THESIS ON CIVIL ENGINEERING F15

On the Coastal Zone Management of the City of Tallinn under Natural and Anthropogenic Pressure

AIN VALDMANN

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Tallinna rannikualade haldamine loodusliku ja antropogeense surve tingimustes

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

/Ain Valdmann/

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Introduction

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Foreword

Tallinn Municipal Engineering Services Department (where the post-graduate works) is responsible for the management of port facilities and coast fortifications. In order to carry out municipal engineering services, various scientific research results should be taken into account, e.g. research concerning the influence of natural storm waves on ports and various hydrotechnical facilities, the influence of passenger high-speed ships on coasts, coast fortifications and small ships docking at ports etc.

Tallinn Municipal Engineering Services Department administers the following areas of Tallinn: the ports of Aegna and Patarei, the right bank of the Pirita River, Pirita pier, coast fortification from the Pirita Yachting Centre up to the Russalka memorial, also the sewerage system and seawater outlets located in the administrative territory of Tallinn. In addition, the city of Tallinn administers the Katariina quay and the coasts of Kakumäe peninsula. Tallinn Municipal Engineering Services Department deals also with crisis management problems in Tallinn, including floods.

In a society with limited resources, the rational use of scientific research enables to achieve greater effectiveness while executing different tasks of municipal engineering services, and contributes to mutual decision-making process in the assessment of public procurement. The evaluation criteria for the construction of hydrotechnical facilities are the following: cost, construction technology, materials to be used, project solution, duration of the warranty period, qualification of the contractor etc. Decisive criteria are the cost of the object, technological solution for the construction of the hydrotechnical facility, quality of construction of hydrotechnical facility etc. To meet all these criteria, a detailed scientific research should be carried out and the results should be taken into account in the decision-making process.

Resulting from the above, the post-graduate has chosen as his topic for dissertation the influence of natural and anthropogenic factors on the coasts and hydrotechnical facilities located in the administrative territory of Tallinn, and analysed the issues of management of ports and hydrotechnical facilities.

Sustainable management of urban coasts

Sustainable management of urbanized coastal areas is connected with a large number of different aspects of vulnerability of coastal and developed areas with respect to hazards from the sea, cost-benefit analysis of the results of different adverse impacts, and the relevant response strategies. Many such aspects are universal and/or generic for the coastal zone in urbanized, agricultural and forested areas as well as for low-lying areas in general, and the related policy implications have been adequately formulated in both scientific literature and in practical handbooks.

Yet each coastal area has its own specific features. The City of Tallinn is located at the coasts of the Gulf of Finland in the north-eastern part of the Baltic Sea, the world's largest brackish water body. This water body is practically non-tidal and has limited variation of monthly mean water level. Still dangerous coastal floodings may occasionally occur in this area. The long-term average wave activity is moderate (Paper III), but extremely rough waves may at times occur even in the inner parts of Tallinn Bay (Soomere 2005c).

The large variety of the types of coasts in Tallinn Bay combined with the presence of several semi-enclosed smaller bays such as Kakumäe Bay or Kopli Bay lead to high susceptibility of certain sections of the coastline with respect to wave action and local wave setup (Soomere 2007). The presence of sea ice during most of the winters (Sooäär and Jaagus 2007) and its potential attacks add another dimension to the vulnerability of the coasts.

On the other hand, the coasts of the City of Tallinn are, and have been for a long time, under extremely heavy anthropogenic pressure. This becomes first evident in the form of various coastal engineering acitivities such as construction of new ports, groins, jetties, and other coastal structures. Less visible but not less important may be the influence of underwater sand mining that recently has been performed in large amounts from a sea area between the Island of Naissaar and Suurupi Peninsula (Kask 2003, Kask *et al.* 2005). In areas close to the City of Tallinn such activities have been accused for damages of the coastal zone. Last but not least, many aspects of the remote influence of long waves from fast ferries are still not exactly quantified, but it is unambiguously clear that they have the potential of substantial influence of the coastal zone (Erm and Soomere 2004, 2006).

A large part of the analysis of the listed aspects in international scientific literature has been made from the viewpoint of potential adverse effects of climate change. In the analysis below we first concentrate on the effect and mitigation needs for existing properties of major marine hazards in the context of the coasts of the City of Tallinn and only outline, where relevant, specific risks connected with the changes of these properties.

While the physical characteristics of even the most extreme coastal hazards can be foreseen with an acceptable accuracy in the Baltic Sea conditions (see, e.g. Suursaar *et al.* 2006, Soomere 2005c), there is a large gap in methodology and implementation of adequate response to such hazards on both national and community level. It is deeply unusual that private persons had to interfere into national crisis warning system to explain the extent of the approaching danger in the very recent past (Suursaar *et al.* 2006). An analogous gap can be identified in the policy of the related business activities. It becomes clearly visible after the flooding in January 2005 when the government had to interfere to the policy of insurance companies, an action that is usually used under extremely critical conditions.

A part of this study is concentrated on the necessities of accounting for and the potential of socio-economic arguments in the response scenarios and strategies of the society to coastal hazards and the general management policy of coastal zone. A large part of examples is related to mitigation of the adverse effects of anthropogenic pressure on the coast. Although unbelievable a few decades ago, it is now widely recognized that anthropogenic influences, directly and indirectly, will be extremely powerful forces in steering the future of coastal geomorphology (Sherman and Bauer 1993).

Traditionally, the treatment of technical and engineering aspects is separated from the analysis of socio-economic and related aspects or from ecosystem problems. This is in a way understandable, because decision making in sustainable management must be made on clearly justified economic analysis of all potential scenarios, while the engineers frequently are simply not aware of the costs of the solutions and the cost/benefit ratio for specific areas. Although joint analysis of both the aspects of the coastal management is gradually becoming more frequent (e.g. Lamberti *et al.* 2005, Lamberti and Zanuttigh 2005), societal aspects of coastal management are still, in general, severely underestimated. For that reason two of the key publications (Papers I and II) and the relevant analysis in this thesis address socio-economic aspects to some extent.

Many technical aspects of coastal engineering have been intentionally left out from this work, because handbooks on these topics are readily available (e.g. Herbich 1999, Dean and Dalrymple 2002, among others). A seminal overview of the specific engineering aspects of coastal protection, technical aspects of developments in coastal engineering research, of recent advances in understanding and modeling of hydrodynamic and morphodynamic processes in the coastal zone as well as some challenges for further developments, is recently presented in (Battjes 2006).

It should also be noted that much of the integrated coastal zone management actually begins with institutional and policy issues and incorporates science as a secondary component. When science is introduced, sometimes clearly too much emphasis is placed on biological issues and on infrastructure development, while non-living resources and physical shore processes are sometimes overlooked (Solomon and Forbes 1999). This approach is widely spread, and is reflected e.g. in the recent scientific program (www.bonusportal.org) of the Baltic Sea science network BONUS where emphasize is made on biological aspects and the basic oceanographic knowledge has a secondary role. Although ecosystem aspects are with no doubt important in the coastal management, there is a large pool of examples that demonstrate that the geological and oceanographic context is absolutely fundamental to the recognition of hazards, delineation of risk, and prediction of changes that may occur from any manipulation in the coastal system. In this context, it frequently happens that the level of vulnerability of beaches is severely underestimated.

Layout of the thesis

The plan of the thesis is as follows. Chapters 1, 2 and 3 summarise the main recent developments and contemporary viewpoints of the principles of optimal and sustainable coastal zone management of marine hazards in low-lying urbanized areas, reflected in major textbooks and publications in leading international scientific journals. The recommendations given in these sources are discussed, where relevant, in the context of Tallinn Bay.

Chapter 4 presents overview of local conditions of the geological setting and coastal processes for the Tallinn Bay and the neighbouring coastal sections. This overview is necessary for understanding the complexity of the process in different sections of the coasts of the City of Tallinn. Also, it reflects the basic conclusions made in Paper IV concerning the problems of sustainable management of beaches under particularly strong anthropogenic pressure.

Chapter 5 is dedicated to the analysis of the properties of one of the major driving forces of the local coastal processes – wind waves in the northern Baltic Proper. One of the main outcomes of the relevant research, the details of which are published in Paper III, is that the wave regime in the Tallinn area is very specific; namely, longer wind wave components are almost missing among the natural waves. The key conclusion from these studies is that the coasts of the City of Tallinn may be much more vulnerable with respect to changes of both natural and anthropogenic forcing than many other coasts of urbanized areas.

Chapter 6, based on Paper I, presents a general insight into the cluster of problems of sustainable planning of coastal environment in urbanized areas. Additionally to the problems that one may encounter in the City of Tallinn, it addresses to some extent other beaches, the functioning of which is heavily influenced by satellite infrastructure of the city, namely, by very large (in the Baltic Sea scale) Muuga Port.

Chapter 7 is based on Paper II and is concentrated on the analysis of a case study vividly demonstrating the complexity of the necessary approaches, even in case of short sections of vulnerable coastlines. It presents the analysis of the main factors affecting the status of the coastal zone and coastal processes of Kakumäe Peninsula, City of Tallinn and a description of the principles of studies that are necessary to adequately determine the litohydrodynamic processes in the coastal and littoral zone. Owing to the complexity of the processes in this area, it is necessary to combine the results of different studies to determine the cost-effective and environmentally friendly type of coastal protection. A scheme of necessary studies and estimates of their cost and duration is presented.

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1. Marine hazards for the coasts of the City of Tallinn

Coasts of the City of Tallinn

As purely geological questions are outside of the scope of this study, we only briefly present the description of the basic features of the sea coasts in the area in question.

The descriptions of general properties of the beaches at the southern coast of the Gulf of Finland, specific features of coastal processes and development of their morphology are mostly published in Russian or Estonian (Orviku 1974; Lutt and Tammik 1992; Orviku and Granö 1992) except for a small number of overviews in English (Raukas 1986; Nõlvak 2007). A number of studies of short sections of the coast (for example, Knaps 1976; Paap 1976; Orviku and Veisson 1979; Loopmann and Tuulmets 1980, for the Pirita Beach and its surroundings) are available as manuscripts.

Some remarks about the classification of coastal zone of the City of Tallinn from the viewpoint of land use are presented in (Sander 1987). A thorough overview of geology and geological history of the entire Gulf of Finland area is presented in the collection of papers edited by Raukas and Hyvärinen (1992). A compressed presentation of geological setting of the City of Tallinn area is given, unfortunately with very scarce literature references (Müürisepp 1976; Künnapuu and Raukas 1976).

Overview of studies addressing the functioning of a part of the coasts of the City of Tallinn and principles of their segmentation from the viewpoint of sediment transport are recently presented by Soomere *et al.* (2007). This short description mainly follows this source and references therein.

Historically, the beaches of Estonia have been investigated on the basis of morphogenetic classifications worked out in the former USSR (Ionin *et al.* 1964; Kaplin 1973; see an overview in Orviku and Granö 1992). An early scheme of the beaches of the whole Baltic Sea is presented in Gudelis (1967) and for Estonia in Orviku and Orviku (1961). An attempt to more detailed categorization (Morozova 1972) was improved and extended in Orviku (1974).

A specific feature of the entire sea area in question is that the beaches of the southern and the northern coasts of the Gulf of Finland are completely different. The northern coast is characterised mostly by "skären" type beaches. Their evolution is weakly affected by hydrodynamic factors (Granö and Roto 1989).

In the contrary, the eastern and southern coasts of the Gulf of Finland were formed and developed predominantly under the effect of wave action (Orviku and Granö 1992). The beaches along the Estonian coast form a large erosional-accretional system, divided into compartments by rocky peninsulas and headlands. Many peninsulas, islands and bays cutting deep into the land can be found in this area. The coasts obtained their contemporary shape only a few millennia ago and can be classified as straightening coasts (group IIIA according to Kaplin 1973).

The volume of sediment and the magnitude of littoral drift are modest. The most common type of coasts here is the straightening accumulation embayed coasts—type 20 according to (Kaplin 1973).

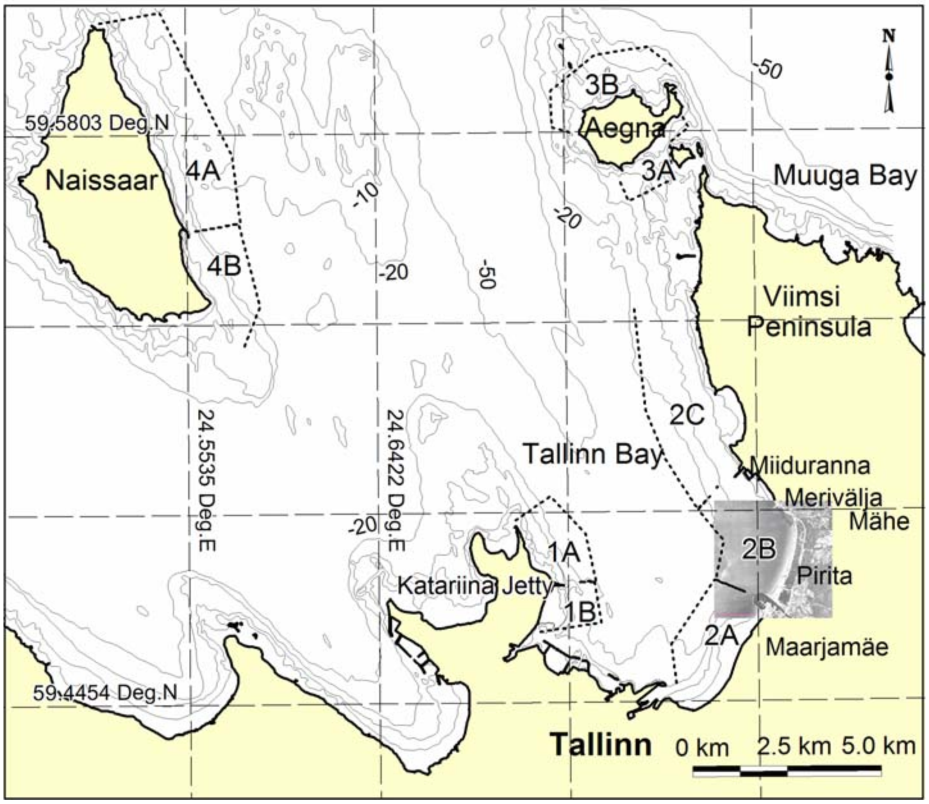


Figure 1.1 Scheme of the coasts of City of Tallinn and compartments of alongshore drift in the inner part of Tallinn Bay and the Islands of Naissaar and Aegna (Soomere *et al.* 2007)

Viimsi Peninsula (Fig. 1.1) divides the embayed beaches of the northern coast of Estonia into two sets. The features of the coast eastwards from this peninsula are mainly related to glacial and glaciofluvial formations and deposits of the Foreklint Lowland. The bays westwards (including Tallinn Bay) features are mostly associated with structural blocks and ancient erosional valleys in the bedrock (Orviku and Granö 1992). Both subtypes suffer from beach sediment deficit. Although littoral drift generally carries sediments to the bayheads, even the healthiest sections of coast at the bayheads are from time to time subject to erosion.

According to Soomere *et al.* (2007), the coasts of Tallinn Bay acquire several sedimentary compartments and a variety of different types of beaches. A steep till bluff can be found at the Island of Naissaar, gently sloping till shore along many parts of Viimsi Peninsula, sandy coast at Pirita and at certain sections of the Island of Aegna, and long sections of artificial shore around Tallinn. The compartment consists of the following parts (Fig. 1.1):

- The mainland coasts of Tallinn Bay form a large compartment that is divided into two independent sedimentary cells by the harbours of the City of Tallinn, namely
  - western cell 1 is divided into two sub-cells 1A and 1B by Katariina jetty constructed in the 1910s.
  - eastern cell 2 that before the 1920s extended from the harbours of the City of Tallinn along the coast of Viimsi Peninsula up to Aegna. Coastal engineering structures have considerably modified this cell. Its south-western part (2A) is nowadays an artificial shore. Miiduranna Port divides the eastern part of cell 2 into two subcells 2B and 2C since the 1970s. The more northward cell 2C may be partially connected with the adjacent cell in Muuga Bay (Fig. 1.1) through a narrow (about 300 m) and shallow (about 1 m before dredging) strait.
- The sedimentary systems at the islands adjacent to Tallinn Bay consist of:
  - sand bodies 3A and 3B at Aegna (northwards from the island and in the strait between the island and the islets adjacent to mainland, respectively) that seem to be separated from the mainland coasts.
  - the eastern coast of Naissaar (cell 4) that contains subcells 4A and 4B that are separated to some extent by a harbour. This cell is completely disconnected from the mainland cells by a strait with a depth of about 30 m.

By analogy of the analysis in Soomere *et al.* (2007), one may expect that the western coast of the Island of Naissaar forms a more or less autonomous sediment transport cell. This coastal section, however, is separated from the sediment recycling system of the mainland. Its functioning is mostly natural and has a minimum amount of connections with that of urbanised zone, and is out of the scope of the present work. Also, one can expect that the coastal sections of Kakumäe Bay and Kopli Bay form semi-autonomous cells of sediment transport, potentially containing subcells separated either by the Tiskre Stream mouth, or by Kakumäe Harbour. The relevant analysis, however, has not been performed yet.

The most studied section of the coastline of Tallinn in terms of coastal processes apparently is Pirita Beach. It forms the south-western part of cell 2B. The rest of the western coast of Viimsi Peninsula (cells 2B and 2C) is mostly covered by very coarse material (pebbles, cobbles, boulders). As typical for the northern coast of Estonia (Orviku and Granö 1992), it has a limited amount of gravel and sand participating in the littoral drift and its development occurs under sediment deficit.

According to the classification of Lutt and Tammik (1992), erosion dominates in the entire nearshore of Viimsi Peninsula northwards from Pirita Beach and up to the depth of about 10 m. Beach erosion, however, is usually modest since the stone pavement protects the shore (Kask *et al.* 2003b). Finer fractions are only released in high water level conditions when waves directly act on unprotected sand, till, or limestone. Accumulation dominates in the deeper parts of the nearshore and in the vicinity of Pirita Beach.

The set of coastal hazards for the shores of the City of Tallinn forms a subset of analogous hazards affecting other cities located at the sea coast. For example, the action of tides is completely negligible here. Also, dangerous tsunamis are virtually impossible in this region. On the other hand, frequent ice attacks, a specific feature, of the Nordic region, form a generic part of functioning of its coasts; yet its influence is very limited. The common marine hazards in this area are sea level changes, coastal floodings, wave action, and potential changes of properties of these phenomena. While none of these hazards can lead to a rapid, large-scale devastation in the conditions of the City of Tallinn, combating and adaptation scenarios do not presume immediate measures of protection of lives; instead, the use of classical cost-benefit analysis of countermeasures is the common procedure in city planning.

Sea level changes

The most important hazard for coastal communities in the long-term run is the possible sea level rise. This threat for selected sections of the the northern coast of Estonia has been analysed in Kont *et al.* (2003). The relevant studies for the low-lying and subsiding deltas have a long history (see, e.g. Milliman *et al.* 1989). This problem is especially actual for the slowly downlifting areas in the southern Baltic Sea such as Polish (Zeidler 1997) and coasts of northern Germany.

In the context of the Polish coast, Zeidler (1997) identified and analyzed three potential adaptation strategies (retreat, limited protection and full protection) and compared the consequences in both physical and socio-economic terms. A selection of sea level rise scenarios (30 and 100 cm by the year 2100, and 10 and 30 cm by the year 2030) has been assumed as boundary conditions along with certain associated wind climate changes for the entire Polish coast. The analysis shows that more than 2,200 km^2 and over 200,000 people are at risk in the most severe case of 100 cm rise by 2100. Although such a dramatic rise of the water level is questionable in the light of the recent IPCC analysis (IPCC 2007), this scenario is not completely impossible and can be interpreted as an upper estimate for the losses in an unfortunate case.

The total cost of land at loss in that case is estimated at nearly 30 billion USD in prices of the mid-1990s. Another loss, estimated about 18 billion USD, is expected to occur owing to coastal flooding. In this case, the cost of full protection reaches 6 billion USD, that is, about 15% from the losses; thus the strategy of full protection is generally preferable. The estimates are given in the prices of the mid-1990s. Since the prices for land and for coastal protection measures change more or less synchronously, the relative costs of the full protection apparently are still relatively small compared to the costs associated with the loss of land. Particular features of vulnerability and adaptation schemes, including specific sites and the effects of not only sea level rise but also other climate change factors, and interactions with other climate change studies in Poland have been examined in Zeidler (1997).

Nicholls and Mimura (1998) examined policy responses to the human-enhanced greenhouse effect, in particular, to the rise of the global sea level and accompanied land loss, increased flooding and salinization, in four contrasting regions using local and national assessments. These regions are: Europe, West Africa, South, South-East and East Asia and the Pacific Small Islands. The impacts of and possible responses to sea-level rise vary at the local and regional scale due to variation in local and regional factors. The most dramatic consequences apparently will occur in South, South-East and East Asia subsiding megacities where the concerns of the sea level rise are overlapping with the major problems of long-term management of deltaic regions (see also Nicholls *et al.* 1999), and integrated models are clearly necessary to provide adequate national assessments of the potential consequences and ways to their mitigation.

The analysis in Nicholls *et al.* (1999) suggests that, by the 2080s, sea-level rise could cause the loss of up to 1/5 of the world's coastal wetlands. Combined with other losses due to direct human action, up to 70% of the World's coastal wetlands could be lost by the 2080s. The largest losses due to sea-level rise in Europe will be around the Mediterranean and the Baltic. In other part of the World Ocean, somewhat lesser extent of damages is expected on the Atlantic coast of Central and North America, and the smaller islands of the Caribbean. Collectively, these results show that a relatively small global rise in sea level could have significant adverse impacts if there is no adaptive response. Nicholls *et al.* (1999) conclude that there is a need to start strategic planning of appropriate responses now. The recent experience in Estonia in January 2005 (Suursaar *et al.* 2006) and during winter 2006/2007 shows that such planning is urgently necessary also in the Estonian coastal zone and could have immediate benefits.

Nicholls *et al.* (1999) together with wetland losses also analyze the associated risk of increased probability and magnitude of coastal flooding, extending so the work of Hoozemans *et al.* (1993) to a dynamic analysis. This problem has been recently shown to be a central one in the eastern Baltic Sea conditions, where the probability of high water levels has drastically increased during the latter decades (Johannesson *et al.* 2001, 2004). Also, statistically almost impossible events of extremely high water seem to occur more or less regularly in the Western Estonia (Suursaar and Sooäär 2007). The analysis serves as an early example of the analysis of joint effects of several simultaneously changing factors such as global sea-level rise and subsidence of certain coastal areas, increasing coastal population, and improving standards of flood defense. The basic normalized parameter characterizing the so-called "ability-to-pay" in their analysis is GNP/capita. The estimate of the global rise in sea level of about 38 cm from 1990 to the 2080s (which roughly matches the later estimate by IPCC 2007) is considered as the basis of the estimates.

The increase of the global water level (IPCC 2007) apparently is not particularly acute in Estonia, where the land uplift typically balances the water level rise. Another threat, still important in the northernmost parts of the Baltic Sea, is the (postglacial) uplift of land with respect to the mean water level. In the northwestern part of Estonia land uplift is up to 3.5 mm/year (Zhelnin 1966) and thus faster than the expected sea level rise according to the most of scenarios. This scenario is relatively irregular in the ocean and sea conditions (except for the Bothnian Gulf) and, to the knowledge of the author, has not been addressed in scientific literature. There are some examples of the relevant analysis in the context of the Great Lakes in North America. The relevant economic costs of harbour and marina dredging are estimated as much as CDN 7.6 million USD for Goderich Harbour and adjacent marinas only (Schwartz *et al.* 2004).

In the Baltic Sea conditions, declination of sea level may also result in extensive motion of fine sediments at medium depths, formed a few centuries ago, and in massive sedimentation in harbours and fairways. This scenario has not been considered in Estonian conditions. Conceptually, it may become evident in the form of theoretically predicted intense motion of medium-depth sediments owing to long waves from fast ferries (Soomere and Kask 2003).

Increased flood risk

Another major long-term hazard accompanied with the gradual increase of the water level is the increased flood risk. This risk is high in several low-lying areas of Estonia (Suursaar *et al.* 2006, 2007). A number of local studies of the long-term hazards associated with the water level rise (Thumerer *et al.* 2000; Zeidler 1997) confirm the significant increase of the estimated damage costs of flood events. The relevant activities consist of two major aspects: first, knowledge of the physical parameters of a hazardous events and their adequate forecast; second, reasonable countermeasures (both active and passive) to a particular event, incl. planning and organization of the countermeasures, and strategy for an overall reduction of the related costs for the whole community.

Traditionally, these aspects have been studied separately. Only in recent years joint studies are appearing. The pioneering works have been performed in the US Army Corp of Engineers where the value of a community approach to improved prediction and characterization of coastal storm hazards is being extensively discussed (Ebersole *et al.* 2006). Mostly, this approach embraces simultaneous modeling of the physical parameters such as hurricane-induced water levels and wave conditions, through field measurements and data analysis. One example is recently completed work by the Interagency Performance Evaluation Task Force, charged with gathering the facts regarding performance of the hurricane protection system in Southeast Louisiana in response to Hurricane Katrina, a case in which the preparedness and the quality of reaction of the local community was clearly insufficient (Ebersole *et al.* 2006). Ongoing work is targeted to design projects that can greatly reduce the likelihood and consequences of flooding for coastal Louisiana and Mississippi. These investigations are being closely coordinated with work of the Federal Emergency Management Agency to update flood insurance rate maps for the region. A lesson to learn from this approach is that similar attempts will only be successful if the efforts at all levels are synchronized.

