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Protecting the Past and Planning for the Future

Results from the project "Cultural Heritage and Water Management in Urban Planning" (Urban WATCH)

CIENS Report 2015:1

Photo: Johannes de Beer

Tittel:
Protecting the Past and Planning for the Future: Results from the project "Cultural Heritage and Water Management in Urban Planning" (Urban WATCH)

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Sammendrag:
Denne CIENS-rapporten oppsummerer hovedfunnene i prosjektet "*Cultural Heritage and Water Management in Urban Planning*" (Urban WATCH), finansiert av Norges forskningsråd gjennom MILJØ2015 programmet, med økonomisk støtte også fra Riksantikvaren og Norges geologiske undersøkelse (NGU). Prosjektet startet i 2012 og ble avsluttet i 2015.

Rapporten består av fem kapitler. Etter en kort introduksjon (kapittel 1), blir funn fra prosjektet presentert i kapitlene 2, 3 og 4. Kapittel 2 gir en presentasjon av hvordan offentlige myndigheter i Norges to største byer håndterer utfordringer knyttet til vann, kulturminnevern og planlegging. Kapittel 3 beskriver hvordan utfordringer med overflatevann kan håndteres. I kapittel fire blir tre ulike tema berørt: spørsmålet om modeller for jord-vannbalanse i umettede arkeologiske lag, overvåkningsmetoder i arkeologiske lag, og sist i kapittelet presenteres data fra en evaluering om bruk av en nasjonal standard (NS9451) for miljøovervåkning og undersøkelser av arkeologiske kulturlag. I siste kapittel (kapittel 5) drøftes, og oppsummeres, noen av funnene i rapporten.

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Abstract:
This CIENS-report sums up the main findings from the project "*Cultural Heritage and Water Management in Urban Planning*" (Urban WATCH), financed by the Research Council of Norway through the MILJØ2015 programme, and co-funded by the Directorate for Cultural Heritage in Norway (Riksantikvaren) and the Geological Survey of Norway (NGU). The project started up in 2012 and ended in 2015.

The report consists of five chapters. After a short introduction (chapter 1), main research results are presented in chapters 2, 3 and 4. Chapter 2 gives a presentation of how authorities in the two largest cities of Norway deal with the challenges associated with water management, cultural heritage and urban planning. Chapter 3 describes how modern urban stormwater management can contribute to improved protection and preservation of archaeological remains. In chapter 4, several issues are being dealt with: Modelling the soil-water balance in unsaturated archaeological deposits. The chapter also raises the question: Should monitoring of oxygen or the redox-potential be used in standard monitoring programs? The last part of the chapter presents data from an evaluation of the use of the Norwegian standard for environmental monitoring and investigation of archaeological deposits (NS9451:2009). The last chapter (chapter 5) discuss, and sums up, some of the main findings in the report.

Preface

This CIENS-report sums up the main findings from the project "Cultural Heritage and Water Management in Urban Planning" (Urban WATCH), financed by the Research Council of Norway through the MILJØ2015 programme, and co-funded by the Directorate for Cultural Heritage in Norway (Riksantikvaren) and the Geological Survey of Norway (NGU). The project started up in 2012 and ended in 2015. The project was coordinated by the Norwegian Institute for Water Research (NIVA), and Tone M. Muthanna (2012-2013) and Pawel Krzeminski (2013-2015) acted as project managers of the Urban WATCH project in the respective periods.

The project comprised a multidisciplinary team of both national and international experts and researchers. From Norway: Tone M. Muthanna (the Norwegian Institute for Water Research/the Norwegian University of Science and Technology, NIVA/NTNU), Johannes de Beer and Anna Seither (Geological Survey of Norway, NGU), Kjell Harvold and Ragnhild Skogheim (the Norwegian Institute for Urban and Regional Research, NIBR), Alexander Rory Dunlop, Kari Larsen and Vibeke Vandrup Martens (the Norwegian Institute for Cultural Heritage Research, NIKU), and Pawel Krzeminski (NIVA). From outside Norway: Floris Boogaard (Delft University of Technology, the Netherlands), Henning Matthiesen (the National Museum of Denmark) and Michel Vorenhout (MVH Consult, the Netherlands). In addition, three Masters students from NTNU were involved in the project, doing the whole or parts of their thesis work at NTNU within the framework of the Urban Watch project. One of them was fully based at NGU.

The project team cooperated closely with Riksantikvaren (the Directorate for Cultural Heritage), Statsbygg and the municipalities of Oslo and Bergen. We wish to thank all partners for a very constructive and fruitful collaboration. The project comprised of three main work packages: one led by NGU, one by NIBR, and one by NIVA. The research from these three packages has led to in-depth knowledge about the key elements described in the project and are reported in separate scientific publications.

Since two of the partners in the project - NIBR, and the overall project manager, NIVA - are members of CIENS (Centre for Interdisciplinary Environmental and Social Research), the CIENS format has been chosen for the final report. However, all partners, whether inside or outside the CIENS organizations have of course contributed to the report. The constructive review and language control done by Rory Dunlop (NIKU) is highly appreciated. Arne Tesli (NIBR) and Sindre Langaas (NIVA) have been quality managers for chapters 1, 2 and 5 and chapters 3 and 4 respectively, and their constructive input is also highly appreciated.

One of the project's main objectives was to strengthen the network of expertise in Norway through the use of existing learning alliances and through building a strong cluster of multi- and interdisciplinary collaboration between national and international specialists, field experts, end-users and other stakeholders. A key goal of the work was to produce a synthesis of the whole project. This report - edited by Kjell Harvold (NIBR) and Kari Larsen (NIKU) - is the main contribution to such a synthesis.

Oslo, June 2015

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1 Cultural Heritage and Water Management in Urban Planning

By Kjell Harvold and Kari Larsen

1.1 Introduction

When Queen Kristina of Sweden was received in Rome in 1655, she believed that the fountains in St. Peter's Square were running in honour of her visit (Bjur 1988:14). Most graciously she decreed that the water could now be turned off! For the queen the principle of running water in an urban community – the *aque ductus* – was totally unknown. Her statement illustrates that the concept of water management in Scandinavia at that time was underdeveloped. The northern urban communities were small, and the challenges were of a totally different scale than in the larger cities of southern Europe.

Even today we see differences in the way water is being managed in various European countries, partly due to different historic roots and challenges. For instance, the Netherlands has - understandably - a long tradition with focus on the management of surface and ground water. Emphasis on these factors has been much weaker in many Nordic cities. However, today we see that the challenges presented by both surface and ground water are increasing in urban areas, not least in Norway. At the same time, the Norwegian system for water management has been built on a tradition that is not in all respects geared to solving the new challenges. Compared to the Netherlands, Norwegian planning **on** the ground and **below** the ground has traditionally been much more divided. This may lead to problems. Even a carefully thought-out plan for a city surface may lead to serious problems if the underground challenges are not included. This can be illustrated by the world heritage site, Bryggen, in the centre of Bergen. Bryggen has for a long time been considered a good example of preservation of historic sites, and cultural heritage management has long had a prominent position with regard to in-situ preservation of individual monuments and site. However, groundwater problems at the Bryggen site, problems first identified some 15 years ago but probably existing since the 1970s, have led to serious challenges. Fortunately, these problems are now being addressed, but they illustrate an important point: physical planning above the ground should be integrated with challenges below the ground.

1.2 The content of the report

The Urban WATCH project aimed at studying exactly these new planning challenges that lie in the tension field between planning above and beneath the ground. The research activities concentrate on the urban environment as well as on known actual threats to vulnerable cultural monuments and sites. The project has addressed specific management challenges related to cultural heritage protection and urban water management, and how cultural heritage considerations can be embedded in the planning system. Integrated in this, indicators and monitoring methods for cultural heritage sites at various scales, both for protection of standing monuments and for in-situ preservation of sub-surface archaeological deposits, have been developed.

Chapter 2 in this report shows how the two largest cities in Norway, Oslo and Bergen, approach and solve these challenges. Chapter 3 presents water management solutions designed to protect cultural heritage. Chapter 4 addresses documentation and monitoring of urban cultural heritage in general, and archaeological deposits in particular: what is a good monitoring practice – and how can we make documentation and monitoring results available and easily understandable? In the final chapter, chapter 5, we summarize the project's findings and point out some areas for further research.

All the chapters in this report draw on experiences from Bryggen in Bergen. In the next part of this introductory chapter, we therefore give a presentation of Bryggen.

1.3 Bryggen in Bergen

Bryggen in Bergen is a UNESCO World Heritage Site. It was included in the World Heritage List in 1979[1]. The site consists of sub-surface archaeological deposits and old, mainly wooden, buildings and constructions (including quays, streets and public spaces). The site is an old waterfront area and contains the oldest parts of the city of Bergen. In the Middle Ages, the Bryggen area was a vibrant quarter and a hub of international trade. The characteristic parallel rows of wooden buildings ('tenements'), running at right angles to the waterfront and separated by passageways and narrow eavesdrops, are remnants of an architectural tradition that has existed for almost 900 years. The existing tenements were built after a major fire in 1702. Today, there are 62 protected buildings at Bryggen, representing about one fourth of the extent of the post-1702 settlement.

"A hidden treasure"

The Bryggen area has burned down several times (for instance in 1248, 1476 and 1702) and the new city was built on top of the old building deposits. As a consequence of this, archaeological deposits remain the ground foundation of the current Bryggen. Today, these archaeological deposits in the Bryggen area reach a depth in excess of 10 metres, counting up to 155,000 m^3, which make it the largest remaining cohesive area of archaeological deposits in Norwegian medieval towns and cities (Christensson et al., in press-a).

The archaeological deposits stayed largely undisturbed by modern urban development for a long time, and therefore extended under the entire Bryggen area - like a hidden treasure. This treasure was first disturbed when the southern part of Bryggen was torn down in the early 1900s, and was later examined through archaeological investigations - especially following a major fire in 1955.

The archaeological heritage at Bryggen is part of the scheduled area "Medieval Bergen" (see Figure 1).

[1] For more information about Bryggen, see http://www.riksantikvaren.no

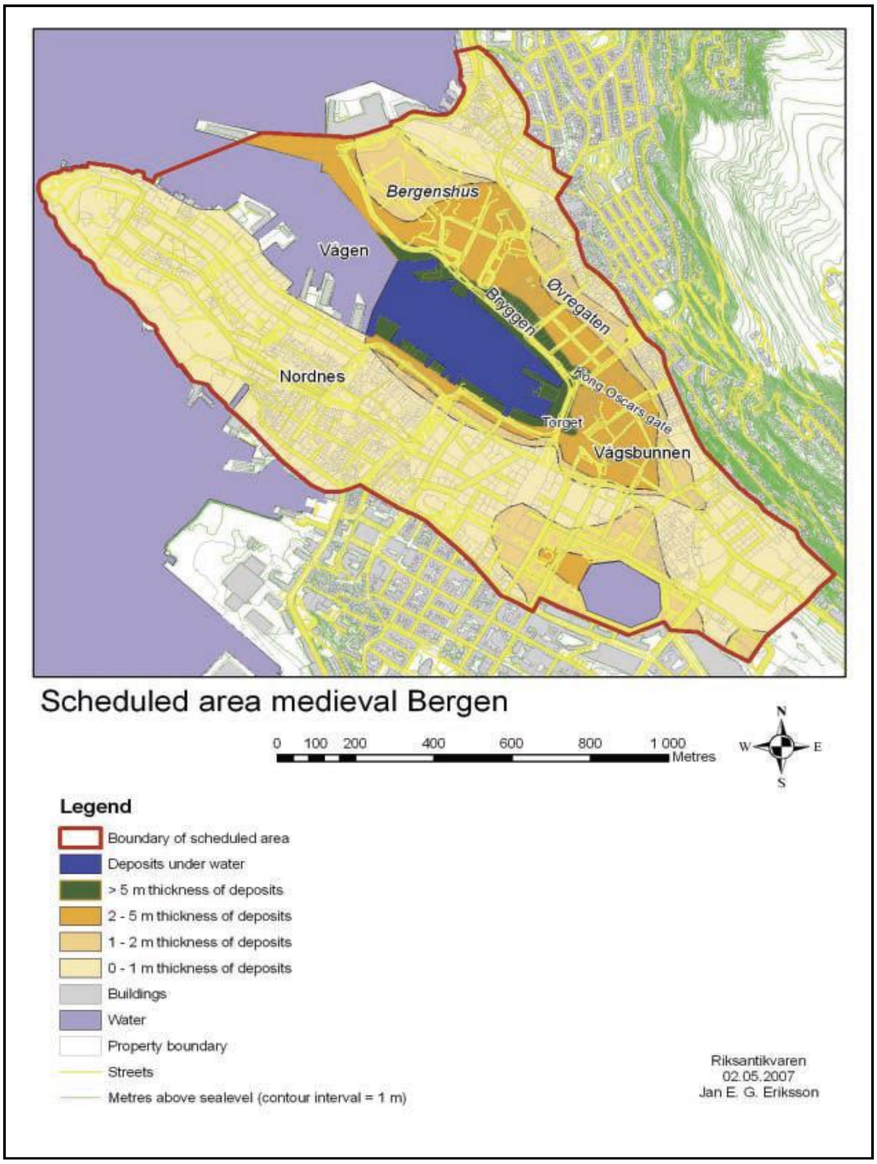

Figure 1: Map of the scheduled area "Medieval Bergen"

Bryggen's intact historic landscape is today managed as a cultural environment primarily through the Planning and Building Act and the current zoning plan for Vågen, Kaiene (the Quays) and Bryggen; interventions in the ground are subject to the Cultural Heritage Act.

