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CIRCULAR WATER CHALLENGE

A study of water and sewage on Oaxen

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Content

1 Summary

The following report presents a comprehensive study of water resources, as well as water use and treatment on the island Oaxen of Södertälje municipality in Stockholm region. The island has a size of about 1 km^2, with the area of settlement about 0,12 km^2. The population comprises about 110 people, with the majority of islanders being all-year inhabitants on Oaxen.

There is a community association created on the island (samfällighet) which has a high level of self-organization and is responsible for managing street lightning, roads maintenance, ferry service, drinking water provision and sewage treatment.

Drinking water is provided from local limestone mining pit lake Kroksbrottet. The average annual drinking water production is about 9 132 m^3, including drinking water export to nearby islands Björnhagen and Skarvarstenarna from May to September. The estimated average annual water demand is however almost 39 % lower and is about 6 582 m^3, which might mean a subsequent potential for more efficient water use on the island, as well as a need for improvements in water piping system.

The possible areas for establishing circular water model on the island include, among all, rainwater harvesting in households, use of sea water for toilet flushing in the ferry house, and utilisation of treated water from the sewage plant for the shipyard.

Key words: water, island life, community, sustainability, resource consumption, Oaxen.

Följande rapport presenterar en omfattande studie av vattenresurser, användning och behandling av vatten på ön Oaxen i Södertälje kommun i Stockholms län. Ön är ca 1 km^2 stor, med bostadsområde ca 0,12 km^2. Befolkningen består av cirka 110 personer, och de flesta öborna är året-runt-invånare på Oaxen.

Det finns en samfällighetsförening som skapats på ön. Den har en hög självorganisation och ansvarar för att hantera gatubelysning, underhåll av vägar, färjetrafik, dricksvattenberedning och avloppsrening.

Dricksvatten tillhandahålls från den lokala sjön Kroksbrottet. Den genomsnittliga årliga dricksvattenproduktionen är cirka 9 132 m^3, inklusive dricksvattenexport till närliggande öar Björnhagen och Skarvarstenarna från maj till september. Det beräknade genomsnittliga årliga vattenbehovet är dock nästan 39 % lägre och är approximativt 6 582 m^3. Det kan innebära en framtida möjlighet för effektivare vattenanvändning på ön samt ett behov av förbättringar i vattenledningssystemet.

De möjliga områden för att skapa en cirkulär vattenanvändning på ön omfattar bland annat regnvattenanvändning i hushållen, användning av havsvatten för toalettspolning i huset vid färjeläget och utnyttjande av behandlat vatten från avloppsverket för varvet.

Nyckelord: vatten, öliv, samhälle, hållbarhet, resursförbrukning, Oaxen.

2 Assignment

2.1 Assignment

The assignment included studying water and sewage situation on the island of Oaxen in spring 2019 in the context of the project "Circular Water Challenge," as well as writing a report which should include a suggestion on how water can be reused on Oaxen or in other words how circular water use can be implemented on the island.

Besides Oaxen, islands of Möja, Sandhamn, Kökar, Brändö (Åland), Örö (Finland) and Korpo (Finland) participated in the project. The project is financed by Region Stockholm, the municipalities of Södertälje, Värmdö, Kökar, Brändö, Företagsam skärgård, Forststyrelsen, the Nordic Archipelago Cooperation and KTH, which leads the work.

2.2 Three-layer model

The three-layer model for describing the water and sewage situation on an island was developed during the project "Water Saving Challenge" for the European Parliament and applied to eight European islands in 2017 (Nordström & Pleijel, 2019).

The model distinguishes (a) the island's natural water resources from (b) islanders' needs and demand for fresh water, and (c) the infrastructure installed to meet the needs of the islanders by the use of resources. The purpose is to make a landscape analysis from a waterfront perspective, to describe, understand and compare islands' resources, needs and solutions. The three system levels are called respectively, the natural landscape, the cultural landscape and the technical landscape.

The natural landscape is the first level and encompasses the physical geographical conditions on the island, regardless of where people live. This includes geology; hydrology and climate; area, depth, flora and fauna of the sea; topography, soil, flora and fauna of the land; water resources. At this level, the islands' *water supply* is being described.

At the next level – the cultural landscape – it is described how people move into the island, build houses and villages, use land and water, support themselves, sing, paint, create, organize their social life with children, school, elderly care, health care and security. At this level, the islands' *water needs* are being described.

The third level – the technology landscape – provides an assessment of how people build a common infrastructure with roads, ports and ships, fossil and renewable energy sources, telephone lines, cables and the water systems that are the focus of the study: waterworks, pumps, pipes, measuring systems and treatment plants. At this level, the islands' *water production* is being described, including technical, administrative, legal and economic aspects.

2.3 Methodology

The working approach included desktop studies, field studies, summarizing, analysing and drawing conclusions. First, descriptions of the general conditions of the island as well as earlier water- and sewage-related studies have been read. Then two study visits to the

island, during March 11-15 and April 9-13, have been performed to interview consumers of water services, people who work with water and sewage systems at the practical level, and the local officials who make decisions on expansion, maintenance and management of the systems.

On site, better maps and schemes of water and sewage systems were accessed, and the observations were made about the state of water supplies, pumping stations, pipes, reservoirs and water treatment. Besides, an important knowledge that has only been assessed on site embraced real population and consumption figures.

Collected observations, calculations and suggestions are compiled in the following report.

Analysis and conclusions will be carried out in the next stage of the project during local and joint workshops with politicians and representatives from all the islands together. Then the islands' representatives through an open and trusting dialogue would get the opportunity to participate, understand and learn from the other islands, reflect on their own situation, and set goals for the development of their own water and sewage systems.

3 About Oaxen

3.1 General information

Province	Södermanland
County	Stockholms län
Municipality	Södertälje kommun
Coordinates	58°58′20″N 17°42′43″Ö
Area of the settlement	0,12 km^2

Oaxen is an island and a small settlement in Mörkö parish of Södertälje municipality, located in Himmersfjärden, which is part of the nationally important fairway Landsort – Södertälje (Oaxens Samfällighetsförening, 2018 b). It lies around 45 km to the south from Stockholm and could be reached within approximately 1,5 hours by car from Stockholm city centre or approximately 2,5 hours by public transportation. The ferry ride from Mörkö side to Oaxen takes about 5 minutes, with the ferry going almost every half an hour (the detailed timetable and tickets cost can be found at http://www.oaxenfarjan.se/). The majority of the housing is located at the southern part of the island (embracing about 10 % of the island land), whereas the northern part is dedicated to the nature reserve which is a part of Natura 2000 network.

3.2 History

Oaxen was originally an uninhabited pasture nearby Hörningsholm's castle. Since 19th century, Oaxen's history has been largely impacted by lime mining, as there were rich lime deposits on Oaxen, same as on the nearby island of Karta. Oaxen lies on a bedrock which

largely consists of limestone. The island is about two kilometres long and half a kilometre wide and used to have a limestone mountain in the middle.

At the beginning of the 1830s, the mining of lime began on Karta. However, it was not until the 1850s when lime production started at Oaxen. The industry was set up by Knut Bonde, after he leased Oaxen. He bought the island completely in 1868 and merged the lime production industries at Oaxen and Karta into the company Karta & Oaxen Kalkbruk (Karlsson, 2018).

Fig.1. Archive photo from Oaxen (source: Södertälje kommun, 2016)

During industry's heyday, nearly 250 people worked on the limestone quarry (Visit Skärgården, n.d.). One third of them were employed to transport wood to the lime kilns. Initially, coal had also been used, but its supplies ceased in connection with World War II. In 1880, so many workers had moved to the island that there had been formed a small village on its southern part. At this time, Oaxen had both a shop and school.

The company Karta & Oaxens Kalkbruk was converted into a limited liability company in 1896. In 1921, AB Skånska Cement became the owner of the lime mill. Later in 1955, the ferry service started with cable ferry, and more of the lime began to be transported by truck.

In 1971 the island became the part of Södertälje municipality, instead of Trosa municipality. Three years later, in November 1974 the last blast was done on the mine. At that time Cementa Group was the owner of limestone quarry at Oaxen. Due to the economic crisis various attempts to sell the island were made, and by 1985 the island was owned by two brothers who got an idea to turn Oaxen into a tourist island and create a marina by opening the sea to the former limestone quarry, which turned into the lake. As some form of protest to these ideas from residents, the community association (samfällighet) was created in 1985. After several years of hard work and negotiations, and when the developer who owned the island at that time went bankrupt, the island was purchased by a group of residents in 1992 for 1,4 million Swedish kronor.

In early 2000s, the community association board (samfällighetsförening) initiated the creation of the new detailed plan and in order to partially finance it, sold several parcels of land around the old industrial area to the company group ALM.

2.1 Community

Oaxen has a mix of summer homes and year-round housing. In recent years, the old workers' houses have been renovated, along with some new being constructed, and today there are around 110 residents on the island. The island is connected to the mainland and bus service with the cable ferry.

The community has a high level of self-organization and is responsible for managing themselves street lightning, roads maintenance, ferry service, drinking water provision and sewage treatment. The work of association is regulated by Swedish law on the management of commons (Lag (1973:1150) om förvaltning av samfälligheter). The board also has statutes (stadgar) which provide more details about management rules. The community association board members are elected every two years, and the board chairman every year at the decision-making annual meeting (årsmöte) of community association shareholders in spring. There is also another regular community meeting (öråd) happening in autumn, at which residents discuss various arrangements on the island and suggest new ideas for the community development.

The community association board has two functional divisions: one responsible for the operations related to ferry, and the other – for the rest of tasks.

All property owners at Oaxen are a part of community association. There are ultimately tree types of households on the island, and thus different rules for vote casting:

- private villas have one share each, and thus one vote per villa/household; such residents pay standard yearly fee for the services management on the island;
- condominiums have a set amount of shares per building, and the residents of such households should discuss within their housing association and agree on the decision before they could use their possibility to vote; such residents pay certain percentage of the fee depending on the amount of shares condominium has (for example, Kalk Palais has 10 apartments and 7 shares in the community association, - thus, its residents pay 70 % of a standard yearly fee);
- rental apartments, residents of which can participate in community discussions but have no vote; instead, the owners of such apartments have the right to vote or to transfer their votes to one or group of tenants.

Community also manages a so-called local culture house (Bygdegård) which earlier housed a workers' association at Oaxen. Nowadays a variety of activities are happening on its premises, ranging from meditation classes and movie club to summer café and a conference area. Besides, the restored "Ettans kalkugn" (limestone kiln) is nowadays an architectural monument located on Oaxen. It is the only kiln remaining on the island today, but during the most active period of the limestone industry there were nine of them scattered on either side of the island. Oaxen has also been classed as the area with cultural-historical values of national interest, mainly related to industrial and social history.

The island has got remarkable popularity while there was the famous Michelin star restaurant Oaxen skärgårdskrog in the old villa on the hill. The restaurant, owned by Agneta Green, Magnus Ek, was an important part of the island and moved closer to Stockholm city center in 2011.

4 Natural landscape

4.1 Geology

Oaxen lies on the limestone bedrock which was formed almost 2 billion years ago. The rock is considered to be at least 200 meters thick, of which about 40 meters lies above the current sea level (Oaxens Samfällighetsförening, 2018 b). The type of mineral presented on Oaxen is the limestone in leptite. The rock is a crystalline limestone from limestone beds in the Svecofennian supracrustal formation of middle Sweden, being surrounded by gneisses (Mars, 1951:135).