One of the goals (that should largely improve the reaction of the local communities) consists in developing open-source, community-based computer software for coastal storm wave and surge predictions. One of the largest threats identified in Ebersole *et al.* (2006) is the today's over-reliance on proprietary software. This is a particularly important issue in Estonia, where the software predicting the sea state is actually run in Sweden and the results have quite a large bias for Estonian coasts. The forecasts for Estonia are given with the use of certain approximations based on statistics of the past events. This sort of "*modus operandi*" combined with outdated information about critical water levels in Tallinn area and inappropriate knowledge of the realistic consequences of slight overshooting of these levels has lead, e.g. to a sequence of false warnings in the City of Tallinn area in winter 2006/2007. The situation is currently being improved; the first step towards more adequate description being a dynamical description of dangerous water levels in different sections of the coasts of the City of Tallinn (Soomere 2007). The preliminary results are already available for the city planning.

The described approach represents an example of the system analysis of disaster prevention design criteria for coastal and estuarine cities. This approach has been widely used in China where estuarine and coastal cities are mostly regional economic development centres. The disasters by the combined effect of upper each flood, storm surge and typhoon waves are primary obstacles to the economic development of such cities (Liu *et al.* 2000), thus the risk analysis and system analysis of (river or coastal) flood, storm surge or wave disaster, accompanied economic loss and flood-storm surge control measures play a central role in the sustainable development of coastal cities.

The leading principle is the combination and forecast of the physical characteristics of the hazardous event with its specific effect in each type of area and an advanced model for economic assessment risk analysis and hazard-control benefit estimation. An important lesson from the relevant studies is that different hazards are the most devastating in different areas, and that regionalization of such models and cost-benefit estimates is generally necessary. This is indeed true in the vicinity of the City of Tallinn, where the coasts are very much different and different physical hazards have greatly different consequences.

Problems of this type have been extensively studied in international literature in the context of potential tsunamis (e.g. Kundu 2007). Although devastating tsunamis in Estonia are virtually impossible, the results of the relevant studies are of direct use in strategic planning of countermeasures to be taken in case of extensive flooding because the appearance and the results of these hazards are fairly similar. Since the relevant efforts are in their initial stage in Estonia, the most instructive is the experience of countries that suffered from the Indian Ocean tsunami in 2004. Several countries in this region have initiated strategic approaches for the protection of lives, ecosystems and infrastructure (e.g. Hettiarachchi and Samarawickrama 2006).

An important lesson is that, additionally to understanding of physics of the tsunami wave (resp. coastal flooding in Estonian conditions) and its hydraulic impact, political and societal aspects such as strategic planning of passive security and establishing an adequate scheme of decision-making issues combined with a feasible system of the planning of countermeasures are equally important. The relevant system is in the planning stage in Tallinn, where the maximum extent of flooding of low-lying areas is quite limited. In Pärnu, where flooding may extend to a large part of the city area, the relevant measures (e.g. an autonomous warning system) is currently being introduced.

The exact level of damage in case of a coastal flooding has a large uncertainty because of uncertainties in the future costs of land and property. However, the use of the 'house equivalent' concept (Thumerer *et al.* 2000) unambiguously demonstrates also the relative increase of the flood-induced costs. Combined with the general increase in price of coastal properties, this tendency creates a strong pressure on the local society and communities who have the responsibility to combat with adverse effects and who have to redirect a large part of their effort to the coastal zone. The societal consequences of this process have not yet been studied in detail.

According to some scientists, the number of people annually hooded by storm surges will be more than five times higher due to sea-level rise by the 2080s. Many areas will probably experience annual or more frequent flooding, which means that greatly increased protection is necessary to avoid substantial migration from the coastal zone, especially in South and South-East Asia. In these regions, a concentration of low-lying populated deltas and the sea level rise will certainly lead to serious consequences. Areas vulnerable to flooding are also in the southern Mediterranean, Africa, in the Caribbean, the Indian Ocean islands and the Pacific Ocean small islands, which may experience the largest relative increase in flood risk.

The situation and relevant scenarios in Poland, an area hosting about 500 km long and predominantly featured by sandy, low-lying beaches where the threats and potential adverse effects of sea level rise are similar to those that would happen in low-lying parts of Estonian coastline, have been analyzed in detail by Pruszak and Zawadzka (2005). The relative sea level rise has manifested itself in the growing intensity of shoreline, dune and cliff erosion during the latter decades in Poland. Pruszak and Zawadzka in the same article also give an insight to various other threats resulting from intensified climate change.

More important in Estonian conditions (where wetlands form a relatively small part of the coastline) is the potential influence of the sea level rise and increased coastal flooding to the coastal forest ecosystems. Frequent flooding and accompanying changes in soil properties (e.g. salination, local erosion of e.g. dunes, sedimentation of mud etc. on fertile areas) may reduce the quality of coastal forests and may lead to deforestation of certain sections (Kozlowski 2000). Combined with direct losses owing to sea level rise and to direct mechanical impact of water and waves, such processes may result in considerable degradation of plant ecosystem in low-lying areas. Within the coasts of the City of Tallinn, such effects are potentially possible in the areas bordering with the bayheads of Kakumäe and Kopli bays (Merimetsa and Tiskre).

The most promising machinery to monitor the changes in the coastal zone is the GIS technology. Combined with the model estimates of losses caused by the water level rise and more frequent coastal flooding, it serves as the generic basis of prototypes of the Decision Support System (DSS) for the coastal area (Thumerer *et al.* 2000, Zeidler 1997).

Another promising technology is the automated video-based monitoring of coastal processes in the most vulnerable sections, recommended for Kakumäe area in Paper II. The major benefits of such systems are their moderate cost and large temporal and spatial coverage while their physical protection may be problematic at Estonian coasts and the digital image processing may require quite expensive software. Such systems have recently shown good performance at Australian coasts (Turner *et al.* 2004) to monitor and quantify the regional-scale coastal response to sand nourishment and constructions in the nearshore. The system described by Turner *et al.* (2004) consists of four cameras and provides continuous coverage of 4.5 km of the coast for very reasonable price. It enables the mapping of changing shoreline position, the measurement of three-dimensional dry beach morphology and resulting changes in the sediment volume; and the estimates of wave breaking frequency and position (Turner *et al.* 2004).

This technology may also be combined with the relevant satellite information that effectively gives a somewhat lower in resolution but richer in context information of changes in larger regions. Result of the use this technology to study land cover change within the Grand Bay National Estuarine Research Reserve in 1974-2001 (Hilbert 2006) show that it can be very useful for the Tallinn Bay conditions. Both bays are protected from the full force of waves, winds, and storms by topographic features (Grand Bay by reefs and barrier islands; Tallinn Bay by numerous shallow areas at its entrances, see Soomere 2003a, 2005a), and provide habitats for a large number of plant and animal species. Such a broad land cover analysis provides resource managers with information regarding the land cover types and spatial distributions that cannot be extracted from point measurements, and allowing for more informed decisions with regard to preserving biodiversity and planning restoration efforts.

Wave action and its changes

Wave action is the principal driving force of the coastal processes in the vicinity of Tallinn. This is a typical property of beaches located in microtidal seas and that host no strong jet currents. Its role has been quantified to some extent for Tallinn Bay in (Soomere 2003b, 2005a; Soomere *et al.* 2005). A large part of waves affecting the coasts around the City of Tallinn are born in the Gulf of Finland. Western winds may bring to this area wave energy stemming from the northern sector of the Baltic Proper. The wind regime in these areas is strongly anisotropic (Mietus 1998, Soomere and Keevallik 2003). Some sections of the shores of Tallinn are well sheltered from high waves coming from a large part of the potential directions of strong winds (Soomere 2005a). As a result, the local wave climate is at places very mild compared with that in the open part of the Gulf of Finland. For example, the annual mean significant wave height varies from 0.29 m to 0.32 m in different sections of Pirita Beach (Soomere *et al.* 2005).

Very high waves, however, occasionally appear in virtually all sections of the coast under consideration. The significant wave height exceeds 2 m each year and may reach 4 m in NNW storms even in the central part of Tallinn Bay (Soomere 2005a). This feature explains well why most of the coasts of Tallinn Bay show features of intense erosion (Lutt and Tammik 1992, Kask *et al.* 2003a). The dominating wave periods at Pirita in western and NNW storms are close to those in the central part of the Gulf of Finland.

The potential consequences of the changes of the wave regime in this area are poorly understood. Since wave-induced processes substantially depend on wave height, length or period, and approaching direction, the knowledge of the wave height only is insufficient in the coastal management. Even quantification of the role of the ferry-induced waves requested extensive efforts from a large team of scientists (Soomere *et al.* 2003) and lead to quite a large uncertainty of their role. A large part of this uncertainty forms the shortage of the knowledge of factual wave regime in the Tallinn Bay that was only estimated approximately with the use of the contemporary wave model WAM (Komen *et al.* 1994). The relevant knowledge can be to some extent constructed, based on long-term statistics of wave properties in the open sea, incl. the Baltic Proper, and with the use of wave propagation models. An attempt in this direction has been made with the use of the longest available instrumentally measured time series of wave properties at Almagrundet (Broman *et al.* 2006).

The results of both numerical studies (Soomere 2003b, 2005) and the analysis of historical wave data (Broman *et al.* 2006) confirm that wave periods in the entire Gulf of Finland and in Tallinn Bay are relatively small. This is the key reason why waves from fast ferries form an appreciable portion of the total wave activity in Tallinn Bay since 1997. Their annual mean energy and its flux (wave power) are about 5–7 % and 20–25 % from that of the total wave activity, respectively. The daily highest ship waves belong to the highest 5 % of wind waves in this area (Soomere 2005b). Since high ferry waves are present during a relatively calm season and at times approach from directions not common for wind waves, they may induce sediment transport directed oppositely to the natural littoral drift or current-induced transport of suspended matter (Elken and Soomere 2004). Their role in coastal processes, although potentially substantial under certain circumstances (Soomere and Kask 2003, Paper I, Valdmann *et al.* 2006), has so far been poorly understood and needs further investigation. The City of Tallinn has launched a relevant process in 2006, which currently is in the stage of identification of key shortages in the relevant knowledge and areas where substantial further research is necessary.

Cost-benefit analysis of coastal protection measures

The simplest (and generally acceptable from the viewpoint of both economical and societal aspects) response to the gradual destructions of recreational sandy beaches consist in their active protection. The majority of Estonian sandy beaches develop under clear deficit of sand. Even beaches that are in a nearly equilibrium stage suffer from storm damages at times (Orviku 1974, 2003, Orviku and Granö 1992, Orviku *et al.* 2003). Orviku suggest that the seemingly increasing storminess (expressed as a statistically significant increasing trend of the number of storm days over the last half-century) in the eastern Baltic Sea has already caused extensive erosion and alteration of depositional coasts, such as sandy beaches (Orviku *et al.* 2003). They express the opinion that destructions of beaches owing to more frequent occurrence of high water level and intense waves, and lengthening of the ice-free time has overridden the stable development of the coast, which is usually expected in the flat and low-lying coastal zone of Estonia experiencing isostatic and tectonic uplift. There is a gradually increasing necessity of their protection.

The best protection measures can only be found, as explained above, based on extensive knowledge of the vulnerable areas. The traditional starting point is a general classification of the vulnerable areas. For example, in Poland, three basic area types according to their geographic and socio-economic background have been specified. After that threats of land loss and the risk of its temporary or partial inundation was analyzed in connection with the assessment of the material and social costs and losses (Pruszak and Zawadzka 2005). In their analysis, two possible adaptation scenarios (retreat - do nothing and full protection) were accounted for. The greatest threat of partial or full land loss and the associated material and social costs are expected to occur in two regions of the Polish coast: heavily urbanized agglomeration of Gdansk and the Zulawy polders, and less urbanized low-lying areas around the Szczecin Lagoon and the vicinity of the Odra river mouth.

An analogous study (Kont *et al.* 2003) identified a similar pattern along the Estonian coast. Both low-lying areas and heavily urbanized spots may be under extensive pressure. The relative water level rise by 1 m (which is somewhat larger than the maximum increase by 2100 according to scenarios of the IPCC but still not totally excluded) would cause serious consequences in certain areas. The land loss in Tallinn area would probably be irrelevant. In the easternmost part of Estonia, an important recreation site adjacent to Narva-Jõesuu with excellent sandy beaches would be under high pressure. Another site of great risk is the Sillamäe dumping site of the former uranium enrichment plant (Kont *et al.* 2003). Although it is currently protected by the new harbour constructions and their access road, possible damages of this site are one of the greatest threats to the environment of the Gulf of Finland. The spatial resolution of the analysis of Kont et al (2003), however, is insufficient to locate vulnerable spots in heavily urbanized sections of the coast of Tallinn and its surroundings which may require both intensive care and protection efforts.

2. Systematic and sustainable adaptation: review

Adaptation to the climate change

Adaptation to climate change in arctic and boreal areas with particularly vulnerable environment is recognized as an important policy issue by international bodies such as the United Nations and by various national governments (e.g. Ford and Smit 2004). In many cases, the awareness of the society, stakeholders and decision-makers is poor, and therefore the starting point of initiatives to identify adaptation needs and to improve adaptive capacity is an extensive assessment of the current situation and potential ways of its improvement. In the framework of Tallinn Bay and the neighbouring areas, the relevant initiative is reflected in Papers I, II, and IV.

The process increasingly starts with an assessment of the vulnerability of the system of interest, in terms of who and what are vulnerable, to what stresses, in what way, and what capacity exists to adapt to changing risks. A classical approach consists in using the procedure of environmental impact assessment (EIA, see, e.g. Morris and Therivel 2001). Both the strategic (Peterson 2001, 2004) and classical EIA have a large role in adequate estimate of the situation, potential adverse effects and ways of their mitigation. A detailed overview of the EIA experience in the coastal zone of Estonia that also reflects the problems of urbanized and artificial coasts is given in Lapimaa and Soomere (2006). Some examples of the EIAs of major underwater minings and post-EIA monitoring in the immediate vicinity of Tallinn are presented and analyzed in Kask 2003 and Kask *et al.* (2003b, 2006).

More generally, vulnerability can be conceptualized as a function of exposure to (e.g. climatically forced) stresses and the adaptive capacity to cope with these stresses (Ford and Smit 2004). The relevant analytical framework involves extensive place-specific case studies involving community residents and integrates information from multiple sources. There are practically no such studies in Estonia (Paper I). For this reason the use of such more advanced methods require extensive preparatory activities to document current exposures and adaptations and to characterize future exposures and adaptive capacity.

An attempt in this direction is the study of processes and potential measures in the Kakumäe area (Paper II). This is one of the few sections where the promising technology of detached or low-crested breakwaters (Lamberti *et al.* 2005) may give the best effect while erection of such structures (although used as artificial reefs in some places) is questionable in sandy beaches. European experience of low crested structures for coastal management is generally encouraging. Among other features, they have certain ecological and socioeconomic benefits compared with the classical means of beach protection. They seem to work effectively under different environmental conditions, providing the opportunity to protect beaches in the context of Integrated Coastal Management (Lamberti *et al.* 2005).

The studies of local processes and the analysis of environmental and economical applicability of potential measures of beach protection form an important part of understanding the role of the present and future technologies and their influence on future coastal and marine resource development and management (Side and Jowitt 2002). These technologies will be substantially affected by the changes in hydrometeorological conditions, and in turn they influence coastal and marine environment through related development work. Some emerging presumptions may not only preclude the use of existing technologies in some cases (e.g. dumping at sea), but may also act as drivers to the development of new technologies, such as offshore wave and wind power generation devices.

Attempts towards systematic analysis and mapping of the situation in selected areas of the scope of the City of Tallinn (Papers I and II) is a step on the way of establishing relevant principles and methods of integrated coastal zone management both in everyday life and in decision-making process, with the final goal of ensuring sustainable development of this coastal section and sharing the relevant experience with sister situations. An important milestone within the process is the formulation of roles of different levels of local, community, and city authorities, and other involved institutions in specific features of decision-making in questions of coastal environment (Paper I).

Sustainable coastal zone management on the national level

Some authors have sharply criticized the participative, "bottom-up" approaches of contemporary European integrated coastal zone management (ICZM). For example in McKenna and Cooper (2006) tackle one of the „sacred cows" in coastal management - the need for a "cheap and transitory" model (under which they understand the tendency to always choose the cheapest option). This is the overall policy also in Estonia that the cheapest offer should be preferred unless very serious arguments are available. McKenna and Cooper (2006) express the opinion that it is simply ineffectual and unsustainable policy (McKenna and Cooper 2006). They claim that this model of coastal management lacks the authority and resources to deliver ICZM and should be abandoned. This is perhaps a too strict approach since the participatory processes, while challenging to manage and under growing scrutiny, seem to remain the most effective manner to engage broad constituencies and ensure that benefits match expectations in many cases (Christie *et al.* 2005).

McKenna and Cooper (2006) propose that a new model of ICZM in a predominantly sectoral administrative framework should be employed. It requires that capacity be built in existing statutory authorities and in-house ICZM groups be established. Time-limited participatory projects (which are dominating today in Europe) would be used to gain information on conflicts and issues that transcend existing sectoral boundaries, but this information would be passed to the established statutory authorities for action. They claim that a sound statutory and legislative basis is the essential prerequisite for effective coastal management and that activities based on voluntary partnerships are unsustainable. This is currently also the position of the City of Tallinn. Since this model has several common features with the system of coastal zone management in the USA (Hershman 1999, Hershman *et al.* 1999), we shortly present some outcome of their system.

Early overviews of the shore protection policy and practices in the US were quite critical as well. The experience of Oregon's public beaches and adjacent developed and undeveloped dunes and bluffs (that experience erosion and other hazards due to winter storm waves as the coasts of Tallinn Bay do) was that in privately owned developed areas, the typical hazard response was to simply install a hard shore protection structure (Good 1994), although the general policy of the state was to discourage such structures that only offer protection to very limited sections are generally not sustainable. Therefore the policies designed to mitigate hazards, control upland development, and protect the beach were often ineffective. Based on this analysis, Oregon's ocean shore protection management regime needed an overhaul. Such a process was initiated at a completely different level since 1990 (Hershman 1999).

This experience well reflects the general principles of integrated solving of coastal management problems in the US – building the relevant national programs and smart combination of them with local management programs. Creating such a multi-level cluster of management and decision-making, when organized professionally, may give large benefits in solving both local and national problems. The results of the relevant analysis of (Hershman 1999) are very instructive in the Estonian context where such programs are in the stage of initiation. He underlines the positive experience of those which have developed such programs have included policies specific to commercial seaports, including "no-sprawl" policies, delineation of areas for port development, permit criteria specific to ports, or expedited permit processes. They employ a variety of strategies for guiding port development, including regional plans, master planning, local zoning, and port-specific environmental criteria. They are active in technical assistance including grants, staff assistance, and engineering and environmental support.

A specifically constructive feature is that organizational learning is occurring in both the institutions running or responsible for such programs as well as in port organizations as a result of their interaction. Some of this learning results in changed objectives within each organization that in turn improves achievement of the multiple objectives of the coastal zone management. Relevant examples include regional port planning, master planning and special area management plans, reservation of land for future port needs, wetland mitigation banking, beneficial use of dredged material, and long-term dredging planning. In this light, recent dumping of high-quality sand dredged from the navigation channel between the islands of Aegna and Kräsuli (instead of using for construction purposes or for beach refill) is simple unacceptable and similar operations should never be permitted in the future.

The results of the effectiveness of the USA coastal zone management policy and programs are reported in Hershman *et al.* (1999) based on study in

1995-1997. They analyze five of the core objectives of the U.S. Coastal Zone Management Act (CZMA), some of which have great relevance in the Estonian conditions: (1) protection of estuaries and coastal wetlands; (2) protection of beaches, dunes, bluffs and rocky shores; (3) provision of public access to the shore; (4) revitalization of urban waterfronts; and (5) accommodation of seaport development. State coastal programs were found to be effective in addressing these objectives. However in Hershman *et al.* (1999) it is noticed that this conclusion is based on very limited information about program outcomes. The problems with the limited amount, quality and timely available information about coastal aspects are an issue also in Estonia (Lapimaa and Soomere 2006). For definitive conclusions and effective measures therefore it is important to ensure much better availability of various types of information.

A major shortage (that is also dominating in Estonia) is that coastal managers have not agreed upon indicators of success. This feature severely inhibits systematic and sustained collection of outcome information. A national outcome monitoring and performance evaluation system is recommended to address these deficiencies and allow better determinations of program effectiveness in the future.

The above has shown that in all actions and initiatives involving societal aspects of coastal zone management a maximally unambiguous measure of success should be used, in order to properly estimate the influence of the initiatives. At some stages, the existence of such measures is one of the factors influencing sustainability of integrated coastal management process (Christie *et al.* 2005). The general principle is that the generation of social and environmental benefits that are equitably distributed among constituencies is a key factor in ICM process success and sustainability. In other words, the process of integrated coastal management should be an object of impartial and rigorous research. This is basically the only way to support the positive and constructive changes in it and to assess future challenges and emerging management models (Christie *et al.* 2005).

Bowen and Riley (2003) stress that the need to better understand the linkages and interdependencies of socio-economic and coastal environmental dynamics has taken on a more deliberate role in the development and assessment of Integrated Coastal Management world-wide. The analysis and establishment of indicator-driven programs to assess change in coastal and watershed systems have increasingly moved to stress socio-economic forcing and impacts. The most important theoretical framework to foster such indicator analysis probably is the so-called Driver-Pressure-State-Impact-Response (DPSIR) framework, now in broad use (Bowen and Riley 2003).

Stojanovič *et al.* (2004) mentioned that there were significant gaps in empirical research in the field of ICM, particularly in reviewing success factors at the level of regional and local initiatives. The problem is generic since the measures of success are time- and place-dependent, and may change together with new challenges for the coastal engineering. For that reason, it is usually not possible to use the methods that academics use in conducting research that measures success.

There are successful experiences of coastal management on national level in Europe. It is natural that coastal management must be perfect in the Netherlands that permanently experiences different marine hazards to its low-lying areas. An interesting and instructive feature in this country is that the policy development is a dynamic and cyclic process characterized by successive stages of development, implementation and evaluation (van Koningsveld and Mulder 2004). Throughout this process, interaction between science and coastal management plays an important role (cf. Solomon and Forbes 1999).

Evaluation in 1995 of the coastal policy of Dynamic Preservation, developed during the late 80's and implemented in 1990, led to a partial redefinition of the policy in 2000. Implementation of the amendments in 2001 gave rise to a combination of small- and large-scale approaches into a sustainable coastal policy. Its successful development and implementation is related to the use of a systematic frame of reference in which both strategic and operational objectives are explicitly defined with the use of a 4-step recipe of (1) a quantitative state concept, (2) a bench marking procedure, (3) a procedure for CZM measures or intervention and (4) an evaluation procedure. Applications of this frame of reference show its high potential to better integrate coastal science and coastal policy and management and to stimulate co-operation between different levels (van Koningsveld and Mulder 2004).

A sort of an extreme approach – establishing Coastal and Marine National Park for the entire Scottish coastline – is debated in Scotland (Stead and McGlashan 2006). This can be interpreted as an analogue of the declaring of the entire Baltic Sea as a particularly vulnerable sea area by the International Maritime Organization in 2005. Potential benefits and constraints of such a solution are of course not clear yet; however, as an initiative converting the principles of ICZM into practice and having a clear legal mechanism (National Parks (Scotland)) to set up such a park in the entire country, it is highly interesting.

Another important dimension of the initiative is strengthening the existing local coastal expertise for a network in partnership with universities that have 'in-house' multi-disciplinary expertise. Such an instrument is nearly completely missing in Estonia and is poorly represented by private enterprises active in the coastal engineering. Similar attempts will probably not be successful in Estonia; however, efforts in this direction might act towards much more intensive involvement of civil society and key sectors of national and regional economy. This approach could also address the fundamental gap in translating stakeholder derived information into practical policy recommendations. Finally, systematic involvement of the local knowledge can aid resource management plans on a local, national and international scale, and can be applied to testing management scenarios (Stead and McGlashan 2006).

In Canada, the major tools in ecosystem-based coastal and marine environment’s management are the so-called Marine Protected Areas and Integrated Management initiatives (Guenette and Alder 2007). Systematic engaging stakeholders into such initiatives results in a number of constructive features: building and maintaining momentum through social capital; using the collective knowledge of stakeholders; consensus through formal and informal rules; and developing leadership capacity. However, as the number of issues or the number of stakeholders increases -- especially where fisheries are involved -- time, resources, and challenges in gaining support and participation increase. Guenette and Alder (2007) mention that political and administrative obstacles and resistance to change still constitute much of the challenge.

Combining local, regional and national aspects

Regional, municipal and local programs play a decisive role in some specific questions of coastal zone management where decision-making at all levels from local to (inter)national has to be synchronized. One of the largest challenges of this kind is the goal of opening of the waterfront of the City of Tallinn. This is a particular question of more general framework of redeveloping deteriorated urban waterfronts (Goodwin 1999). The above has shown that in the US it is identified as one of the national goals of developing the coastal environment (Hershman *et al.* 1999). In Estonia it has also a wider context, because many sections of coasts used for military purposes during the USSR period need urgent attention.

