Göteborgs Universitet
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Hydrogeologi

Grundvatten på Koster – status och framtida utveckling

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1 Sammanfattning

Den hydrogeologiska forskningsgruppen vid Institutionen för geovetenskaper vid Göteborgs universitet, ledd av Professor Roland Barthel, utförde en vetenskaplig utredning av grundvattnets kvalitet och kvantitet på Koster, Strömstads kommun, mellan december 2015 och oktober 2016. Dessa undersökningar utgör grunden för tre pågående masteruppsatser och för två pågående kandidatuppsatser och genomförs inom ramen för utredningen Kostervatten (www.kostervatten.com).

De första mätningarna utfördes i december 2015 men merparten av utredningen startade i april 2016. De huvudsakliga metoderna som använts är: litteraturstudier (rapporter, annat digitalt eller tryckt material), enkäter, insamling av muntlig/skriftlig information, grundvattennivåmätningar, grundvattenprovtagning, kemisk analys av vattenkvalitet, kontinuerliga mätningar av salthalt och grundvattennivåer i utvalda brunnar, djupprofiler av salthalt i bergborrade brunnar, GIS-analys samt vattenbalansberäkningar.

Fältarbete samt laboratorieanalyserna utfördes av studenterna under handledning av Prof. Barthel samt Dr. Banzhaf. Studenterna har tillsammans spenderat 42 dagar i fält på Koster samt 40 dagar i laboratorium för analys av prover. Mätprogrammet i fält har omfattat mätningar i 207 brunnar. 291 vattenprover togs från 82 brunnar och har analyserats i laboratoriet. Ytterligare information har samlats in via en online-enkät, personlig kommunikation samt via befintlig dokumentation. Sammantaget har vi fått tillgång till data från cirka 300 brunnar (av 800-1000 brunnar på ön).

Huvudsyftet med undersökningarna var att bestämma hur grundvattensystemet (grundvattenkemi samt grundvattennivåer) på Koster svarar på ökad vattenförbrukning under turistsäsongen, juni-augusti, samt att utvärdera om vattenanvändning via brunnar på ön kan vara hållbart i framtiden. Mätningarna har därför anordnats så att information om grundvattnets tillstånd innan vattenbehovets topp (april/maj), under toppen (juli) samt efter (september/oktober) samlats in. Redan här skall nämnas att grundvattensystemet ännu (oktober 2016) inte fullständig återhämtat sig från sommarens ökade uttag samt dess låga grundvattenbildning. Undersökningen visar därför inte en fullständig bild av grundvattensystemets reaktion under ett helt hydrologiskt år.

1.1 Anmärkningar

Detta dokument innehåller en sammanfattning av slutrapporten samt slutsatser och rekommendationer på svenska (kapitel 1). Huvuddelen av rapporten, som beskriver metodik och redovisar enskilda resultat, är skriven på engelska (kapitel 2 till 5).

Vi beslutade att inte ange namn och ägare, adresser eller fastighetsbeteckningar, för de brunnar eller fastigheter där mätningar utförts, i denna rapport.

1.2 Resultat - sammanfattning

1.2.1 Begränsningar

Nedanstående resultat från mätningarna skall beaktas med följande begränsningar:

1. Det var, trots ansträngning, inte möjligt att få information om alla befintliga brunnar på Koster (dvs deras placering och hur de används). Därför kvarstår osäkerheten kring huruvida resultateten är representativa.
2. Förutsättningarna för grundvattenundersökningar på Koster är begränsade, eftersom nätverk av observationsrör (rör för att mäta vattennivå samt ta prover ifrån) inte existerar. De tillgängliga brunnarna är antingen aktiva eller övergivna pumpbrunnar. Grundvattennivåmätningar är därför svåra att tolka och provtagningar av vattenkemiska prover kan inte utföras enligt standard utan betydande ansträngning och kostnad. De flesta pumpbrunnar tillåter som bäst begränsade möjligheter att utföra godtagbara mätningar och provtagningar. I vissa brunnar är det inte alls möjligt. Att installera ett grundvattenobservationsnätverk som är anpassat för frågeställningen uppskattas kosta 1–5 miljoner kr.
3. Mätningarna av vattenkvalitet syftade huvudsakligen till att utreda kvaliteten på naturligt grundvatten, dvs. den kemiska sammansättningen av grundvatten som ett resultat av vatten som interagerar med naturligt förekommande jordar och berg. Huvudfokus lagdes på salthalt pga. saltvatteninträngning. Det fanns tyvärr inte utrymme att utreda den mikrobiologiska kvaliteten på grundvattnet som inte är ett resultat av naturliga (geologiska) förhållanden, utan främst beror av felaktig hantering av vatten och avlopp samt olämplig placering av brunnar.
4. Tidsramen för mätningarna var väldigt kort, vilket betyder att mätningarna inte sträcker sig över ett fullständigt hydrologiskt år (november-oktober). Tiden räckte inte heller för att hitta de bäst lämpade platserna för provtagning samt installation av mätinstrument. Vidare har tidsramen gett utrymme för provtagning före, under och efter högsäsongen, däremot har den inte varit tillräcklig för en omfattande vetenskaplig analys av all insamlad data. I synnerhet saknas modellberäkningar som skulle kunna användas för att simulera framtida scenarier.