4.2 Hydrology and climate

The type of climate at Oaxen, as in the whole Stockholm region, is characterized as humid continental climate with warm summers (code *Dfb* according to Köppen climate classification). The yearly average temperature varies between +6,5 to +7,5 °C. For winters, average temperature is -2 to 0 °C; for summers +16 to +18 °C. The yearly average precipitations comprise 650-700 mm, with average winter precipitations being around 140-160 mm, spring – 100-120 mm, summer – 200-220 mm, and autumn – 180-200 mm (Asp et al., 2015).

The average sea surface temperature is +8 to +10 °C (SMHI, 2017). The current medium sea level is about 55-60 cm, with sea level being defined as the height of the sea surface above an equipotential surface or, in other words, how high the sea level can rise during an intense storm. The highest observed sea level is up to 100 cm. As the prognosis for future climate, under the moderate scenario (supposing that the radiation would be stabilized at 4.5 W/m^2 before the year 2100) the average sea level might sink to 10-20 cm with the highest estimated sea level jumping up to 140 mm (SMHI, n. d.).

4.3 Sea: area, depth, flora and fauna

The island is located in Himmerfjärd that is a Swedish estuary bordering on the Northern part of Baltic sea. At the inner end of estuary, the major Stockholm sewage treatment plant SYVAB is located. The plant started its operations in 1974 and nowadays works in cooperation with municipalities of Botkyrka, Nykvarn, Salem, Stockholm, and Södertälje AB. It receives wastewaters from the Essinge islands in the north to Järna in the south (SYVAB Himmerfjärdsverket, n. d.). The map of Himmerfjärd and location of SYVAB treatment plant are shown at the figure 2.

Himmerfjärd is a common estuarine system along the Baltic coast. It covers a total area of 218 km^2 and contains 3,95 km^3 of water. Average basin depth measures 18 m with sill depth typically at 10 m. The maximum water depth is 54 m. The Himmerfjard system is characterized by low salinities varying up to 7 ppt. Freshwater inputs to the system are modest and comes from lake Mälaren through Södertälje canal and from various non-point sources of freshwater. Himmerfjärd is usually frozen during the winter (Wilmot, Toll, & Kjerfve, 1985:163).

The exposed rocky shores of Oaxen are characterized by macroalgal communities. The main species of the top, filamentous, zone of macroalgal community are the green alga *Cladophora glomerata* and the brown alga *Pilayella littoralis*. The filamentous algae are important as food sources and a habitat for many invertebrates. Below it, the macroalgal community is dominated by the perennial bladder wrack (*Fucus vesiculosus*). The bladder wrack zone provides shelter and a source of food to many of the invertebrates and fish of the coastal zone, such as barnacles (*Amphibalanus improvatus*), mysids (*Praunus spp.*), pike (*Esox lucius*), and perch (*Perca fluviatilis*). The bottom zone is characterised by red algae. The faunal community in the red algal zone is similar to that of the bladder wrack zone, although the Pacific blue mussel (*Mytilus trossulus*) are more abundant in the lower red algal zone (Furman et al., 2014:47).

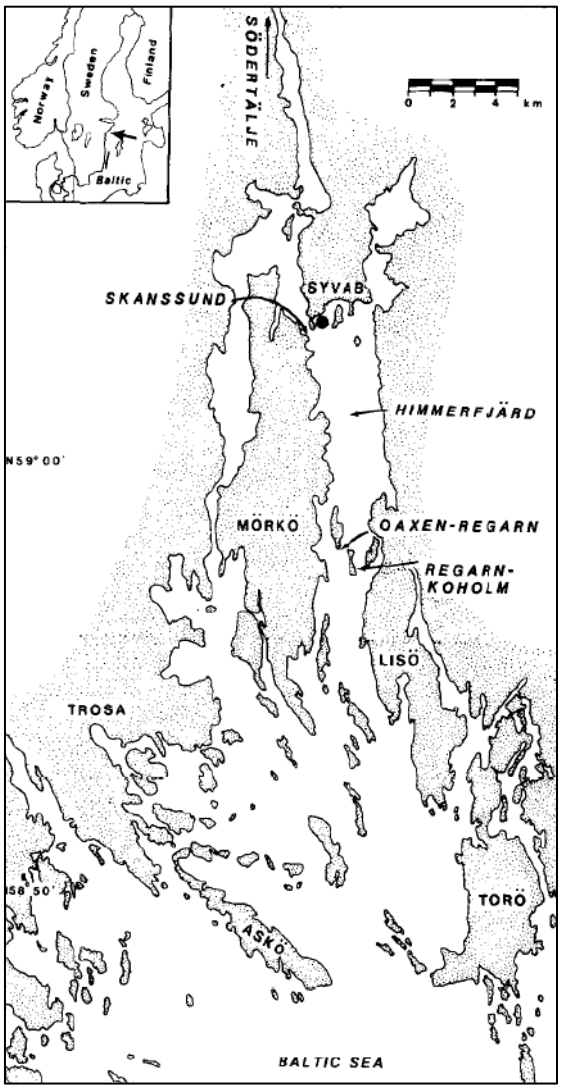

Fig. 2. The map of Himmerfjärd location (source: Wilmot, Toll, & Kjerfve, 1985)

4.4 Land: topography, soil, flora and fauna

The entire island of Oaxen is a precambrian limestone plateau. Before the beginning of limestone mining, the limestone mountain lied in the middle of the island, having a height of 35-40 m. During the industry period, the lime quarry was opened in 1930 in the central part of the island and became the major open pit. When the mining industry ceased in 1975, the depth of the quarry was about 37 m, and gradually it was filled with water, creating a freshwater lake in the middle of the island. There is also a small lake of a size approximately 650 m^2 on the eastern side of the island near former industrial facilities. A deep bay – Kroksviken – used to lay on the eastern side in about the middle of the island but was gradually filled out with lime residues from the mining, as well as with bricks and mortar.

The soils on the island contain about 35-45 % of clay and are identified as brown soil type and brown soil with podzol type (Söderström & Piikki, 2016; The Royal Academy of Agricultural and Forest, 1986). The thickness of soil on the most part of the island is about 0-1 m, and only on the small part on the southern side of the island the average depth to the bedrock amounts to 10-20 m (Geological Survey of Sweden, 2019).

The high steep limestone cliff that forms Oaxen's northern cape embraces the Natura 2000 area (figure 6). On the rest of the island there are buildings, limestone quarries and industrial remains. The area of protected site is 0.211 km^2, and the main subject for protection is the flora with many rare plants, particularly ferns, fungi and orchids (Länsstyrelsen Stockholm, 2016).

The area is dominated by woodland which over the history time was affected by limestone production industry. Mixed forest dominates on slopes along with seedlings of deciduous forest. The main protected habitats include calcareous flatrocks, limestone cliffs with unique vegetation, and herb-rich forest with *Picea abies* (spruce).

There are 13 red-listed fungi found in the area, and 7 of them are dependent on old limestone spruce forest. Besides, 5 of the other present in the area red-listed fungi are dependent on oak or hazel. The most endangered species, *Onnia triquetra* (figure 3), grows in association with pine (Länsstyrelsen Stockholm, 2016).

The other protected species include lime moss *Tortella rigens* (figure 4) and shell mollusc *Vertigo angustior* (figure 5) (Natura 2000, 2019). There are also such interesting species growing in the area as *Truncatellina cylindrica*, *Vitrea contracta* and the very rare in the Stockholm area *Ena obscura*.

Fig. 3. *Onnia triquetra*. (source: Kulbis, 2016).

Fig. 4. *Tortella rigens*. (source: Hagström, 2015).

Fig. 5. *Vertigo angustior*. (source: Wiese, 2004).

Another rarity of the island is common gromwell (*Lithospermum officinale*) (Ek & Green, 2011:77). On the rocks such lime-loving plants are growing as Adam and Eve orchid (*Aplectrum hyemale*), bloody cranesbill (*Geranium sanguineum*), field wormwood (*Artemisia campestris*), tasteless stonecrop (*Sedum sexangulare*), rue-leaved saxifrage (*Saxifraga tridactylites*), hepatica (*Anemone hepatica*), and marjoram in abundance. Besides, wild oregano, sagebrush, basil thyme and chive could be found on the island. On the countless areas grow wild strawberries. There are also typical limestone mosses such as frizzled crisp-moss (*Tortella tortuosa*) and silky wall feather-moss (*Homalothecium sericeum*) (Tutturen, 2016).

As for the big mammals, sometimes deer might be noticed on the island. The old tunnel between the lake to the east side of the island also hosts bats over winter period. Besides, there are also many birds coming to Oaxen, such as eider, merganser, swan, grey goose.

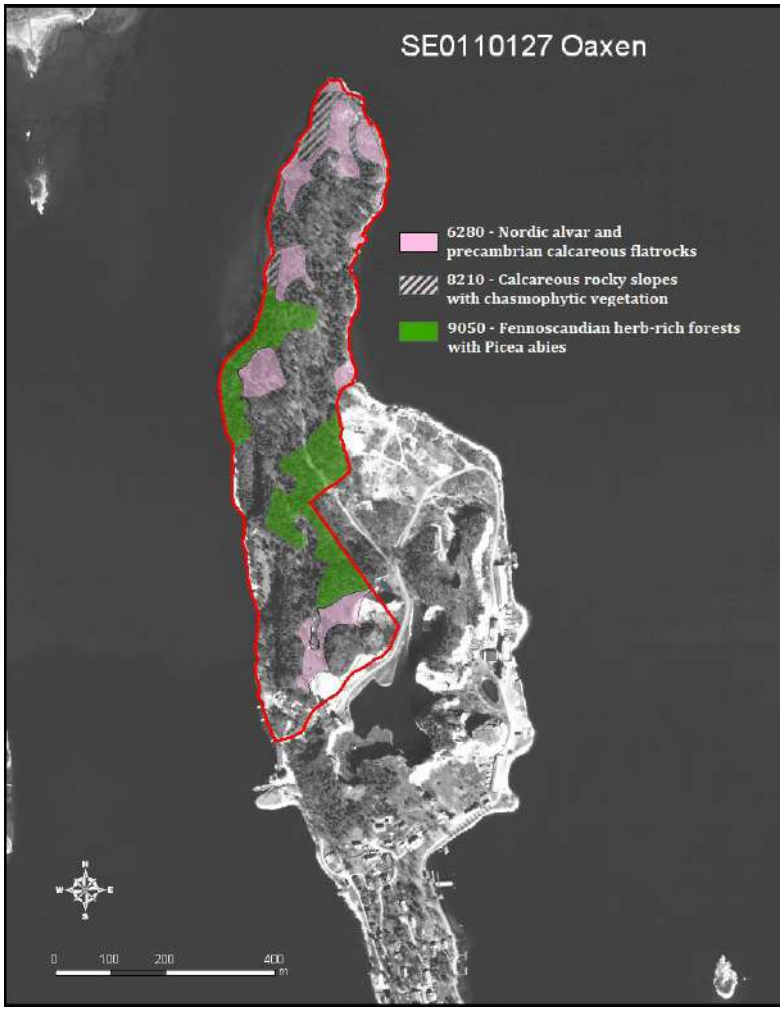

Fig. 6. The map of Natura 2000 area at Oaxen with types of protected habitats (source: Länsstyrelsen Stockholm, 2016)

4.5 Drinking water resources

As it is mentioned in the section 4.4, at the time of limestone industry closure the quarry of a depth about 37 m was formed. It was gradually filled with water and in about 10 years after the end of industrial operations, the level of water in the limestone pit reached the current level that is of about 2 m higher than sea level. Since 1984 the lake formed in the limestone mining pit, called Kroksbrottet, is used by Oaxen residents as the only natural source of drinking water present on the island.

