviousness to 25% in 2030, a level higher, than in the neighbouring areas in Vantaa. The development of imperviousness in subcatchment 2 is shown in figures 5.11 – 5.15.

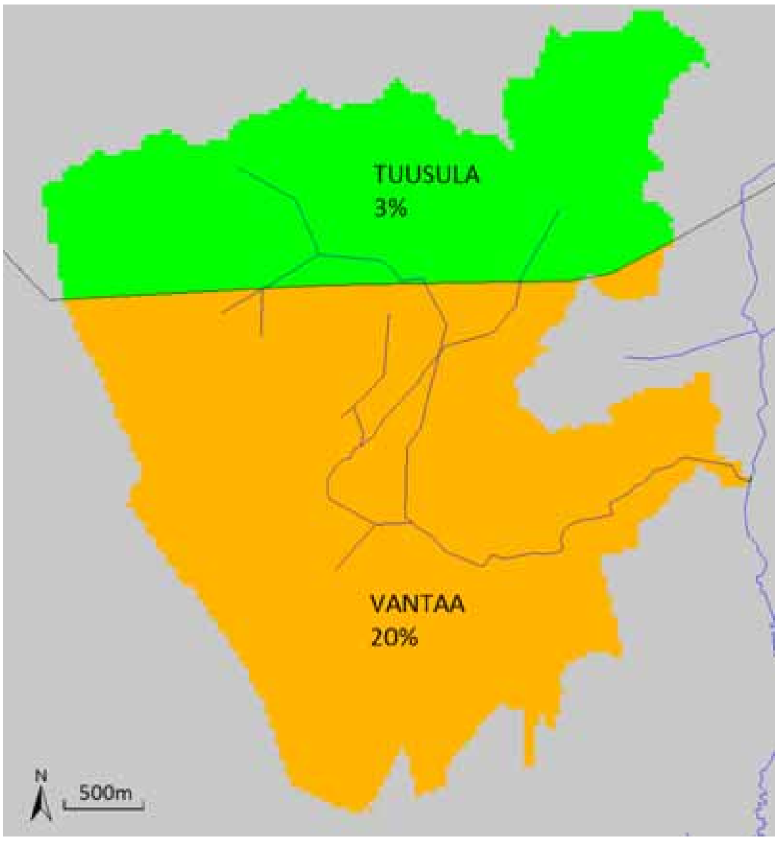


Figure 5.11 The level of imperviousness in subcatchment 2, separated for Vantaa and Tuusula in 1977.

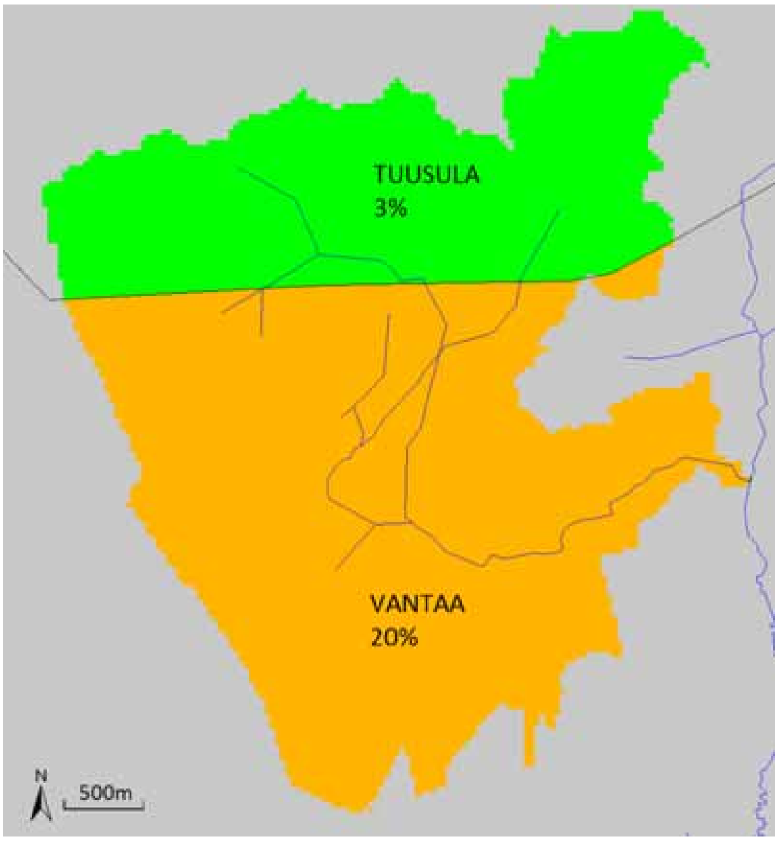


Figure 5.12 The level of imperviousness in subcatchment 2, separated for Vantaa and Tuusula in 1982.

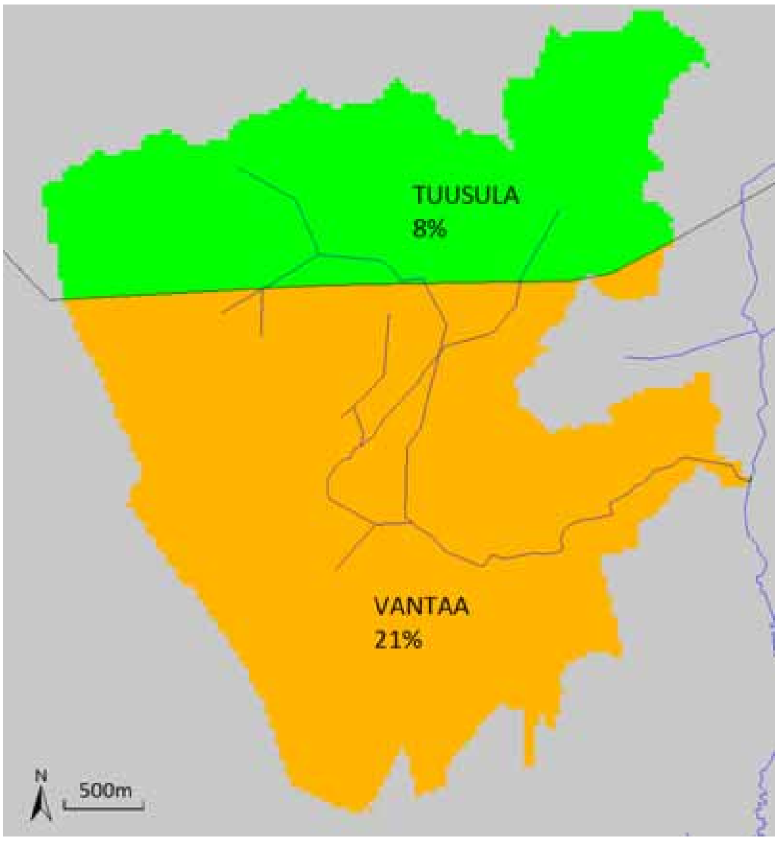


Figure 5.13 The level of imperviousness in subcatchment 2, separated for Vantaa and Tuusula in 1992.

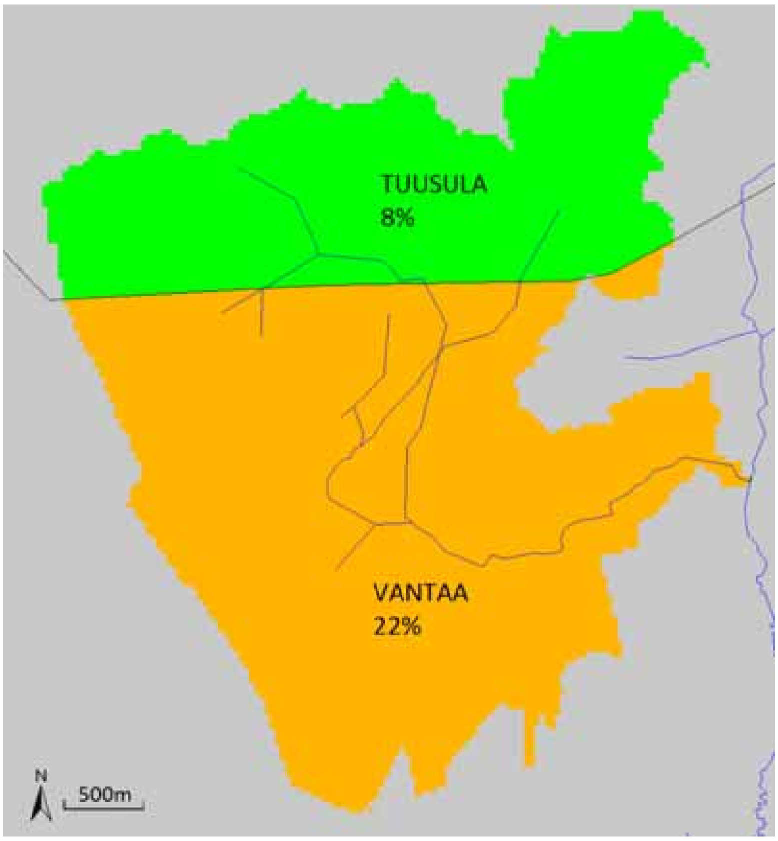


Figure 5.14 The level of imperviousness in subcatchment 2, separated for Vantaa and Tuusula in 2007.

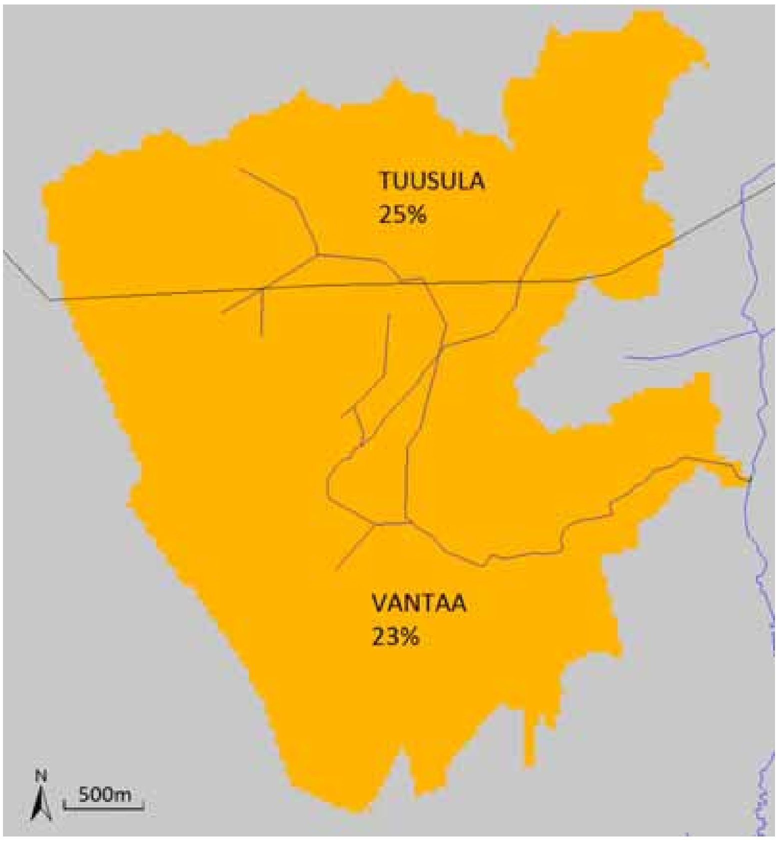


Figure 5.15 The level of imperviousness in subcatchment 2, separated for Vantaa and Tuusula in 2030.

5.2.1.3 Subcatchment 6

The subcatchment of the western branch has a total size of 4.74 km^2, of which 2.76 km^2 or 58% are located within the city of Vantaa and 1.98 km^2 or 42% are located within the municipality of Tuusula.

The subcatchment includes a protected green area (named korpi) on Vantaa's side as well as residential (in the city of Vantaa) and industrial development (in the municipality of Tuusula). The whole subcatchment was widely undeveloped until 1992 (imperviousness of 3% in Vantaa and 4% in Tuusula) when industrial development started in Tuusula raising the imperviousness to 12% in the Tuusula side. The continuing development in Tuusula and the residential development in Leinelä (Vantaa) increase the imperviousness to 21% in Tuusula and 12% in Vantaa until 2030. The development of the imperviousness in this subcatchment is shown in figures 5.16 – 5.18.

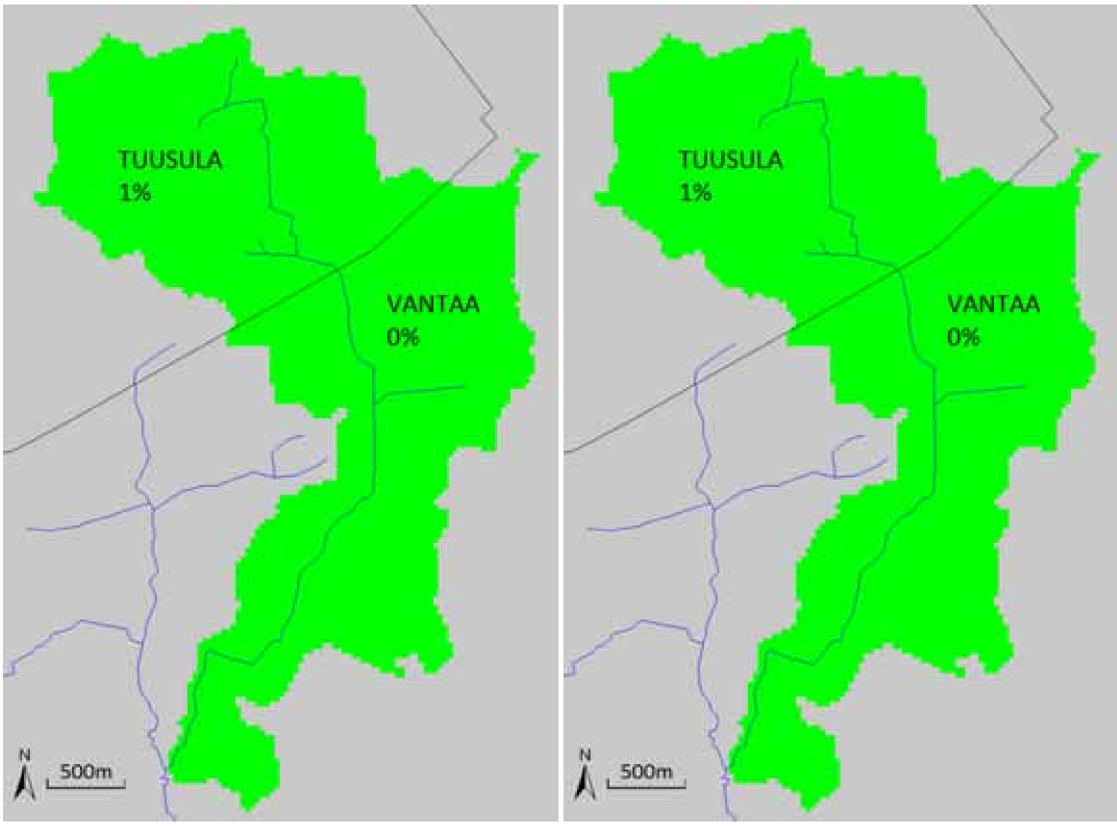


Figure 5.16 The level of imperviousness in subcatchment 6, separated for Vantaa and Tuusula in 1977 (left side) and 1982 (right side).

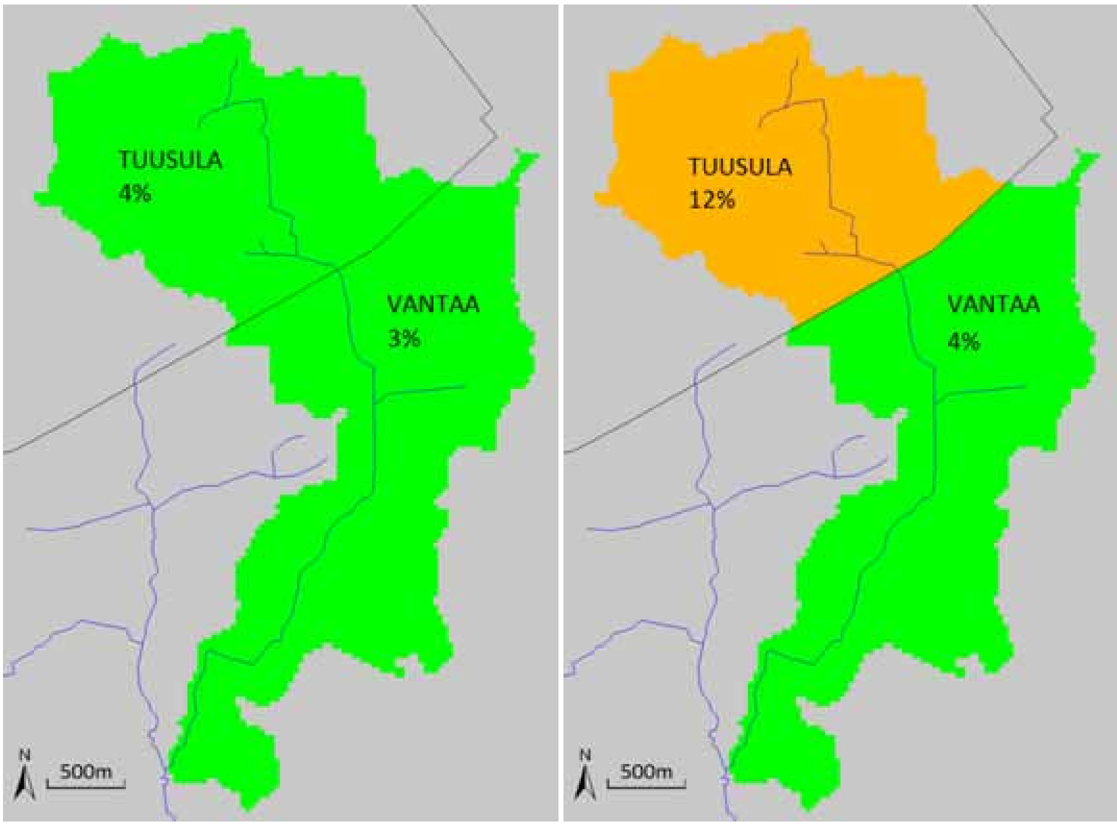


Figure 5.17 The level of imperviousness in subcatchment 6, separated for Vantaa and Tuusula in 1992 (left side) and 2007 (right side).

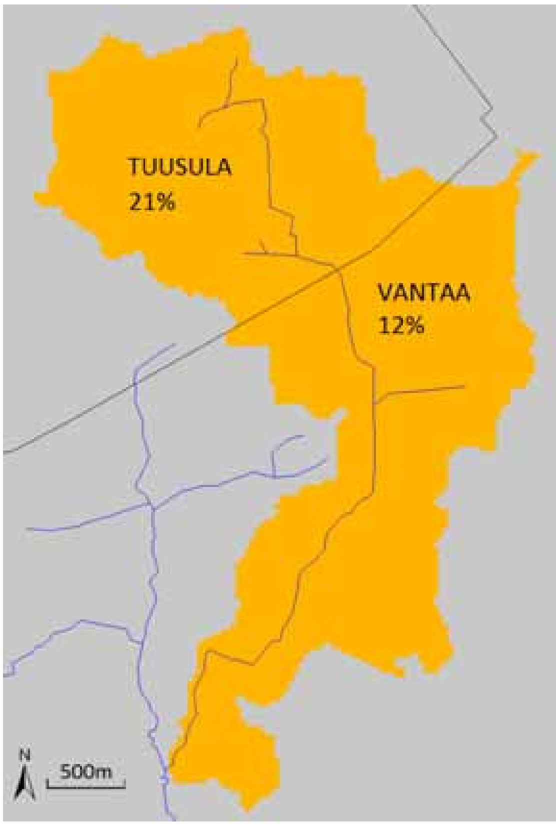


Figure 5.18 The level of imperviousness in subcatchment 6, separated for Vantaa and Tuusula in 2030.

5.3 Run – off calculations

Rough run-off estimates were calculated based on the rational method to investigate the development of run-off generated from constructed imperviousness (roofs, yards, roads and the Helsinki-Vantaa airport).

The rational method calculates the peak discharge (Q [l/s]) from the drainage area (A [ha]), the rainfall intensity (q [l/s*ha]) and the run-off coefficients c.

$$Q\left[\frac{l}{s}\right] = A\ [ha] *\ q\left[\frac{l}{s * ha}\right] * c[-]$$

Even though according to Kibler (1982) the applicability of the rational method is traditionally limited to basins less than one square mile in area, Gupta (1989) defined the method as commonly used for catchments less than 20 mi^2 (around 52 km^2) in area.

Since the hydrological interpretation in this study shall only give a picture of the development of impervious surfaces in the catchment, without trying to achieve the results of a detailed hydrological model, the method will be used recognizing the inaccuracies implied.

The peak run-off is calculated for each subcatchment separately and since retention in the catchment is neglected, a calculation for the total catchment area is not carried out.

The stormwater management design rainfall intensity used in the city of Vantaa at the moment is 120 [l / s * ha] for a rain duration of 10 minutes. However, the work of Kilpeläinen (2006) showed, as a result of the investigation of summer rainfalls in Helsinki-Kaisaniemi, that the rainfall intensity for a storm event with a return period of fifty years is 297 [l / s * ha] for a duration of 10 minutes.

For a flow velocity of 1 to 2 [m / s] in the stream and the stream sections in the subcatchments measuring between 1 and 2 km in length, a storm event of 15 minutes in duration is applicable. According to Kilpeläinen (2006), the intensity for such a rainfall event is 255 [l / s * ha] or 1.53 [mm / min]. For the run-off estimation conducted during this work, the intensity used was chosen to be 255 [l / s * ha].

The run-off calculation was carried out utilizing two different sets of run-off coefficients. The run-off coefficients used for the first calculation are based on literature values (as RIL 2004) used in the city of Vantaa. Table 5.3 below shows the values given in a publication of the Finnish association of civil engineers (RIL 2004).

Table 5.3 Run-off coefficients for different surface condition according to RIL 2004.

Type of surface	Run-off coefficient
Roofs	0.90
Concrete and asphalt surfaces, rock	0.80
Stone pavement	0.70
Well preserved gravel road	0.50
Loose gravel surface	0.30
Cultivated parks	0.20
Natural parks and rocky forests	0.15
Natural forest	0.05

For the second run-off calculation, coefficients published in the German code were used (ATV-DVWK-REGELWERK 2000). Suggested run-off coefficients from this manual are shown in table 5.4. Since the run-off coefficients given as well in the Finnish as also in the German code are independent from the soil type and the slope of the surface, hence only concern the type of the impervious surface addressed. The differences in climate between Germany and Finland are obvious, but even when taking them into consideration while checking the applicability of continental European run-off coefficients in northern Europe it becomes obvious that the warmer climate in Germany should not result in lower run-off coefficients, as a result of higher temperatures and hence higher evaporation on hotter impervious surfaces. Concluding, the applicability of the run-off coefficients suggested in the German code is given and the run-off coefficients are therefore applied during this estimation, to compare the results with the output of the estimation applying the run-off coefficients suggested in the Finnish code.

Table 5.4 Run-off coefficients for different surface condition according to ATV-DVWK-REGELWERK 2000.

Type of surface	Run-off coefficient
Roofs	0.80 – 1.00
Concrete and asphalt surfaces	0.90
Pavement with narrow joints	0.75
Compact gravel cover	0.60
Pavement with open joints	0.50
Loose gravel surface	0.30
Grass pavement	0.15
Cultivated park areas	0.00 – 0.30

The run-off coefficients suggested by the German code (ATV-DVWK-REGELWERK 2000) are in average higher than the values recommended by the Finnish code (RIL 2004). The run-off coefficients used for the run-off estimation conducted during this work are shown in table 5.5.

Neither coefficient set applied here recognizes the effects of soils and slope, which are further neglected in this average and rough comparative estimate conducted here.

For all roofs existing in the Kylmäoja catchment, the run-off coefficient 0.90 was used according to RIL (2004) and 0.95 according to ATV-DVWK-REGELWERK (2000).

Roads were considered in the run-off calculation with a factor of 0.80 in case of asphalt cover and 0.50 in the case of gravel roads according to RIL (2004) and 0.95 and 0.60 according to ATV-DVWK-REGELWERK (2000). Compact gravel covers are only represented in the subcatchment areas located partly in Tuusula. No alternative pavers such as pervious asphalt were found in use within the Kylmäoja catchment.

For yard areas of detached houses as well as two family houses, both similar in structure, investigation showed a proportion of approx. 50 – 50 between asphalt and gravel being in use. The combined run-off coefficient yields to 0.55 (RIL 2004) or 0.63 (ATV-DVWK-REGELWERK 2000). The value derives from 0.80 (RIL 2004) or 0.95 (ATV-DVWK-REGELWERK 2000) for asphalt and from the coefficient 0.30 (RIL 2004 and ATV-DVWK-REGELWERK 2000) for loose gravel. This coefficient was also used for similar areas defined in the Master Plan 2007, e.g. low-rise housing areas.

For yards of row and terraced houses a relation of 80% asphalt and 20% gravel was found, generating a combined run-off coefficient of 0.70 (RIL 2004) or 0.82 (ATV-DVWK-REGELWERK 2000). This value was also used for areas defined as dense low-rise housing areas.

Yard areas of apartment blocks, industrial buildings and other service facilities were found to have asphalt covered yard areas. The run-off coefficient used for all these building types was 0.80 (RIL 2004) or 0.95 (ATV-DVWK-REGELWERK 2000).

For a little number of buildings a yard surface consisting of 100% gravel was identified and taken into account with a coefficient of 0.30.

For schools and kindergartens a run-off coefficient of 0.30 for attached yards was applied. The number derives from the existence of parking lots, normally covered by asphalt and larger playgrounds or sport fields, for which Kibler (1982) suggested a coefficient between 0.20 and 0.35.

The yard areas of the two churches existing in the Kylmäoja catchment, one of them with a cemetery attached, were given the coefficient 0.20 (Kibler 1982).

Table 5.5 Run-off coefficients for various surfaces investigated during this work. Calculation was carried out separately for RIL 2004 and ATV-DVWK-REGELWERK 2000, in case of absent definitions in those sources, values defined by Kibler (1982) were used.

Type of surface	**Run-off coefficient (RIL 2004)**	**Run-off coefficient (ATV-DVWK-REGELWERK 2000)**
Roofs	0.90	0.95
Roads Concrete and asphalt surfaces	0.80	0.95
Roads Compact gravel cover	0.50	0.60
Yards 100 % asphalt cover	0.80	0.95
Yards 80% asphalt over – 20% loose gravel	0.70	0.82
Yards 50% asphalt over – 50% loose gravel	0.55	0.63
Yards 100 % loose gravel cover	0.30	0.30
Schools and kindergarten yards	0.30 (Kibler 1982)	0.30 (Kibler 1982)
Cemetery	0.20 (Kibler 1982)	0.20 (Kibler 1982)

5.3.1 Development until 2007

The peak discharge for each subcatchment was calculated utilizing the run-off coefficients given above (table 5.5) and the rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2000).

The result of the run-off calculation, utilizing the run-off coefficients suggested in the Finnish code (RIL 2004) is shown in table 5.6.

Table 5.6 The peak run-off generated from impervious areas in the Kylmäoja basin calculated for the eleven subcatchments applying the run-off coefficients suggested by RIL (2004).

	Area [km²]	**1977 Q [l / s]**	**1982 Q [l / s]**	**1992 Q [l / s]**	**2007 Q [l / s]**
Subcatchment 1	2.109	1556	1667	2235	7465
Subcatchment 2	7.574	21487	21597	25133	26570
Subcatchment 3	1.332	1544	1735	3397	6802
Subcatchment 4	0.361	627	627	754	763
Subcatchment 5	0.532	1661	2228	2679	3742
Subcatchment 6	4.738	631	657	3150	7044
Subcatchment 7	0.765	679	790	3528	4537
Subcatchment 8	0.258	584	628	662	778
Subcatchment 9	0.432	727	1083	1555	1999
Subcatchment 10	1.702	5215	6225	9298	10679
Subcatchment 11	1.031	2824	3429	6214	8151

The result of the run-off calculation, applying the run-off coefficients suggested in the German code (ATV-DVWK-REGELWERK 2000) is shown in table 5.7.