It seems that the importance of the visual perception is at times severely underestimated in decisions. Lessons from other regions indicate that level of nature content, level of neglect or care, manicured designs, and proximity to water are important factors that affect preferential judgements of waterfront design treatments (e.g. Gabr 2004). It is well known that sea or river waterfront users express higher preferences when they can freely access the water. This suggests that design developments of the waterfront are only successful if they are in harmony with nature and do not deny the general public physical and visual access. Solutions taken with extreme care are necessary e.g. when building skyscrapers along Pirita street or mounting artwork that may dominate the city view.

Goodwin (1999) recommends using three basic outcome indicators were designed to score the dimensions of revitalization: the extent of revitalization occurring in a state, the stage of revitalization achieved in each waterfront district, and the scope of waterfront improvements, programs, and activities realized. The largest progress in the USA has been achieved in partnership of states and local communities whereby actively promoting their financial and technical assistance programs. Less successful were a few attempts in which finding the solution or the responsibility for urban waterfront revitalization was delegated to networked specialized (but private) agencies (Goodwin 1999). In the context of the City of Tallinn this would mean that the usage of solely private developers probably will not lead to an appropriate development solutions, and both the government and the city authorities should actively participate in finding the best solution.

An instructive case of Lido di Dante in Italy (Lamberti and Zanuttigh 2005) demonstrates the clear benefits derived from the synergy of different monitoring methodologies an integrated approach to coastal zone management. This area suffers from great erosion and is well documented under engineering, socio-economic and ecological aspects. In these aspects, it has much in common with Pirita Beach. The study of Lamberti and Zanuttigh (2005) is one of the few examples in which effects of shore protection works and wave climate on beach morphology are examined by combining the analysis of field measurements of waves and currents together with hydrodynamic simulations and bathymetry surveys in the area and socio-economic impact of coastal defense. The latter is documented by the statistics derived from face-to-face interviews that provided beach valuation and user preferences. Such a study is recommended in Paper I, but not performed yet in Estonia. Another dimension reflected in Lamberti and Zanuttigh (2005) is that the above research is also combined with ecological surveys of the influence of the new structures. Therefore the study looks at the complex interaction among the beach, the structures, the hydrodynamics, the eco-system and the society, and, as such, is an example of and demonstrates the necessity of multi-disciplinary guidelines for constructing beach protection systems.

An important dimension in the coastal management is the large spatial extension and potential remote influence of many related problems. In many cases in the past, a sort of sectoral approach was used, with emphasize on a particular section and ignoring influence of and problems with the neighbouring areas. The degree of confidence in the long term reliability of local engineering solutions now appears unjustified and the problems caused by short term, localized sectoral decisions are increasingly recognized (Taussik 2000). The contemporary approaches in developed countries are based on much deeper understanding of the complexity and cyclicity of natural systems, in particular, of risks from (tidal) flooding, coastal instability and erosion to people and property in the coastal zone. Collaboration between the separate sections and regimes of coastal defense and planning is becoming the universal feature of planning and implementing shoreline management policy. Its important constituents are: sharing objectives; identifying common approaches and elements in shoreline management and planning; achieving cross representation on groups; developing and maintaining mechanisms of consultation, exchange, communication and liaison; sharing and collating information; sharing multi-disciplinary continuing professional development; and ensuring mutual consistency in all appropriate contexts (Taussik 2000).

Interesting experience of municipal initiatives for managing dunes in coastal residential areas is reported from Avalon, New Jersey, USA (Nordstrom *et al.* 2002). The characteristics of foredunes (similar to those planned for Pirita Beach, see below) created in a municipal management program are evaluated to identify how landforms used as protection structures can be natural in appearance and function yet compatible with human values. A disastrous storm in 1962 (with consequences in New Jersey similar to those of the January 2005 storm in Estonia) resulted in an aggressive program for building dunes using sand fences, vegetation plantings, purchase of undeveloped lots, and sediment backpassing to maintain beach widths and dune elevations.

Comparison of the status of four types of environment (a naturally evolving, undeveloped segment; a noneroding, developed segment; eroding and noneroding segments of an "improved beach" where dunes have been built by artificial nourishment; and a privately built, artificially nourished dune on the shoreline of an inlet) reveals that the nourished and shaped foredune in the improved beach is higher, wider, and closer to the berm crest than the natural dune. As a result, the improved beaches are practically stable, have a wider beach whereas sand fences (similar to those currently used in Pärnu Beach) have created a higher foredune with greater topographic diversity. It is interesting to notice that the privately built dune is low, narrow, and located where it could not be created naturally.

The beach protection also has an important economic aspect that sometimes is driven by secondary factors. For example, willingness to enhance beaches and dunes for protection has reduced insurance premiums and allowed the municipality to qualify for funds from the Federal Emergency Management Agency to replace lost sediment, thus placing an economic value on dunes (Nordstrom *et al.* 2002). This might be one of the lessons for dune management in Estonia.

Nordstrom *et al.* (2002) conclude that the success of the entire coastal management program results from a smart combination of the following aspects: (i) timing property-purchase and dune-building programs to periods immediately after storms (causing residents to temporarily accept high dunes that restrict access or views); (ii) instituting a vigorous education program (reminding residents of hazards during nonstorm periods); (iii) maintaining control over local sediment supplies (to keep pace with erosion and create new shoreline environments) (iv) investing private and municipal economic resources in landforms (qualifying them for external funds for replacement); and (v) maintaining, augmenting, or simply tolerating biodiversity and natural processes (retaining a natural heritage). Not all of the listed measures are directly applicable in Estonian conditions; however, high dunes at the seaside entrance to the Rannapark in Pärnu might prevent a large part of the low-lying city areas from flooding.

Currently, the principles of the integrated coastal zone management have been implemented practically all over the world. Successful examples are reported from extremely complex post-war conditions such as Kuweit (AlSarawi *et al.* 1996), to some extent resembling post-USSR conditions in several locations of the Estonian coast, incl. sections of Aegna, Naissaar, Pringi, Paljassaar and military harbours in the heart of Tallinn. The classical starting point of such activities is the classification of the coast into zones, identification of the major items controlling the coastal development (in particular, the wave and tidal conditions, equivalent to the water level conditions in Tallinn), and building a detailed coastal zone management map for future development. The overall goal is to provide decision-makers with guidelines for the future development.

Conflict situations and their management

Sustainable development of marine resources and the conservation of priority habitats and species must involve sustainable mechanisms for conflict resolution and decision-making in local, regional, and global scale (Side and Jowitt 2002). The reason behind is that a typical feature of coastal management is the frequent occurrence of various conflict situations. Apart from classical controversies between developers and environmentalists that are generic and solutions to which are classical, the most well-known conflict in the Tallinn Bay conditions is the discussion about the role of ship traffic. Before treating this issue, it is instructive to highlight several aspects that are not decisive in Tallinn Bay yet but the importance of which in the future is without doubt.

In the microscale, a similar conflict becomes evident already in the question of the use of water jets where the interests of water-based recreation are conflicting with the conservation interests. This mini-conflict turns out to be a useful framework of reconciling the disparate nature of the recreation and conservation interests through the production of a strategic framework that would act as a mechanism under which conflicts could be identified and resolved (Roe and Benson 2001). The principles adopted, the study approach and methods illustrate a useful way to provide locally relevant proposals to deal with such dilemmas in ecologically sensitive and aesthetically important coastal landscapes.

The conflict may be further enhanced by quite delicate environmental aspects that have been realized only recently and the awareness of which is very limited. On instructive feature that may potentially have some importance in Estonia in the future is the wide use of antifouling paints (that contain copper as one of the principle biocides) on small to medium recreational vessels. These paints were first recognized as a source of pollution already in the 1970s. A clear correlation between recreational boat numbers at anchorage sites and water column Cu concentrations was recently established by Warnken *et al.* (2004) for the Gold Coast Broadwater, Queensland, Australia. It is well known that drastic changes in species composition can occur at copper concentrations encountered in polluted coastal areas (de la Broise and Palenik 2007). Therefore, results from the study of Warnken *et al.* (2004) warn that even seemingly minor aspects may become an important factor in design solutions.

The even larger number of boats causes new threats; for example, the large number of movements of sailing boats is an important issue to be considered in management of boat traffic. Such boats have restricted maneuverability and right of way over motorized recreational craft in most situations. This is evidently an important issue in the Tallinn Bay basin which hosts extremely heavy fast ferry traffic and where first collisions of ferries and small boats (fortunately with no loss of lives) have been reported in summer 2007. The recreational boat traffic usually has a clear pattern (Widmer and Underwood 2004). Managers can use this information to develop strategies aiming at the improvement of boating safety and the prevention of potential environmental impacts in urban waterways.

The frequent occurrence of such conflicts shows that, as a part of any good strategy for the coastal zone management, general principles for solving conflicts should be worked out. The coastal zone is indeed attractive for human settlement because it tends to be resource rich, providing a good location to generate incomes and livelihoods. Equally, it is an extremely complex and powerful natural environment. This means that the coastal zone often becomes a focus of conflict with multiple users. Understanding the causes of, and determining solutions to, the ensuing problems requires inputs from a range of analyses across sectors and disciplines (Le Tissier et al 2004). The situation is furthermore accomplished, because different disciplinary and sectoral approaches frequently use different investigative methods, language, and means of presenting results (even on the level of the EIAs that actually should be performed in a unified manner, cf. Lapimaa and Soomere (2006). Only recently this complex of problems and possibilities of their translation into policy action have been addressed on the scientific level (Le Tissier et al 2004).

More generally, there is a fundamental shift in recent years in how the problems confronting a practicing coastal manager are being defined (Olsen 2000). Coastal zone management began as an expression of an environmental protection strategy and has evolved into a vehicle for progressing towards more sustainable forms of development. The contemporary practice of coastal management requires integrating within a curriculum a diverse mix of knowledge and skills that emphasize the two defining features of adaptive management: a governance process footed in the principles of participatory democracy and the application of the scientific principles that produce reliable knowledge.

Finally, it is interesting to notice that the concept of sustainable development has an interesting interpretation in terms of the contemporary theory of nonlinear structures (Seifritz 1996). Basically sustainable development implies that the progress be clearly defined, without dispersing into independent minor activities that only result in temporary improvement of the situation, long-living and highly organized process. These features, at least on the qualitative level, have much in common with the general definition of a soliton.

In the classical nomenclature, a soliton is a localised entity (e.g. a solitary wave or impulse) of permanent form that retains its identity and shape in interactions with other similar entities (Drazin and Johnson 1989). A development obviously only is sustainable when it works like an impulse to or activity within society that unifies and organises single efforts into a long-living wave of positive changes carried through time. Of course it must retain or perhaps even strengthen its basic features in cooperation (resp. interaction) with similar efforts. The lesson to learn from this comparison is that even very “soft” societal studies, in fact, have much wider meaning than simply improving of the quality of life of single community, or a selected section of sea coast.

3. Shores of the City of Tallinn: examples of management

Variety of shores of Tallinn Bay

The shores of Tallinn Bay are subject to extremely intense human impact in a variety of forms: from different hydrotechnical constructions up to the intence ship traffic. Coasts of the City of Tallinn show features of typical North Estonian bays. A short literature review of the relevant publications is presented in the previous chapters. So far I repeat here the major points just to help the reader to follow.

The northern coast of the Gulf of Finland that predominantly is skären type is weakly affected by hydrodynamic factors (Granö and Roto 1989). The eastern and southern coasts of the gulf were formed and develop further under the effect of wave action predominantly (Orviku and Granö 1992). The coasts obtained their contemporary shape only a few millennia ago and have undergone relatively modest changes since their formation, and can be classified as straightening coasts (Kaplin 1973). Owing to the modest amount of sediments in motion, prominent accumulation features such as baymouth sandbars, barrier islands, and long spits are lacking. Instead, many peninsulas, islands and bays cutting deep into the land can be found in this area. Coasts here are mainly the straightening accumulation embayed coasts (type 20 according to Kaplin 1973). Littoral (alongshore) drift generally carries sediments to the bayheads where beaches are stable. However, even the sections that have reached an almost (dynamic) equilibrium state are from time to time subject to erosion.

Tallinn Bay lies on the border of two subtypes of the southern coast of the Gulf of Finland, divided by Viimsi Peninsula. The features of the coast eastwards from this peninsula are mostly related to the glacial and glaciofluvial formations and deposits of the Foreklint Lowland, while the bays westwards (incl. Tallinn Bay) are mostly associated with ancient erosional valleys in the bedrock (Orviku and Granö 1992). This separation is the reason why the properties of and processes in Tallinn Bay and Muuga Bay have to be considered separately (Paper I).

A variety of beaches exist along the shores of Tallinn Bay. Bluff shore can be found at the island of Naissaar, till shore along large parts of Viimsi Peninsula, sandy coast at Pirita and at certain sections of the Island of Aegna, and long sections of artificial shore around Tallinn. Numerous harbours divide the sediment transport and recycling systems along its coasts into small virtually independent cells (Soomere *et al.* 2007), a feature that further enhances vulnerability of the coasts and fosters the need of sustainable management activities.

Such cells are the primary objects of environmentally sound coastal zone management strategies since they provide the most relevant scale of the coastal zone management (Sherman and Bauer 1993). The processes at this scale are manageable using traditional geomorphic techniques. Even in open ocean conditions, such cells are frequently rather small with dimensions in the order of 1–3 km, whereas even the neighbouring and seemingly quite similar cells may need completely different approaches for adequate and sustainable coastal zone management (Krause and Soares 2004).

A large part of coasts of Tallinn Bay is covered by a coarse material (pebbles, cobbles, boulders) and has a limited amount of gravel and sand. Their development, except for a very few sections (Orviku and Granö 1992), occurs under sediment deficit. Beach erosion is not necessarily active since the stone pavement protects the shore. Finer fractions are only released in high water conditions when waves directly act on unprotected sand, till, or limestone. According to Lutt and Tammik (1992), erosion dominates in the entire nearshore of Viimsi Peninsula northwards from Pirita Beach and up to the depth of about 10 m. Accumulation dominates in the deeper part of Tallinn Bay and in the vicinity of Pirita Beach. An overview of bottom sediments and their sources for the entire Gulf of Finland can be found in (Lutt 1992, Lutt and Kask 1992); certain results of coastal monitoring reflecting the changes of selected sections of Tallinn Bay is presented in the reports of national coastal monitoring (e.g. Kask and Kask 2002, Suuroja *et al.* 2004).

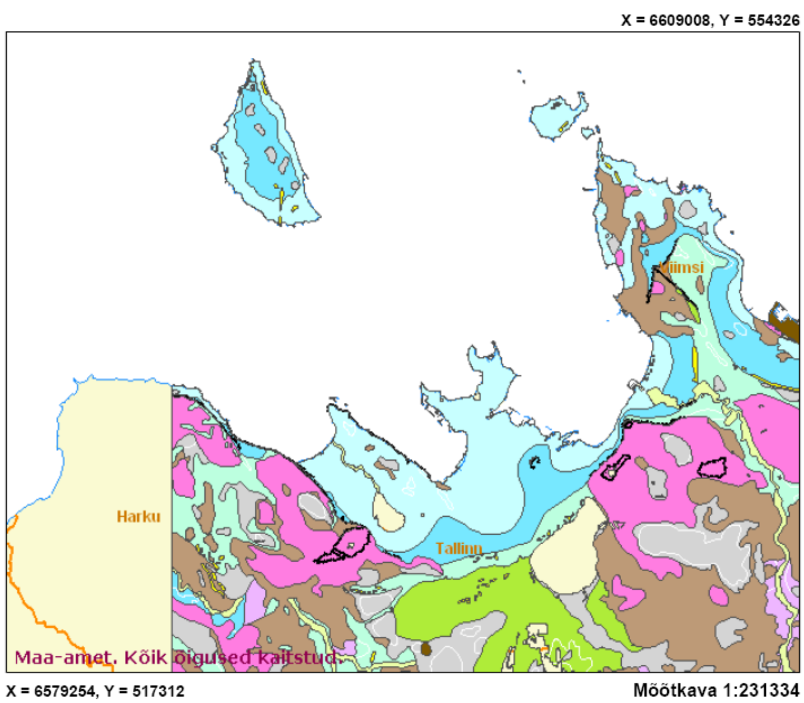
There exist a large number of marine and coastal systems similar to Tallinn Bay in the world. The general experience of their management is, as stressed above, that management is only successful if sufficient amount of background information is available. An analogue to Tallinn Bay is Thermaikos Gulf coastal system in Greece, NW Aegean Sea (Poulos *et al.* 2000). It is a micro-tidal system, the coastal zone of which includes the second most important socio-economic area of Greece and in the southern Balkans, the Thessaloniki region. This area, like Tallinn, has a large concentration of population (> 1 million people), industry, agriculture, aquaculture, trade and services. The geomorphology of the coastal zone there is controlled, as in Tallinn Bay, by sediment inputs, nearshore water circulation, and the level of wave activity. The major difference from the Tallinn Bay conditions is that large quantities of sediments are delivered annually into Thermaikos Gulf by rivers (Axios, Aliakmon, Pinios, and Gallikos) and other seasonal streams, causing the general progradation of the coastline – a process which to some extent is similar to the one caused by postglacial uplift in Tallinn Bay.

Various human activities within the coastal system place considerable pressure on the natural evolution of the coastal zone in both areas. While in Thermaikos Gulf the construction of dams along the routes of the main rivers has highly reduced the sediment fluxes and caused retreat of the deltaic coastlines and seawater intrusion into the groundwater aquifers, analogous effects have occurred in the Tallinn area owing to construction of Miiduranna and Olympic harbours (Soomere *et al.* 2005, 2007) and excessive extracting of water from lower horizons. Similarly, pollution and/or eutrophication of the nearshore marine environment have resulted from the inputs of industrial wastes, urban untreated sewage, and agricultural activities on the coastal plains. This effect is demonstrated by high levels of pollutants, nutrients, and by the increased concentrations of non-residual trace-metals within the surficial sediments. Thus, systematic and thorough monitoring is needed in order to protect the coastal ecosystem.

Geological setting of the Tallinn area

The geological structure of the City of Tallinn area is typical of the whole southern coast of the Gulf of Finland. The lower part of the city and its coast is represented by the so-called Foreklint Lowland with its peculiar indented shoreline and numerous islands. There are several shallows and rocky reefs, sometimes emerging above the water level in the coastal sea and endangering navigation.

The Proterozoic crystalline basement in the Tallinn area is covered with the Upper Proterozoic and Lower Palaeozoic rocks, up to the Middle Ordovician (some 460 million years ago). The upper boundary of the basement is at a depth of 130-150 m b.s.l. The sedimentary cover has a gentle southward inclination, on average 3-4 m per km. On the basis of the lithology of sedimentary rocks, the Lower Palaeozoic in Tallinn can be divided into two parts: the Vendian, Cambrian, and the lowermost Ordovician (Tremadockian), composed mostly of terrigenous rocks, and the Ordovician from the Arenig to the Lower Caradoc, formed prevailingly of carbonate and fine-terrigenous rocks. Cambrian sand - and siltstones crop out at Rocca-al-Mare and in the valley of the Pirita River.



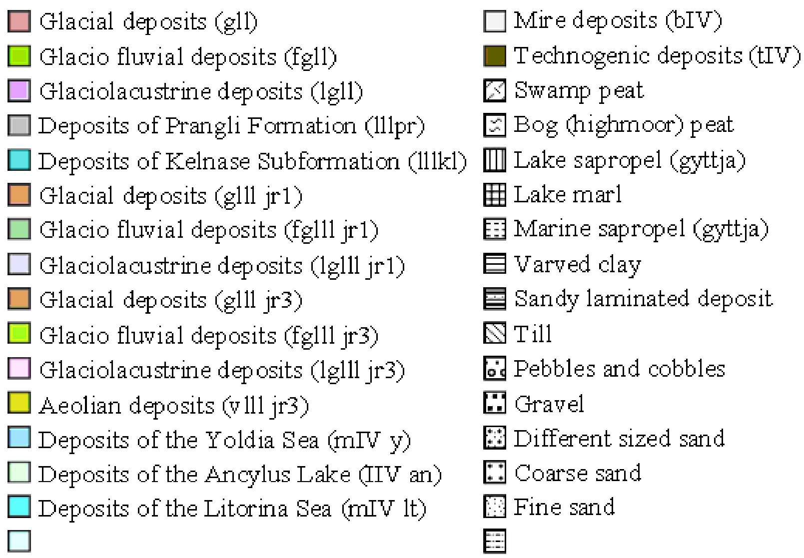


Figure 3.1 Geological setting of the City of Tallinn area and its coasts. Reproduced from http://xgis.maaamet.ee/

The bedrock topography within the town and its surroundings is characterized by several relatively small positive and negative features. The most notable positive relief form is the North Estonian Klint, which consists of rocks of variable hardness. The section at Suhkrumägi displays pure hard limestones and dolostones in the topmost 6.5 m, which are underlain by soft Cambrian and Ordovician terrigenous rocks. The klint is highest at Maarjamägi, where it rises to 47 m a.s.l. In some places at the foot of the klint, there are terraces of different stages of the post-glacial Baltic Sea.

The klint divides Tallinn and its surroundings into two geomorphologically markedly distinct areas: the Limestone Plateau and the Foreklint Lowland. The latter is significant from the marine aspect and all the harbours of Tallinn are located here. From the engineering-geological perspective, regular alteration of highlands of different heights (Kakumäe, Kopli, Viimsi, ete.) and plains (Harku, Lilleküla, Kadrioru, Pirita, etc), and the existence of valleys cut deep into the foreklint plains are of importance. One valley, with an approximate depth of 100 m, proceeds from the western coast of Lake Ülemiste to Kopli Bay; another, a couple of dozen metres less deep, from an area between Toompea and Lasnamäe to Tallinn Bay; a third one, 145 m deep, from below Lake Harku to Kakumäe Bay. These are ancient river valleys, formed already in pre-Quaternary time and subsequently reshaped by glaciers and their meltwaters.

Pleistocene glacial deposits in the Foreklint Lowland are covered by the sediments of the local ice-lakes and the Baltic Sea. The thickness of soft varved clays amounts to 10 m. The most prominent coastal forms, about 35 m high, are referred to the initial stage of the Ancylus Lake, when the shoreline remained stable for a long time, favouring the formation of extensive scarps and accumulation of sediments in Tallinn. The Litorina Sea deposits and coastal forms are observed at a height of 12-23 m a.s.l. By the beginning of the Limnea Sea 4000 years ago, the last stage in the Baltic Sea development, the water had dropped to the present-day level.

The uplift of the Earth's crust takes place at present as well, however it is not as intensive as before, only 1-2 mm/yr. In the 13th— 14th centuries the sea reached almost as far as the present Viru hotel and the area of Narva Street was presumably under water. The port of Tallinn was situated evidently near the Big Coast Gate.

The sea controls the development of the Tallinn topography also nowadays. At the tops of peninsulas it abrades the coast, and evidence has been derived of contemporary erosional scarps in Kakumäe, Kopli, and Merivälja. Sandy deposits accumulate at the tops of the bays as, for example, in Kopli Bay and Pirita.

Natural processes and anthropogenic pressure

A number of different natural factors such as waves, wind-induced transport, coastal currents and wave-induced alongshore flows, variations of water level, sea ice, etc. affect the processes along sea coast. Changes of theses factors, either natural or anthropogenic, may substantially affect the further evolution of small circulation cells. Hummocky ice may cause extensive damage to the dune forest under unfavorable conditions. Although it has served as acute danger to the Pirita coastal restaurant several times (Tavast and Donner 1992), usually its effect is mostly indirect and consists in reducing the wave loads during the ice season (Soomere *et al.* 2005). The tidal range is 1–2 cm and the tidal currents are hardly distinguishable from the other motions in this area; for this reason the effect of tides is negligible in entire the Tallinn area.

Aeolian transport and the direct effect of coastal currents to the development of beaches of Tallinn Bay and its neighbourhood are usually negligible or immaterial in the local circumstances (Alenius *et al.* 1998, Orlenko *et al.* 1984, Soomere *et al.* 2005. 2007). The coastal currents, however, play a decisive role in many other hazards out of the scope of the current study, e.g. by transporting oil pollution etc. Local currents may also provide extensive transport of suspended matter (finer fractions that are suspended into water column by other processes) since they are at times highly persistent in this area (Erm *et al.* 2006). The typical settling time of fractions brought into water column by waves outside of the surf zone is a few minutes (Erm and Soomere 2004, 2006).

One of the most important sources of natural hazards, as explained above, is the coastal flooding. The City of Tallinn area is relatively vulnerable with respect to local sea level variation. The water level in the Gulf of Finland and in the Tallinn area is mainly controlled by hydrometeorological factors. The range of its monthly mean variations is 20–30 cm (Raudsepp *et al.* 1999). Typical deviations of the water level from the long-term average are larger and frequently reach a few tens of centimeters. Water levels exceeding the long-term mean more than 1 m are rare although their probability has increased during the latter decades in the entire Gulf of Finland (Johansson *et al.* 2001). The total range of the historical water level variation is 247 cm. The highest measured level in Tallinn Bay is 152 cm on 09.01.2005 (Suursaar *et al.* 2006) and the lowest is -95 cm in December 1959 (Suursaar and Sooäär 2007).

