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Inventory of hydrological measurements in Sweden

Inventering av hydrologiska mätningar i Sverige

Ida Enjebo

ABSTRACT

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This thesis aimed to study how different actors perform hydrological observations in Sweden. Target groups for the study were institutions that regularly measure water stage and river discharge, including water councils, water- and wastewater departments in municipalities, water authorities and hydropower companies. After the identification of the different actors, the study investigated how, where and why they perform hydrological observations as well as the way actors perceive the accuracy of these measurements.

Information was collected through interviews and the development of a number of questionnaires. A total of 447 actors were contacted and 260 replied. The majority of them, 209, answered that they do not perform any hydrological measurements while the remaining 51 answered that they measure water stage. One of the main reasons for measuring is that many actors are facing water-rights court ruling. There were also several actors that stated that they perform hydrological measurements to make sure that the water body where water from wastewater treatment plants and storm water is emitted has sufficient water stage for environmental concerns. The hydropower companies replied that they, in addition to maintaining a water-rights court ruling, used water stage data to control the functioning of the plant. They also calculate river discharge based on production, floodgate position and stage.

There were also seven municipalities, which stated that they had implemented a flood-monitoring model and that water stage data were used as input to the model. These municipalities and two other actors stated that they measure discharge or use a stage-discharge relationship (rating curve) to derive discharge data. However, in some cases, control measurements were lacking. Most actors used pressure sensors to measure stage. Their perceived levels of accuracy varied from ± 1 mm to ± 5 cm. Only five actors stated that they level their instruments regularly, which is a precondition for maintaining a correct data series.

The results are useful for SMHI's continued review of their hydrological network, although continued attempts to receive answers from all contacted actors would provide a more complete overview of hydrological observations. A study that thoroughly investigates how actors perceive the accuracy of their measurements would also give further knowledge in this field.

Keywords: Hydrological observations, water stage, river discharge, accuracy

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REFERAT

Inventering av hydrologiska mätningar i Sverige
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Examensarbetet syftade till att undersöka hur olika aktörer genomför hydrologiska mätningar i Sverige. Målgrupper för studien var aktörer vars verksamhet innefattar mätningar av vattenföring och vattenstånd. De målgrupper som identifierades var vattenråd, kommunala VA-avdelningar, vattenmyndigheter och vattenkraftbolag. När aktörerna identifierats undersöktes hur, var och varför aktörerna mäter samt hur de uppfattar noggrannheter i sina mätningar.

Informationen samlades in genom frågeformulär och intervjuer. Totalt kontaktades 447 aktörer varav 260 svarade på frågorna som ställdes. Majoriteten, 209 aktörer svarade att de inte utför några hydrologiska mätningar medan resterande svarande att de mäter vattenstånd. Den anledning som flest aktörer gav till att de mäter var att de har en vattendom. Det var även flera aktörer som mätte för att försäkra sig om att recipienter för dagvatten och avloppsreningsverk hade tillräckligt högt vattenstånd för utsläpp. Vattenkraftproducenterna svarade att de, utöver att de har vattendomar, använder vattenståndsdata för att reglera kraftverken. De beräknade också vattenföringen utifrån lucköppningsgrad, vattenstånd och producerad effekt.

Det var även sju kommuner som svarade att de hade implementerat modeller för översvämningsövervakning och använde vattenståndsmätningar som indata i prognosmodellerna. Dessa kommuner och två ytterligare aktörer svarade att de mäter vattenföring eller använder avbördningskurvor men i flera fall är kontrollmätningar av vattenföringen bristande. De flesta aktörerna använde tryckgivare för att mäta vattenståndet och de gav noggrannhetsintervall mellan ± 1 mm och ± 5 cm. Endast fem aktörer uppgav att de avväger mätinstrumentet vilket är en förutsättning för att upprätthålla en korrekt mätserie.

Resultaten är användbar information i SMHIs utvärdering av sitt nätverk av hydrologiska mätstationer, dock skulle fortsatta försök att få svar från samtliga kontaktade aktörer ge en mer heltäckande bild av hydrologiska mätningar utförda av de olika målgrupperna. Det vore även intressant med en studie som går djupare in på hur noggrannhet uppskattas och uppfattas av de olika aktörerna.

Nyckelord: Hydrologiska mätningar, vattenstånd, vattenföring, noggrannhet

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PREFACE

This thesis is the final project of the Master Programme in Environmental and Water Engineering at Uppsala University. The project corresponds to 30 ECTS and has been conducted at the Swedish Hydrological and Meteorological Institute, SMHI. Supervisor at SMHI was Lena Eriksson Bram and subject reviewer was Giuliano Di Baldassarre at the Department of Earth Sciences, Uppsala University.

I would like to thank Giuliano Di Baldassarre for the help and guidance he gave me with the report and through the thesis work and Lena Eriksson Bram for the feedback she gave me throughout the project. I would also like to thank Mikael Lennermark and Gustav Sandehed, hydrologists at SMHI, for the day of field work I got to experience.

This project would not have been possible without all the employees at municipalities, hydropower companies, water authorities etc. who have taken time to answer my questions. Thank you all so much for your participation.

Finally I would like to thank my dear friends and my family for supporting me through my ups and downs and double-computer-trouble, I don't know what I would have done without you. And David, for being there when I needed you.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

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Vatten spelar många viktiga roller i våra liv; som livsnödvändigt livsmedel, som något vi använder i våra hushåll till tvätt, disk och städning, i industriprocesser, som källa till elproduktion, i jordbruket och som badplatser. Sverige har rik tillgång på färskvatten för att tillfredsställa samhällets och naturens behov. Viljan att dokumentera förändringar i våra vatten har funnits länge. Sedan 1700-talet har man mätt vattenstånd i de stora svenska sjöarna och i början av 1900-talet bildades det som senare skulle bli SMHI, Sveriges meteorologiska och hydrologiska institut, som idag bland annat har i uppdrag att samla in data och ta fram prognoser för både väder och vattenflöden.

SMHI har idag ett nätverk av drygt 300 mätstationer som kontinuerligt registrerar vattenytans läge i åar och älvar, det så kallade hydrologiska grundnätet. Att mäta vattenstånd är relativt enkelt och ett vanligt sätt är att helt enkelt läsa av en pegel, en sorts linjal, som är monterad på en lodrät yta i vattenkanten. För att vara säker på att pegelns läge inte förändras är det viktigt att veta hur pegeln förhåller sig, i höjdled, mot en fixpunkt i närheten; att man gör regelbundna avvägningar. Det finns också mätinstrument som automatiskt registrerar vattenståndet antingen på papper eller digitalt. Vid de flesta av SMHIs mätstationer registreras vattenståndet på papper som byts en gång i månaden. Ett annat vanligt sätt att mäta vattenståndet idag är med hjälp av tryckgivare; mätare som använder luft- och vattentryck för att få fram vattenståndet.

Det är inte möjligt att vid mätstationerna också kontinuerligt mäta vattenföring, istället har man tagit fram samband mellan vattenstånd och vattenföring, så kallade avbördningskurvor. Det gör man genom att mäta flödet vid olika vattenstånd uppströms en bestämmande sektion, vilket är en plats i vattendraget där vattenståndet nedströms den bestämmande sektionen inte påverkar vattenståndet uppströms sektionen. En bestämmande sektion kan till exempel vara en byggd fördämning eller ett utlopp från en sjö.

På SMHI har ett arbete med att se över det hydrologiska grundnätet påbörjats. I samband med det arbetet genomfördes den här studien där det har undersökts vilka andra aktörer som utför hydrologiska mätningar. Ifall SMHI i sin utvärdering kommer fram till att nätverket behöver utökas är det värdefullt att ha information om vilka andra aktörer som redan utför mätningar för att eventuellt kunna samarbeta. Det här projektet har därför syftat till att ta reda på vilka som mäter vad och var samt hur och varför mätningar sker och hur de som mäter uppfattar noggrannheten i sina mätningar.

De målgrupper som valdes för studien var kommuner, vattenråd, vattenmyndigheter och vattenkraftbolag. Aktörerna kontaktades via epost med frågan ifall de genomför några hydrologiska mätningar, till exempel vattenstånd eller vattenföring. De som svarade att de mäter fick därefter ett formulär med frågor om hur mätningarna går till, om mätplatsen, kontrollrutiner mm. Många hänvisade till andra aktörer i sitt närområde varvid de också kontaktades och en ytterligare målgrupp, övriga, identifierades. I målgruppen övriga placerades gruvbolag, fiskeriorganisationer, intressegrupper, universitet, konsulter och pappersbruk. Totalt kontaktades 447 aktörer.

Svarsfrekvensen var 59 % och kom från aktörer från hela landet. En klar majoritet av de som svarade, 80 %, svarade att de inte genomför några hydrologiska mätningar. Av de som mäter gav de flesta att de har en vattendom som anledning. Vattendom är ett begrepp som finns kvar från vattenlagstiftningen som fanns innan miljöbalken trädde i kraft 1998. En vattendom styrde hur till exempel anläggning av dammar och vattenkraftverk eller dränering av åkermark fick reglera vattennivåer. Det var till exempel vanligt att den som fick en vattendom fick gränser inom vilka vattennivån skulle hållas under olika delar av året. Även efter att miljöbalken trädde i kraft fortsätter de gamla vattendomarna att gälla men numera är det andra regler som gäller för vattenverksamhet.

Det var i första hand VA-avdelningar på kommunerna som kontaktades eftersom deras verksamhet är starkt kopplad till vattnets kretslopp. Lite drygt 20 % av kommunerna som svarade mätte vattenstånd som en del i övervakningen av sina vatten- och avloppsnät eller avloppsreningsverk. Ungefär lika många hade system för översvämningsövervakning som krävde mätningar för att göra flödesprognoser. Vattenkraftproducenterna i sin tur använde vattenståndsmätningarna till att styra kraftverken. Alla som svarade på enkäten mätte vattenstånd på olika sätt men endast ett fåtal hade avbördningssamband för att generera vattenföringsdata också.

Trots att många aktörer använde samma teknik i form av tryckgivare för att mäta vattenståndet hade de spridda uppfattningar om hur noggranna deras mätningar var. Ungefär en tredjedel av de som automatiskt registrerade vattenståndet jämförde sin data med en vanlig pegelskala för att se om de stämde överens. Dock var det bara 10 % som svarade att de väger av sina mätinstrument för att vara säkra på att de inte rubbas.

GLOSSARY

Current meter	Flygel
Environmental Code	Miljöbalken
Gauging station	Hydrologisk mätstation
Levelling	Avvägning (med avvägningsinstrument)
Rating curve	Avbördningskurva
River basin	Avrinningsområde
River discharge	Vattenföring
Sill	Tröskel
Sonar	Ekolod
Staff gauge	Pegel
Stilling well	Mätbrunn
Water authority	Vattenmyndighet
Water council	Vattenråd
Water Framework Directive	EUs ramdirektiv för vatten
Water-rights court ruling	Vattendom
Water stage	Vattenstånd

CONTENT

1 INTRODUCTION

Our modern society is certainly affected by weather, water and climate. Urban planning relies on prognoses of high and low water flows. In the same sense, farmers who use irrigation need to know that their water source has sufficient water storage to make extractions. Hydrological observations and hydrometric measurements are essential to model and forecast when and where, for instance, high (or low) flow will occur. Nowadays, as climate change is likely to lead to more extreme weather, it is more important than ever to have hydrological observations. They can provide basis for adaptations that are to be made to cope with a changing climate.

The Swedish Meteorological and Hydrological Institute (SMHI) has a mission to provide information on water, weather and climate to serve the general public and public and private sectors. Within the hydrological field they make observations of water stage and river discharge around the country. The gauging stations that are in the network today were built during the 1970’s and 1980’s but many sites have time series reaching back to the early 1900’s. SMHI is now in the process of evaluating their network of hydrometric stations to see if it matches the requirements of today. To supplement the evaluation it is valuable to collect information on other actors who conduct hydrometric measurements. If there is need to expand the existing hydrometric network, knowledge of other observation sites is useful in the decision-making process.

1.1 OBJECTIVES

This thesis aims to explore how different actors perform hydrological observations in Sweden. To this end, the first step was the identification of the actors that measure river discharge and water stages. Secondly, the study investigated how (and where) different actors perform hydrological observations as well as how they perceive the accuracy of their measurements. Information was collected mainly through the development of questionnaires and the implementation of interviews.

2 BACKGROUND

This study’s focus is on actors that perform hydrological measurements. When collecting information about other actors it is also important to have an understanding of SMHI’s activities in this field. SMHI’s network of gauging stations is therefore presented in this section. Furthermore, the legislation regarding water and water activities play a role when it comes to hydrometric activities and are hence also presented.

2.1 SMHI’S NETWORK OF GAUGING STATIONS

SMHI’s network of hydrological stations consists of circa 320 gauging stations of which 220 are their own. In addition, SMHI receives hydrological data from 20 stations that are co-owned with other actors and from 80 stations owned by mostly hydropower plants (Nyman & Lennermark, 2013). This network covers most of Sweden, in the northern parts you find the majority of the external gauging stations and in the south

SMHI's stations dominate (Figure 1). At the gauging stations stage is measured continuously in stilling wells using floats and either digital angle sensors or horizontal drum recorders. Each gauging station has a rating curve for translating stage data into discharge data (Eriksson Bram, 2014). Stage-measurement techniques and rating curves will be further described in section 3. Data is collected in real time from 70 stations and from the remaining stations data is collected and digitized monthly. The data are mainly used to calibrate SMHI's hydrological models (Eriksson Bram, 2014). The stations are inspected every other year or more frequently if required. At the inspection it is made sure that the stilling well is in working order, the sill is not dammed and the gauge is levelled with local benchmarks (Sandehed, 2013).