Since the design principle in any civil engineering code and thus also regarding stormwater management is, to assume the worst possible scenario, the higher values calculated according to the German code have to be taken into account. For the estimation of run-off in 2030 and the presented improvement and mitigation approaches, the latter one is the base to estimate the results.

Table 5.7 The peak run-off generated from impervious areas in the Kylmäoja basin calculated for the eleven subcatchments applying the run-off coefficients suggested by ATV-DVWK-REGELWERK (2000).

	Area [km²]	**1977 Q [l / s]**	**1982 Q [l / s]**	**1992 Q [l / s]**	**2007 Q [l / s]**
Subcatchment 1	2.109	1776	1896	2523	8482
Subcatchment 2	7.574	25427	25537	29232	31317
Subcatchment 3	1.332	1769	1974	3837	7781
Subcatchment 4	0.361	722	722	866	877
Subcatchment 5	0.532	1885	2529	3036	4241
Subcatchment 6	4.738	725	755	3628	8065
Subcatchment 7	0.765	768	887	3974	5109
Subcatchment 8	0.258	669	717	753	884
Subcatchment 9	0.432	818	1228	1745	2246
Subcatchment 10	1.702	5869	7005	10477	12031
Subcatchment 11	1.031	3194	3870	7080	9284

The calculated run-off estimates follow coherently the logic and results of the spatial analysis conducted. Since the subcatchments are not equal in size, the larger subcatchments show naturally higher run-off contribution.

The largest peak discharge is generated in the subcatchment 2, caused by the presence of the Helsinki-Vantaa airport. As mentioned earlier, it is notable that the influence of the airport on the Kylmäoja catchment gradually lessens with construction in other parts of the basin. The peak discharge calculated for the subcatchment 2 for the year 1977 was only 20% lower than the run-off evaluated for 2007.

The values also show the strong development in subcatchment 1 within the past 15 years, where the run-off increase by 236% in opposite to subcatchment 10, containing the most urban areas, where the increase of run-off within the past 15 years is less significant increasing by 15%.

5.3.2 Scenarios for 2030

For the target year 2030, three different scenarios were calculated based on different assumptions – one based on the results of the spatial analysis conducted and two alternative approaches.

First, the peak discharge in 2030 was calculated based on the spatial analysis conducted and factors and coefficients derived during the process.

Higher structures comprise less roofage in comparison with the constructed floor area. For the first alternative peak run-off calculation, it was assumed, that industrial and commercial buildings as well as apartment blocks – a variation for detached houses is not reasonable – would be constructed higher, than the coefficients derived from the analysis determine. The change does not affect existing buildings, but only new structures built until 2030. The results of this assumption are presented in the discussion chapter under point 6.1.1 as an approach for improvement.

The second alternative approach concentrated on the yard areas. The investigation showed the importance of this run-off contributor and its influence in the catchment. In comparison with roofs, the design of yards offers several alternative solutions, concerning both the size of the impervious area itself and the type of surface used. An alternative would be to address yard areas with regulation on maximum imperviousness surface areas and better design practices. In regard the surface materials, for a detached house impervious surface a loose gravel cover might be as suitable as asphalt or bricks. Large tiles with gaps as an alternative would already support infiltration of the rainwater into the soil below and reduce the run-off. As an estimation of potential change, a calculation was carried out with run-off coefficients reflecting different surface types. This change was only applied for the yard areas of new constructed buildings between 2008 and 2030. The results of this assumption are presented under point 6.1.2.

A third alternative approach is presented without calculation in chapter 6.1.3. The possible positive influence of green roofs in the Kylmäoja catchment is estimated based on a study conducted by Mentens (2005) for the metropolitan region of Brussels.

5.3.2.1 Development based on the situation 2007

Based on the relations determined between floor area, roof area and yard area, the peak discharge generated from impervious areas in the Kylmäoja catchment was calculated. The rainfall intensity used is the same as for the years before 2007 to achieve comparable result – 255 [l / s * ha].

The table below shows the run-off for 2007 and 2030, to illustrate the increase of run-off in the catchment (table 5.8).

Table 5.8 The peak run-off generated from impervious areas in the Kylmäoja basin calculated for the eleven subcatchments in 2007 and 2030.

	Area [km²]	**2007 Q [l / s] (table 5.7)**	**2030 Q [l / s]**	**Relative increase 2007 – 2030**
Subcatchment 1	2.109	8482	12760	50 %
Subcatchment 2	7.574	31317	42557	36 %
Subcatchment 3	1.332	7781	10872	40 %
Subcatchment 4	0.361	877	1057	21 %
Subcatchment 5	0.532	4241	4740	12 %
Subcatchment 6	4.738	8065	17941	122 %
Subcatchment 7	0.765	5109	6589	29 %
Subcatchment 8	0.258	884	1349	53 %
Subcatchment 9	0.432	2246	3016	34 %
Subcatchment 10	1.702	12031	13714	14 %
Subcatchment 11	1.031	9284	12620	36 %

Figures 5.19 – 5.23 show the influence of yard area surfaces on the run-off in the Kylmäoja catchment and the importance of their consideration in urban planning. The run-off generated from yard areas follows the increase of run-off accumulated from roofs over the five decades in observation and in 2030 the yard areas will account for 34% of the generated run-off exceeding the contribution by the building roofage which will account for 30% of the generated run-off.

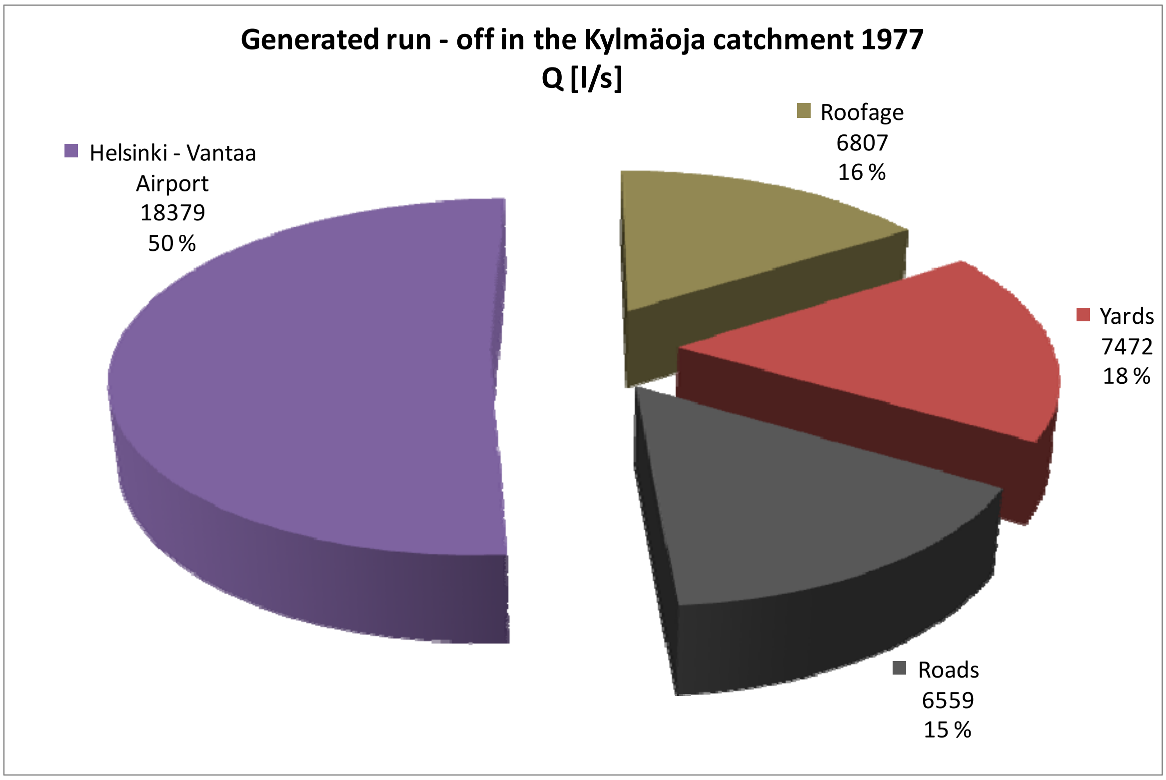


Figure 5.19 The run-off in the catchment assorted by origin in 1977 calculated with a rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2006) and the imperviousness determined during this work.

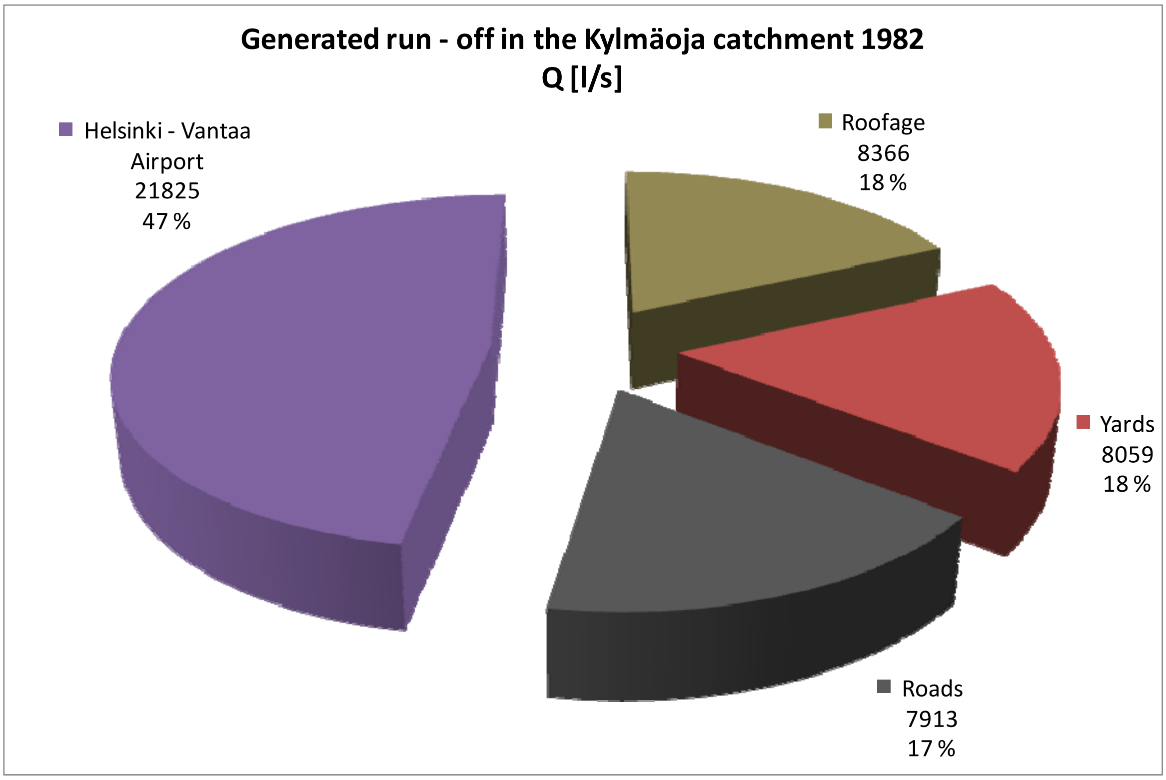


Figure 5.20 The run-off in the catchment assorted by origin in 1982 calculated with a rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2006) and the imperviousness determined during this work.

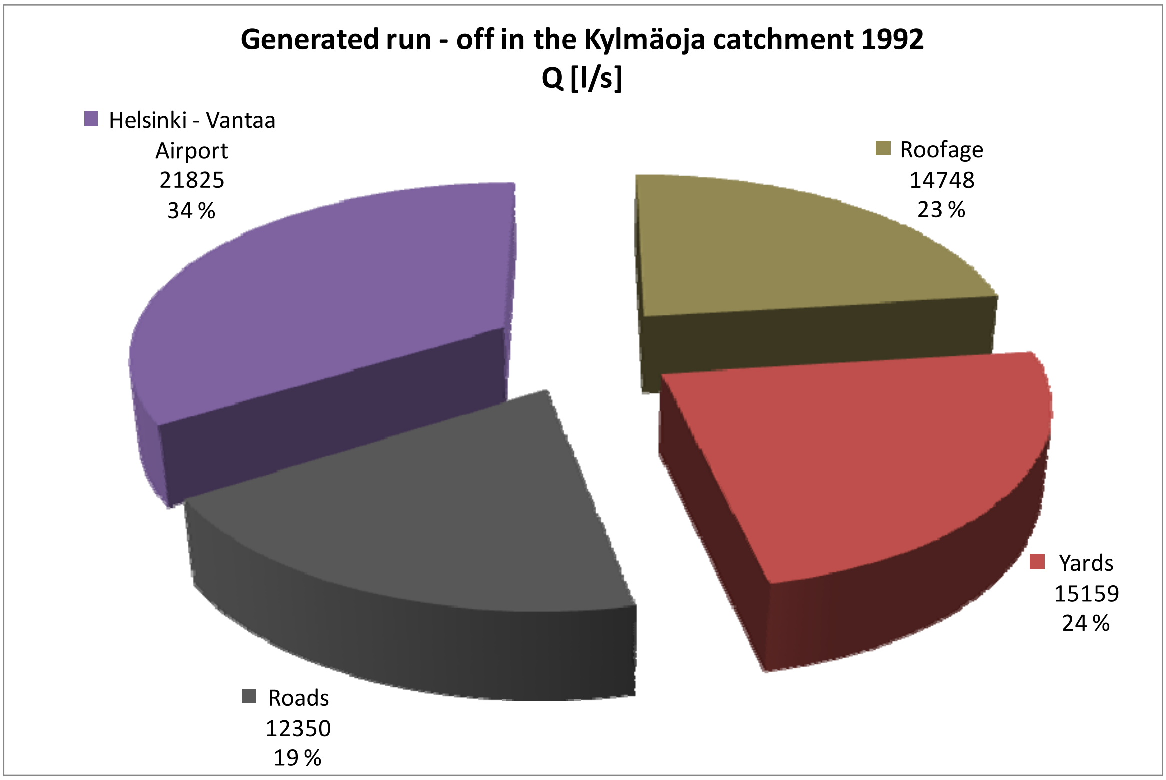


Figure 5.21 The run-off in the catchment assorted by origin in 1992 calculated with a rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2006) and the imperviousness determined during this work.

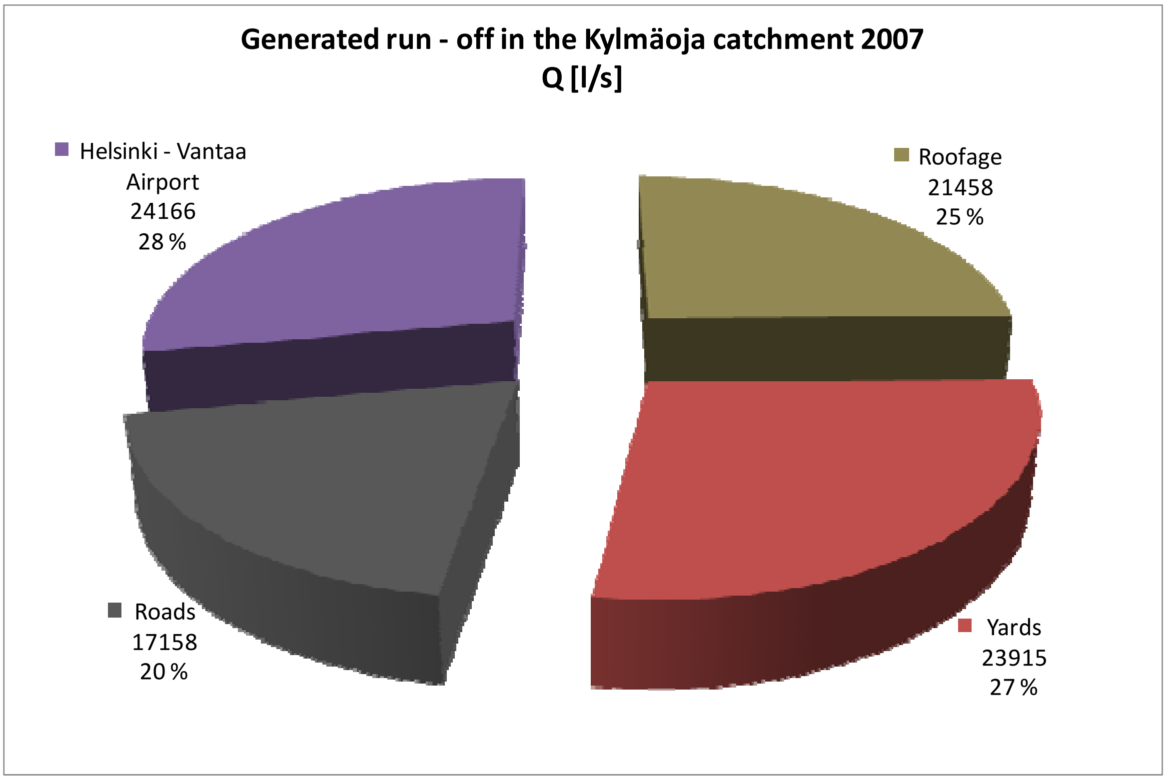


Figure 5.22 The run-off in the catchment assorted by origin in 2007 calculated with a rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2006) and the imperviousness determined during this work.

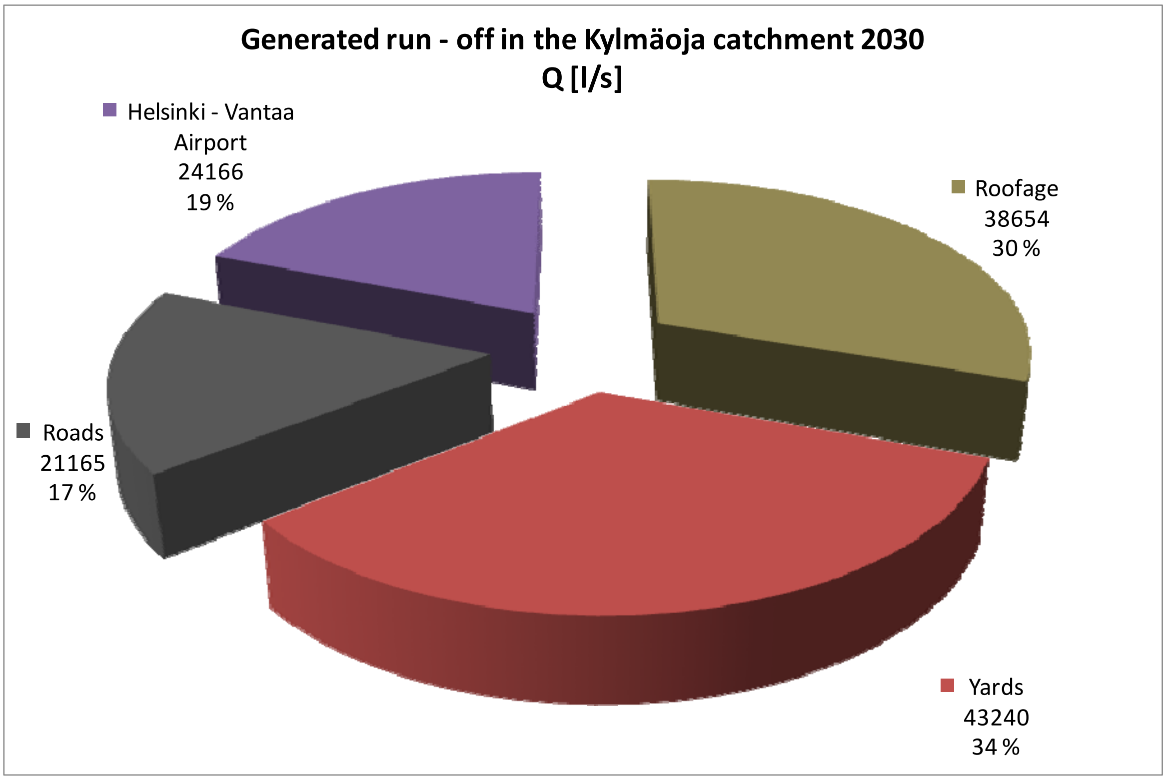


Figure 5.23 The run-off in the catchment assorted by origin in 2030 calculated with a rainfall intensity of 255 [l / s * ha] (Kilpeläinen 2006) and the imperviousness determined during this work.

6 Discussion and concluding remarks

The overall aim of this Master's thesis was to investigate the development of land-use within the urbanizing Kylmäoja watershed and associated effects of these land-use changes on the Kylmäoja urban stream. To investigate changes that both have a significant effect on the stream and are quantifiable focus was narrowed down analyzing the significance of development regarding three types of impervious surfaces generally represented in urban surroundings: building roofs, yard areas and roads.

Since watersheds are naturally independent from municipal borders, this project had to cope not only with the variety of data existing in the city of Vantaa where the majority of the catchment resides in but also with the differences in the nature of the datasets available in Vantaa and in Tuusula. Varying levels of city planning as well as varying quality of datasets had to be equalized to achieve uniform results for the entire Kylmäoja catchment.

The catchment area for the Kylmäoja stream was delineated utilizing a digital elevation model and then modified, based on the stormwater sewage system data available. The area of the Kylmäoja catchment was found to be 20.84 km2 of which 15.72 km² or 75% is located in the city of Vantaa and 5.12 km² or 25% is located in the municipality of Tuusula. The stream consists of three major headwater regions uniting to the main stream, further three lower branches join the main stream along its lower course. The catchment was therefore divided into six subcatchments for each separate branch and five subcatchments for the sections of the main stream between the junctions, resulting in a total of eleven subcatchments.

An investigation of the development of the three surface types (roofs, yards and roads) was carried out, based on existing and newly created databases for the time span between 1977, the year of the earliest documented discharge measurements in the stream, and 2007, the introduction year of a new city of Vantaa Master Plan. Base, on the other hand, for the forecasted development in the basin until 2030 and therefore also base for the analysis for Vantaa was the land-use map of the Vantaa 2007 Master Plan in combination with estimated data on future construction provided by the Vantaa city planning department of the city of Vantaa. The 2030 estimation for areas in Tuusula was based on land-use plans existing on various city planning scales.

Due to different availability of information in the city of Vantaa and the municipality of Tuusula, the investigation of impervious areas had to use different approaches.

The research for areas within the borders of the city of Vantaa for rooftops and yard areas was based on the floor area of buildings, determined from the plot-ratio used in urban planning. The roof area (using a database provided by the city of Vantaa) and the yard area (determined by the investigation of orthophotos) were set into relation with the floor area and coefficients were determined. Those coefficients were then used to estimate the impervious area from roofs and yards in 2030 based on plot-ratios on potential building sites and the difference of utilized and possible maximum plot-ratio on a lot. Road surfaces were directly analysed using a database provided by the city of Vantaa and general maps to identify unknown years of construction.

For areas located within the borders of the municipality of Tuusula, orthophotos and general maps were used for identification of rooftops, yard areas and road surfaces. Since the created database contained no information about the floor area, the relation between roof area and yard area was established with coefficients. However, the 2030 forecast utilized plot-ratios and hence floor area, as it is the common urban planning tool and therefore a relationship between floor area and roof area was needed after all also for Tuusula, despite the lack of information on the floor area situation before 2007. To define this relationship also for the areas in Tuusula, areas in Vantaa similar in land-use were selected, and the established Vantaa coefficients applied to the areas in Tuusula.

Impervious area in the Kylmäoja catchment grew between 1977 and 2007 and will continue to increase by almost 38% from 2007 until the year 2030. The investigation carried out also showed the growing influence of the municipality of Tuusula land-use on the Kylmäoja stream within the coming decades. The areas north of the city of Vantaa borders contributing run-off to the stream have been mainly in their natural shape till the mid 1980’s, not generating significant run-off to Kylmäoja. Focus on industrial development in these areas since the 1990’s has resulted in constant construction and permanent increase of impermeable surfaces, at a much higher pace than occurring in Vantaa. The results of the analysis showed, that share of impervious areas in Tuusula will reach 25% of the total impervious area in the catchment by 2030 and thus reach the proportion of catchment between the municipalities also in terms of constructed impervious surface area.

In 2007 the roof area within the Kylmäoja catchment accounted for 23% of ultimate imperviousness, with a total roof area of almost 890000 m^2. The roof area in the catchment is expected to grow by 80% to reach 1595625 m^2 in 2030, based on the spatial analysis carried out. In 2030, 30% of the ultimate imperviousness within the Kylmäoja catchment will be contributed by rooftops. A comparison of the development in Vantaa and Tuusula showed the following result. In 2007, 19% of the ultimate imperviousness in the catchment was contributed by roofs in Vantaa and 4% came from roofs in Tuusula, in 2030 this values will raise to 23% for Vantaa and 7% from Tuusula. In terms of total roof area in the catchment, that means that the proportion between Vantaa and Tuusula was 84% (Vantaa) to 16% (Tuusula) in 2007 and will be 77% (Vantaa) to 23% (Tuusula) in 2030.

The analyzed figures allow the conclusion, that the increase of roof area in Vantaa will also until 2030 be at a very high level, even though the relative fragment is smaller compared to earlier years, which is mainly caused by the higher number of densely built areas existing. Nevertheless the addition of 468430 m^2 between 2007 and 2030 is the highest increase over a time span of 23 years in the Kylmäoja catchment ever. More than 10% of the total growth of roofage in the Vantaa part of the catchment will happen in the subcatchment 6, indicating the importance of stormwater management for this area.

The increase of road surface is minor from 2007 until 2030, due to the dense road network existing in Vantaa by 2007. The explanation for the minor increase of road surface, compared to building roofs and yard areas, in Tuusula's part of the catchment might be the type of land-use. Industrial buildings are large in dimension and therefore industrial areas require a wider or less dense road network than residential areas. Nevertheless, the positive effect interpretable from a scarce road network is more than questionable, since the saved area is more than only compensated by the vast yard surfaces of these buildings.

An important aspect of the spatial analysis was the focus on the yard area condition. Aim was to investigate the dimension, the condition and their fraction of the ultimate imperviousness within the Kylmäoja catchment. The investigation first revealed that neither of the two municipalities involved has a database about these areas, hence a new database had to be created based on ortho-photos accompanied by site visits to verify surface materials. Research found that yard areas will account for 36% of impervious surface in the Kylmäoja basin in 2030, more than one third of the total imperviousness. The extent and ongoing growth of impervious yard surface in Tuusula is especially significant, caused by the high degree of industrialisation. The impervious yard area in Tuusula alone will account for 14% of the ultimate imperviousness within the catchment in 2030, twice as much as roofs (7%) and even almost four times more than roads (3%). Besides the extension of these areas the industrial focus in Tuusula also implies, that practically 100% of these yard areas is asphalt covered, thus highly impervious. Detached houses, as an example were found to have typically 50% of their driveways covered with asphalt and 50% with gravel surface. The yard area determined within the borders of the city of Vantaa accounted for 21% of the ultimate imperviousness in the catchment in 2007 and is expected to reach 22% in 2030. In terms of total impervious yard area in the Kylmäoja catchment, the proportion between Vantaa and Tuusula was 72% (Vantaa) to 28% (Tuusula) in 2007 and will be 58% (Vantaa) to 32% (Tuusula) in 2030.

The importance of the traffic component, which is not sufficiently considered yet in urban planning, became apparent in the results of this study. Trafficking area associated with roofage can, according to Schueler (1994) range from 63% to even 70%, depending on the layout of parking facilities and streets, for a medium density suburban area. In the case of this study carried out, the run-off generated from impervious area accounting for traffic, in this case yards and roads, accounts for 51% of the total run-off in 2030. The proportion of little above 50% might be explained with the influence of the Helsinki-Vantaa airport on the catchment (19% of the run-off in 2030 will be generated there), lowering the influence of conventional traffic area.

The imperviousness of the catchment and the effects on the Kylmäoja stream according to the three integrity urban stream classification by Schueler (1994) was investigated during this work. No such classification exists for catchments in Finland whereas the Schuler's classification is based on a large number (18) of catchment-stream relationship studies carried out across the USA. Schueler defined three classes, regarding the effects of imperviousness level in the catchment in his work: Sensitive streams (0-10% of imperviousness), impacted streams (11-25% of imperviousness and non-supporting streams (26-100% of imperviousness).