The lake was formed as a result of industrial processes, as in most cases large open pits eventually intersect the water table during mining, and water starts coming into the pit. During mining operations consequent steps were taken to dewater the pit. As dewatering was stopped after mining ceased, and water tables started to rebound, thus forming the lake. The natural process of filling the open pit took place, through hydrological processes such as precipitation and ground water outflow (Gammons et al., 2009).

According to the estimates, the lake surface is approximately 18 400 m^2, and it holds approximately 400 000 m^3 of water. The catchment area is presumed to lie between the highest points around the lake, and its size is estimated to be approximately 75 000 m^2 (Oaxens Samfällighetsförening, 2018 b). The map of the primary water catchment area is presented on the figure 7. The total water catchment area, however, might be larger, as the limestone rock is naturally rich in cracks, and the crack formation has been increased by extensive blasting during industry times.

It has been presumed also that the groundwater and the water in Kroksbrottet has contact with a small lake on the eastern side of the island and flow to the sea.

The maximum percolation of groundwater comprises 250 mm per 1 m^2 and year, considering that:

- the annual precipitation averages 700 mm,
- the annual evaporation from the ground averages 400 mm (SMHI, 2009 b),
- the annual evaporation from the lake averages 500 mm (SMHI, 2009 a),
- the average annual runoff is 50 mm.

However, due to varied runoff, outflow to the sea, differences in bedrock cracks and soil pores, the real value of water percolation to the lake catchment area is estimated to range from 150 to 200 mm.

Thus, the annual reservoir recharge is estimated to be between 11 250 m^3 and 15 000 m^3. This means that daily amount of freshwater available for extraction from the lake without its further disruption averages from 30,8 m^3 to 41,1 m^3.

4.6 Summary

The natural landscape of Oaxen is highly impacted by its geological origins as an island of limestone bedrock. Furthermore, it is shaped by the outcomes of limestone mining industry that defined the current topography of the island and led to creation of the remarkable open source of the freshwater on Oaxen, Kroksbrottet lake.

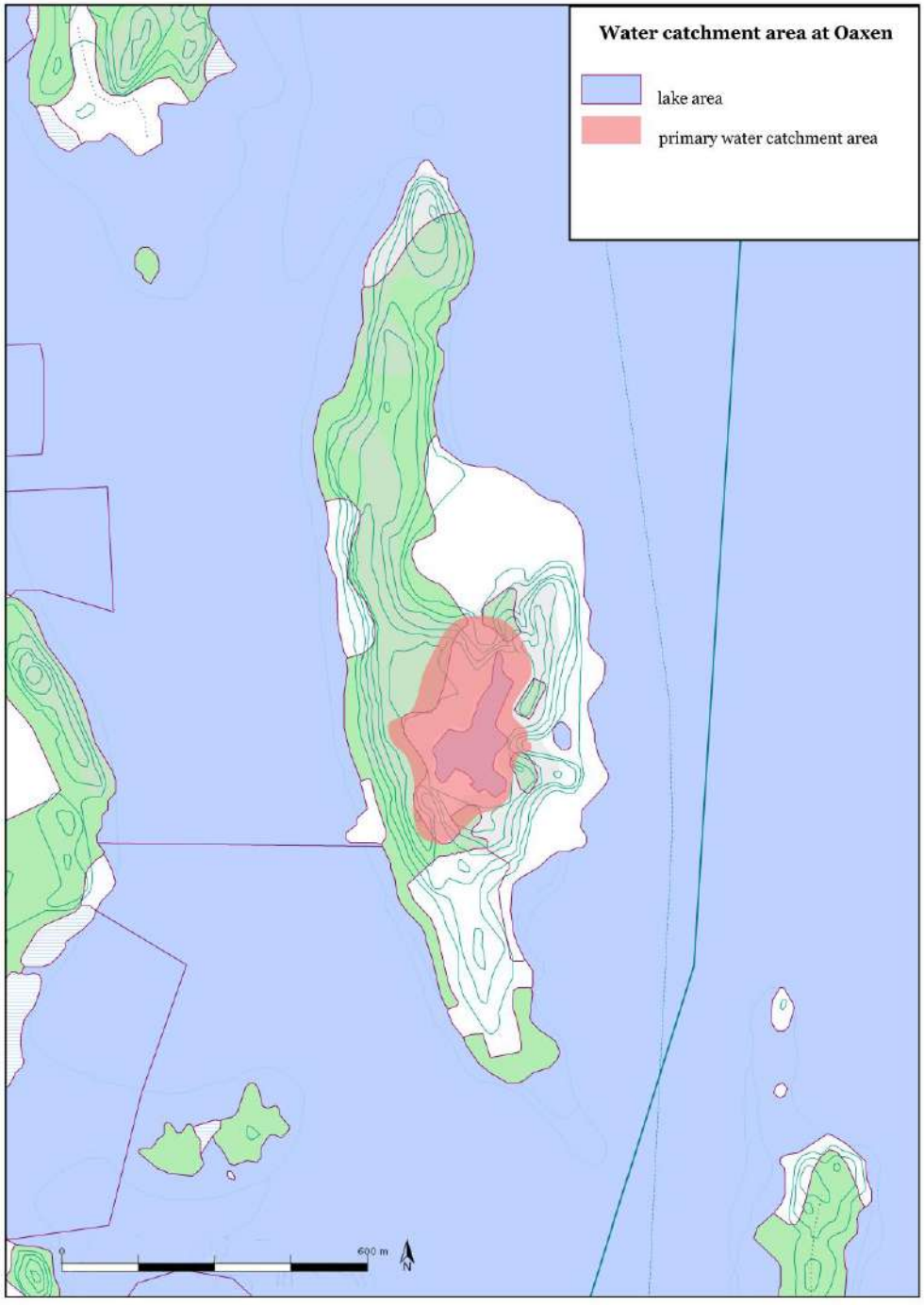

Fig. 7. The map of water catchment area on Oaxen.

5 Cultural landscape

5.1 Population and housing

As it was mentioned in the section 2.1, there are about 110 residents on Oaxen, living in three various types of households: private villas, condominiums, and rental apartments. The majority of the housing consists of private villas. Condominiums (bostadsrättsförening) are mainly represented by *Kalk Palais* (2007-year building near Bygdegården) and *Sjövillan* (2018-year building on the eastern side of the island). Four buildings on the southernmost side have the size of 2-3 floors and are divided on several households, most of which are rented. Thus, there about 12 rental apartments on the island. Another rental apartment is located on the second floor of *Gillet*, which is part of community culture house Bygdegården.

The map of administrative division and property boundaries at Oaxen is depicted on the figure 9. There are about 69 households on the island.

Most of the population of the island are permanent residents, and estimated distribution between permanent and summer residents is about 75 % to 25 % respectively. Besides, during summers the average household size on the island is getting bigger, as many residents have their relatives and friends coming to Oaxen for a weekend or short vacation.

5.2 Agriculture, animal husbandry and fishing

Currently, there are no agricultural, husbandry or commercial fishing activities happening at Oaxen. Previously, during the days when *Oaxen* restaurant occupied the villa on the island, there was a relevantly big garden and greenhouse for herbs and vegetables. Besides, local fish and shrimps were caught by some islanders (Ek & Green, 2011). Nowadays, one of the households has a bee garden and produce honey and bee-wax products in moderate quantities (figure 8). Several other households have small gardens, primarily with flowers, herbs, and some fruit trees.

Nevertheless, there is a number of farming estates near Oaxen, both in the direction to Södertälje and Trosa or Nyköping. Some of them are organic farms, such as Skilleby Trädgård and biodynamic farms of Ytterjärna community.

Recently, there has been an idea to rent several sheep from local farmers to help keep shores and area near the lake clean from weed and tree seeds. However, this is still to be discussed with all residents and municipality.

Fig 8. The bee-wax product from Oaxen bee gargen.

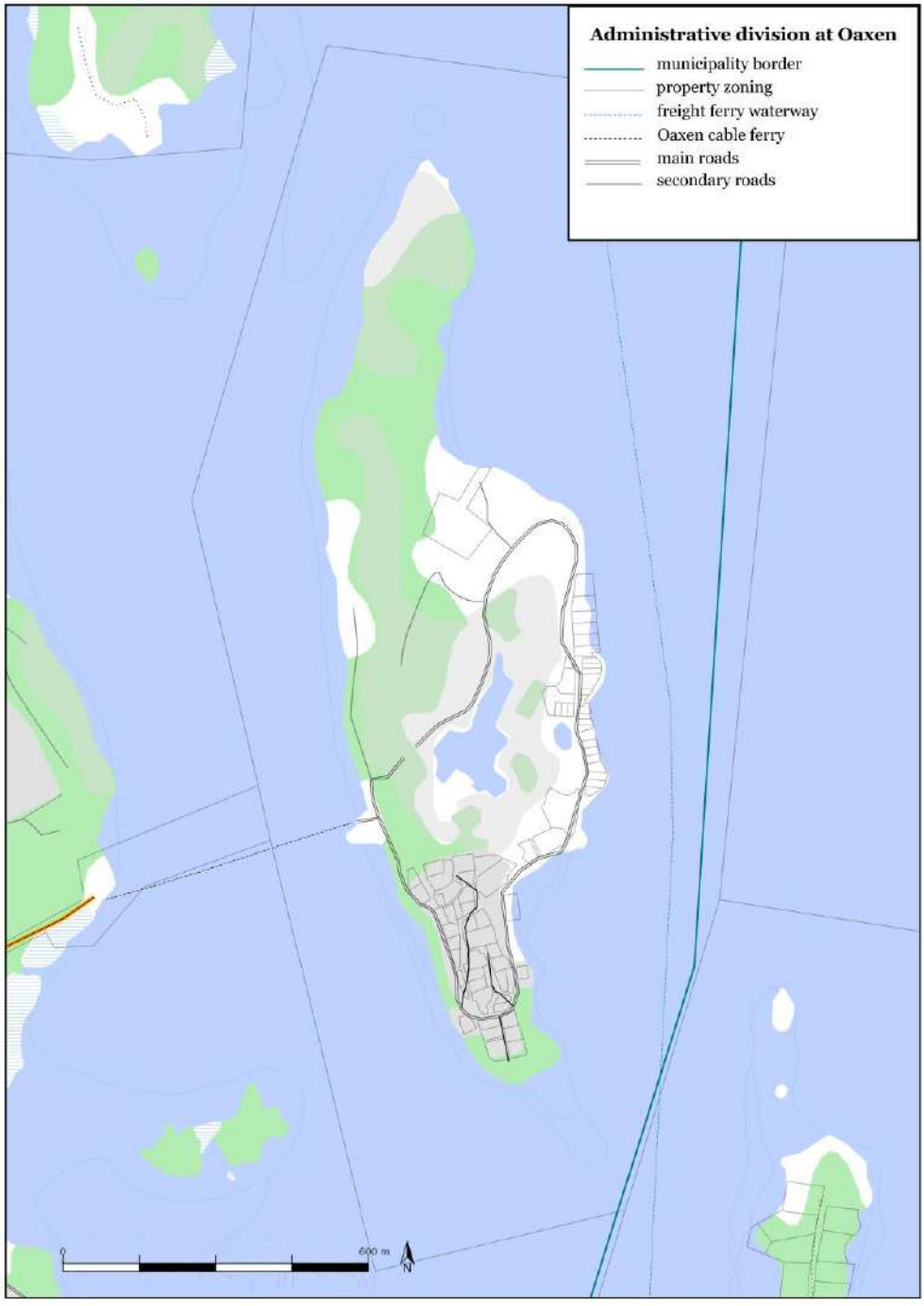

Fig. 9. The map of administrative division at Oaxen.