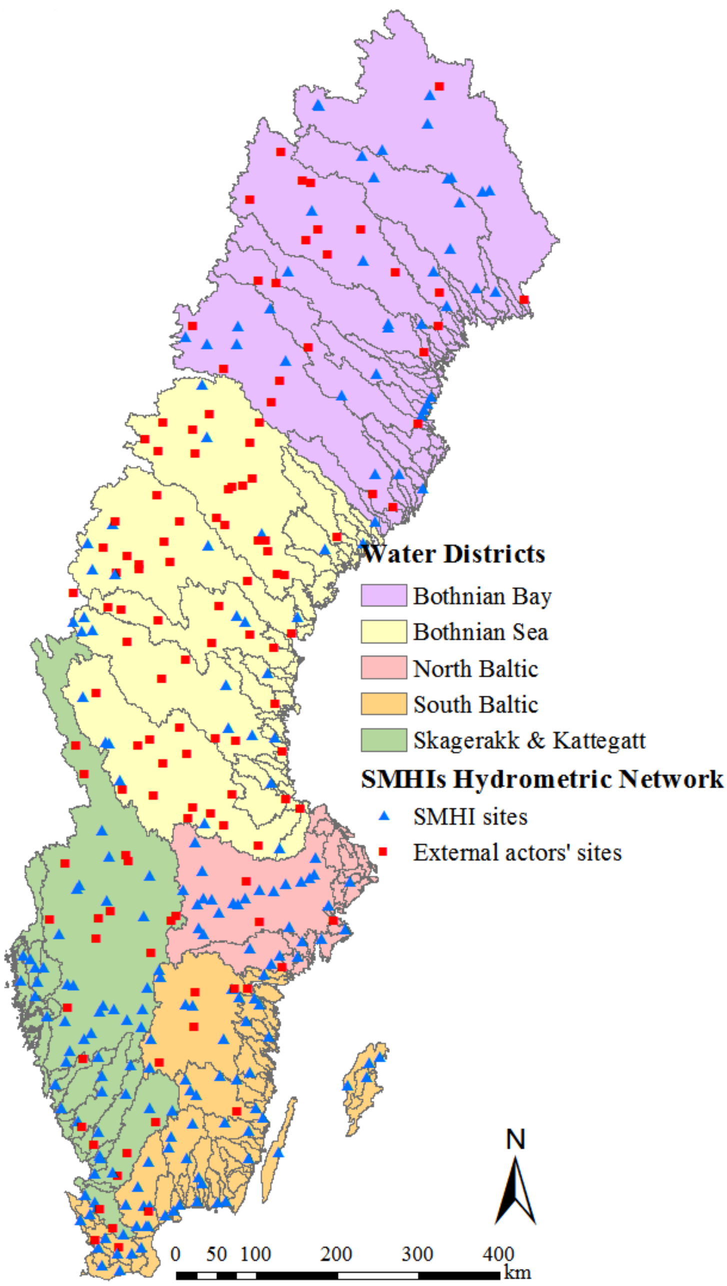

Figure 1. SMHI's network of gauging stations. Blue triangles represent SMHI's own stations and red squares external actors (SMHI, 2013) (SMHI, 2012).

2.2 WATER FRAMEWORK DIRECTIVE

The water framework directive came into force in the year 2000 and was implemented in Swedish legislation in 2004. The aim of the directive is to achieve good ecological and chemical status in all ground- and surface waters by 2015 or 2027 (Vattenmyndigheterna, 2014). Overall goals of water management are, in addition to good status by 2015, to relieve effects of floods and droughts, ensure access to water with good quality and a sustainable and fair water use, address impacts from acidification and eutrophication and involve interested parties in the planning process (Länsstyrelsen Västernorrland, 2014).

The directive introduces river-basin districts as a mean to reach good status. The boarders between the districts are not administrative but the same as the boarders between river basins (European Parliament & Counil of the European Union, 2000). In Sweden this means that the municipalities and counties are collaborating in five water authorities that see to the groundwater, lakes, rivers, streams and coastal waters in their districts (Figure 2) (Vattenmyndigheterna, 2014).

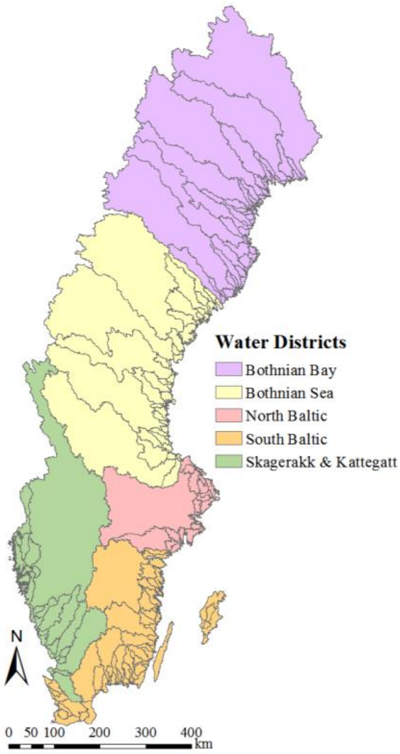

Figure 2. The five water authorities in Sweden (SMHI, 2012)

Article 14 in the directive concerns the involvement of interested parties and that the member states are required to encourage participation (European Parliament & Counil of the European Union, 2000). Within the five water districts in Sweden there are several water councils that consist of different stakeholders such as forestry-, hydropower- and mining companies, municipalities, local-interest groups and individuals. These councils are meant to capture local knowledge of the area and issues related to the waters (Vattenmyndigheten Bottenviken, 2014).

2.3 WATER-RIGHTS COURT RULING

In the early 1900's many rivers were exploited for hydropower. Around the same time, the desire to have more arable land led to drainage of large areas of land. These activities were regulated in water legislation from 1918 and earlier. When the Environmental Code took effect in 1998, water-rights court rulings already in effect would stay so, even though the new legislation had stricter demands. The water-rights court ruling typically stated the allowed upper and lower limits for water levels of a regulated river, lake or dam. These limits are often specified to the centimetre and vary throughout the year, typically to cope with spring floods and summers' lower flows (Scholz, 2011).

3 THEORY

Hydrological observations of water stage and river discharge can be performed using several different techniques. A common way to collect river-discharge data is to establish a stage-discharge relationship, a rating curve. In all types of measurements it is important to minimize uncertainty and error.

3.1 MEASURING STAGE

Techniques for measuring stage can be divided into two main groups; non-recording and recording techniques. In this section some of the most common stage-measuring techniques will be described. Regardless of which stage-measurement technique is used, it is necessary to level the instrument from local benchmarks and to repeat the procedure regularly. It is also necessary to keep the same datum throughout the recording period (WMO, 2008). SMHI requires levelling every two years (Sandehed, 2013). Stage data that is used to calculate discharge should have a level of accuracy of 3 mm or 0.2 % of the effective stage, i.e. vertical distance between the water surface and the point of the sensor that is exposed to the water body (WMO, 2010).

3.1.1 Non-recording techniques

Non-recording techniques can be very straightforward with a simple staff gauge; a scale attached to a vertical service (Figure 3). Similar to a staff gauge is a ramp gauge. Instead of a vertical graduated staff, a scale is mounted on a surface that inclines similarly to the bank of the stream. It is important that the ramp gauge lies on a line perpendicular to the flow direction (SIS, 2008).

Tape or wire gauges have a weight attached to it which is lowered to the surface, hence determining the water level relative a benchmark above the surface. The staff-, ramp-, tape- and wire gauges all have triangularly distributed uncertainty that can be calculated as

$$u(x_{mean}) = \frac{1}{\sqrt{16}} \cdot \frac{x_{max} - x_{min}}{2} \qquad (1)$$

where
x_{max}= the discernible upper limit
x_{min}= the discernible lower limit.

A stage-measurement technique often used in wells and boreholes is a dipper. It is a device that it lowered from a local benchmark and signals when it is in contact with the water surface. It requires a degree of conductivity of the water in order to work (SIS, 2008).

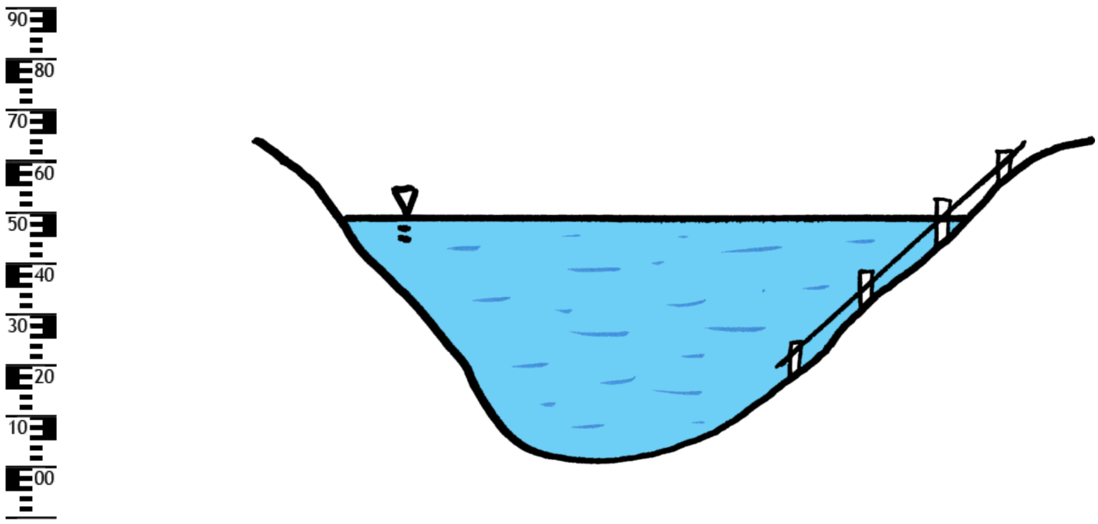

Figure 3. Sketch of a staff gauge (left) and of the concept of a ramp gauge (right).

3.1.2 Recording techniques

The technique used in most of SMHI's gauging stations is mechanical gauges with a float and counterweight (Eriksson Bram, 2014). When the water level changes the pulley rotates and the displacement can be read on a graduated tape or wire. The most common recorder at SMHI's gauging stations is a horizontal drum recorder (Figure 4) (Eriksson Bram, 2014). A pen is connected to the pulley and draws on a paper placed on a rotating drum (SIS, 2008).

3.1.3 Stilling wells

The water level can change rapidly in rivers and streams. The use of stilling wells makes the changes in level smoother and removes the measurement noise that would otherwise be found in the data. At SMHI's gauging stations stage is measured in stilling wells. The stilling well construction consists of one or two intake pipes that connect the well with the stream, a measuring device connected to a recorder and a protective and supportive building structure (Figure 4). SMHI's stations that report stage in real time have recorders with shaft encoder that record the stage digitally (Eriksson Bram, 2014).

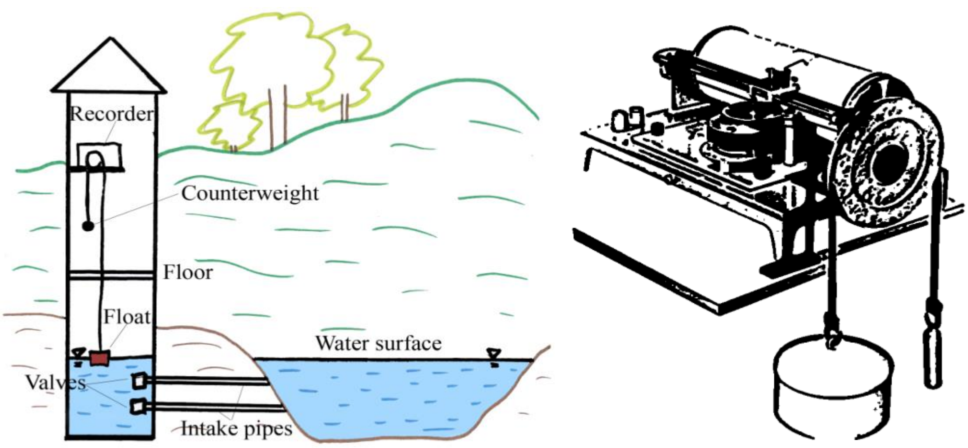

Figure 4. Sketch of a stilling well (left) and an example of a horizontal drum recorder (right).

The intake pipes in the stilling wells have a tendency to clog with sediments. This requires maintenance and a typical act is to pump water into the well in order to rinse the pipes (Sandehed, 2013). Because of the risk of clogging it is useful to place a staff gauge directly in the stream as a reference measurement (WMO, 2010).

3.1.4 Pressure Transducers

Another type of stage recorder is the pressure sensors. These transducers are based on the relationship between the head of liquid above a point and the static pressure at that point. This relationship is typically assumed to be linear and can be described as

$$W = (P_{static} - P_{atmospheric}) \cdot C \tag{2}$$

where W is the water stage, P_{static} is the pressure in a fix point in the water, $P_{atmospheric}$ is the atmospheric pressure at the water surface and C a factor of the water's weight (WMO, 2008).

3.1.5 Acoustic instruments

Instruments that use ultrasound measures the time elapsed from transmission to reception of the echo from the water surface. This time is then converted into a distance. This technique can be used in two types of instruments; either mounted above maximal water level transmitting down to the water surface or mounted below minimum water level transmitting upward. Since speed of sound is very dependent on temperature these instruments are also equipped with a thermistor (SIS, 2008). Similar devices can be used to measure water velocity. This is useful since it does not require a stage-discharge relationship (WMO, 2008).

3.2 MEASURING DISCHARGE

There are no easy and practical ways to continuously measure water velocity in rivers and streams to determine discharge. With help from a few discharge measurements it is relatively easy to establish a rating curve (Section 3.3) to calculate discharge from continuous measurements of water stage (White, 2014). There are several different ways to measure discharge and many of them are based on measuring water velocity and cross-section area and using the equation

$$Q = A \cdot v \tag{3}$$

where Q is the discharge, A the cross-section area and v the mean velocity in the cross section. The average velocity can be determined with different methods. The following sections describe some of these methods.

3.2.1 Velocity-area methods

The water velocity is not constant through the cross section and profile. This makes it necessary to measure the water velocity at several points in the cross section and at several depths. The velocity is generally lowest at the bed and banks and highest at the surface in the middle of the river. The cross section is divided into multiple vertical segments, how many depends on the width of the river, at which the velocity is measured. International standards suggest that for streams wider than five meters the segments should be such that, if possible, <5% of the total discharge passes through a single segment, but never more than 10%. The recommendations for smaller streams are presented in Table 1 (ISO, 2007).