World Heritage Site under threat

During the 1990s, the owners of the buildings within the World Heritage Site noticed increasing signs of damage to their buildings, damage that was linked to subsidence. Subsidence measurements were carried out and showed that in some areas there was vertical downward movement of up to 5-7 mm a year (Christensson et al., in press-b).

Investigations concluded that groundwater drawdown under the hotel resulted in the intrusion of oxygen into the soil, causing rapid decay of the organic substrata of the archaeological layers, and consequently the subsidence of the ground and buildings (Tuttle, in press).

In fact, the whole World Heritage Site was under threat; in spite of all planning efforts, in spite of all protection and conservation efforts; Bryggen was at risk of being destroyed. How could this happen? This question is in many ways the starting point of this research project.

1.4 Research questions

The basic premise for the Urban WATCH project is that planning -and protection- of vulnerable areas in a city is no easy matter: There are challenges from above the ground, like rain, stormwater and flooding; from below the surface, where subsidence can cause serious damage to buildings; and of course, challenges that arise when new developments are to be implemented. There is no simple recipe for solving this. However, when experiences from different fields and from different countries are put together, planners will have a much better basis for the development of a sustainable city.

The Urban WATCH project has an **interdisciplinary** approach, where impacts of new developments and climate change on vulnerable city areas are in focus. How do city planners today reconcile development and protection? What can be learned from today's practice, and can it be improved? These are the kinds of questions we raise in chapter 2.

As a result of climate change, stormwater is an increasing threat to all urban settlements, not least to one like Bryggen, with its tightly packed, old wooden buildings. How does stormwater influence vulnerable cultural sites - and how can stormwater be "tamed" in the city? In chapter 3 we discuss this kind of questions. In chapter 4 we go below the ground, asking among other things how changes in the sub-surface can lead to subsidence and damages to the buildings above the ground -and how these changes may be prevented. In chapter 5 we sum up some of the results from the project.

Figure 2: Passageway between the hotel built in 1982 and the tenement of Bredsgården, Bryggen's northernmost intact tenement (photo: Tone Olstad, NIKU)

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2 Urban WATCH and Sustainable Planning

By Kjell Harvold, Kari Larsen and Ragnhild Skogheim

2.1 Introduction

Over the past decades increased urbanization has created more pressure -not only on the suburban outskirts- but also on the inner cities, putting important environmental concerns, such as water management and cultural heritage under stress. In Norway - as in many other European countries - the historic city centres face the challenge of new developments.

This development/redevelopment is typically part of a planned renewal, but at the same time it directs attention to how historic buildings and archaeological sites and deposits in the inner city should be managed. One of the principal problems connected with the sub-surface urban environment is that what is done in one area may have considerable impacts on neighbouring areas. As a result, construction work in an area adjacent to a specific protected area can lead to serious changes in groundwater levels within the neighbouring area, and thereby cause serious damage to historic buildings and archaeological deposits. Management of cultural heritage is therefore often closely -and, nowadays, increasingly- related to groundwater and surface water management.

Urban developments are often very complex affairs. Typically, there are many actors and the processes may be quite complicated (Børrud 2005). In these processes the value of culture heritage is one of many elements that should be taken into considerations. Moreover, urban development and planning processes involve several stakeholders that often represent opposing interests.

In a number of cases, innovative options are available, but their implementation is often hindered by barriers linked to multidisciplinary working and institutional regimes (de Beer et al., 2012). Sometimes, the stakeholders' perspectives are constrained to their own particular sphere. This also leads to tensions in local planning systems –especially in urban areas.

2.2 Research questions

In this chapter we will highlight how authorities in the two largest cities in Norway –Oslo and Bergen- deal with this kind of challenges: to what extent, and on what issues, do different municipal segments cooperate when it comes to planning for cultural heritage and water management?

In particular, we will highlight the relationship between three important actors in the two cities: water management, planning authorities and, of course, cultural heritage authorities.

2.3 Main findings

Before we go deeper into the research questions, we will give a short, general introduction of the two cities we study, Oslo and Bergen. At the end of the section we will present the methods for our study and the objectives for the whole project of which our study is a part. We will then present an analytical framework and an analysis of the two case studies. Here we also give a presentation of the Norwegian planning system and, in section 2.4 we, sum up our findings.

Oslo and Bergen are the two largest cities in Norway. Like the country's other larger centres they have experienced considerable population growth these last years. According to the city's own website, Oslo is the fastest growing capital in Europe (www.byradet.oslo.kommune.no). From 2005 to 2009 the population growth in Oslo was nearly 11 per cent. The growth in Bergen in the same period was 7.3 %, nearly 2 % above the average for the whole country (5.5 %). The municipalities of Oslo and Bergen both cover a fairly large area; 454 and 465 square kilometres (www.ssb.no). However, much of these areas are not available for urban development; large tracts like "Marka" in Oslo and "Byfjellene" in Bergen are set aside for recreational and/or agricultural purposes only. The populated areas cover 136 (Oslo) and 112 (Bergen) square kilometres.

Figure 3: Bryggen, in the heart of Bergen. © Universitetsmuseet Bergen

Our ***empirical material*** includes in-depth, semi-structured interviews with personnel from the cultural heritage sector in the two municipalities. We have also included interviews with representatives from planners and water management authorities in the two cities. Furthermore, we have included interviews with cultural heritage actors in institutions above the municipality level, i.e. the county level and the state (The Directorate for Cultural Heritage, Riksantikvaren).

We have also analysed policy documents from the cities' councils as well as different types of plans: strategic plans, zoning plans etc. We have focused on the relationship between the following three sectors: cultural heritage, planning and water management. However, we must emphasize that the primary objective of the project is how cultural heritage is managed and handled. The selection of Oslo and Bergen as study areas is further motivated by the fact that both cities have important areas in their centres containing (protected) highly valuable archaeological sites and deposits stretching from prehistoric times and up through the Middle Ages to the present day.

Norway has a long tradition as a decentralized, democratic welfare state, where, since the Second World War, -municipalities "kommuner")- have been of vital importance in implementing the Scandinavian welfare model (Montin 2000). They have demonstrated a strong ability to deliver locally adapted public services in an efficient manner. However, local governments are, more than instruments of the central government and its political ambitions. The municipalities are political bodies in their own right, headed by a democratically elected council. Accountable to the local populace, the councils are expected to promote local interests and values, and to fulfil local demands (Amnå 2000).

When the relationship between central and local government change, they can be analysed from the perspective of an "autonomous" or an "integrational" model. The autonomous model reflects the traditional liberal view of central-local government relations. In this perspective, central and local governments constitute two clearly separated spheres of government, with the state limiting itself to monitoring the activities of local government. According to the integrational model, the relationship between central and local government is viewed as a question of function, not as two separate political spheres (Montin 2000: 11-12). In Norway, relations between central and local levels have long been characterized by a relatively strong integrational bias. However, integrational policy is up against certain institutional obstacles, not least in the Norwegian planning system..

Studies of urban planning and development typically distinguish between different modes of governance (see for instance Winsvold et al., 2009:476) One type can be called a *hierarchical* mode, in which coordination of different actors is ensured through formal regulations, command and control. In a *market* mode of governance, coordination is ensured by the price mechanism of the market. Yet another type can be characterized as a *network* mode of governance, in which coordination ideally occurs through discussion and bargaining among the involved actors. The choice of coordination mechanism may impact the actual solutions- and different solutions may be more or less sustainable.

In this chapter we will in particular address how the three main actors at the administrative level (cultural heritage, planners and water management) interact with each other: do we for instance see attempts by one -or several- of the actors to take command and control, or do we see a more network-based mode of cooperation between the actors?

We will in other words try to describe how interaction between the three actors works in practice. This interaction will be of major importance for how cultural heritage will be taken care of in the two cities, as indicated in Figure 4.

Figure 4: Urban cultural heritage considerations in planning, as a result of the interaction between three key actors

Figure 4 illustrates that the interaction between all these three bodies is of major importance. One important challenge is to enhance urban water-management practice, and integrate cultural heritage management as early as possible in the urban land- and water-planning processes to avoid loss of cultural values. The interaction between the water management office and the cultural heritage office is therefore of major importance. Likewise, it is crucial that cultural heritage considerations are integrated in urban planning- and that city planners and water management experts cooperate.

Below, we will describe this cooperation as it is seen by central actors in the three offices in Bergen and Oslo. The information is based on structured interviews with eleven key informants in the two cities. Our informants in both Oslo and Bergen pointed out that there in general is comprehensive and constructive cooperation between the cultural heritage authorities, the planning authorities and water management.

In Bergen, there are regular formalized meetings at executive level, to facilitate and agree upon important strategies and particular cross-sectoral measures. This is partly due to the fact that cultural heritage issues and urban planning belong under the same department: the Department for Urban Development, Climate and Environment, headed by an Agency Director. This department also handles large infrastructure developments in the city, such as new water and sewage systems, waste management and power/heating systems, which has facilitated and necessitated cross-sectoral cooperation. The city has also experienced several extreme events (such as flooding), due i.a. to climate change, which have necessitated cooperation. One of our informants points out that

> "Dialogue between departments within the municipality means a lot in order to achieve cross-sectoral cooperation."

In Oslo, these fields of expertise are organized in a similar manner. Cultural heritage and planning belong to the same department, the Department of Urban Development, and their respective executives meet regularly. They also have formalized routines on how to cooperate.

The department has a strong cooperative predisposition towards other offices, and prefers to consult with other offices instead of building their own "competing" expertise. As a consequence, the dialogue and communication between planning, water management and cultural heritage is based upon cooperation in specific cases or through common initiatives, such as the "Underground-project" that seeks to produce maps of groundwater structures, rather than by means of frequent and formal contact.

On a general level the experiences appear to be much the same: there are routines for cooperation between all three actors in their respective cities.

However, when it comes to concrete examples, there could be differences in priorities. This was especially the case regarding sub-surface archaeological deposits. One of our local informants in the cultural heritage field pointed out that:

> "It's a problem in urban planning, which has so many pressing issues, that cultural heritage in the ground is invisible. That means that we have a special responsibility to address cultural heritage issues in the planning process, which can be difficult at times."

One particular challenge relates to the lack of standards or common professional guidelines, and this was expressed by a local heritage management officer in one of the two cities:

> "In general, cultural heritage is considered a policy field open for any kind of public opinion, whereas, for instance, assessments advanced by a civil engineer are regarded an indisputable technical proof."

Even if cross-sectoral collaboration is considered to work relatively well both in Bergen and Oslo, one of our informants in Oslo pointed to the lack of standards, consistency and precise professional criteria as a particular challenge. This makes argumentation and dialogue between heritage management and other actors, such as planners and developers, important for building shared understanding and establishing a common knowledge platform in urban development processes and projects. Both in Bergen and Oslo, cultural heritage officers point to specific joint projects between cultural heritage and water management as constructive ways of collaborating. In these projects, focus has been on solving specific problems. Our informants consider the learning outcome of these projects as high: they have led to mutual understanding and professional respect for each other's discipline and skills.

A project at Bryggen in Bergen provides a good example. In 2005, the World Heritage Site at Bryggen suffered quite severe flooding. At first, local actors believed this to be a consequence of climate change, and the event brought raised awareness about climate challenges both locally and nationally. However, they soon discovered that the flooding was caused first and foremost by clogged pipes and faulty sewage/drainage systems, a problem that could be -and was- fixed with little difficulty. This was the start of a large collaborative project between the local and national cultural heritage management and the local water management offices, initiated by the municipality. The project has proven to be a fruitful way of handling cross-cutting environmental challenges at a local level. Likewise, there has been a project in Oslo ("Midgardsormen") that representatives from both the cultural heritage and the water management side have singled out as a good example of cooperation across organizational boundaries.