Med dessa begränsningar i åtanke, kan de viktigaste resultaten av undersökningarna sammanfattas på följande sätt:

1.2.2 Resultat grundvattenkvantitet

Den tillgängliga mängden grundvatten på en ö beror på möjligheten att lagra grundvatten (porositet och tjocklek på grundvattenmagasinen) och grundvattenbildningen. Lagringsmöjligheten på Koster är begränsad, därför är den årliga grundvattenbildningen mycket avgörande. Detta betyder att väderförhållanden under ett år är en viktig parameter för kvantitetsberäkningar. Vädret under högsäsongen 2016, i synnerhet veckorna före det andra provtagningstillfället i juli, var nära genomsnittet för referensperioden 1961-1990. 2000-talet har redan varit varmare än genomsnittet för 1961-1990 referensperiod och prognoser för 2000-talet förutspår ännu högre temperaturer. De erhållna resultaten kan således vara representativa för ett ”normalår” i förhållande till referensperioden 1969-1990, men troligtvis inte visa hur grundvattnet på Koster kan komma att bete sig under varmare och torrare år i framtiden. För utredningen, som utförts under en kort period i förhållande till det långsiktiga perspektivet på projektet hade en starkare signal, dvs. en varmare och torrare sommar varit att föredra.

1. I ***sin helhet*** (d.v.s. summerad över hela ön och ett längre tidsrum, > ett år) är grundvattenbildningen och lagringsmöjligheterna för grundvatten på Koster tillräckliga för att leverera och lagra den mängd vatten som krävs för att tillgodose nuvarande vattenbehov med en permanent befolkning på 320 samt betydligt fler personer utan problem, även under ett torrare och varmare år än 2016. Problemet är fördelningen av vattnet i tid och rum. Utan tekniska installationer (ledningar, konstgjord grundvattenlagring) kommer tillgången till vatten vara ojämnt fördelad och risken för vattenbrist under vissa tider och på vissa platser finns.

2. Grundvattenbildningen är volymmässig nästan lika stor som grundvattenlagring i många områden där grundvattenanvändning sker. Det betyder att grundvattenbildningen är helt avgörande för grundvattentillgången. Två år i följd med mycket låg grundvattenbildning kan framkalla en svårt hanterbar situation. Med Kosters klimatförhållanden är låg grundvattenbildning två år i följd osannolikt.

3. Trots märkbart sänkta grundvattennivåer i alla brunnar samt kraftiga sänkningar i vissa under högsäsong har de flesta av brunnarna som ingår i mätprogrammet inte uppvisat direkt vattenbrist. Vi har dock fått muntlig information om vattenbrist under sommaren samt senare på hösten (till och med i början av november) samt att boende måste ha en mycket sparsam vattenanvändning för att undvika vattenbrist.

4. Grundvattennivåerna i de flesta av de borrade brunnarna återhämtade sig snabbt efter högsäsongen, även utan betydande grundvattenbildning (augusti samt oktober 2016 var ganska torra). Detta innebär att de kraftiga nedgångar i grundvattennivån som observerats främst är lokala och kompenseras snabbt genom horisontellt återflöde av grundvatten som finns lagrat i det omgivande berget/jordvolymer. Vattenlagring i berg är stor jämfört med grundvattenuttaget från berg och det går att utnyttja större andelar av lagringen utan större grundvattenbildning. Å andra sida är uttagsmöjligheten mycket begränsat utav bergets genomsläpplighet.

5. För grävda brunnar är situationen mer varierande. I grävda brunnar är de lokala förhållanden och grundvattenbildningen avgörande. Den viktigaste parametern är den vattenmättade tjockleken av sedimentlagret där brunnen finns samt brunnens djup. Förenklat kan man säga att: ju högre grundvattennivån ligger över brunnens botten / pumpen, ju mer grundvatten går att utvinna. Den genomsnittliga tjockleken av jordlagren på Koster är bara 1,1 m (jordtäckta områden på hela ön!). Om grundvattennivåer sjunker

pga. den naturliga avrinningen och avdunstningen, blir marginalen för sänkningen av grundvattennivån genom pumpning mycket begränsad.

6. Vi har sett att grundvattennivåerna i de flesta grävda brunnar inte hade återhämtat sig mycket till oktober 2016. Detta beror på att augusti samt oktober 2016 var torra och utan grundvattenbildning. Det visar också att underskottet från sommaren inte ersätts av horisontellt återflöde från en större reservoar. En torr vinter och vårsäsong 2016/2017 skulle skapa en mycket besvärlig situation under sommaren 2017.

7. I allmänhet varierar villkoren för vattenuttag mycket över ön på grund av heterogen geologi och på grund av det faktum att utvinningen av grundvatten sker koncentrerat i mindre områden på öarna. Lokalt kommer några enskilda brunnsägare alltid att ha begränsad tillgång till vatten. Genom enkäten vi genomförde och många personliga meddelanden/samtal kan slutsatsen dras att en stor andel av brunnsägarna har eller någon gång haft problem med vattentillgång. Många boende måste använda vattnet sparsamt under sommarmånaderna för att det skall räcka.