Table 1. Recommended number of verticals for different channel widths

Channel width	Number of verticals
<0.5 m	5 to 6
>0.5 and <1 m	6 to 7
>1 and <3 m	7 to 12
>3 and <5 m	13 to 13
>5 m	≥22

The velocity should also be measured at several depths in each segment as long as the total depth is sufficient. A seldom used method is the integration method, when the current meter is lowered and raised through the profile while continuously measuring velocity (ISO, 2007). More common is point measurements at specific depths; one, two, three, five or six different ones. The velocity difference through the profile makes it suitable to measure at 0.6 of the total depth if only one measurement is made in each segment. When two points are used, international standards says that 0.2 and 0.8 of the total depth is most suitable and for three points 0.2, 0.6 and 0.8 are used. With five points as near as possible to the surface and bed are added and for six points 0.4 of the total depths is added as well. The mean velocity in each segment is then calculated by weighting the different depths (Table 2).

Table 2. Equations for calculating mean velocity in vertical segment of cross section (ISO, 2007)

One point	$\bar{v} = v_{0.6}$
Two point	$\bar{v} = \frac{v_{0.2} + v_{0.8}}{2}$
Three point	$\bar{v} = \frac{v_{0.2} + 2v_{0.6} + v_{0.8}}{4}$
Five point	$\bar{v} = \frac{v_{surface} + 3v_{0.2} + 3v_{0.6} + 2v_{0.8} + v_{bed}}{10}$
Six point	$\bar{v} = \frac{v_{surface} + 2v_{0.2} + 2v_{0.4} + 2v_{0.6} + 2v_{0.8} + v_{bed}}{10}$

The discharge of each segment is calculated either with the mean-section method or the mid-section method. In the mean-section method the velocity is measured on the boarders between two segments and in the mid-section method the velocity is measured in the middle (Figure 5). The discharge is calculated as

$$q = (b_{n+1} - b_n)\left(\frac{d_{n+1}+d_n}{2}\right)\left(\frac{\bar{v}_{n+1}+\bar{v}_n}{2}\right) \tag{4}$$

using the mean-section method and

$$q = \bar{v}_n d_n \left(\frac{b_{n+1}-b_{n-1}}{2}\right) \tag{5}$$

using the mid-section method. In equation 4 and 5

q is discharge through a section
b_n is the distance from a fixed point on the bank to vertical n
d_n is the depth at vertical n
$\bar{v}_n$ is the mean velocity in section n.

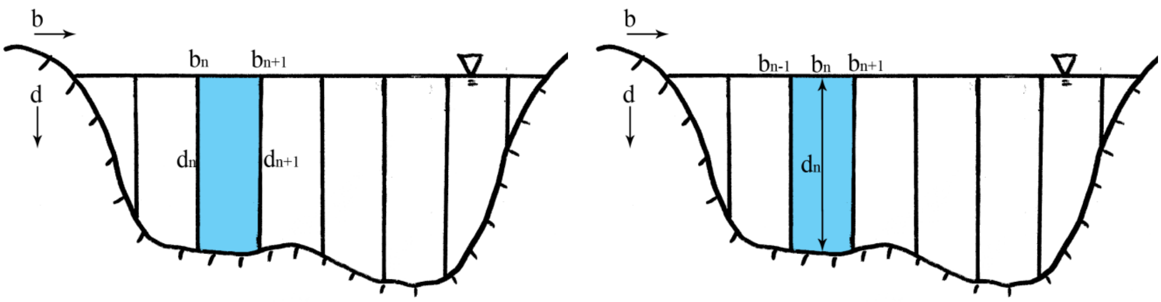

Figure 5. Mean-section method (left) and mid-section method (right).

Sources for error when measuring velocity are unsteady flow, suspended material in the channel, skew flow, use of a measuring device outside its calibration range, disturbance by wind and that the measuring device is not held/mounted properly (ISO, 2007).

3.2.1.1 Mechanical current meter

The velocity-measuring instrument used during most of the 20th century is a current meter (Figure 6). It can have either a horizontal axis and a propeller that rotates or a vertical axis with several revolving cups around it. When used in smaller streams, the current meter is mounted on a wading rod and placed in each vertical segment and the set depths. It measures the number of rounds and the elapsed time to determine the velocity (WMO, 2010).

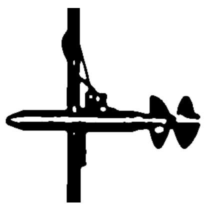

Figure 6. Mechanical current meter.

3.2.1.2 Uncertainties in velocity-area methods

The total uncertainty of discharge measurements is a combination of the uncertainty in all components; measurement of width and depth, interpolation of depth between verticals and in each velocity measurement. The random and systematic uncertainty in width measurements is less than ±1 %. For depth measurements the random uncertainty is between ±1 % and ±3 % and the systematic less than ±1 (Pelletier, 1988). Depth can be difficult to assess due to variation in stage throughout the measurement. If velocity is measured at two depths in 20 to 25 verticals under non-extreme conditions, the standard error in the discharge measurement is about 5 % with the 95 % confidence level (WMO, 2008).

The uncertainty in depths measurements is usually negligible if it was done by using a reference point on the bank and a tag line or when using a moving trolley and measuring the movement of the wire. If an optical method is used the uncertainty depends on the distance measured. The uncertainty in depths measurements is determined by the person who performs the measurement. It can be difficult to assess due to variation in stage throughout the measurement. Additional sources of error when assessing depth are that the river bed can be soft hence making it hard to determine where the bed is and also rocks and boulders on the bed giving a false image of the topography. Additional uncertainty comes from the interpolation of depths between verticals. Not using a sufficient number of verticals greatly contributes to uncertainty in discharge measurements. In the case that a mechanical current meter is used there are also the exposure time and instrument calibration to consider (Turnipseed & Sauer, 2010) (ISO, 2007).

3.2.2 Techniques using the Doppler Effect

The Doppler Effect is the change in frequency when a sound wave is reflected on or originating from an object in motion. An example of this is the sound from the sirens on an ambulance (Figure 7). When it comes towards the observer the sound has a higher pitch than when it is moving away from the observer. The sound wave coming to the observer is pressed together as the ambulance approaches, hence the wavelength is shortened and vice versa when it is moving away.

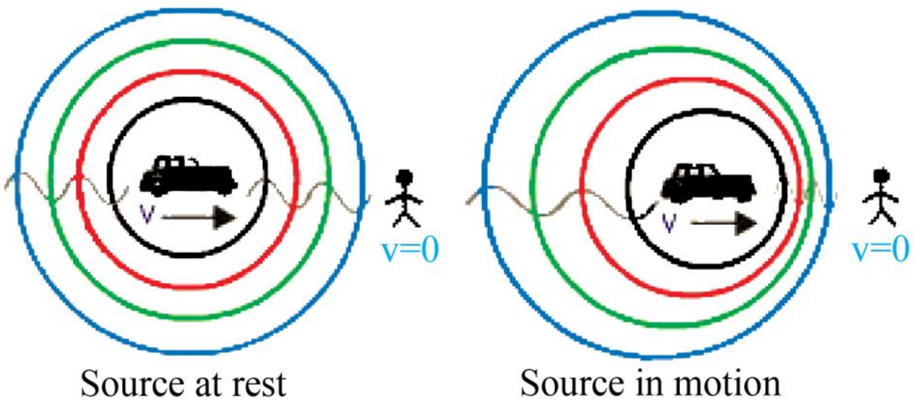

Figure 7. A stationary object emits sound at a certain frequency. When the object is set in motion the observed frequency is different if the object moves towards or away from the observer. This is the basic concept of the Doppler Effect (Tutor Vista, 2014).

Measuring devices that use the Doppler Effect to determine the velocity of the water transmit a sound pulse with a known frequency that hits particles suspended in the water and registers the reflected pulse and its new frequency.

3.2.2.1 *Acoustic Doppler Velocity meter (ADV)*

An alternative to the mechanical current meter is an Acoustic Doppler Velocity meter (ADV). Similarly to the mechanical current meter, it is mounted on a wading rod and used in streams where wading is possible and therefore not deep enough for using a profiling measuring method such as an Acoustic Doppler Current profiler (ADCP) that is describe later in this section.

ADVs can measure in either 2D or 3D, depending on the device. A 2D meter, which is what SMHI uses, has one transducer and two receivers (Figure 8). The signal received in the upstream receiver is used to calculate the velocity component perpendicular to the stream direction and the downstream is used for the velocity component in the stream direction (Jonsson & Lennermark, 2009).

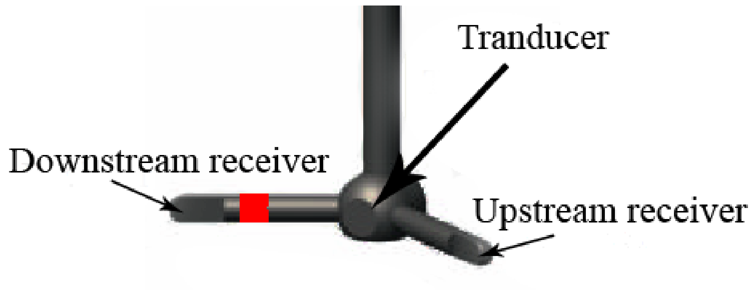

Figure 8. A sketch of a Flowtracker, a type of Acoustic Doppler Velocity meter (ADV). The red marking indicates which receiver is to be placed downstream in the flow direction (Jonsson & Lennermark, 2009).

Speed of sound in water depends on temperature and salinity. According to US Geological Survey (USGS) an error in temperature of 3 ^{o}C and a 5 ‰ error in salinity measurement both result in a 1 % error in the velocity measurement respectively. USGS recalibrate their ADVs every three years (Turnipseed & Sauer, 2010).

3.2.2.2 *Acoustic Doppler Profilers*

In rivers too deep to wade it is more practical to use profiling measuring devices. There are two types of acoustic Doppler profilers: mounted on boats and mounted on the river bed or bank (under the surface). SMHI mostly uses boat-mounted profilers, ADCPs, but they also have a few stations with bed-mounted profilers, ADVMs, where they use an index method to calculate discharge. Both types emit signal with known frequency and receive signals reflected on suspended particles.

From the Doppler shift the velocity can be calculated as

$$V = \frac{CF_D}{2F_S} \quad (6)$$

where

V is the water velocity in the same direction as the sound pulse
C is the speed of sound in water
F_D is the Doppler shift, i.e. the change in frequency cause by the Doppler Effect ($F_B - F_S$)
F_S is the transmitted signal's frequency
F_B is the received signal's frequency, also known as backscatter).

The speed of sound is highly dependent on the temperature in the water and the ADCP has therefore a thermistor to enable the use of (6). To be able to measure the water velocity there has to be a sufficient concentration of suspended matter in the water for the sound pulses to reflect on. Large objects in the water, such as branches or fish, do not give the correct Doppler shift and cause incorrect observations of water velocity. Most ADCP software has algorithms that can detect such disturbances (Mueller & Wagner, 2009).

The size of the boat on which the ADCP is mounted depends on the size of the river. The boat then moves across the river with a known velocity and direction. The technique is sensitive to rapid spatial variations and ideally it requires homogenous flow. The ADCP is also equipped with sonar to determine the profile of the cross section when the boat crosses the river.

To determine the water velocity in the flow direction it is necessary to know the velocity in three directions. The ADCP has either three or four transducers evenly spaced in a circle, hence the angle between them is known. The offset angle from the vertical is also necessary for the calculation. Depending on how many transducers the ADCP has, they are to be placed in different directions relative the flow (WMO, 2010).

The discharge is calculated in real-time but since the instrument is slightly submerged it cannot measure all the way to the surface. Nor is it possible to accurately measure all the way to the stream bed due to side-lobe interference. However, by measuring the return time for the signal, the depths of the stream can be determined as well (Mueller & Wagner, 2009). SMHI use ADCP to measure river discharge and they assess that uncertainty in these measurements is 3-7 %. The uncertainty is mainly due to the extrapolations made at the river banks and natural fluctuations in river flow (Eriksson Bram, 2014).

The bed-mounted profiler, ADVM, is based on the same principle as the boat mounted: determining water velocity through the Doppler shift. The main different between ADCP and ADVM is that the ADVM is stationary and can therefore only give the velocity in a part of the cross section. However, these devices also measure the vertical profile and by applying velocity distribution models a reasonable estimation of flow can be made. To estimate the discharge, the relationship between the mean velocity at any stage and the measured velocity has to be known as well as the relationship between water stage and cross-section area. The relation between measured velocity (index velocity) and mean-cross sectional velocity is called velocity-index rating and the method to determine discharge is therefore called the index method. The mean cross-sectional velocity is determined by performing discharge measurement with another device and dividing the discharge with the cross-section area (ISO, 2010 a).

3.2.3 Weirs

In small streams it can be necessary to build a weir in order to be able to measure discharge. The most common kinds in Sweden are the triangular weirs but there are also rectangular weirs (Marklund & Westman, 2008). The discharge over a weir is calculated from the height of the water column and the known angle of the weir crest for a triangular weir and width of the weir for a rectangular weir as

$$Q = \frac{8}{15} \cdot C \cdot \sqrt{2g} \cdot \tan\frac{\alpha}{2} \cdot W^{2.5} \quad (7)$$

$$Q = \frac{2}{3} \cdot C \cdot b \cdot \sqrt{2g} \cdot W^{1.5} \quad (8)$$

where

Q = Discharge [m^3/s]

C = Dimensionless coefficient

b = Width of the rectangular weir [m]

g = Acceleration due to gravity [m/s^2]

α = Angle of weir crest (triangular weir)

W = Height of water column above weir crest [m]

When the weir-crest angle is 90^o the weir is a Thompson weir (Shesha Prakash & Shivapur, 2003).

3.2.4 Other methods

There are other techniques to measure water velocity as well, such as electromagnetic current meter, tracer methods etc. that are not described in this report.