Here the imperviousness, defined as the proportion between impervious and other area ("green" area in Schueler's definition) in catchments of urban streams was quantified and the stream sections classified accordingly. The imperviousness of the whole catchment was 9% in 1977 and 10% in 1982, classifying Kylmäoja as a sensitive stream in those years. By the year 1992 Kylmäoja reached the class of an impacted stream, with 14% of imperviousness in 1992 and 19% in 2007. In the year 2030 the imperviousness in the catchment is expected to reach 26% classifying Kylmäoja as a non-supporting stream. The results at the subcatchment scale showed that in 1977 six subcatchments were sensitive and five subcatchments impacted. In 2007, only one subcatchment was classified as sensitive anymore, whereas five subcatchments were impacted and another five subcatchments were already above the threshold of 26%, classifying the sections as non-supporting. This trend is expected to continue and in 2030, no section of Kylmäoja will be sensitive anymore. Four subcatchments, namely C2, C4, C6 and C8 will be impacted according to Schueler (1994) and seven subcatchments, C1, C3, C5, C7, C9, C10 and C11 will be non-supporting.

This development is alerting and has to be taken into account in urban planning processes, as well in the city of Vantaa as also in the municipality of Tuusula.

The estimation of generated run-off in the Kylmäoja catchment was conducted with two different sets of run-off coefficients. The first one applied was based on the Finnish code (RIL 2004) which is currently used in the city of Vantaa and the second set was the one suggested in the German code (ATV-DVWK-REGELWERK 2000). Since the run-off coefficients in the German code were higher in average than those suggested by RIL (2004) and used in Vantaa, the German recommendation was used for the further calculation for two reasons: First run-off coefficients in Finland as well as in Germany are independent from climate conditions and should hence be the same for impervious surfaces in both countries and second, the ultimate limit state scenario, base of any civil engineering code and hence also applicable in stormwater management practices requires the application of German coefficients, since their application results in higher run-off.

The estimation of run-off generated from the observed areas showed a significant increase until 2030. The more detailed influence of the changes on the discharge in Kylmäoja stream require more detailed hydrological modelling, which was beyond the focus in this thesis. The accumulated run-off will increase in each subcatchment until 2030, and for the whole catchment will grow by 41%.

The distribution of generated run-off, different run-off coefficients taken into consideration, for the four categories analyzed (besides roofs, yards and roads the Helsinki-Vantaa airport) was found to be as follows. In 1977, 50% of the run-off in the catchment was accumulated at the Helsinki-Vantaa airport, 16% came from rooftops, 18% from yards and 15% were generated from road surfaces. In 2007, to proportion of the run-off from Helsinki-Vantaa airport decreased to 28%, whereas all the other components increased: 25% from rooftops, 27% generated from yards and 20% from road surfaces. This trend is expected to continue and in 2030. The Helsinki-Vantaa airport will account for mere 19% of the generated run-off within the Kylmäoja catchment, road surfaces will contribute 17%, rooftops 30% and yard areas will account for 34% of the total run-off within the Kylmäoja catchment. Due to the fact that the asphalt paved area of the airport residing in the catchment grew only very little within the past decades and will not grow anymore, the domination of the airport in the Kylmäoja catchment imperviousness share decreases with further construction in the other areas of the basin. Besides the restriction of construction on the airport territory itself, the existence of the airport also restricts construction in areas reserved for aviation traffic in the approach paths. This prohibition of construction leads to large unbuilt areas, especially north and northeast of the territory. As a conclusion in can be said that, even though the impact of the existence of the airport in Vantaa and the Kylmäoja catchment brings inconveniences for residents and impacts on nature, its existence with the side effects mentioned, can be also seen as an advantage for the catchment, even from the environmental point of view. While the airport area is a large concentration of imperviousness, it sets aside vast forested areas. Naturally this mitigation by new construction is relative, since the importance only lessens in comparison with the total impervious area in the catchment and does not consider near the site of formation effects on peak flow and water quality.

The run-off generated from the asphalt surfaces of the Helsinki-Vantaa airport, which is contaminated with de-icing materials used in aviation, has specific impact on the water quality of recipients, distinct from roofs, yards and roads. The effects of the airport run-off on the Kylmäoja stream water quality have been investigated by Maria Tiensuu (2008) in a *pro-gradu* work, and the reader is referred to her study for more detailed information.

6.1 *Approaches for improvements*

6.1.1 Higher structures reduce the roof area

Since the generated run-off from a building depends on the contributing roof area, a structure designed high – with several floor levels – seems, in first place preferable to a low structure with the same overall floor area. Due to the fact that detached row houses very rarely consist of more than two floors, the importance of this conclusion is restricted to industrial buildings, office and apartment blocks.

Assuming furthermore, that the demand of parking lot area for these types of buildings depends on the number of workplaces or inhabitants of the apartment block, and hence on the floor area after all, the positive effect of the high-rise buildings on the run-off will be reduced by the constructed impervious yard area.

High estate prices and limitation of available space, as the case for the entire Helsinki metropolitan area, consequently lead to the result that construction will always try to meet the maximum plot-ratio defined for an estate, to optimize both profit and utilisation of the land purchased and available.

As a conclusion of these three points it is obvious that an available piece of land will always be used in the most efficient way, in first place in the economical point of view. And since the investment for parking lots even with the ground is much lower than the financial investment for parking garages, the latest new parking garage at the Helsinki-Vantaa airport is documented with a price of 11250€ / car space (Aho, O. - Betoni 03/2008), it is likely that available space on an estate will be used for construction of parking lots, if not needed for the building structure itself, even so far, that the positive effect of the high-rise building tends to zero. Nevertheless the influence of floor area-roof area factors and the effects of possible variation of those are discussed here to investigate the potential of this mitigation approach.

The lowest coefficient between roof area and floor area for apartment blocks in the Kylmäoja catchment is 0.37 in subcatchment 11. The lowest factor for industrial buildings identified is 0.40 in subcatchment 5. Both values derive from buildings constructed between 1993 and 2007. A coefficient of 0.40 would mean practically, that a building with a floor area of e.g. 500 m² would have a corresponding roof area of 200 m². Including outer walls and areas not counted to the living area, this value would be valid for a building with three to four floors, not an unusual picture in Vantaa as well for residential buildings as for office buildings at the moment.

If we would now progressively try to use a coefficient of 0.20, that would describe a building of approximately six floors, no skyscraper yet, but higher than the average in the catchment. With this relation the run-off generated would look as follows (table 6.1).

Table 6.1 The peak run-off generated from impervious areas in the Kylmäoja basin calculated for the eleven subcatchments in 2007 (conventional) and 2030 (conventional and alternative).

	Area [km²]	**2007 Q [l / s] (table 5.7)**	**2030 Q [l / s] (table 5.8)**	**2030 Q [l / s]**	**Reduction potential**
Subcatchment 1	2.109	8482	12760	11672	-9 %
Subcatchment 2	7.574	31317	42557	39003	-8 %
Subcatchment 3	1.332	7781	10872	10590	-3 %
Subcatchment 4	0.361	877	1057	1026	-3 %
Subcatchment 5	0.532	4241	4740	4717	0 %
Subcatchment 6	4.738	8065	17941	15031	-16 %
Subcatchment 7	0.765	5109	6589	6589	0 %
Subcatchment 8	0.258	884	1349	1186	-12 %
Subcatchment 9	0.432	2246	3016	3016	0 %
Subcatchment 10	1.702	12031	13714	13588	-1 %
Subcatchment 11	1.031	9284	12620	12196	-3 %

Since the height of buildings only affects multi storey buildings and office blocks to be constructed, the largest effect can be seen for subcatchments having a large potential for these building types. A reduction of approximately 3550 [l / s] or 8% is possible for subcatchment 2, and 2900 [l / s] or 16% could be the reduction potential for subcatchment 6. Both subcatchments are dominated by industrial development in Tuusula and subcatchment 6 additionally by the residential development in Leinelä. The reduction in subcatchment 1 could be 1100 [l / s] or 9%.

Even though the attempt to support high and therefore slim structures for these building types offers a potential for reduction of run-off, it is uncertain how large the effect could really be in reality. The question how the yard areas belonging to structures are designed is crucial. The reduction of roofage is only then a reasonable approach, if the saved impervious area is not compensated by construction of parking lots, clearing the positive effect.

6.1.2 Focus on the yard areas

As stated earlier the yard areas contribute significantly to the total storm water run-off. The investigation showed a share of 50% asphalt and 50% gravel for detached houses, 80% asphalt and 20% gravel for row houses and 100% asphalt for apartment blocks, office buildings and structures with industrial purpose.

Alternatively to the previous calculation, the run-off was calculated with different run-off coefficients. The run-off coefficient for detached houses and low-rise housing areas used was 0.63. If we now assume that instead of asphalt, the utilisation of gravel, wide tiles, alternative pavers or vegetated areas would be supported, the combined run-off coefficient could be 0.43 – still 20% asphalt cover, but more pervious materials (80% of the area).

For row-houses we could lower the value from 0.82 identified earlier, to 0.63, the value used initially for detached houses. That would mean a reduction of asphalt by 40% compared to the situation for buildings constructed between 1993 and 2007. The difference would be replaced by loose gravel.

The definition of yard areas for offices and apartment blocks is difficult, because of the large dimension of this surfaces and the high degree of use. But we could anyway try to assume, that 20% of the area could receive a pervious vegetated surface instead of the pavement which would result in a run-off coefficient of 0.82.

All the changes are, as conducted for the higher structure approach, applied for buildings to be constructed until 2030.

The results of the peak run-off, if all new buildings yards would be constructed like described above, would look as follows (table 6.2).

Table 6.2 The peak run-off generated from impervious areas in the Kylmäoja basin calculated for the eleven subcatchments in 2007 (conventional) and 2030 (conventional and alternative).

	Area [km²]	2007 Q [l / s] (table 5.7)	2030 Q [l / s] (table 5.8)	2030 Q [l / s]	Reduction potential
Subcatchment 1	2.109	8482	12760	11978	-6 %
Subcatchment 2	7.574	31317	42557	41349	-3 %
Subcatchment 3	1.332	7781	10872	10526	-3 %
Subcatchment 4	0.361	877	1057	1040	-2 %
Subcatchment 5	0.532	4241	4740	4707	-1 %
Subcatchment 6	4.738	8065	17941	16584	-8 %
Subcatchment 7	0.765	5109	6589	6409	-3 %
Subcatchment 8	0.258	884	1349	1315	-3 %
Subcatchment 9	0.432	2246	3016	2907	-4 %
Subcatchment 10	1.702	12031	13714	13527	-1 %
Subcatchment 11	1.031	9284	12620	12162	-4 %

Even though the reduction of run-off achieved with this attempt does not reach the effect of the reduction of roof area, the approach still does cause positive effects with very little constructive and financial effort. The reduction possible in the subcatchments 2 would be 1200 [l / s] or 3% and in subcatchment 6 would be around 1400 [l / s] or 8%.

In contrast to the attempt of supporting higher structures and also the later discussed green roofs (chapter 6.1.3), the reduction of impervious yard area is applicable also to existing yards, even though the changes in yard surface types were only applied for the buildings to be constructed.

6.1.3 Green roofs

More green areas in cities would not only have a positive ecological effect, and especially rain-water run-off quantity and quality improvement, but also enhance life quality in urban areas. Unfortunately, due to limited space and high land prices, the recreation and preservation of green areas in urban circumstances have been viewed very expensive if not even impossible. (Mentens 2005)

Since in the Kylmäoja catchment in 2030, roofs will account for almost one third of the run-off, the mitigation of these areas is worth evaluating.

Mentens (2005) conducted an intensive literature review to investigate the actual effect of green roofs on the yearly run-off in Brussels and found that extensive roof greening – a substrate layer between 30 and 140 mm in depth – on 10% of the roofs would reduce the annual run-off in the urban area by 2.7%.

Table 6.3 Run-off coefficients for green roofs (Mentens 2005).

Substrate layer depth (mm) and runoff (% of total annual precipitation) characteristics of the literature data set on an annual level

	Intensive green roof ($n = 11$)	Extensive green roof ($n = 121$)	Gravel-covered roof ($n = 8$)	Non-greened roof ($n = 5$)
Substrate layer Depth (mm)				
Minimum	150	30	50	/
Maximum	350	140	50	/
Median	150	100	50	/
Average	210	100	50	/
Runoff (%)				
Minimum	15	19	68	62
Maximum	35	73	86	91
Median	25	55	75	85
Average	25	50	76	81

Table 6.3 shows the differences in run-off coefficients between a non-greened roof and extensive and intensive green roof covers. The average run-off coefficient reduces from 0.81 down to 0.50 for an extensive (substrate layer depth 100mm) green roof and further to only 0.25 for an intensive (substrate layer depth 210mm) green roof. An extensive green roof is applicable for almost any roof inclination. (Mentens 2005)

Since the run-off behaviour of green roofs undergoes seasonal changes and requires more detailed peak run-off calculation, the actual effects for the Kylmäoja catchment are not evaluated here. Nevertheless, the following estimation can be concluded:
We assume, as done in the study for Brussels, that 10% of the buildings in the Kylmäoja catchment receive an extensive green roof, reducing the run-off by approximately 38%, till 2030. The investigation showed that 30% or almost one third of the generated run-off in 2030 will derive from roofs. The reduction of run-off by 38%, applied for 10% of the rooftops in the catchment, results in a total reduction of 3.8% for the run-off generated from roofage. Applying this reduction valid for one third of the run-off on the overall discharge in the catchment, the run-off in the catchment could be reduced by 1.15%. As mentioned, neither seasonal changes nor climate differ-

ences between the area in Belgium and Finland were considered, but the estimation shows the potential of run-off reduction.

Figure 6.1 The roof of the city hall in Chicago 2000 (City of Chicago).

Figure 6.2 The city hall after installation of the green roof in summer 2004 (City of Chicago).

6.2 Concluding remarks

The results of this investigation showed the importance of including roof area as well as detailed yard area information to municipal building databases to allow for run-off estimation. A database, which contains run-off related information, as well for buildings as also for the discussed yards, is the base of a realistic run-off analysis.

This investigation showed that the land-use changes within the Kylmäoja catchment have been very rapid. The magnitude of effects on the stream morphology and habitat are largely yet to be seen in the coming decades. Strong efforts should be made for cross boundary sustainable planning and management to save the Kylmäoja as an as lively stream as possible to the delight of people and wildlife living within the catchment impact area.

Based on the estimated run-off, approaches for reduction of stormwater run-off were evaluated. The attempt to support construction of higher buildings, thus having less roofage, applicable only for buildings to be constructed, resulted in significant run-off reduction. Nevertheless this tool is not powerful without care for the green areas saved on plots then. If the green area recreated with the reduction of roof is replaced by parking places, the positive effect is diminished.

The investigation of yard area dimension and quality brought unexpected results. The contribution of impervious yard area for low-rise housing areas equals approximately the roof area of buildings, in the observed time spans. The results also showed the importance of close investigation of the yard area for run-off estimation. As shown in the hydrological interpretation (chapter 5) earlier in this document, more than one third of the accumulated run-off in the Kylmäoja catchment in 2030 will derive from impervious yard surfaces, which are not fully considered yet during urban planning processes.

The attempt to reduce asphalt surfaces on yard areas seems to be the easiest mitigation approach applicable in the Kylmäoja catchment. In a proposed mitigation scheme yard areas of detached houses contained no asphalt, row houses at the maximum 50% and apartment blocks, office buildings and industrial facilities not more than 80%. These changes were only applied for development yet to be constructed, and in such an estimate proved to be less effective than the reduction of roof area for to be constructed buildings. Nevertheless, reduction of impervious yard surfaces is, compared to the reduction of roofs, applicable for any building, also already constructed, and related with little financial expenses. Recognizing that 34% of the accumulated run-off for Kylmäoja will derive from impervious yard areas, the run-off mitigation potential of those is of major importance to reduce degrading the effects of developed land in the catchment on the Kylmäoja stream.

The approach of introduction and support of green roofs in the catchment showed an estimated reduction potential of stormwater run-off of 1.15% for the assumption, that 10% of the roofs in the catchment would have an extensive green roof installed. Exact calculation requires a detailed stormwater run-off model not carried out during this project – especially considering climate conditions and seasonal changes in the Kylmäoja catchment. Since 30% of the stormwater run-off in the catchment is generated from building roofs, the reduction potential of these surfaces is obvious.

The development of ultimate imperviousness within the Kylmäoja catchment showed that the key resource objective for the Kylmäoja is to mitigate the impact of land-use by applying effective stormwater management practices. In 2007 only one section of the stream, namely the eastern headwaters, is evaluated to be sensitive. Five sections have to be classified as impacted streams and for five sections the ultimate imperviousness is already above the threshold value of 25%, and hence these are classified as non-supporting. Thus, in accordance with research on urban stream health reviewed by Schuler (1994), it is of high importance to maintain or improve the impact of land-use for these sections, to avoid a continuous decrease of stream health and water quality. For the five non-supporting sections of the stream, downstream water quality protection has to be the main objective, achieved by effective urban pollutant removal. Without the application of suitable actions the condition of Kylmäoja will further degrade until 2030, and as a result of land-use development, in four subcatchments the stream section will be impacted and will in seven subcatchments reach the conditions of non-supporting streams.

The name of the Kylmäoja stream, ‘Cold Stream’, reflects the many springs, cold water, and cold water associated species that relate to Kylmäoja. It is evident that reintroduction of such species as trout to Kylmäoja will never succeed unless the catchment land-use planners and managers will recognize the degrading habitat effect of heat from impervious urban surfaces on the stream.

This thesis and the conducted research should be the base of a detailed hydrological model applied to the Kylmäoja basin, which exceeded the limits of this work and was therefore not carried out.

REFERENCES

Aho, O. (2008). *ELEMENTTIRAKENTEINEN PYSÄKÖINTILAITOS,* Betoni, Vol. 3, 2008, online available at *www.betoni.com/download.aspx?intFileID=1847&intLinkedFromObjectID=10420 - ,* visited 15.01.2009

ATV – DWMK – M 153 (2000). *Handlungsempfehlungen zum Umgang mit Regenwasser,* Arbeitsgruppe 1.4.3 “Regenwasserbehandlung. 2000. ISBN 3-927729-85-X

Canters, Frank, Jarek Chormanski, Tim Van de Voorde, Okke Batelaan (2006). *Effects of different methods for estimating impervious surface cover on runoff estimation at catchment level*, In: Caetano, M. and Painho, M. (eds). Proceedings of the 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, pp. 557 – 566, 5 – 7 July 2006, Lisbon, Instituto Geográfico Português, Available online at http://www.spatial-accuracy.org/system/files/Canters2006accuracy.pdf, visited 12.08.2009

Finavia. *Passengers 12/07.* Available online at http://www.finavia.fi/files/finavia/matkustajat_eng_pdf/0_INET_matk_lentoasemittain_EN_joulu07.pdf, visited 25.09.2008

Freund, Peter, George Martin (1993). *The ecology of the automobile*, Institute of Policy Alternatives, Montreal, Canada, ISBN 1-895431-83-2

Gupta, R.S. (1989). *Hydrology and Hydraulic Systems*; Waveland Press, Inc., Prospect Heights, IL.

Helsingin sanomat – Ref. 1. *Kasvavalla Sipoolla on paikka Helsinki – Porvoo - akselilla.* Helsingin sanomat, Monday 05.01.2009, available online on request at www.hs.fi

Helsingin sanomat – Ref. 2. *House prices rocketing in Helsinki metropolitan area*. Available online at http://www.hs.fi/english/article/House+prices+rocketing+in+Helsinki+Metropolitan+Area/1076154234130, visited 07.01.2009

Helsinki – Vantaa Airport – Ref. 1. *Helsinki – Vantaa History.* Available online at http://www.helsinki-vantaa.fi/history, visited 25.09.2008

Helsinki – Vantaa Airport – Ref. 2. *Helsinki – Vantaa in brief.* Available online at http://www.helsinki-vantaa.fi/hkivan_inbrief, visited 25.09.2008

Holtz, Kay Jane (1998). *Asphalt nation – How the automobile took over America and how we can take it back*, University of California Press, Berkeley and Los Angeles, California, ISBN 0-520-21620

Kehärata. *Rail Master Plan Report, draft 29.08.2008* Available online at http://www.keharata.net/Keharata_raportti_290808.pdf, visited 25.09.2008

Kibler, David F. (1982). *Urban stormwater hydrology*, Water resources monograph Vol. 7, American Geophysical Union, Washington, D.C.

Lee, Joong Gwang, James P. Heaney. (2003). *Estimation of Urban Imperviousness and its Impacts on Storm Water Systems*, Journal of Water Resources Planning and Management, Vol. 129, No. 5, pp 419 – 426, 2003. Available online at http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JWRMD5000129000005000419000001&idtype=cvips&prog=normal, visited 12.08.2009

Maanmittauslaitos – National Land Survey of Finland. *Pinta-alat kunnittain 2008*. Available online at http://www.maanmittauslaitos.fi/default.asp?id=894, visited 25.09.2008

Mentens, J, D. Raes, M. Hemry. (2005). *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century*, Landscape and Urban planning, pp. 217 – 226, Available online on request at http://www.sciencedirect.com

Nye, David E. (edited) (1999). *Technologies of landscape – from reaping to recycling, Technologies of landscape*, pp. 3 – 20, University of Massachusetts press

Nye, David E. (edited) (1999). *Technologies of landscape – from reaping to recycling, The landscape's crown – Landscape, perceptions and modernizing effects of the German Autobahn system, 1934 – 1941*, pp. 218 – 238, University of Massachusetts press

RIL 124-2 (2004). *Vesihuolto II,* Helsinki. Suomen Rakennusinsinöörien Liitto (RIL). 2004. ISBN 951-758-438-5

Ruth, O. (2003). *The effects of de – icing in Helsinki urban streams, southern Finland*, Water Science and Technology, Vol. 48, No. 9, pp 33 – 43, 2003

Schueler, T.R. (1994). *The importance of imperviousness*, Watershed Protection Techniques, Vol. 1, No. 3, pp 100 – 111, 1994, available online at http://yosemite.epa.gov/R10/WATER.NSF/840a5de5d0a8d1418825650f00715a27/159859e0c556f1c988256b7f007525b9/$FILE/The%20Importance%20of%20Imperviousness.pdf, visited 08.07.2009

Tiensuu, M. (2008). *Vantaan Kylmäojan ekologinen tila pohjaeläimistön perusteella arvioituna,* pro-gradu, Bio- ja ympäristötieteiden laitos, Akvaattiset tieteet / limnologia, 2008, available online at http://www.vantaa.fi/i_liitetiedosto.asp?path=1;221;224;2112;74691, visited 16.07.2009

Tuusulan kunta, *A new area called focus*, Available online at http://www.tuusula.fi/web/focus/tekstisivu.tmpl?numero=17367040, visited 08.01.2009

United Nations (2007), *World urbanization prospects: The 2007 Revision Population Database*, Available online at http://esa.un.org/unup/, visited 29.01.2009

Vantaan kaupunki – Ref. 1 – The city of Vantaa. *Vantaan Väestoraportti 07.* Available online at http://www.vantaa.fi/binary.asp?path=1;2075;6962;16187;23602;60107&field=FileAttachment&version=1, visited 25.09.2008

Vantaan kaupunki – Ref. 2 – The city of Vantaa. *Vantaan Väestoennuste 07.* Available online at http://www.vantaa.fi/binary.asp?path=1;2075;6962;22200;23603;58689&field=FileAttachment&version=1, visited 25.09.2008

Vantaan kaupunki – Ref. 3 – The city of Vantaa. Available online at http://www.vantaa.fi/i_alaetusivu.asp?path=1;135;137;221;1761;6113;6118, visited 25.09.2008

Vantaan kaupunki – Ref. 4 – The city of Vantaa. Available online at http://www.vantaa.fi/i_alaetusivu.asp?path=1;135;137;221;1761;6113;6117, visited 25.09.2008

Vantaan kaupunki – Ref. 5 – The city of Vantaa. *Historia lyhyesti.* Available online at http://www.vantaa.fi/i_perusdokumentti.asp?path=1;12743;1871, visited 02.10.2008

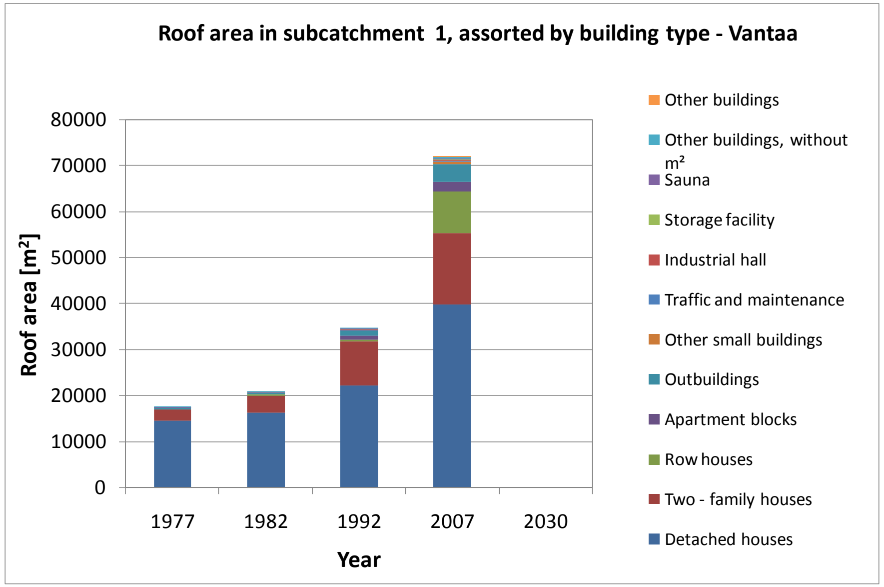
Vantaan kaupunki – Ref. 6 – The city of Vantaa. *Leinelä 1 – Keháradan ensimäinen asuntoalue (nro 700400).* Available online at http://www.vantaa.fi/i_perusdokumentti.asp?path=1;135;137;222;2394;2966;2977;17613, visited 09.01.2009

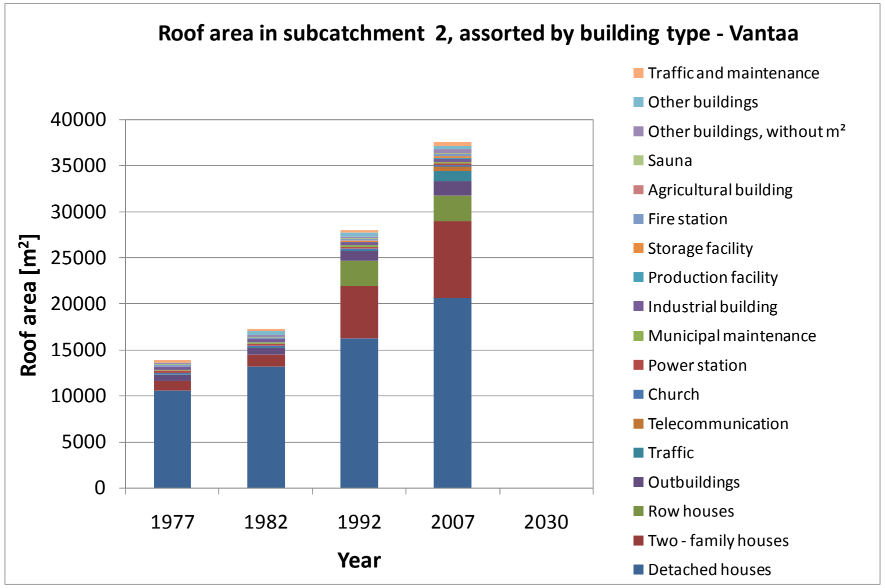
Vuosaari harbour. Available online at http://www.vuosaarensatama.fi/en, visited 01.02.2009