Sediment deficit at Pirita Beach and technical solutions

An example of an area under extremely heavy anthropogenic pressure is Pirita Beach, one of the most important recreational areas of the City of Tallinn (Soomere *et al.* 2007). It is located at the south-eastern bayhead of Tallinn Bay next to the Olympic sailing centre. The stability of Pirita Beach has been discussed during several decades starting from the middle of the 20th century when the coastal processes seemingly became more active. Frequently the overall increase of the intensity of coastal processes is found responsible for destructions of naturally developing beaches experiencing weak postglacial uplift (Bird 1981, Orviku and Granö 1992, Orviku *et al.* 2003). Alterations of natural conditions such as large-scale changes in storminess in the 1960s (Alexandersson *et al.* 1998), certain changes of directional distribution of winds in the Baltic Sea basin (e.g. the increase in intensity of NNW winds from the 1970s, Soomere and Keevallik 2001) or shifts of the mean direction of air flow at certain altitudes (Keevallik and Rajasalu 2001) do affect the functioning of the beaches. Observations of bathymetry, sediment properties and sources, sediment transport processes and their potential changes owing to coastal engineering activities are reported for Pirita Beach in Soomere *et al.* (2007).

However, much more probable reason for changes at Pirita is anthropogenic influence that is mostly caused by extensive coastal engineering activity in its vicinity (Soomere *et al.* 2007). Pirita Beach is directly or indirectly affected by a number of hydrotechnical constructions starting from the 1920s. Since practically all the beaches along the northern coast of Estonia suffer from sediment deficit (Orviku and Granö 1992), it is not surprising that a certain net loss of sand at times occurs in the Pirita area (Soomere *et al.* 2005, 2006). There is very limited data about the earlier status of Pirita Beach. It is usually assumed that the material eroded from the coast of Viimsi Peninsula and the river-induced sand flow together with the postglacial rebound balanced the sand loss in this area in the past, at least, until the middle of the 20th century (Loopmann and Tuulmets 1980).

Some aspects of its sustainable development under anthropogenic pressure are discussed in Paper IV. The shortage of data about sediment transport of the vicinity of vulnerable areas is, in fact, one of the largest problems in making sustainable decisions. It is a widely spread practice even in developing countries that an extensive survey is performed prior to any (potentially costly) decision. A recent example of such strategy is described in Ari *et al.* (2007) for the fishery harbour of Karaburun coastal village is located at the south west coast of the Black Sea. The problems there were a sort of mirror reflections to contemporary ones in Pirita but exactly equivalent to those at Pirita in the past: the sediment deposition near and inside the harbour entrance prevents the boat traffic and cause a vital problem for the harbour operations. In order to identify the optimal solution, long-term observations of shoreline changes, long-term statistical analysis of wind and wave characteristics in the region, and sediment properties have been performed in combination with the numerical study of wind waves and one-line model of shoreline changes (Soomere *et al.* 2005, 2007). Similar complex studies have been recently performed in Estonia for Narva River mouth (Laanearu *et al.* 2007).

Major changes in the sand budget at Pirita evidently occurred when (i) Miiduranna harbour and its fairway largely blocked the alongshore transport, and when (ii) the Pirita Olympic harbour drastically decreased the river-induced sand transport (Soomere *et al.* 2007). The magnitude of the natural supplies of sand evidently is greatly reduced already in the end of the 1920s when first bulwarks at the Pirita River mouth and a small jetty at Merivälja were constructed, and particularly after constructing a port at Miiduranna and Pirita Olympic harbour during the 1970s (Soomere *et al.* 2005, 2007). A substantial shift of the isobaths closer to the waterline was reported as early as in the 1970s (Paap 1976). Several studies were performed before the 1980 Olympic Games for this area (Nugis 1971, Orviku and Veisson 1979, Knaps 1976, among others); unfortunately their results are mostly not published in international literature. A description of the properties of bottom sediments of entire Tallinn Bay is given in Lutt and Tammik (1992). Studies of contemporary bottom sediments at Pirita are presented in Lutt (1992).

Since the Olympic games, a gradual decrease of the width of the dry sandy beach, recession of the till bluff at the northern end of the beach, and extensive storm damages to the foredunes have occurred despite of quite fast postglacial rebound in this area (about 2.5 mm/year, Zhelnin 1966, Miidel and Jantunen 1992) and of attempts to refill the beach with material dredged from Pirita harbour or transported from mainland quarries (Soomere *et al.* 2007). The largest damages occurred in November 2001 and in January 2005 when high and long waves attacking the beach from northwest or west were accompanied with exceptionally high water level. Additionally to the deficit of river-carried fine sediments (about 400 m^3 annually), another 400 m^3 has been eroded annually from the dry beach since 1997 (Soomere *et al.* 2007). Attempts to protect the coastal forest and to reconstruct the beach are reported in popular overviews (Orviku 2003). Several beach protection measures such as a revetment in the northern part of the beach have been ineffective.

The deficit of relatively fine river-transported material has been to some extent compensated by pumping of the material dredged from the river mouth to the southern section of the beach. The blocking of alongshore drift of coarser sediments by Miiduranna port and Merivälja jetty probably is the main reason of the sediment deficit in this area. It can be speculated that the specific deficit of coarser material leads to the gradual decrease of the grain size at the beach, a process which is undesirable from the recreational viewpoint (Soomere *et al.* 2007).

About 50% of Pirita Beach suffers from substantial damages at times (Soomere *et al.* 2005, 2007). Another hypothetical reason is the influence of long waves from fast ferries on the deeper part of the nearshore. Given the circumstances, one cannot expect that Pirita Beach will further develop in a stable manner although the natural variability of storms may provide relatively long periods during which the evolution is fairly slow.

A more delicate challenge is connected with the gradual decrease of the grain size and its potential consequences. The largest recreational values have sand beaches consisting of relatively coarse sand. Since waves effectively sort the sediments and the finer fractions are gradually transported offshore, the coarsest material is usually concentrated in the vicinity of the breaker line and at the waterline (Dean and Dalrymple 2002). This is only partially true for Pirita where the local maximum of the mean grain size is found in the vicinity of the waterline whereas it generally decreases offshore (Soomere *et al.* 2007). The explanation is that owing to highly intermittent nature of wave activity at Pirita (where mean wave conditions are very mild but severe wave storms may occur, see above), the breaker line is poorly defined and the relevant stripe of relatively coarse sand not necessarily becomes evident (Soomere *et al.* 2007).

An important implication from this feature is that the mean grain size along the waterline more than twice exceeds the grain size in the rest of the study area. This feature is not entirely typical but also not very surprising (Dean and Dalrymple 2002). It plays an important role in planning of beach nourishment activities because material with the grain size much smaller than the one at the waterline usually is lost relatively fast. In other words, beach refill with sand matching the properties of “typical” sand found in the entire Pirita beach, incl. underwater slope, will lead to the decrease of the quality of this beach.

A feasible way of restoring the sand balance at Pirita and to make the beach stable consists in increasing the sand volume at the beach (Soomere *et al.* 2005; 2007). The fastest result would bring the classical beach nourishment methods. They consist in placing of high-quality (that is, relatively coarse) sand either to the dry land area or into the immediate vicinity of the coastline. There are several delicate aspects and restrictions connected with the activities towards restoring the beaches and sustainable management of the coasts. Let us consider one of such aspects in more detail since its ignoring may nullify large refill activities that are currently under planning. An artificial dune of a moderate height (about 1.5 m) along the existing coastline will effectively protect the coastal forest and will not distort the sea view (Soomere *et al.* 2005).

Doing so is fully compatible with the European experience with and recommendations for shore nourishment (Hamm et al. 2002). Dumping of sand to the sea (Verhagen 1992) is ineffective owing to the relatively small closure depth. Filling the beach with sand from the Pirita River mouth or from the Olympic harbour basin should be undertaken with great care, because the sand there is relatively fine and there is an overall deficit of coarse sand in Estonia. Another feasible way, eventually bringing to good results in the long-term run, consists in sand bypassing to the southern side of Miiduranna port. Doing so would eventually compensate the sediment deficit along the coast at Merivälja (and thus reduce the coastal erosion in this area) and would supply medium and coarse sand to Pirita Beach.

Currently, the City of Tallinn has initiated a large-scale beach renourishment based on recommendations of Soomere *et al.* (2005). This process includes the stage of the Environmental Impact Assessment. Although the results of this EIA will obviously be encouraging for the nourishment, this process is necessary in the existing legislation, because it offers the legal way to the strongly recommended long-term monitoring of the resulting changes at a regional scale, including the use of innovative monitoring technologies. Doing so matches the need for a better understanding and quantification of autonomous shoreline variability (Hamm *et al.* 2002).

Sustainable planning of coastal engineering activities

During the latter decade the intensity of various development activities at the shores of Estonia has explosively increased. A major part of the construction works has been concentrated in the vicinity of Tallinn. The above has shown that this area is specifically under anthropogenic pressure, which beside including intense construction works at the coasts, release of large amount of waste water, which is properly pre-treated but still carries components favourable to eutrophication with it, and unique level of long-wave hydrodynamic activity due to wake waves from fast ferries.

A large part of activities is connected with development of ports in the area in question. Their eventual extension towards the sea requires a vast volume of landfill material. Approximately 3 mio m^3 of landfill material was required for the construction of a coal terminal of Muuga Harbour located in a bay neighbouring to Tallinn Bay. In the future, construction of major breakwaters for Muuga Harbour is planned, which requires even larger volumes of filling material. Large amount of sand is also necessary for nourishment of the major recreation area in the Tallinn region, the sand beach at Pirita. The relevant aspects are discussed in Paper IV.

From both economical and environmental points of view, mainland sources of landfill, which are quite limited in the area in question, have been left aside, and the material has been, and apparently will be, taken from coastal sea areas in the vicinity of Tallinn. Since the mining areas are located relatively close to sensitive beaches, a thorough study of the local wave climate and its potential changes was undertaken. The main concern was that bathymetric changes may change the downwind wave regime and cause enhanced coastal erosion. The use of a fast method for assessment of wave properties specifically developed for semi-enclosed sea areas allowed making high-resolution wave climate simulations covering a few decades for both the original and after-mining bathymetry within reasonable computing time. For specific patterns of sand removing the wave climate at the coasts located leeward from the mining area will be even milder than the existing one. This occurs due to specific combination of the geometry of the Gulf of Finland and the directional distribution of dominating winds. In certain perspective mining areas the potential influence of long waves from fast ferries has been shown to play a role as well.

Despite of extensive studies of wave regime and its potential alteration, and encouraging results of these, problems arose in the neighbourhood of one of the sand mining areas. A sandy headland underwent substantial erosion after the mining was completed. However, the probable reason of the enhanced erosion was a combination of extremely heavy wave conditions in a storm after the mining and apparent ignoring the requirements formulated in the environment impact assessment. According to reports in daily newspapers, at places several meters of a thicker layer was probably mined and a part of mining was evidently performed in a restricted area.

Another major study was performed to understand the consequences of the release of suspended matter into marine environment (Kask *et al.* 2005). Since the models of currents and suspended sediment transport are not perfect yet, forecasting the sedimentation areas of suspended matter (both intermediate and final deposition) is a problematic issue to-day. The basic hope is that most of the material is fine–grained and therefore it will finally be deposited in a deeper sea area where the benthic communities are either absent or poorly represented. The intermediate sedimentation may cause certain substantial problems but it apparently has no crucial effect on a long-term balance of benthos in shallow sea. To mitigate the short-term adverse impact of increased (re)sedimentation of suspended matter, underwater mining the mineral resources has been forbidden during the spawning period of fish.

The presence of long ship wakes creates a specific concern in beach nourishment projects in the vicinity of Tallinn Bay. The dimensions of such a project at Pirita beach as well as sections of coastline with increased seaward and landward sediment transport were identified based on *in situ* measured profiles, numerical estimates of wind wave conditions, and theory of equilibrium beach profiles. The largest impact of wake wash from intense high-speed traffic on the bottom of certain non-tidal areas occurs on considerably larger depths than the impact of storm waves. Although the presence of ship wakes formally does not change the closure depth in inner parts of Tallinn Bay, it still may add a substantial component to near-bottom sediment transport, the amount of which has to be quantified in order to correctly desing the whole project. Another feature of potential importance of this nourishment project is the asymmetry of wakes from inbound and outbound traffic, which may modify the estimates of longshore sediment transport obtained from simulations of wind waves.

4. Wave fields in the north-eastern part of the Baltic Sea

Long-term wave observations

The exceptional storm named Erwin/Gudrun of January 2005 indicate an inadequate understanding of extreme wave properties (Soomere *et al.* 2006a) and of the height and spatial extent of extreme water level conditions (Suursaar *et al.* 2006) under existing climatological conditions. This event motivated studies of existing long-term wave measurements in the area in question. The studies of the longest available instrumental wave measurements in this area are described in Paper III and the presentation in this chapter mostly follows this paper.

Wave observations in the Baltic Sea area extend back more than 200 years. For example, records of hydrometeorological parameters at Tallinn Harbour, started in 1805, optionally contained visually estimated wave parameters (Soomere 2005a). These data, however, represent only wave properties in the near-coastal regions and often inadequately reflect open-sea wave fields.

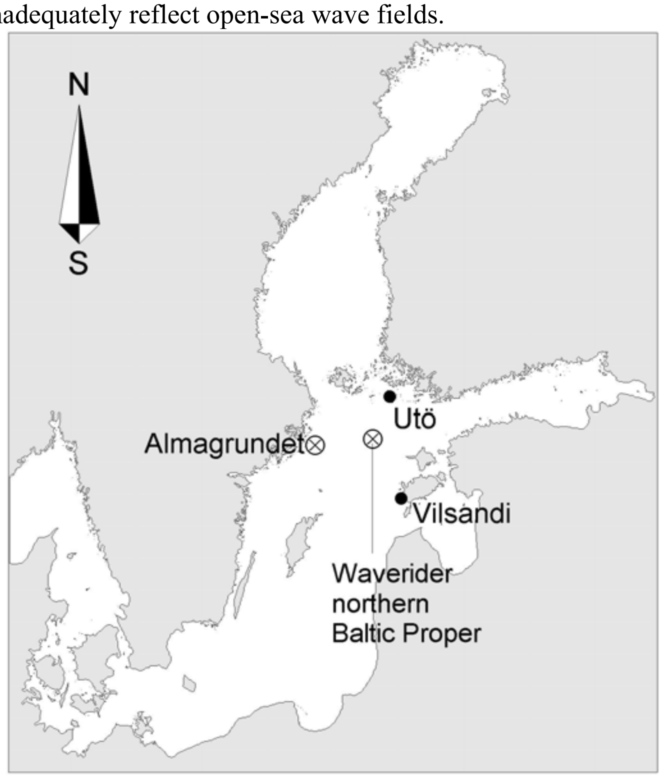


Figure 4.1 The location of the wave measurement sites at Almagrundet and in the NBP and the wind measurement sites at Vilsandi and at Utö (Paper III)

Contemporary wave measurements in the northern Baltic Sea were launched about three decades ago when several semi-autonomous measurement devices were deployed in different parts of the sea. In particular, bottom-fixed devices were installed and operated by the Swedish Meteorological and Hydrological Institute (SMHI) near the caisson lighthouse of Almagrundet (located in the eastern sector of the northern Baltic Proper, 59°09' N, 19°08' E, Fig. 4.1). The wave data from this site form the main object of study in this paper. An analogous device was installed at Ölands södra grund (south of Öland) in 1978, as was an accompanying waverider buoy near Hoburg, south of Gotland. This was done within the framework of studies of the technical and economical possibilities of wave power plants in Swedish waters (Mårtensson and Bergdahl 1987).

An important step towards understanding open-sea wave conditions in the northern Baltic Proper (NBP) was made when the Finnish Marine Research Institute deployed a state-of-the-art directional waverider there at a depth of about 100 m (Fig. 4.1, 59°15' N, 21°00' E). The relevant data set now covers 10 years, starting from September 1996 but excluding ice seasons.

High-quality wave data sets have been obtained in the areas around Finland since the 1970s. Some of these sets contain directional wave information (Kahma & Pettersson 1993, Pettersson 1994, Pettersson 2001, Kahma *et al.* 2003) that was not recorded in the Almagrundet data. This data has considerably modified our awareness of extreme wave conditions in the semi-enclosed sub-basins of the Baltic Sea. For example, until in November 2001 a value of $H_S = 5.2$ m was recorded, experts had generally agreed that the significant wave height should not normally exceed 4 m in the central part of the Gulf of Finland (Pettersson and Boman 2002).

The significant wave height H_S is approximately equal to the average height $H_{1/3}$ of the highest 1/3 of all the waves during a certain time interval. In contemporary wave measurement devices and in numerical wave models it is estimated directly from the (directionally integrated or non-directional) wave energy spectrum as

$$H_S = 4\sqrt{m_0} \, ,$$

where m_0 is the zero-order moment of the wave spectrum (correspondingly, the total variance of the water surface displacement time series).

Unfortunately, hardly any instrumentally measured wave data are available from the coastal areas of Estonia, Latvia and Lithuania, except for visual observations from the coast and for sporadic measurements made with pressure-based sensors (Soomere 2005a). This makes it virtually impossible to identify basic features of the spatial distribution of wave properties in the Baltic Proper from the measured data. This gap has been partially filled by the use of numerical models that adequately represent the sea state of the northern Baltic Sea even in extreme conditions (Jönsson *et al.* 2002, 2005, Soomere *et al.* 2006a). The overall picture of wave activity follows the well-known anisotropy of the wind and wave regime in the Baltic Proper (Mietus 1998, Soomere 2003a). Statistically, the regions of the largest wind wave activity are found along the eastern coasts of the Baltic Proper.

To complete this overview of existing knowledge, mention should be made of several numerical wave studies performed for the southern part of the Baltic Sea (e.g. Gayer *et al.* 1995, Paplińska 1999, Blomgren *et al.* 2001) or for limited areas of the northern Baltic Proper (Soomere 2003a). A number of wave studies have focused on specific problems of Baltic Sea wave fields, such as the frequent occurrence of multi-peaked wave spectra (Kahma *et al.* 1983), possible changes in the wave climate caused by changes in storminess (WASA Group 1995), methods of estimating the wave climate (Mietus and von Storch 1997), the persistence of wave statistics (Boukhanovsky *et al.* 1999), wave fields in slanted fetch conditions (Kahma and Pettersson 1994, Pettersson 2004), and the wave climate in small semi-enclosed basins (Soomere 2005a). Valuable wave data can also be found in books published in the former USSR (Davidan *et al.* 1978, 1985).

The pattern of dominant winds and the geometry of the Baltic Proper suggest that the highest and longest waves appear to occur near the entrance to the Gulf of Finland and off the coasts of Saaremaa, Hiiumaa and Latvia (Jönsson *et al.* 2002, 2005, Kahma *et al.* 2003, and Soomere *et al.* 2006a, among others). This feature has caused some discussion about whether the Almagrundet wave data correctly represent open-sea wave conditions (Kahma *et al.* 2003). Almagrundet is fully open to the east and south-south-east, but the fetch length for the dominant winds from the south-east and possibly north (Mietus, 1998, Soomere and Keevallik 2001) is quite limited. Measurements at this site may therefore give a somewhat biased picture of wave properties in the northern Baltic Proper.

Nonetheless, the Almagrundet wave data constitute one of the most valuable data sets for the Baltic Sea. The wave measurement devices at the site have been active during a quarter of a century (1978-2003). Therefore, the data set is one of the longest instrumentally registered time series of wave properties in the Baltic Sea area. It contains the highest ever recorded significant wave height ($H_{1/3} = 7.8$ m, estimated from the 10th highest wave, assuming Rayleigh distributed wave heights, $H_S = 7.3$ m estimated from the wave spectrum) and the highest single wave (12.75 m, both filed in January 1984) until a comparable significant wave height and an even higher single wave were recorded in the NBP in December 2004. The actual possibility of extremely severe wave conditions at this site confirms that the data are particularly valuable for understanding the behaviour of wave fields in the Baltic Sea. Note that some sources (e.g. Kahma *et al.* 2003) mention the value $H_S = 7.7$ m as the highest in the Almagrundet data. This probably reflects a certain ambiguity in significant wave height estimates from different approximations of the observed parameters of the complex wave fields. Although there is some evidence that the significant wave height reached 10 m in some other areas of the Baltic Sea in January 2005 (Soomere *et al.* 2006a) and that $H_S = 7.7$ m was registered in the NBP in December 2004, the formal record of the highest significant wave height from Almagrundet has not been exceeded.

A small part of the Almagrundet data has been discussed in conference papers and local reports (e.g. Svensson 1984, Mårtensson and Bergdahl 1987 and references therein). Some excerpts from this data set have been used elsewhere (e.g. Kahma *et al.* 2003). However, a comprehensive analysis of this longest contemporary wave measurement activity in the northern Baltic Sea area has yet to be undertaken. The current paper is directed towards filling this gap. Its main purpose is to analyse the typical and extreme wave conditions at this site and to identify overall trends in the wave activity. It begins by describing the measurement site, apparatus and measurement routine. The wave height distribution and the joint distribution of wave heights and periods (scatter diagram) are then presented, and the reliability of the wave data is discussed at length. Extreme wave conditions, seasonal and interannual variations in the wave field are also discussed. The results presented here were obtained exclusively from the measured data, that is, Type A statistics in terms of the classification of Kahma *et al.* (2003); no corrections have been made to compensate for missing values, for the uneven distribution of data, or for ice cover.

Main properties of the wave climate

According to the SimRad data the mean wave height $H_{1/3}$ at Almagrundet between 1978 and 1995 is 0.876 m. The median wave height is 0.7 m and the most frequent wave conditions correspond to H_S = 0.25–0.375 m. The frequency of occurrence of different wave heights is presented in Fig. 4.2.

The WHM wave data show somewhat more intense wave activity. The mean wave height over the whole measurement cycle of this device (1993-2003) is 1.04 m. The wave height median is 0.73 m, that is, practically the same as for the SimRad data.

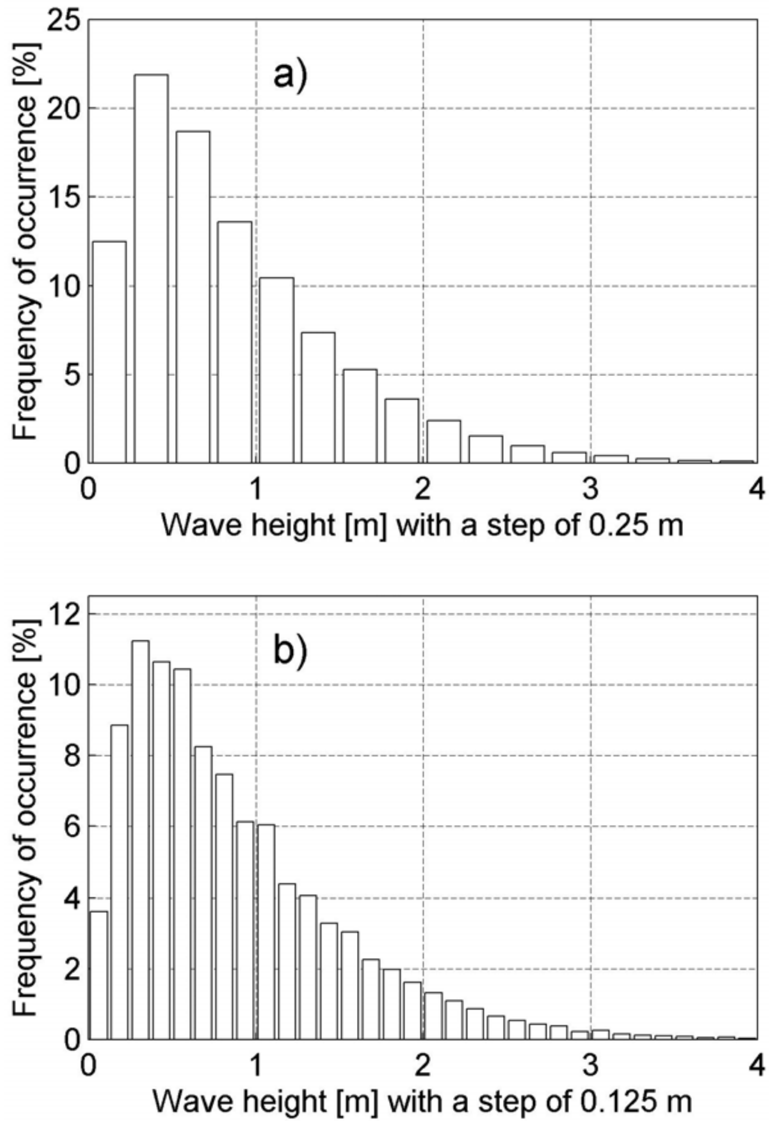


Figure 4.2 Frequency of occurrence of wave heights at Almagrundet 1978–1995 according to the SimRad wave data 1978-1996 for the step of the wave height of (a) 0.25 m and (b) 0.125 m (Paper III)

The wave height statistics from the WHM data (Fig. 4.3) are very close to those obtained from the SimRad data for the most common wave heights of 0.25–1 m. The largest differences are for practically calm situations ($H_{1/3} < 0.25$ m), the frequency of which is clearly smaller in the WHM data than in the SimRad data.

The larger proportion of sea states with $H_{1/3} > 1$ m in the WHM data suggests that this equipment either tends to overestimate wave heights in relatively rough seas or that the data in question contain some portion of unrealistic values.