3.3 RATING CURVES

Most river-discharge data are based on stage measurements used in combination with an approximated stage-discharge relationship: the so-called rating curve. The rating curve is determined to simplify the collection of continuous time series of discharge data from a specific river cross section. Discharge measurements are carried out for a number of different stages at a control point, i.e. a cross section of a river or stream where it is plausible to assume the existence of a unique, one-to-one stage-discharge relationship (Figure 9). Rating curves are constructed by interpolating a number of contemporaneous measurements of discharge and stages by using analytical expressions (Di Baldassarre & Montanari, 2009), such as the power function:

$$Q = a \cdot (h - b)^c \tag{9}$$

or a polynomial function:

$$Q = a \cdot h + b \cdot h^2 + c \cdot h^3 \tag{10}$$

where Q is the discharge, h the stage and a, b and c are calibration parameters. SMHI uses power functions and usually 1-2 equations for each rating curve. The parameters are estimated by applying regression analysis. As a guideline, the function that describes the highest stages should not have the c-value in (9) higher than 3.When the function is established, the curve is extrapolated to zero discharge as the lowest and the calculated maximum daily mean within 100 years as the highest. SMHI requires at least seven measurements to build a new rating curve (Blomgren, 2013) although the international standard recommends 12-15 measurements (ISO, 2010 b). At SMHI the rating curves are calibrated by doing discharge measurements at their stations periodically. How often these measurements are required is determined for each gauging station. The frequency depends on the stability of the sill and the time elapsed since the last measurement at that water stage (Eriksson Bram, 2014). WMO (World Meteorological Organization) recommends a minimum of ten discharge measurements per year (WMO, 2008).

In rivers with unstable banks, which are exposed to significant erosion as they transport a lot of sediments, it is difficult to find a cross section that does not change with time. A study under such conditions in Honduras explored the possibility of using time-variable rating curves. They found that changing the parameters after every measurement partially solved the problem of inaccurate rating curves, but that the lack of continuous data to a high degree contributed to the inaccuracy of the estimation (Guerrero, et al., 2012).

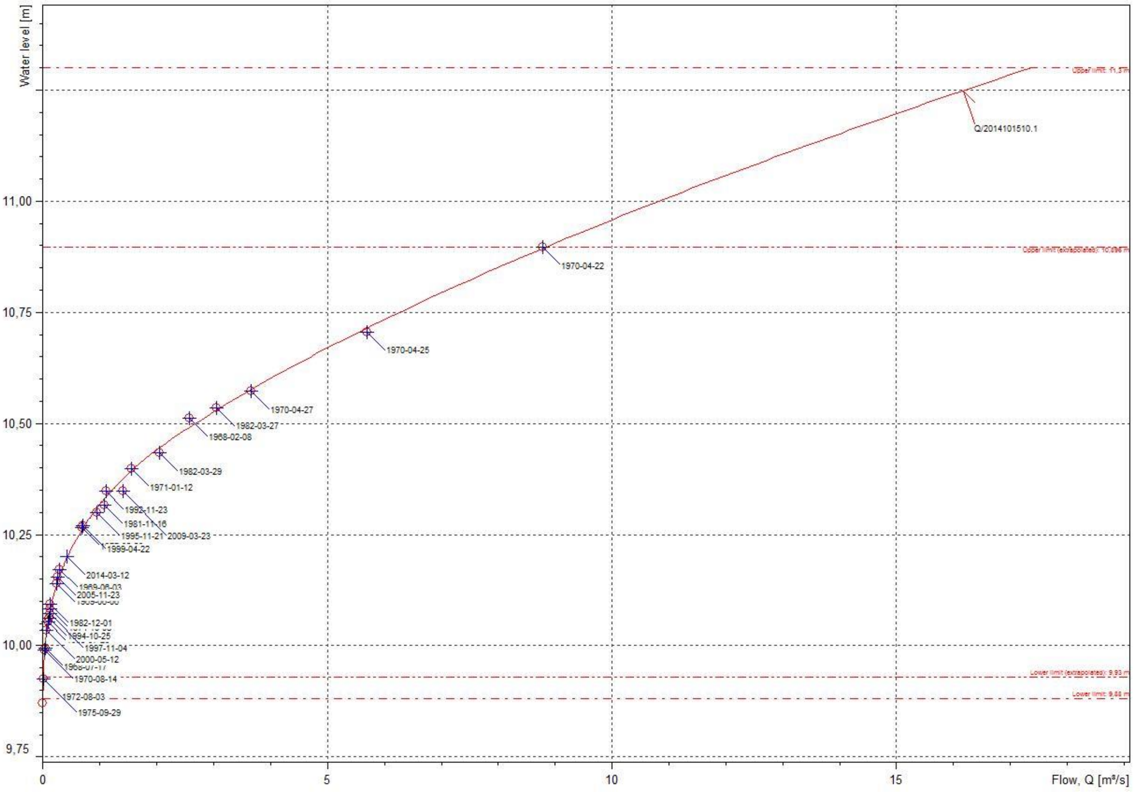

Figure 9. Example of a rating curve from SMHI. Water stage, W, is on the vertical axis and river discharge, Q, is on the horizontal axis. The red circles with blue crosses show the discharge measurements that are used to create the rating curve. The -·- and -··- lines mark the intervals where the rating curve has been extrapolated.

3.3.1 Uncertainty in stage-discharge relationship

Discharge data are derived from stage measurement through a stage-discharge relationship, as described in section 3.1. The uncertainty in the derived discharge can be written as

$$u^2(Q_t) = u_{RC}^2(Q) + u_{HC}^2(Q_t) + \left(\frac{\partial Q}{\partial h}\right)^2 u^2(h_t) \qquad (11)$$

where

$u_{RC}^2(Q)$ is uncertainty related to the extrapolation of the rating curve to include high and low flows,

$u_{HC}^2(Q_t)$ is the uncertainty due to difficult conditions at the time of measuring such as hysteresis, vegetation grows or change in geometry at the control section and

$u^2(h_t)$ is the uncertainty related to the stage measurement at the time of the discharge measurement.

The conditions at the control section may vary during the year due to vegetation or downstream boundary conditions and it may therefore be necessary to have different rating curves for different time periods. It is also important to take into account the uncertainty related to discharge measurement techniques used to establish the rating curve (Le Coz, 2012).

Ideally stage should be constant while a discharge measurement is being conducted but such conditions are rarely found in nature (Di Baldassarre & Montanari, 2009). Therefore, uncertainty is established through identifying different sources to uncertainty (WMO, 2008).

Hydrological measurements are not strictly random since each measurement depends on previous values. Statistical analyses can reduce systematic and spurious error from data. Although such analyses can improve data, taking precautions to ensure that data are correct from the start will give more reliable results. Random errors can be characterized with statistical analysis (WMO, 2008).

3.3.2 Three types of errors

There are three main types of errors in measured data; spurious, systematic and random. Spurious errors are typically caused by human mistakes or equipment malfunctioning and should be eliminated by discarding those values. Spurious errors can be identified by an outlier test such as a box plot. Systematic errors cannot be reduced by making more measurements. A systematic error can be that the measured value is continuously two units higher than the true value. This can be caused by the instrument not being properly adjusted or an instrument not suitable for the present conditions being used. If the systematic error is known the measurements can be corrected. A random error, unlike a systematic, can be reduced by increasing the number of measurements. More measurements reduces the uncertainty in the computed mean value (Di Baldassarre & Montanari, 2009).

4 MATERIAL AND METHODS

To explore which actors there are that carry out hydrological measurements, and how they measure, several interviews were held via email or telephone. All contact with actors was in Swedish. The following sections describe the interviewees and the questionnaires used.

4.1 INTERVIEWEES

The interviews were carried out for the following target groups: water councils, municipalities, counties and hydropower companies (Table 3). The interviewees were contacted via email with an invitation to reply either by email or telephone. The water councils were contacted through their coordinator, secretary or chairperson depending on what contact information was available. The municipalities were contacted through the water- and wastewater departments. In some cases the water- and wastewater department referred to another department, mainly the department of environment and health. In several areas two or more municipalities collaborated over the water- and wastewater management. In those cases the shared organization was contacted. The water authorities were contacted and through them the different counties. The last group, the hydropower companies, were selected from the list of members in the trade association *Svensk energi - Swedenergy* and companies that were referred to by other actors.

Actors in all groups referred to other actors in their surroundings, such as paper- and mining industry, government agencies, interest groups, fishery-management organisations, consultants, and hydropower companies. These actors were placed in an additional target group called Others (Table 3). If the actor had not replied within 2-4 weeks a second email was sent. Thereafter, no further attempts to contact the actor were made due to the time limits of the project.

Table 3. Number of actors contacted in each target group

Water councils	Municipalities	Water authorities	Hydropower companies	Others
100	288	5	29	25

A list of all contacted actors can be found in Appendix A – Contacted actors.

4.2 QUESTIONNAIRE

The actors were initially asked if they do any hydrological measurements. When the answer was affirmative, a questionnaire was sent with more specific questions regarding the measurements. The questionnaire had five sections. The first one was for contact information for the interviewee and the second one contained general questions about the measurements: reason for measuring, requirements of the data, inspections, review of data etc. The third part concerned the measurement sites: name of the lake or stream, catchment, coordinates etc. Section four contained questions about stage and discharge measurements: technique, frequency, duration, collection of data, calibration etc. The final part addressed rating curves.

4.2.1 The four different questionnaires

The original questionnaire was adapted in three different ways to make it easier to fill in. This report refers to the original questionnaire as questionnaire 1. Questionnaire 2 only contained questions about water stage measurements, while questions about discharge measurements were deleted. Questionnaire 3 was the same as the original except for extra rows to fill in information about more than one measurement site. Most adaptation was made for questionnaire 4. It was adapted to make it easier to fill in for actors with many measurement sites. Hence, all questionnaire 4 were slightly different, adapted for each actor. During the study it was discovered that a question about data storage wold have benefitted the questionnaire. However, no further adaptations of the questionnaire once the interviews had started. Questionnaire 1 can be found in Appendix B – Questionnaire.

5 RESULTS

In total, 447 actors were contacted. Of these, 47 % replied that they did not measure or that they did not know of any measurements (Table 4). From all the target groups, 51 actors answered the questionnaire fully or partly. The highest response rate was from the water councils, however, out of the 66 that replied 64 councils stated that they did not perform any measurements. 53 % of the municipalities replied and 20 % of those answered the questionnaire. The answering municipalities were well distributed throughout the country (Figure 10). The five different water authorities were asked to forward the question to the county administrative boards and it is therefore the replies from the county administrative boards that are shown in Table 4 marked with *. Of the hydropower companies that replied half answered that they did not perform any measurements and the other half answered the questionnaire.

Table 4. Actors contacted in the different target groups, number of answers in each group and number of questionnaire answers

	Water councils	Municipalities	Water authorities	Hydropower companies	Others	Total
Contacted	100	288	5	29	25	447
Total replies	66	165	6*	19	11	267
Answered no	64	134	4*	9	4	215
Questionnaire answers	2	31	2*	10	7	52

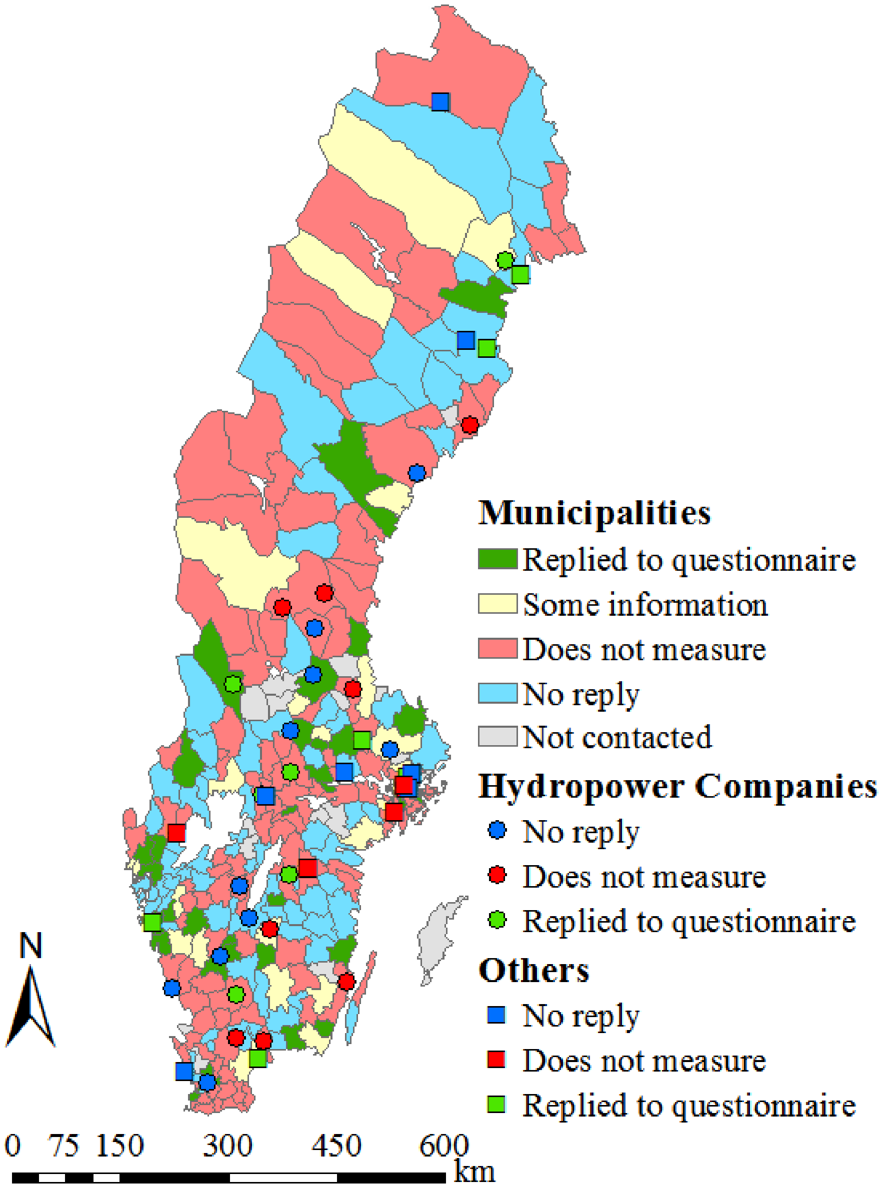

Figure 10. Swedish municipalities' contact status shown by different-coloured areas. The circles represent contacted hydropower companies and the squares other actors who were contacted.