8. Vi bedömer det möjligt, att i de flesta områden på Koster installera ytterligare borrade brunnar för mindre uttag av grundvatten då grundvattenuttag från enskilda brunnar endast påverkar lokalt. Detta gäller även för grävda brunnar, förutsatt att anläggning och placering av brunnen sker på ett korrekt sätt.

9. I de mest tätbefolkade områdena på ön är det osannolikt att många fler brunnar kan borras. Anläggning av grävda brunnar bör ske med stor försiktighet för att undvika infiltration av vatten av dålig kvalitet.

Sammanfattningsvis kan vi dra slutsatsen att, under ett normalt år med avseende på väder, kommer mängden grundvatten på Koster vara tillräckligt för de allra flesta permanenta boende samt tillfälliga besökare om antalet personer och deras vattenanvändning inte förändras nämnvärt. I ett scenario med två eller flera varma och torra år i rad och/eller en betydande ökning av vattenförbrukning, är det mycket troligt att vattenbrist kommer att påverka en större andel invånare, i synnerhet de med grävda brunnar. Med de undersökningar som genomförts under 2016 är det inte möjligt att ge ett klart svar på frågan om grundvattenanvändningen på Koster i dess nuvarande läge är hållbar och miljömässigt ofarlig (avseende t.ex. saltvatteninträngning). Utökade modellberäkningar är nödvändiga för att kunna besvara denna fråga.

Vi vill tydliggöra att det grundläggande problemet med grundvattentillgångar på Koster inte är den genomsnittliga, generella grundvattenmängden som finns på ön, utan dess olika fördelning i rum och tid samt risken att extrema väderförhållanden kan framkalla allvarliga bristsituationer. Situationen i sydöstra Sverige, främst Öland är tydligt exempel på den typ av bristsituation som kan komma uppstå.

1.2.3 Resultat grundvattenkvalitet

1. Från utförda mätningar bedömdes den kemiska sammansättningen av det naturliga grundvattnet på Koster vara bra men med flera undantag. Ett antal grävda brunnar har vatten som luktar, är gulaktigt till färgen och/eller har en oangenäm smak. Det innebär ingen hälsorisk i sig men tyder på risk för andra föroreningar (ytvatteninflöde). Både grävda och borrade brunnar har visat förhöjda värden för främst salthalt, natrium, calcium, järn och mangan. I några fall har resultat från laboratorier även visat på nämnvärda halter av t.ex. uran och andra tungmetaller.

2. Den ökade vattenanvändningen under högsäsong gav generellt inte upphov till en markant försämring av vattenkvaliteten. Endast i ett fåtal brunnar (5 %) ökade salthalten avsevärt. Men koncentrationen av andra kemiska parameter ökar också under sommaren. Det är troligen pga. en utspädning med färsk grundvattenbildning (regnvatten) som sker under vinterhalvåret. På sommaren sker då en höjning av koncentrationer pga utebliven grundvattenbildning. Höjning av salthalt på sommaren är därför inte nödvändigtvis en indikation för saltvatteninträngning.

3. Någon generell vertikal förflyttning uppåt av gränsskiktet mellan salt- och sötvatten, vilket kunde indikerat på saltvatteninträngning kan inte styrkas, däremot har denna förflyttning observerats i ett flertal av de borrade brunnarna. Utan information om var gränsskiktet var beläget för 10 eller 50 år sedan, är det svårt att dra några större slutsatser utifrån detta. Skulle det gå att påvisa att gränsskiktet har varit beläget betydligt djupare för 50 år sedan, hade det varit ett tecken att gränsskiktet position påverkats av grundvattenuttaget. Tillgänglig information ger inga indikationer på att så är fallet.

4. Sammanställningen av kemisk data från tidigare årtionden indikerar på en svag försaltning av grundvattnet men trenden är mycket otydlig. Ytterligare undersökningar, främst utvärdering av alla kemiska undersökningar av privata brunnar sedan 70-talet, är nödvändig för att säkerställa detta[1].

5. Genom att kombinera data från denna undersökning med kemisk data från tidigare år kan man dra slutsatsen att en stor andel av brunnsägare haft eller har problem med lukt, smak och färg. Många vattenprover som skickats till laboratorium för analys har erhållit bedömningen "tjänligt med anmärkning" med avseende på järn, mangan, salthalt, färg, smak och/eller lukt. Dessa bedömningar är oftast inte en anledning till oro och kan oftast åtgärdas genom vattenrening hos konsument.

6. Utifrån prover vi tagit i 11 utvalda brunnar på Koster är grundvattnet inte kontaminerade av organiska föroreningar, som vanligtvis förekommer där hanteringen av bränsle, lösningsmedel, färg och träskyddsmedel förekommer. Brunnarna valdes utifrån

[1] Vi har inskannat 874 analysresultat från över 30 pärmar från miljöavdelningen, Strömstads kommun, men har bara digitaliserad värden till några få utvalda parametrar. Digitalisering kan inte anses som forskningsarbete som studenter ska utföra utan betalning.

information om potentiella föroreningar mottaget från Strömstads kommuns miljöavdelning. Dessa 11 plaster är dock inte nödvändigtvis representativa för hela ön. Trots att jordbruk, industrier och hantverksaktivitet inte förekommer eller förekommit i någon större skala på öarna, kvarstår vissa misstänkta fakta. I en brunn upptäcktes det höga koncentrationer av perfluorerade ämnen. Vattnet från den brunnen används inte som dricksvatten. Miljöavdelningen på Strömstads kommun utreder situationen.