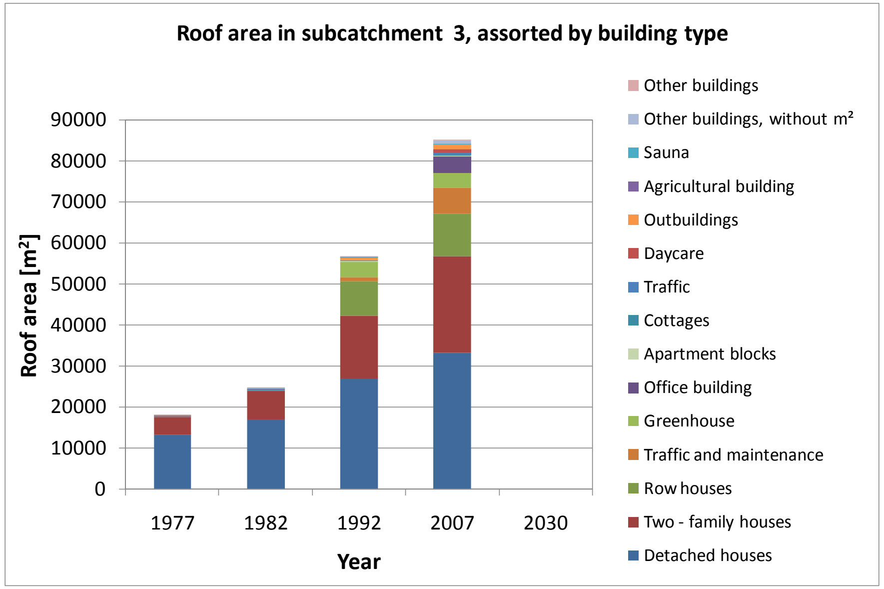
Väestörekisterikeskus. Available online at http://www.vaestorekisterikeskus.fi/vrk/files.nsf/files/E8F0B4E7D90F6587C22573D10046E647/$file/071231.htm, visited 25.09.2008

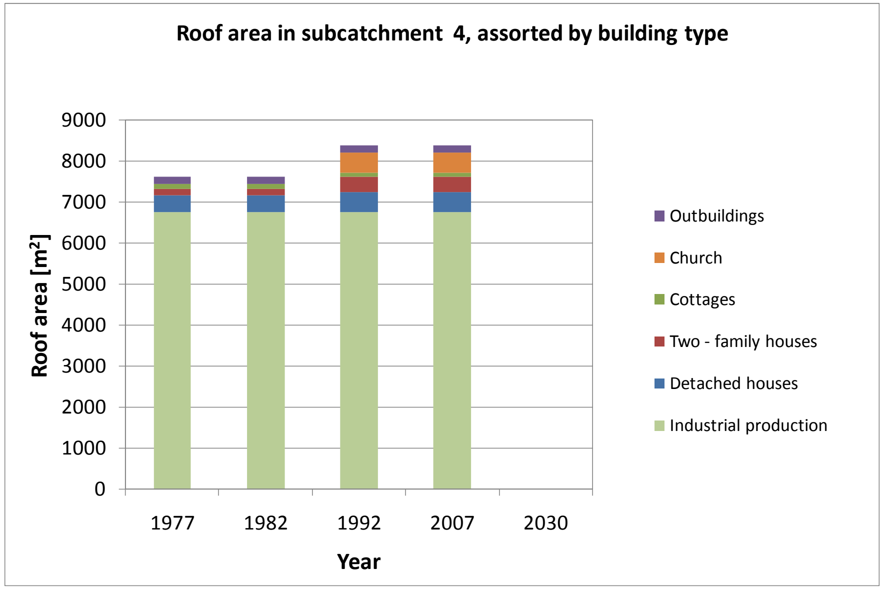
APPENDICES

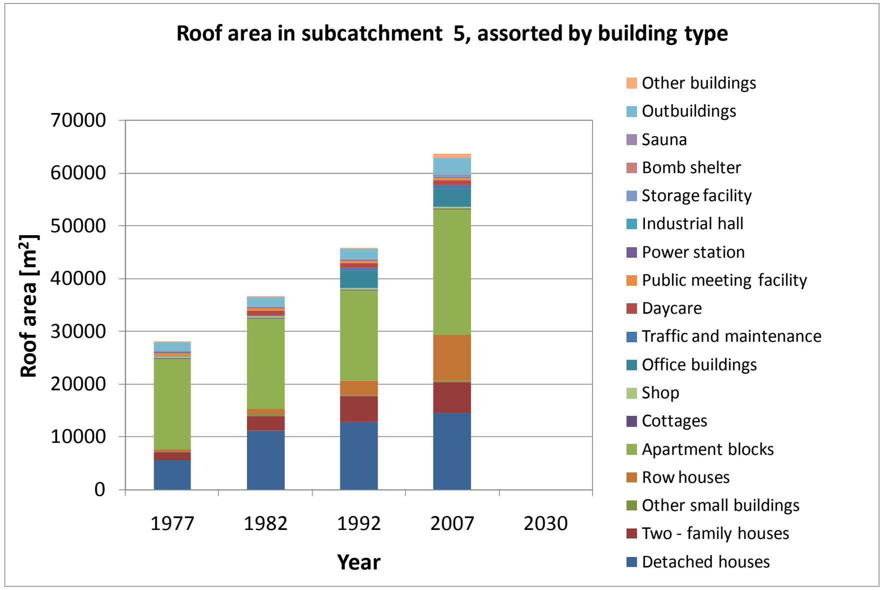
Appendix A The development of the roof area in Vantaa between 1977 and 2007, assorted by the subcatchments and the building categories used by the city of Vantaa.

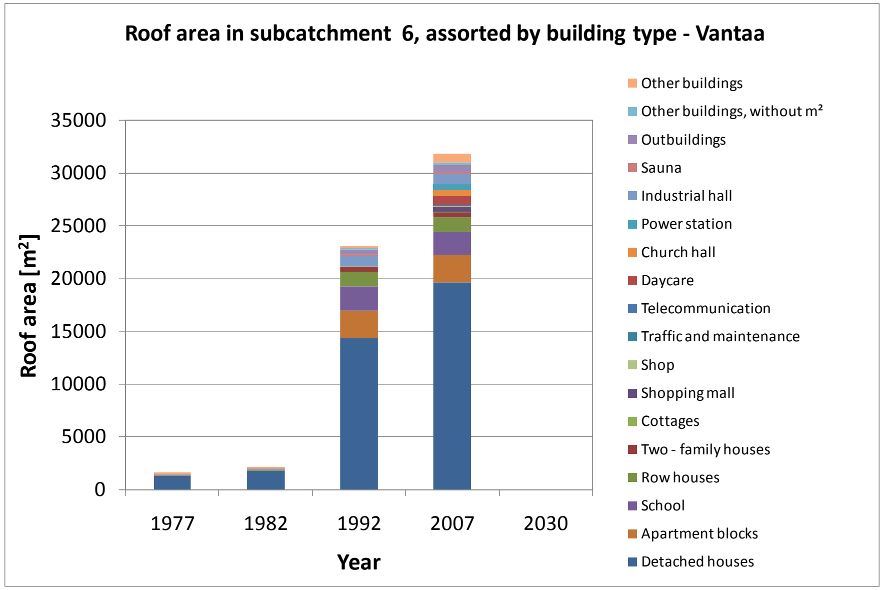


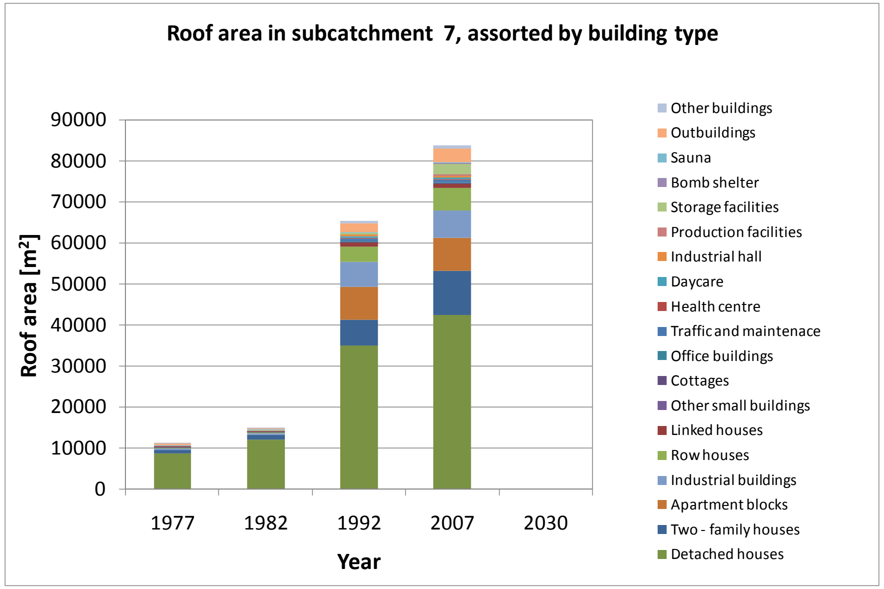



Roof area in subcatchment 3, assorted by building type
Roof area [m²]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Other buildings
Other buildings, without m²
Sauna
Agricultural building
Outbuildings
Daycare
Traffic
Cottages
Apartment blocks
Office building
Greenhouse
Traffic and maintenance
Row houses
Two - family houses
Detached houses

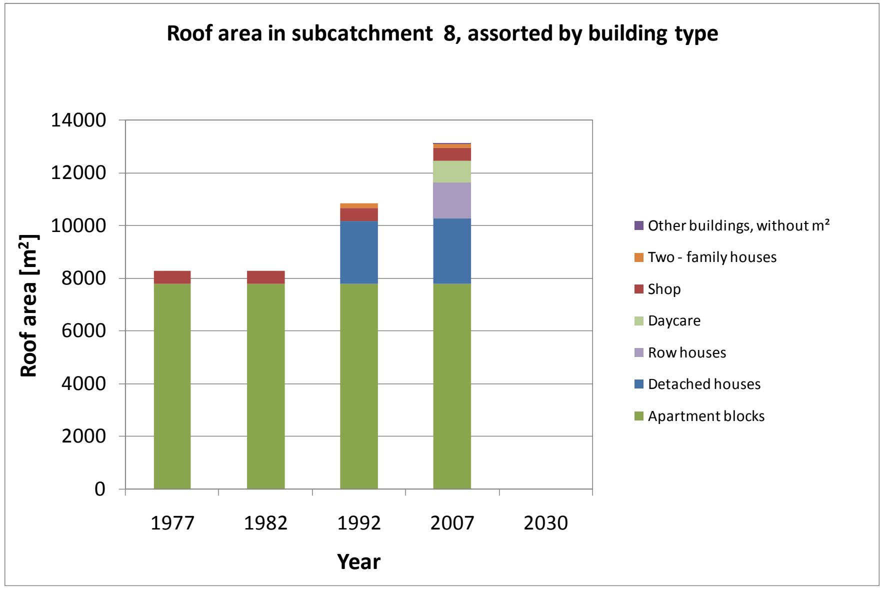

Roof area in subcatchment 4, assorted by building type
Roof area [m²]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1977
1982
1992
2007
2030
Year
Outbuildings
Church
Cottages
Two - family houses
Detached houses
Industrial production


Roof area in subcatchment 5, assorted by building type
Roof area [m²]
70000
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Other buildings
Outbuildings
Sauna
Bomb shelter
Storage facility
Industrial hall
Power station
Public meeting facility
Daycare
Traffic and maintenance
Office buildings
Shop
Cottages
Apartment blocks
Row houses
Other small buildings
Two - family houses
Detached houses

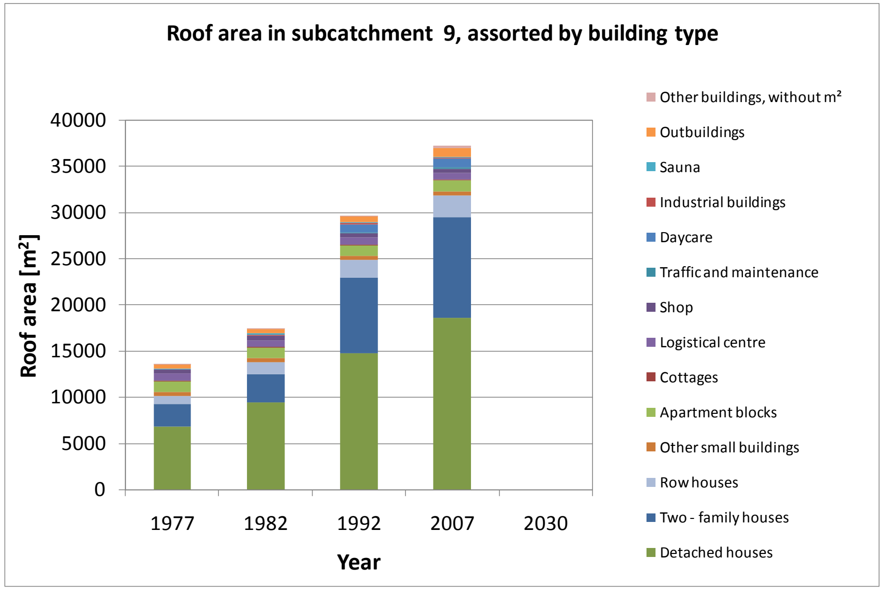

Roof area in subcatchment 6, assorted by building type - Vantaa
Roof area [m²]
35000
30000
25000
20000
15000
10000
5000
0
1977
1982
1992
2007
2030
Year
Other buildings
Other buildings, without m²
Outbuildings
Sauna
Industrial hall
Power station
Church hall
Daycare
Telecommunication
Traffic and maintenance
Shop
Shopping mall
Cottages
Two - family houses
Row houses
School
Apartment blocks
Detached houses



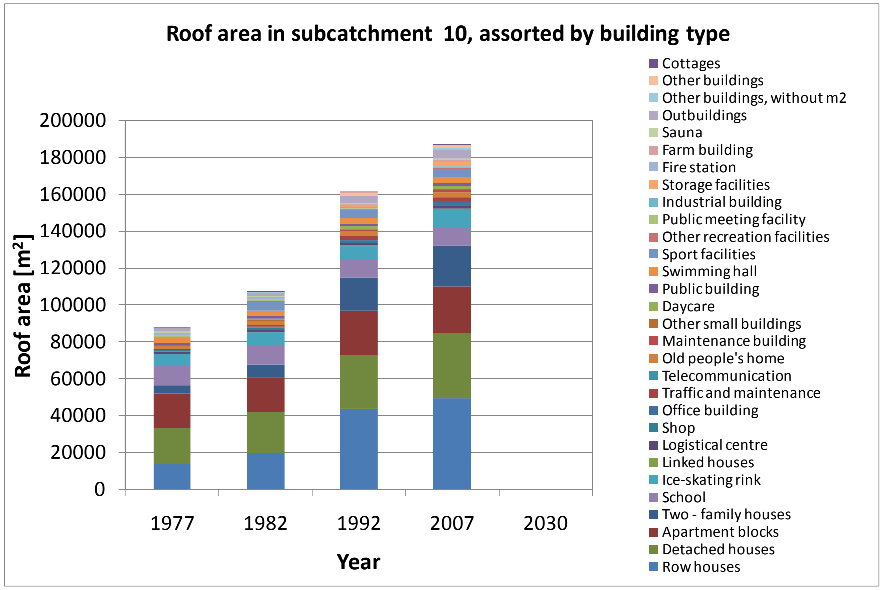
Roof area in subcatchment 7, assorted by building type
Roof area [m²]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Other buildings
Outbuildings
Sauna
Bomb shelter
Storage facilities
Production facilities
Industrial hall
Daycare
Health centre
Traffic and maintenace
Office buildings
Cottages
Other small buildings
Linked houses
Row houses
Industrial buildings
Apartment blocks
Two - family houses
Detached houses



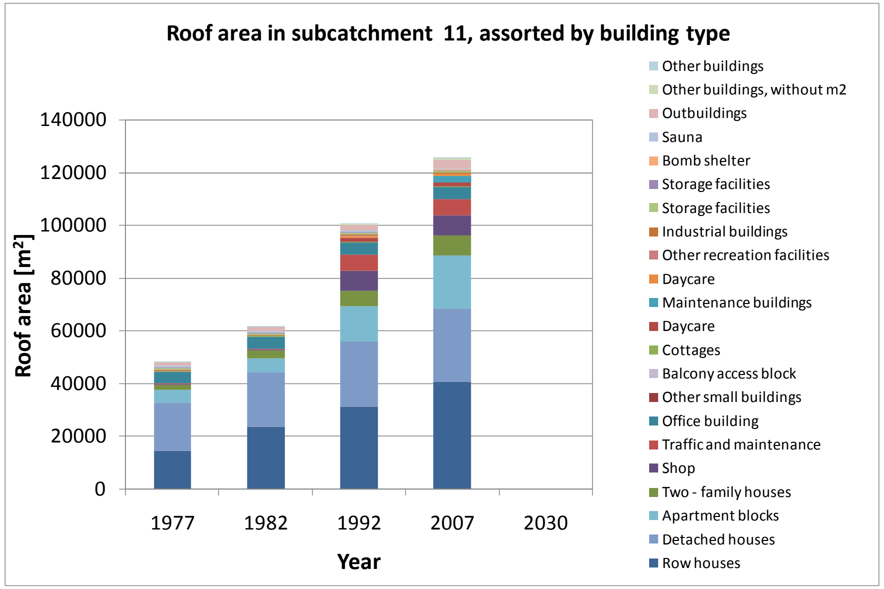
Roof area in subcatchment 8, assorted by building type
Roof area [m²]
14000
12000
10000
8000
6000
4000
2000
0
1977
1982
1992
2007
2030
Year
Other buildings, without m²
Two - family houses
Shop
Daycare
Row houses
Detached houses
Apartment blocks



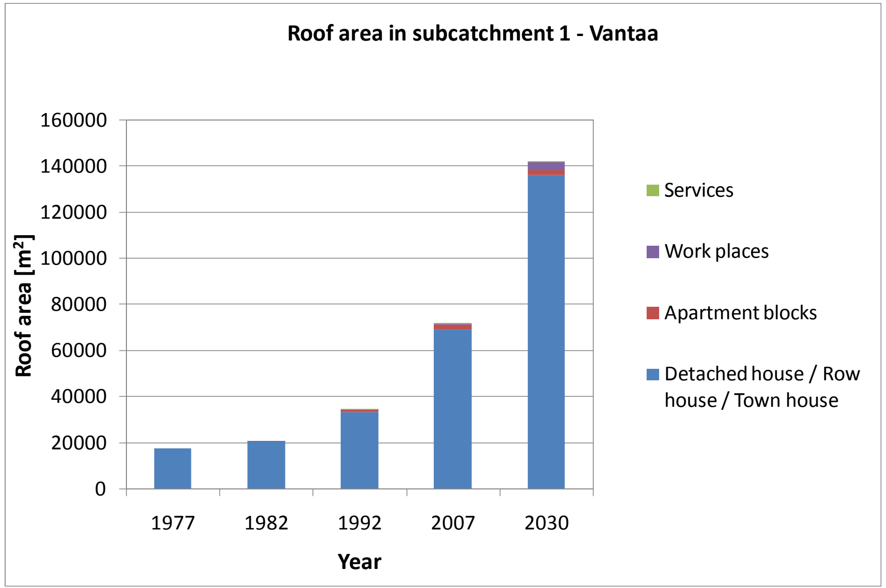
Roof area in subcatchment 9, assorted by building type
Roof area [m²]
40000
35000
30000
25000
20000
15000
10000
5000
0
1977
1982
1992
2007
2030
Year
Other buildings, without m²
Outbuildings
Sauna
Industrial buildings
Daycare
Traffic and maintenance
Shop
Logistical centre
Cottages
Apartment blocks
Other small buildings
Row houses
Two - family houses
Detached houses

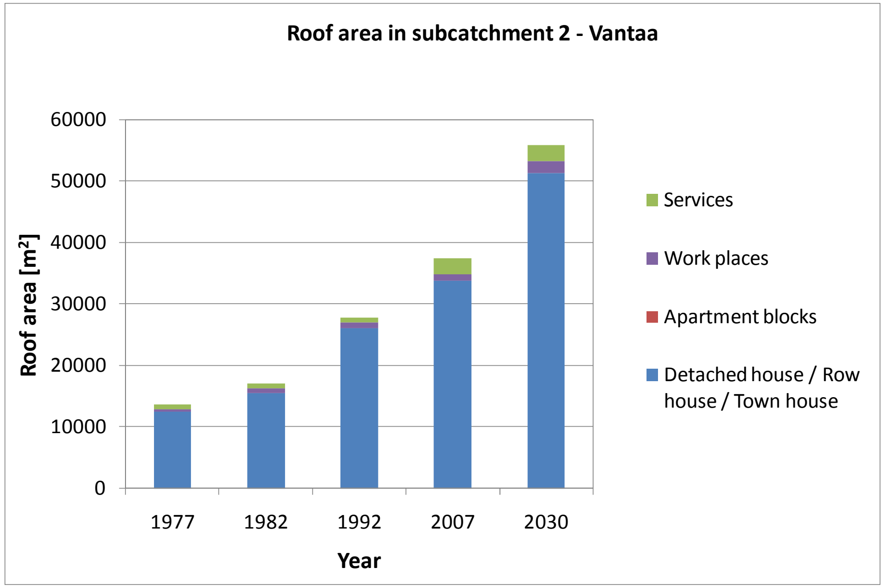


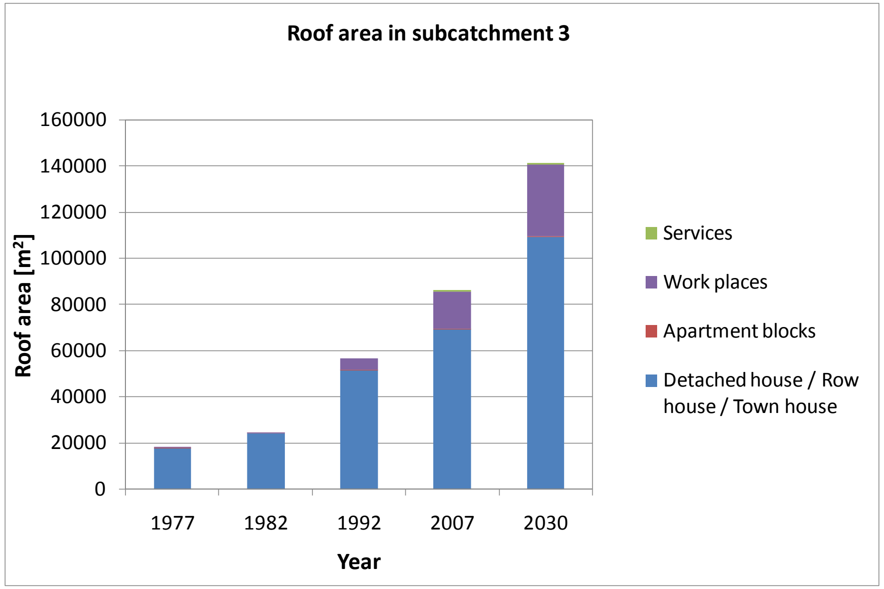
Roof area in subcatchment 10, assorted by building type
Roof area [m²]
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Cottages
Other buildings
Other buildings, without m2
Outbuildings
Sauna
Farm building
Fire station
Storage facilities
Industrial building
Public meeting facility
Other recreation facilities
Sport facilities
Swimming hall
Public building
Daycare
Other small buildings
Maintenance building
Old people's home
Telecommunication
Traffic and maintenance
Office building
Shop
Logistical centre
Linked houses
Ice-skating rink
School
Two - family houses
Apartment blocks
Detached houses
Row houses

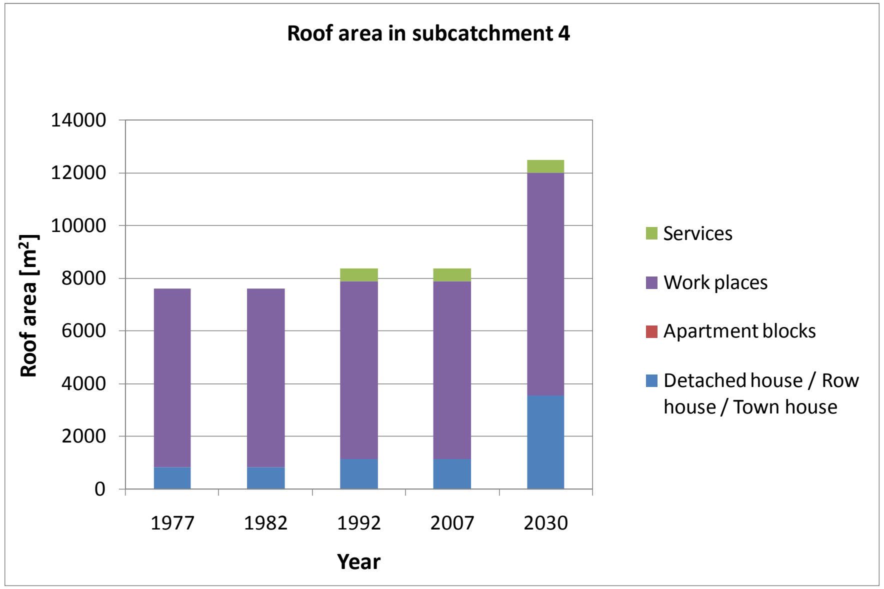

Roof area in subcatchment 11, assorted by building type
Roof area [m2]
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Other buildings
Other buildings, without m2
Outbuildings
Sauna
Bomb shelter
Storage facilities
Storage facilities
Industrial buildings
Other recreation facilities
Daycare
Maintenance buildings
Daycare
Cottages
Balcony access block
Other small buildings
Office building
Traffic and maintenance
Shop
Two - family houses
Apartment blocks
Detached houses
Row houses

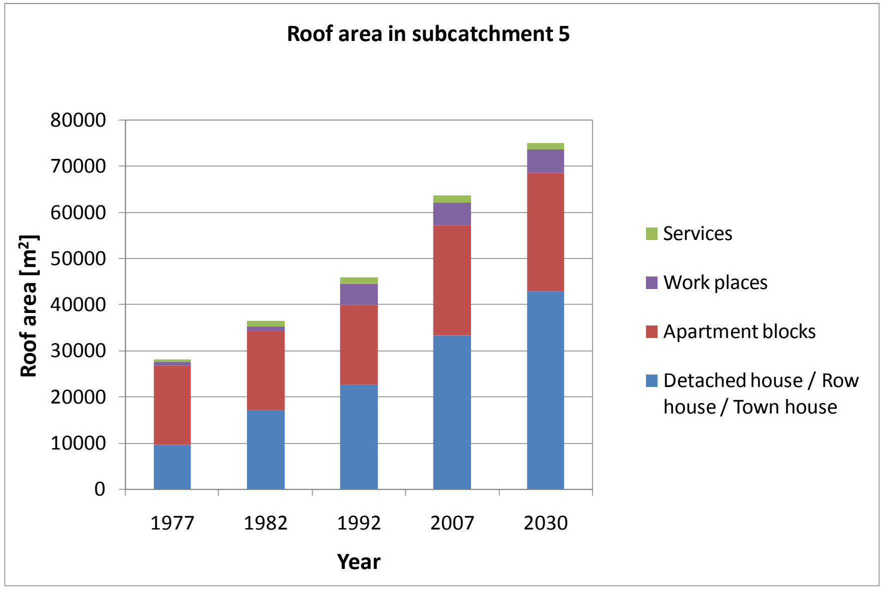
Appendix B The development of the roof area in Vantaa between 1977 and 2030, assorted by the subcatchments and the building categories defined during this project. These are detached houses / row houses / town houses and apartment blocks for residential buildings, services for public buildings and maintenance and work places for industrial buildings and office blocks.