From the questionnaire answers, 269 measurement sites are defined. Of the defined sites, 113 had either information about coordinates and reference system or other information about the site that was enough to identify them on a map (Figure 11). In addition to the actors that answered the questionnaires, 97 site were described via email from different actors who did not answer the questionnaire. The sites shown in Figure 11 are categorized based on target group. Two actors in the group Others gave enough information to plot the sites on a map, Luleå University of Technology and Vallentunasjöns fiskevårdsområdesförening. Their sites are marked with purple and pink circles respectively The cluster of sites in South Baltic and Skagerakk & Kattegatt show actors with many measurement sites located in a small area. Some of clusters of yellow circles represent municipalities that have developed flood-monitoring systems and therefore use hydrometric data as input in their models. The turquoise circles in South Baltic represent Emåförbundet, a water council with 27 sites and the green cluster in Skagerakk & Kattegatt represent Karlskoga Energi, a hydropower company with 58 sites. The blue circles in Bothnian Bay and Bothnian Sea, with the exception of the one furthest to the north in Bothnian Bay, represent measurement sites that are part of the liming program of the county administrative board of Västerbotten.

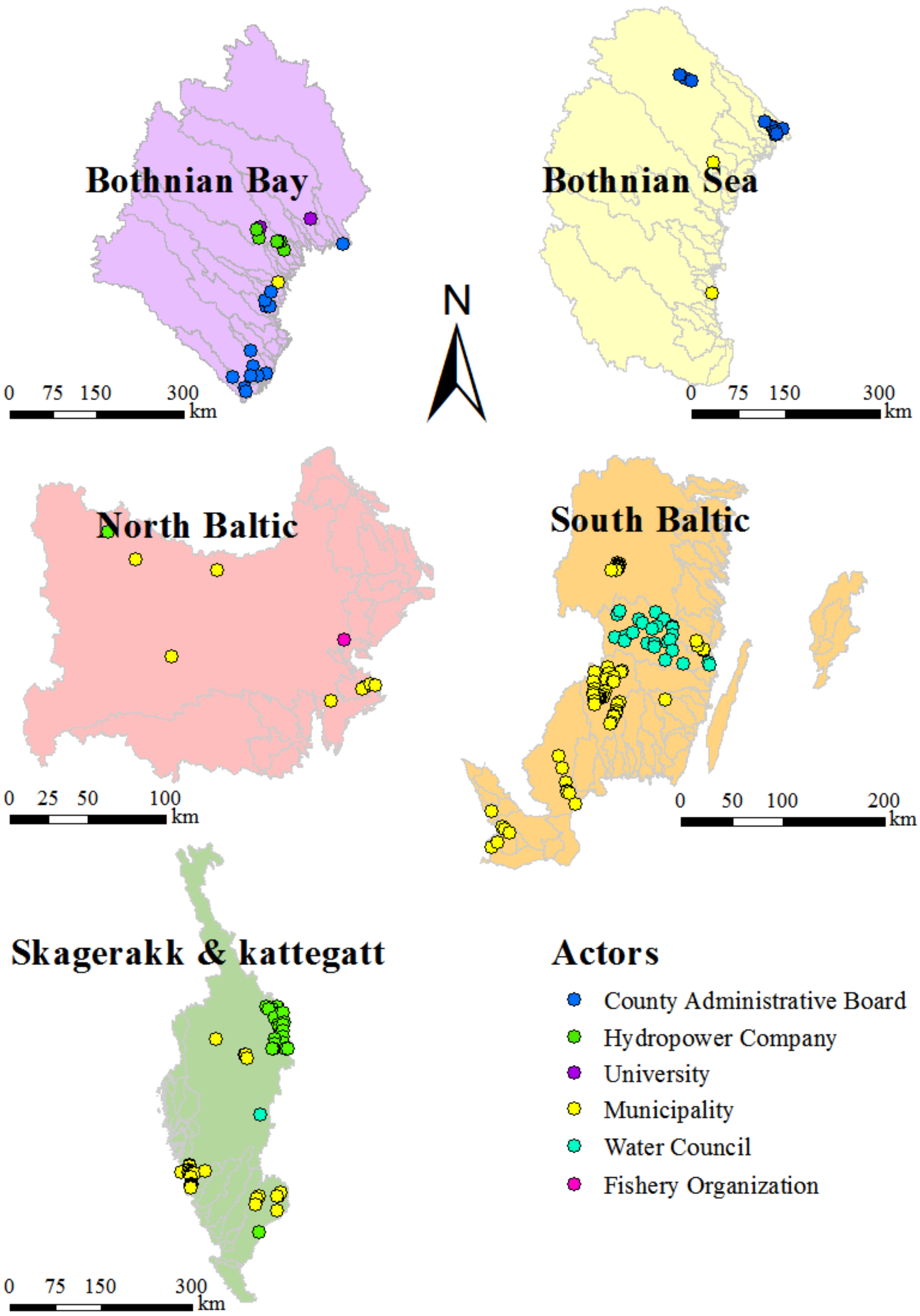

Figure 11. Hydrometric sites identified through questionnaires or email communication.

A few identified sites are located very close to SMHI sites but the majority of the identified sites are located in areas that are not covered by SMHI's hydrometric network. In all five districts there are sites located in the same rivers or streams as SMHI gauging stations, both upstream and downstream, but there are also many actors that measure in other streams and some in tributaries to rivers where SMHI measure. Maps showing all sites, SMHI's and the ones identified in this study can be found in Appendix C – Measurement sites.

5.1 Reasons for measuring

The answer most frequently given to the question why the actors measure is that they have a water-rights court ruling that requires it (Table 5). Other common answers were related to management of water- and wastewater systems, flood monitoring, controlling hydropower plants and managing drinking-water production. Not all answered the question why and a few gave more than one answer. In those cases, all reasons are presented in Table 5.

Table 5. Reasons the interviewed actors gave in the questionnaires for measuring

Reason	Number of actors
Water-rights court ruling	20
Managing water- and wastewater systems	7
Managing flood risks	4
Control hydropower plants	5
Drinking water production	3
Control liming	2
Statistics of levels at high flow	2
For urban planning	1
Fishery	1
Research	2
Environmental protection & water quality	3

Sävsjö municipality in the south part of Sweden and the county administrative board in Västerbotten were the two actors that gave liming control as their reason for measuring. Nybro and Härjedalen municipalities also mentioned liming in emails but did not answer the questionnaire. These two stated that they use a liming company that is active in Kalmar, Kronoberg, Halland and Jämtland County.

5.2 Stage measurements

The techniques the actors used to measure stage can be sorted into three groups: recording techniques, non-recording techniques and temporary/simple techniques (Table 6). 32 actors use recording techniques and the most common is pressure sensors. Nine actors collect stage data by reading a staff gauge and four use a temporary measuring device such as a folding ruler or a temporary staff. Some actors answered that they use different techniques at different sites. In those cases all techniques are counted in Table 6.

Table 6. Techniques used to measure stage

		Actors
Recording techniques	Pressure sensor	23
	Angle sensor	1
	Sonar	1
	Ultra sonic	2
	Non-specified sensor	7
Non-recording techniques	Sounding from fix point	1
	Staff gauge	10
Temporary/simple techniques	Temporary staff gauge	2
	Folding ruler from fix point	3
	Not specified	10

In the questionnaires, ten actors mentioned the word accuracy when answering the question about requirements of data. These were actors who used pressure sensors, staff gauges or folding ruler to measure stage. The levels of accuracy the actors using pressure sensors give are 1 mm, 1, 2 and 5 cm and 0.2 and 5 %. The actors using staff gauges and folding ruler stated that they have 1 cm accuracy (Table 7). In addition to those actors who mentioned accuracy, four actors stated that they require their data to be within certain limits. Three of them use pressure sensors and stated the limits as ± 1 mm, 5 mm and 1 cm respectively of the correct value. The fourth used staff gauge and stated the limits as ± 5 mm.

Of all actors who answered the questionnaire, 11 stated that they regularly compare collected data with a staff gauge and 5 that they level their instrument or staff gauge regularly. 6 actors stated that they inspect the instruments if there are unusual values in the data.

Table 7. Actors who have stated either an interval of accuracy or that they level their instrument regularly

Actor	Technique to register stage	Stated accuracy	Control routines
Piteå Renhållning och vatten	Pressure sensor	± 5 %	-
Luleå University of Technology	Pressure sensor	-	Levelling regularly
Falu energi	Pressure sensor	5 cm	Compare with staff gauge
Botkyrka municipality	Staff gauge	1 cm	-
Nybro municipality	Pressure sensor	1 cm	Compare with staff gauge
Oskarshamn municipality	Staff gauge	1 cm	Levelling after damage
Tranås municipality	Folding ruler	1 cm	-
Arvika municipality	Pressure sensor	± 0.2 %	Compare with staff gauge
Göteborg Vatten	Pressure sensor	± 2 cm	Levelling 3 times/year
Malungs Elverk	Pressure sensor	1 mm	Compare with staff gauge
Karlskoga Vattenkraft	Pressure sensor	-	Levelling every 5 years
Vallentunasjön Fishery organization	Staff gauge	-	Levelling several times/year

5.3 Discharge measurements

Most answering actors, 94 %, measure stage in rivers, stream, lakes or dams. Of those, 20 % also measure water temperature and 30 % also keep a record of discharge. The hydropower companies calculate discharge based on production, floodgate position and stage. Two municipalities, Härnösand and Tyresö, use constructed controls where they use stage measurements to derive discharge data. Härnösand also has a Thompson weir that has a marking at the stage for the lowest accepted flow.

Kristianstad municipality, Kungsbacka municipality and Växjö together with Alvesta municipalities use a flood-monitoring software developed by DHI. Their measurements are input parameters in the flood modelling. Kungsbacka municipality has a stage-discharge relationship based on three discharge measurements that they use to derive discharge.

On the west coast three municipalities; Göteborg, Mölndal and Härryda have another monitoring system for River Mölndalsån. The information is used for regulation of dams along the river. Discharge from the larger dams is estimated based on calibrated equations. Discharge is also measured using Doppler technique at two sites in the lower part on the river.

Two actors, VA Syd (a water and wasterwater collaboration in Skåne) and the County Administrative Board of Västerbotten, stated that they use rating curves that were not very good. VA Syd also stated that they don't have the resources to check the rating curve.

6 DISCUSSION

This study focused on interviews with different types of actors who perform hydrological measurements. The preparations for the interviews consisted of designing the questionnaires and selecting actors to contact. Throughout the project, questions regarding both processes came up; these are discussed in this section. Furthermore, the results from the interviews were interoperated and are also discussed in this section.

6.1 THE METHOD

The approach of using email as the main form of communication was on the whole successful. All actors were given the opportunity to reply via telephone if they wished to and some did. Initially the plan was to contact the actors by phone. However, when compiling the list of actors it was evident that such an approach would be too time consuming.

6.1.1 Questionnaire design

The design of the questionnaire probably had an impact on the results. The most noticeable was that many actors did not answer all the questions. A few of them commented that they did not have the time, while others said that they answered all the questions they knew how to answer.

The four versions of the questionnaire contained the same questions with the exception of questionnaire 2 in which the questions about river discharge had been removed and questionnaire 4 that was adapted for actors with many sites. Despite the adaptations in questionnaire 4, none of the actors who received it answered all the questions.

Early in the interview process the choice was made not to edit the questionnaires further during the project. The main reason was that it was desirable that all actors answered the same questions to get comparable results. Another reason for not altering the questionnaire was that, even though it could be seen that all questions were not answered, it was not evident what types of changes would improve the questionnaire.

There were two topics that would have improved the results if they had been included in the questionnaire: data storage and perception of accuracy. In all questionnaires, the question *"for how long have measurements been conducted?"* was asked. A follow-up question such as *"for how long is data stored"* would have added information relevant for SMHI if and when they want to investigate the site further. The topic of perceived accuracy would have enabled further analysis of difference between calculated and perceived accuracy. The questionnaires as they were contained the question *"what requirement do you have of the data?"*. It is difficult to interpret the answers since the actors probably thought of different aspects when answering the questions. Some of them answered with the accuracy for the instrument given by the manufacturer, while others gave their estimations of the accuracy and yet others answered that they did not have any defined requirements. Perhaps the results would have been clearer if a question such as *"What is the level of accuracy on your data?"* had been added.

6.1.2 Who were contacted

The municipalities were the main focus when contacting actors. The first choice was to contact the water- and wastewater departments. As mentioned in section 4.1 they sometimes referred to other departments in which case those were contacted. However, there were several cases when the person replying to the initial contact answered *I don't know of any such measurements* or similar. Since all initial emails included a question such as *To whom should I address this question*, those replies were categorized as no-answers. It is possible, however, that some of these municipalities do in fact measure hydrological parameters, but the question was simply addressed to the wrong person.

The hydropower companies that were contacted were mainly found in the members list of the trade association Svensk energi – Swedenergy. Svensk vattenkraftförening is another hydropower trade association with members who are mainly small scale hydropower companies and could have provided interesting information to this project. Their members list is not accessible on their website and Svensk vattenkraftförening did not reply to attempted contact. It would have been valuable for the results to have had answers from their members as well.

Had there been more time, it would probably have been valuable to contact each of the county administrative boards directly as well as through the water authorities. By not receiving replies from them, some information about measurements related to liming might have been missed.

6.2 THE RESULTS

Out of 447 contacted organizations, about half replied. Even though it was desirable to receive as many replies as possible, the response rate is still satisfactory since none of the actors had any obligations to participate in this study. The information collected in this study about who does what (and where) is a good foundation for further inquiries for SMHI. As mentioned in section 6.1.1, an alternative formulation of the question about requirements or an additional question about accuracy could have improved the possibility to analyse the perceived accuracy. Although only nine actors mentioned the word accuracy when answering the requirement question, it is possible that others also thought of their perceived accuracy when answering.

6.2.1 Perceived accuracy

The actors' perception of the accuracy of their data varies from maximum error of 1 mm to 5 cm for pressure sensors and 1 cm for staff gauges. To assess the accuracy in stage measurements, it is necessary to have knowledge of levelling of the instruments. Assuming that the measuring devices have been installed properly, controlling the levelling is important to maintain a correct time series of data. 5 actors stated that they level their instruments and 15 that they check automatically logged data against readings of a staff gauge. These actions increase the level of certainty that the data is correct. Moreover, further inquiries in how the accuracy was assessed would have given more background to the analysis. One actor stated the accuracy given by the manufacturer but without controlling the levelling of the instrument it doesn't say much about the true accuracy of the data.