Sammanfattningsvis dras slutsatsen att, under ett normalt år är den naturliga grundvattenkvaliteten på Koster tillräckligt god för de allra flesta permanenta och tillfälliga gäster på Koster om antalet personer och deras vattenanvändning inte förändras avsevärt. Det finns ett tydligt samband mellan torka och sämre vattenkvalitet. Vid uteblivet regn som infiltrerar marken, ökar koncentrationerna av de flesta kemiska parametrarna avsevärd. Även mikrobiologiska problem är mycket mer sannolik under varma, torra perioder. I ett scenario med två eller flera varma och torra år i rad och/eller en betydande ökning av efterfrågan på vatten, kan det inte uteslutas, och är även troligt att ett större antal människor kommer påverkas av försämrad grundvattenkvalitet. Ett stort antal brunnsägare har rapporterat om antingen tillfälliga eller permanenta problem med färg, smak och lukt på vattnet. Vissa har vatten som är alltför salt eller överstiger andra gränsvärden för dricksvatten. Om detta är acceptabelt för brunnsägaren verkar vara en fråga om personlig smak och anpassning. Värden (och bestämmelser) kan ändras i framtiden. Ansvaret för detta ligga hos Livsmedelsverket. Vi rekommendera att kolla med dem om det finns planer för hårdare regler kring vattenkvalitén i privata brunnar.

Vi vill tydliggöra att problemet med grundvattenkvaliteten på Koster inte är den genomsnittliga, generella grundvattenkvaliteten på ön, utan de lokala förhållandena. En väldig liten, lokal mineralisering i en spricka kopplat till en gång kan leda till, t.ex. höga koncentrationer av tungmetaller som inte finns i en brunn 10m bort.

1.2.4 Generella observationer och upptäckter

1. Ett stort antal brunnar är i ett skick som indikerar att de inte blivit väl underhållna de senaste åren. Många saknar skydd mot infiltration av ytvatten och vissa har inte placerats på ett sätt som exkluderar möjligheten för hushållsavfall eller djuravfall att kontaminera vattnet (vi har inte kollat om respektive föroreningskällor existerar). Det ligger utanför vårt expertisområde och utanför omfattningen av vår undersökning att kvantifiera detta problem. Vi rekommendera att alla brunnsägare tar del av informationen som erbjuds av livsmedelsverket och SGU, t.ex. broschyren: ”*Sköt om din brunn*” på http://www.livsmedelsverket.se/globalassets/matvanor-halsa-miljo/egen-brunn/rad-om-egen-brunn/broschyr-skot-om-din-brunn-20-sid-a4-final.pdf

2. Generellt sett verkar inte invånarna på Koster, både när det gäller permanent bosatta och säsongsbesökarna, vara speciellt intresserade av sin dricksvattenkvalitet bortsett från smak, färg och lukt. Endast några få skickar sitt vatten på analys vart tredje år, vilket är rekommendationen från Livsmedelsverket. Inte ens de som fått ”tjänligt med

anmärkning" som mikrobiologisk eller kemisk bedömning från labbanalyser vidtar åtgärder eller skickar sitt vatten på analys oftare. Om vattenkvalitetsdata från pärmarna som vi fick från Strömstad kommun och våra övriga källor anses kompletta, saknar ungefär 500[2] brunnar aktuell bedömning av vattenkvalitet.

3. I vår enkät svarade 50 % att de aldrig har upplevt problem med vattenkvalitet och 70 % har aldrig haft problem med vattenkvantitet från deras privata brunnar. Kombinerat har 35 % aldrig haft problem med varken kvalitet eller kvantitet. I de flesta fall var de problem som fanns mindre och kortvariga (lukt, smak, färg, tillfällig vattenbrist).

1.2.5 Övergripande sammanfattning av resultat

Grundvatten har under många decennier varit öbornas dricksvattenresurs, vilket överlag har fungerat bra för många utav invånarna på Koster. Kosterborna är vana med viss vattenbrist under torra somrar och anpassar sin förbrukning därefter. Detta scenario kommer fortsätta råda förutsatt att varken klimatet förändras eller att vattenförbrukningen ökar drastiskt. Vara undersökningar visar dock att viss del av befolkningen inte har tillräckligt vatten med bra kvalitet. Om detta är acceptabelt eller inte beror på a) egna krav och tolerans, b) Livsmedelverkets syn på enskild vattenförsörjning i framtiden. Givet att klimatet förändras och vattenförbrukningen ökar samt att regler och standarder för hantering av dricks- och spillvatten har förändrats och kommer fortsätta förändras, kvarstår flera problem:

Ett problem är att många privata brunnar på Koster är grävda brunnar (ca 70 % enligt enkätundersökningen vi gjorde), vilka är sårbara mot både föroreningar[3] och långvarig vattenbrist. Mot föroreningar på grund av att de är grunda och oftast inte täckta av ett lager med filtrerande eller skyddande egenskaper. Mot vattenbrist på grund av att de grävda brunnarnas grundvattenmagasin ofta är tunna och därför inte kan förvara vatten under längre torrperioder. Extra problematiskt skulle det bli en torr och varm sommar efter en höst/vinter/vår med låg grundvattenbildning (se Öland 2016 som exempel). En möjlig lösning på problemet med grävda brunnar skulle kunna vara att ersätta dem med borrade brunnar. Det fungerar dock inte i alla fall eftersom lagringskapaciteten i berg oftast är låg och grundvattnet blir salt i genomsnitt 50 meter under havsnivån, som ett medelvärde.

Ett annat problem är att ett framtida scenario utan ett tydligt förändrat klimat inte är troligt. Ett "normalt år" definieras som medelvärden från perioden 1961-1990 av SMHI. Statistik visar dock att nästan alla år sedan år 2000 har varit varmare, vissa betydligt varmare, än referensvärdena från ett "normalår". Simuleringar av framtida klimat förutser även mer nederbörd i västra Sverige. Den kombinerade effekten av ökad temperatur och ökad nederbörd

[2] Baserat på uppskattningen att det totalt finns 800-1000 brunnar på Koster
[3] http://www.livsmedelsverket.se/matvanor-halsa--miljo/egen-brunn/dricksvattenkvalitet---egen-brunn/:
"En sammanställning över dricksvattenkvalitet från enskilda brunnar som Socialstyrelsen gjorde 2007 visade att nästan 35 procent av de grävda brunnar hade dricksvatten som inte var hälsosamt att dricka (otjänligt). Motsvarande andel av de bergborrade brunnarna var 10 procent .
Livsmedelsverket rekommenderar att man regelbundet provtar sitt vatten för att vara säker på att vattnet inte är ohälsosamt.

och deras årstidsfördelning är svårbedömd och inte fullständigt förstådd. Extrema väderförhållanden kommer att kraftigt påverka de små och tunna grundvattenmagasinen på Koster. Det finns indikationer på att extrema väderförhållanden kommer att pågå längre och vara mer frekvent förekommande i framtiden. Vår undersökning inkluderar inte en detaljerad analys av framtida klimatförändringsscenarier, så dessa överväganden är preliminära.

Ett ytterligare problem som kommer att kvarstå om vattenförsörjningen bygger på enskilda privata brunnar är det att kvaliteten och tillgången på vatten för varje individ beror på de lokala förhållandena för just den brunnen. På grund av den heterogena geologin på öarna innebär detta att vissa har god tillgång på vatten och/eller hög kvalitet medan andra måste hantera låg kvalitet och/eller vattenbrist under högsäsong. Det är bortom syftet med denna undersökning att spekulera i vad en acceptabel kvalitet eller en tillräcklig kapacitet kommer att vara om 10, 20 eller 50 år. Erfarenhet visar att medvetenheten och försiktigheten är högre hos yngre generationer än hos äldre. Det finns också indikationer på att lagstiftningen gällande enskilda brunnar kommer att skärpas.

Baserat på den generella vattentillgången på Koster och den ojämna fördelningen av grundvattenreseurser och utan att ta hänsyn till de tekniska förutsättningarna och kostnaderna, tror vi att mindre, lokala nätverk är möjliga (5-10 hushåll). Vi tror att det kan finnas platser med möjlighet att utvinna grundvatten som försörjer ett större antal hushåll. Dessa platser karakteriseras av stora jordtjocklekar kombinerat med stor grundvattenbildning. Vi rekommenderar också att undersöka möjligheten för konstgjord infiltration. Vi är övertygade om att bergborrade brunnar inte är en tillförlitlig, hållbar källa till dricksvatten för större folkmängder.

1.3 Rekommendationer

Om beslut fattas att fortsätta med en dricksvattenförsörjning som delvis eller helt baseras på enskilda, privata brunnar på Koster, är våra rekommendationer följande:

1. Att skapa en komplett förteckning över brunnar på Koster, både sådana som används och inte, samt att få en tydlig uppfattning om hur mycket vatten som behövs och som används i varje enskild brunn.
2. Att vatten från brunnar som inte analyserats inom de senaste två åren skickas på både kemisk och mikrobiologisk analys. I framtiden bör dessa analyser göras vart tredje år, i enlighet med Livsmedelsverkets rekommendationer. Vi vill upplysa om att mikrobiologiska problem kan uppstå vid bristande underhåll av tekniska delar, som pumpar, ledningar, filter etc. Den naturliga grundvattenkvaliteten kan också ändras med tid (salthalt). Grävda brunnar kan samla in allt som finns i den närliggande jorden och på markytan och den naturliga filtreringskapaciteten kan försämras med tiden.
3. Att alla privata brunnar genomgår en inspektion med avseende på:

a. Position i förhållande till spillvatten och andra potentiella källor för mikrobiologisk förorening
b. Övervakning av salthalt varje år, mest lämpligt i augusti
c. Teknisk och hygienisk lämplighet av installationen
d. Uppskatta sårbarhet för vattenbrist