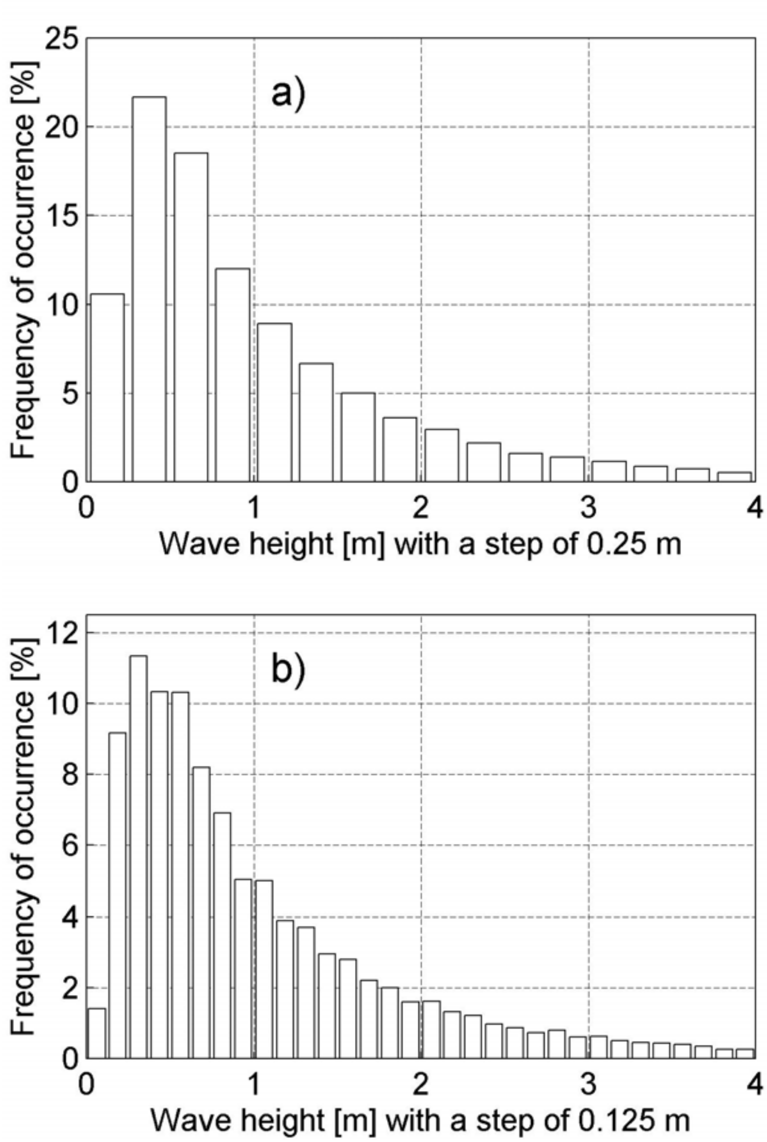


Figure 4.3 Frequency of occurrence of wave heights at Almagrundet 1993–2003 according to the WHM wave data 1993-2003 for the step of the wave height of (a) 0.25 m and (b) 0.125 m (Paper III)

Seas with $H_{1/3} \geq 4$ m have occurred about 400 times during the period in question, that is, such wave conditions occur with a probability of about 0.42 % or, on average, during about 20 hours each year. The storms causing such high waves, however, usually occur several times a year, each lasting a few hours.

The shape of the plot of the number of records of different wave heights $H_{1/3}$ and mean periods (Fig. 4.4) is typical of Baltic Sea conditions (see Kahma *et al.* 2003). The typical mean wave periods are 4–5 s for wave heights below 1 m, about 6 s for wave heights around 2 m, and exceed 7 s only when wave heights are 3 m or higher.

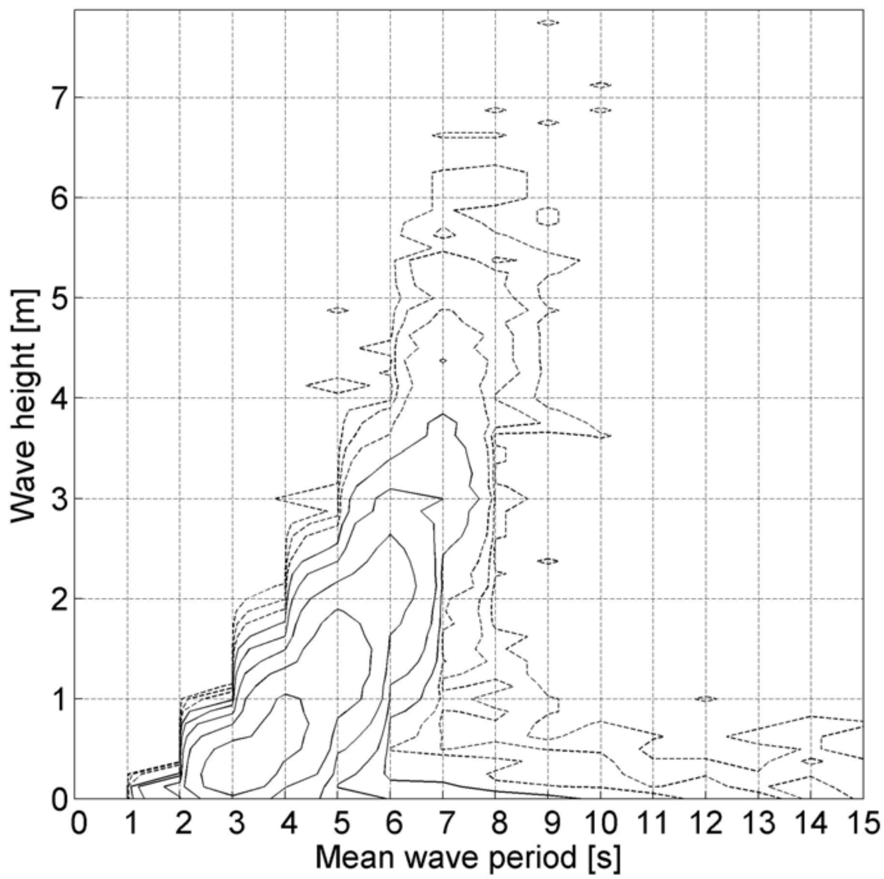


Figure 4.4 Scatter diagram of wave heights $H_{1/3}$ and mean periods in the SimRad data. The wave height step is 0.125 m. The range of periods is shown on the horizontal axis, for example, 2 s means $T_z < 2.5$ s, 3 s means $2.5 \leq T_z < 3.5$ s etc. Isolines for 1, 3, 10, 33, 100, 330, 1000 and 3300 cases are plotted whereas isolines for 1–10 cases are dashed lines. Notice that the in the figure published in Paper III the horizontal axis was shifted by 1 s

Note that the data set in question contains the mean period. The corresponding values of the mean period, found from the recorded wave spectra, are about 20 % larger than the defined peak; however, not all spectra have a clearly peak periods.

In a certain number of situations long waves with periods over 10 s dominate in the wave field. This usually happens in the case of swell-dominated low wave conditions when the wave height $H_{1/3}$ is well below 1 m. Very large mean periods may also occur during extremely rough seas. For example, the mean period reached 11 s in one case of rough seas with $H_{1/3}$ around 4 m, and also in the final stage of the January 1984 storm, when waves with periods 11 s dominated the wave field with $H_{1/3}$ about 7 m.

Extreme wave conditions

The most violent storm recorded by the SimRad device occurred in January 1984. The wave data from this storm were used in the description of wave statistics in (Kahma *et al.* 2003). The wave height $H_{1/3}$ was very close to or exceeded 6 m during 10 hours that night. In the late evening of 13 January (23:00 GMT, i.e. 01:00 hrs local time on 14.01.1984) the wave height $H_{1/3}$, estimated from the 10th largest wave, reached 7.82 m (Fig. 4.5). This is the highest experimentally measured wave height in the northern Baltic Sea to date. The significant wave height, calculated directly from the SimRad wave spectrum, is somewhat smaller – $H_S = 7.28 \approx 7.3$ m at the storm maximum.

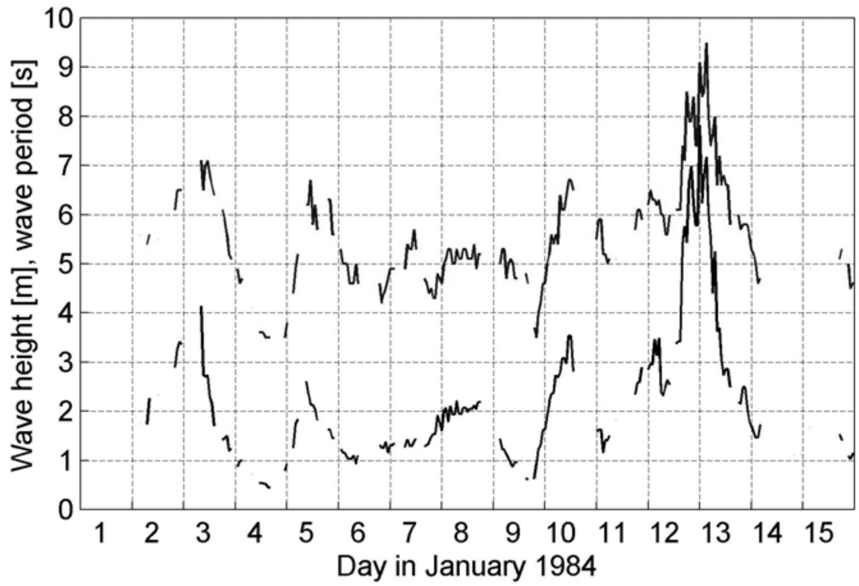


Figure 4.5 The wave height $H_{1/3}$ (lower line) and the mean period (upper line) at Almagrundet in January 1984 according to the SimRad data. Note the large amount of gaps in the lines, which correspond to the missing data (Paper III)

The wave periods during the storm in question remained fairly modest. When the maximum wave height occurred, the mean wave period was 9.1 s and the peak period was 10.7 s. Both periods are considerably smaller compared with the wave periods in the roughest seas measured in the NBP (12 s (Kahma *et al.* 2003)) or with those that occurred in the eastern part of the NBP in January 2005 (about 11-12 s measured in the NBP, about 13 s forecast in the eastern part of the sea (Soomere *et al.* 2006a)).

The SimRad data set contains one more case when the significant wave height at Almagrundet was close to 7 m. A severe storm occurred on 30 January 1988 when the wave height was close to or exceeded 6 m and reached $H_{1/3} = 6.73$ m at 04:00 GMT. Since Almagrundet is somewhat sheltered, the significant wave height in the open part of the northern Baltic Proper could theoretically have reached 7 m during this storm.

Other extreme wave storm events in the northern Baltic Proper reflected in the wave data from Bogskär and by the waverider buoy in the central part of the NBP are not so significant in the Almagrundet data. Kahma *et al.* (2003) report that three very strong wave storms took place in the 1990s. There are no reliable wave data at all in the Almagrundet data set from the severe storm in January 1993. The maximum wave height during two extremely violent storms in December 1999 (when the significant wave height in the NBP exceeded 7 m (Kahma *et al.* 2003)) was about 6 m at Almagrundet. This is still quite high for this somewhat sheltered site.

There are several candidates in the WHM data set for the highest significant wave height and for the highest single wave. However, closer examination shows that the relevant records are probably erroneous.

The highest formally recorded wave height in the WHM data occurred on 25–26 March 1997 (Fig. 4.6).

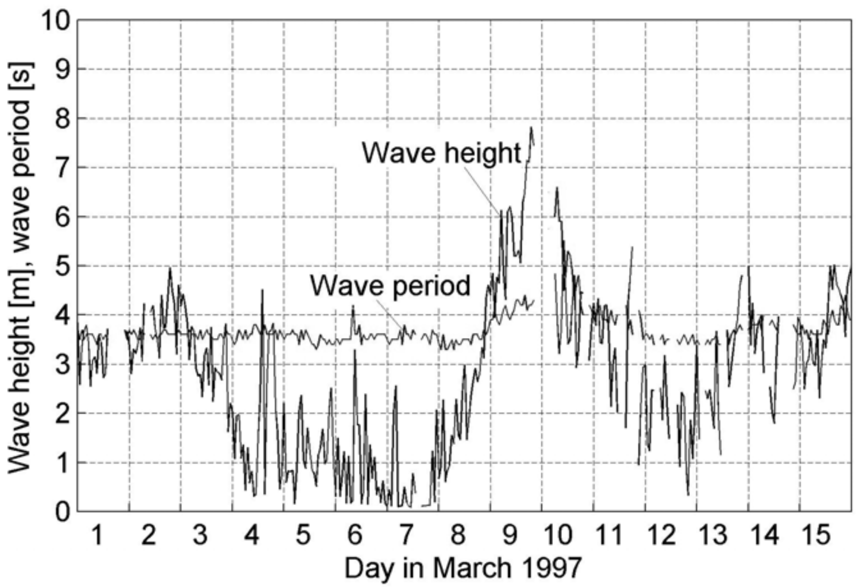


Figure 4.6 The wave height H1/3 and the mean period at Almagrundet in March 1997 according to the WHM data (Paper III)

The wave height $H_{1/3}$, estimated from the 10th highest wave, reached 7.83 m during a severe, long-lasting storm, which affected nearly the whole of the Baltic Proper. The maximum wind speed at Utö was 22 m·s^{-1} and at Vilsandi 19 m·s^{-1} during this event. On the Estonian coast, the storm winds were blowing from the south, and so were capable of exciting high waves at Almagrundet. Yet the significant wave height, estimated from the wave spectrum, was 5.7 m and the highest single wave reached 10.24 m. Therefore, although this was certainly a case of severe seas, the above mentioned value of 7.83 m is either incorrect or only reflects the situation when a group of large waves occurred during a certain measurement interval.

An extremely high single wave with a height of 12.79 m is present in the WHM wave data on 25 December 1996 at 03:00 GMT. The significant wave height, estimated from the 10th highest wave, was 6.37 m during this measurement interval, thus formally supporting the possibility of that single high wave occurring. There was a fierce, long-lasting north-easterly storm on the sea, with wind speeds up to 21 m·s^{-1} at Utö, and thus favourable conditions existed for the occurrence of high waves at Almagrundet. Still another feature suggesting that this record is most probably incorrect is that the significant wave height, estimated from the wave spectrum, was only 3.8 m.

Annual and interannual variations of the wave conditions

An extremely important question is whether the data set in question reveals any long-term changes in the wave activity in the Baltic Proper. The total coverage of the measurements is about 25 years, which is usually long enough to extract basic long-term trends. Fig. 4.7 presents the annual mean wave height measured by both devices at Almagrundet over the whole measurement period together with the percentage of available (i.e. successful) measurements in each year.

The measurements with the SimRad equipment started on 27 October 1978 and cover only 14% of the calendar year 1978. Since the late autumn and early winter months are the windiest and wave conditions are then usually the most severe (Mietus 1998, Kahma *et al.* 2003), the average wave height for this year $H_{1/3} = 1.12$ m is apparently overestimated. For this reason, data from this year have been ignored in estimates of the long-term trends; they are included, however, in the following analysis of seasonal variability.

The SimRad data for the years 1979-95 show a linear rising trend of 1.8% per annum in the average wave height. The correlation coefficient between the trend line and the measured wave data is about 0.66. Such a trend follows the general tendency of the wind speed to increase over the northern Baltic Sea (see below). The increase in wave heights at Almagrundet, however, is much more intense than analogous trends for the southern Baltic Sea or for the North Sea, which are estimated as less than 1% per year (Vikebo *et al.* 2003, Gulev and Hasse 1999). Yet it is comparable with the analogous trend reported by Bacon and Carter (1991) for the North Atlantic.

Comparison of annual mean wave heights with the percentage of available measurements (Fig. 4.7) suggests that the variation in the number of successful measurements during a specific year may not affect this trend. There are several reasons why wave data are missing. For example, it is plainly pointless to attempt wave measurements when the sea surface is ice-bound. Many years have a data coverage of about 90 %. There are prolonged periods in 1982, 1986, 1987 and 1992-94 when the instrumentation failed to produce data. The gaps in the 1980s occur mostly during winter and early spring, and most of them are apparently caused by the presence of sea ice. In 1990s the failures occur more regularly; only about 12 % of the measurements for 1993 exist in the data set. The lack of a lot of data from these years is apparently caused by the failure of data flow during certain time intervals. Yet a fairly steep rising trend in wave height by about 1.3 % per annum can be inferred from the data of 1979-92.

There is an evident match in the temporal behaviour of the Utö wind data (Fig. 4.8) and the SimRad wave data. The wind data from this small island in the northern Baltic Proper (Fig. 4.1) well represents wind conditions in the NBP (Soomere 2003a, Kahma *et al.* 2003). This match can be traced even in years poorly covered by measurements and suggests that the increase in the annual mean height at Almagrundet is a part of the long-term changes in hydrometeorological conditions in the Baltic Sea.

The WHM data cover only a small part of the years 1993 and 1994; however, the average properties of the wave field closely match those measured by the SimRad equipment. There are no WHM data from 1998, and there is a relatively long gap in the time series from July to December 2001.

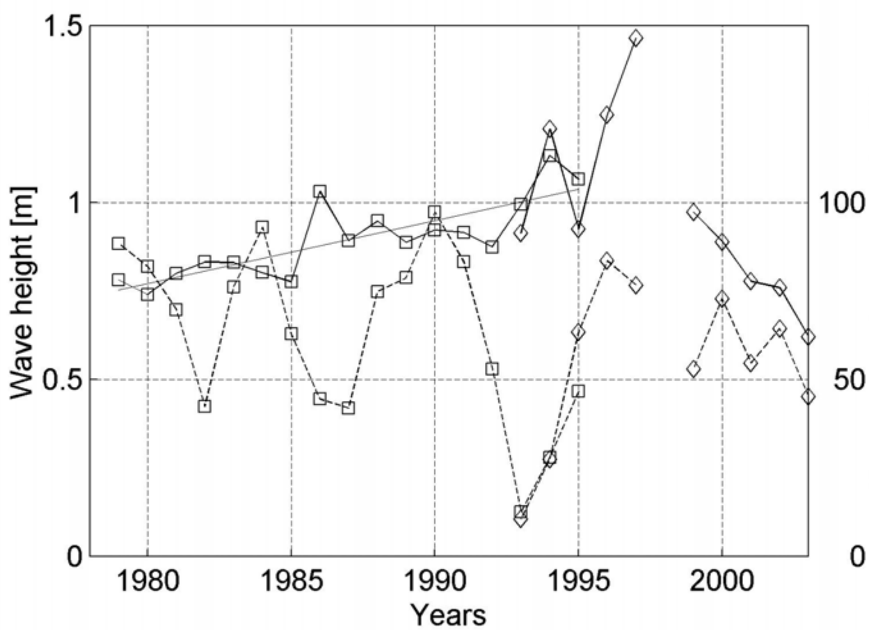


Figure 4.7 The annual mean wave height H1/3 measured by the SimRad equipment (squares on solid line), the relevant trend line for the years 1979-1995, and the wave height measured by the WHM equipment (diamonds on solid line). The measurement success rate (squares and diamonds on dashed lines) is the percentage of acceptable measurements within a particular year (Paper III)

The trends extracted from the WHM data are indistinct (the relevant correlation coefficient of a formal trend of the rapid decrease in the annual mean wave height is about 0.2) and possibly less reliable. While the average wave height measured by the WHM at the turn of the century is generally in line with the changes in the average wind speed, the rapidly falling trend in the annual average wave height in

1999-2003 does not match the relevant wind data (see Fig. 4.7 and Fig 4.8) and appears to be fictitious.

There is also some doubt whether the WHM data recorded in 1996-97 correctly represent the actual sea state. The wave conditions recorded in some months (June 1996 with a monthly mean of $H_{1/3}$ over 1 m, and particularly March-April 1997 with a monthly mean of $H_{1/3}$ of 2.6 and 2.8 m, respectively) are (partially unrealistically) severe (see Fig. 4.8). This becomes clear from a comparison of these data with wind data from Utö.

Although the annual mean wind speed does not necessarily exactly match the average wave height, it is intuitively clear that a larger wind speed generally causes greater wave activity. The wind speed in March-April 1997 (when the WHM data report extremely high wave activity) differs insignificantly from the relevant mean value over several consecutive years. Also, the measured annual mean wave height in 1996-97 is much higher than in other years. This feature does not correspond to Utö wind data either, which suggests that these years were relatively calm and that the wind speed in 1996 was exceptionally low compared to adjacent years (Fig. 4.8).

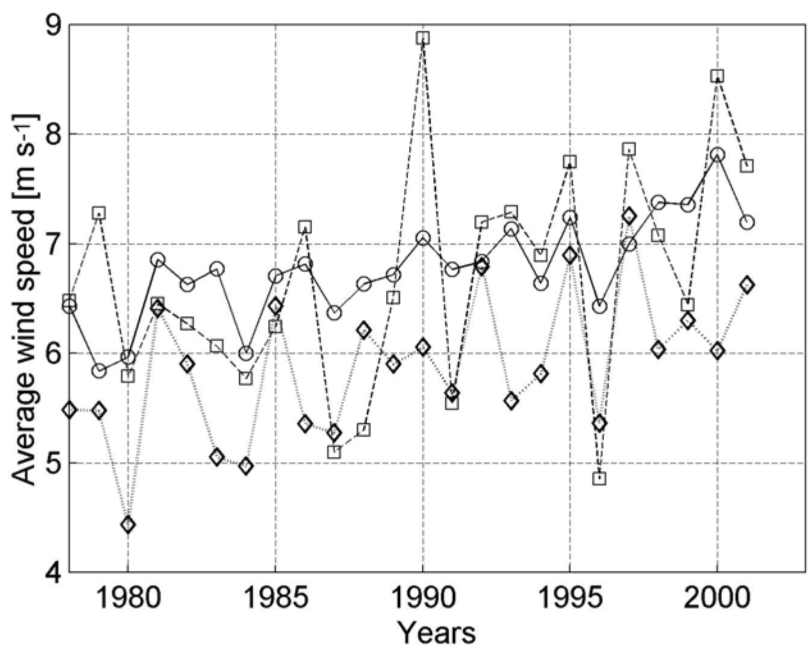


Figure 4.8 The annual average wind speed (circles on solid line) and average wind speed in March (squares on dashed line) and April (diamonds on dotted line) at Utö 1978-2001 (Paper III)

Wave conditions at Almagrundet exhibit a strong seasonal variability (Fig. 4.9). In this respect both the SimRad and the WHM data exhibit mostly similar behaviour. The annual variation in the monthly mean wave height is impressive, varying from about 0.5 m during the summer to 1.3-1.4 m in winter. The highest wave activity occurs from November to January. The WHM data suggest that another wave height maximum may occur in March. The above has shown that this feature may be questionable, although Fig. 4.8 shows that in some years March can be fairly windy.

The calmest months are in the late spring and summer months from May to July or August. Such an annual variation mostly matches the annual variation of the wind speed in the northern Baltic Proper (Mietus and von Storch 1997).

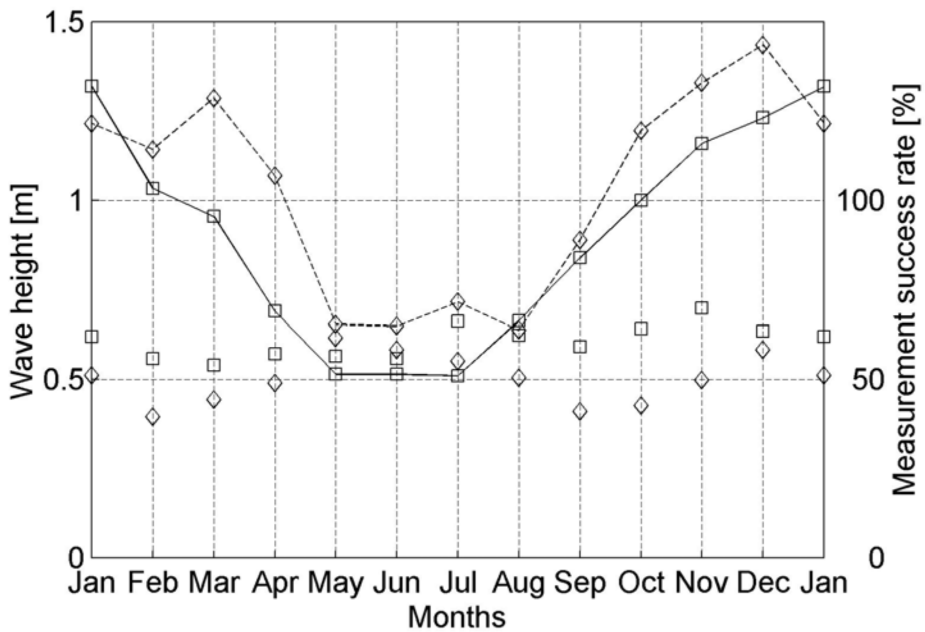


Figure 4.9 The monthly mean wave height measured by the SimRad (squares on solid line) and the WHM (diamonds on dashed line) equipment. The measurement success rate (separated squares and diamonds) is the percentage of acceptable measurements within a particular month (Paper III)

From Kahma *et al.* (2003) and Soomere *et al.* (2006) it follows that since the beginning of measurements in the open part of the NBP in 1996, the significant wave height has exceeded 7 m only four times. This happened twice in December 1999, again twice in three weeks during the 2004-05 winter storms (once in December 2004, and once on 9 January 2005 during windstorm Gudrun).

The above analysis has shown that the significant wave height probably exceeded this threshold on at least two occasions in the 1980s. The 1984 January storm was probably the most ferocious and long-lasting one until the 2005 January storm.