The level of required accuracy depends on what the data is to be used for. Most of the answering actors gave water-rights court ruling as the reason for measuring. Most water-rights court ruling state limits that are specified to the centimetre which suggest that an error margin of ± 5 mm is often sufficient. It is difficult to determine the level of accuracy required for controlling hydropower plants or flood monitoring since those practices have not been studied in this project. Regardless of reason for measuring, being aware of what level of accuracy is required and having a strategy for maintaining it is important.

Only a few actors measured discharge and they gave various views of the accuracy. The actors that commented on accuracy in discharge observations were either not content with the rating curves they had or thought it too complicated to make additional discharge measurements to improve them. The actors who expressed concern about their rating curves were probably more realistic in their perception of accuracy then those who stated that they did not check their stage-discharge relationship to make sure it is still correct. To base a stage-discharge relationship on only three discharge measurements opens for significant uncertainty, especially at high- and low water stages. Discharge data are valuable and it would be desirable that these actors received support in their efforts to produce discharge data.

6.2.2 Reasons for measuring

The reasons for measuring can be sorted into two categories; proactive and reactive. Measuring to maintain the stage within set limits is a reaction to water-rights court ruling. The proactive reasons can also be categorized with regards to what the knowledge intends to benefit: the environment or society. Measuring to control liming or to make sure there is enough water in the recipient to storm water are actions that intend to serve the environment whereas flood monitoring and collecting data for urban planning are for the benefit of people and the built structures.

6.2.3 Cooperation and coordination

Several municipalities have collaborated with hydropower companies to receive stage and discharge information and some have built monitoring systems together with other municipalities. There could be a lot to gain for municipalities connected by a river by sharing hydrological information. Some already do this through water councils, but more cooperation and exchange of information would improve the knowledge of hydrological measurements. In small organizations it is difficult to maintain high competence regarding hydrological measurements, which in many cases makes the uncertainty unnecessarily high. By coordinating measurements performed by different actors, some of the errors could be limited.

The measurement sites identified in this study are generally quite far from each other and none of the actors have sites located in the same rivers or streams. However, many municipalities did not reply and still others answered that they do not perform any hydrological measurements. It is therefore possible that there are actors who could benefit from each other's hydrometric activities. Storing data at SMHI could be a way to achieve more coordination of measurements.

The municipalities invest in measuring systems without knowing how accurate their data is. By coordinating with other departments in the municipality and with other similar organizations the data could come to use to more purposes. Another important aspect of the investment the municipalities make is the storing of data. To evaluate the measurements or to expand the use of the data, long time series are vital. Data are valuable and it takes investment and maintenance to store it in a way that it is still accessible.

7 CONCLUSIONS

Many municipalities, companies, interest groups and other actors were willing to contribute to this inventory. 59 % of the contacted actors replied and 80 % of them answered that they do not perform any measurements. The remaining 20 % answered that they do measure and hence answered the questions in the questionnaire.

The most common reason for measuring is to maintain the given upper- and lower stage limits given in water-rights court rulings. Other reasons were: control of hydropower plants, management of water- and wastewater systems, and flood monitoring.

Only a few actors were found that collect discharge data, and none of them measure discharge regularly to calibrate their stage-discharge relationship. However, two actors expressed a wish to improve their rating curves.

By storing collected data the actors would enable expansion of the use of field observations. There is also a lot to gain by a better coordination of the measurements performed by different actors in terms of competence and knowledge of hydrological measurements.

Continued attempts to obtain replies from all contacted actors would give a more complete overview of the present situation. Especially, contact with the members of Svensk vattenkraftförening would allow a better inventory of the hydrological measurements performed by small-scale hydropower companies. A supplementing approach for continued study would be to make further inquiries into the activities of the actors who answered that they do hydrometric measurements. Such studies would give a deeper understanding of the reasons behind measuring and the actions taken to maintain accuracy.

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PERSONAL COMMUNCATIONS

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Appendix A – Contacted actors

Table A- 1. The contacted municipalities. Those marked with green replied to the questionnaire, those marked with yellow gave some information via email and those marked with red replied that they do not make any hydrological measurements

Ale kommun	Färgelanda kommun	Karlshamns kommun
Alingsås kommun	Gagnefs kommun	Karlskoga kommun
Alvesta kommun	Gislaveds kommun	Karlskrona kommun
Aneby kommun	Gnesta kommun	Karlstads kommun
Arboga kommun	Gnosjö kommun	Katrineholms kommun
Arjeplogs kommun	Grums kommun	Kils kommun
Arvidsjaurs kommun	Grästorps kommun	Kinda kommun
Arvika kommun	Gullspångs kommun	Kiruna kommun
Askersunds kommun	Gällivare kommun	Klippans kommun
Avesta kommun	Gävle kommun	Knivsta kommun
Bengtsfors kommun	Göteborgs kommun	Kramfors kommun
Bergs kommun	Götene kommun	Kristianstads kommun
Bjurholms kommun	Habo kommun	Kristinehamns kommun
Bjuvs kommun	Hagfors kommun	Krokoms kommun
Bodens kommun	Hallsbergs kommun	Kumla kommun
Bollebygds kommun	Hallstahammars kommun	Kungsbacka kommun
Bollnäs kommun	Halmstads kommun	Kungsörs kommun
Borgholms kommun	Hammarö kommun	Kungälvs kommun
Borlänge kommun	Haninge kommun	Kävlinge kommun
Borås kommun	Haparanda kommun	Köpings kommun
Botkyrka kommun	Heby kommun	Laholms kommun
Boxholms kommun	Hedemora kommun	Landskrona kommun
Bromölla kommun	Helsingborgs kommun	Laxå kommun
Bräcke kommun	Herrljunga kommun	Lekebergs kommun
Burlövs kommun	Hjo kommun	Leksands kommun
Båstads kommun	Hofors kommun	Lerums kommun
Dals-Eds kommun	Huddinge kommun	Lessebo kommun
Danderyds kommun	Hudiksvalls kommun	Lidingö kommun
Degerfors kommun	Hultsfreds kommun	Lidköpings kommun
Dorotea kommun	Hylte kommun	Lilla Edets kommun
Eda kommun	Håbo kommun	Lindesbergs kommun
Ekerö kommun	Hällefors kommun	Linköpings kommun
Eksjö kommun	Härjedalens kommun	Ljungby kommun
Emmaboda kommun	Härnösands kommun	Ljusdals kommun
Enköpings kommun	Härryda kommun	Ljusnarsbergs kommun
Eskilstuna kommun	Hässleholms kommun	Lomma kommun
Eslövs kommun	Höganäs kommun	Ludvika kommun
Essunga kommun	Högsby kommun	Luleå kommun
Fagersta kommun	Hörby kommun	Lunds kommun
Falkenbergs kommun	Höörs kommun	Lycksele kommun
Falköpings kommun	Jokkmokks kommun	Lysekils kommun
Falu kommun	Järfälla kommun	Malmö kommun
Filipstads kommun	Jönköpings kommun	Malung-Sälens kommun
Finspångs kommun	Kalix kommun	Malå kommun
Flens kommun	Kalmar kommun	Mariestads kommun
Forshaga kommun	Karlsborgs kommun	Markaryds kommun

Marks kommun	Skövde kommun	Upplands Väsby kommun
Melleruds kommun	Smedjebackens kommun	Upplands-Bro kommun
Mjölby kommun	Sollefteå kommun	Uppsala kommun
Mora kommun	Sollentuna kommun	Uppvidinge kommun
Motala kommun	Solna kommun	Vadstena kommun
Mullsjö kommun	Sorsele kommun	Vaggeryds kommun
Munkedals kommun	Sotenäs kommun	Valdemarsviks kommun
Munkfors kommun	Staffanstorps kommun	Vallentuna kommun
Mölndals kommun	Stenungsunds kommun	Vansbro kommun
Mönsterås kommun	Stockholms kommun	Vara kommun
Mörbylånga kommun	Storfors kommun	Varbergs kommun
Nacka kommun	Storumans kommun	Vaxholms kommun
Nora kommun	Strängnäs kommun	Vellinge kommun
Norbergs kommun	Strömstads kommun	Vetlanda kommun
Nordanstigs kommun	Strömsunds kommun	Vilhelmina kommun
Nordmalings kommun	Sundbybergs kommun	Vimmerby kommun
Norrköpings kommun	Sundsvalls kommun	Vindelns kommun
Norrtälje kommun	Sunne kommun	Vingåkers kommun
Norsjö kommun	Surahammars kommun	Vårgårda kommun
Nybro kommun	Svalövs kommun	Vänersborgs kommun
Nykvarns kommun	Svedala kommun	Vännäs kommun
Nyköpings kommun	Svenljunga kommun	Värmdö kommun
Nynäshamns kommun	Säffle kommun	Värnamo kommun
Nässjö kommun	Säters kommun	Västerviks kommun
Ockelbo kommun	Sävsjö kommun	Växjö kommun
Olofströms kommun	Söderhamns kommun	Ydre kommun
Orsa kommun	Söderköpings kommun	Ystads kommun
Orusts kommun	Södertälje kommun	Åmåls kommun
Osby kommun	Sölvesborgs kommun	Ånge kommun
Oskarshamns kommun	Tanums kommun	Åre kommun
Ovanåkers kommun	Tibro kommun	Årjängs kommun
Oxelösunds kommun	Tidaholms kommun	Åsele kommun
Pajala kommun	Tierps kommun	Åstorps kommun
Partille kommun	Timrå kommun	Åtvidabergs kommun
Perstorps kommun	Tingsryds kommun	Älmhults kommun
Piteå kommun	Tjörns kommun	Älvdalens kommun
Ragunda kommun	Tomelilla kommun	Älvkarleby kommun
Robertsfors kommun	Torsby kommun	Älvsbyns kommun
Ronneby kommun	Torsås kommun	Ängelholms kommun
Rättviks kommun	Tranemo kommun	Öckerö kommun
Sala kommun	Tranås kommun	Ödeshögs kommun
Salems kommun	Trelleborgs kommun	Örebro kommun
Sandvikens kommun	Trollhättans kommun	Örkelljunga kommun
Sigtuna kommun	Trosa kommun	Örnsköldsviks kommun
Simrishamns kommun	Tyresö kommun	Östersunds kommun
Sjöbo kommun	Täby kommun	Österåkers kommun
Skara kommun	Töreboda kommun	Östhammars kommun
Skellefteå kommun	Uddevalla kommun	Östra Göinge kommun
Skinnskattebergs kommun	Ulricehamns kommun	Överkalix kommun
Skurups kommun	Umeå kommun	Övertorneå kommun

Table A- 2. The contacted water councils in Bothnian Bay water district. Those marked with red replied that they do not make any hydrological measurements

Water Councils – Bothnian Bay	
Tornedalens Vattenparlament (VPO1)	Mellanbygdens vattenråd (VRO9)
Sangisälvens och Keräsjoki VR (VRO2)	Ume-och Vindelälvens vattenråd (VRO10)
Kalix- och Töreälvens vattenråd (VRO3)	Södra Västerbottens vattenråd (VRO11)
Råne-/Luleälvens vattenråd (VRO4)	Norra Bottenvikens kustvattenråd (VRO12)
Fyrkantens vattenråd (VRO5)	Södra Bottenvikens kustvattenråd (VRO13)
Piteälvens vattenråd (VRO6)	Ume-Vindelälvens vattenvårdsförbund
Åby,-Byske-och Kågeälven VR (VRO7)	Torne- & Kalix älvars vattenvårdsförbund
Skellefteälvens vattenråd (VRO8)	

Table A- 3. The contacted water councils in Bothnian Seas water district. Those marked with red replied that they do not make any hydrological measurements

Water Councils – Bothnian Sea	
Ljusnan och Voxnans vattenvårdsförbund	Ljusnan och Hälsinglands skogs- och kustvattenråd
Dalälvens Vattenvårdsförening	Ångermanälven och Vapstälvens vattenråd

Table A- 4. The contacted water councils in North Baltic water district. Those marked with yellow gave some information via email and those marked with red replied that they do not make any hydrological measurements

Water Councils – North Baltic	
Arbogaåns vattenförbund	Nyköpingsåarnas Vattenvårdsförbund
Bällstaån	Stockholms Vattenprogram
Tyresåns vattenvårdsförbund	Trosaåns vattenvårdsförbund
Oxundaåns vattenvårdsprojekt	Hjälmarens Vattenvårdsförbund
Mälarens vattenvårdsförbund	Kolbäcksåns Vattenförbund
Sagåns Vattenråd	Himmerfjärdens och Kaggfjärdens Vattenråd

Table A- 5. The contacted water councils in Skagerakk & Kattegatt water district. Those marked with yellow gave some information via email and those marked with red replied that they do not make any hydrological measurements

Water Counils – Skagerakk & Kattegatt	
Bohuskustens vattenvårdsförbund	Mölndalsåns vattenråd
Bohuskustens vattenråd, VRBK	Nissans Vattenråd
Bäveåns Vattenråd	Norsälvens vattenråd
Dalbergså och Holmsåns Vattenråd	Ringsjöns vattenråd
Dalslandskanals vattenråd	Rönneåns vattenråd
Enningdalsälvens Vattenråd	Strömsåns/Strömstads Vattenråd
Gullmarns Vattenråd	Suseåns Vattenråd
Gullspångsälvens Vattenvårdsförbund	Säveåns vattenråd
Göta älvs vattenråd	Tidans Vattenförbund/Vattenråd
Göta älvs vattenvårdsförbund	Vegeåns Vattendragsförbund
Klarälvens vattenråd	Viskans vattenråd
Kungsbackaåns vattenvårdsförbund	Vänerns sydöstra tillflöden
Lagans vattenråd	Ätrans Vattenråd

Table A- 6. The contacted water councils in South Baltic water district. Those marked with green answered the questionnaire and those marked with red replied that they do not make any hydrological measurements