5.3 Island industry

Although Oaxen used to be an industrial island in the old days, now it is almost fully residential place. The only relevantly big industry present on the island is a shipyard *Oaxen Båtvarv*, which is located on the north-east side of the island (the northernmost property area on the figure 9), near the former sea bay Kroksviken. It also used the premises and space for boat storage in front of old industrial facilities, however starting from 2018 all boats were moved to the northern site.

Oaxen Båtvarv is a family owned shipyard that provides outdoors winter storage, engine service, rebuilding and renovation. There are about 120 boats on service in the shipyard.

Apart from that, there is a small coffee roastery which rents out a space within one of the Bygdegården premises. The roastery is described as one of the smallest Swedish coffee roasteries. Other businesses include small private enterprises, primarily providing various consulting services.

5.4 Tourism

Oaxen had quite remarkable popularity among residents of Stockholm region at the times when the famous restaurant and pub was located on the island. Nowadays, various efforts are made by the community to make Oaxen more visible on the map of Stockholm archipelago. The island attracts more visitors over holidays and during the summer period. The weekend summer café is also being run by community in Gillet to serve guest curious to discover industrial past and spectacular nature of the island.

There are two bed & breakfast premises on the island: *Direktörsvillan Oaxen* with two double rooms and *Oaxen Art B&B* with two double rooms and one quadruple room. Within *Gillet*, there is also a four-room cabin that can be rented out for with three quadruple rooms and one twin room. During winters, approximately 14-18 person per month visit the island and stay overnight. During summers, the number of visitors is approximately 20-26 each weekend.

According to observations of residents running the summer café, there are approximately 75 visitors per day on weekends. In winters, there is a traditional Christmas market organised every year, hosting about 300-400 visitors. Besides, Bygdegården premises, which could be rented out for a conference or party, host about 450-500 people in a year.

5.5 Community services and culture

In the old times during the limestone industry operations on the island, during the 1880s, Oaxen got a shop and school. However, the school was closed in 1961 and the building has been converted into a permanent residence. Nowadays the nearest to the island school is in Hölö, with approximately 15,5 km distance from Oaxen. The nearest supermarket is also in Hölö, or within approximately similar distance on the northern side of Mörkö. However, most of the residents make shopping in Södertälje when they go after work or any other business.

The main healthcare center is located in Södertälje, however there is a person in Oaxen community who is responsible for the emergency service.

The nearest church is Mörkö kyrka, which is within approximately 6 km reach.

In Oaxens Bygdegården there is a library and a community space with cinema club, yoga classes and other activities. Various meditation classes and art workshops are organized in Bygdegården and Oaxen Art B&B. Furthermore, in the summer 2019 community will hold the second sculpture exhibition in the old lime kiln. It is also planned to have a publicly open workshop in stone carving.

Behind Bygdegården, a court for boule is located. The children playground is on the southern side of the island near the beach place. The yearly running fest Oaxen Runt is organised by the community every autumn.

Nearby beach side there are two jetties for boats, as well as two more in front of Bygdegården and one near ferry house. There is also a garage for boats to the north from the lakeside, as well as two boat clubs to the north from the ferry house, with 19 boats owned by islanders and 12 guest boats.

Transport connection with the mainland is provided by the cable ferry, which is owned by Oaxen community association. Nowadays ferry is operating on diesel, however this year it was decided to electrify it. The cost of the ride id SEK 20 for pedestrians and SEK 70 for cars; residents pay a yearly fee of SEK 2500 per each household for the ferry service.

5.6 Water needs and demand (consumption perspective)

According to 2019 Statistical Yearbook for Stockholm, water consumption in 2017 averaged 283 litres per person and day, including small industries, public amenities and leakage (Stockholms Stad, 2019:110). At the same time, according to Svenskt Vatten, on average each person in Sweden uses 140 litres of water per day (Svenskt Vatten, 2019). Out of that, the distribution of the amounts of water used for various needs in the households is the following:

- 60 litres for personal hygiene,
- 30 litres for toilet flushing,
- 15 litres for dishes,
- 15 litres for washing,
- 10 litres for food and drink,
- 10 litres for other use (Svenskt Vatten, 2019).

For Oaxen, due to the fact that households do not have water metering systems and the only accounting of water consumption is done in central pumphouses, the average water use was estimated based on interviews with residents about their water use habits. Interviews were done during the field studies in March and April 2019. In total, residents from about 10 % of households were questioned about their water use habits. About half of all respondents represent residents of condominiums, 25 % – residents of villas, and 25 % – residents of rental apartments. Based on responses, the approximate water consumption was estimated

using online water usage calculator (available at https://www.hunterwater.com.au/Save-Water/Water-Usage-Calculator.aspx). It was also taken into account, that there are three households with swimming pools or outdoor bathtubs on the island, and one with a swimming pool which is not in use. Some of the residents also collect rainwater in barrels or decorative ponds and use it in their gardens. Besides, nineteen households own boats that go through the yearly service near the ferry house on the island (20-30 minutes boat wash and 5-minutes engine wash with the pressure machine twice per year).

Thus, the average water consumption on the island was estimated to be about 155 litres per person and day in cold season (from October to April) and about 187 litres per person and day in warm season (from May to September).

The distribution of the amounts of water used for various needs in the households on Oaxen is presented on the figure 10. Over the course of the year, the biggest share of water is consumed for personal hygiene and toilet (category "Bathroom"), whereas the difference between water consumption in cold and warm seasons is driven mainly by use of water for boats (and rarely – cars) wash.

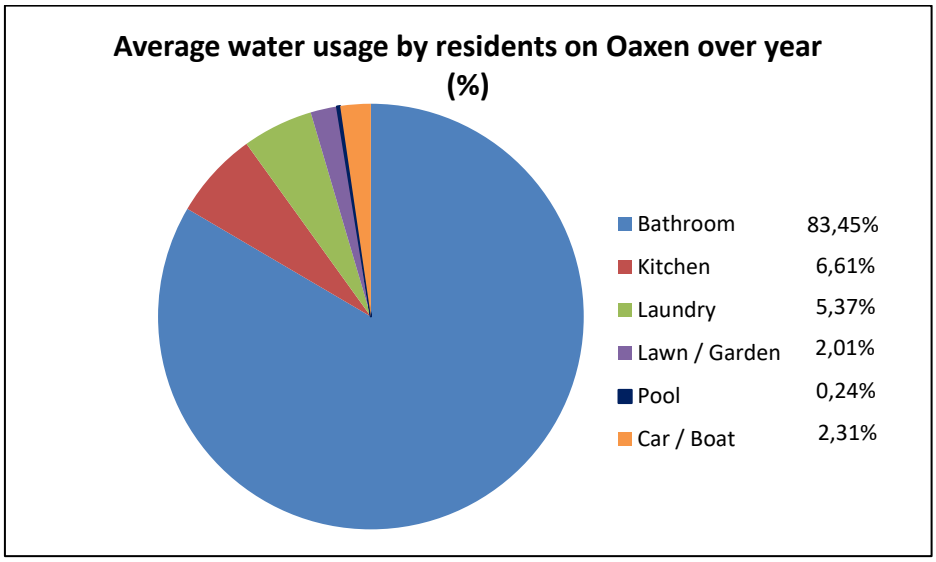

Fig. 10. The chart representing the distribution of the amounts of water used for various needs in the households on Oaxen over year.

To evaluate the average yearly water consumption on Oaxen, including both residents and visitors, the number of persons per day was calculated, as well as and their respective water use. The estimated average water demand of the island over the course of one year is presented in the table 1.

Assuming that about 75 % of people who live on Oaxen are permanent residents, about 82 persons live on the island during the cold period (212 days). Over the warm period (153 days) there are both permanent and summer residents, 110 persons. The number of one day visitors was estimated based on the observations and data from summer café and Bygdegården, their average water consumption was assessed with the help of water usage

calculator. The number of summer visitors who stay overnight was estimated based on the capacity of hosting facilities on the island and on the assumption that at least one third of residents have their friends or relatives visiting them during weekends. It was assumed, that visitors stay for two days (usually weekend) every week during the summer. For cold season (Sep-May), the number of visitors staying overnight (2 days) was estimated to be 16 person per month. It was assumed, that water consumption of visitors who stay overnight is the same as average water use in homes in Sweden, as they stay not in hotels but in the same type of housing as usual residents.

So far, the yearly water consumption by residents and visitors on Oaxen was estimated to be 6 440 m^3. This averages to 17,64 m^3 per day yearly or about 13,1 m^3 per day in winter and 24 m^3 per day in summer.

However, to estimate the full water consumption on the island, the water use by the shipyard should be taken into account as well. The assumption was made that there are in average 120 boats in the shipyard that go through yearly service which includes 20-30 minutes boat wash and 5-minutes engine wash with the pressure machine twice per year, and that water use amounts to approximately 8 litres per minute (Kärcher, n.d.). With such numbers, the water use by shipyard averages to 67,2 m^3 per year.

Besides, approximately from May to September the water from Oaxen is supplied to nearby islands of Björnhagen (about 14 m^3 per month over period from May to September, or approximately 70 m^3 per year) and Skarvarstenarna (about 5 m^3 per year).

Hence, the full yearly water demand on Oaxen was estimated to be 6 582 m^3, with the daily average 18,03 m^3.

Table 1. Water demand on Oaxen from the consumption perspective.

Category		Number of people each day	Number of days	m^3/p/d	Sum
Oct-Apr residents		82	212	0,155	2694,520
May-Sep residents		110	153	0,187	3147,210
Visitors	Summer 1-day	100	26	0,095	247,000
	Christmas market (1-day)	16	25	0,095	38,000
	Summer overnight	75	26	0,140	273,000
	Sep-May overnight	16	18	0,140	40,320
Total per year					6440,050

5.7 Summary

Oaxen is an island with a total population of about 110 people, most of whom live on the island permanently over the year. There is no agriculture on the island, and the industry sector is represented by Oaxen shipyard. Tourism is steadily developing on the island, and there are already two households offering bed & breakfast and one hostel-type facility on the island. Besides, summer café is operating in community culture house on weekends.

Based on interviews with people living in different types of households, the average water use by residents of Oaxen was estimated to be about 155 litres per person and day in cold season (from October to April) and about 187 litres per person and day in warm season (from May to September).

Gross water demand by residents and visitors was estimated to be 6 440 m^3 per year or in average 17,64 m^3 per day. The total water demand, including water use by shipyard and export to nearby islands, was estimated to be 6 582 m^3, with the daily average 18,03 m^3.

6 Technical landscape

6.1 Energy, waste, transport, and telecommunications

The island has connection to the electricity line from *Telge Energi* company in Södertälje. The connection goes from the side of Mörkö by underwater powerline and then continues on the island by overhead line. As for the electricity itself, each household has the possibility to choose the energy supply from different companies that are serving municipality. The community association board is responsible for managing electricity supply for street lightning, pump stations and treatment plant, as well as to ferry house.