In both Oslo and Bergen the local cultural heritage authorities considered the advisory role as important: i.e., giving professional guidance and advice to owners and developers, and internally to the planning office in connection with the handling of spatial plans, development projects etc.

The municipal planning office is, on the other hand, responsible for the Planning and Building Act. According to our informant from the cultural heritage administration in Bergen, this gives the office an interesting role both as part of the cultural heritage management and as a municipal department, and our informant expressed the importance of the office in finding its place in this interaction, in order to:

> "(…) explore this space of opportunity and use it in the best interest of the cultural heritage field."

Our informant in Oslo -as in Bergen- emphasizes the importance of the free flow of information:

> "We try to give relevant information about cultural heritage to other departments in the municipal apparatus and, when appropriate, will also hold courses (and seminars?) for employees in, for instance, the planning department."

In our interviews with representatives from the planning departments and water management departments, we found that the most critical viewpoints on cultural heritage authorities came from the planning side, where the cultural heritage authorities were perceived as unpredictable:

> "We have experienced that there is sometimes a lack of professional strength in the argumentation from cultural heritage authorities. This creates a lack of predictability.

There should be clear criteria on what is important and what is not, when it comes to cultural heritage. (…)
We sometimes feel that the local cultural heritage department considers the whole city as something that should be protected, from a national point of view. That is very difficult to relate to."

Lack of standards was an aspect that the cultural heritage representatives we interviewed were concerned about too (as mentioned earlier in this chapter). In other words, both parties (planners and representatives from cultural heritage) appear to agree that more standardized and predictable sets of criteria would be an advantage. However, it may be difficult to develop such criteria in this particular field. Another challenge in the relationship between planning and cultural heritage has to do with time constraints in planning. As one of our informants pointed out:

"Today, there is common public consensus that we need to build more houses. The pressure on the local planning authorities is therefore considerable. The public wants new housing plots fast, and this is not always easy to combine with a proper process for cultural heritage and other considerations."

The relationship between cultural heritage and water management is, according to all our informants, fairly good. So far, much of this cooperation has been based on concrete projects (like the one at Bryggen, and the "Midgardsormen" project, as mentioned above). A challenge in the relationship between these two actors may be to develop their cooperation from project-based to a more routine-based interaction. This may also be the case when it comes to the relationship between the planning authorities and the water management authorities.

2.4 Conclusion

In this chapter we have explored how three key actors reflect upon their roles when it comes to taking care of cultural heritage in urban contexts. We have found, fortunately, a functioning network of cooperation between the actors. However, solutions are often disputed.

In relation to the sharing of knowledge between water management, cultural heritage and planning, all of the engaged offices pointed to the need for this, and had several good examples of joint projects that had contributed to common understandings of complex issues and mutually beneficial solutions. We have tried to summarize the challenges in the triangle between cultural heritage, planning and water management in Figure 4, below.

The relationship between cultural heritage and water management is, as we have mentioned, fairly good. So far, much of this cooperation has been based on concrete projects. A challenge in the relationship between these two actors may be to develop the cooperation from project-based to a more routine-based interaction (as indicated in the Figure). This may also be the case, when it comes to the relation between planning and water management authorities.

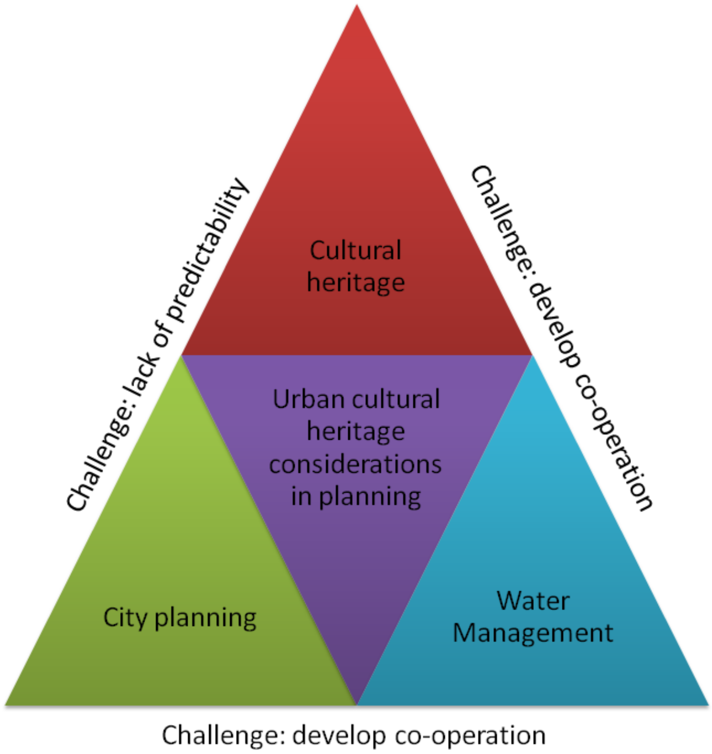

Figure 5: Challenges in the triangle between cultural heritage, city planning and water management

Recent works have indicated that to be successful, strategies for sustainable development require a multi-level governance framework (see for instance Tompkins and Adger 2005). This will probably require a broader integration across different arenas of management as well as sectors (Hovik et al., 2009, Nordahl et al., 2009, Harvold et al., 2010, Harvold 2012). Our results indicate that, when it comes to planning, cultural heritage and water management in the two Norwegian cities, there is quite a lot of networked governance activities. However, there might be a potential for improvement in the cooperation between all three key actors -as indicated in the triangle.

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3 Sustainable water management to preserve cultural heritage

By Tone M. Muthanna, Floris Boogaard, Johannes de Beer and Henning Matthiesen

3.1 Introduction

This chapter describes how modern urban stormwater management can contribute to improved protection and preservation of archaeological remains.

Sustainable urban stormwater management has evolved over the past decades. We have gradually moved from a "collect and transport" philosophy towards a viewpoint where "retain, detain and use locally with safe floodpaths" are key terms, see Figure 6.

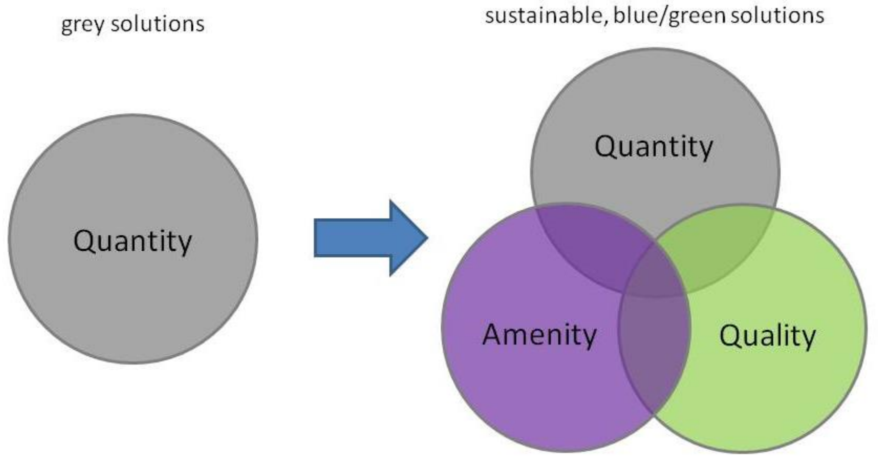

Figure 6: Evolution of urban stormwater management over the past decades

Urbanization and increased pressure on growing urban areas have inspired and forced a shift in focus from conveyance and transport towards water balance. Urbanization drastically alters the natural water balance in a watershed as illustrated in Figure 7, resulting in increased runoff generation, decreased infiltration and decreased evapotranspiration. It is a short-circuiting of the water cycle that leads to decreasing groundwater levels, increased stream erosion, increased sediment transport, urban floods and urban water-quality degradation.

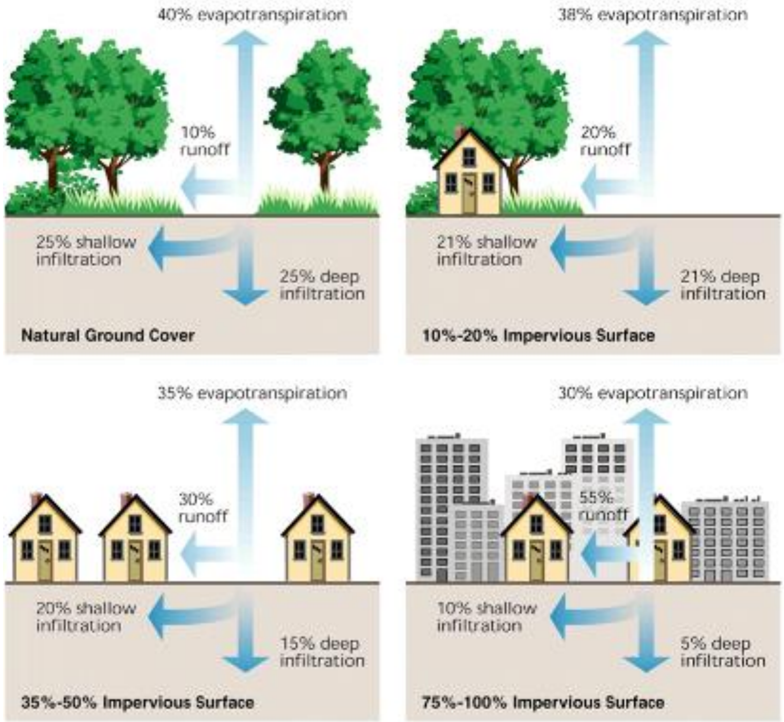

Figure 7: Impact of urbanization on the natural water balance, Source: FISRWG (1998)

Sustainable urban drainage systems (SUDS)

The appropriate use of sustainable urban drainage systems (SUDS) can reduce urban surface-water flooding, reduce the impacts of urban stormwater pollution discharges on receiving water bodies, and maintain water tables in dry periods.

In keeping with the above description, the focus of urban stormwater management has changed over the last few decades, and it now considers more than only flood mitigation and public-health protection aspects. The stormwater industry has developed and adopted new concepts to describe these new approaches (Fletcher et al., 2013) including: best management practices (BMPs); green infrastructure (GI); integrated urban water management (IUWM); low impact development (LID); low-impact urban design and development (LIUDD); source control; stormwater control measures (SCMs); water-sensitive urban design (WSUD) and sustainable urban drainage systems (SUDS).

Most SUDS use some or all of the following techniques for the purposes of sustainable water management:

- source control,
- permeable paving such as pervious concrete,
- stormwater detention and infiltration,
- evapotranspiration (e.g. from a green roof).

Some examples of SUDS are (Boogaard et al., 2007):

- pervious pavements (several types),
- green roofs,
- bioretention,
- sand and organic filters,
- grassed filter strips,

- grassed swales (dry) and (wet),
- infiltration trench/soakaway,
- filter drains,
- infiltration basins,
- extended detention pond,
- wet ponds,
- stormwater wetlands,
- sediment trap and oil separator,
- several detailed filtration techniques.

The use of SUDS results in most cases in many more benefits than water management alone. There are several guidelines to visualize and quantify multiple (monetary, social and environmental) benefits of SUDS. Multiple benefits of green infrastructure can be expressed in terms of (Ashley et al., 2012):

- improves water quality,
- reduces grey infrastructure needs (otherwise other water sources should have been used in dry times to keep foundation wet to stop decay),
- reduces flooding,
- improves air quality,
- reduces atmospheric CO_2,
- reduces urban heat island effects,
- improves aesthetics,
- improves ecology/habitat,
- raises awareness of cultivation for educational purposes,
- reduces oxidation and degradation of archaeological remains.

Urban stormwater management and protection of archaeological deposits
The previously described gradual change towards retention and local use of stormwater instead of direct transport and drainage has potentially large benefits for the protection and preservation of organic archaeological remains in situ. The water balance is fundamentally important for the preservation conditions with respect to organic archaeological materials through its influence on oxygen supply (Matthiesen et al., 2014). In general, a significant increase in the water content will reduce the rate of oxygen supply (through soil air) to the archaeological remains and reduce the rate of decay.

It has to be emphasized that the presented results reflect the situation for this specific case study, and are not intended to offer conclusions at a national level.

3.2 Research questions

The main objective was to characterize the stormwater quality in the catchment area of Bryggen in Bergen, with a view to determining this water's suitability for groundwater recharge in an area with vulnerable organic archaeological deposits.