Water Councils – South Baltic	
Alsteråns Vattenråd	Tullstorpsåprojektet
Bruatorpsån-Grisbäcken-Brömsebäcken	Rååns vattendragsförbund
Bräkneåns Vattenråd	Alnarpsströmmen Sammarbetskommittén
Emåförbundet	Saxån Braåns vattenvårdskommitté
Gotlands vattenråd	Segeåns Vattendragsförbund och Vattenråd
Hagbyåns och Halltorpsåns Vattenråd	Skivarpsåns och Dybäcksåns vattendragsförbund
Helge å Kommittén för samordnad kontroll	Skräbeåns vattenråd
Helgeåns Vattenråd	Snärjebäcken, Törnebybäcken, Åbyån-Surrebäcken och Nävraån-Danesjökanalen
Ivösjökommitten	Svarteåns Vattenråd
Höje å Vattenråd	Stångåns Vattenråd
Kalmar läns kustvattenkommitté	Sydkustens vattenvårdsförbund
Kävlingeåns vattenvårdsförbund	Trelleborgs åar
Kävlingeåns Vattenråd	Hanöbukten, Vattenvårdsförbundet för Västra Hanöbukten
Ljungbyåns Vattenråd	Vegeåns vattendragsförbund
Lyckebyåns vattenförbund	Vellingebäckarna
Motala ströms vattenvårdsförbund	Västar Gotlands Vattenråd
Motala ströms sydvästra vattenråd	Vätternvårdsförbundet
Nedre Motala ströms och Bråvikens vattenråd	Ölands Vattenråd
Mörrumsåns Vattenråd	Öresunds vattenvårdsförbund
Norra Gotlands Vattenråd	Österlens vattenråd
Norra Möre Vattenråd	Östra Gotlands vattenråd
Nybroån, Kabusaån och Tyge å Vattenråd	

Table A- 7. The contacted hydropower companies. Those marked with green answered the questionnaire, those marked with yellow gave some information via email and those marked with red replied that they do not make any hydrological measurements

Hydropower Companies	
Bodens Energi AB	Malungs Elverk AB
Borlänge Energi AB	Mjölby-Svartådalen Energi AB
Brittedal Elnät ek för	Nässjö Affärsverk AB
Edsbyns Elverk AB	Olofströms Kraft Nät AB
Envikens Elkraft ek för	Sandviken Energi AB
Falkenberg Energi AB	Skellefteå Kraft AB
Falu Energi & Vatten AB	Skånska Energi AB
Gislaved energi	Smedjebacken Energ AB
Hamra Kapellags Besparingsskog	Strömfallet AB
Holmen Energi AB	Tidaholms Energi AB
Jönköping Energi AB	Tived Energi
Karlskoga Energi & Miljö AB	Umeå Energi AB
Linde Energi AB	VB Energi
Ljungby Energi AB	Ålem Energi AB
Ljusdal Energi AB	

Table A- 8. The other actors who were contacted. Those marked with green answered the questionnaire and those marked with red replied that they do not make any hydrological measurements

Other Actors	
Mälarhamnar	Stockholms Universitet
Vallentunasjöns fiskevårdsområdesförening	Snoderåns vattenråd
Angarngruppen	Kågeälvens nedre FVO
Svensk vattenkraftförening	Ekologgruppen i Landskrona
Vansjö-Nordsjöns väl	Moelven Valåsen ab
Tämnaren vatten	FOI
LKAB	Stora Enso Nymölla
Boliden	Luleå Tekniska Universitet
Alcontrol	Mölndals kvarnby
Dalslands kanal	

Appendix B – Questionnaire

Inventering av hydrologiska mätningar i Sverige

Detta frågeformulär är en del av ett examensarbete inom civilingenjörsprogrammet i miljö- och vattenteknik vid Uppsala Universitet och Sveriges Lantbruksuniversitet. Projektet görs på uppdrag av SMHI och syftar till att kartlägga och utvärdera hydrologiska mätningar som utförs av aktörer utöver SMHI. Utöver att få en bild av var och vilka som mäter hydrologiska parametrar i Sverige idag kommer mätmetoderna hos dessa aktörer utvärderas utifrån ett mätnoggrannhetsperspektiv och därefter kommer rekommendationer ges till SMHI huruvida mätdata från aktörerna kan vara användbar i SMHIs prognosarbete.
Formuläret består av fem delar. Först en del med den svarandes kontaktuppgifter ifall det skulle finnas behov att följa upp något av svaren samt för att kunna delge de svarande resultaten från studien. Den andra delen berör generella frågeställningar kring mätningar, syfte, kontrollrutiner och liknande. Del tre berör mätplatsen, del fyra vattenstånds- och vattenföringsmätningar den sista delen berör avbördningskurvor. Det finns även möjlighet att komplettera med ytterligare information på slutet.
Fyll i dina svar i rutorna under respektive fråga. Se inte rutans ursprungliga storlek som en platsbegränsning utan skriv så långa svar som är nödvändigt. Dokument med ifyllda svar skickas sedan till ida.enjebo@gmail.com.
Har du några frågor eller funderingar nås jag på ida.enjebo@gmail.com eller 076-130 44 11.

Tack på förhand för ditt deltagande!

1. Kontaktuppgifter

1. Namn

2. Organisation/Företag/Kommun eller dylikt

   a. Telefonnummer — Epostadress

3. Person ansvarig för mätning av vattenstånd och flöde (hoppa över om samma som ovan)

   a. Telefonnummer — Epostadress

4. Övriga upplysningar

2. Generellt

5. Vilka paratetrar mäter ni?
   Vattenföring, vattenstånd, vattentemperatur, vattenhastighet, snödensitet mm.

6. Varför mäter ni?

7. Vilka krav ställer ni på mätdata?

8. Hur inspekteras/underhålls utrustning och mätplatsen?

9. Hur granskas data som samlas in?

10. Utförs kontrollmätningar?
    Om ja, hur och hur ofta? Om nej, varför inte?

11. Utförs kalibrering av mätutrustning och avbördningskurva?
    Om ja, hur och hur ofta? Om nej, varför inte?

3. Mätplatser

Om ni har fler än en mätplats, besvara då frågorna för platserna i de olika numrerade rutorna för att hålla isär informationen. Om informationen är den samma för samtliga platser behöver det bara skrivas en gång, men kommentera gärna att så är fallet. Om ni har fler än fyra mätplatser går det jättebra att lägga till fler rader.

12. Parameter som mäts

1.
2.
3.
4.

13. Vattendragets namn

1.
2.

3.	
4.	

14. Huvudavrinningsområde alternativt ett större vattendraget som detta vattendrag mynnar i

1.	
2.	
3.	
4.	

15. Namn på platsen där mätningarna sker

1.	
2.	
3.	
4.	

16. Kordinater för mätplatsen — Referenssystem

Om detta inte finns, hoppa över.

1.	
2.	
3.	
4.	

17. Annan upplysning om platsen – adress till närliggande fastighet, riktmärken eller dylikt.

1.	
2.	
3.	
4.	

18. Hur valdes platsen? Vilka kriterier sattes upp inför val av plats?

1.	
2.	
3.	
4.	

19. Övriga upplysningar om platsen?

1.	
2.	
3.	
4.	

4. Vattenstånds- och vattenföringsmätningar

20. Utför ni vattenståndsmätningar?
    Ja, enbart vattenstånd, ja, för att räkna ut flödet eller nej

1.
2.
3.
4.

21. Hur länge har mätningar pågått?
    Ange även eventuella uppehåll, t.ex. "1999-2001 samt 2004-2014".

1.
2.
3.
4.

22. Vilken teknik används för att registrera vattenståndet?

1.
2.
3.
4.

23. Vilken är mätfrekvensen?
    Är det alltid samma mätfrekvens eller olika beroende på årstid eller dylikt?

1.
2.
3.
4.

24. Vilken är insamlingsfrekvensen?

1.
2.
3.
4.

25. Hur sker insamlingen?

1.
2.
3.
4.

26. Finns det en bestämmande sektion på platsen – konstgjord eller naturlig tröskel?

1.
2.
3.
4.

27. Finns det objekt i vattnet nedström mätplatsen som kan verka dämmande vid mätplatsen? *Vad är det, i vilka situationer är det dämmande och hur långt från mätplatsen ligger det?*

1.
2.
3.
4.

28. Vilken teknik används för att mäta flödet?

1.
2.
3.
4.

29. Hur ofta sker kontrollmätningar av flödet?

1.
2.
3.
4.

30. Vilka är rutinerna för underhåll av mätinstrumenten?

1.
2.
3.
4.

31. Övrigt angående vattenföringsmätningar

1.
2.
3.
4.

5. Avbördningskurvan

32. Använder ni en avbördningskurva för att beräkna vattenföring från vattenståndsmätningar?

1.
2.
3.
4.

33. Hur många mätningar ligger till grund för avbördningskurvan?

1.
2.
3.
4.

34. Har avbördningskurvan uppdaterats sedan den skapades?
Om ja, när? Varför? Om nej, varför inte?

1.
2.
3.
4.

35. Övrigt angående avbördningskurva

1.
2.
3.
4.

6. Övrigt

36. Övriga upplysningar

Appendix C – Measurement sites

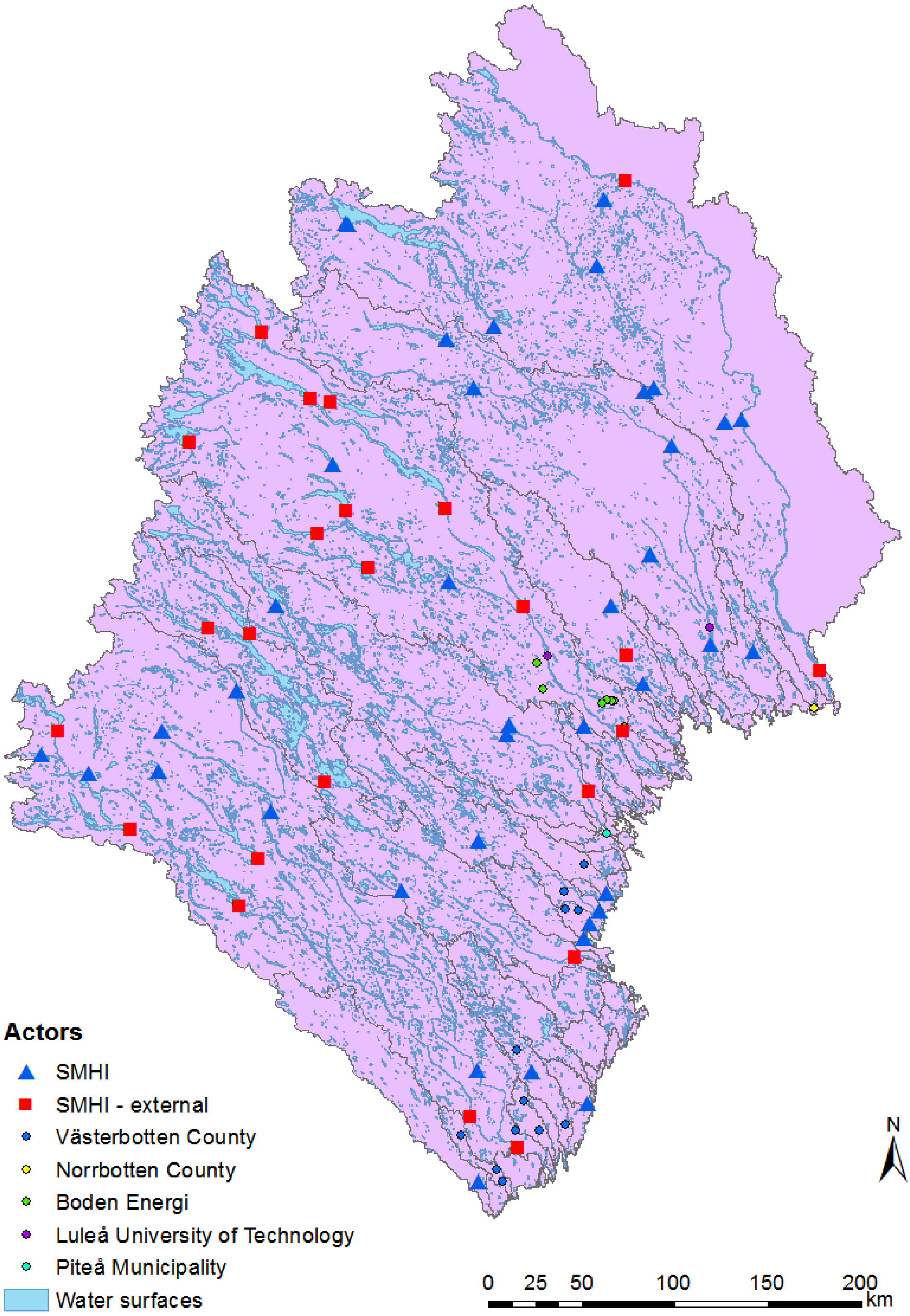

Figure C- 1. Bothnian Bay water districts and identified measurement sites.