In 1990, the first in the Stockholm area major energy windmill (figure 11) was erected on Oaxen, having the power capacity of 99 kW (Fjaestad, 2013:125; Dominkovic´, 2007:14). However, the windmill was taken down by 2014 due to noise and proximity to the residential area. Nowadays Oaxen residents discuss the possibility of solar park installation.

Fig.11. The location of former energy windmill at Oaxen.

Heating is organized on the individual basis by each house. There are two premises that use heat pumps, the villa which was previously occupied by the restaurant and one of the houses on the southernmost side. Of the island. Many households also have one or several fireplaces.

Waste collection is provided by *Telge Återvinning* company and is being paid for by each household separately to Södertälje municipality. Trucks for waste collection are directed by ferry operators to drive by the western side of the island, and not pass by the lake. Apart from the central waste collection, some households use composting for organic waste.

There is one main road that goes around the island, to the south from the ferry side through the settlement and to the north from the ferry side through the tunnel near the lake. The most common modes of transportation around the island are by foot and by car.

Broadband connection to the island is being discussed at the moment. One of the options that might be viable for the island is land connection to telecommunications from the side of Mörkö. The other option that is being evaluated is satellite broadband connection.

6.2 Water production: sources and system

During the industry times on the island, the water was supplied from several groundwater wells and, by bigger extend, was imported from the mainland. In summer, water was pumped to the tank on the top of the hill, and it run down thanks to gravity forces, being distributed around via pipelines that were laid on the ground (figure 12). After the industry was over, this system started collapsing, and since 1984 drinking water provision on Oaxen was organized and managed locally by community association, with water being supplied from Oaxen's limestone mining pit lake (figure 13).

Fig. 12. The residues of old water system.

Fig. 13. Pumphouse for major water intake.

The map of water supply system on Oaxen is shown on the figure 14, and the principal scheme of drinking water provision is depicted on the figure 15. Piping network, however, is reasonably old in some places, and the recent mapping (which was made in parts thanks to knowledge of older residents) attempts to present a wholistic picture of the system, though not necessarily reflect it with absolute precision.

The majority of residents of the island get water supplied from the major water intake pumphouse (labelled on the figure 14 under number "2"), via the distribution pumphouse (labelled on the figure 14 under number "3"). The new water intake pumphouse on the eastern side (labelled on the figure 14 under number "1") provide water to the new housing near old industrial facilities.

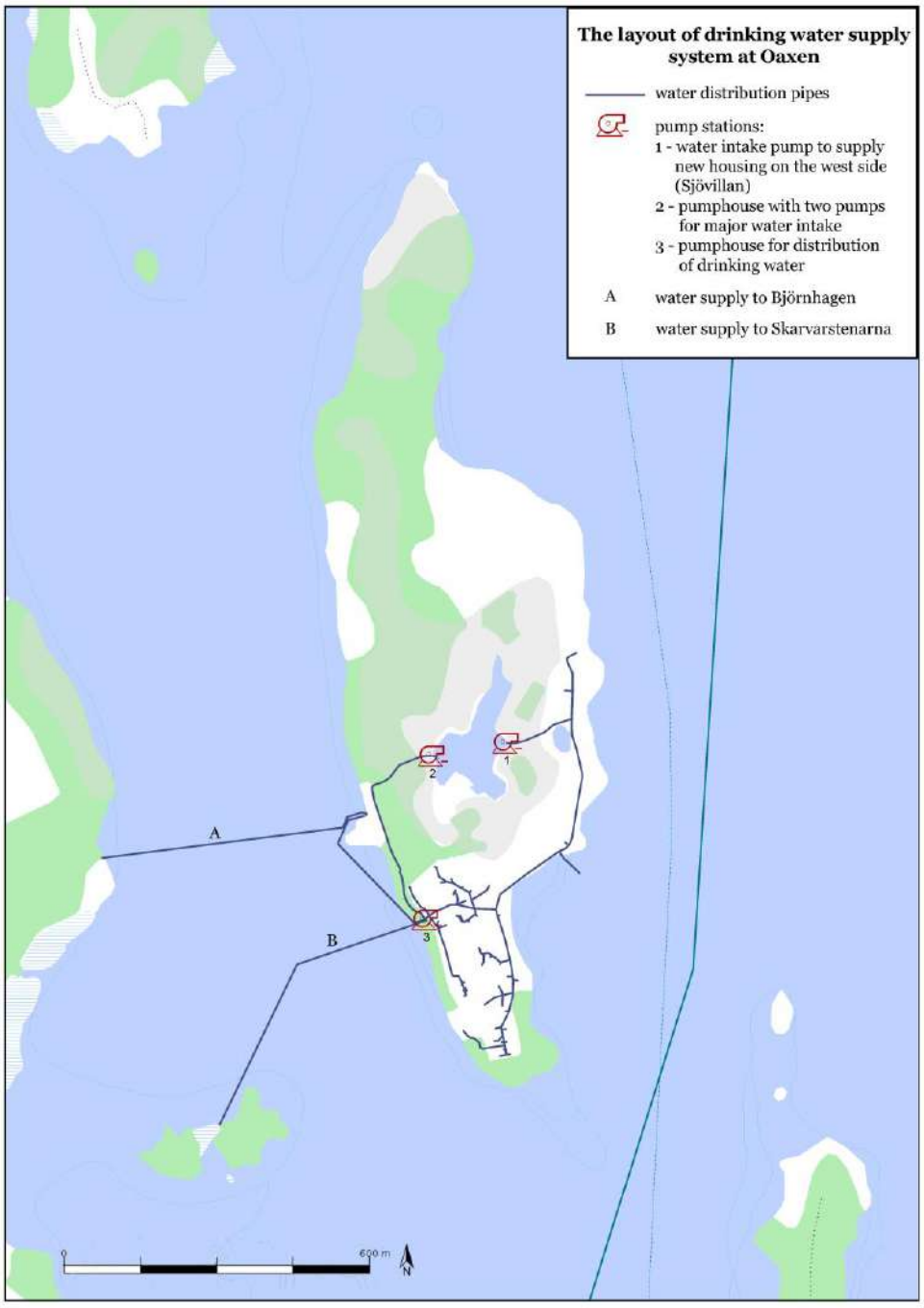

Fig. 14. The map of water supply system on Oaxen.

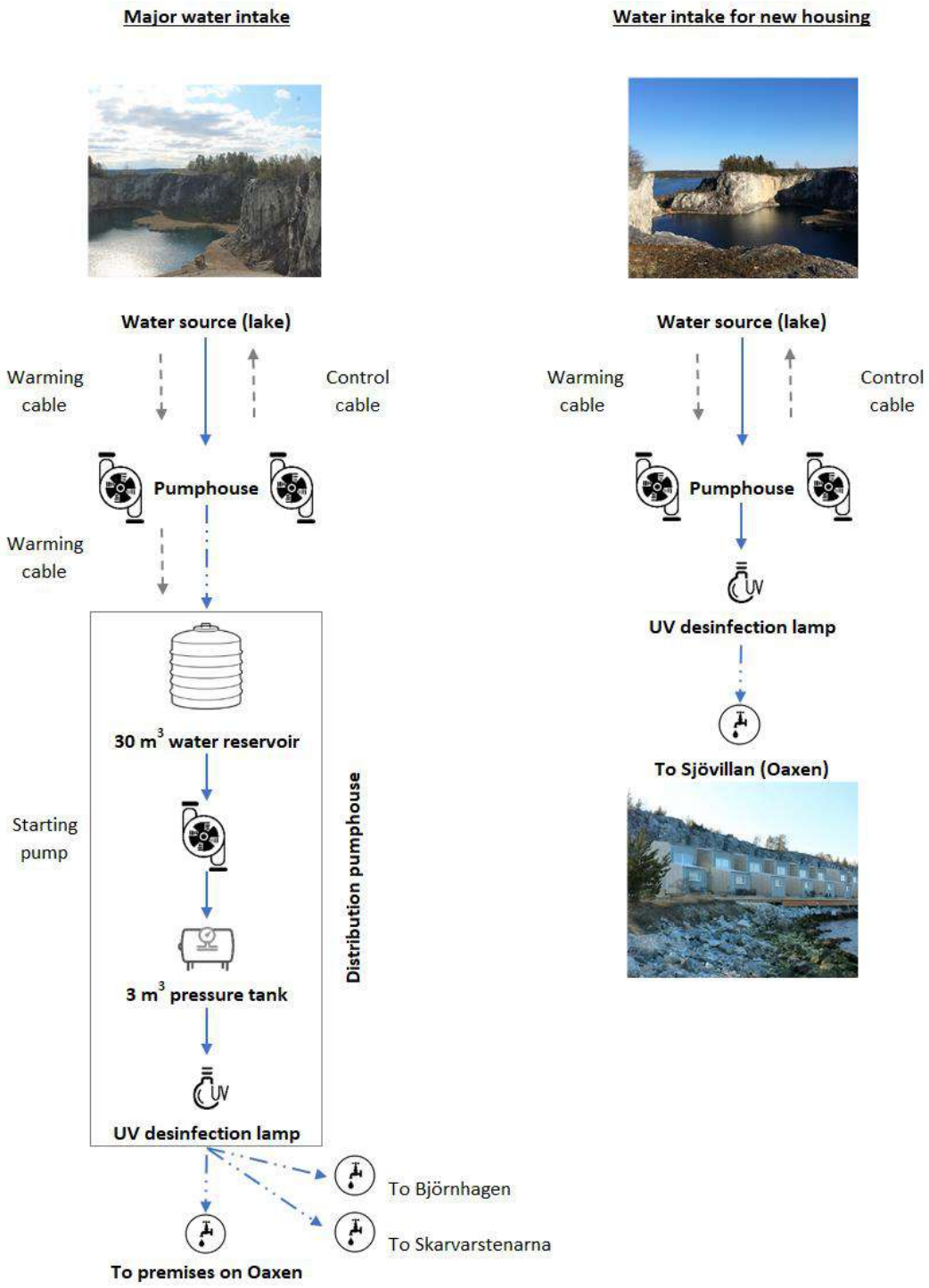

Fig. 15. The principal scheme of drinking water provision system on Oaxen.

The water intake is done on the depth of approximately 2 m. First, water goes through the coarse filter, and then it gets transported from the major water intake pumphouse to the distribution pumphouse. On this part of the way, warming cable helps to keep the water running during low temperatures, as due to the geological specifics water pipe cannot be laid deeper in the ground.

In the distribution pumphouse water goes in first to the 30 m^3 storage tank, which may mitigate the peaks in water consumption and reduce risk of water supply disruption for up to two days. From the tank, it goes through hydrophore to create necessary pressure for water distribution up to Kalk Palais on the eastern side. Then water is disinfected via UV-filter (figure 16) and supplied to consumers.

Similar process works in the new water intake pumphouse on the eastern side, though there is no separate water distribution system with water storage tank, and both hydrophore and UV-filter are located in the water intake pumphouse itself.

The intensity of the UV light in both cases is measured by the built-in UV censor.

Water meters on the island are located in the distribution pumphouse (for the users on Oaxen and separate for metering exported water) and in the new water intake pumphouse.

Fig. 16. UV-filter in the water distribution pumphouse.

Fig. 17. Pumphouse and water protection zone sign.