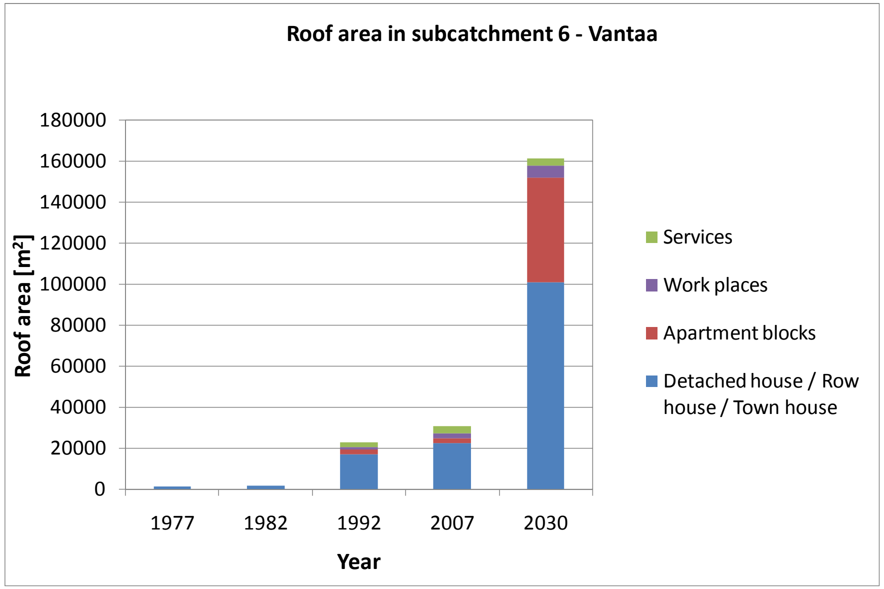


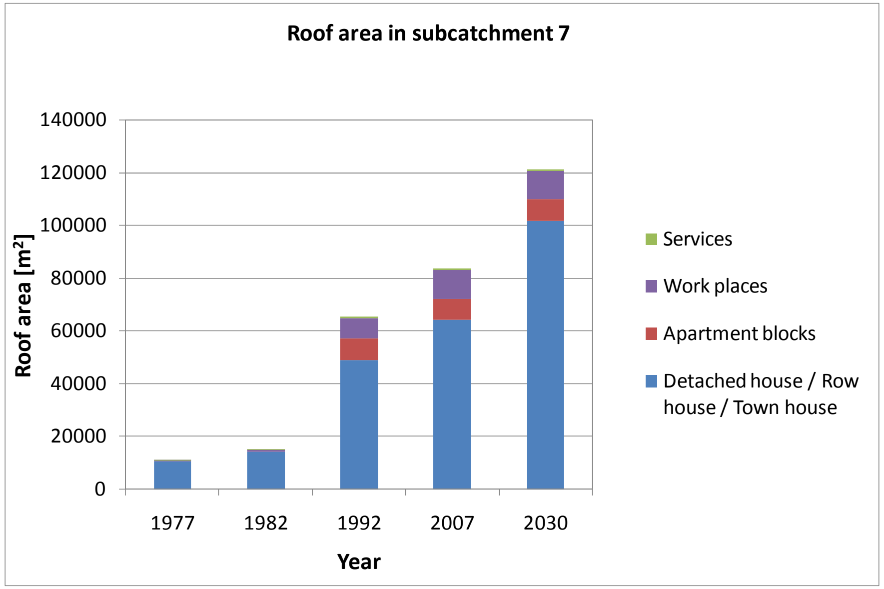


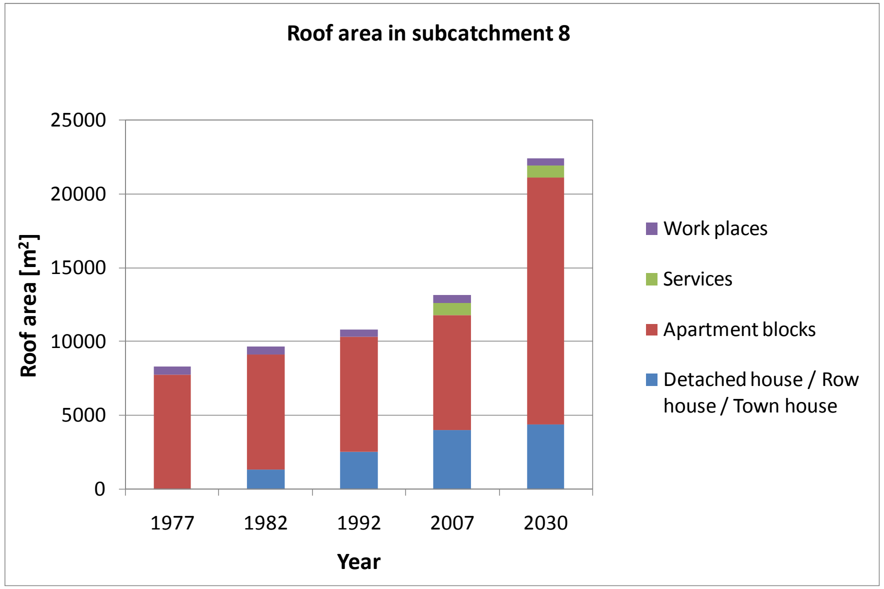

Roof area in subcatchment 3
Roof area [m2]
160000
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

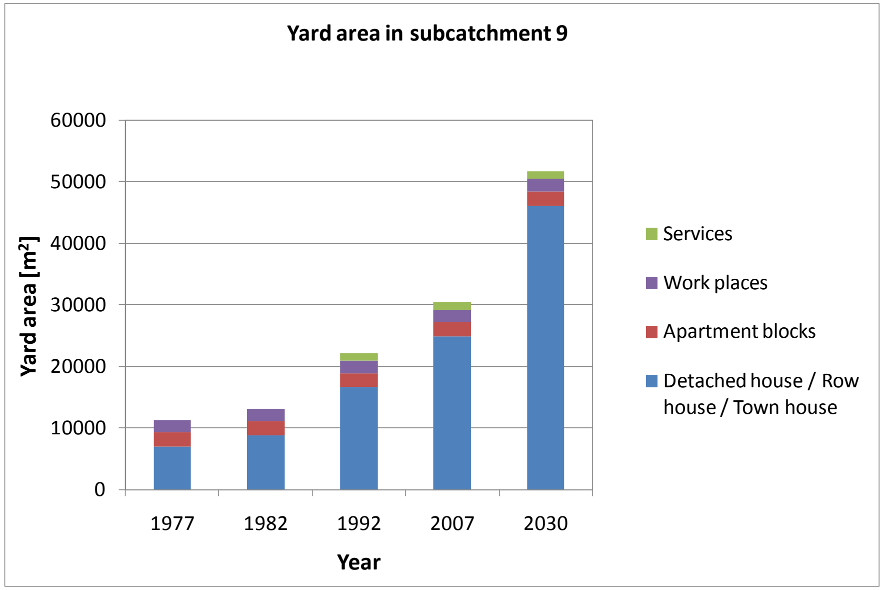

Roof area in subcatchment 4
Roof area [m2]
14000
12000
10000
8000
6000
4000
2000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

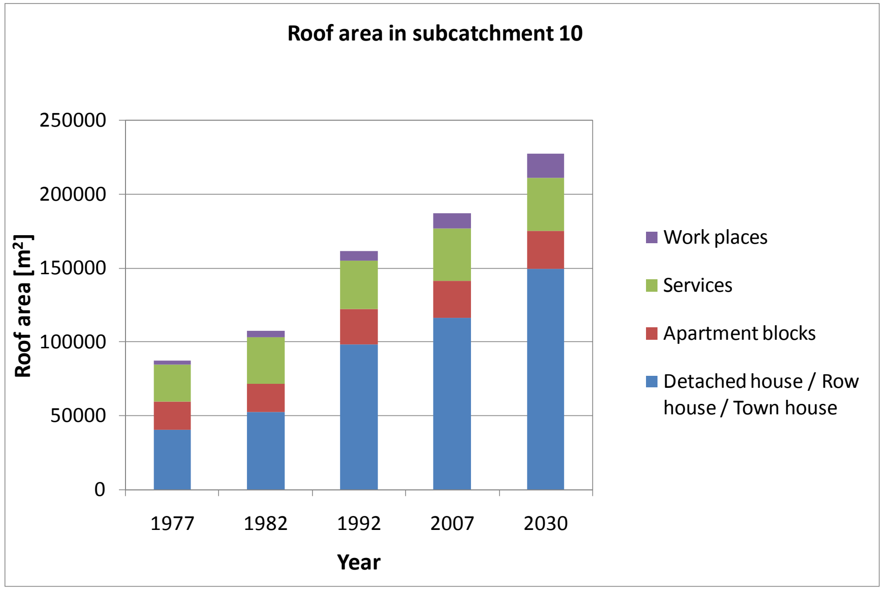

Roof area in subcatchment 5
Roof area [m2]
80000
70000
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

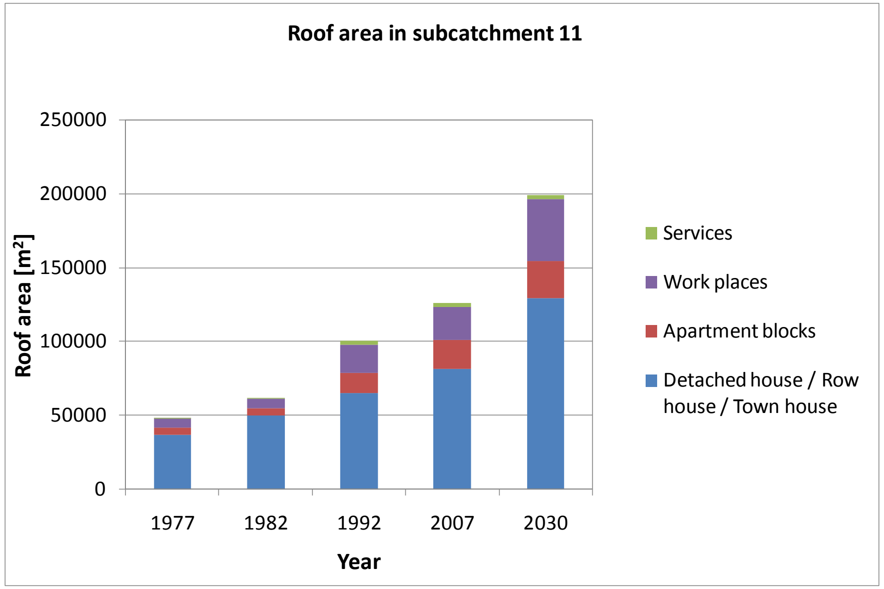

Roof area in subcatchment 6 - Vantaa
Roof area [m2]
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house


Roof area in subcatchment 7
Roof area [m²]
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

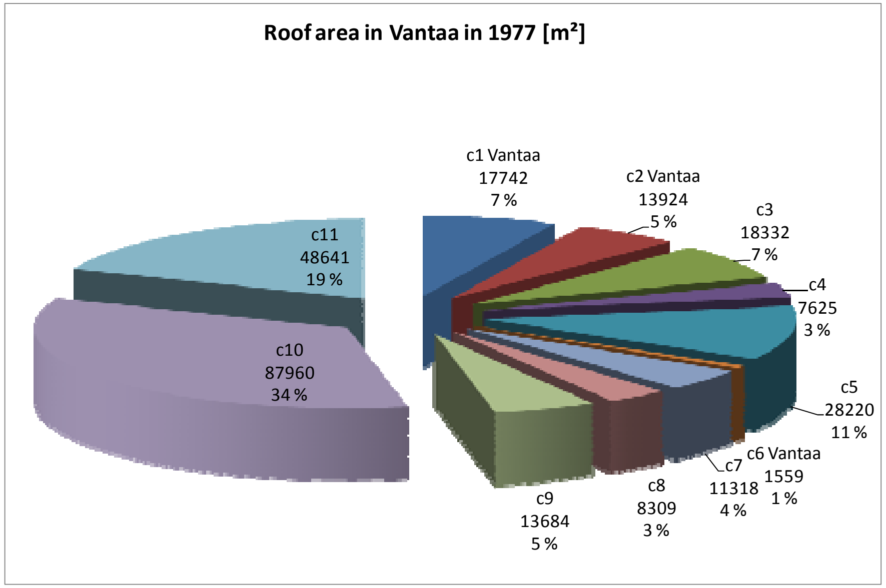

Roof area in subcatchment 8
Roof area [m²]
25000
20000
15000
10000
5000
0
1977
1982
1992
2007
2030
Year
Work places
Services
Apartment blocks
Detached house / Row house / Town house

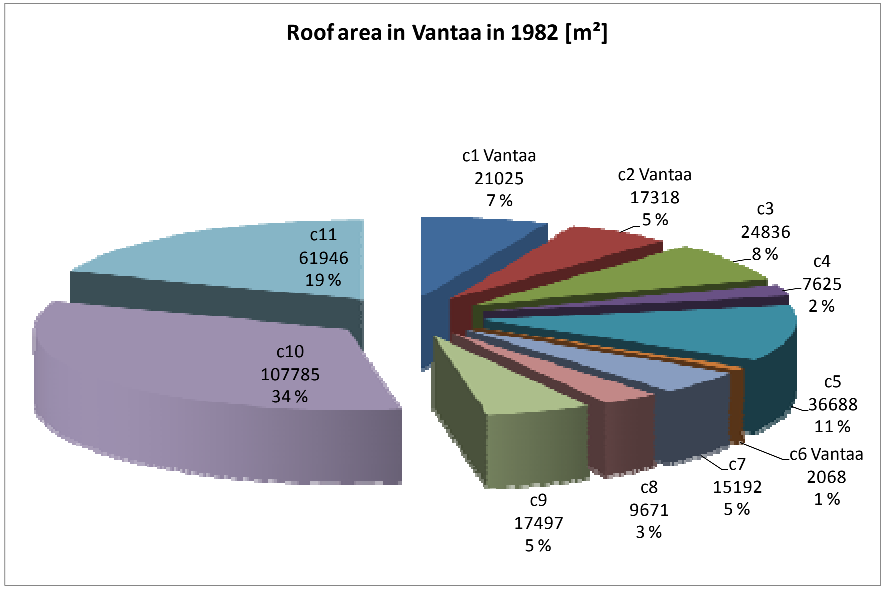

Yard area in subcatchment 9
Yard area [m²]
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

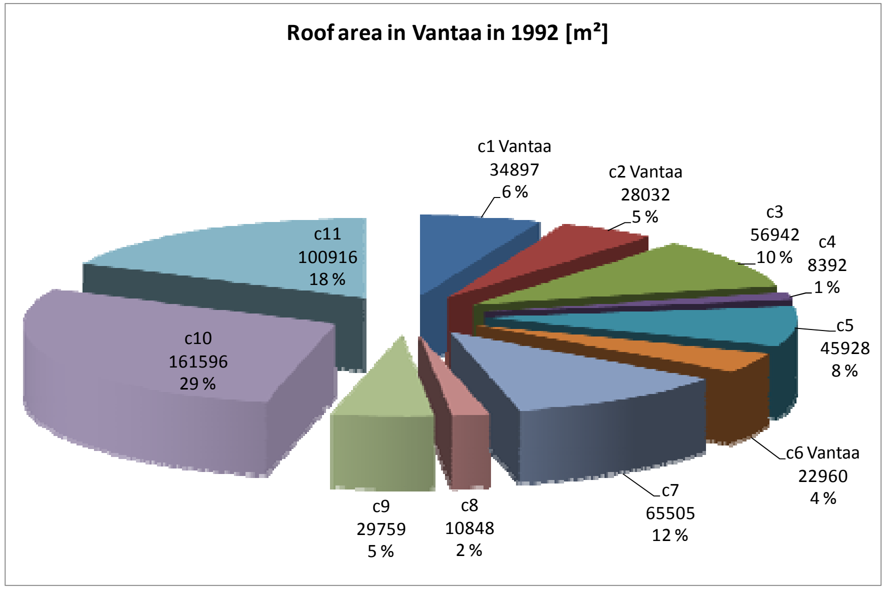

Roof area in subcatchment 10
Roof area [m²]
250000
200000
150000
100000
50000
0
1977
1982
1992
2007
2030
Year
Work places
Services
Apartment blocks
Detached house / Row house / Town house

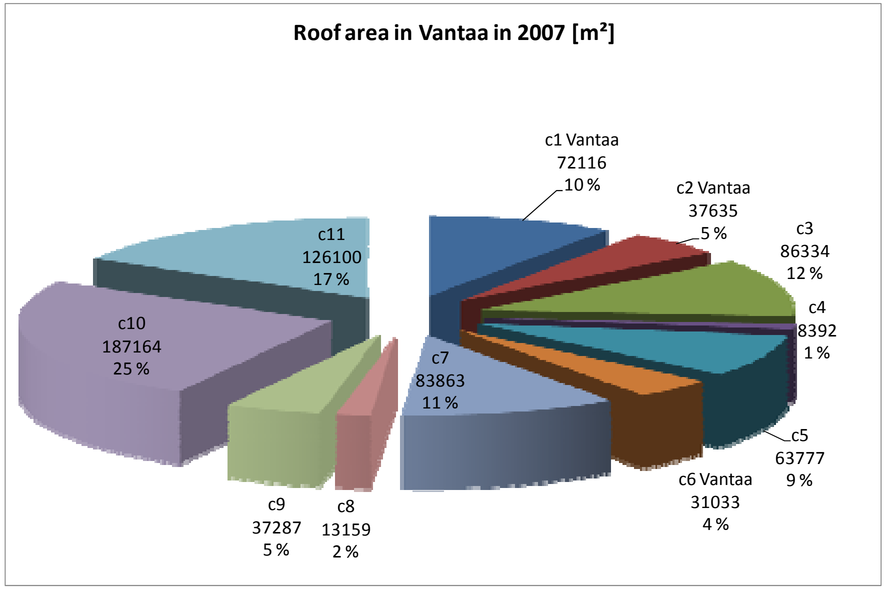

Roof area in subcatchment 11
Roof area [m²]
250000
200000
150000
100000
50000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

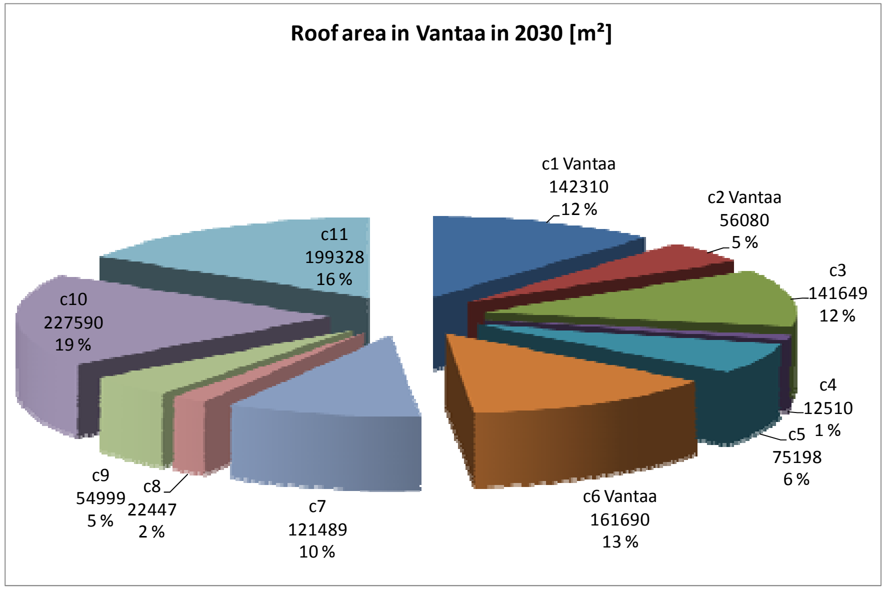
Appendix C The development of the roof area in Vantaa between 1977 and 2030, assorted by the 11 subcatchments.



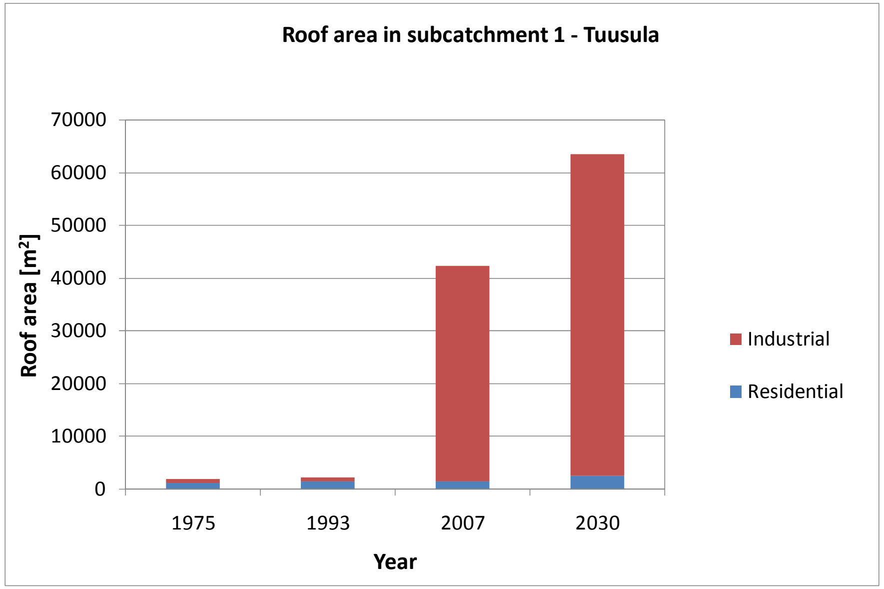


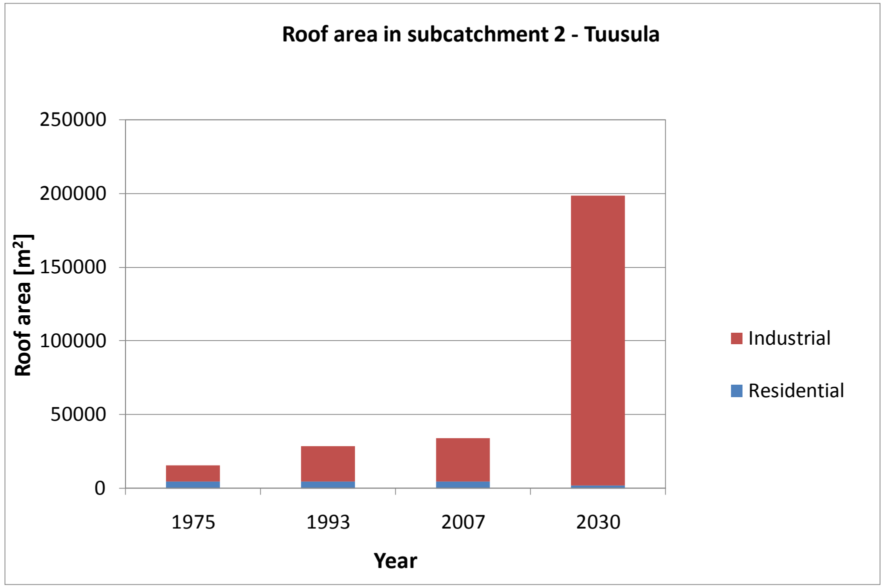

Roof area in Vantaa in 1992 [m²]
c1 Vantaa
34897
6 %
c2 Vantaa
28032
5 %
c3
56942
10 %
c4
8392
1 %
c5
45928
8 %
c6 Vantaa
22960
4 %
c7
65505
12 %
c8
10848
2 %
c9
29759
5 %
c10
161596
29 %
c11
100916
18 %

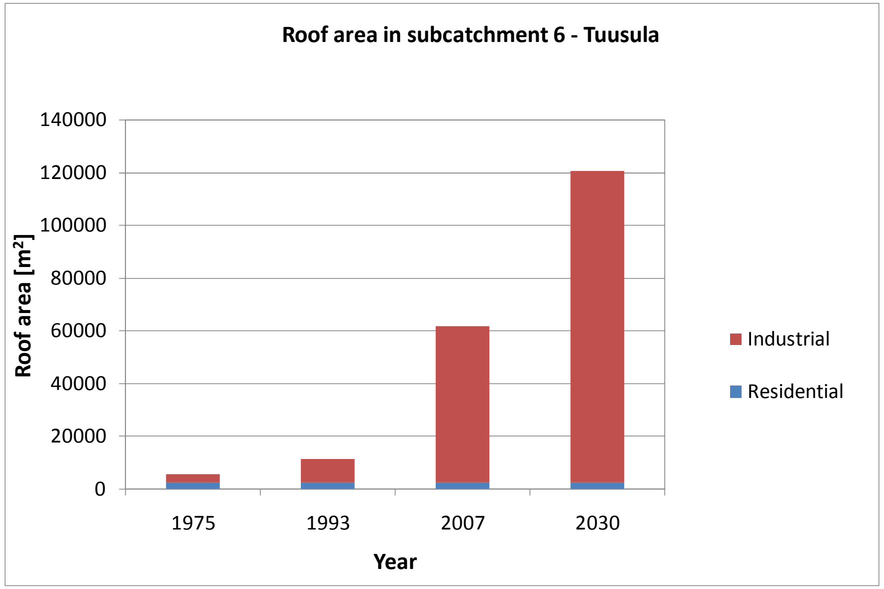

Roof area in Vantaa in 2007 [m²]
c1 Vantaa
72116
10 %
c2 Vantaa
37635
5 %
c3
86334
12 %
c4
8392
1 %
c5
63777
9 %
c6 Vantaa
31033
4 %
c7
83863
11 %
c8
13159
2 %
c9
37287
5 %
c10
187164
25 %
c11
126100
17 %


Roof area in Vantaa in 2030 [m²]
c1 Vantaa
142310
12 %
c2 Vantaa
56080
5 %
c3
141649
12 %
c4
12510
1 %
c5
75198
6 %
c6 Vantaa
161690
13 %
c7
121489
10 %
c8
22447
2 %
c9
54999
5 %
c10
227590
19 %
c11
199328
16 %

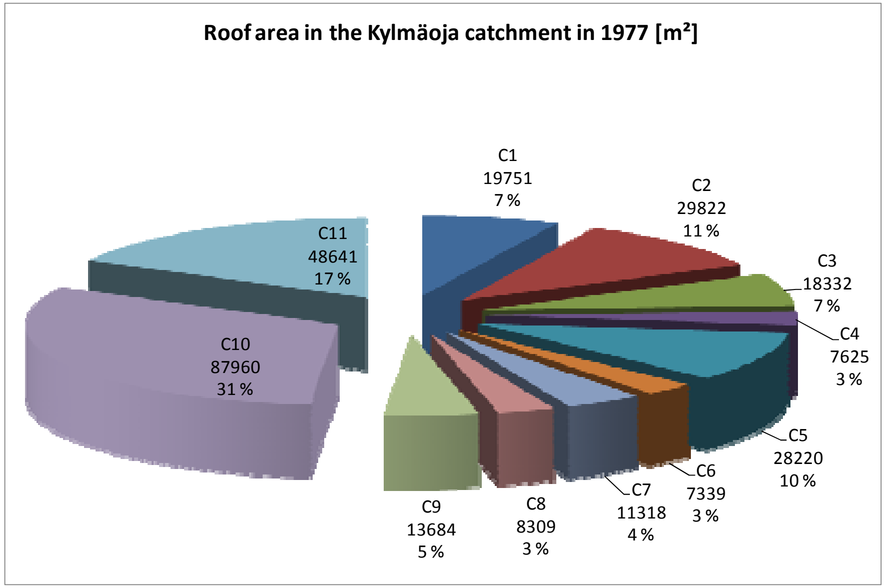
Appendix D The development of the roof area in Tuusula between 1975 and 2030, assorted by the subcatchments and the building categories defined during this project for Tuusula. These are residential for all buildings with private utilisation and industrial for all buildings with work – related purposes.