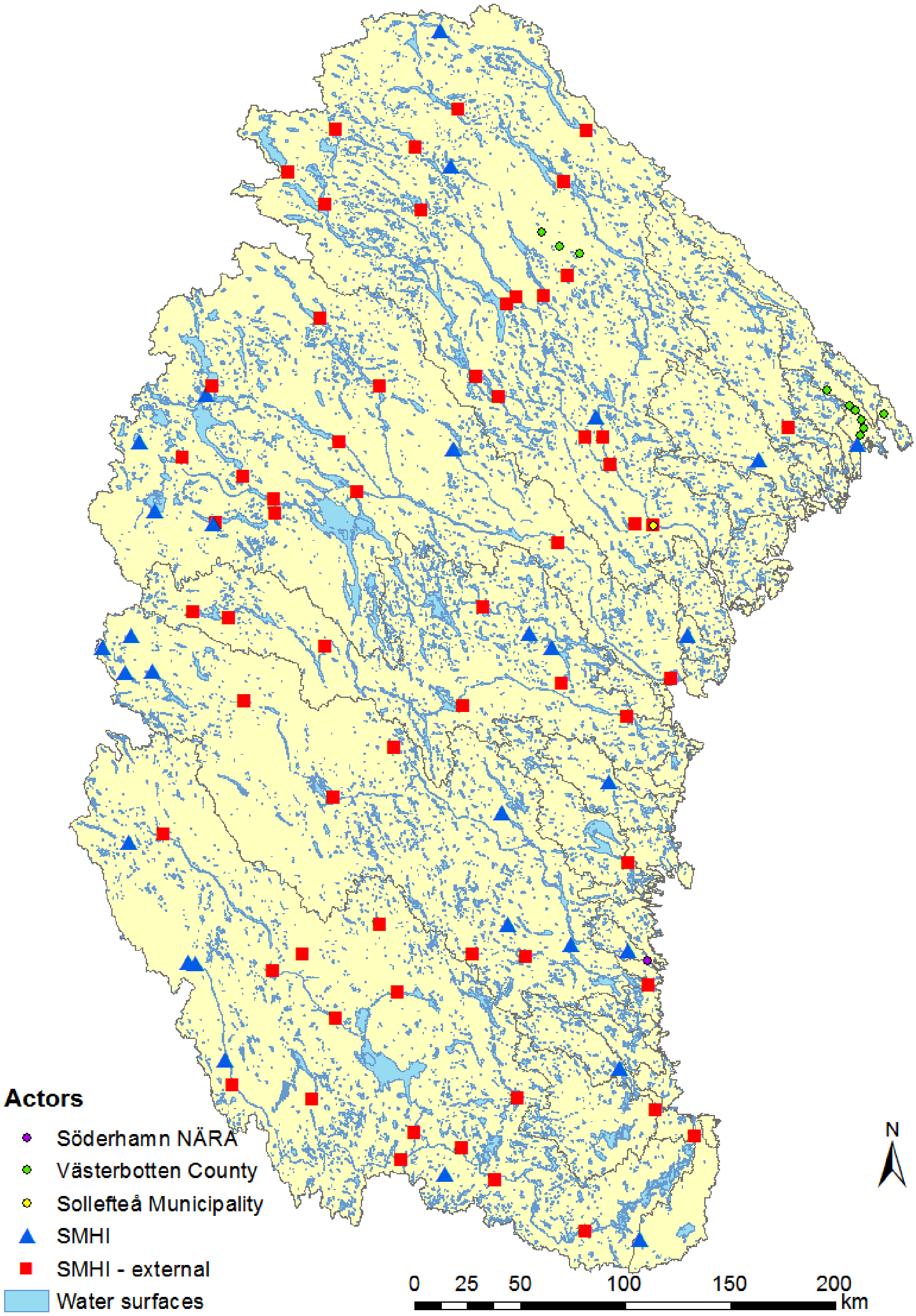

Figure C- 2. Bothnian Sea water districts and identified measurement sites.

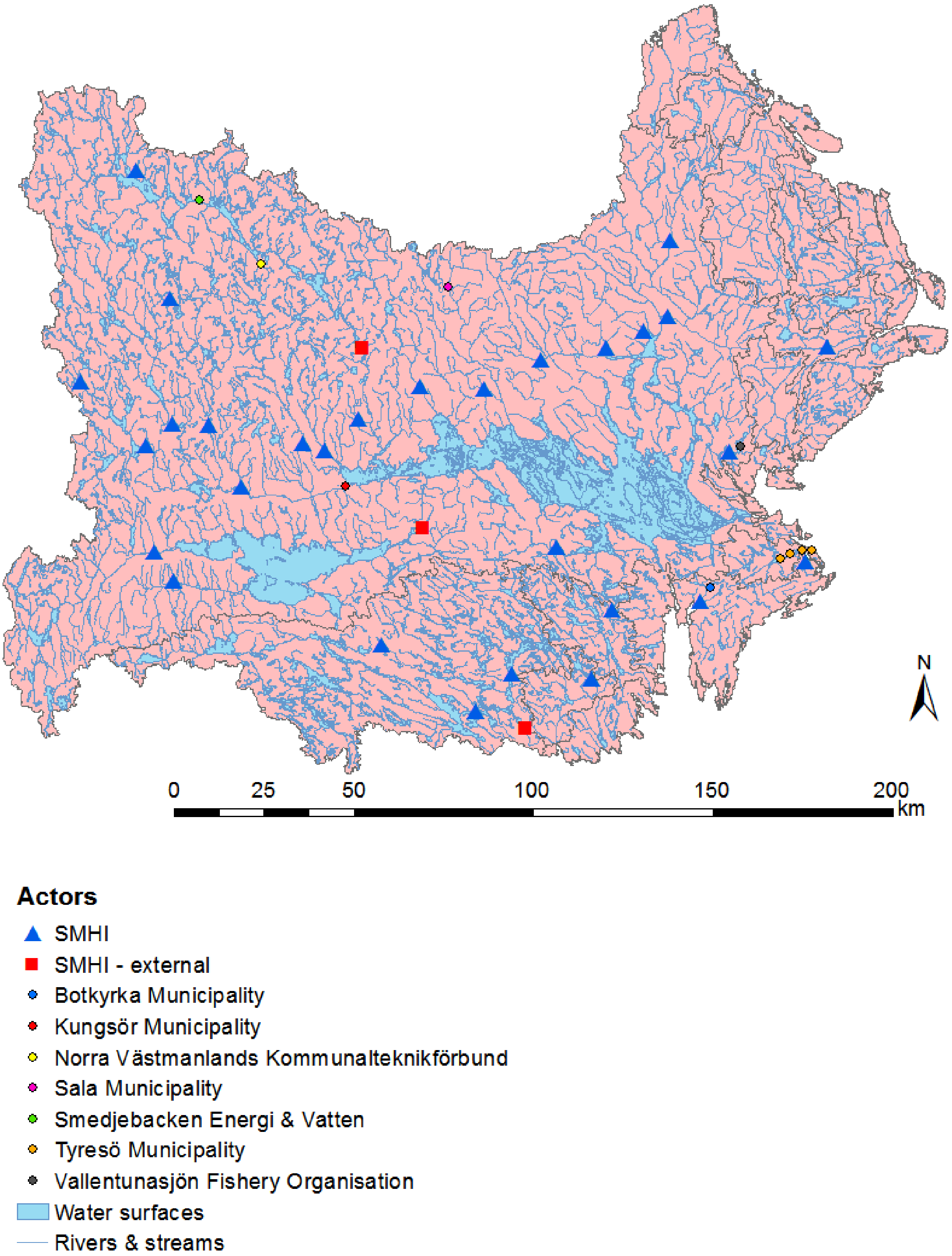

Figure C- 3. North Baltic water districts and identified measurement sites.

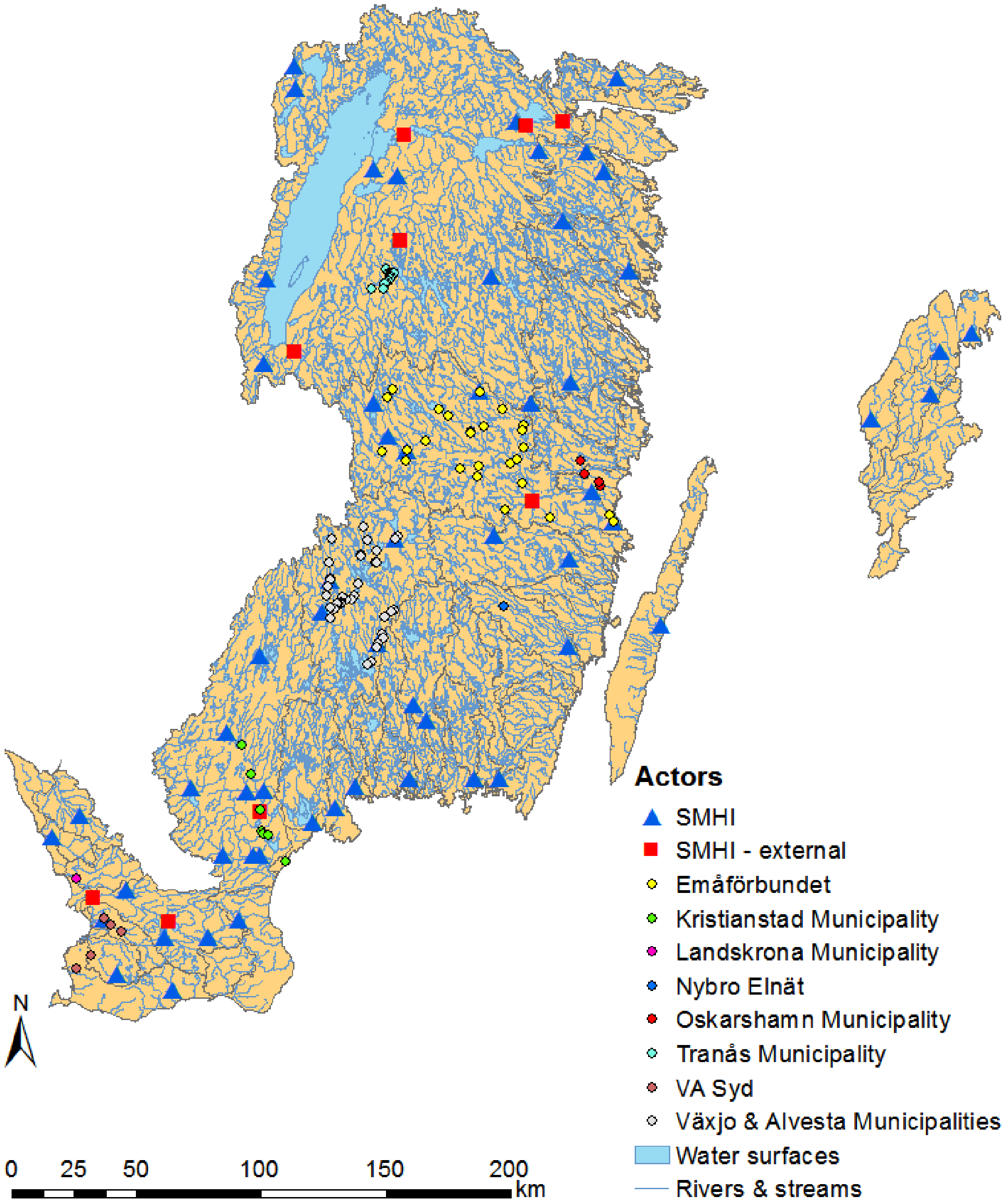

Figure C- 4. South Baltic water districts and identified measurement sites.

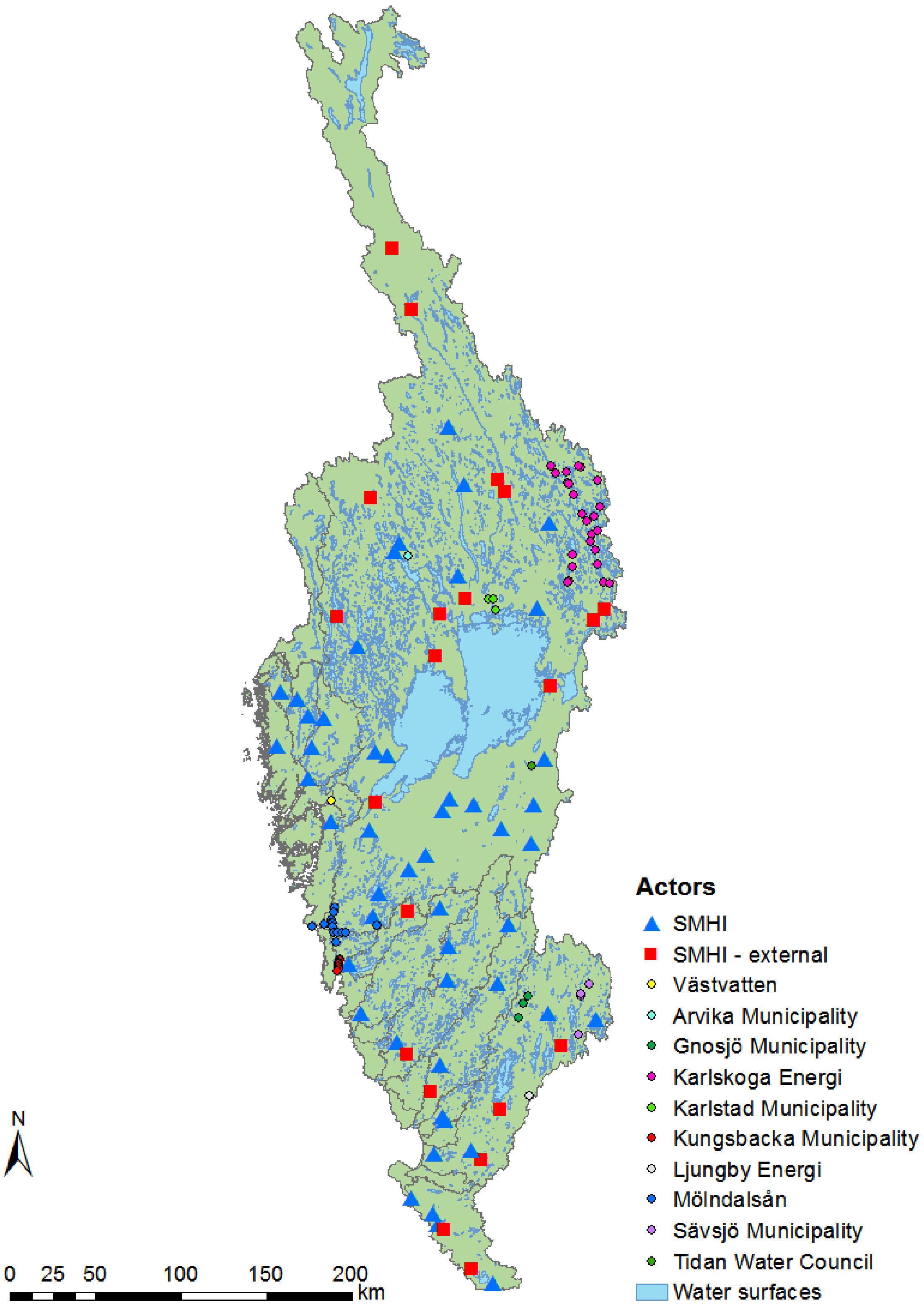

Figure C- 5. Skagerakk & Kattegatt water districts and identified measurement sites.