Secondly, the research focused on identification of the main challenges involved in using urban stormwater in an area with archaeological remains, and how stormwater treatment can be used in connection with infiltration solutions to create a soil-water balance that is beneficial for in-situ preservation of those remains.

Methodology

The case study involved an area behind and upstream of the World Heritage Site Bryggen. Numerous infiltration solutions have been designed and constructed at the site to facilitate infiltration of water into ground containing plentiful archaeological remains. Stormwater from most of the catchment area upstream of the Bryggen site will be separated from the current mixed storm- and surface-water systems and transported to the Bryggen site (Figure 8). The catchment area contains mostly narrow residential streets, apart from Øvregaten (the High Street), which divides the residential area from the Bryggen site itself and has relatively heavy traffic. The expected primary sources of pollutants include rooftops, road runoff and urban debris from anthropogenic activities.

Figure 8: Catchment area behind Bryggen (blue colour) for stormwater collection for potential recharge into the Bryggen area (illustration: Multiconsult AS).

Based on the above site description and the research questions, a stormwater sampling programme was designed and carried out (Gremmertsen, 2013). A visual inspection of the rooftops in the catchment area indicated that rooftop materials were slate, brick and metal (Figure 9). No copper roofs were identified.

Figure 9: Types of roofing material in the Bryggen catchment area.

Sampling was conducted at four different locations, giving a sampling distribution between rooftop runoff, and street runoff with and without heavy traffic (Figure 10). All samples were analysed at NIVA.

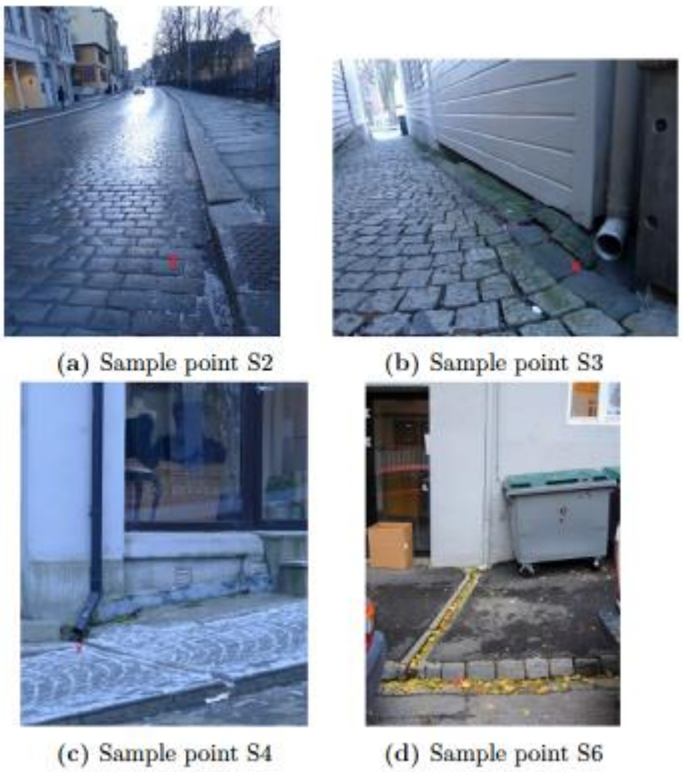

Figure 10: Location of sampling points

A wide range of pollutants can be found in stormwater. Review papers have identified several hundred compounds in urban stormwater (e.g. Makepeace et al., 1995). From this long list, a shortlist including 10-20 priority pollutants was produced. For this case study it was particularly important to include chemical compounds that could pose a possible threat to in-situ preservation, such as sulphate, nitrate and dissolved oxygen (see also chapter 4.3). The shortlist of relevant chemical compounds and indicator parameters is presented in Table 1.

Table 1. Shortlist with selected pollutants of concern for the case study

Parameter	Description	Units	Field/Lab	Importance
TSS	Total Suspended Solids	mg/L	Lab	Amount of suspended solids affects maintenance of SUDS.
Particle counting	Particles 0-1000 μm	Number	Lab	Amount and size of particles indicates treatability of absorbed particles and pollutants.
Phosphorus		μg/L	Lab	Nutrient availability (factors into rainwater garden design).
TKB	Total coli bacteria	#/100 mL	Lab	Indicator of sewage leakage.
Conductivity		mS/cm	Field	Indicator of water quality (e.g. salinity).
pH			Field	Metal solubility.
Metals (Cu, Zn, Pb, Ni, Cr)		μg/L	Lab	Micro-pollutants from atmospheric deposition and leaching roofs and roads can be found in high concentrations.
Salts (Cl, Na, Mg)		μg/L	Lab	Road salts influence metal solubility and salts will not be retained in the rainwater garden.
Oxidants (O_2, NO_3, SO_4)		mg/L	Lab and field (O_2)	May oxidize organic archaeological material.

Based on the analyses and national and international data the urban stormwater quality at the cases study area was assessed. Since stormwater quality is highly variable by its nature, it is difficult to make generalizations about "typical" stormwater quality. In addition, the chosen sample size for the case study is small to make valid generalizations to other urban archaeological sites in Norway and should thus only be regarded as an indication. However, by sampling several rainfall events it was possible to estimate a range of variability for the priority pollutants. In the following section, the main results are presented.

3.3 Main findings

Stormwater quality

The results showed that stormwater quality from the impervious surfaces in the study area varies with location, surface use and within rain events. Different roofing material and traffic volumes have clear effects on pollutant distribution and concentration. The main road "Øvregaten" with the most traffic (5,000-10,000 vehicles per day) had the highest pollution levels for 8 parameters (TSS, Conductivity, total P, PO_4, Ni, Zn and Cu), while the smaller residential road "Koren Wibergsplass" had the highest pollution level of lead (Pb). This could indicate old lead-based paint on the buildings as a source. The roof surfaces had significantly lower pollutant levels, but do still not achieve the insignificant pollution level that would be required for receiving surface waters according to the Norwegian Environment Agency (SFT, 1997).

The total monthly sediment transport in the catchment area was estimated to be 654 kg, based on data collection during the period from February to April 2013. However, sediment concentrations are typically high in early spring due to snowmelt. The estimate may therefore be higher than the annual average (Bønsnes and Bogen, 2010). Size distribution of particles will vary based on land use. Roads and rooftops will have different sediment distributions. From a treatment-potential point of view, the particle size distribution will be important for the treatment efficiency of infiltration-based solutions, where filtration of particles is the active mechanism. The minimum average particle size for effective treatment would be dependent on filtering media and residence time. The analysed stormwater samples had a minimum volume percent of particles with diameter below 1.2 µm at 70 % for S2, 10 % for S6, while S3 and S4 had a maximum at 15 % and 30 % respectively.

Field data on composition of the suspended material, particle size distribution and settling velocities are essential to rate the efficiency of sedimentation devices. Several studies demonstrated that particles less than 50 µm in diameter make more than 70 % by weight of total suspended sediment (TSS) load carried by runoff (German and Svensson et al., 2002; Roger et al., 1998; Andral et al., 1999). Furumai et al. (2002) showed that particles less than 20 µm accounted for more than 50 % of the particulate mass for runoff samples with TSS concentration less than 100 mg/L. Based on observed average particle size distributions in stormwater runoff at 25 locations in the Netherlands, about 50 % of the mass of the suspended sediment consists of particles smaller than 90 µm (Boogaard et al., 2014). Most pollutants are attached to the finer fractions, especially heavy metals, oil and poly-aromatic hydrocarbons (PAH) (Sansalone et al., 1997; Roger et al., 1998; Viklander et al., 1998, Morquecho et al., 2003, Li et al., 2006). Most nutrients (TP and TN) are bound to sediments with fractions between 11 and 150 µm; it is suggested that treatment facilities must be able to remove sediments down to 11 µm (Vaze et al., 2004).

In Figure 11, the particle size distribution found at Bryggen is shown in comparison with other international data.

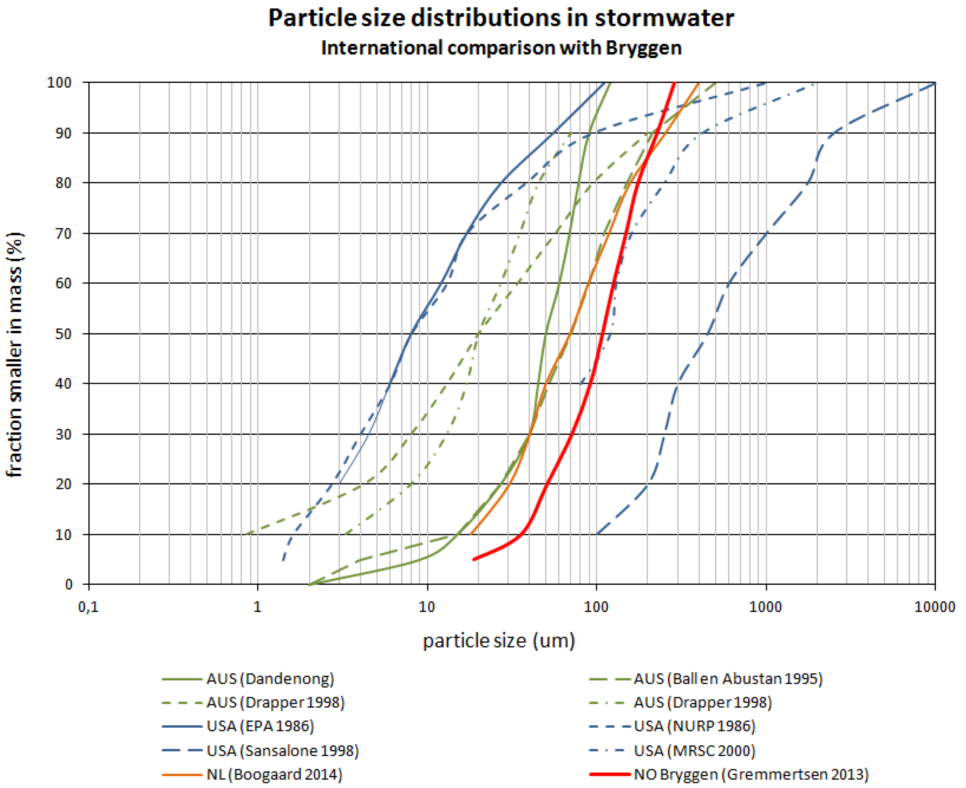

Figure 11: Particle size distributions in Bryggen stormwater in an international perspective (Bryggen data added to survey in Boogaard et al., 2014)

A comparison between filtrated and non-filtrated heavy metal samples from Øvregaten showed that minimum 65 % of the metals were particle bound, while a value of 75 % particle-bound metals was more common. Through literature review of pollutant retention in rainwater gardens, it is estimated that the rainwater garden (the second treatment step at Bryggen, see description "treatment train" below), with its high content of organic material, will be able to retain heavy metals concentrations from 55 % to 99 %. No literature data on the removal efficiency for oxidants have been found, but it is expected that rainwater gardens and swales with a high organic content are quite effective if the water flow is sufficiently slow. Still, it was advised that the stormwater from Øvregaten should not be used for infiltration to groundwater, due to the high pollutant level.

The pollutant removal rates of stormwater treatment strongly depend on the chemical and physical characteristics of the water and the dimensions of SUDS:

- The concentrations of pollutants in stormwater vary strongly between and during storm events, both at Bryggen and internationally (Table 2).
- The concentrations found at Bryggen are within the wide ranges of concentrations found in other parts of the world. The analysed copper and zinc concentrations seem to be relatively high from an international perspective (Table 2).
- There is no existing quality standard in Norway for stormwater treatment. To achieve the quality standards used by the Water Framework Directive (2006/118/EC), the removal efficiencies for Cu, Pb and Zn have to be in the order of 95 %, 79 % and 88 % respectively. For particle-bound contaminants these removal rates are not likely to be achieved by settling facilities if small particles (<45 um) are captured and retained (Boogaard et al., 2014).
- To match the current median concentrations in the groundwater at Bryggen, the concentrations of O2, NO3 and SO4 in water entering the archaeological deposits should be lower than 0.5, 0.5 and 10 mg/L respectively (Matthiesen 2012). Slightly higher concentrations may be acceptable, as the beneficial effects of an increased infiltration on the preservation conditions will overshadow the negative effects from solubleoxidants.
- Monitoring data on particle distribution in the Bryggen catchment area show that the proportion of fine sediment is comparatively high compared to international data. As the fine fraction is responsible for most of the pollution load, it is important to know whether the SUDS planned for implementation at Bryggen are capable of removing the finer solids.