I samband med tredje rekommendationen vill vi uppmärksamma om följande informationskällor som alla brunnsägare som använder dricksvatten från privata brunnar borde ta del av:

- http://www.livsmedelsverket.se/matvanor-halsa--miljo/egen-brunn/rad-om-egen-brunn/
- http://www.sgu.se/grundvatten/brunnar-och-dricksvatten/enskild-vattenforsorjning/
- http://www.sgu.se/grundvatten/brunnar-och-dricksvatten/provta-vattnet-i-din-brunn/
- http://www.sgu.se/grundvatten/brunnar-och-dricksvatten/dricksvattenforsorjning-i-kustnara-omraden/

Med tanke på den korta övervakningsperioden och delvis oklara resultaten av de mätningar som utförs hittills, rekommenderar vi att detta projekt fortlöper med:

1. Minst en till provtagnings- och mätningsomgång under vintern 2016/2017 i syfte att ha en mätserie från ett helt hydrologiskt år. Detta är extra viktigt i områden där vi observerat en försämring av vattenkvaliteten och där grundvattennivån inte återhämtats efter sommaren. I dessa områden skulle det vara bra att se om vattenkvaliteten och grundvattennivån återhämtar sig och återgår till det normala eller om den fortsätter försämras.

2. Att använda observationer och data från 2016 för att simulera scenarier och utvärdera grundvattensystemets känslighet och sårbarhet på Koster och att utföra en detaljerad konsekvensanalys för klimatförändring med fokus på extrema väderförhållanden, som inkluderar havsnivåförändringar. Vid en situation som den på Koster, där små marginaler kan råder, blir det missvisande att använda medelvärden för klimatvariabler. Kritiska situationer kommer uppstå vid kombination av extrema väderförhållanden och maximal vattenförbrukning.

3. Att komplettera mätningarna som gjorts hittills med geofysiska mätningar för att lokalisera potentiella grundvattenbärande zoner och för att undersöka statusen på saltvatteninträngning. Här kan även existerande brunnar väljas ut för en detaljerad analys av deras placering och deras potential för hydrogeologisk optimering.

4. Att fullborda datauppsättningen och utföra en betydligt mer noggrann analys än den som var möjlig att utföra under den korta tiden för detta projekt.

5. Konstgjort grundvatten genom en eller flera infiltrationsanläggningar kan vara ett alternativ och borde utredas. På vissa platser är sedimenttjockleken och infiltrationskapaciteten tillräcklig stora. Geofysikaliska mätningar kan vara ett bra sett att undersöka ett större antal potentiellt lämpliga områden.

Vi vill också påpeka att Kosteröarna tillhandahåller mycket bra förutsättningar för att undersöka ett hållbart användande av grundvatten i kustnära områden i Sverige. Det skulle vara bra om Koster kunde fortsätta vara en fallstudie i ett större projekt som behandlar kustnära grundvatten och enskilda brunnar i Sverige. Mastersstudenterna arbetar vidare med data från Koster fram tills juni 2017. Vi rekommenderar att ta till vara på denna möjlighet att utföra mätningar som annars skulle varit dyra. Vi på Göteborgs Universitet har mycket bra förutsättning att göra sådana undersökningar genom att kopplar forskningen med utbildning av framtida hydrogeologer.

1.4 Avslutande anmärkningar

Svaret på frågan om vattenförsörjningen på Kosteröarna kan utgöras av enbart grundvatten från privata- eller kommunala brunnar i framtiden och om en sådan vattenförsörjning kommer vara hållbart ur ett miljöperspektiv, kan tyvärr endast bli: ”Det beror på”.

Det beror på faktorer som:

- Vilken nivå av försörjningssäkerhet och -kvalitet vill öborna ha? Är det acceptabelt att till och från ha situationer liknande den på Öland sommaren 2016? Är det acceptabelt om vattnet är gulaktigt i perioder?
- Bör det finnas utrymme för ytterligare utveckling i de områden där befolkningsdensiteten är som högst?
- Är det acceptabelt att vissa har god tillgång till vatten av hög kvalitet och andra inte?

Färskt grundvatten på en ö är en strikt begränsad resurs. Detta innebär risk för tillfällig vattenbrist samt risk att förstöra resursen för en lång tid genom saltvatteninträngning. Vatten från grävda brunnar i grunda magasin överlagrade av organisk jord kan vara mer benägna att ha färg, smak, lukt och eventuell oönskad infiltration av ytvatten än borrade brunnar. Grävda brunnar är också mer benägna att gå torra under längre torrperioder än borrade. Djupt borrade brunnar kan, om uttaget är stort, ta in saltvatten och till följd få förhöjda halter av tungmetaller.

I genomsnitt finns det tillräckligt med vatten av god kvalitet på Koster, sett till en ettårs period. Det är dock inte genomsnittet för ett år som är problematiskt ur en vattenkvalitets och kvantitets perspektiv, utan det är snarare säsongsvariationer, lokala variationer och extremvärden. Genomsnittliga värden är alltså svåra att använda i en kvalitets- och kvantitetsanalys av vattnet på Koster och därför behövs detaljerade undersökningar.