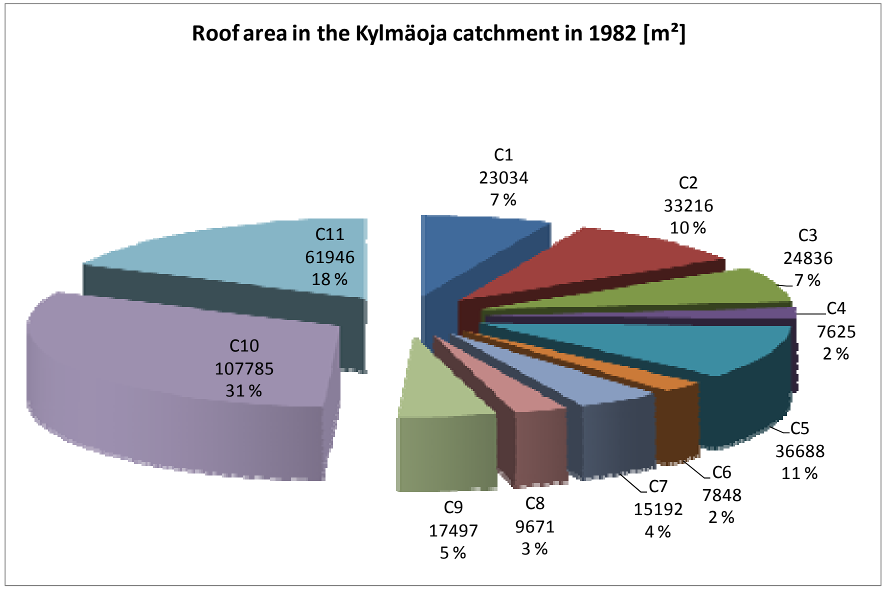


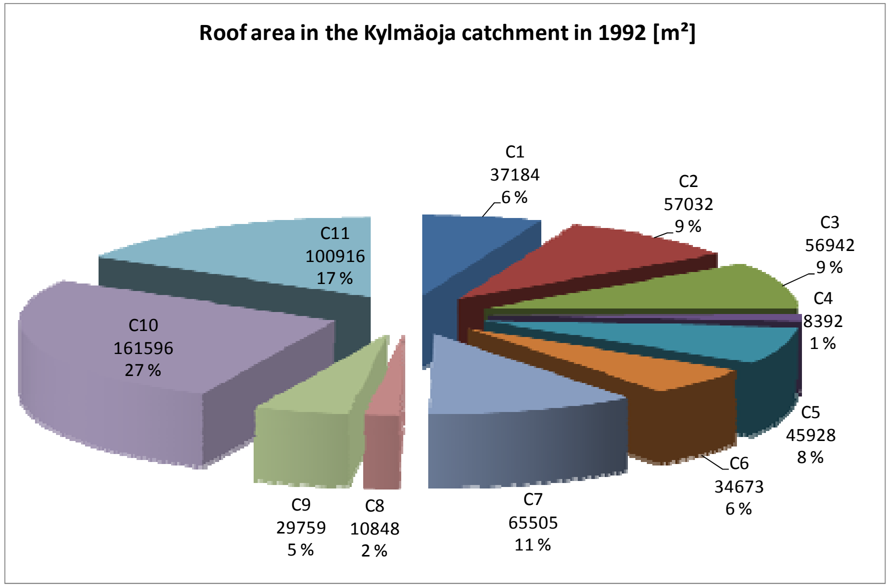


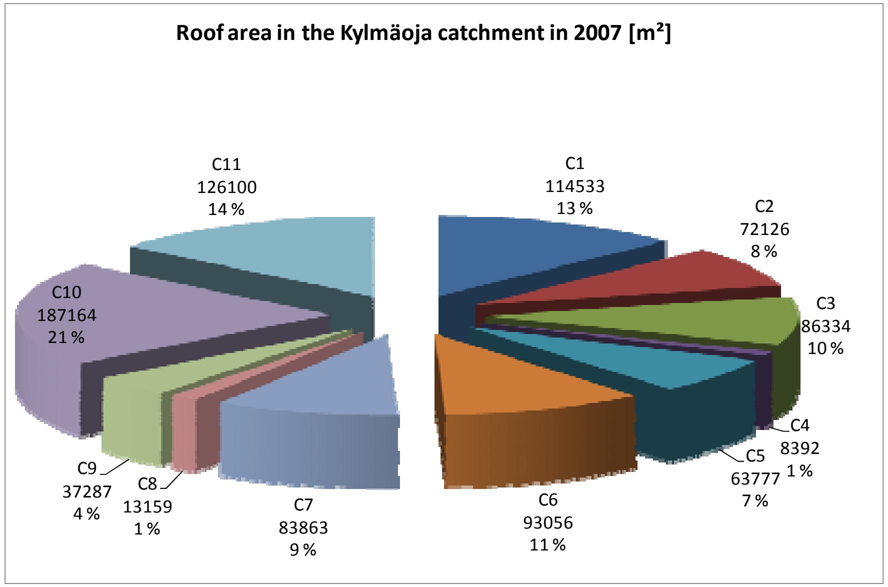

Roof area in subcatchment 6 - Tuusula
Roof area [m2]
140000
120000
100000
80000
60000
40000
20000
0
1975
1993
2007
2030
Year
Industrial
Residential

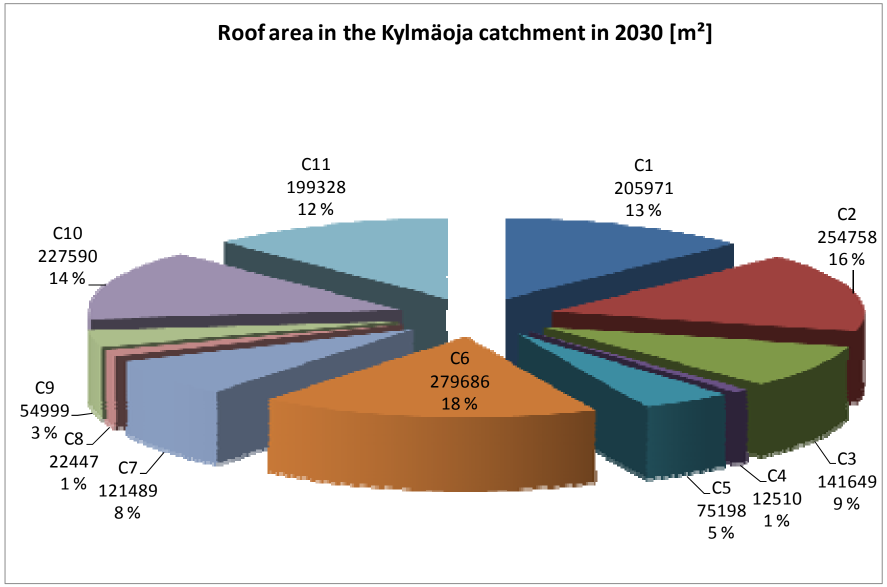
Appendix E The development of the roof area in the entire Kylmäoja catchment between 1977 and 2030, assorted by the 11 subcatchments.



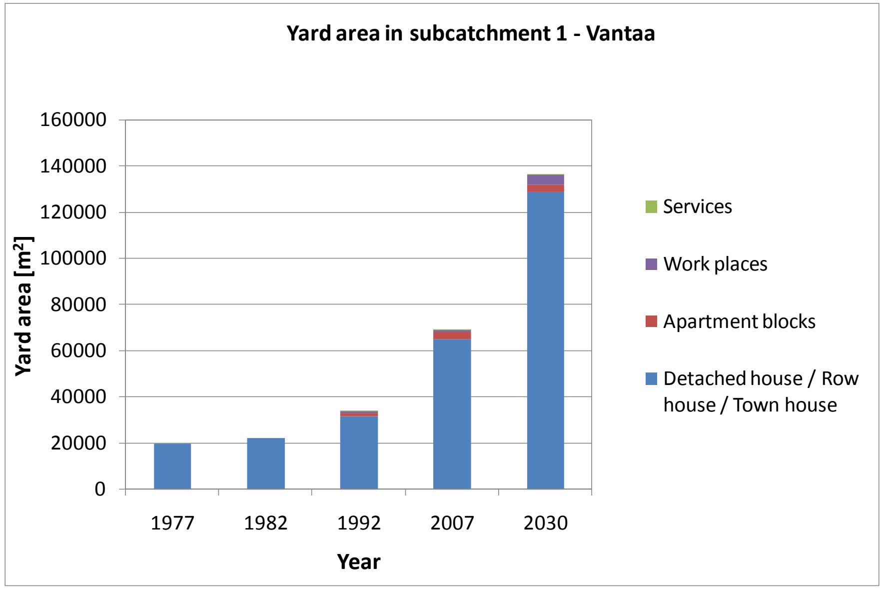


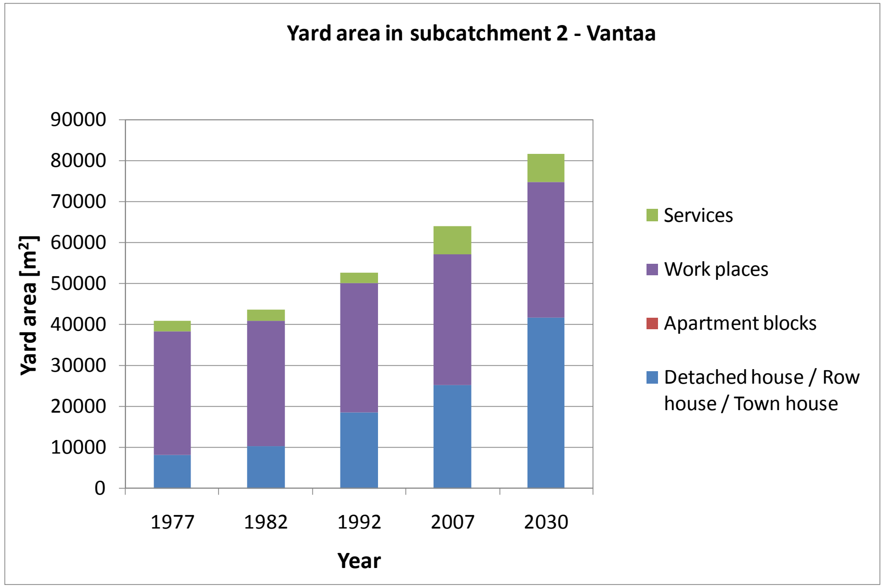

Roof area in the Kylmäoja catchment in 1992 [m²]
C1 37184 6 %
C2 57032 9 %
C3 56942 9 %
C4 8392 1 %
C5 45928 8 %
C6 34673 6 %
C7 65505 11 %
C8 10848 2 %
C9 29759 5 %
C10 161596 27 %
C11 100916 17 %

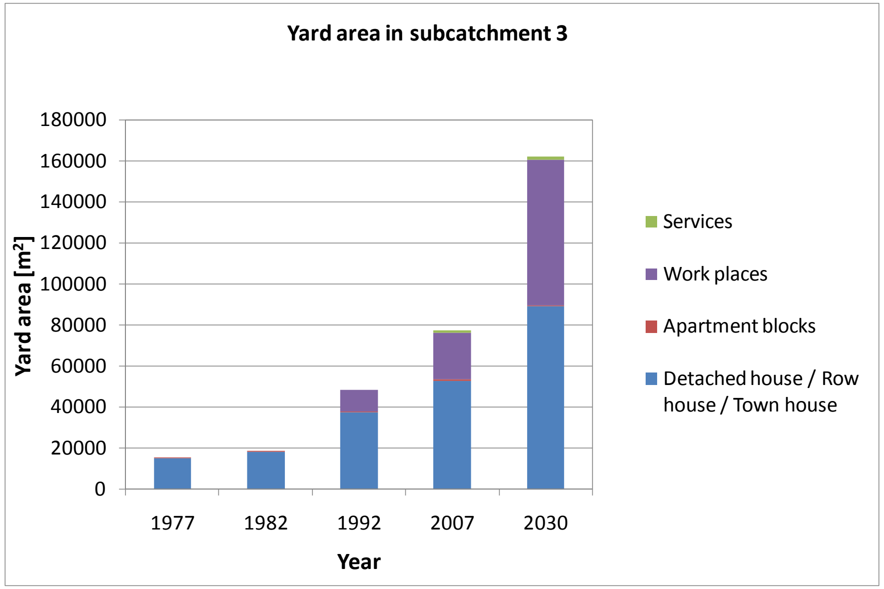

Roof area in the Kylmäoja catchment in 2007 [m²]
C1 114533 13 %
C2 72126 8 %
C3 86334 10 %
C4 8392 1 %
C5 63777 7 %
C6 93056 11 %
C7 83863 9 %
C8 13159 1 %
C9 37287 4 %
C10 187164 21 %
C11 126100 14 %

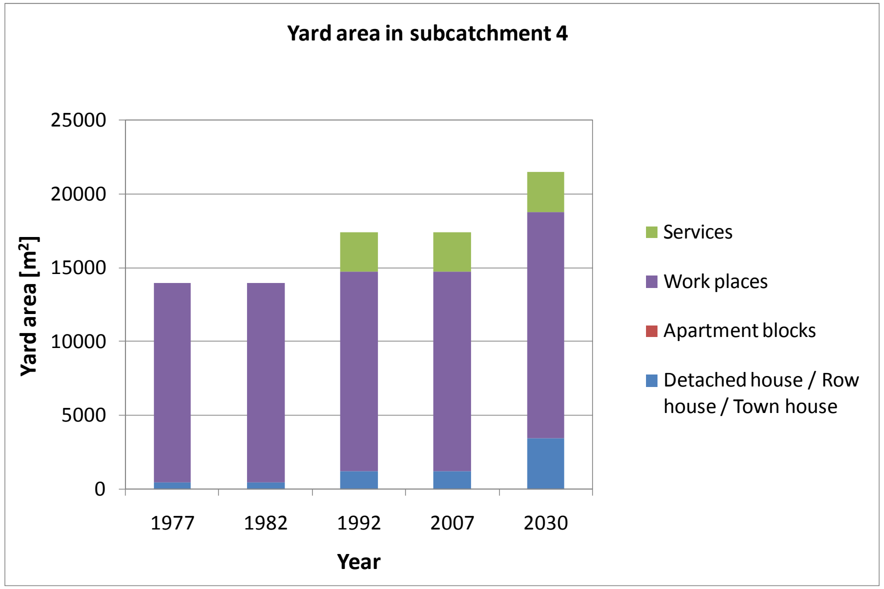

Roof area in the Kylmäoja catchment in 2030 [m²]
C1 205971 13 %
C2 254758 16 %
C3 141649 9 %
C4 12510 1 %
C5 75198 5 %
C6 279686 18 %
C7 121489 8 %
C8 22447 1 %
C9 54999 3 %
C10 227590 14 %
C11 199328 12 %

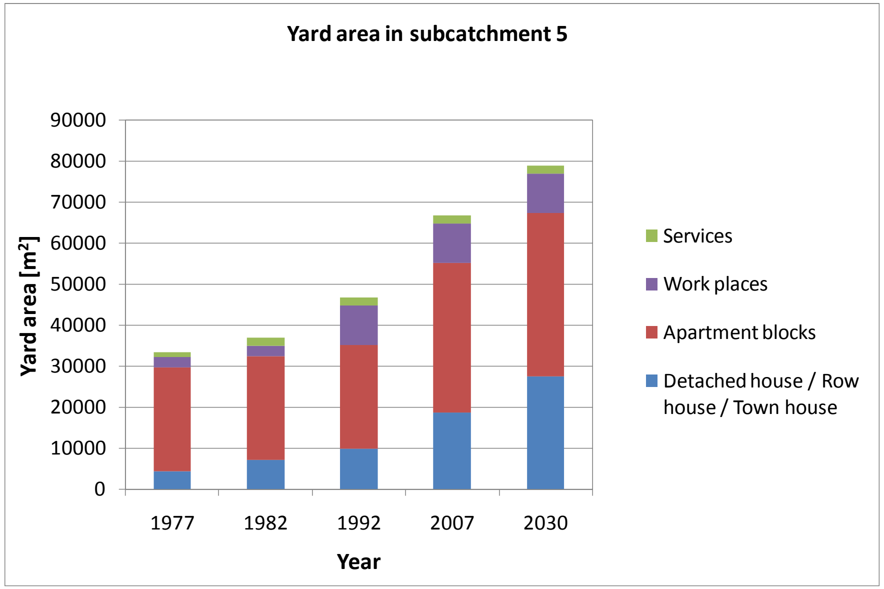
Appendix F The development of the impervious yard area in Vantaa between 1977 and 2030, assorted by the subcatchments and the building categories defined during this project. These are detached houses / row houses / town houses and apartment blocks for residential buildings, services for public buildings and maintenance and work places for industrial buildings and office blocks.

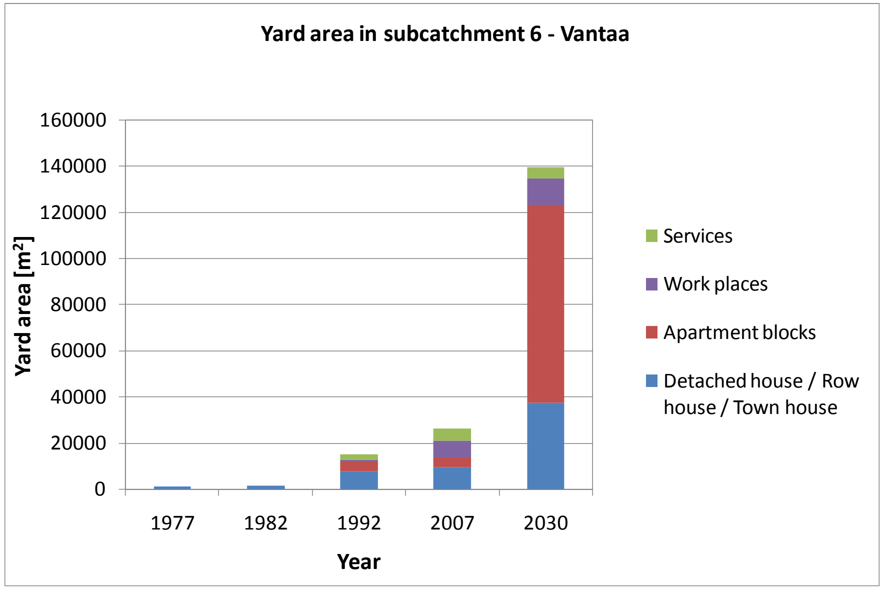


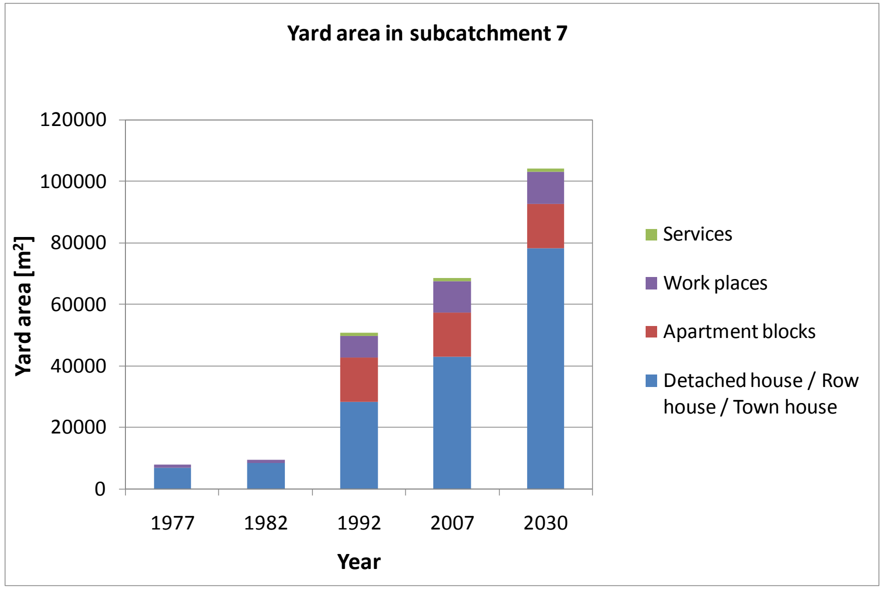


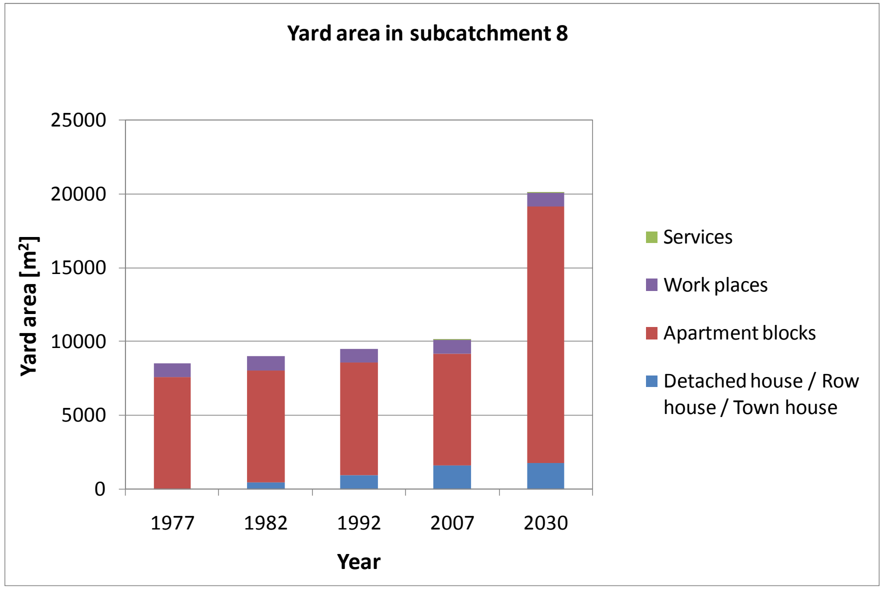

Yard area in subcatchment 3
Yard area [m²]
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

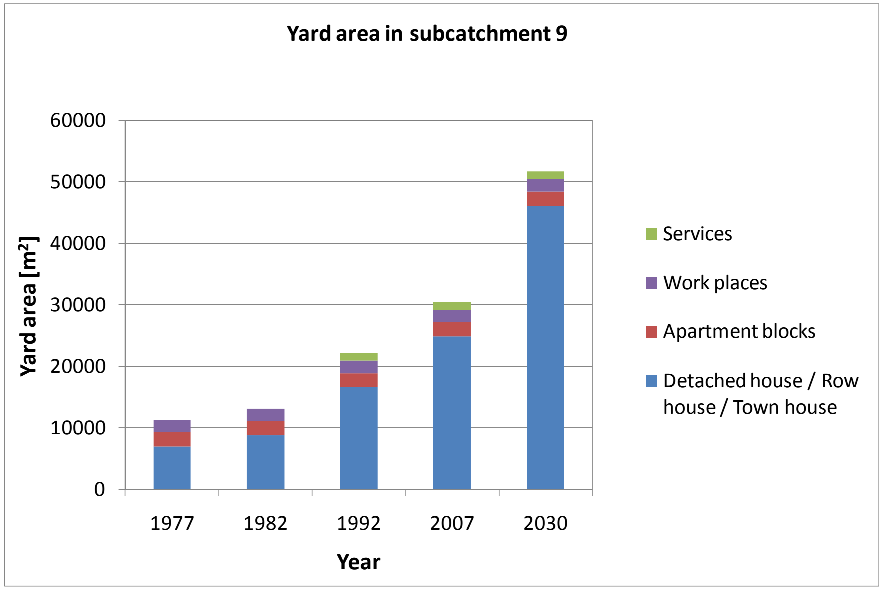

Yard area in subcatchment 4
Yard area [m²]
25000
20000
15000
10000
5000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

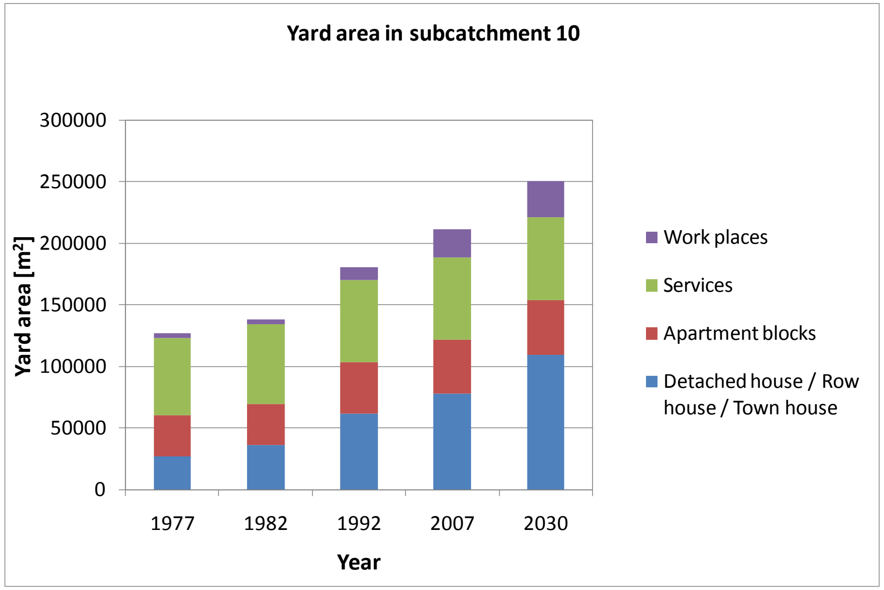

Yard area in subcatchment 5
Yard area [m²]
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

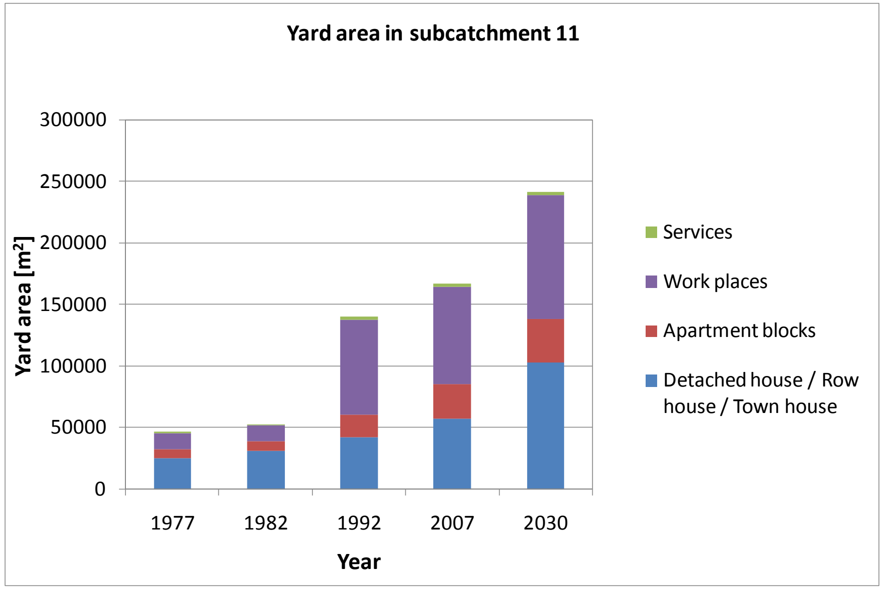

Yard area in subcatchment 6 - Vantaa
Yard area [m²]
160000
140000
120000
100000
80000
60000
40000
20000
0
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house


Yard area in subcatchment 7
120000
100000
80000
60000
40000
20000
0
Yard area [m²]
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

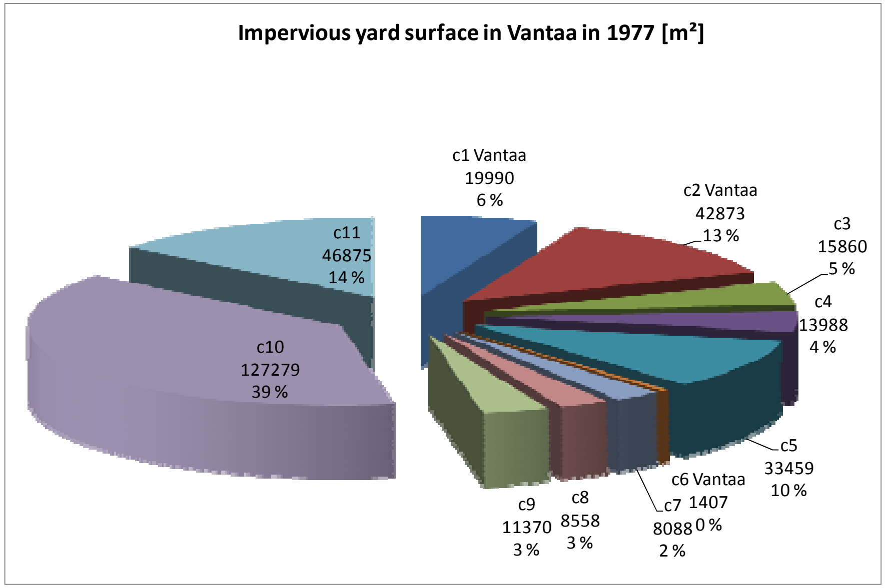

Yard area in subcatchment 8
25000
20000
15000
10000
5000
0
Yard area [m²]
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