Table 2. Bryggen and international stormwater quality data from residential areas in USA, Australia and Europe

Parameter	Bryggen		World[a]	The Netherlands[b]		USA[c]	Europe/Germany[d]
	Mean	Median	mean	Mean	median	Median	mean
Pb (μg/l)	36	22	140	18	6	12	118
Zn (μg/l)	434	153	250	102	60	73	275
Cu (μg/l)	111	11	50	19	11	12	48
NO_3 (mg/l)	1,1	0,6					
SO_4 (mg/l)	12,7	11,4					
Cl (mg/l)	213	30		18.3	11.0		

a) Bratieres et al., 2008. Typical pollutant concentrations based on review of worldwide (Duncan, 1999) and Melbourne (Taylor et al., 2005) data.
b) Boogaard, 2008. Dutch STOWA database (version 3.1, 2013), based on data monitoring projects in the Netherlands, residential and commercial areas, with n ranging from 26 (SS) to 684 (Zn).
c) NSQD, 2004. Monitoring data collected over nearly a ten-year period from more than 200 municipalities throughout the USA. The total number of individual events included in the database is 3,770, with most in the residential category (1,069 events).
d) Fuchs et al., 2004. ATV database, like Duncan (1999) partly based on the US EPA nationwide runoff programme (NURP), with n ranging from 17 (TKN) to 178 (SS).

SUDS implemented at Bryggen

The selection of SUDS that has been implemented at Bryggen during the Urban WATCH project is a result of several workshops in which international examples and infiltration techniques have been discussed. The methods that have been identified are transferable to other sites in Norway and abroad where organic archaeological deposits are in danger of desiccation. Important criteria that have led to the final selection of measures at Bryggen are:

- space requirements (space is limited and alterations are restricted at the World Heritage Site Bryggen),
- damage inflicted on archaeological deposits to be kept to a minimum (no-dig methods preferred),
- ability to store and infiltrate as much water as possible,
- removal efficiency,
- construction costs,
- maintenance work and costs,
- aesthetics.

Shallow infiltration-based systems (where no significant digging is required) include infiltration trenches, rainwater gardens, swales, bioswales and permeable pavement.

3.4 Sustainable urban drainage

At Bryggen the most important criterion is to provide water in amounts sufficient to keep the archaeological deposits wet enough to retard decay. A high removal efficiency of micropollutants and longest-possible travel times are advisable. This will reduce oxygen, nitrate and sulphate levels that might induce decomposition of deposits (Boogaard et al., 2007). High removal rates are achieved with SUDS that have several treatment processes or a 'treatment train' where several SUDS are placed in series. To achieve a high removal efficiency, the removal of particles by settlement only will not be sufficient. The treatment train at Bryggen consists of the following solutions:

1. The first treatment step is settlement of large particles in a basin or gross-pollutant trap.
2. As a second step, a rainwater garden is used to store and clean stormwater.
3. As a third step a dry swale is added to increase the travel time (reducing oxygen levels by slow infiltration to groundwater) and provide additional removal.
4. Fourthly, rainwater that falls directly on hard surfaces (cobblestones etc.) will be encouraged to infiltrate through implementation of permeable pavement.

The treatment train

Figure 12 and Figure 13 display the treatment train with SUDS in the Bryggen area. On the far left side one can see the road (Øvregaten) from where water is collected from the stormwater sewer at the inlet with a gross-pollutant trap. From the inlet the water will flow into the rainwater garden and from there to the swales in the middle of the picture. In addition, permeable pavement and perforated pipes (infliltratin and transport, IT) drainage is used in the rest of the area's surfaces for additional infiltration. The individual elements are discussed in more detail in the following paragraphs.

Figure 12: Plan overview of treatment train with rainwater garden, swales and permeable pavement on the lower side of the swales.

Figure 13: Impression of the treatment train with rainwater garden (under construction, left) and grassed swales (in the middle) and permeable pavement (lower right). (photo: F. Boogaard)

Step 1: Gross-pollutant trap
A gross-pollutant trap is a stormwater basin with settlement facility for larger particles. Stormwater from roads and roofs is led directly to this facility, which prevents flooding of the subsequent rainwater garden through a limited outflow pipe. Inflow is also limited, ensuring that large amounts of water during intense rainfall events are directed to secure floodpaths. At Bryggen the gross-pollutant trap consists of a large manhole with sediment trap and limited in- and outflow capacity.

Step 2: Rainwater garden
A rainwater garden is a shallow depression that is planted with deep-rooted native plants and grasses. The garden should be positioned near a runoff source like a downspout, driveway, gross-pollutant trap or sump pump to capture rainwater runoff and stop the water from reaching the sewer system. Native soils are removed and replaced with a special blend of highly organic soil. Rainwater gardens are planted with aesthetic, hardy, low-maintenance perennial plants. A transect of the constructed rainwater garden at Bryggen is shown in Figure 14.

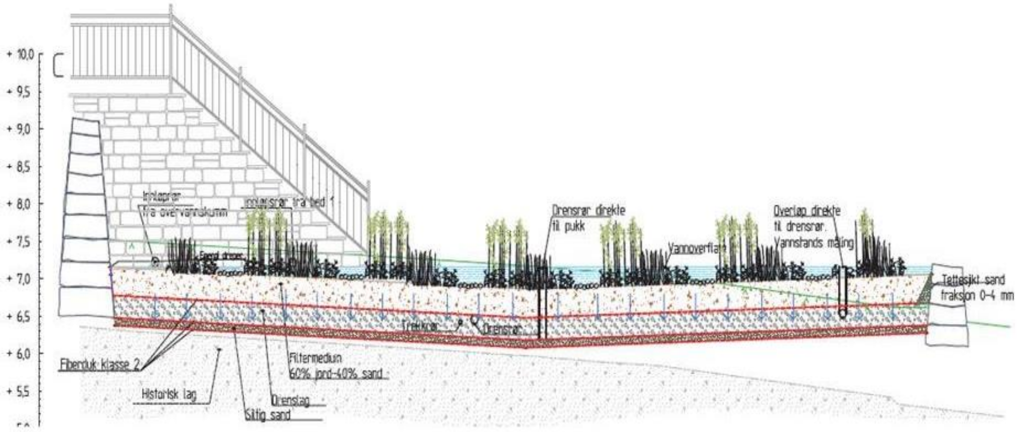

Figure 14: Transect of rainwater garden at Bryggen (source: Multiconsult AS).

Step 3: Swales or bioswales
Vegetated swales are built for conveyance and infiltration. The vegetation is most often grasses based with native or imported soils with high infiltration capacity.

A properly designed bioswale system buffers rainwater and allows it to infiltrate; this improves the quality of rainwater, which can then be re-used for different purposes. A bioswale is a ditch with vegetation and a porous bottom. The top layer consists of enhanced soil with plants. Below that layer different infrastructure can be constructed, such as a layer of gravel, scoria or baked clay pellets packed in geotextile (Figure 15).

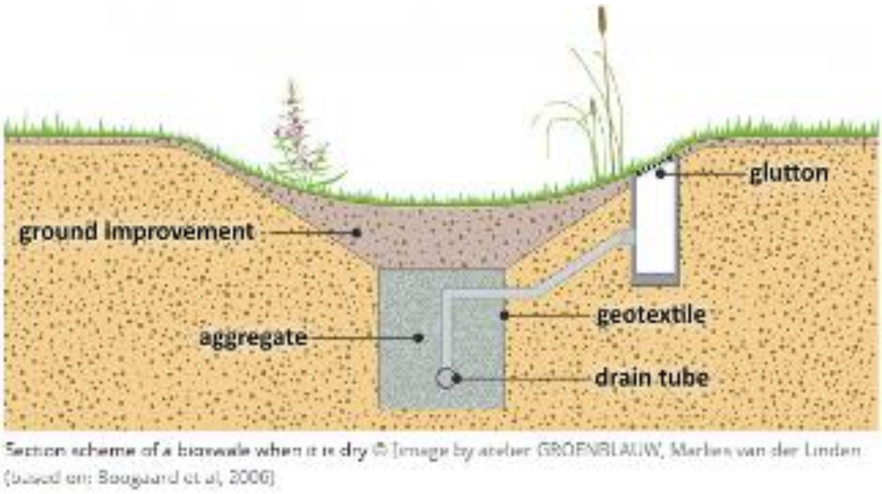

Figure 15: Principle design of swales implemented in Enschede (NL), 1998.

These materials have large empty spaces, allowing large volumes of rainwater to be stored for re-use. An infiltration pipe/drainpipe is situated below the second layer. To prevent the bioswale from overflowing its banks during heavy rainfall, overflows are added that are connected directly to the infiltration pipe/drainpipe. With the filtration and absorption of particle-bound pollutants, high removal efficiencies are achieved. The swales constructed at Bryggen are shown in Figure 13.

<u>Step 4: Permeable pavement</u>
The existing hard pavement at the Bryggen site has been made permeable at key locations by removing the existing cobblestones and laying a permeable granulate underneath. Permeable pavement is an integral part of the treatment train at Bryggen (Figure 13 and Figure 16).

Figure 16: Permeable pavement at Bryggen (photo: F. Boogaard)

In areas without cobble- or flagstone pavement but where it was very clear that the topsoil was compacted and practically impermeable, the uppermost decimetres of the soil were removed and replaced by highly permeable gravel that was also more aesthetically pleasing.

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4 Monitoring and modelling in Urban WATCH

By Johannes de Beer, Anna Seither, Vibeke Vandrup Martens, Henning Matthiesen and Michel Vorenhout

4.1 Introduction

Archaeological deposits are considered a non-renewable resource by the Norwegian government, and direct or indirect damage to them poses a threat to continued preservation of these heritage features. The archaeological deposits (also referred to as 'cultural' deposits) older than AD 1536 in Norway's eight medieval towns are automatically protected under the provisions of Norway's Cultural Heritage Act. Collectively, these deposits represent the largest concentrations of cultural heritage assets in Norway. Protection of the archaeological remains requires baseline reference data on the state of preservation as well as detailed knowledge about physical and chemical degradation processes and scientifically sound monitoring data to develop protection strategies.

This chapter summarizes part of the work that has been carried out in the framework of the Urban WATCH project to improve environmental monitoring methods and strategies.

1. An innovative modelling study has been carried out by the Geological Survey of Norway (NGU), based on the Bryggen case. The study assessed if soil moisture and temperature monitoring data can be used in numerical modelling to improve understanding of the hydraulic processes and their influence on the supply of oxygen and other oxidants that drive decay in unsaturated cultural deposits. The main results are presented in section 4.2.
2. A general question that has been raised by heritage authorities is whether oxygen or oxidation-reduction potential (redox potential) measurements should be prescribed as environmental monitoring parameters for archaeological deposits. The latter is considerably cheaper, but the results are more difficult to interpret in terms of preservation conditions and decay rates. We will briefly present - in section 4.3 - some results of laboratory experiments that have been carried out by the National Museum in Denmark and MVH Consult to address this question.
3. The Norwegian Standard NS9451:2009 (Standard Norge 2009) stipulates requirements concerning environmental monitoring and investigation of organic cultural deposits. In section 4.4 we present a first evaluation of the practical use of the standard, five years after its introduction. The evaluation was carried out by the Norwegian Institute for Cultural Heritage Research (NIKU).

4.2 Modelling the soil-water balance in unsaturated archaeological deposits

Over recent years, vast amounts of data have been collected at Bryggen. These data include archaeological descriptions, time series of the piezometric head in numerous monitoring wells, as well as chemical analyses and measurements of the rate of subsidence of both the ground surface and the buildings. To better understand the preservation conditions in these complex surroundings, many of these data were applied in a groundwater flow model covering the area (De Beer et al., 2012). The installation of monitoring equipment that records soil-water content and temperature at different depths in the unsaturated zone in a test-pit at the rear of Bryggen enabled the construction of another kind of model - a soil-water storage model. To the best of our knowledge, building such a model for urban archaeological deposits has never been attempted previously.

The complete scientific report is published by the Geological Survey of Norway: "Modelling water content and soil temperature in unsaturated urban deposits" (Seither, 2014).

Research questions
The main objectives were to investigate to what extent the collected data on soil-water content and temperature in the unsaturated zone can be used to construct a transient model to gain additional knowledge about hydraulic processes at the site. The soil-water balance is fundamentally important for the long-term preservation of organic archaeological remains through its influence on oxygen supply (Matthiesen et al., 2014). A better understanding of the hydraulic systems/mechanisms that influence decay processes is thus highly relevant for protection and management of archaeological deposits at Bryggen and elsewhere.