Since there is some difference in the measurement routine and in the principles of raw data analysis at Almagrundet compared to the directional waverider data, these time series are not directly comparable with each other. Yet this analysis suggests that, in general, neither the frequency nor the intensity of extreme wave storms has increased during the last thirty years. Extremely strong storms with significant wave heights close to or exceeding 7 m seem to occur roughly twice a decade. This is consistent with the observation that the number of active cyclones has not radically changed during recent decades.

However, the tendency towards an overall increase in wave activity in terms of the annual mean significant height can be identified from the analysed data. The rate of this increase is approximately the same as for the North Atlantic. It is important to emphasise that, given the specific conditions of the Baltic Sea and the Almagrundet measurement site, this trend may be either partially or wholly caused by other changes in the wind field. A theoretically possible but unlikely explanation is that the intensity of winds from the south and east has increased.

Since the wave conditions at Almagrundet are relatively strongly dependent on the wind direction, a part of the seasonal variation in the wave intensity at this site may reflect differences in the dominant wind directions in different seasons. In particular, a large portion of easterly winds occurs in the northern Baltic Proper during the late winter and early spring (Mietus and von Storch 1997). This feature may be one of the reasons for the relatively high wave intensity at this site in February and March.

Wave action and its changes on the coasts of the City of Tallinn

Coastal hazards connected with large wind waves and associated management issues are usually regarded as decisive along open ocean coasts where wave heights over 10 m may occur regularly, rapid erosion and accretion can result from both short-lived storms as well as transient sub-decadal water-level changes, cyclone waves are responsible for extensive damage in low-lying atolls and on the coastal fringes of high islands, and even infrastructure perched on 20 m cliffs may not be immune during severe storms (Solomon and Forbes 1999). The role of even small waves, however, may be extremely large under unfortunate conditions (see Dean and Dalrymple 2002 for examples). These examples demonstrate that integrated coastal management (ICM) plans, to be successful, must explicitly incorporate a realistic range of coastal processes and responses based on an understanding of the environment, whatever small or weak the relevant processes seem to be for an unarmed eye.

Wave action is the principal driving force of the coastal processes in the vicinity of City of Tallinn. This is a typical property of beaches located in microtidal seas and that host no strong jet currents. A large part of waves affecting the coasts around the City of Tallinn are born in the Gulf of Finland. Western winds may bring to this area wave energy stemming from the northern sector of the Baltic Proper (Soomere 2005b). The wind regime in these areas is strongly anisotropic (Soomere and Keevallik 2001, 2003). Some sections of the shores of Tallinn are well sheltered from high waves coming from a large part of the potential directions of strong winds. As a result, the local wave climate is at places very mild compared with that in the open part of the Gulf of Finland (Soomere 2005a). For example, the annual mean significant wave height varies from 0.29 m to 0.32 m in different sections of Pirita Beach.

Very high waves, however, occasionally appear in virtually all sections of the coast under consideration. The significant wave height exceeds 2 m each year and may reach 4 m in NNW storms even in the central part of Tallinn Bay. This feature well explains why most of the coasts of Tallinn Bay show features of intense erosion. The dominating wave periods at Pirita in western and NNW storms are close to those in the central part of the Gulf of Finland.

The potential consequences of the changes of the wave regime in this area are poorly understood. Since wave-induced processes substantially depend on wave height, length or period, and approaching direction, the knowledge of the wave height only is insufficient in the coastal management. Even quantification of the role of the ferry-induced waves requested extensive efforts from a large team of scientists and lead to quite a large uncertainty of their role. A large part of this uncertainty forms the shortage of the knowledge of factual wave regime in the Tallinn Bay that was only estimated approximately with the use of the contemporary wave model WAM. The relevant knowledge can be to some extent constructed based on long-term statistics of wave properties in the open sea incl. the Baltic Proper and with the use of wave propagation models. An attempt in this direction is made with the use of the longest available instrumentally measured time series of wave properties at Almagrundet.

The results of both numerical studies and the analysis of historical wave data confirm that wave periods in the entire Gulf of Finland and in Tallinn Bay are relatively small. This is the key reason why waves from fast ferries form an appreciable portion of the total wave activity in Tallinn Bay since 1997. Their annual mean energy and its flux (wave power) are about 5–7 % and 20–25 % from that of the total wave activity, respectively (Soomere *et al.* 2003). The daily highest ship waves belong to the highest 5 % of wind waves in this area. Since high ferry waves are present during a relatively calm season and at times approach from directions not common for wind waves, they may induce sediment transport directed oppositely to the natural littoral drift or current-induced transport of suspended matter. Their role in coastal processes, although potentially substantial under certain circumstances, has been poorly understood yet and needs further investigation. The City of Tallinn has launched the relevant process in 2006 which currently is in the stage of identification of key shortages in the relevant knowledge and areas where substantial further research is necessary.

5. Economical and environmental aspects of shore protection activities

This Chapter mostly follows the material presented in more detail in Paper I.

Development and protection of the coasts in the Tallinn area

The protection and usage of coastal areas in the vicinity of Tallinn have been a long-debated issue due to the geological peculiarities of the area and alteration of the coastline under the impact of nature and port construction. Problems have also arisen with obtaining the materials for the reinforcement of the coast and port buildings and arrangement of cooperation between the owners of coastal areas and local authorities administering the state and coastal areas, aimed at the protection and development of the coasts. These problems have been solved in various ways in different periods of the history of City of Tallinn. In the past decades the proprietary relations and the administration of coastal areas have undergone a drastic change. The present paper deals with the problems related to the protection and development of coasts and with the possible solutions that could be reached by the owners of coastal lands and buildings in cooperation with the state and local authorities under the present legislation.

The present treatise considers the Tallinn area as part of the Gulf of Finland stretching from Kakumäe Bay to Muuga Bay, including Aegna, Naissaar, and Prangli islands (Fig. 5.1). The islands, peninsulas, and shallows make up an area relatively well protected from the waves, with coasts suitable for harbours, which has favoured the development of Tallinn as a city of harbours, where people and companies form a socio-economic whole. The problems of the protection and development of the coasts of that area and their solution are closely connected with each other and with Tallinn city as the centrum.

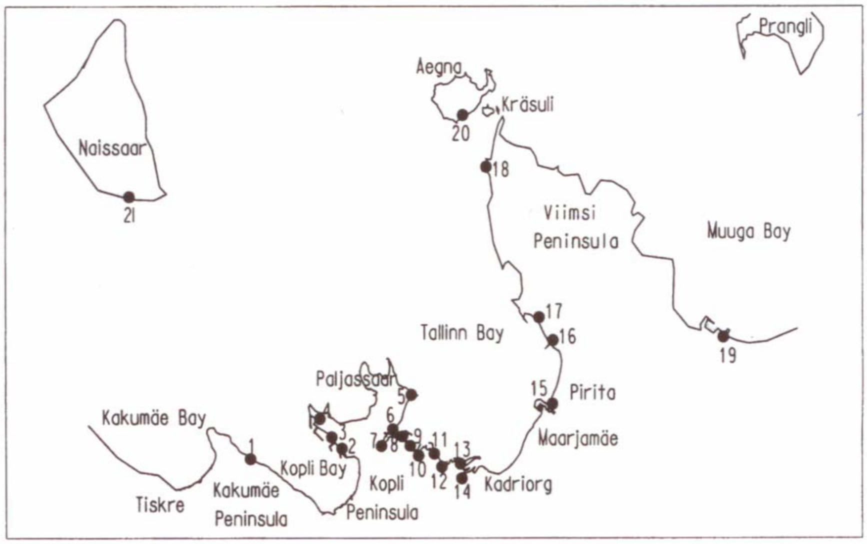


Figure 5.1 The coast and harbours of the Tallinn area. 1. Kakumäe Harbour; 2, Meeruse Harbour; 3, Bekkeri Harbour; 4, Vene-Balti Harbour; 5. Katariina Quay; 6, Paljassaare Harbour; 7. Lahesuu Harbour; 8, Hundipea Harbour; 9, Miinisadam Harbour; 10, Peetrisadam Harbour; 11, Lennusadam Harbour; 12, Kalasadam Harbour; 13, Patareisadam Harbour (called also Linnahalli Harbour); 14, Vanasadam Harbour; 15, Pirita Harbour; 16, Merivälja Quay; 17, Miiduranna Harbour; 18, Rohuneeme Harbour; 19, Muuga Harbour; 20, Aegna Harbour; 21, Naissaare Harbour (Paper I)

Dangers to the coasts in the Tallinn area

Tallinn is a good natural area for harbours. The harbours have existed here since the foundation of the town on a trade route in the 11 th century. The Hansa, a powerful economic unit of the Baltic towns, had great influence on the construction and expansion of the port in Tallinn. Riga and Tallinn were among the first to join the Hanseatic League on March 15, 1285.

However, the coastal area and harbours of Tallinn are open to northwestern and northern storms. The coasts and the buildings on the coast and in coastal waters (harbours, quays, breakwaters, etc) are endangered mainly by the high storm waves formed by strong winds, which are able to shift the sediments in the coastal area, and also by the currents that can obtain a high speed with gales, and a sudden rise in the water level. A permanent ice cover inhibits the formation of storm waves and therefore spares the shore, but pack ice that can be formed out of a permanent ice cover during a storm, is particularly dangerous to the coasts and buildings.

The waves generated by fast boats are also considered as dangerous to the shores. The research has shown that their impact differs from the one of the natural waves, being negative on the marine environment and the use of the shores, however, their considerable negative impact on the shore and coastal buildings has not been proven yet.

Till shores are relatively resistant to storm waves. Storm waves abrade from till the finer sediments: mud, clay, sand, and gravel. Only the coarsest part of the abraded till, which the waves would be unable to move, will remain on the shore. The remaining harder and heavier rocky material forms a bench protecting the coast from further abrasion. Sometimes there may form also walls of gravel, when the initial rock includes enough material with the proper grain size. The motion of the waves in such boulder-rich coasts is restricted and in some places vegetation will develop inbetween the boulders.

Yet, till terraces typically recede towards the land due to the impact of the sea. The processes that have taken place on the coastal terraces are displayed by their recent nature, fallen trees, big boulders, etc. The recession of the coastal terrace decreases the land area at the site and can impair the buildings, roads, and other facilities located nearby and make them unfit for use.

The most serious damage happens at such shores in the autumn-winter season with severe storms, accompanied by a high seawater level. During warm winters the formation of storm waves and their impact has been favoured by the absence of sea ice, in cold winters, by the movement of pack ice. Extremely unfavourable conditions cause essential spasmodic changes of the coasts: the coastal terraces are heavily damaged, in places high quantities of sand are swept away from the sandy coasts, in other places massive accumulation of coastal sediments takes place. A severe storm occurred in January 2005, which caused extensive destruction to the coasts of Aegna Island and the Kakumäe Peninsula and damage to several buildings.

The displacement of sand or its accumulation is a typical damage to the sandy coasts of the bays. Due to the displacement of the sand the buildings and facilities located too close to the shoreline can be damaged in case of a high sea and storm. The accumulation of the sand can have both positive and negative effect. Special reinforcements of the coasts enable either avoiding the displacement of sand or increasing its accumulation, according to the need.

The incompetent alteration of the shoreline by humans usually weakens the natural ability of the coast to resist the storm waves, quickens the abrasion, and extends the scope of the coastal damage in places with a natural prevalent recession of the shoreline towards the land. This can result in the continuation of the coastal damage and the extension of the area suffering from the storm damage to both sides along the shoreline, jeopardizing also the adjacent coasts.

In order to prevent the damage to the coasts, projects have to be made for each coastal protection measure and other objects planned to the coast, their thorough expertise should be conducted and environmental impacts assessed, considering the cumulative effect of the natural conditions and all the facilities and other objects nearby. The largest coastal defence building is the Pirita road, stretching from Kadriorg to Pirita. Some coastal protection buildings occur also in other regions.

Figure 5.2 The damage to the Aegna Island coast after the storm in January 2005 (Photo by H. Udusaar)

Figure 5.3 The damage caused to Aegna Harbour by the storm in January 2005 (Photo by H. Udusaar)

Several of these were heavily damaged in the storm of January 2005 (Fig. 5.2, Fig. 5.3), except for those with expert planning and of high-quality construction.

The coasts and coastal facilities and buildings get damaged mainly if the valid requirements and practical experience have not been taken into account at their planning stage, or if the construction is of low quality and as inexpensive as possible. Sometimes the damage may also be caused by the shortcomings of the valid legislative acts. Thus the minimal allowed distance from the shoreline has been validated for constructing the buildings, but the requirement for minimal height from the mean water level (the Kroonlinn zero) has not yet been enforced. The results of the January 2005 storm in Pärnumaa and Läänemaa demonstrate the need for local height restrictions. In planning the harbours, bridges, and other major seaside objects it is necessary to conduct, beside meeting all the demands of valid legislative acts, also the required scientific research to forecast the possible dangers.

Status and means of protection of the coasts of the Tallinn area

The coasts of the Tallinn area are under the administration of several local authorities. Beside the city of Tallinn, they include Harku Rural Municipality in the west, and Viimsi and Jõelähtme rural municipalities in the east. Aegna Island lies within the administrative boundaries of Tallinn, while Naissaar, Prangli, and Kräsuli islands are located on the territory of Viimsi Rural Municipality.

The coasts and coastal areas belong to several owners, including the state and the local authorities, and private persons, and their number is gradually increasing. Some coastal areas are still not reformed. The coastal lands and harbours in the administrative area of the city of Tallinn are mainly state-owned. Kalasadam Harbour, Pirita Harbour. Merivälja Quay, and Rohuneeme Harbour are a private property. Tallinn has only Patareisadam Harbour in its ownership. In all the harbours, functioning as trading companies, there are also active operator firms and leaseholders, many of them having their own property in the harbours.

The wide circle of the coast and harbour owners and administrators and the combination of their interests, rights, obligations, and potential complicate settling the coastal protection and development issues. The primary causes underlying the drawbacks in this matter are the careless and negligent attitude of several owners, their ignorance and economic incapacity and the resultant lack of the required facilities or the unpurposeful thrift of resources and technical failures in building them. Beside the care of each party involved, the effective continuous coastal protection requires also a good mutual cooperation of the parties. Otherwise the coastal protection or the alteration of shoreline that has been carried out with good intents will only harm the neighbouring areas and worsen the general condition. The local authorities and the Harju County Government uniting them play a leading role in the regulation of their cooperation. Tallinn Municipality and the Viimsi Rural Municipality Government play the main role in the regulation and realization of coastal protection.

As well as the entire marine legislation of Estonia, the legislation covering the protection of coasts and their development is still in its formation stage and does not provide solutions to all problems. The local authorities, including Tallinn Municipality, have to consider this in their attempts to regulate the protection and development of coasts.

Status and development harbours of the City of Tallinn

As a rule, the harbours of the Baltic Sea are whether the property of the city or a local authority, administering the territory of their location. This aspect guarantees the recognition of local interests in the planning of harbours, which may recede to the background in the course of the development of harbours in the interests of the state or private owners. Besides, a well-functioning harbour is an efficient generator of income and a development mechanism to the local authority. Also in Tallinn the harbours belonged to the city until the late Middle Ages, but as Russia changed these to military ports, they were transferred into the state ownership and continued to be in that status also after Estonia regained its independence. The city got only re-established Patareisadam Harbour with Linnahalli Harbour and later on also Kalasadam Harbour into its possession, with the immediate privatization of the latter, after its conveying to the city. The remaining harbours of Tallinn and the land under these are owned by the state. Such a situation has made the use, maintenance, and development of Tallinn harbours very problematic. The state has not made any plans for the development of the harbours in its ownership and has also avoided cooperation in this field with Tallinn Municipality, who has repeatedly turned with the respective suggestions to the Ministry of Economy and Communication administering the harbours. After fruitless attempts to obtain a positive response to solving the burning issue of city planning, Tallinn Municipality by itself ordered a research for the development of the harbours, railroad juncture, and road transportation connections in 1997.

The company Eesti Tööstusprojekt *(The Estonian Industrial Project* Ltd.) conducted a research in 1998, which provided an overview of the condition and problems of the harbours in Tallinn and contained a number of suggestions for re-specializing the harbours and municipalizing some of them to make the activities of the harbours from the perspective of both its owner and the city more purposeful, safer to the environment and the population in general.

Muuga Bay and Muuga Harbour play a special role in the development of the coasts in the Tallinn area. Muuga Harbour has developed into one of the major oil transit harbours of the Baltic Sea region. It could relieve the load of the other harbours within Tallinn Bay and develop also other transport and services. However, the harbour is dangerous in a strong northerly wind and impossible to handle in case of gale.

The role and activities of Tallinn Municipality

The main role of Tallinn Municipality is the regulation of cooperation and participation in planning and realizing the measures for the protection and development of the coasts located within the administrative boundaries of Tallinn. The major problem is the cooperation of the Municipality with the organs of the state, aimed at increasing the role of the Municipality as the owner of the coasts and harbours in the Tallinn area. In Tallinn the coastal protection and harbours are under the administration of the Municipal Engineering Services Department.

At present the following activities concerning the coasts of the Tallinn area are in progress:

1. The coastal facilities, moles, and breakwaters of Patareisadam (Linnahalli) Harbour and the area surrounding the City Hall - it has been planned to expand Patareisadam Harbour for the reception of large vessels, tidy up the area for the common weal, and reinforce the coast outside the boundaries of the harbour.
2. The right bank of the Pirita River estuary with coastal facilities, also moles, breakwater, and waterway of Pirita Harbour - these constructions are owned by Tallinn Municipality and a harbour for smaller craft is planned to be developed here.
3. The reinforcement of the south coast of Tallinn Bay by the road from Kadriorg to Pirita is partially damaged and needs inspection and repair. The remaining portion of the road needs either repair or renovation.
4. The care and protection of Aegna Island and the restoration of Aegna Harbour. Aegna used to be a popular place for resting and a region of summer cottages. In the meantime the use of the island decreased drastically and both its coasts and the harbour were damaged by the storms. In the recent years the harbour was restored and the causes of coastal damage and the possibilities for the protection of the coasts were investigated. The storm of January 2005 hit Aegna, its coasts and harbour severely. The present task is to make the island again fit for use and open it to the inhabitants of Tallinn as a proper resting place. In future the harbour has to be reconstructed and made stronger and safer.
5. According to the decisions of the authorities of the local city districts, the Pirita and Kopli sandy coasts are tidied up for the common weal.

Tallinn is interested in increasing its role as the owner of the harbours located on the coasts of the city area. This is necessary for increasing future income of Tallinn and for better regulation of the use, defence, and development of the coasts. The state-owned Paljassaar Peninsula and Katariina Quay are of primary interest. For several reasons it would be purposeful to transform Miinisadam Harbour into a civil harbour and convey it to the city ownership. Also Lennusadam Harbour should be developed in the interests of the city. In order to reduce the transport of dangerous cargoes through the city centre, it is necessary to close the transit of oil products via Vene-Balti Harbour. For the complex development of the Tallinn harbours, the development plan for the harbours, connection roads between different harbours, and the railway juncture is needed. The harbours will be gradually re-specializcd as passenger, tourism, and yacht harbours with thc required infrastructure and security systems.

The farthest Aegna Island, an extension of the Viimsi Peninsula, is at present located in the administrative area of Tallinn. Naissaar Island, however, located farther from Viimsi, is part of the territory of Viimsi Rural Municipality. From the perspective of the administration, economic management of the islands, their protection and development, the assignment of Aegna Island to the administration of Viimsi Rural Municipality and Naissaar to Tallinn might be considered.

Cooperation with the other owners of the coasts and coastal buildings located within the administrative boundaries of Tallinn and participation in planning and accomplishing the measures for the protection and development of the coasts are carried out according to the regulations of Tallinn Municipality. In the same way, cooperation with the other local authorities in planning the protection and development of the coasts in the Tallinn area is carried out.

6. Planning experience for Kakumäe Peninsula, City of Tallinn

The presentation in the chapter mostly follows Paper II. First main factors affecting the status of the coastal zone and coastal processes of Kakumäe Peninsula, City of Tallinn, are reviewed. Principles of studies that are necessary to adequately determine the lithohydrodynamic processes in the coastal and littoral zone are described. Owing to the complexity of the processes in this area it is necessary to combine the results of different studies to determine the cost-effective and environmentally friendly type of coastal protection. A scheme of necessary studies and estimates of their cost and duration is presented.

Factors affecting the coastal zone of the Kakumäe Peninsula

Kakumäe Peninsula is located in the northwestern part of the City of Tallinn (Fig.5.1). During last years there have been extensive damages of the coastal scarp. At places the scarp is located only by a few meters from public streets (Seaver 2004, 2006) and its further recession is very undesirable.

The coastal processes of Kakumäe Peninsula (Fig.6.1) are mostly driven by hydrodynamical factors. The most important components of hydrodynamical activity are surface waves, coastal and wave-induced currents, and sea level. Also, severe ice conditions may also essentially affect local coastal processes during certain winters. Rapid events of coastal evolution occur when specific combinations of the listed factors occur. In particular, extensive coastal destruction may occur during certain storms during which the combination of extreme sea level and high waves occurs.

The geological structure of the coastal zone of this peninsula largely varies in its different parts. The different sections of the peninsula are open to winds and waves from different directions.

The geological and lithohydrodynamical processes are very complicated in this area and have largely intermittent nature both in time and space (Soomere *et al.* 2006a). The coast of the peninsula forms an extremely complicated pattern of erosion, transit and accumulation regions. Active sediment transport in different parts of the coastal zone is the key factor that has to be accounted for when coastal protection measures are planned.

The coastal processes in different parts of the peninsula strongly depend on each other and the area in question thus forms a unitary system. In that context it should be noted that the coastal protection structures usually exert large influence on sandy and gravel beaches nearby. Disturbing the natural balance of sediments is often the reason for coastal destructions. In many cases, coastal protection or engineering structures themselves are the main factors that hinder the transport of sediments along the coast and cause additional coastal destruction in their vicinity

(Dean and Dalrymple 2002). Therefore it is important to account for the possibility that protecting one part of the coast may lead to fast destructions in other parts.

Studies considering the coastal processes in the region of Kakumäe Peninsula are fragmentary. They have mostly been performed in connection with specific activities planned in small sections of the coastline. The results are usually not published but distributed only as manuscripts to a small user groups. The information that has been published in books and journals is mostly very general. While hydrometeorological information from neighbouring sea areas is often valuable for characterising local conditions, characteristics of bottom sediments in nearby bays are hardly of any use for a particular area of interest.

The listed features make the planning of coastal protection measures and the estimates of their costs and economic feasibility extremely complex.

The aim of the current study is (i) to locate the most important milestones of planning of coastal defence structures, (ii) to identify the necessary time scales, (iii) to pinpoint possible failures of the whole process and (iv) to get an idea about the costs of the pilot studies of local factors necessary for making a decision about optimal types of coast defence structure and their locations.

The key feature of the geological structure of Kakumäe peninsula is that its different parts have different lithological composition. Let us start the description from the south-eastern part of Kakumäe peninsula. The peninsula starts from the Tiskre region where many building activities have been carried out during the last decade. Formally, coastal sections eastwards from the Tiskre stream can be considered as belonging to the peninsula.

The easternmost section of the peninsula forms sandy Kakumäe beach which has been very popular as a recreational area. The sea deepens slowly there (Kask, Talpas, Suuroja 1999). The area of the beach is partially sheltered from strong northerly winds by the head of the peninsula.

Towards north-west from the beach sand is replaced by pebbles and cobbles between which in places gravel and sand can be found. Closer to the tip of the peninsula a sort of pavement exists in the vicinity of the waterline (Fig. 6.2). It consists mostly of pebbles, cobbles and coarse gravel, which partially protect old terraces from further erosion.

Several parts of the coast of the peninsula contain cliffs and bluffs which are currently subject to active erosion by the sea. At the north-western tip of the peninsula there is a sandstone cliff with a height varying from 1–2 up to 8–10 m. It consists of relatively soft material and is subject to active erosion during high water conditions (Fig. 6.2, Fig. 6.4, Fig. 6.5, and Fig. 6.7). Along the eastern coast of the peninsula the active erosion zone is gradually replaced by transit and accumulation of sediments in the coastal zone (Fig. 6.3, Fig. 6.6).