During the last evaluation of water system in early 2000s, it was stated that only 30 more apartments could be connected to water supply from the lake, and the houses that would be built after should seek for alternative freshwater sources. Nowadays 26 apartments out of the allowed 30 are built. However, as the baseline conditions have changed since the last assessment, the state of water system might be revised and new number of allowed additional housing might be proposed in case of thoughtful and careful water use.

The water protection area embraces the surroundings lying within the highest points around the lake. Besides, the area within approximately 2-3 m around the water supply is physically protected with a fence which has two locked gates. Signs inform that drinking water supply is located within the premises and that stopping with a motor vehicle is

prohibited (figure 17). The lake surroundings are cleaned, and abundant vegetation is removed during community cleaning days in spring and autumn.

The quality of water is ensured by performing chemical and microbiological analysis of raw water, water directly after UV-treatment, and water from user's tap. Samples are taken by community association representatives, the analysis is done in *Synlab*, Linköping. The schedule for samples taking is made following Swedish regulations about drinking water.

Continuous water quality monitoring shows that the brackish water from Himmerfjärden does not intrude into the surface water of the lake, and that the limestone does not affect water hardness.

6.3 Water demand (production perspective), seasonal variation

The water meters installed in the pump houses on Oaxen serve as a single point for measuring both the amount of produced and used water.

In 2017, water consumption on average was 26 m^3 per day. The maximum daily consumption was 44 m^3 in June, and the minimum was 11 m^3 in December. The year before, in 2016, the average number was lower – 24 m^3 per day. The maximum daily consumption reached 41 m^3 in June, and the minimum was 15 m^3 in February (figure 18).

The average monthly consumption over two years was about 761 m^3, with maximum amount of 1330 m^3 in June 2017 and minimum of 323 m^3 in December 2017 (figure 19).

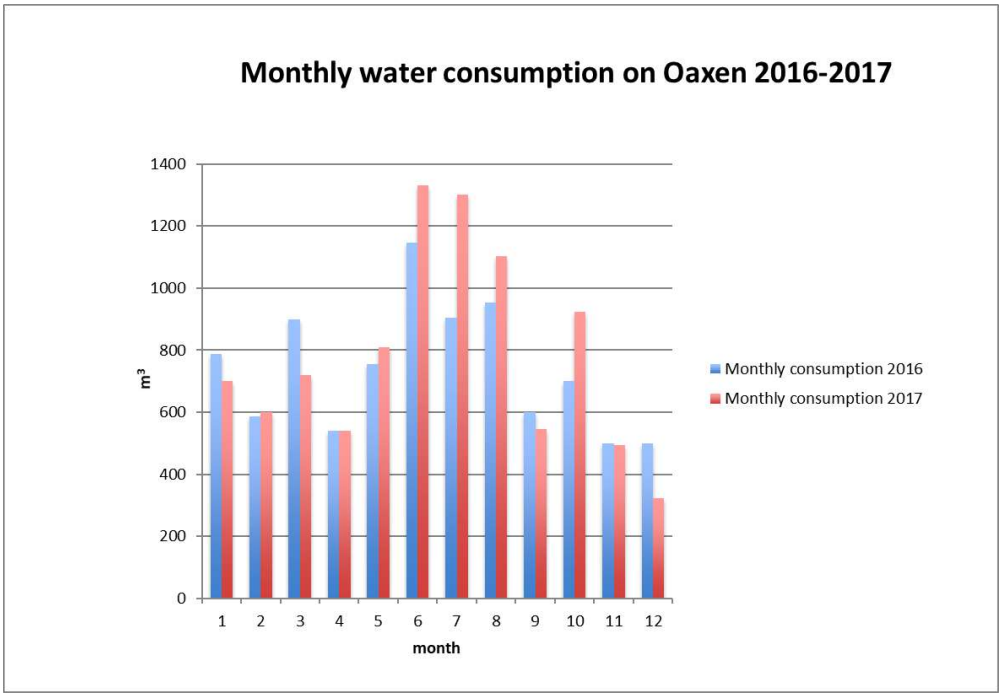

Fig. 18. The histogram depicting monthly water consumption on Oaxen in 2016 and 2017 (production perspective).

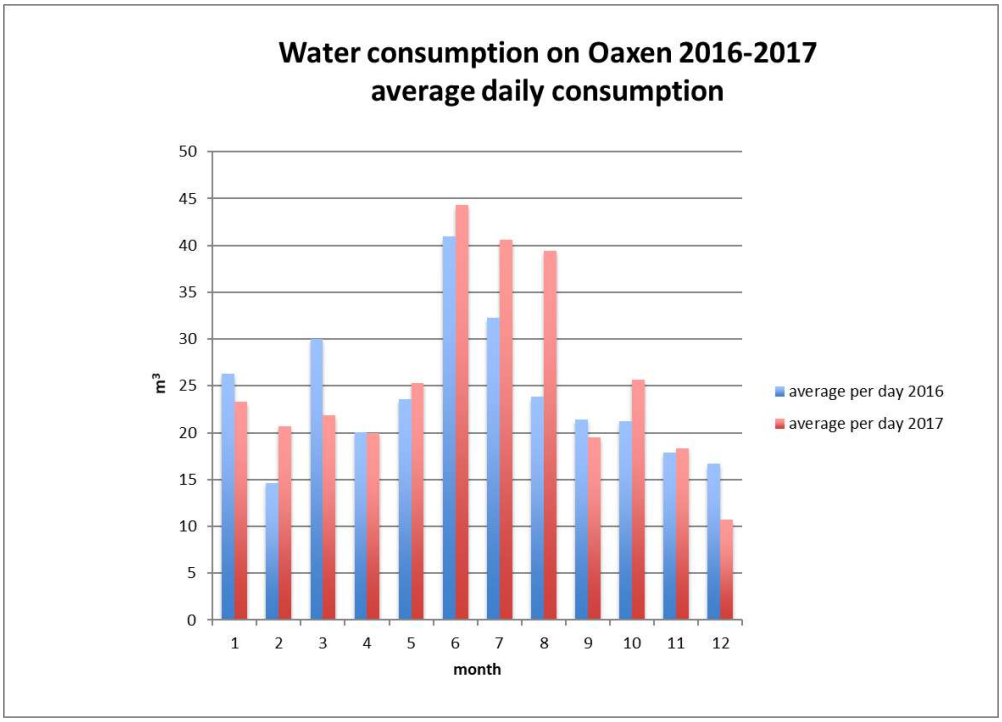

Fig. 19. The histogram depicting average daily water consumption on Oaxen in 2016 and 2017 (production perspective).

Thus, the average water consumption calculated with the notion that there are in total 110 residents on Oaxen, amounts to 220 litres per person and day, which is about 40 % higher than the average assessed water use in holiday homes. However, such estimation account only people who live on Oaxen, and distribute between them also amounts of water used by visitors, shipyard, and two other settlements which purchase water from Oaxen during summer.

The average total annual water production on Oaxen was 9 132 m^3, which is almost 39 % more than estimated full yearly water demand of 6 582 m^3. As the water demand from consumption perspective lacked full relevant data for estimation and was based on interviews with residents about their water use habits, the higher water production level might indicate that

- the actual household water use behaviour is less restricted than assumed (e.g. less efficient bathroom appliances used, more water consumption for watering gardens or lawns, etc.);
- the number of visitors is higher than the one retrieved from island residents' observations (e.g. due more residents' family members and/or friends are coming to the island);
- some amount of water is being lost in the water piping system due to the leakages.

6.4 Sewage: system and sewage treatment arrangement

Same as water provision, wastewater collection and treatment are managed locally by community association on Oaxen. The stormwater treatment, however, is not included in the central sewage system and is managed by each household individually.

Parts of the network are old and originate from the industrial time before 1974. When the community association was created, in the year 1986, the wastewater collection network was built for 21 apartments and after a few years another 12 apartments were added. The network was linked to a three-chamber well system and then to infiltration bed (Oaxens Samfällighetsförening, 2018 a). The central community sewage treatment facility and the infiltration bed had been placed near the former sea bay Kroksviken, on the padding of lime residue from the mining and bricks.

Until 2011, all wastewater on the island was collected and treated in the system of three-chamber septic tank type. In such system, in the first step sludge is being sedimented, then wastewater goes through aeration and digestion stage, and in the third step the residue waste is being sedimented before the treated water is being let out to the infiltration bed.

In 2011, under the agreement with ALM company group which purchased part of land on the island, a new water treatment system TOPAS was installed to complement three-chamber well tank. This system serves all residents of Oaxen, whereas the ferry house and several small boat cabins on the western side near ferry are served by the smaller three-chamber septic tank located nearby ferry house.

The map of wastewater collection and treatment system on Oaxen is shown on the figure 21, and the principal scheme of central wastewater treatment system is depicted on the figure 22.

The wastewater is transported to the treatment plant via gravity flow and with the help of five pump stations, locations of which are shown on the figure 21. In the treatment site water goes first through the three-chamber tank, and then it is pumped to one of two identical wastewater systems provided by TOPAS company. The presence of two systems, instead of just one, allows to secure continuous treatment of water and to carry out various service works without major disruptions of the whole system.

The work of TOPAS system corresponds to a continuous process of classical wastewater treatment based on active sludge. At the first – biological – step the water is being aerated to avoid odours and dissolve residual solid matter, then it is processed in the tank with active sludge to clean up the water by biological mass. After biological treatment, the cleaning process is supplemented by adding chemical reagent to reduce the level of phosphorus in the treated water. In the system installed on Oaxen, the chemical mix Kemira PAX 21 is being used, with the active component of Polyaluminium chloride hydroxide that is one of the chemicals that are typically used for treatment of water intended for human consumption (Svenska institutet för standarder, 2004). The dosage of chemicals is done automatically and is adjusted during the technical check-ups of the system (figure 20).

Fig. 20. The chemicals' dosage equipment at the central wastewater treatment system on Oaxen.

After the stage of chemical precipitation – or flocculation – the water is being cleaned from sediments through the sand filter. At the final treatment step, purified water goes through UV-filter for disinfection and then is let out to the infiltration bed.

The average flow of the wastewater in the sewage treatment system is 3-5 m^3 per hour, and as one of the advantages of used technical solution, the system can handle uneven operational flows and long breaks in the operation.

The treatment plant is also equipped with water meter to monitor how much water is being processed. So far, since the beginning of operation the facility has treated about 56 110 m^3 of water, which averages to 7 500 m^3 of wastewater per year or about 21 m^3 per day.

The quality of treated water is checked twice per year, water samples are taken by the representatives of TOPAS company and are sent for analysis to *Synlab* laboratory in Linköping. The analysis result is controlled by the community association board and is sent to Södertälje municipality.

Besides water quality check service, the treatment plant is being flushed every week by representative of community association and checked by TOPAS company representative three or four times per year. Pumps undergo the routine service every year, and sludge from both central sewage treatment plant and three-chamber septic tank near ferry house is being moved away by truck once per year.