Methodology
The different water flows in the water balance of the test-pit were explored with the open source software CoupModel. This is a physically based model that simulates water and heat flux through a one-dimensional soil profile using a combination of the Richards and Fourier equation (Jansson, 2012). It comprises a substantial range of sub-models, such as infiltration, evapotranspiration, heat storage, soil frost, crop growth, and C/N cycle. In order to keep the model as simple as possible, functions that added model complexity without influencing model performance were omitted. The core of the model was a 3.5 m deep soil profile that was parameterized according to field and laboratory investigations. Figure 17 provides an overview of the model setup with the individual flow-components of the water balance.

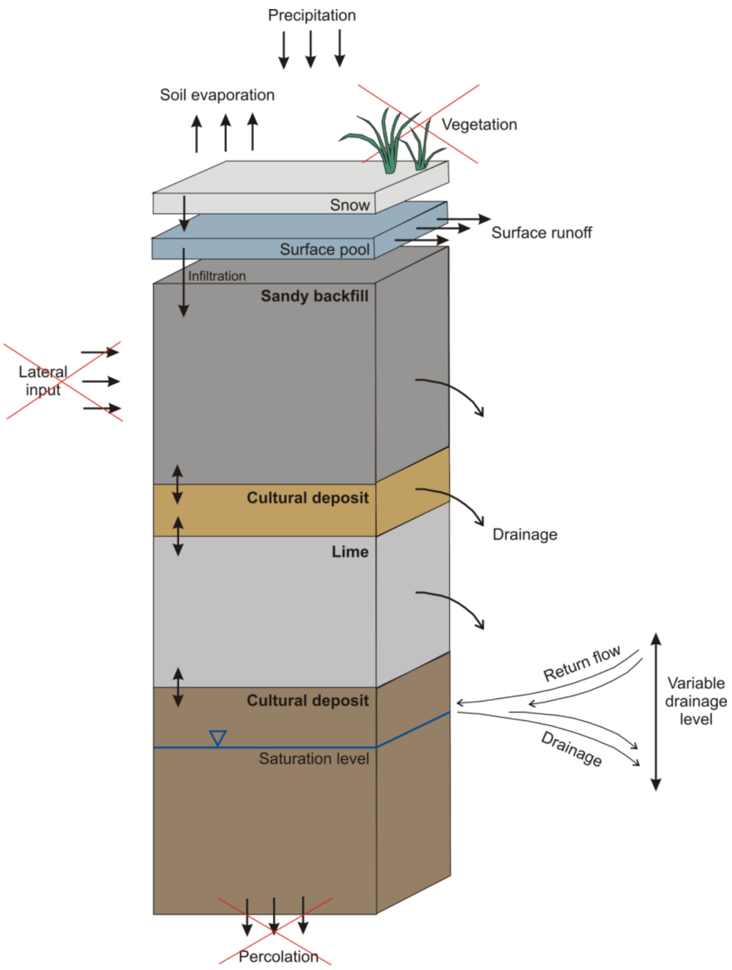

Figure 17: Model setup scheme of the mass balance. Crossed-out components were not included.

Meteorological data from the Bergen-Florida weather station, and a time series of measured groundwater levels in close proximity to the test-pit, served as driving variables. Continuous measurements of soil temperature and water content at several depths were used for calibration. Details regarding setup and results are given in a separate scientific report (Seither, 2014).

Main results
The model performed well in reproducing measured temperature series, but relatively poorly in reproducing corresponding series of water content. Accordingly, model outcome must not be over-interpreted. Nevertheless, the model exercise has given valuable insight into the physical processes involved and it is possible to retrieve a few approximations. Figure 18 summarizes the development of soil-water storage and drainage through the course of a calendar year. In order to visualize the effects of measures that improved infiltration at Bryggen, two different time periods, namely 2007-2011 and 2012-2013, are compared.

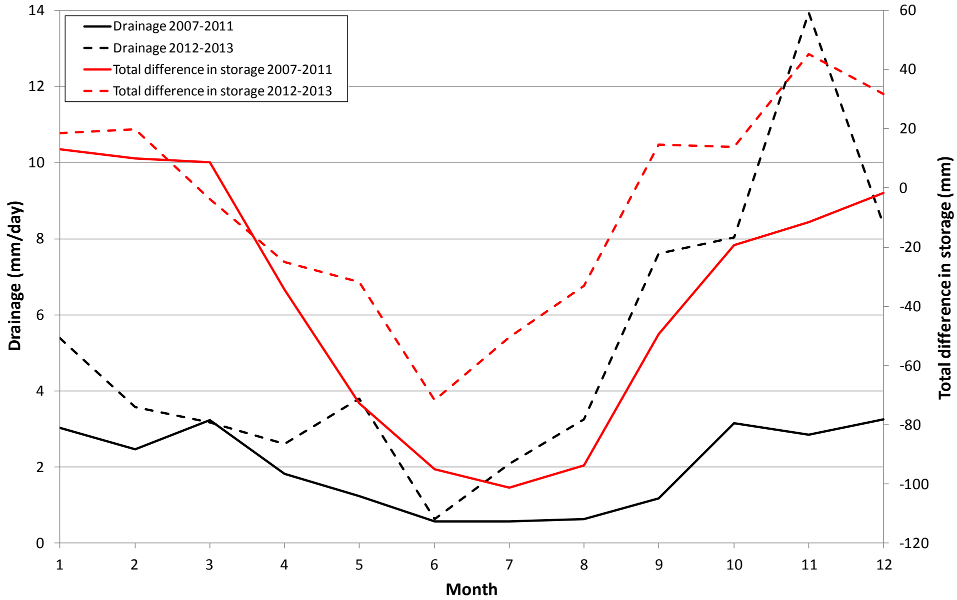

Figure 18: Monthly average values for drainage (mm/day) and the total difference in storage (mm) compared to January 2007 (start of simulation).

According to storage simulations, the total water storage can vary more than 150 mm between summer and winter, corresponding to 150 L/m^2. The soil drains approximately 3 mm/day, but there are large differences between the summer and winter months. Due to increased evaporation, average drainage during summer declines to less than 1 mm/day. The discrepancy between the different time periods reflects the fact that infiltration increased substantially due to various physical measures at the site. In order to protect the organic deposits from desiccating - and thus at risk of accelerated decay - during the summer months, the loss of water must be compensated. According to the conducted simulations and compared to average conditions in the soil, about 0.1 L of water per hour and for every square metre of soil surface is necessary to counterbalance the deficit.

An important outcome of the CoupModel simulations was that traditional soil sampling, analyses and monitoring should be complemented by time series of the soil matric potential, when simulating a heterogeneous site such as Bryggen. Theoretical functions for estimating hydraulic conductivity and water-retention curves are based on the inorganic, <2 mm fraction of the soil. Urban archaeological soils, however, are typically composed of highly disturbed materials of various origins and do not necessarily reflect the local geology and climate, but represent an archive of human history of the area. Accordingly, their physical, chemical and biological properties can differ entirely from soils that have grown naturally over a long period of time. In the case of Bryggen, wooden foundations and other organic remains of various ages, size, composition and degree of decay also influence the hydraulic properties of the soil considerably, as does their position and alignment. Loss-on-ignition values for extracted soil samples cannot account for the complexity of organic materials and their respective influence on the soil-water retention curve. Similar challenges are met with respect to gravel and other coarse, inorganic materials.

We therefore recommend that a sensor-pairing method is applied for the determination of a soil-water characteristic curve in connection with studies of preservation conditions in the unsaturated zone.

4.3 Should monitoring of oxygen or redox potential be used in standard monitoring programmes?

Information about preservation conditions and decay rates at archaeological sites may be obtained by using probes measuring the oxidation-reduction potential (redox potential), oxygen probes, and analyses of water/soil chemistry. The Norwegian monitoring standard NS9451:2009 (Standard Norge 2009) actually mentions that monitoring of oxygen and/or the redox potential in the soil shall be considered. Within the framework of the Urban WATCH project, an evaluation has been carried out to evaluate whether or not these parameters should be included in standard monitoring programmes. This clarification in the guidelines for archaeological investigations would contribute to more standardized, comparable and cost-efficient preservation studies.

Figure 19 shows a simplified illustration of the different biochemical decay processes that occur in organic archaeological deposits, and the corresponding approximate range of the redox potential. Generally, degradation increases with increasing redox-potential values, with aerobic respiration (which involves consumption of oxygen) being the most aggressive and rapid process affecting the decay of organics, especially under unsaturated conditions.

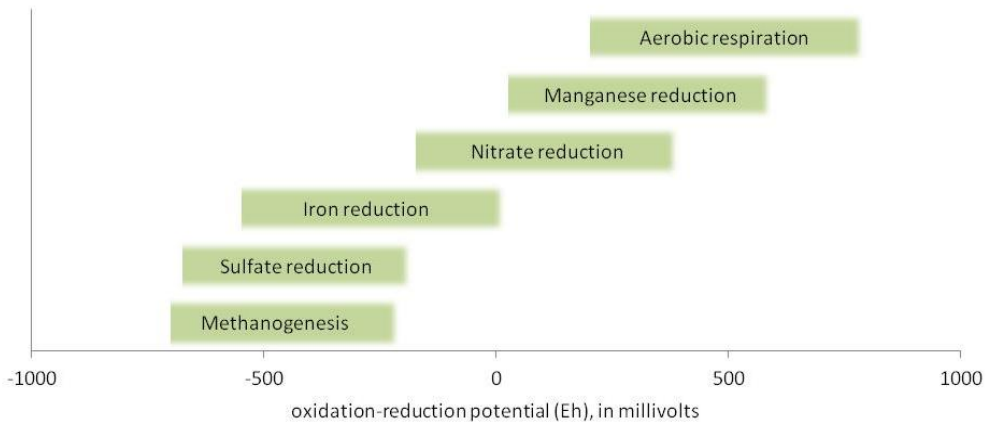

Figure 19: Decay processes and redox-potential values

Earlier work, including field studies at Bryggen in Bergen (Walpersdorf et al., 2012) and laboratory experiments (Mortensen et al., 2013), concluded that under unsaturated conditions, redox potentials were fluctuating and difficult to interpret, while giving more promising results under saturated conditions. Oxygen measurements seemed to give good results under both saturated and unsaturated conditions. The study that has been carried out in the framework of the Urban WATCH project takes a closer look at the saturated conditions and how redox-potential measurements can reflect changes, different processes, concentrations of different oxidants, and decay rates.

The study also yields information on the effect of adding different dissolved oxidants (oxygen, nitrate, sulphate) to waterlogged archaeological soil material, which may be used to discuss the effects of infiltrating different types of water into archaeological deposits.

The complete report is published by the National Museum of Denmark: "Measurement of oxygen, nitrate, sulphate and redox-potential in microcosms with waterlogged organic cultural deposits" (Matthiesen et al., 2013).

Key research questions related to the use of oxygen and/or redox-potential measurements in standard monitoring programmes are:

- Will the extra expenses give a significantly better evaluation of the preservation conditions?
- Can the two methods substitute each other, or are both types of measurement necessary?
- Can the results be readily interpreted in terms of rates of decay of organic archaeological material?

In recent years, it has become clear that desiccation of organic archaeological remains is one of the biggest threats to their preservation. Therefore, infiltration of water to reduce the decay has been suggested at several sites, most notably at Bryggen, where shallow infiltration basins ("swales") and trenches for sub-surface water infiltration have been constructed during the Urban WATCH project-period. Oxygen and redox potential are monitored in the archaeological deposits in connection with this infiltration. Besides oxygen and redox-potential measurements, it is also highly relevant to investigate what types of water (in terms of chemical composition and temperature) can be used for infiltration and what is the effect on the decay of the archaeological deposits. This is relevant not only for the protection and long-term preservation of archaeological deposits at Bryggen, but also for mitigation or protection by infiltration at other sites. In light of the increased need for responses to climate change, and for local infiltration of surface water, it is essential to know if surface-water quality will have a positive or adverse effect on preservation conditions. Water quality aspects related to the infiltration facilities are discussed in chapter 3 of this publication.

Methodology

The study was performed by placing samples of organic archaeological material retrieved from a single borehole at Bryggen in closed 100 ml screw-cap vials, creating microcosms (Figure 20).

Figure 20: Photo of single microcosm used in laboratory test

Optical oxygen sensors were installed on the inside of the glass wall, along with optical test-sensors for carbon dioxide and pH. Syringes through holes in the lid allowed the addition of different oxidants (oxygen, nitrate, sulphate) and the retrieval of water samples for analysis. Soil from each of the four depths was split into three sub-samples, yielding 12 samples in total (Figure 21).