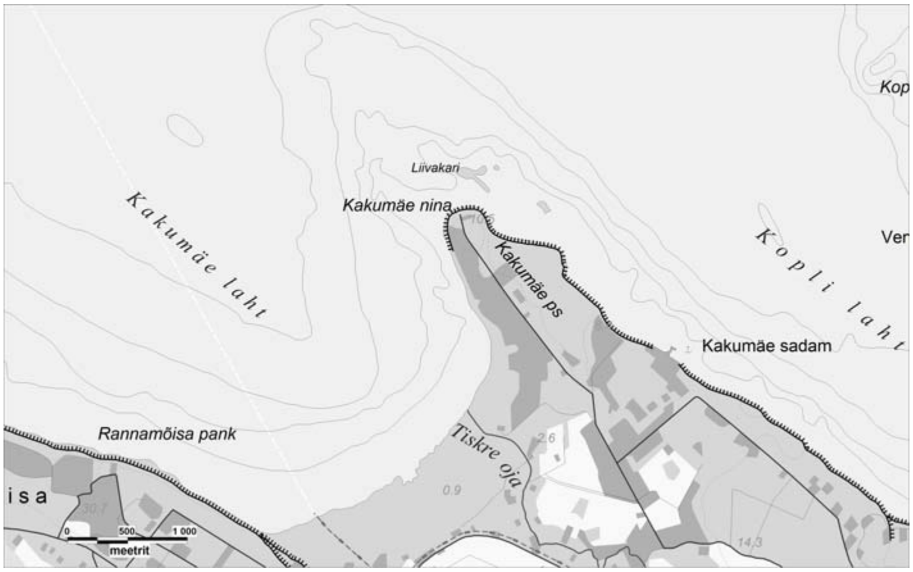


Figure 6.1 Map of Kakumäe Peninsula

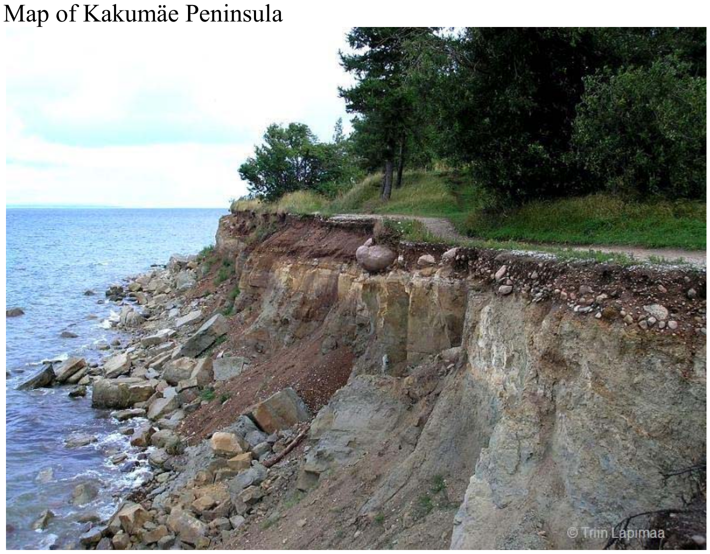


Figure 6.2 Cliff at the north-western coast of Kakumäe Peninsula, NW side (Photo by Triin Lapimaa, 2005)

Another vulnerable cliff is located south-eastwards from the present Kakumäe harbour. This cliff is one of the most interesting geological heritages in the surroundings of Tallinn. It serves as one of the oldest sedimentation complexes in Estonia.

Figure 6.3 Eastern coast of Kakumäe Peninsula near the existing harbour. The changed appearance of the cliff is in the background (Photo by Triin Lapimaa, 2005)

Establishment of a new dwelling district (Merirahu) has caused substantial changes on the eastern coast of the peninsula (Sula 2001, Kask 2001). The appearance of the coast was changed to a great extent during the construction works (Fig. 6.3). The original steep sandstone terrace was transferred to a gently sloping bank covered with turf and grass. A new harbour is planned in this district. Detailed information about the harbour can be found in harbour's design and materials of its environmental impact assessment (Ratas 2001, Raud 2001).

Figure 6.4 Cliff at the western coast of Kakumäe Peninsula, NW side, subject to intense erosion during high water (Photo by Triin Lapimaa, 2005)

In the section between Merirahu and the southern border of the open-air museum the actively abraded cliff continues along the vicinity of the Rocca al Mare School. South-westwards from the school the cliff diminishes. The coast of the bayhead is very gently sloping and mostly consists of fine sediments.

Figure 6.5 Cliff at the western coast of Kakumäe Peninsula, NW side, which was intensively eroded in January 2005 (Photo by Triin Lapimaa, 2005)

Most of Kakumäe Peninsula's coastal zone from the mouth of Tiskre stream to the Rocca al Mare School is a lithohydrodynamically active area. The intensity of processes at a certain time depends greatly on hydrometeorological conditions.

The openness of the coast to northerly storms may cause, in particular, in high water conditions, extensive destruction to the cliff. The most intense recessions of the cliff took place during extreme storms in November 2001 and in January 2005 when extraordinarily high and long waves occurred simultaneously with extremely high water level (Soomere *et al.* 2006b).

Figure 6.6 The material of the cliff, which is a combination of clay and silty components, is easily eroded (Photo by Triin Lapimaa, 2005)

The combination of loose sediments and high scarp of the cliff means that the scarp is relatively unstable with respect to action of waves. In other words, the structure and location of the cliff favour lithohydrodynamical processes in this area.

The material abraded from the vicinity of the waterline and from the cliff is mostly carried to the bayhead (or, to a lesser extent to deeper sea areas) where it accumulates. Hydrodynamical factors usually do not move pebbles, cobbles and boulders. They mostly remain in their initial positions and can be transported only by specific ice conditions.

The scarcity of hydrometeorological data

From the viewpoints of sediment transport, intensity of coastal processes, potential coastal destruction and planning of coastal protection measures the know-how of local wave matters is decisive (Dean and Dalrymple 2002). In particular, characteristics of wave fields in the vicinity of the area of interest during high water level events are of utmost importance. Detailed studies of these aspects are time-consuming and costly, and have been performed only for a very few locations.

There are no known extensive surveys of hydrodynamical or meteorological parameters in the vicinity of Kakumäe Peninsula. Some processes can be described by means of extrapolation of the results of surveys performed in the neighbouring regions.

Hydrodynamical conditions in the Kakumäe Peninsula coastal zone reflect the prevailing conditions in the Gulf of Finland. The average wave height in that region is moderate as one might also conclude from the results presented in Paper III. With the 50% probability significant wave height does not exceed 0.25 m (Soomere 2005c).

However, wave conditions in this area may vary significantly. In strong storms very high waves occur. Hindcast of wave conditions in an extreme storm in November 2001 suggests that in the close vicinity of this peninsula the significant wave height probably exceeded 3 m (Soomere 2005c).

Exact description of water level and wave regime in the vicinity of coastal protection structures is the key factor in their planning and design. Alenius *et al.* (1998) give a general overview of these conditions for the Gulf of Finland. Detailed analysis of the trends of water level, the probability of occurrence of extreme values and the amplitudes of short-term variability have been recently performed for the northern coast of the Gulf of Finland (Johansson *et al.* 2001). However, no similar survey has been performed for the southern coast of this gulf. To some extent such analysis has been done for Estonian coastal waters in Väinameri and in the Gulf of Pärnu (e.g. Suursaar *et al.* 2002).

The network of water level measuring points in the Gulf of Finland is relatively dense. The nearest measurement site is at Tallinn Vanasadam (Oldharbour) where measurements have already been carried out since 1805 (Ojaveer *et al.* 2000). Analysis of the water level data from this site is yet fragmentary and is mostly performed based on daily mean and extreme values (Raudsepp *et al.* 1999, Suursaar *et al.* 2002) or monthly mean values of the water level. Therefore, only rough estimates of extremely high levels and characteristics of annual variability are well known (Kõuts *et al.* 1995).

The amplitude of annual variation of the monthly average water level is about 20–30 cm, which is nearly by an order of magnitude smaller than typical short-term variations of water level in this area (Johansson *et al.* 2001). In extreme storms the water level in the area in question may exceed the long-term mean by 1.5 m (Suursaar *et al.* 2006).

Such a specific manner of water level variations suggests that for reasonable estimates of hydrodynamic activity and the planning of coastal protection measures a detailed survey of water level variability should be performed for the Kakumäe Peninsula area. This can be done with the use of water level measurements in Tallinn and Muuga harbours. If necessary, the historical data has to be digitised. The owner of the data from Tallinn Harbour is Estonian Meteorological and

Hydrological Institute (EMHI). The relevant costs consist of digitization cost and copying costs, the latter being 0.1 EEK per entry.

An intrinsic feature of ice conditions in the Estonian coastal areas is their extreme interannual variability. This variability has been extensively studied for the coastal waters of Finland as well as for the open part of the Baltic Proper (Climatological … 1982, Seinä and Palusuo 1993). The data from the latter decades suggest that there exist trends of shortening of ice periods and shift of their beginning and end dates. The relevant statistics can be extracted from the data in EMHI (e.g. Saaremäe 2002) but its profound analysis for the Kakumäe region has not been performed.

Strong storms often shorten ice periods. When storms occur during relatively weak ice sheet, the ice is broken down and can then be frozen again. In this way pack ice is formed which in places is very thick and may cause significant damage in different parts of the coast. Sometimes pack ice can deform harbour structures, seawalls and coastal protection structures, and also damage buildings and trees near the waterline. For that reason, analysis of potentially dangerous ice conditions has to be performed for a reasonable planning of coastal protection measures.

The wave atlas of the Gulf of Finland (Rzheplinsky and Brekhovskikh 1967) basically contains interesting wave data. However, the understanding of wave properties in this and other sources from 1960s does not meet contemporary standards. Its resolution is quite modest and thus unsuitable to characterize waves in Kakumäe region. Also, the wind regime probably has changed much since then (Keevallik and Rajasalu 2001). There are other interesting surveys (e.g. Davidan and Lopatoukhin 1982) about waves in the Gulf of Finland but these data cannot be extrapolated to the Kakumäe region. Coastal wave data from this areab usually give a completely distorted picture of wave conditions on the open sea (Orlenko 1984).

Contemporary wave measurements have been performed in the open part of the Gulf of Finland at a distance of less than 100 km from the Kakumäe Peninsula (Kahma and Pettersson 1993, Kahma *et al.* 2003, Pettersson 2001, Pettersson and Boman 2002). Specific characteristics of wave propagation in the Gulf of Finland have been studied in (Pettersson 2004) and in the very strong storm in January 2005 in (Soomere *et al.* 2006b). The use of data from the listed sources is undoubtedly necessary but the cost of using the data must be specified.

Yet data measured in the open part of the Baltic Proper (e.g. Broman *et al.* 2006, Jönsson *et al.* 2002) or the Gulf of Finland cannot be used directly for the Kakumäe region. This area is sheltered from several dominating wind directions and the local wave climate not necessarily reflects the features of the Gulf of Finland.

In order to link the open sea wave data with local conditions, frequently wave modelling systems are used. Modern wave models describe the main processes of wave generation, propagation and damping correctly provided that the wind conditions at the open sea are known well enough. Therefore, the critical aspect in wave modelling is the quality of wind data.

There exist wave models for certain areas adjacent to Kakumäe (Soomere 2001). Resolution of some of them has been increased to resolve the long-term variability of waves with the use of a 500-meter grid step within a reasonable computation time (Soomere 2003a, 2005). These models have been used in the environmental impact assessment of underwater mining in areas neighbouring to Kakumäe region (Kask *et al.* 2003a) and in the following monitoring (Kask *et al.* 2005). The modern wave models and the relevant competence of the Institute of Cybernetics at Tallinn University of Technology enable an adequate mathematical analysis of wave parameters.

Wave modelling alone cannot be used as acceptable basis for designing of coastal protection structures in such complex areas as the Kakumäe region. For the needs of the planning of coastal protection measures it is necessary to carry out *in situ* wave measurements, in particular, during strong storms. Doing so is the only way to link together the open sea wave data, modelled wave properties in the vicinity of the peninsula, and factual wave properties in its coastal zone.

For coastal engineering purposes the values of wind speed and direction are the most important among standard meteorological data. They are necessary to analyse wave regime and water level in the Kakumäe region. General historical descriptions (e.g. Prilipko 1982) are not usable for this purpose.

The wind regime differs to a great extent in different parts of Estonia (Kull 1996). This feature suggests that the wind regime in Kakumäe Bay may be somewhat different from wind properties in the adjacent areas. Therefore, generally it may be necessary to analyse the specific wind data from sea areas affecting the Kakumäe region.

Kakumäe region is mostly affected by waves that are generated by winds blowing in the central part of the Gulf of Finland. In case of westerly winds wave characteristics are also affected by wind conditions in the northern sector of the Baltic Proper. Coastal wind data usually give a distorted picture of wind conditions on the open sea (Launiainen and Saarinen 1982). As the parameters of waves affecting the coastal zone depend mostly on the characteristics of the open sea winds, the possibilities of usage of available data must be critically reviewed. The experience from the Gulf of Finland and from the Väinameri (Moonsund) area suggests that numerically modelled wind fields cannot be used for this purpose in the area in question (Ansper and Fortelius 2003, Ennet 1998).

Some experts recommend that regularly measured wind data in Tallinn Vanasadam (Oldharbour), Miiduranna harbour and Cityhall district may be used for a more exact analysis of wind regime in the vicinity of Kakumäe Peninsula (T. Soomere, private communication). As these data belong to private companies, it is not clear yet if and on which conditions they can be used.

The nearest meteorological station to Kakumäe is located at Harku (Keevallik 2003a,b). Its data is often used to characterize the wind regime in sea areas near city of Tallinn (e.g. Saat and Järvik 2003, Saaremäe 2002). More precise surveys have, however, shown that on the basis of Harku data it is not possible to reconstruct the winds blowing on the Gulf of Finland or even Tallinn Bay

(Keevallik 2003a,b). They are usable only to reconstruct east-west components of open sea winds in some seasons.

Wind data from the southern coast of the Gulf of Finland give a strongly distorted picture of open sea wind properties (Soomere and Keevallik 2003). Also they inadequately describe directional distribution of wind events (Keevallik 2003a). The data from these stations are strongly affected by the Estonian mainland (Keevallik 2003a). Only the data measured in Pakri observation station in Paldiski represent to some extent the westerly winds blowing on the Gulf of Finland.

Of meteorological data measured in Estonia the best ones for describing wind conditions on the Gulf of Finland have been measured at a Soviet Union military meteorological station on the Island of Naissaar. The data were restored on the basis of observation diaries in 2003 (Keevallik 2003a). The step of measurements of the wind direction is moderate (only 16 directions with a step of 22.5˚ have been used until 1990), thus the data is more suitable to assess wind speeds.

The most representative data describing winds in the central part of the Gulf of Finland has been measured at Kalbådagrund (59˚59'N, 25˚36'E; Launinainen and Laurila 1984, Keevallik 2003b). It is also possible to use data registered on ships (Mietus 1998, Niros *et al.* 2002) and at meteorological stations in coastal waters of Finland. Finnish meteorological data is relatively homogenous, registered eight times a day for a long time already. Most of the data is reliable for reconstructing wind conditions on the open sea.

The existing scientific publications (e.g. Soomere and Keevallik 2003) contain many interesting details of the wind climate in the central part of the Gulf of Finland such as occurrence frequencies of winds from different directions, dominating wind directions, and estimates of maximum wind speed in long-lasting storms.

In assessing wave loads the most important data are the maximum values of average wind speed in storms that last for several hours. The data about wind speeds of 30–35 m/s are not usable in wave analysis because such strong winds blow rarely here and are located in very small areas, thus the generated waves remain low. Launinainen and Laurila (1984) have analyzed the frequency of strong storms occurring on the Gulf of Finland. The maximum average wind speeds in storms lasting for 3 hours and which occur in different parts of the Gulf of Finland with a return period of 1–100 years have been found and compared to relevant estimates in the northern sector of the Baltic Proper in (Soomere and Keevallik 2003).

Therefore waves in Kakumäe are mostly affected by wind conditions on the open sea of the Gulf of Finland and the Baltic Sea. As local winds and wind conditions do not affect considerably waves in Kakumäe region it is perhaps not necessary to carry out measurements in that area. This feature can save some funds.

Although the cost of the commercial usage of wind data from Finland may be quite high, purchase of the relevant permission may be important for an adequate description of wind, wave and current fields in the Kakumäe area. For example, for adequate estimates of e.g. wave loads in a certain area the realistic wind data must be used to force the wave model (Soomere 2005a).

Therefore it is essential to get permission to use the meteorological data measured at Kalbådagrund. For estimates of hydrodynamic loads in extreme storms analogous data from Bogskär (located in the northern sector of the Baltic Proper) may be the most appropriate (Soomere 2003b, 2005). The data belong to the Meteorological Institute of Finland and it is possible to use them for free for scientific studies only.

Visual observations of coastal processes with contemporary means

The morphodynamic processes at the coasts of Kakumäe depend on several external factors (water level, waves, ice conditions etc.) as well on details of the local geological structure.

Already assessment of external driving forces is a very complicated problem in bays which are strongly affected by the open sea. The reason of complexity is that the different hydrodynamic processes frequently depend less on local forcing factors and many of the processes are mostly driven by remote forces (Laanearu 2003). In other words, in semi-sheltered bays it is often necessary to take into consideration impacts which originate from large sea areas (e.g. storm waves from the open sea, currents induced by open sea water circulation). In particular cases, the joint impact of underground fresh water flow (which destabilises some layers of the cliff), remotely generated waves and currents dominate the cliff recession as well as the hydrodynamic influence on the characteristics of sediment transport (Koppel and Laanearu 2005).

The coast and coastal processes of Kakumäe Peninsula are extremely intermittent. The regions of abrasion and accumulation depend directly on the geological structure in the immediate vicinity of the waterline. Thus, the spatio-temporal variation of coastal processes at the coastline of Kakumäe should be taken into account to obtain a comprehensive picture of their main properties.

The dynamics of the coastal zone elements is a three-dimensional problem. As a first approximation, frequent geodetic surveys would give an adequate picture about functioning of coastal processes. Owing to the complexity of coastal processes in this area, their long-term visual monitoring with the use of video cameras/recorders may be necessary to obtain an overview of different processes. This apparently allows localizing naturally protected regions as well as areas of erosion, transit and accumulation. Some years of coastal monitoring in the hot spots would give information about the trends of coastal processes and about the location of erosion-sensitive areas.

Another important goal of visual monitoring consists in determining the range of the surf zone, which is one of the decisive factors in analysing the dynamics of sediments in the coastal zone (Dean and Dalrymple 2002). Usually the properties of the surf zone are analysed with the use of high-resolution wave models (e.g.

Soomere *et al.* 2005). Visual monitoring apparently gives more exact information about the characteristics and peculiarities of breaking waves. An ideal solution would be installing 4–5 videocameras in certain sections of the coast of interest.

Recording temporal and spatial variability in fast-changing sections of coast enables to analyse different processes in detail. It will also give ground for practical recommendations to ensure the protection of natural resources, protection of existing buildings, and for planning of further activities on Kakumäe Peninsula.

Novel and integrated approaches

Coarse-grained sediments dominate in most of Kakumäe coast. Therefore the concept of equilibrium (sandy) beach and the relevant analytical methods (Dean and Dalrymple 2002, see applications for Estonian conditions in Soomere *et al.* 2005) are not directly applicable in the Kakumäe region. Detailed modelling of sediment transport in such regions are connected with great difficulties and uncertainties concerning sea bottom relief, sediment characteristics, local currents and variability of waves (e.g. Kuhrts *et al.* 2004). Modelled and measured amounts of sediment transport often differ by tens and hundreds of times. Estimations in the magnitude of sediment transport are frequently regarded as satisfactory (Davies and Villaret 2002).

The inaccuracy of wind data is one of the reasons of such uncertainty. The resolution in wind directions is 22.5° and the wind speed is measured with a step of 1 m/s in the historical data. This coarse resolution does not allow accurate reproducing of necessary details of wave dynamics and sediment transport, in particular, to correctly resolve the wave attack angle at the vicinity of the shoreline.

In this region the coast and its topography are very complicated and the temporal and spatial distribution of sediments is irregular. Usually the properties of bottom sediments are known only in places and only for the top layer. Strong storms generate a resuspension of the fine fraction of sand of about 200–300 kg/m^2. In other words, they can move sediment-layers of some tens of centimetres (Jönsson 2005). Hence the characteristics of bottom sediments may substantially change during storms, which may e.g. remove the entire sand layer and reveal gravel underneath it.

However, modern models of waves and sediment transport enable to determine adequately the direction of sediment transport and its relative intensity in different parts of the coast. By comparing these results with the outcome of geological studies and with the results of coastal monitoring it is usually possible to estimate the average intensity of sediment transport in different parts of the coast (cf. Soomere *et al.* 2005).

Classical solutions of coastal protection structures are based mainly on field data. For their adequate design, long-term monitoring of local processes is necessary in order to ensure that the data series are long and profound. The solutions based solely on field data are very costly and time-consuming. The modern means of data analysis and modelling of natural processes can be used for lowering the costs and accelerating the planning process.

The aim of the decision-makers is usually to find the most cost-effective and environmentally acceptable type of coastal protection structure(s) and determining its (their) location. To a great extent this work can be done by combining estimates based on historical hydrometeorological data, mathematical modelling, and relatively short-term geological, geodetic and hydrometeorological surveys.

In the light of the above presentation it is obvious that a solution for coastal protection cannot be 100% exact, effective and environmentally friendly. For example, at certain places of the Kakumäe coast lie big clusters of boulders which act as natural breakwaters. They modify locally the dynamics of sediments. When coastal protection measures will be effective, their role can be changed and may result, e.g. in a trend of forming tombolos. Therefore, after applying large-scale coastal protection measures, certain sections of coast may need specific solutions. It may also become necessary to involve experts from other fields or domains afterwards. This aspect also has to be taken into account when planning long-term coastal protection.

The existing experience has shown that to get a desired result very different technical solutions of variable cost may be implemented (Dean and Dalrymple 2002). The cost of relevant field and modelling studies, and research directed to establishing the best solution usually forms a tiny part of the total budget of the coastal defence measures. This suggests that a thorough underlying study of local processes, scrutinising of many different protection ideas and extensive modelling of their effect may lead to the most innovative and cost-effective solutions. Contrariwise, stingy planning of the budget of the research of coastal processes and other environmental aspects preceding the decision may result in large additional costs in the construction stage.

Restrictions for the development process

Coastal protection activities inevitably lead to substantial changes of the situation at the sea coast. Although the results of the activities are directed towards improving the natural conditions, one has to follow the existing legal rules for these activities as well.

Estonian legislation requests that before any artificial alteration of the coast (line) there has to be carried through a process called the environmental impact assessment (EIA). It is something that most of the people have heard about and think they know what it is when in fact it has become more and more frequent that very few people know what it actually is, how expensive it could be and, last but not least, how much time it may take (Kask *et al.* 2006, Lapimaa and Soomere 2006). Such a controversial phenomenon occurs mainly due to ambiguities in legislation and sometimes owing to general incompetence of many people in coastal matters.

Depending on the particular case, the EIA may take relatively much time and work. This would probably be so in the case in question, because the Kakumäe area and its coastal sea clearly form a vulnerable region.

In order to effectively perform the EIA, the developer (which can be either the City of Tallinn or some private company, depending on the relevant decision) has an obligation to present to the EIA expert all necessary data. Usually the EIA experts ask for the data described in the above sections. The above has shown that high-quality and reliable data for this area is virtually non-existent. Therefore a reasonable EIA process may only be started after a certain amount of field and numerical studies have been already carried out.

From the description above and in the closing section of this paper it follows that the EIA procedure can be started after a year or so after launching the hydrodynamical and geological studies. This is somewhat inconvenient, because, in principle, the EIA expert may decide that the coastal defence structures are unacceptable from the environmental viewpoint. In this case, the funds already used for preliminary studies will mostly be lost.

However, this phase cannot be excluded from the process. This policy corresponds to the principles of precaution and of sustainable development (which are the fundamentals of European Union Law). Also, formally, the Act of EIA and environmental management systems, valid in Estonia since 2005, says that if the data is insufficient it has to be collected and analyzed until a profound decision will be made. Not until then can the development process continue.

The described features may somewhat increase the total budget of the coastal defence constructions. However, the more important factor to be accounted for during the planning stage is the duration of the EIA process, which usually takes from 4 to 6 months. Since the place in question is of considerable public interest, delays may occur during public discussions of the results.

The need of performing the EIA, however, can be used in an economically effective way. One of the principles of the existing practice of EIAs in Estonian coastal waters consists in inviting leading marine and coastal experts to participate in the EIA process (Lapimaa and Soomere 2006). The idea behind doing so is that the coastal zone is, so to say, a *rendez-vous* place of four elements – earth, water, air, and human – where very specific processes can occur. In this extremely complex ecosystem human activity may be a decisive factor and together with the other three elements it may have a synergic effect.

This suggests that it is of utmost importance that the best available experts be included in large-scale projects such as the coastal protection. Of course competent experts should be included in projects of any scale but, without doubt, in big projects if anything goes wrong the consequences are of far greater extent. The best available experts can take numerous different conditions into consideration. The experience formulated during the EIA procedure can be used in other planning stages where usually local experts and civil and coastal engineers are involved. A wise use of such an expertise may reduce costs of, e.g. project preparation activities.

The European Commission (EC) has set up how coastal zone can be best managed. As many of the coastal zones in Europe have gone through a significant deterioration, the EC has launched the Integrated Coastal Zone Management (ICZM) program. Since 1996, the European Commission has been working to identify and promote measures to remedy this deterioration and to improve the overall situation in our coastal zones (see http://europa.eu.int/comm/environment/iczm/home.htm). The aim of this programme is to provide technical information about sustainable coastal management and to bring up an intense public discussion between the interested actors who use the coastal zone in Europe.

The EU is also concerned about biodiversity. As a result of erosion habitats diminish in area, hence the biodiversity shrinks. The EC says that "although erosion and accretion are natural phenomena, ill-planned human activities aggravate the occurrence and consequences of coastal erosion." From January 2002 to May 2004 a € 5 billion pan-European study called "EUrosion" was carried out to map the real current situation in the coastal zones and to give recommendations how to protect these areas (see http://www.eurosion.org/). In this framework, the strategic environmental impact assessment has been connected to the ICZM as it enables to deal with the project in an early stage and to avoid cumulative effects.