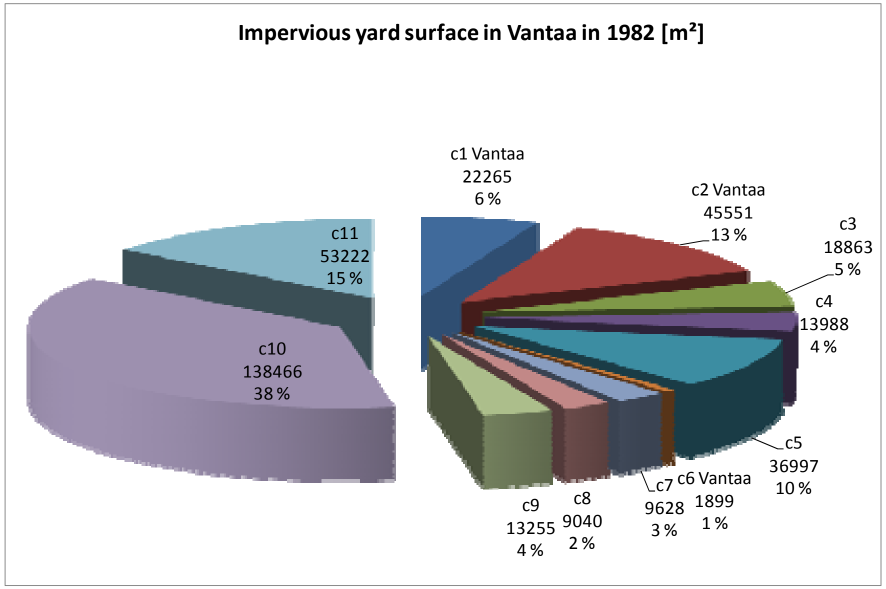

Yard area in subcatchment 9
60000
50000
40000
30000
20000
10000
0
Yard area [m²]
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

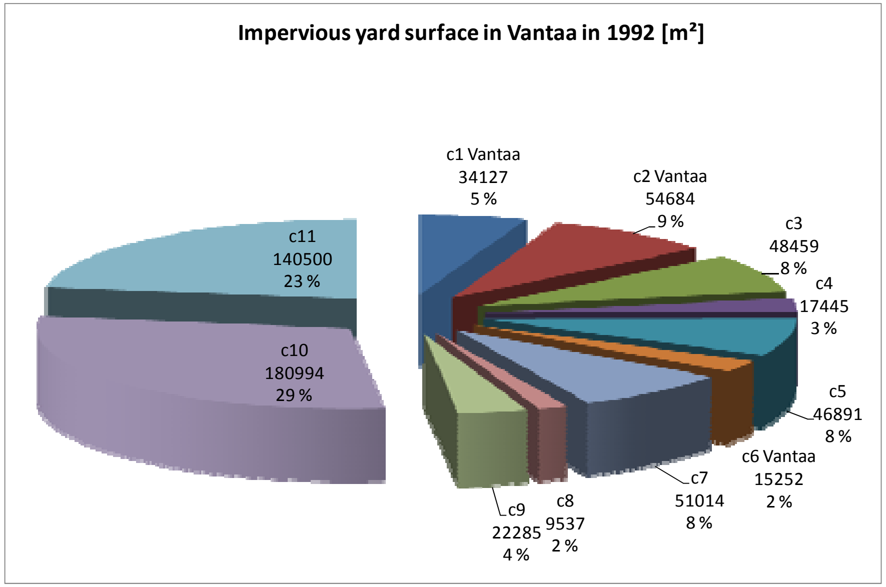

Yard area in subcatchment 10
300000
250000
200000
150000
100000
50000
0
Yard area [m²]
1977
1982
1992
2007
2030
Year
Work places
Services
Apartment blocks
Detached house / Row house / Town house

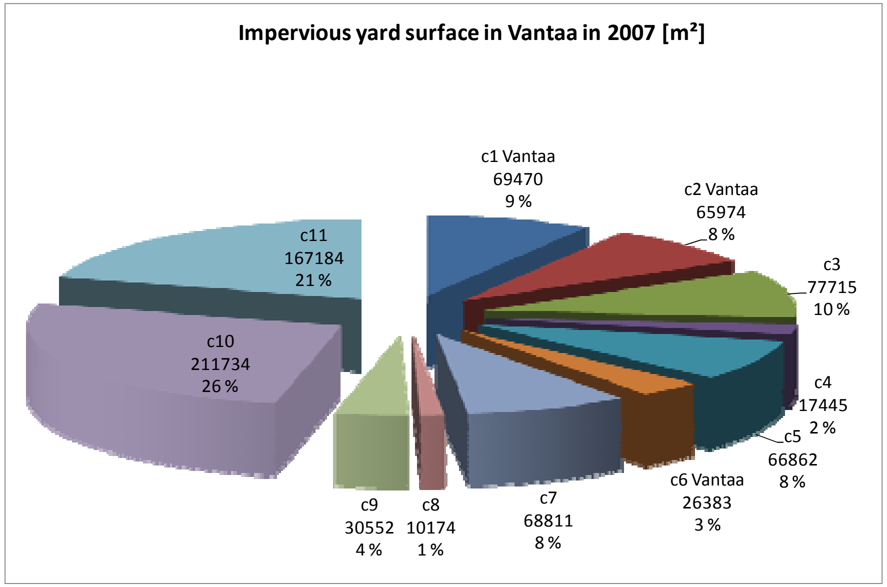

Yard area in subcatchment 11
300000
250000
200000
150000
100000
50000
0
Yard area [m²]
1977
1982
1992
2007
2030
Year
Services
Work places
Apartment blocks
Detached house / Row house / Town house

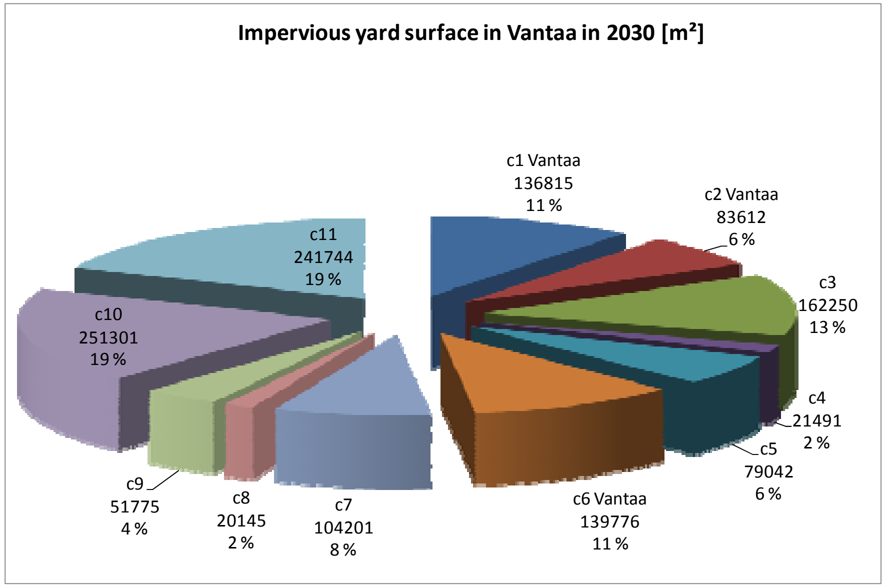
Appendix G The development of the impervious yard area in Vantaa between 1977 and 2030, assorted by the 11 subcatchments.



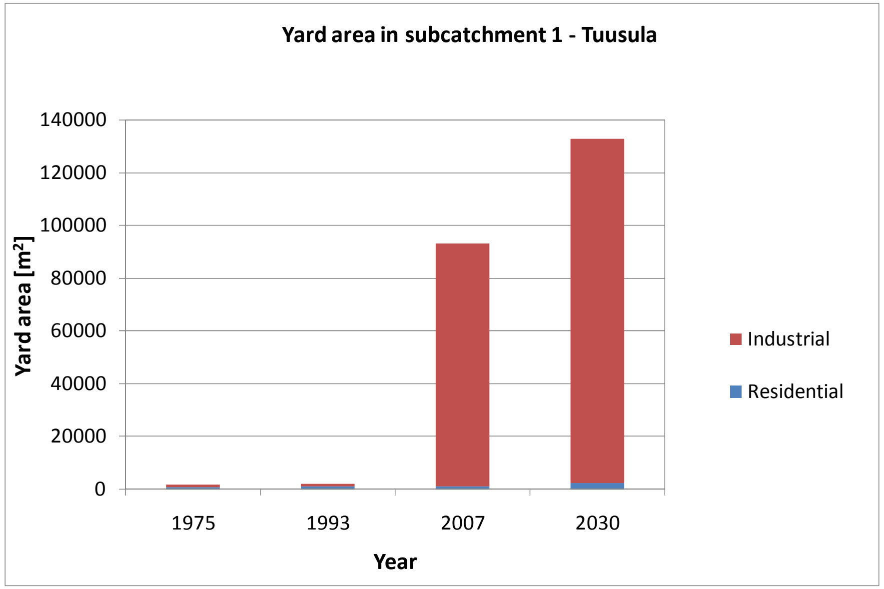


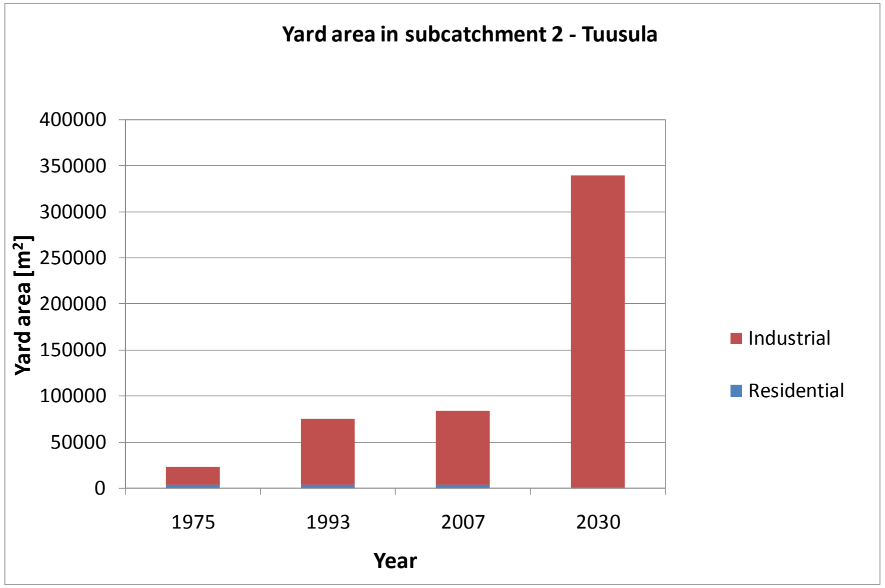

Impervious yard surface in Vantaa in 1992 [m²]
c1 Vantaa 34127 5 %
c2 Vantaa 54684 9 %
c3 48459 8 %
c4 17445 3 %
c5 46891 8 %
c6 Vantaa 15252 2 %
c7 51014 8 %
c8 9537 2 %
c9 22285 4 %
c10 180994 29 %
c11 140500 23 %

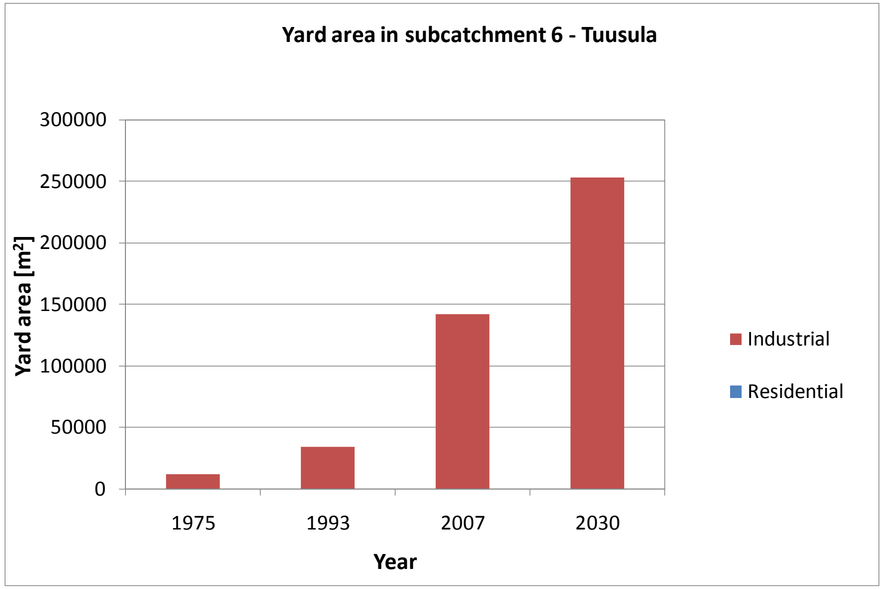

Impervious yard surface in Vantaa in 2007 [m²]
c1 Vantaa 69470 9 %
c2 Vantaa 65974 8 %
c3 77715 10 %
c4 17445 2 %
c5 66862 8 %
c6 Vantaa 26383 3 %
c7 68811 8 %
c8 10174 1 %
c9 30552 4 %
c10 211734 26 %
c11 167184 21 %


Impervious yard surface in Vantaa in 2030 [m²]
c1 Vantaa 136815 11 %
c2 Vantaa 83612 6 %
c3 162250 13 %
c4 21491 2 %
c5 79042 6 %
c6 Vantaa 139776 11 %
c7 104201 8 %
c8 20145 2 %
c9 51775 4 %
c10 251301 19 %
c11 241744 19 %

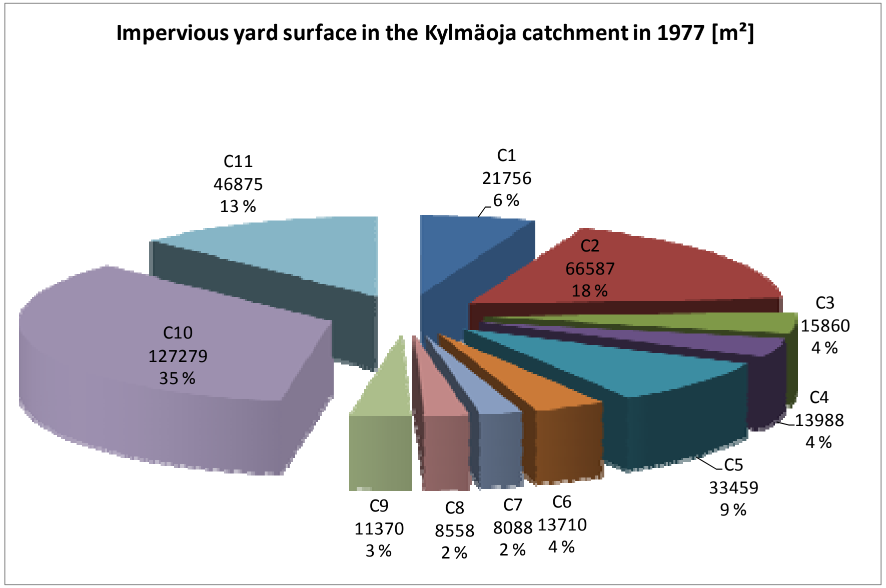
Appendix H The development of the impervious yard area in Tuusula between 1975 and 2030, assorted by the subcatchments and the building categories defined during this project for Tuusula. These are residential for all buildings with private utilisation and industrial for all buildings with work – related purposes.

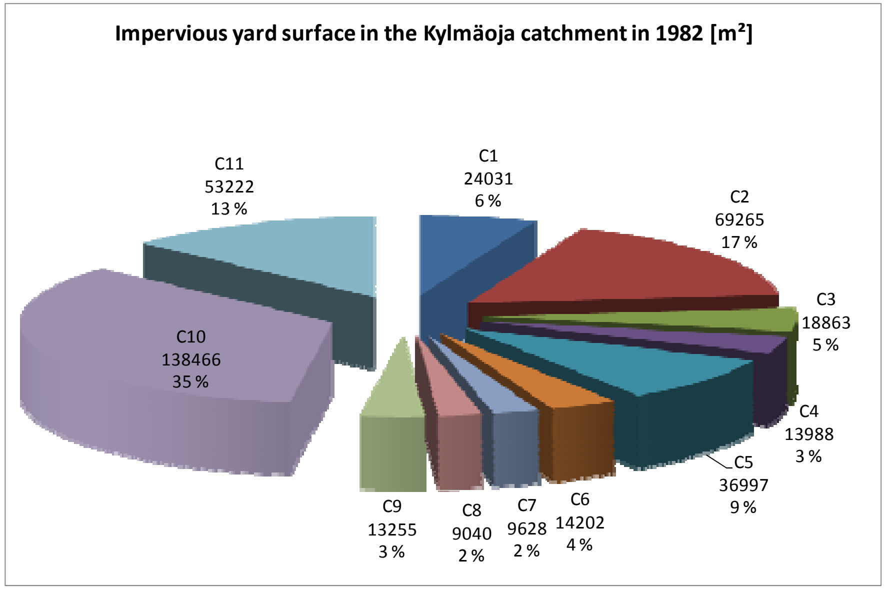


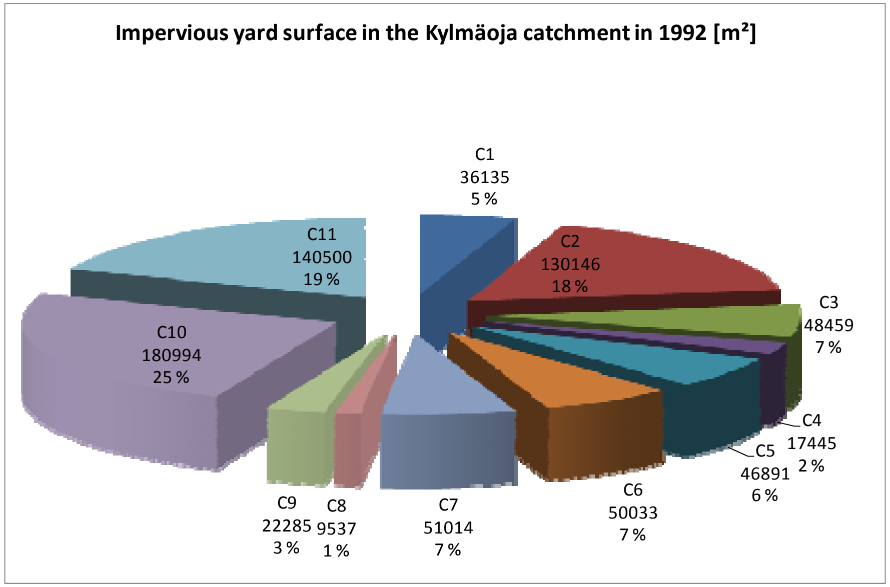


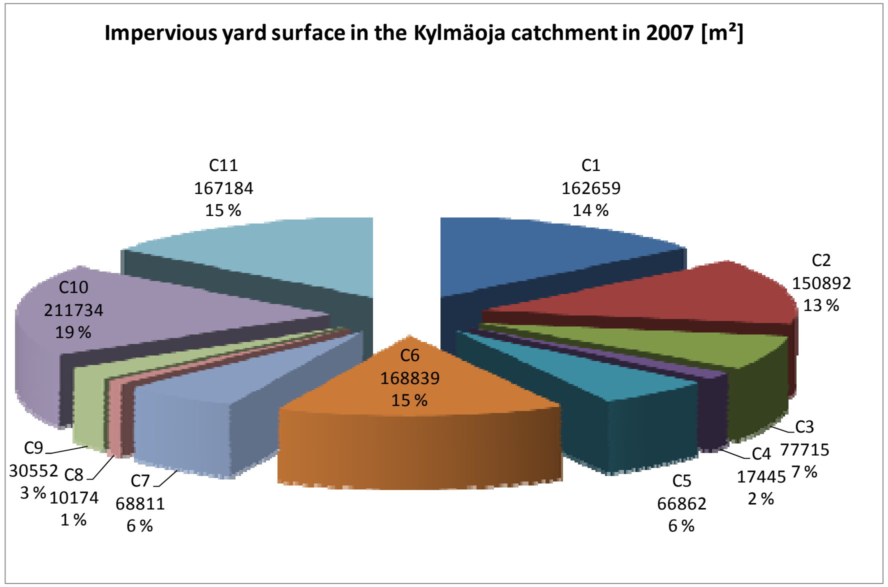

Yard area in subcatchment 6 - Tuusula
300000
250000
200000
150000
100000
50000
0
Yard area [m²]
1975
1993
2007
2030
Year
Industrial
Residential

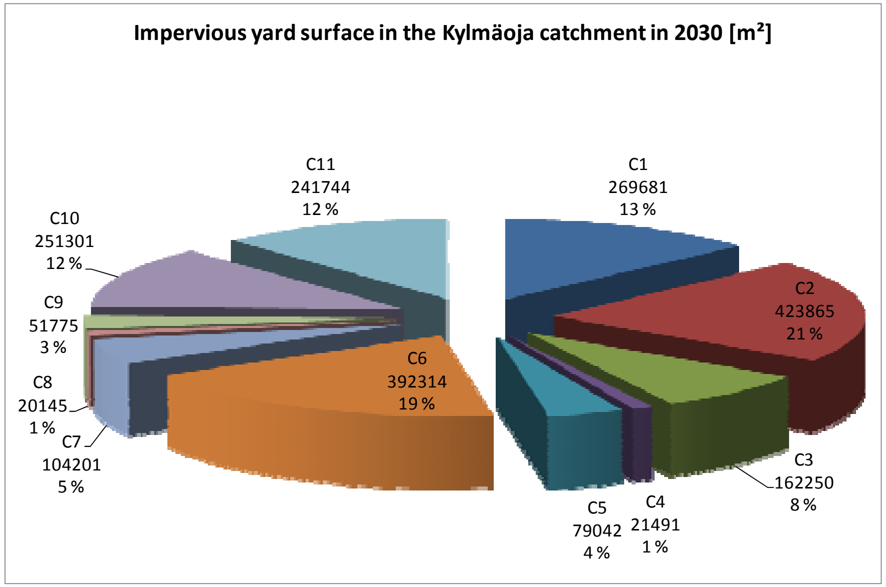
Appendix I The development of the impervious yard area in the entire Kylmäoja catchment between 1977 and 2030, assorted by the 11 subcatchments.



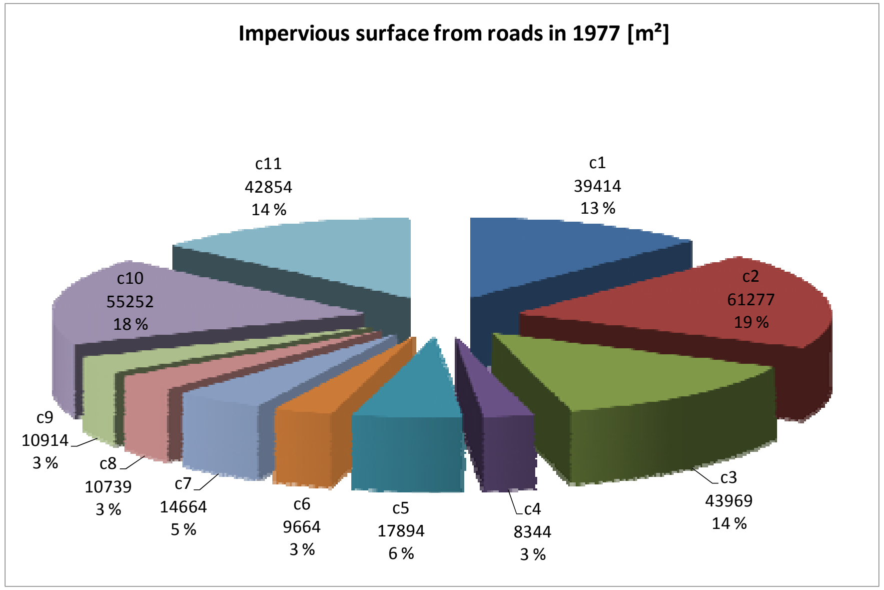


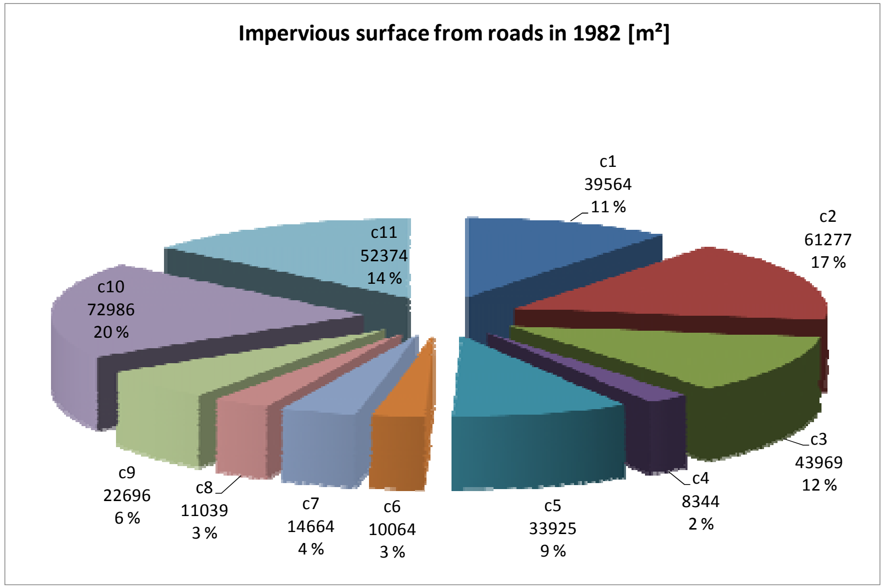

Impervious yard surface in the Kylmäoja catchment in 1992 [m²]
C1
36135
5 %
C2
130146
18 %
C3
48459
7 %
C4
17445
2 %
C5
46891
6 %
C6
50033
7 %
C7
51014
7 %
C8
9537
1 %
C9
22285
3 %
C10
180994
25 %
C11
140500
19 %

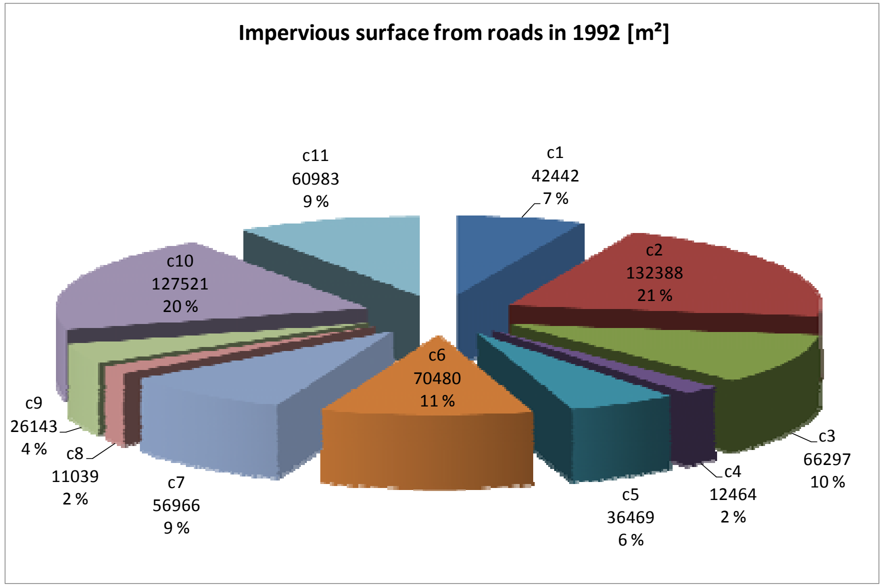

Impervious yard surface in the Kylmäoja catchment in 2007 [m²]
C1
162659
14 %
C2
150892
13 %
C3
77715
7 %
C4
17445
2 %
C5
66862
6 %
C6
168839
15 %
C7
68811
6 %
C8
10174
1 %
C9
30552
3 %
C10
211734
19 %
C11
167184
15 %

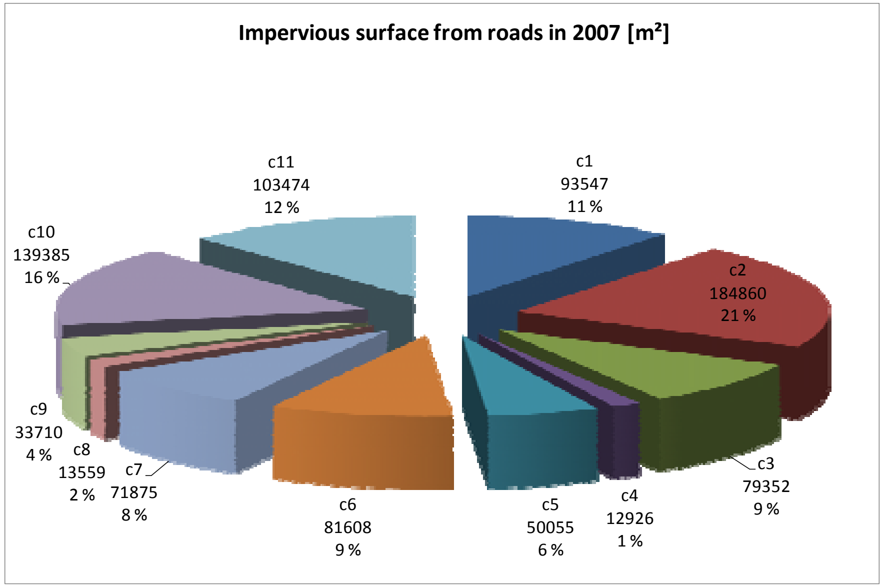

Impervious yard surface in the Kylmäoja catchment in 2030 [m²]
C1
269681
13 %
C2
423865
21 %
C3
162250
8 %
C4
21491
1 %
C5
79042
4 %
C6
392314
19 %
C7
104201
5 %
C8
20145
1 %
C9
51775
3 %
C10
251301
12 %
C11
241744
12 %

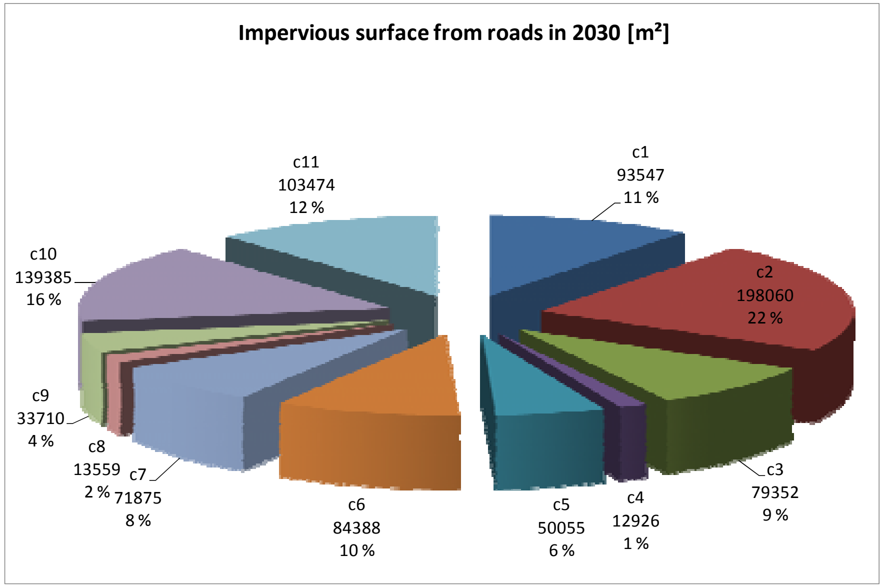
Appendix J The development of impervious road surface in the entire Kylmäoja catchment between 1977 and 2030, assorted by the 11 subcatchments.