Figure 21: Laboratory setup with microcosms in climate chamber

Redox potential was measured down in the waterlogged soil sample using a Pt electrode and an Ag/AgCl reference electrode installed through the lid of the vial and the potentials were monitored by a *Hypnos III datalogger*). Most experiments were carried out at 15°C and the samples were also kept at this temperature in a climate chamber or a water bath between experiments.

With the above microcosms, a series of experiments was carried out to determine the consumption rate of different oxidants over time. The consumption rates have been used as a basis for calculation of decay rates.

Main results

The laboratory experiments with microcosms allowed us to measure redox potential and decay processes under controlled conditions.

With respect to the use of redox-potential measurement for monitoring environmental conditions related to decay of archaeological deposits, the following conclusions have been drawn based on the laboratory experiments:

- Redox-potential measurements are very sensitive and react to even minor changes in the environment. The measurements can to some extent indicate which oxidants are present and which processes are ongoing, but there is no correlation between the concentration of individual oxidants and the redox–potential values.
- There is some correlation between redox potentials and measured decay rates. The highest decay rates are found at potentials higher than 0 mV vs SHE (standard hydrogen electrode). Still, for some samples unacceptably high decay rates are found even at lower potentials.

Overall, redox-potential measurements work better under saturated than unsaturated conditions. They are particularly suited for showing if environmental conditions are stagnant or dynamic, but interpretation of absolute values is difficult. Monitoring of the reduction/oxidation state of the archaeological deposits will, however, provide insights into the effect of the raised water tables.

Oxygen is the most reactive oxidant and the decay rate under unsaturated conditions is higher than in all other setups, as can be seen in Figure 22. This conclusion supports the general recommendation that "any water is better than no water" to reduce decay rates. As for monitoring under unsaturated conditions, this has been investigated through the Bryggen Groundwater Project. The results show that oxygen measurements in situ are feasible and that the oxygen supply is highly correlated to the soil-water balance (Matthiesen et al., 2014). The results can be interpreted in terms of decay rates of archaeological material when they are combined with laboratory decay studies under controlled conditions (Hollesen & Matthiesen, 2014).

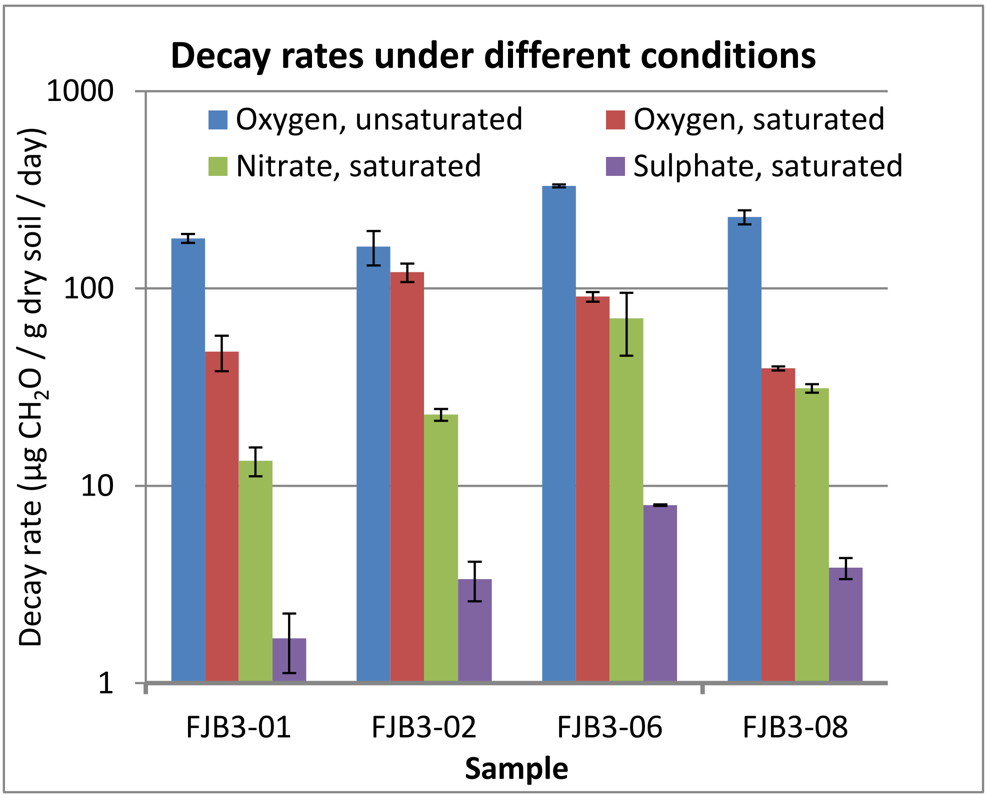

Figure 22: Calculated decay rates in four samples from Bryggen under unlimited supply of different oxidants. Error bars show standard deviation of triplicate samples. Note logarithmic scale.

4.4 Evaluation of the use of the national standard for environmental monitoring and investigation of archaeological deposits

Environmental monitoring of preservation conditions and the state of preservation is important for knowledge-based archaeological heritage management. To secure the best possible management and policy formulation regarding spatial planning in urban areas, and to enable the implementation of preventive measures or mitigation strategies, baseline reference and monitoring data are essential.

In 2009, the Norwegian Directorate for Cultural Heritage adopted a first national standard for environmental monitoring and investigation of archaeological deposits (Standard Norge, 2009). From both a national and an international perspective, environmental monitoring and investigation of archaeological deposits is a relatively new subject in archaeology. Only a few guidelines and standards exist: in the Netherlands (Smit et al., 2006; Huisman, 2009), the United Kingdom (English Heritage, 2007) and Norway (Riksantikvaren, 2008; Riksantikvaren & NIKU, 2008). The Norwegian standard describes procedures for environmental monitoring and documentation of state of preservation and preservation conditions with regard to archaeological deposits. Use of the standard is required in any urban spatial planning project within the automatically protected areas of the medieval towns in Norway. The standard aims to contribute to the protection of archaeological heritage by requiring collaboration between professionals from a variety of disciplines (chemistry, archaeology, hydrology, geotechnical engineering etc.), as well as authorities and the private sector.

One of the anticipated advantages of the monitoring standard was the use of a standardized documentation of archaeological deposits in situ. It allows for a more objective comparison of observations within and between sites. However, this requires that all archaeologists actually adhere to the standard and understand what is meant by the classification systems used.

Besides the official document (Standard Norge, 2009), an unofficial English translation of the standard has been published that is freely available (Riksantikvaren, 2012). Within the Urban WATCH project, an initial evaluation has been carried out to assess the practical use of the standard NS9451:2009.

Research questions
The main objectives of the enquiry into the practical use of the standard NS9451:2009 have been to assess the outreach and extent of use, as well as the users' perception in terms of the standards user-friendliness. The results may be used by heritage management authorities to evaluate content and dissemination activities.

Methodology
A multiple-choice web-survey (SmartSurvey®) was carried out from mid-June to late August 2013, directed to Norwegian cultural heritage management and heritage research organizations. The survey was carried out online, in such a way that answers are confidential. It is impossible to link single responses to the identity of the respondent. The survey consisted of eight questions and was sent to 305 recipients.

The response percentage was 55 %, equal to 167 respondents. The response is statistically valid (Hellevik, 1977) and considered satisfactory. The survey resulted in a substantial amount of data, and in addition to the quantitative statistical data, several of the respondents gave supplementary comments in a number of free-text input fields.

Main findings
The questions raised in the survey were focused on identifying the outreach, use, understanding and user-friendliness of the Norwegian Standard NS9451:2009. In this paragraph, the responses to some key questions are summarized, analysed and briefly discussed.

Are you aware of the Norwegian Standard NS9451:2009?
87 respondents (52 %) were aware of the existence of the standard. This was an expected outcome, considering the target groups of the survey: heritage management, archaeologists in research institutes, and university museums with license to carry out fieldwork. The affiliation distribution among the 87 respondents is indicated in Figure 23.

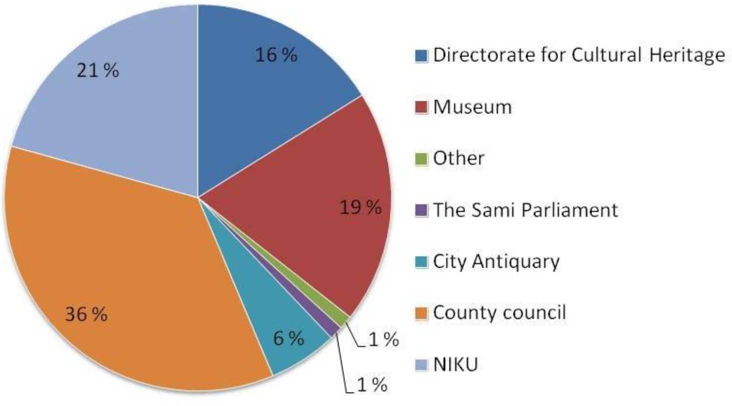

Figure 23: Affiliation of users of NS9451:2009

Have you ever used the standard, and if so, how many times?
30 of 167 (18 %) respondents indicated that they had used the standard at least once. Only 25 (15 %) respondents indicated that they had used it for archaeological field investigations. 9 (5 %) respondents had used the standard (also) for purposes other than archaeological field investigations.

An overwhelming 122 (73 %) of the respondents indicated that they had never used the standard, while 15 (9 %) skipped this question, presumably because they did not use it either.

Of the 30 (18 %) respondents, 8 (5 %) had used the standard once, 12 (7 %) between two and five times, 1 (1 %) six to ten times and 9 (5 %) respondents had used it more than ten times, see Figure 24.

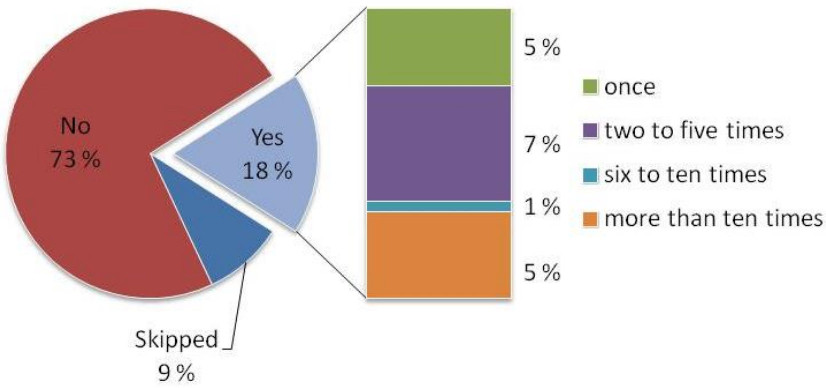

Figure 24: Use of NS9451:2009

These numbers show a lack of awareness and use of the standard. Even though 87 people had heard of the standard, only 30 had ever used it practically during archaeological excavations and/or for other purposes. Among the reasons to use the standard the following topics were mentioned:

- research projects;
- general information to stakeholders;
- other archaeological studies;
- municipal planning.

How user-friendly do you consider the standard?
The respondents were asked to assess each grade of user-friendliness on a scale of agreement as illustrated in Figure 25 and Figure 26. Of the 87 respondents that had heard of the standard, a rather neutral distribution was found, as shown in Figure 25. A positive skewness is found towards the opinion that the standard is useful, while more than 50 % of the respondents did disagree with the option that the standard is incomprehensible. It must be mentioned that only around 50 respondents actually answered the user-friendliness question. The other 37 apparently were not able to give an opinion on the user-friendliness, although they were aware of the existence of the standard.

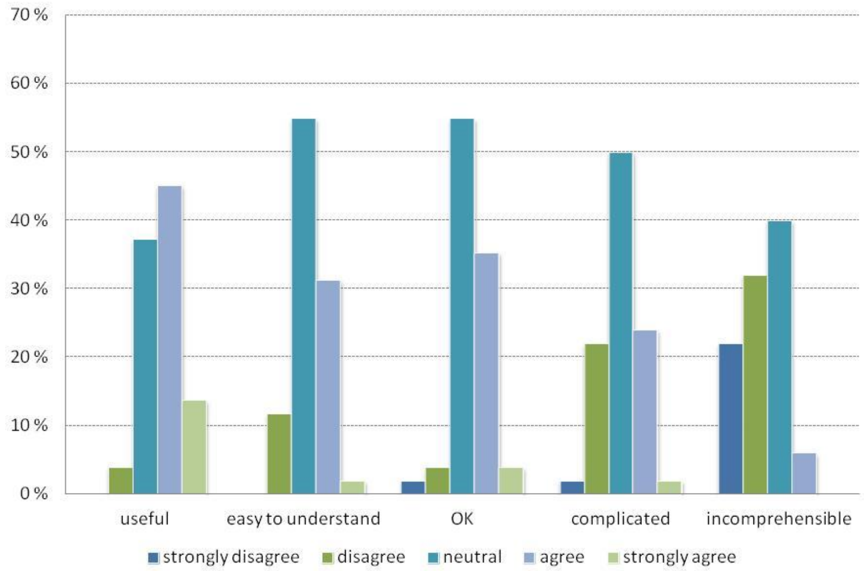

Figure 25: User-friendliness of NS9451:2009 among 87 respondents that had heard of the standard.