En fortsatt vattenförsörjning baserad på grundvatten på Koster ser vi som fullt möjlig (eventuellt kompletterad med ytvatten, regnvatten och avsaltat havsvatten). I ett sådant fall krävs det dock förändringar. Någon borde kontrollera och ta ansvar för att grundvattenutvinning sker på ett hållbart och säkert sätt, överallt.

2 Introduction

Based on previous communication with Jerry Johansson, Strömstads kommun and Christian Pleijel, process coordinator of "*Kostervatten*[4]", the Hydrogeology research group of the department of Earth Science, University of Gothenburg presented a research proposal for an investigation of groundwater quantity and quality on the Koster islands in in February 2016, which was finally accepted by "*Strömstads kommun, Tekniska Förvaltningen, på uppdrag av styrgruppen för project: Alternativ lösning på VA-system för Koster*". The project proposal is attached as an Appendix.

The project *Kostervatten* addresses a future solution for drinking and wastewater on the Koster Islands, i.e. if there is an alternative to the construction of a municipal fresh- and wastewater pipeline from the mainland. As of today, most households on the Koster Islands have private wells for drinking water supply and many apply pit drainage for their wastewater. Only a smaller number of households on South Koster is connected to a local waterworks. In the past, local shortage in water supply due to increased water demand during the summer months occurred occasionally according to anecdotal evidence.

The University of Gothenburg is part of the consortium and works on the following tasks within the *Kostervatten* project:

1. To determine the actual status of groundwater quantity and quality on Koster based on existing data from previous studies and own measurements
2. To make a prognosis of how the availability and quality of groundwater on Koster will develop under different scenarios (different modes of groundwater usage)

2.1 Remarks

Please note that this report is not the result of consulting work according to a specific contract but an intermediate summary of a research project, mainly carried out in form of Bachelor's and Master's Thesis carried out at the University of Gothenburg, Department of Earth Sciences.

2.2 Problem description: Groundwater in coastal areas and islands

The use of groundwater as drinking water in coastal areas and in particular on islands is constraint by the proximity of salty groundwater below the sea bottom, which also extends under land. On islands the availability of fresh groundwater is thus strictly limited. If the extraction of fresh groundwater exceeds the amount of groundwater which is renewed by natural groundwater recharge, the fresh groundwater will be eventually replaced by salty groundwater. This process is called saltwater intrusion.

Saltwater intrusion into freshwater aquifers forms a major threat to drinking water resources in many coastal areas worldwide. Climate change, which can result in changes in groundwater recharge and sea level rise will most likely intensify the problem. In Sweden coastal aquifers

[4] *Alternativ lösning på VA-system för Koster* (http://kostervatten.com)

are usually not used for public (municipal) drinking water supply. Therefore, the problem affects mainly private wells and small-scale water supply systems. In coastal areas, in particular on islands, with a high density of permanent housings and summer houses, groundwater systems can be under stress in the summer month – a period where no natural groundwater recharge takes place but extraction rates are high. This can lead to saltwater intrusion and to economic and ecological damages.

In addition to the salinization problem, groundwater problems, in particular on small islands may result from the limited area available for groundwater recharge and the shallowness of the aquifers (groundwater storing formations). The following sections describe the individual problems:

2.2.1 Saltwater intrusion

Groundwater in coastal areas is characterized by a very specific situation: groundwater below the sea floor typically has salinity similar to sea water. This salty groundwater extends also across the shoreline under the terrestrial system. On land, fresh rain water can infiltrate into the ground and form a stable layer of fresh groundwater that floats on the saltwater due to its lower density. This phenomenon makes it possible that fresh groundwater can be pumped and used even on small islands or very close to the shore line. However, the freshwater layer is sensitive to changes of the pressure in the groundwater system (e.g. because of changes in groundwater recharge or pumping from groundwater) and to sea level change. According to the Ghyben-Herzberg relation (see also Figure 1), a rise of the sea level or a drop of the groundwater level will cause the interface between salt and freshwater to move upwards and landwards, i.e. at locations which previously had fresh groundwater the water will become salty. Less than 1% of saltwater (~250 mg/l Cl-) will thereby result in groundwater that cannot longer be used as drinking water. While natural changes (climate change, sea level rise) occur quite gradually, over-pumping can locally lead to a very fast salinization of fresh water aquifers. To reverse this situation, i.e. to remove the salt from an aquifer by natural recharge, is almost impossible within human timeframes.

High salinity can also lead to secondary problems with water quality, for example increased concentrations of heavy metals. Little is known about this so far.