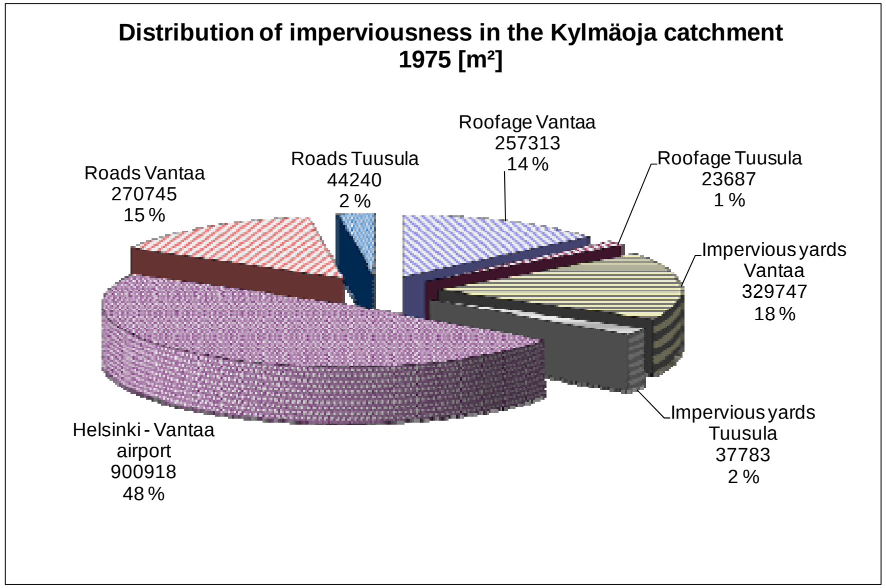


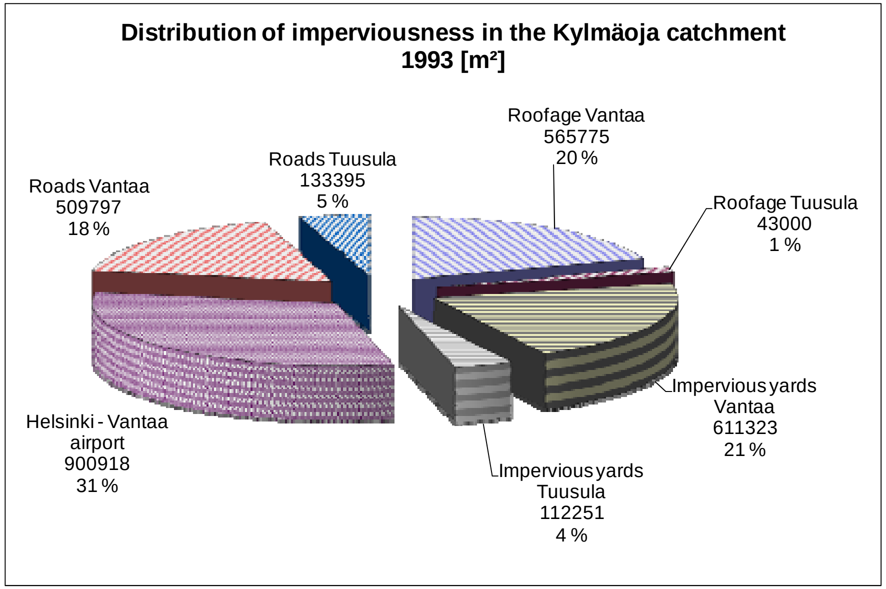

Impervious surface from roads in 1992 [m²]
c1
42442
7 %
c2
132388
21 %
c3
66297
10 %
c4
12464
2 %
c5
36469
6 %
c6
70480
11 %
c7
56966
9 %
c8
11039
2 %
c9
26143
4 %
c10
127521
20 %
c11
60983
9 %

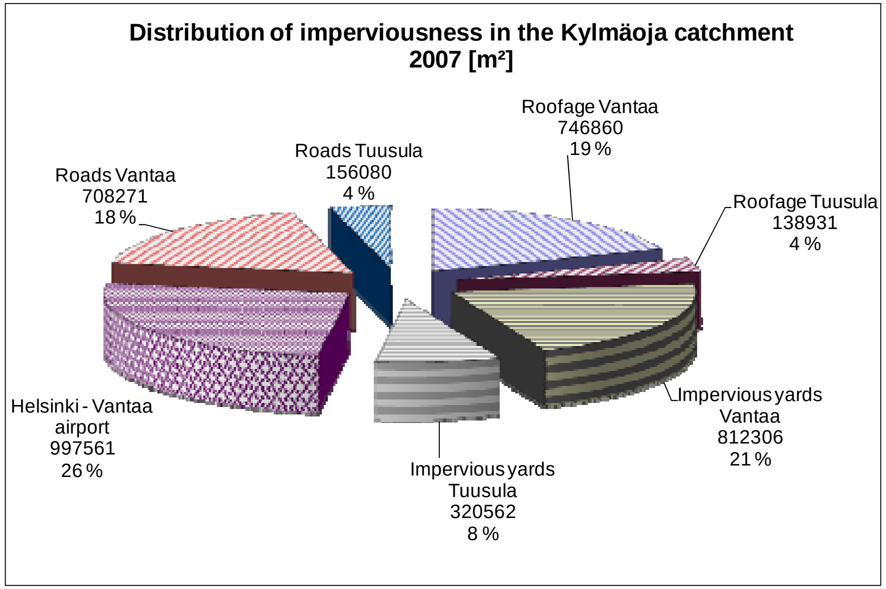

Impervious surface from roads in 2007 [m²]
c1
93547
11 %
c2
184860
21 %
c3
79352
9 %
c4
12926
1 %
c5
50055
6 %
c6
81608
9 %
c7
71875
8 %
c8
13559
2 %
c9
33710
4 %
c10
139385
16 %
c11
103474
12 %

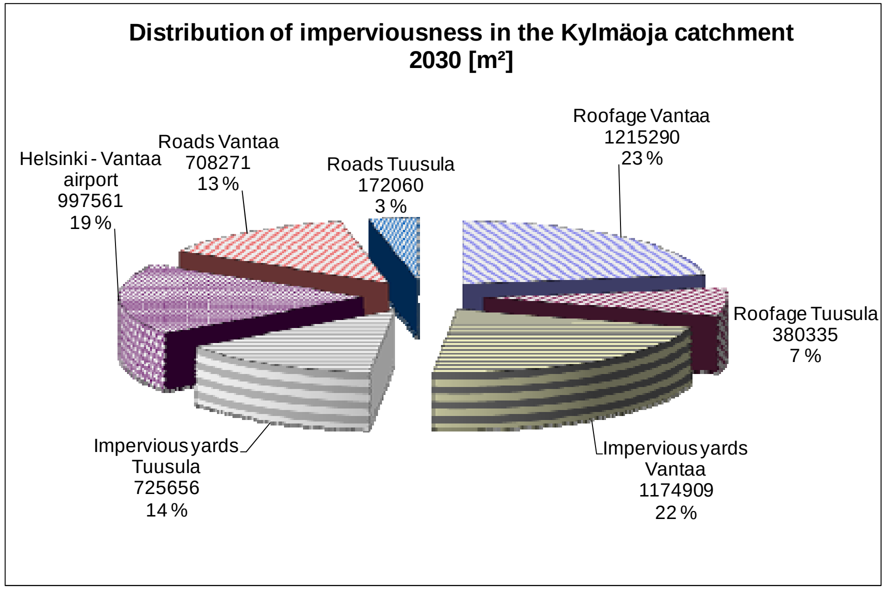

Impervious surface from roads in 2030 [m²]
c1
93547
11 %
c2
198060
22 %
c3
79352
9 %
c4
12926
1 %
c5
50055
6 %
c6
84388
10 %
c7
71875
8 %
c8
13559
2 %
c9
33710
4 %
c10
139385
16 %
c11
103474
12 %

Appendix K The development of the total impervious surface in the entire Kylmäoja catchment between 1975 and 2030, assorted by the investigated categories. These are the roof area, the impervious yard area and road area, all separated for Vantaa and Tuusula, and the Helsinki – Vantaa airport.

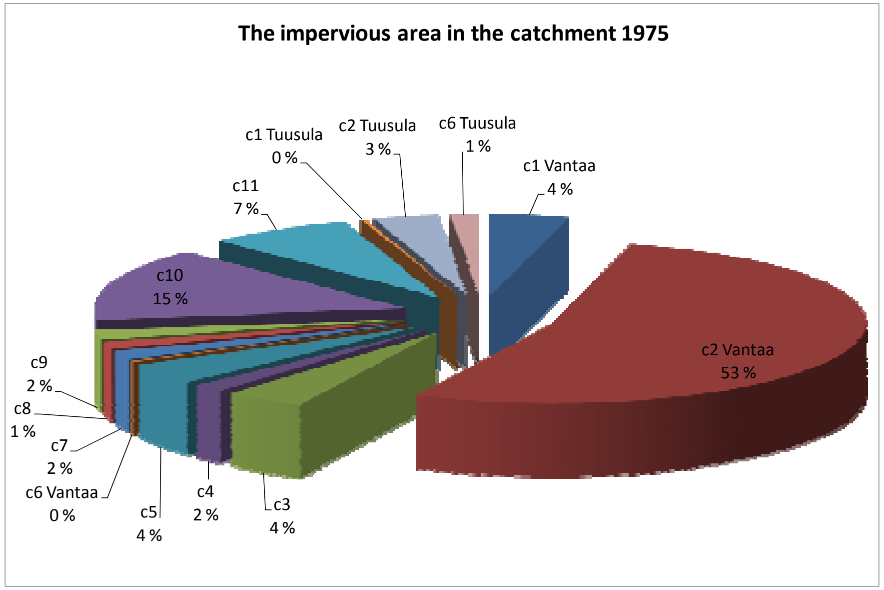


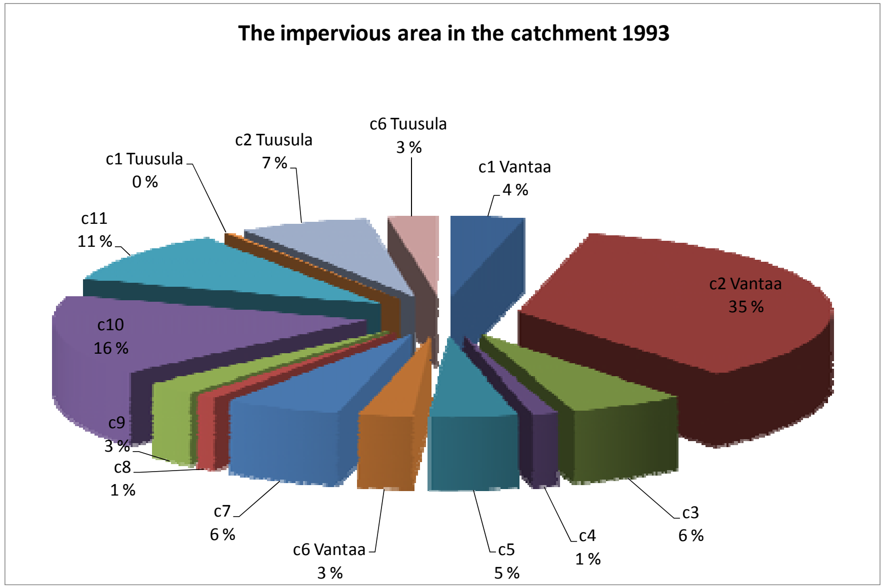


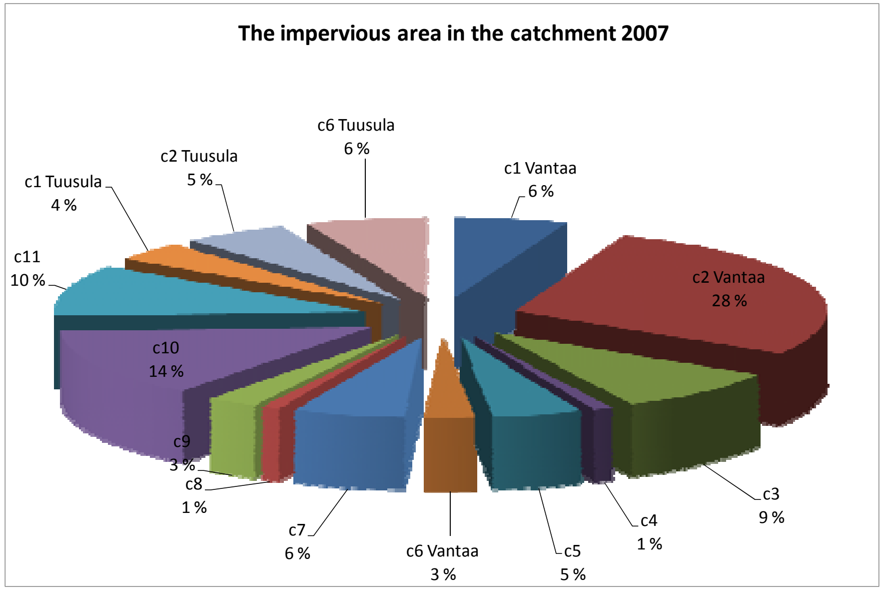

Distribution of imperviousness in the Kylmäoja catchment 2007 [m²]
Roofage Vantaa 746860 19 %
Roofage Tuusula 138931 4 %
Impervious yards Vantaa 812306 21 %
Impervious yards Tuusula 320562 8 %
Helsinki - Vantaa airport 997561 26 %
Roads Vantaa 708271 18 %
Roads Tuusula 156080 4 %

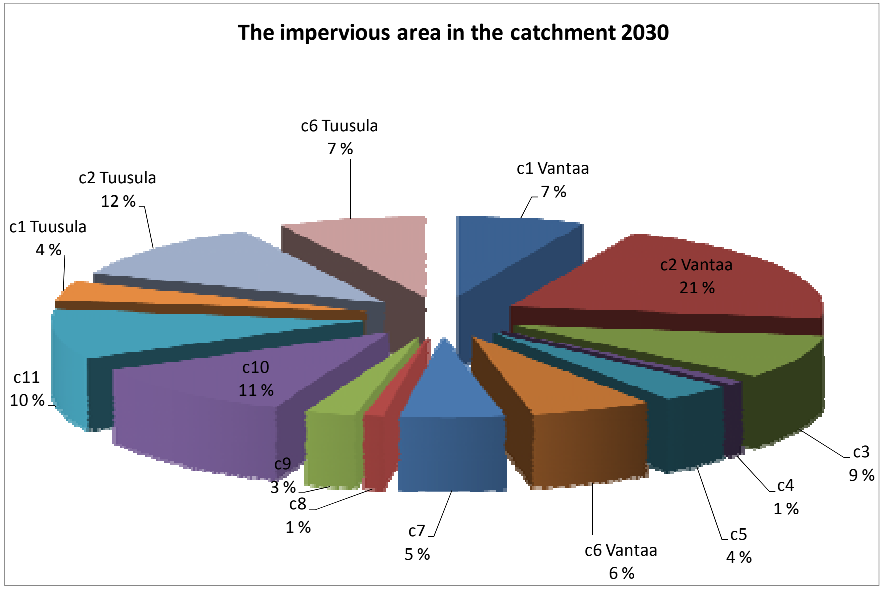

Distribution of imperviousness in the Kylmäoja catchment 2030 [m²]
Roofage Vantaa 1215290 23 %
Roofage Tuusula 380335 7 %
Impervious yards Vantaa 1174909 22 %
Impervious yards Tuusula 725656 14 %
Helsinki - Vantaa airport 997561 19 %
Roads Vantaa 708271 13 %
Roads Tuusula 172060 3 %

Appendix L The development of the total impervious surface in the entire Kylmäoja catchment between 1975 and 2030, assorted by the 11 subcatchments (separated for Vantaa and Tuusula).

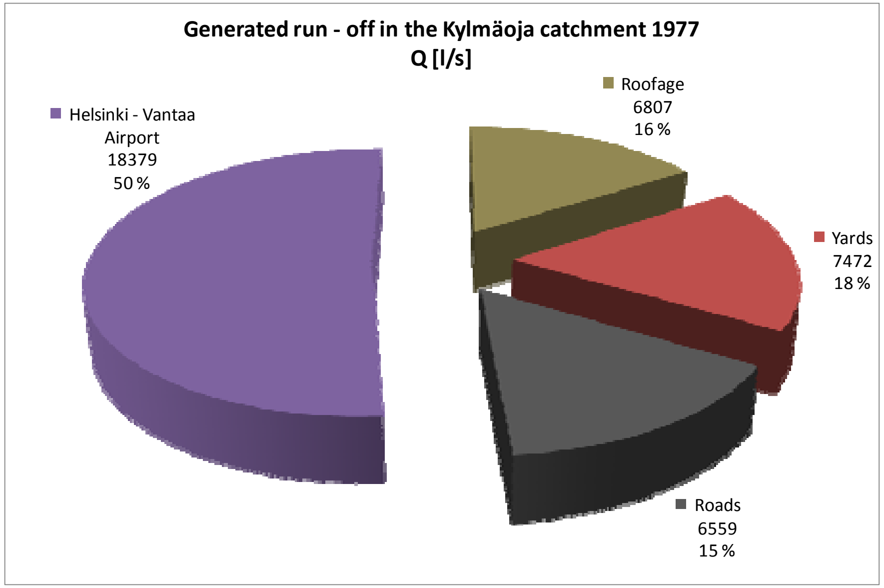


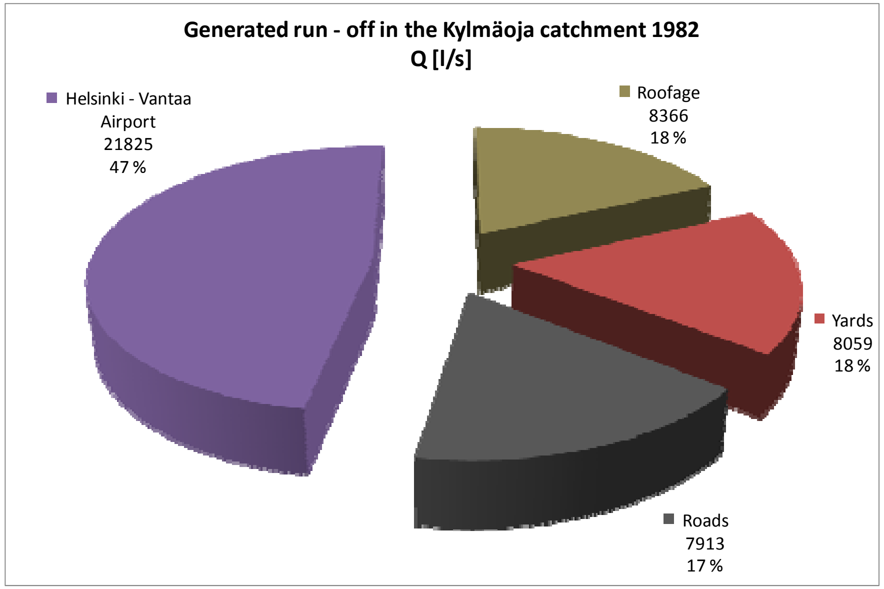


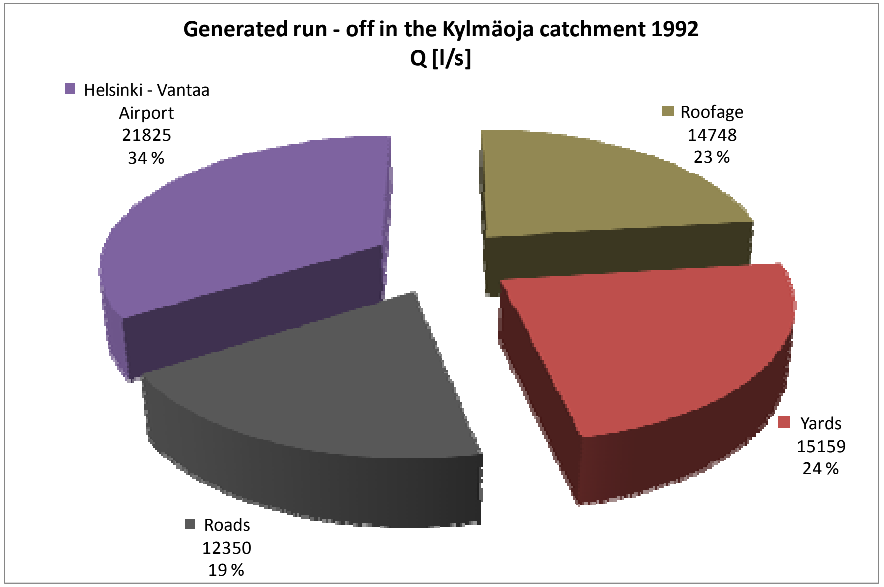

The impervious area in the catchment 2007
c6 Tuusula
6 %
c2 Tuusula
5 %
c1 Tuusula
4 %
c1 Vantaa
6 %
c11
10 %
c2 Vantaa
28 %
c10
14 %
c9
3 %
c8
1 %
c7
6 %
c6 Vantaa
3 %
c5
5 %
c4
1 %
c3
9 %

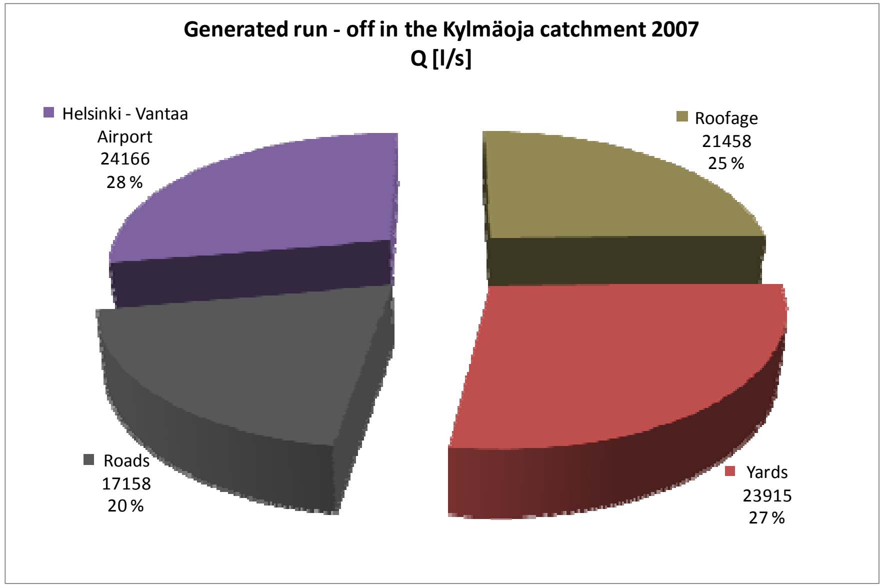

The impervious area in the catchment 2030
c6 Tuusula
7 %
c2 Tuusula
12 %
c1 Vantaa
7 %
c1 Tuusula
4 %
c2 Vantaa
21 %
c11
10 %
c10
11 %
c9
3 %
c8
1 %
c7
5 %
c6 Vantaa
6 %
c5
4 %
c4
1 %
c3
9 %

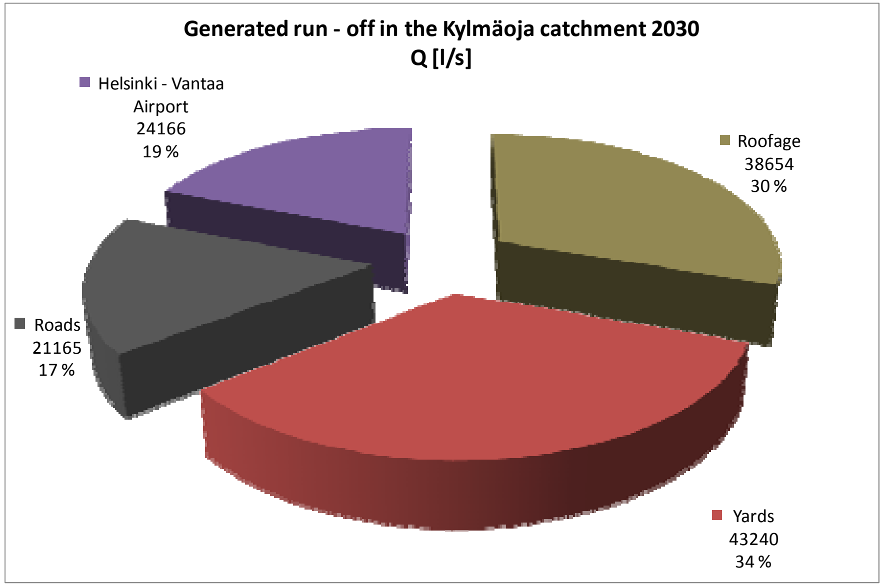
Appendix M The development of the total impervious surface in the entire Kylmäoja catchment between 1975 and 2030, assorted by the 11 subcatchments.






Generated run - off in the Kylmäoja catchment 1992
Q [l/s]
Helsinki - Vantaa Airport
21825
34 %
Roofage
14748
23 %
Yards
15159
24 %
Roads
12350
19 %


Generated run - off in the Kylmäoja catchment 2007
Q [l/s]
Helsinki - Vantaa Airport
24166
28 %
Roofage
21458
25 %
Yards
23915
27 %
Roads
17158
20 %


Generated run - off in the Kylmäoja catchment 2030
Q [l/s]
Helsinki - Vantaa Airport
24166
19 %
Roofage
38654
30 %
Yards
43240
34 %
Roads
21165
17 %