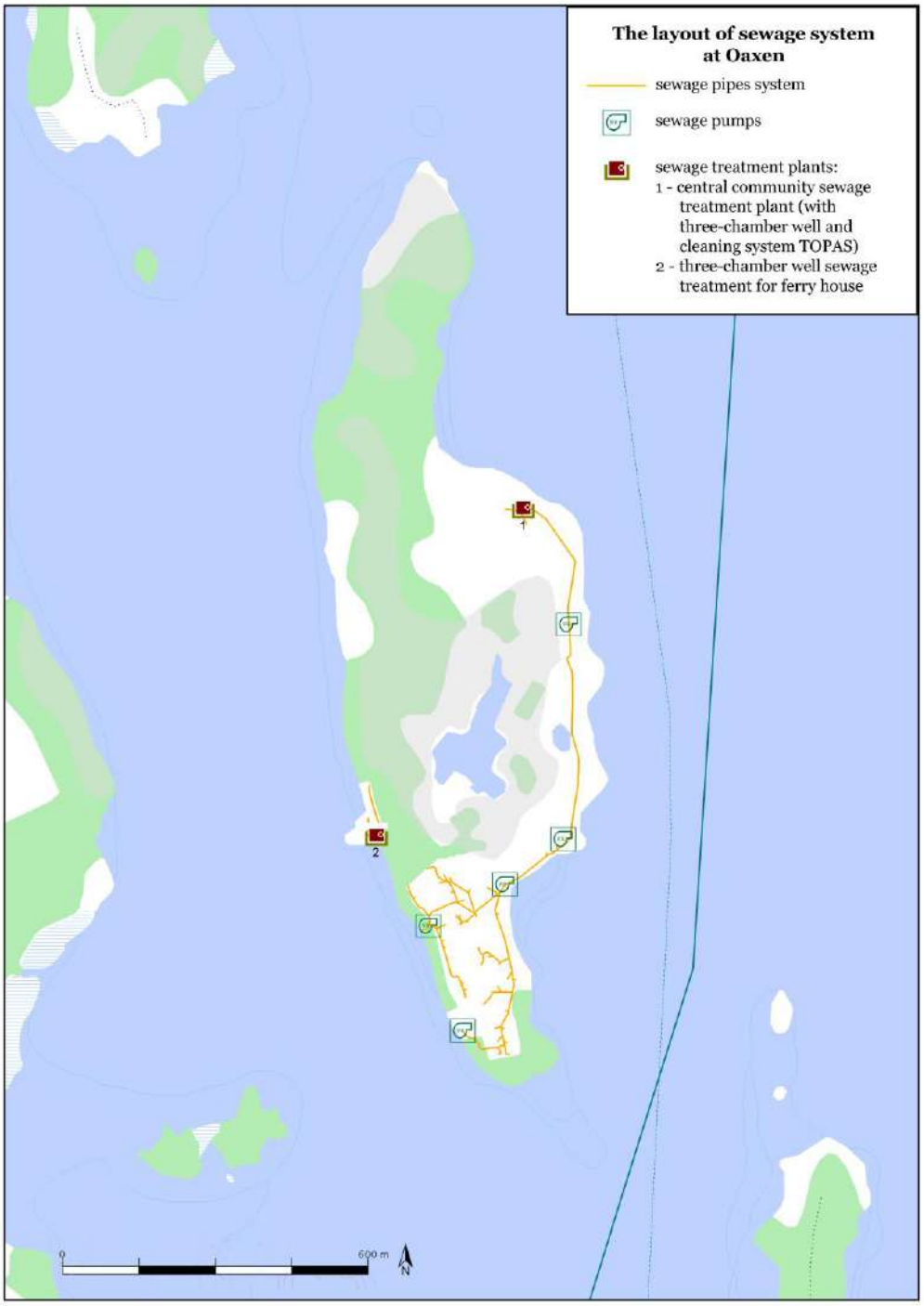

Fig. 21. The map of wastewater collection and treatment system on Oaxen.

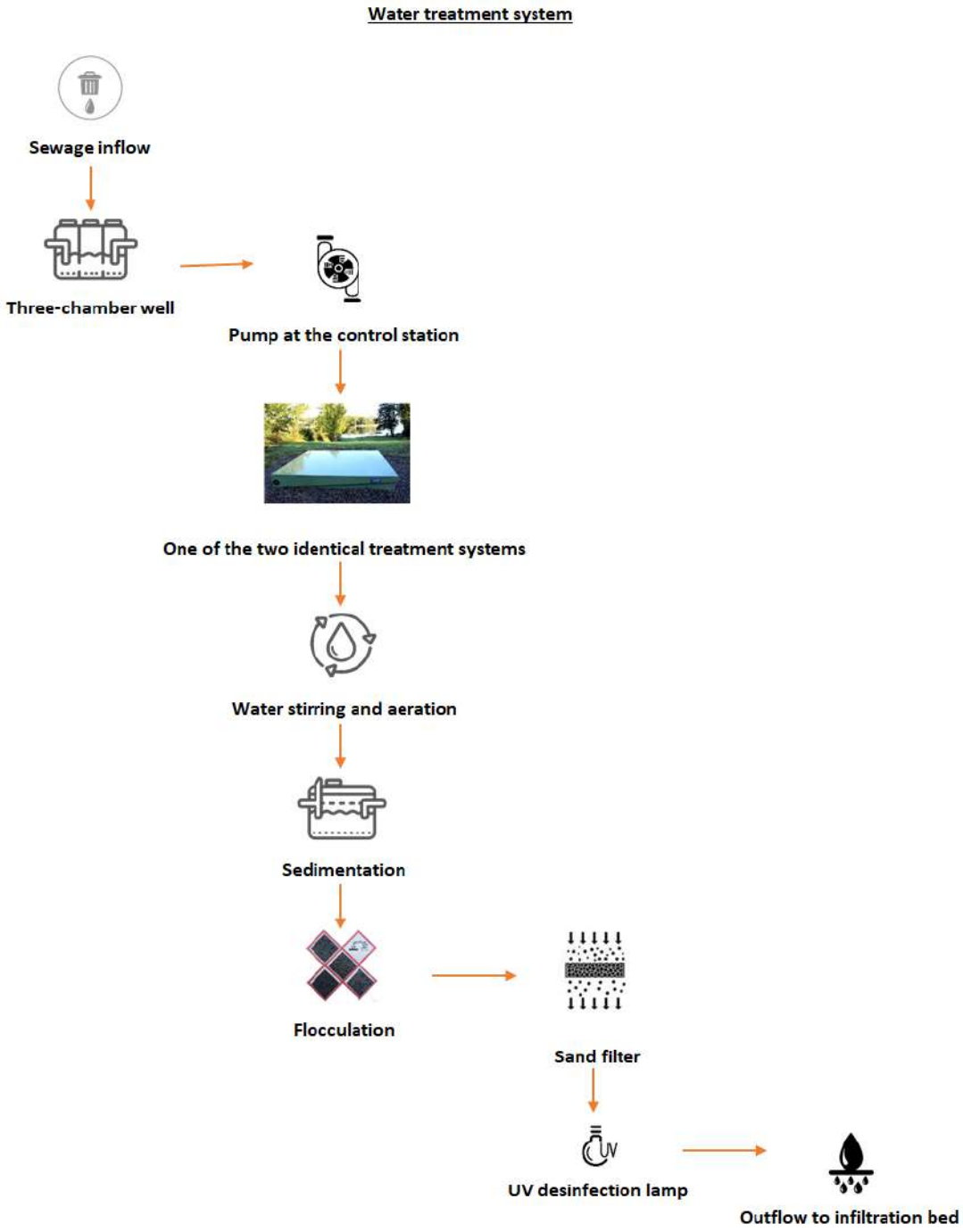

Fig. 22. The principal scheme of central wastewater treatment system on Oaxen.

6.5 Private water and sewage wells

Nowadays, there are no active private wells on Oaxen for water provision and sewage.

The open source database of Geological Survey of Sweden contains information about three wells at Oaxen: two energy wells and one well of unknown purpose. The energy well which is located in the southernmost house has the depth of 36 m, and the one located in the former restaurant villa is 200 m deep. The well of unknown purpose is located nearby old silos and has a depth of 96 m (Sveriges geologiska undersökning, 2019).

Besides, during the old times there were several wells on the island that were used for sewerage. Two of such wells are nowadays used for sewage pump stations – one nearby the water distribution pump house, and the other down the hill near former restaurant villa. Two others are located on the southern side near children playground and on the shore at southwest side. Furthermore, one well of such type was spotted during field studies near the old industrial facilities on the western shore

As for the water wells, one that was used during the old times is located nearby the water distribution pumphouse. It was equipped with manual water pump, which still stays on the island, though unused (figure 23). Three other water wells of old times were identified in the northern part of the island, near abandoned house and two desolate barracks (one of such wells is shown on the figure 24).

Furthermore, near the smaller lake on the eastern side a single-standing broken tap was spotted, the origin of which is unclear (figure 25). It might have been though a part of water distribution system from industrial times.

Locations of identified old wells are depicted on the figure 26.

Fig. 23. Old manual water pump.

Fig. 24. Old well near the path to the hilltop.

Fig. 25. Broken water tap near small lake.

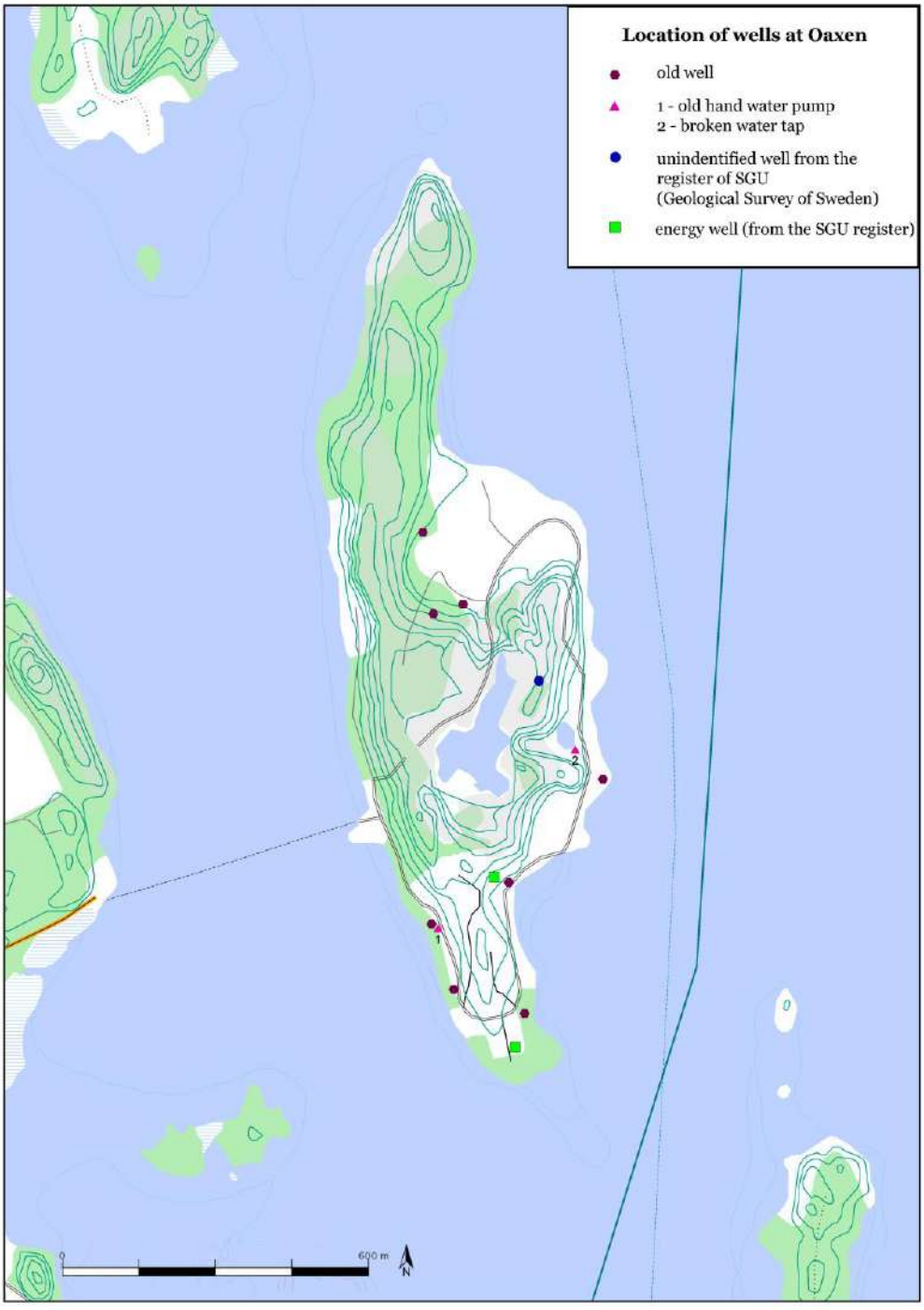

Fig. 26. The map of various types of wells on Oaxen.