Using a filter to extract only the 25 respondents that had actually used the standard during an archaeological field investigation, the distribution shown in Figure 26 was obtained. Here the general trend is clearly more positive than neutral. Although some respondents consider the standard complicated, only very few consider it incomprehensible and the majority assesses the standard as useful. Of the 25 respondents, almost all did answer the question completely.

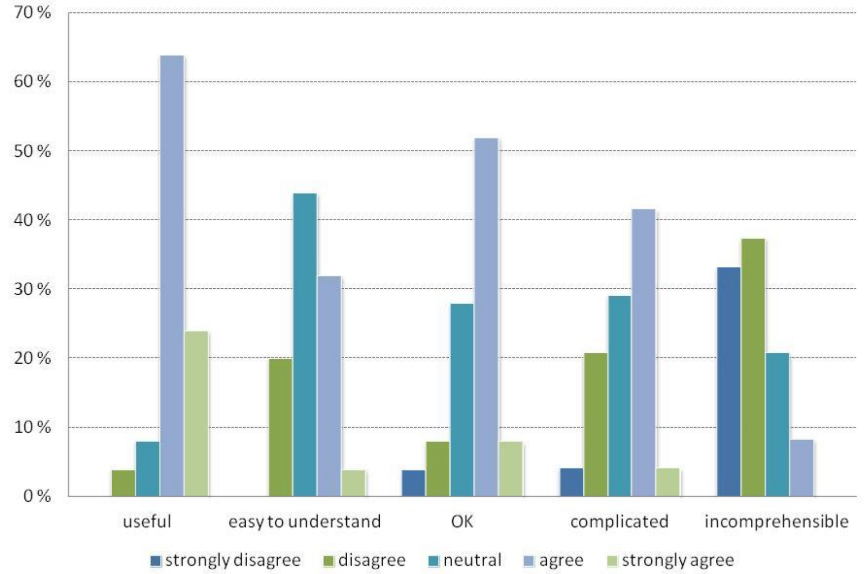

Figure 26: User-friendliness of NS9451:2009 among 25 respondents that had used the standard during archaeological field investigations.

Conclusion

The survey response of 55 % is considered satisfactory. More than half of the respondents had heard of the standard, and these came from a wide range of stakeholders. However, a noticeably low percentage of this group was affiliated with Norwegian cultural heritage management and research. And even fewer had actually used the standard. It may be concluded that the outreach of the standard can be improved, not least among heritage management and the heritage research community. One reason may be the barrier that is being maintained by the relatively high cost of

Norwegian Standards. The availability of the free non-official English version may improve outreach in Norway and further afield. The survey itself, as well as various ongoing research projects, may also contribute to increased awareness and use of the standard.

With respect to the user-friendliness of the standard, the results indicate that the standard is assessed as more useful by those people who actually use it in practice.

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5 Urban WATCH – concluding remarks

By Kari Larsen and Kjell Harvold

5.1 A more integrated planning

As was pointed out in chapter 1, at the end of the 1990s the owners of buildings at Bryggen started to notice that their properties were increasingly suffering structural damage, damage that was linked to subsidence. Measurements were carried out and showed that the annual rate of subsidence was up to 5-7 millimetres in some places. Intrusion of oxygen into the soil caused rapid decay of organic components in the archaeological deposits, resulting in subsidence of the ground and buildings. This development represented a serious threat to the whole heritage site-area. In the old part of Oslo (Gamlebyen, to the east of the modern city centre), where there are similar deposits, many buildings potentially face a similar threat.

Subsidence of the ground at archaeological heritage sites emphasizes the importance of a holistic planning focus. Norwegian cultural heritage management has long been known for its leading role in terms of in-situ preservation of monuments and sites. Groundwater management, on the other hand, has been lagging behind compared to numerous other countries.

Traditionally, Norwegian planning has focused on the challenges above the ground. Our study of the present planning situation in Norway's two largest cities indicates that this is now changing. When looking into how cross-cutting issues relating to water management, cultural heritage management and urban planning are handled in public management (chapter 2), our main impression is generally *positive*: one of the project's main findings is that there is co-operation between various offices and agencies in the case-study cities. Employees in water management, cultural heritage and urban planning tell us that cross-sectorial co-operation works well, and that it has been moving in the right direction during the recent years. Based on our analyses in chapter 2, we conclude that water management is currently high on the agenda in urban management and development. Knowledge on how to integrate cultural heritage with groundwater and surface water issues for greater protection is getting better, within both the heritage management and the water management offices. Some important preconditions for this have been pointed out by our interviewees: a strong commitment at top administrative level, and concrete projects that have proven innovative in terms of both practical solutions as well as modes of co-operation.

However, there are still some challenges in taking this co-operation further and raising it to an optimal level. Some relationships could definitely do with being expanded and strengthened in the triangle comprising cultural heritage management – water management – urban planning (see Figure 4 in chapter 2). One particular challenge is to change cross-sectorial co-operation from being based on and confined to single projects to becoming more fully integrated in ongoing, daily operations.

There are -at least- two different challenges associated with city centres that 'float' on an organic substrate. First of all, it is important to find ways to prevent subsidence and associated damage to buildings and infrastructure supported by these, in principle, unstable deposits. Secondly, many of these deposits have an intrinsic archaeological value, as defined by statute in Norway. These deposits should be preserved for future generations. Both stability and archaeological values can easily be destroyed by changes in the water balance. *In situ* preservation is therefore both from an archaeological point of view, as well as from a geotechnical one, the optimal solution. As pointed out in chapter 4, the soil-water balance is fundamentally important with regard to environmental conditions governing the *in situ* preservation of organic archaeological remains, due to its influence on oxygen supply.

With the increasing manifestation of damages to the historic buildings at Bryggen towards the end of the 1990s, a comprehensive monitoring programme was gradually developed to assess the underground situation. The programme comprised extensive monitoring of the area's groundwater and archaeological deposits, along with regular surveying of fixed points to monitor subsidence of the surface and buildings. By 2011, enough groundwork had been done and sufficient data acquired to enable the implementation of mitigation measures designed to stabilize the water balance.

The monitoring data indicate that the Bryggen site is a heterogeneous one with, among other things, locally significant fluctuations in groundwater levels from winter to summer (see chapter 4.2) as a consequence of changes to the natural hydrological situation by urban development in the 1970s. One (of many) mitigation measures is therefore to compensate the loss of water during summer with increased rainwater infiltration, to protect the organic deposits. The Bryggen case shows that it is important to understand the local site heterogeneity, even if this particular site is relatively small in size, before transferring and applying solutions to others. The modelling as described in chapter 4 helps us to better understand the most important flow paths and processes in the soil-water balance, and to find better monitoring methods for other sites in the future.

We can expect that, owing to climate change, more intense weather conditions with heavy stormwater runoff will occur more frequently in the future. The examinations and tests carried out to assess stormwater quality (Chapter 3) at Bryggen in Bergen indicate that the concentrations of pollutants in stormwater vary strongly between and during storm events. The concentrations documented at Bryggen lie within the range of concentrations found in other parts of the world, though the measured copper and zinc quantities seem to be relatively high in an international context. Today, there is no existing quality standard for stormwater treatment in Norway.

As mentioned above, the water balance is fundamentally important for preservation conditions. In general, a significant increase in the water content will reduce the rate of oxygen supply (through soil pores) to the archaeological remains and thereby reduce rates of decay. However, not only the water balance but also the quality of stormwater is of importance in preserving archaeological deposits, at least when stormwater is actively used in mitigation measures such as Sustainable Urban Drainage Systems (SUDS). Measured distributions of particle sizes in the stormwater sources that have been connected to SUDS at Bryggen show that the proportion of fine sediment is comparatively high compared to international data. As the fine fraction is responsible for most of the pollution load that may negatively affect archaeological deposits, it is important to know whether or not implemented SUDS are capable of removing the finer solids. The types of SUDS that have been constructed at Bryggen have been assessed as part of the Urban WATCH project and have been found to be well suited to the purpose. They can, in fact, provide an exceptional combinations of multiple benefits: creating a more sustainable stormwater management system (reducing flooding events and thus lessening pressure on existing drainage systems); improving water quality; enhancing green spaces (the aesthetic aspect); and last but by no means least, contributing to the preservation of archaeological deposits.

Urban cultural heritage in general, and archaeological deposits in particular, are vulnerable to environmental changes. As part of the project, we have looked into how documentation and monitoring can be optimized in order to furnish professionals from different disciplines with relevant information. A national standard of methods for environmental monitoring and investigation of archaeological deposits NS9451:2009 (Standard Norge 2009) was issued in 2009. Our evaluation of its practical use indicates that relatively *few practitioners* within the field of heritage management and research *have knowledge of the standard*. Less than one in five (18%) have used the standard. On the other hand, those who have actually used it find it very user-friendly. This is good news. When it comes to the monitoring standard, one of the main challenges will therefore be to ensure that it becomes more widely known.

The Urban WATCH project has also focused on the aspect of monitoring parameters. A general question is whether oxygen and reduction-oxidation potential (redox-potential in short) measurements should be prescribed either singly or in combination as part of the set of methods for environmental monitoring of archaeological deposits. Recent data (see section 4.3) indicate that redox-potential measurements are very sensitive and react to even minor changes in the environment. The measurements can to some extent indicate what oxidants are present and what processes are ongoing, but there is no correlation between the concentration of individual oxidants and the redox-potential values. It has also been shown that measurement of redox potential is better suited to water-saturated than unsaturated conditions, and for revealing whether environmental conditions are stagnant or dynamic, but the interpretation of absolute values is difficult. Monitoring of the reduction/oxidation state of the archaeological deposits will provide insights into effects in areas where groundwater levels have been raised.

As for monitoring under unsaturated conditions, results from the monitoring work at Bryggen show that oxygen measurements in situ are feasible and that the supply of oxygen is highly correlated to the soil-water balance. The field results can be translated into approximate rates of decay of organic archaeological material when they are combined with laboratory studies of decay under controlled conditions.

In order to define the strengths and limitations of modelling tools in multidisciplinary planning and decision-making, an innovative modelling study was carried out as part of the project. The study assessed if soil moisture and temperature monitoring data can be used in numerical modelling to improve understanding of the hydraulic processes and their influence on the supply of oxygen and other oxidants that drive decay in unsaturated organic deposits. The exercise has yielded some valuable insights into the physical processes involved. Generally speaking, the model performed well in reproducing measured temperature series, but did relatively poorly in reproducing corresponding series of water content. It was concluded that more data is needed on the hydraulic properties of archaeological deposits.

5.2 Planning for the future?

We started this report by pointing out that water management in Scandinavia was somewhat underdeveloped compared to Southern Europe. There have been some major challenges when it comes to water management, cultural heritage and planning in the sense that coordination between urban planners, heritage management authorities and staff in municipal water-management divisions has traditionally been weak. This has sometimes led to problems, as in Bergen. The old wooden settlement of Bryggen was indeed preserved as a world heritage site, but modern building developments resulted in groundwater drawdown and a serious and increasing threat of subsidence. This illustrates how statutory protection of standing architectural heritage may have little value if the historic buildings are being damaged by insidious subterranean processes.

For successful planning, authorities usually need two things: knowledge about the actual challenges - and the ability to act according to that knowledge. The Urban WATCH project has been instrumental in producing fresh knowledge about effects on cultural heritage as far as critical factors such as stormwater and the soil-water balance are concerned.

Also when it comes to acting on the acquired knowledge, the Urban WATCH project's findings are quite encouraging. Knowledge and information in one sector, such as cultural heritage, is passed on to other relevant sectors, such as water management or urban planners. We now find quite a lot of interaction between the key actors. This should secure a good level of coordination in urban planning, from knowledge to action.

Through several studies - not at least related to Bryggen in Bergen, both through this report and the *Ground water project* (Rytter and Schonhowd 2015.) - we now know a lot more about what effects (lack of) groundwater and surface water may have on historic buildings and archaeological deposits, and what ways and means can be applied to mitigate and/or avert negative impacts on this constellation. In combination with the fact that the various involved authorities acknowledge the necessity of working together, and have stated their interest in doing so, this forms a solid springboard for further cooperation and action.

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