Steps to follow

The above has shown that a large complex of studies is necessary prior to adequate planning of coastal defence. In this section, we estimate the minimum extent and costs of such studies in the particular case of Kakumäe Peninsula. The relevant estimates are mostly based on the expert opinion (Soomere *et al.* 2006b). The expenses reflect prices in 2005 and apparently are subject to gradual increase in the future.

Hydrodynamic studies and modeling

The analysis may take about 5–8 months. The necessary procedures for the analysis are:

- Measuring the characteristics of waves near the peninsula during storms.
- Collecting, systematizing and analyzing historical data about water levels, ice conditions, waves and wind conditions near Kakumäe peninsula and its vicinity.
- Analysis long-term statistics, data series and extreme characteristics of waves and water level on the basis of wind data and mathematical modeling.
- Analysis of characteristics and properties of simultaneous occurrence of waves and high water level in extreme conditions.
- Estimation of the probability of joint occurrence of high wave and extremely high water level.

- Analysis of the wave-induced intensity and direction of sediment transport processes in different parts of the coastline on the basis of modeled wave statistics.

The last phase of the analysis can be only started after the geological survey of the coastal zone bathymetry has been completed. The measurements of waves must be done during a stormy period.

Geological research, geodetic and hydrographic surveys

The analysis may take about 15 months. Combining different works may somewhat shorten the period. The necessary procedures for the analysis are:

- Establishing peculiarities of sediments in Kakumäe Peninsula coastal zone.
- Separating areas of erosion, transport and accumulation.
- Establishing transport of and sedimentation characteristics of bottom sediments.
- Geodetic surveys should be performed 2-3 times per year during at least 2 years.
- Repeated surveys of coastal relief and bathymetry in the most important and active parts of Kakumäe coastline may be necessary.
- Determining the location and height of the erosional scarp.
- Measurement of the profile of the coastal slope up to 5 m depth, with a step of 50-100 m.

Synthesis

The results of the listed studies enable to:

- determine naturally preservable segments of the coast;
- determine segments that need active of passive protection;
- formulate the principal concept and possible special conditions of coastal protection structures, which may be used as the initial problem for project works;
- or, alternatively, to formulate the technical conditions for the competition of design of the coastal protection concepts and sketch of relevant measures;
- present at least one acceptable draft of protection measures;
- give an evaluation of the cost and realisation time of at least one method;
- analyze the need for applying for necessary environmental permits and the need for an environmental impact assessment.

This phase may take about 1-2 months provided that the former studies have lead to unambiguous results. However, the existing practice suggests that at this stage questions needing short additional surveys or modelling efforts arise frequently. Therefore, the realistic time allocated for this stage should be about 4-6 months.

The material presented in Paper II vividly demonstrates the enormous complexity of the decision-making process of planning of coastal protection measures. Although the Baltic Sea is one of the best - studied sea area in the world both from scientific and applicational aspects, the typical situation with coastal engineering is that there is a great lack of data for sea or coast areas of particular interest.

In many cases the data can be interpolated between spatially scattered areas; however, this method seldom gives good results for coasts with very complex geometry and bathymetry. The relevant experience in the Estonian coastal areas is that even adjacent and qualitatively similar areas have greatly different features of dominating hydrodynamical loads and properties of coastal sediments (e.g. Elken *et al.* 2001, Paper I, Valdmann *et al.* 2006), and, therefore, may need drastically different measures to protect the coasts.

The necessity of performing specific analysis of relevance of data, filling gaps in the data and performing necessary *in situ* measurements greatly increases both the cost and duration of the planning stage of the coastal protection measures. This is the situation also in the case of Kakumäe area. Despite an extremely large pool of existing data and estimates concerning hydrometeorological and geological conditions in the very neighbourhood of the area of interest – which is partially reflected in the References section of this paper – only very few data can be directly used for design of coastal protection measures.

Some information definitely can be extrapolated from open sea data or data measured in adjacent areas. For example, the open sea wind fields usually are relatively homogeneous and data measured at a distance of many tens of kilometres can be used for adequate wave analysis (Soomere 2005c). In the contrary, sea currents are highly variable in the Gulf of Finland (Andrejev *et al.* 2004) and their measurements have to be carried out in the vicinity of the area in interest.

There are two basic possibilities to perform a thorough analysis to give a grounded prognosis about the possible changes, construction perspectives and risks in the coastal zone of Kakumäe Peninsula. First, one may use long-term observation data. Second, mathematical modelling in combination with short-term but reliable data series is an opportunity. The best choice to decrease the costs and shorten the duration of the decision-making procedure consists in reasonable combining of both the listed possibilities.

The key factor is the quality of observation data. The longer the series is the more reliable the prognoses are. Existing observation data are scattered in both space and time and do not make up a unitary system. The current situation is that the existing data allow forecasting neither the impact of single storms nor long-term changes at the Kakumäe coast with a satisfactory accuracy for the need of construction-works. Therefore, collection and analyze of data is of crucial importance.

The study should start with the analysis and monitoring of coastal processes. That way it is possible to locate the areas of erosion and accumulation as well as naturally protected sites on the coast, and to determine the characteristics of bottom sediments in the coastal zone. Field works should be carried out during at least two relatively stormy periods.

A monitoring program with a duration of at least two years will enable to describe the characteristics and intensity of litohydrodynamical processes at the coast and in the coastal zone. The results of monitoring will help determine areas sensitive to impact of various factors. The minimum cost of the studies is of the order of 100 000 euro.

The developer, therefore, must bear in mind that the process of finding suitable experts, performing the EIA, then of planning, finding the means, and finally construction-works take a lot of time, patience and money. The above has shown that Kakumäe Peninsula's coastal processes are very intermittent and may reveal many unexpected features which may delay the whole process and/or increase its cost.

Finally, we emphasise that planning long-term coastal protection measures is a multi-faced problem, adequate and successful handling of which needs a lot of time, substantial material resources, extended knowledge of specific features of coastal environment and art of unifying different views to the whole process. However, this is the only way to effectively handle many problems of coastal zone management.

Final remarks

The presented material demonstrates the enormous complexity of the decision-making process of planning coastal protection measures. Although the Baltic Sea is one of the best – studied sea areas in the world both from scientific and applicational aspects, the typical situation with coastal engineering is that there is a great lack of data for sea or coast areas of particular interest.

In many cases the data can be interpolated between spatially scattered areas; however, this method seldom gives good results for coasts with very complex geometry and bathymetry. The relevant experience in the Estonian coastal areas is that even adjacent and qualitatively similar areas have greatly different features of dominating hydrodynamical loads and properties of coastal sediments, and, therefore, may need drastically different measures to protect the coasts.

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A monitoring program with duration of at least two years will enable to describe the characteristics and intensity of litohydrodynamical processes at the coast and in the coastal zone. The results of monitoring will help determine areas sensitive to impact of various factors. The minimum cost of the studies is of the order of a few millions of crones even for relativelt short coastal sections (Paper II).

Finally, we emphasise that planning long-term coastal protection measures is a multi-faced problem, adequate and successful handling of which needs a lot of time, substantial material resources, extended knowledge of specific features of coastal environment and art of unifying different views to the whole process. However, this is the only way to effectively handle many of problems of coastal zone management.

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Summary and main conclusions proposed to defend

1. The possibilities of protecting the coasts of the Tallinn area have been systematically analysed and protection measures have been partly worked out on the initiative of the post-graduate.

2. The principles of sustainable development and integrated coastal zone management and methods for a more uniform distribution of anthropogenic load for the coastal area of the bay of Tallinn have been worked out.

3. The roles of decisive and executive bodies of different levels for the management of Estonian coastal areas have been defined and the principles of cooperation for reasonable development of coasts have been presented.

4. The influence of underwater mining on the natural development of the coastal area has been specified based on the example of mining underwater sand and gravel in the Tallinn area for the needs of port construction and coast fortification.

5. Based on the example of the Kakumäe Peninsula the problems linked to the development and protection of the coastal area have been analysed. The thesis specifies the need for a detailed analysis of the processes influencing the Kakumäe area. The principles of planning coastal fortification facilities have been formulated, taking into consideration Estonian legislation. The thesis presents a sample plan for the implementation of protection measures for the Kakumäe area.

6. It has been demonstated that due to the geological structure of the coast and coastal slope of the Bay of Tallinn, also due to relatively great anthropogenic load and the specific features of the waves of the Baltic Sea the hydrodynamic influence of the high-speed traffic on the coastal area is one of the most substantial factors.

7. Typical and extreme parameters of natural waves in the open part of the northern sector of the Baltic Sea have been specified in cooperation with the scientists of the Institute of Cybernetics at TUT and the Swedish Meteorological and Hydrological Institute.

8. The thesis demonstrates that the intensity of wind waves is characterized

by great seasonal variability: the average monthly wave altitude varies up to three times (from 0.5m up to 1.4m). It affects the formation of coasts differently.

9. It has been shown that the period of wind waves in the open part of the Baltic Sea lasts usually for 4-6 seconds and up to 10 seconds in case of extreme storms which is generally shorter than the periods of the highest speed ship waves.

10. The postgraduate with his co-authors shows that the average annual altitude of natural waves grew approximately 1.8% per year during 1979-1995, but the intense growth of waves has probably come to a halt at the change of the century.

Kokkuvõte ja kaitstavad seisukohad

Tallinna rannikualade haldamine loodusliku ja antropogeense surve tingimustes

1. On süstematiseeritud Tallinna piirkonna rannikute kaitse võimalused ja hinnatud Tallinna lahe rannavööndi arendamisega seotud ohud. On välja töötatud neutraliseerimise või leevendamise võimalused. Osa vastavaid meetmeid on doktorandi eestvedamisel ka ellu viidud.

2. On välja töötatud Tallinna lahe ja selle lähiümbruse ranniku ja rannikumere piirkondade jätkusuutliku arengu ja kompleksse haldamise printsiibid ning võtted antropogeense koormuse ühtlasemaks jaotamiseks.

3. On formuleeritud erineva tasandi otsustuskogude ja täitevvõimu rollid Eesti rannikualade haldamisel ning esitatud nende koostöö printsiibid rannikupiirkonna mõistliku arendamise vallas.

4. Veealuse liiva ja kruusa kaevandamise näitel Tallinna piirkonnas planeeritavate sadamaehitustööde ja rannakaitserajatiste vajadusteks on positsioneeritud veealuse kaevandamise mõju rannikupiirkonna loomulikule arengule.

5. Kakumäe poolsaare näitel on analüüsitud rannikupiirkonna arendamise ja kaitsmisega seotud probleemideringi keerukust ning seda piirkonda mõjutavate protsesside detailse analüüsi vajalikkust. On formuleeritud rannikute kaitserajatiste planeerimise printsiibid ja vajalikud sammud Eesti seadusandluse valguses ning esitatud näidisplaan Kakumäe piirkonna kaitse meetmete rakendamiseks.

6. On demonstreeritud, et Tallinna lahe ranna ja rannanõlva geoloogilise ehituse, suhteliselt suure antropogeense koormuse ning Läänemere lainetuse spetsiifika tõttu on kiirlaevaliikluse hüdrodünaamiline mõju randade arengule üks arvestatavaid tegureid.

7. Koostöös TTÜ Küberneetika Instituudi ja Rootsi Meteoroloogia ja Hüdroloogia Instituudi teadlastega on leitud looduslike Läänemere avaosa põhjapoolse sektori lainete tüüpilised ja ekstreemsed parameetrid.

8. On näidatud, et tuulelainete intensiivsusel on tugev sesoonne muutlikkus: kuu

keskmine lainekõrgus varieerub kuni kolm korda (0,5 meetrist kuni 1,4 meetrini). Sellel on oluline sesoonne mõju randade arengule.

9. On näidatud, et tuulelainete perioodid isegi Läänemere avaosas on tavaliselt 4-6 sekundit ning ulatuvad 10 sekundini vaid ekstreemsetes tormides ning on seega üldjuhul väiksemad kõrgeimate kiirlaevalainete perioodidest.

10. Dissertant kaasautoritega on tõestanud, et looduslike lainete aasta keskmine kõrgus kasvas aastail 1979-1995 ligikaudu 1,8% aastas, kuid lainetuse intensiivsuse kasv on sajandivahetusel tõenäoliselt pidurdunud.

Appendix: Curriculum Vitae

Personal data:

Name	Ain Valdmann
Date and place of birth:	February 11, 1950, Rakvere, Estonia
Contact:	Department of Engineering Services, Mündi 2, 15197 Tallinn, Estonia;
	Phone: 640 46 44;
	E-mail: Ain.Valdmann@tallinnlv.ee
Marital status:	married, 3 children
Education and qualifications:	
1968	Rakvere Secondary School No 1
1968 - 1974	Tallinn University of Technology, Diploma in Mechanical Engineering (5.5-year curriculum)
2006 - 2008	Tallinn University of Technology, Faculty of Civil Engineering, postgraduate study
Language competence:	Estonian – native language, Russian, Finnish – intermediate level, English – primary level

Professional training:

1996	*Computer course.* EUROTEC
1997	*Problem set-up and systematic solutions. Rational work organisation.* AS PRO Konsultatsioonid
1997	*Management training.* Dartford Town Council and The University of Greenwich, Department of Economy
1998	*Occupational safety courses.* AS TIGRIS
1998	*Training programme for the EU contact persons.* ESKO koolitus

1999	*Local governments and the EU.* Eesti Eurokonsultatsioonid
1999 - 2000	*TUKEVA 9 (9-stage programme).* Helsinki Training and Development Centre
02.02.2001	*Basic computer course.* 20h, BCS Tallinna Arvutikool
26.-27.04.2001	*Impressive presentation.* Invicta
24.-25.05.2001	*Negotiating and influencing skills.* Invicta
27.-28.09.2001	*Strategy compilation and effectuation.* Amix Consulting
19. and 26.10.2001	*Adaptation to changes in working environment. Team work.* Psychologist M. Torokoff
13.-14.03.2002	*Conference of winter roads.* 2002 Helsinki
22.03.2002	*Estonian National Development Plan – the role of local governments and their associations in ENDP*. EAHI
14.05.2002	*Stress management of officers.* 16h, AS PE Konsult
24.05.2002	*Leaders' development program.* OÜ Inscape Koolitus
05.12.2002	*Personality of the leader and psychological principles of leadership.* Addenda OÜ
31.03.-02.04.2003	*Training on the EU funding*
28.03.2003	*Computer training MS Outlook 2000*. BCS Koolitus
03.-04.2003	*FIDIC seminar*
04.04.2003	*Special seminar "City Tree".* Estonian Association of Municipal Engineering
21.-26.05.2003	*Kiev VII International scientific-practical conference "Creativity Saves the World"*
30.09.2003	*III International Information Day on road care and municipal engineering*
10.-13.02.2004	*Conference of winter roads* in Vaasa
11.-12.03.2004	*Leadership training for the executives of admininstrative agencies. Part I*. OÜ Unity Eesti
23.-24.04.2004	*Leadership training for the executives of admininstrative agencies. Part II.* OÜ Unity Eesti
10.-11.06.2004	*Municipal Equipment Days of Vantaa*
21.10.2004	*How to improve work organisation.* Meistrite Tee MTÜ
27.10.2004	*Work and cooperation culture at school.* Tartu University
19.11.2004	*Management of changes.* Meistrite Tee MTÜ
25.11.2004	*Team-work with contract partners.* Municipal Engineering Services Department
03.-04.02.2005	*Leadership training for the executives of admininstrative agencies. Part III.* Meistrite Tee MTÜ
14.04.2005	*Connection between purposeful management, strategic*

	planning and city budget. Urmas Hallika, Ahti Kallaste, Tallinn City Office
28.-29.04.2005	*Leadership training for the executives of admininstrative agencies. Part IV.* Meistrite Tee MTÜ
25.-28.05.2005	*Municipal Equipment Days of Lahti*
08.06.2005	*Implementation of city illumination modules.* LUCI Association
08.11.2005	*Basic knowledge for executives about state procurement.* Addenda
30.11.2005	*Adoption of the EU common currency in Estonia.* Bank of Estonia
2.-3.02.2006	*Leadership training for the executives of admininstrative agencies. Part V.* Meistrite Tee MTÜ
5.05.2006	*Basic knowledge of internal audit.* KPMG Baltics AS
08.-10.06.2006	*Municipal Equipment Days of Vaasa 2006*
7.-29.09.2006	*Leader's role in financial management of the Tallinn City Government*. Sander Karu
19.-20.10.2006	*Crisis regulation team training.* Tallinn Emergency Medical Service Training Centre.
2.-3.11.2006	*Work efficiency.* Unity Eesti OÜ
8.-9.11.2006	*Project management.* Helvetia Balti Partnerite OÜ
24.11.2006	*Work stress management.* PE Konsult AS

Professional career:

02.1974-01.1977	Estonian Consumers Co-operative Society ETKVL - Engineer, Chief Engineer
01.1977-12.1980	Tallinn Dwelling Administration - Director of Planning Department
12.1980-08.1987	Tallinn Dwelling Administration - Chief Engineer
08.1987-02.1991	Tallinn Dwelling Administration - Director
05.1991-08.1993	AS BELO - Director General
09.1993-05.1995	Mustamäe District Administration - Deputy to the District Elder
06.1995-01.1997	Nõmme Real Estate Municipal Entrust - Director
02.1997 ...	Municipal Engineering Services Department – Director

Additional information:

Membership:	Tallinn Technical University - Member of Alumnus Board
	Academic Male Choir of the Tallinn Technical University, Honorary member
	Association "Lighting Urban Community International" (LUCI) - Representative of the city of Tallinn Estonian Association of Municipal Engineering - Member of Management Board

Appendix: Elulookirjeldus

Isikuandmed:

Ees- ja perekonnanimi:	Ain Valdmann
Sünniaeg ja -koht:	11.02.1950, Rakvere
Kontaktandmed:	Tallinna Kommunaalamet, Mündi 2, 15197 Tallinn, Eesti;
	Telefon: 640 46 44;
	E-post: Ain.Valdmann@tallinnlv.ee
Perekonnaseis:	Abielus, 3 last

Hariduskäik:

1968	Rakvere 1. Keskkool
1968 - 1974	Tallinna Polütehniline Instituut masinaehitustööstuse insener-ökonomist viie ja poole aastase õppekavaga
2006 - 2008	Tallinna Tehnikaülikool, Ehitusteaduskond, doktorantuur
Keelteoskus:	Eesti keel – emakeel, vene ja soome keel – kesktase, inglise keel – algtase

Täiendusõpe:

1996	*Arvutikursus*. EUROTEC
1997	*Probleemi püstitamine ja süsteemne lahendamine. Ratsionaalne töökorraldus.* AS PRO Konsultatsioonid
1997	*Juhtimiskoolitus.* Dartfordi Linnavalitsus ja Greenwichi Ülikooli majanduskateeder
1998	*Töökaitsekursused..* AS TIGRIS
1998	*Euroopa Liidu kontaktisikute koolitusprogramm.* ESKO koolitus
1999	*Kohalik omavalitsus ja Euroopa Liit.* Eesti Eurokonsultatsioonid

1999 - 2000	*TUKEVA 9 (9 osaline programm).* Helsingi linna koolitus- ja arenduskeskus
02.02.2001	*Arvuti põhikursus.* 20 t, BCS Tallinna Arvutikool
26.-27.04.2001	*Mõjuv esinemine.* Invicta
24.-25.05.2001	*Läbirääkimis- ja mõjutamisoskused.* Invicta
27.-28.09.2001	*Strateegia koostamine ja elluviimine.* Amix Consulting
19. and 26.10.2001	*Töökeskkonna muudatustega kohanemine.Meeskonnatöö.* Psühholoog mag M. Torokoff
13.-14.03.2002	*Talveteede kongress.* 2002 Helsingis
22.03.2002	*Riiklik arengukava ja omavalitsuste ning nende liitude roll selles*. Eesti Avaliku Halduse Instituut
14.05.2002	*Ametniku tööstressi ohjamine.* 16 t, AS PE Konsult
24.05.2002	*Juhtide arendusprogramm.* OÜ Inscape Koolitus
05.12.2002	*Juhi isiksus ja juhtimise psühholoogilised põhimõtted.* Addenda OÜ
31.03.-02.04.2003	*Eurorahastamise koolitus*
28.03.2003	*Arvutikoolitus MS Outlook 2000*. BCS Koolitus
03.-04.2003	*FIDIC seminar*
04.04.2003	*Eriseminar „Linnapuu“.* Eesti Kommunaalamjanduse Ühing
21.-26.05.2003	*Kiievi VII rahvusvaheline teaduslik-praktiline konverents „Loomingulisus päästab maailma“*
30.09.2003	*III Teehoiu ja kommunaalmajanduse rahvusvaheline teabepäev*
10.-13.02.2004	*Talveeteede kongress* Vaasas
11.-12.03.2004	*Juhtimiskoolitus ametiasutuste juhtidele, I osa*. OÜ Unity Eesti
23.-24.04.2004	*Juhtimiskoolitus ametiasutuste juhtidele, II osa.* OÜ Unity Eesti
10.-11.06.2004	*Vantaa Kommunaaltehnika Päevad*
21.10.2004	*Kuidas parandada töökorraldust..* Meistrite Tee MTÜ
27.10.2004	*Töö- ja koostöökultuu koolis.* Tartu Ülikool
19.11.2004	*Muutuste juhtimine.* Meistrite Tee MTÜ
25.11.2004	*Meeskonnatöö lepingupartneritega.* Kommunaalamet
03.-04.02.2005	*Juhtimiskoolitus ametiasutuste juhtidele, III osa.* Meistrite Tee MTÜ
14.04.2005	*Eesmärgipärase juhtimise, strateegilise planeerimise ja linna eelarve omavaheline seos.* Urmas Hallika, Ahti Kallaste, Tallinna Linnakantselei
28.-29.04.2005	*Juhtimiskoolitus ametiasutuste juhtidele, IV osa.* Meistrite

	Tee MTÜ
25.-28.05.2005	*Lahti Kommunaaltehnika Päevad*
08.06.2005	*Linnavalgustuse moodulite rakendamine.* LUCI Association
08.11.2005	*Mida peab teadma juht riigihangete korraldamisest..* Addenda
30.11.2005	*Eesti liitumine Euroopa ühisrahaga..* Eesti Pank
2.-3.02.2006	*Juhtimiskoolitus ametiasutusjuhtidele,Vosa.* Meistrite Tee MTÜ
5.05.2006	*Siseauditi baasteadmised.* KPMG Baltics AS
08.-10.06.2006	*Vaasa Kommunaaltehnika Päevad 2006*
7.-29.09.2006	*Juhi roll Tallinna Linnavalitsuse finantsjuhtimises*. Sander Karu
19.-20.10.2006	*Tallinna kriisireguleerimiskoolitus.* Tallinna Kiirabi Koolituskeskus
2.-3.11.2006	*Töö tõhustamine.* Unity Eesti OÜ
8.-9.11.2006	*Projektijuhtimine.* Helvetia Balti Partnerite OÜ
24.11.2006	*Tööstressi ohjamine.* PE Konsult AS

Teenistuskäik*:*

02.1974-01.1977	ETKVL Tööstuskoondis, insener, vaneminsener
01.1977-12.1980	Tallinna Linna RSN TK Elamute Valitsus, plaaniosakonna juhataja
12.1980-08.1987	Tallinna Linna RSN TK Elamute Valitsus, peainsener
08.1987-02.1991	Tallinna Linna RSN TK Elamute Valitsus, juhataja
05.1991-08.1993	AS BELO, peadirektor
09.1993-05.1995	Tallinna Mustamäe Linnaosa Valitsus, vanema asetäitja
06.1995-01.1997	Nõmme KME direktor
02.1997 ...	Tallinna Kommunaalameti juhataja

Lisainfo:

Liikmelisus:	Tallinna Tehnikaülikooli Vilistlaskogu liige
	Tallinna Tehnikaülikooli Akadeemilise Meeskoori auliige
	Tallinna linna esindaja Rahvusvahelises Linnavalgustuse Liidus
	Eesti Kommunaalmajanduse Ühingu juhatuse liige

Papers published by the applicant

I Levald, Heino and Valdmann, Ain. 2005. Development and protection of the coasts in the Tallinn area. *Proceedings of the Estonian Academy of Sciences. Geology*, **54** (2), 119–136.

II Valdmann, Ain and Käärd, Arvo. 2006. Economical and environmental aspects of planning of shore protection activities: A case study of Kakumäe peninsula, City of Tallinn. *Vadyba. Management*. Vilnius University, **2** (11), 148–160.

III Broman, Barry; Hammarklint, Thomas; Rannat, Kalev; Soomere, Tarmo and Valdmann, Ain. 2006. Trends and extremes of wave fields in the north-eastern part of the Baltic Proper. *Oceanologia*, **48** (S), 165–184.

IV Valdmann, Ain; Kask, Andres; Kask, Jüri and Rannat, Kalev. 2006. Sustainable planning of underwater sand mining and beach protection in vulnerable semi-enclosed sea areas under heavy anthropogenic pressure. Geophysical Research Abstracts, *Geophysical Research Abstracts*, **8**, Paper 05578, CD, 4 pp, SRef-ID: 1607-7962/gra/EGU06-A-05578).

V Valdmann Ain, Käärd Arvo, Kelpšaitė Loreta and Soomere Tarmo. 2008. Marine hazards for the coasts of the City of Tallinn. Accepted for publishing in journal *Baltica*.

VI Valdmann, Ain. 2006. Pair method used in Cost-Benefit Analysis upon involving private sector in public procurement. *Vadyba. Management*. Vilnius University, **1** (10), 112–123.