6.6 Governance, cost structure and pricing

The community association board consists of six or seven board members, each of whom is appointed to carry on responsibilities within one of the main management areas:

- finance,
- roads and lightning,
- ferry – employees,
- ferry – technical support,
- water and sewage systems.

One more person in the board is appointed as a secretary to carry on work concerning communication with municipality and reports. Besides, for each project that community comes up with to implement on the island, a working group is being created and responsible person is appointed.

Nowadays, there are two persons in the community association who are responsible for the operation of the water and sewage systems as well as for the reporting to community and municipality. Until 2018, the practical work on maintenance and sampling had been carried out by the person employed by the community association. As the previous employee has resigned recently for the retirement leave, the practical work and constant monitoring around drinking water system is performed now by the person employed part-time via the ferry management division of the community board, and the daily practical work around sewage system is performed by responsible community board members.

Such services as electric maintenance, plumbing, pump service, hydrophore maintenance, checks-up of UV-filters, treatment plant control, sludge removal etc. are purchased from the relevant companies on a contract basis.

Apart from the routine monitoring of the system, water samples analysis, and water consumption metering, once per year the vegetation around the lake is being cleaned up in order to prevent excessive biological decay in the water. Besides, the water level in the lake is measured once per month from April to October (figure 27).

In case the water level drops down significantly from the normal number of 140 cm, all islanders get informed via SMS and e-mails about the necessity to limit water use as well as about restriction to use drinking water for lawns, gardens, and swimming pools.

Similarly, in case of any water or sewage system disturbance, all islanders are informed immediately via SMS. Extensive disturbances and planned operational interruptions are also informed via e-mail, regular letters in mailboxes and via bulletin board. In case of serious disturbances, the municipality's environmental office is informed. After works are finished, islanders are instructed on actions to do when the water is released.

The community association board has also the maintenance plan for both drinking water and sewage systems. The most recent major work that has been done within water management was the complex inventory and inspection of the sewage system. This allowed to produce a comprehensive map of both drinking water and wastewater networks, as well as to identify the issues present in the system and develop a future action plan for maintenance.

The major report about the state of the systems and performed works is done via the yearly report prepared by community association board and disseminated to all residents via e-mail, as well as during the yearly meeting of community.

As for the pricing of the water services, islanders pay a yearly fee of SEK 7 500 per one share in community association, which includes payment for all services organized by community association. This means that there is no separate fee specifically for water provision and sewage treatment.

Nevertheless, according to the evaluations made basing on the budget allocated for water services in 2019, the approximate cost of 1 m^3 of water on Oaxen (including drinking water provision and wastewater treatment, though excluding capital investments in maintenance) is estimated to be about 45 SEK.

For the water sold to the nearby islands, however, the annual price is SEK 1 250 per household, which makes around SEK 11 000 in total per year (according to the information retrieved from community association board representatives). As the water is being supplied over the course of five months in average, the daily price of drinking water supply comprises about SEK 8 per household.

To compare, one-household villa residents in Stockholm pay about SEK 2 260 per year for water services (meaning both drinking water provision and wastewater treatment), or nearly SEK 6 per day (Stockholm Vatten och Avfall, 2019). In Södertälje, water service provided by *Telge* company costs about SEK 2 730 per year for villa, or approximately SEK 7,5 per day (Telge, 2019).

Fig. 27. Measuring the water level in the lake.

6.7 Summary

The technical landscape on Oaxen functions like the one of a small municipality – with centrally organized and managed drinking water provision and wastewater treatment.

The water is supplied from the local limestone mining pit lake and is being cleansed through coarse filter and disinfected with UV-light.

The sewage treatment plant is located to the north from the settlement on the island, on the padding of lime residue from the mining. Wastewater first goes through the cycle of sludge sedimentation via three-chamber well system and then is being treated through the typical sewage treatment cycle in the treatment plant installed by TOPAS company. At the final stages, water is disinfected via UV-filter and let out to the limestone infiltration bed.

The average total annual water production on Oaxen was 9 132 m^3, whereas the amount of wastewater being processed in the local treatment plant averages to 7 500 m^3 per year. It is assumed that apart from being lost for gardening purposes and washing boats, some amount of water is being lost in the water piping system due to the leakages.

The management of systems is performed by community association board, with the technical maintenance being provided by corresponding companies on contractual basis.

7 Circular water use

7.1 About circular water use

Nowadays, the conventional linear model of growth "take-make-consume and dispose" is being challenged by the shift towards sustainable development. As a response to this model, the concept of circular economy is steadily emerging all over the world. The main principle of the circular economy is decoupling economic growth and development from the consumption of finite resources (International Water Association, 2016:1). Such principle is based on three main beliefs:

- all durables, which are products with a long or infinite life span, must retain their value and be reused but never discarded or down cycled (broken down into parts and repurposed into new products of lesser value);
- all consumables, which are products with a short life span, should be used as often as possible before safely returning to the biosphere;
- natural resources may only be used to the extent that they can be regenerated (Stuchtey, 2015 b).

For the water sector, transitioning to a circular economy means mainly turning to an approach of water circulation in closed loops. In such model, water is reused time and again, retaining full value (Stuchtey, 2015 a). Besides, water utilities have an opportunity to turn water into a medium of valuable resources and play an important role as resource stewards (International Water Association, 2016:1).

The urgency of shifting the usual attitude to water resources is supported by the estimations that with the continuous linear approach to water use the global demand for water will

exceed viable resources by 40 % by 2030 (Stuchtey, 2015 b). At the same time, it has been identified by European Union policies that the use of treated wastewater could be a potential solution to water scarcity (WBCSD, 2017:6).

Redesigning water network into a circular system might be done taking into consideration three different points of view:

- the resource perspective, which calls for a balance between withdrawals and return flows;
- the product perspective, which calls for a strict distinction between water as a consumable and water as a durable, since there are different strategies for reducing waste in each category;
- the utility perspective, which focuses on maximizing the value of the existing water infrastructure by increasing utilization and ensuring better recovery and refurbishment of assets (Stuchtey, 2015 b).

7.2 Suggestion 1

The first suggestion about circular water on Oaxen takes the resource perspective and considers taking more measures for protection of natural water resources on the island.

The monitoring of water level in the lake Kroksbrottet should be kept routine and during the summer period should be performed on a weekly basis (especially during June, when the water consumption on the island is usually the highest). Besides present drinking water area protection measures, more distinctive barrier is recommended to be made between the road surface and lake.

Furthermore, it is recommended to make a buffer protection zone around the small lake near old industrial facilities to restrict dumping of any materials or activities that might potentially have hazardous effect on environment. Over the course of the field studies on Oaxen it has been assumed that the small lake has some connection with Kroksbrottet and play a balancing role in the water system on the island. Thus, the small lake should be kept on its place and in no occasions be dumped or dried out.

7.3 Suggestion 2

The second suggestion takes the product perspective and propose some behavioural changes regarding the water use on the island, as it has been argued that the behaviour of citizens underpin strategies of water systems operation.

It is recommended that the use of drinking water for pools or bathtubs as well as for washing boats be restricted over the summer period. In various municipalities of Stockholm region, such as Värmdö, similar rules are already in place, attempting to leverage high water demand during hot and dry periods. In case of Oaxen, such regulation may help to lower demand for drinking water at least on 2,5 % (figure 10). The level of water use can be controlled by everyday monitoring of water consumption displayed on the central water

meter. Alternatively, the payment structure for water services on the island might be altered so that every household pays separately for the amount of water it uses.

As the biggest share of water consumption is used for bathroom needs, common guidelines for more careful personal water use may help to save more water. This includes both behavioural changes such as turning off the water tap while brushing teeth or washing hands and small technological adjustments in households such as installing aerators on water taps and changing full-flush toilets for the ones with lover water use. Moreover, the treatment of wastewater should be also taken into consideration, and such substances as phosphorus compounds from phosphorus-containing detergents, toxic ink found on poor-quality toilet paper, and any other hazardous compounds should be eliminated from the sewage system.

Besides, there is still an untapped potential of rainwater use on the island – only small number of households have some appliances for rainwater collection. However, using rainwater for gardening and watering lawns can save at least another 2 % of water used on the island. Furthermore, rainwater harvesting may be used to flush toilets and wash clothes, which may reduce household water consumption by as much as 40% (Ferguson, 2014).

7.4 Suggestion 3

The third suggestion is made from the utility perspective and comprises technical amendments of water infrastructure on the island.

As quality of the water processed in the local sewage treatment plant is claimed to be very high and follows the standards for drinking water, it can be used for washing boats at the Oaxen shipyard which is located right nearby the treatment facility. The treated water from sewage plant might be collected in a special tank and when necessary – used by the shipyard. Besides, in case water after washing boats is suitable for treatment in local sewage plant (meaning that it has no additional toxic elements which should be removed via special treatment cycles) – it should be collected and diverted back for treatment at the sewage plant. Such water use would create a closed loop and has a potential to reduce water consumption on Oaxen for approximately 65-70 m^3.

Furthermore, ferry house has separate sewage treatment network where wastewater is being processed in three-chamber well system and then released through limestone infiltration bed to the sea. Considering that, it might be relevant to alter water for toilet flushing in the ferry house with brackish sea water.

Moreover, as the model of circular water use includes recovering resources (other than water) out of wastewater and putting them to use, the sludge from sewage treatment facility on Oaxen could be utilized for energy production. The energy produced can be used for the treatment plant itself, as there are examples where anaerobic digestion of treated wastewater sludge alone produces biogas that covers more than 60 % of energy consumed at wastewater treatment plants (International Water Association, 2016:14). Besides, organic waste from households on the island could supplement energy production from sludge.

8 Sources and references

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9 Appendix

The Table A1 provides an overview of interviews from the research on Oaxen.

Table A1. Overview of interviews that were used for the study. Interviews were performed during site visits to Oaxen on February 5, March 11-15 and April 9-13.

Interview ID	Type of interview
Interview 1	Group discussion with members of community association board (samfällighetsförening)
Interview 2	Recorded semi-structured interview with the member of community association board
Interview 3	Recorded semi-structured interview with the head of community culture house board (Bygdegårdsförening)
Interview 4	Recorded semi-structured interview with the former member of community association board
Interview 5	Recorded semi-structured interview with the chairman of community association board
Interview 6	Recorded semi-structured interview with two member of community association board responsible for drinking- and wastewater systems
Interview 7	Recorded semi-structured interview with the member of community culture house board