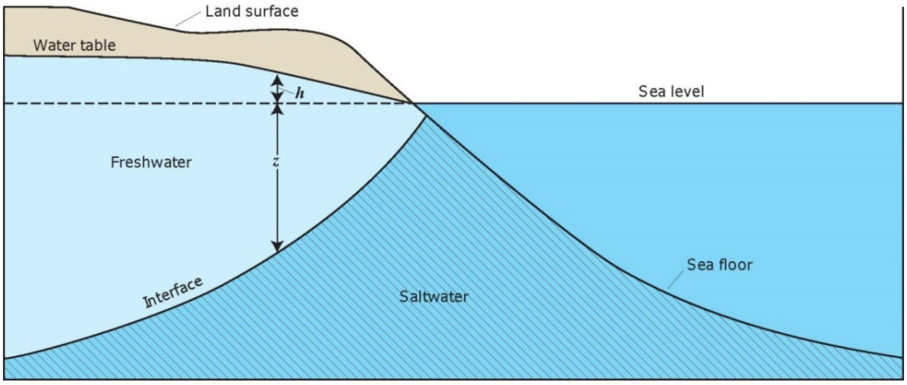

Figure 1: Schematic visualization of the salt–freshwater interface according to Ghyben-Herzberg. $z = h * \rho_w/(\rho_s - \rho_w)$, *where z is the thickness of the freshwater lens,* ρ_w *is the density of fresh water,* ρ_s *is the density of saltwater, and h is the position of the water table above sea level.*

From the previous section, it is clear that the availability of fresh groundwater will change if

a) the water extraction increases,
b) the sea level rises or
c) the natural groundwater recharge decreases.

Sea-level rise and changes of groundwater recharge will most likely occur as a result of climate change, changes of water demand can be the results of changes in water use and demographic changes. To be sustainable, that is if the fresh groundwater should be available for future generations and for the environment, groundwater extraction has to be adjusted to the natural climatic conditions such that saltwater intrusion cannot occur. Groundwater extraction must under no circumstances exceed natural groundwater recharge.

One of the big problems associated with saltwater intrusion and availability of fresh groundwater in general, is that problems can go unnoticed for a long time, but when they are there, it is impossible, or takes very long to reverse the situation. As with any resource, if you use more than is replaced, the resource will eventually disappear. That can take 1 year, 10 or 100 years. For a long time, the situation may seem to be good, but once it turns from good to bad, it will impossible to reverse the trend quickly. Therefore, groundwater use in coastal areas, and on islands particular has to be performed very cautiously. It is thereby important to point out that saltwater intrusion can be progressing in greater depth.

The particular problem on Koster is, that hardly any information exists that could tell us in which direction the system develops: We don’t know if the interface between freshwater and saltwater on the island was much deeper several centuries ago, or if the human development has not changed the freshwater availability at all. To find this out a long term monitoring over 10 or more years would be necessary. The challenge of our investigations is to try to replace the long term monitoring with measurements carried out within several months.

2.2.1 Groundwater quality in regions dominated by crystalline rocks

As shown in the previous section, the groundwater quality on islands is strongly influence by the surrounding and underlying saltwater. This has consequences for the salinity of the water and concentrations of typical elements/ionic associated with seawater. The interaction of seawater with crystalline bedrock may also result in solubility and in general reactions between groundwater and minerals, but little is known about this.

Other than that, there are some typical groundwater quality problems associated with groundwater from Swedish crystalline bedrock. The most prominent problems are high concentrations of metals in groundwater, for example iron, manganese, lead, uranium, cadmium, zinc, nickel. Iron and manganese are very common in Sweden. Heavy metals occur often randomly as their presence is the result of very local conditions in the bedrock, e.g. specific fracture mineralisation or consequences of weathering. In many parts of Sweden, Radon (radioactive gas) is present in groundwater. The Radon is coupled to the occurrence of Uranium in the bedrock. Uranium is poisonous as such and also emits gamma-radiation (Barregård and Maxe, 2012; Ek et al., 2008; Gustafson, 2010; SGU, 2013).

2.2.2 Groundwater quality in shallow quaternary deposits

Problems with groundwater from shallow quaternary deposits are very often the short distance to the land surface which carries the risk of fast infiltration of (contaminated) surface water and in particular waste water and animal waste. Other problems, in particular common in very shallow wells, are the influence of humic substances from top soil, that lead to changes in colour, taste and smell. Humic substances are not believed to be harmful to human health. At higher concentrations, humic substances can impart a characteristic yellowish to brownish colour in water, and can cause drinking water to have a bitter taste or unpleasant odour. However, humic substances can be an indicator of contamination with other substances, because they indicated short cuts between land surface / surface water and groundwater and thus potential entry path for contamination.

2.2.3 Groundwater availability on an islands

The general problem of water availability on an island can be described as follows:

Natural freshwater availability, (not taking into account desalination of sea water or imported water), is generally determined by the amount of natural precipitation. On smaller islands, there are usually no larger lakes, rivers or streams that could be used for water supply. Therefore, the only ways to use precipitation for water supply are rain water harvesting (storage tanks or artificial infiltration) and groundwater usage. Today natural groundwater is the resource that is almost exclusively used on Koster for drinking water supply together with sea water desalination in the municipal water works and occasional rain water harvesting. Here we focus on natural groundwater only:

Groundwater availability is limited by three main factors:

- groundwater recharge,
- groundwater storage capacity of natural aquifers and the
- permeability[5] of these natural aquifers.

Groundwater storage capacity: Groundwater can be stored in geological formations that have sufficient porosity. Gravel, sand, silt and clay have high porosity and can store large amounts of water. Bedrock has a very low porosity only due to fractures, and thus a very low storage capacity.

Permeability: To be able to extract the groundwater from the storage, the aquifers have to have a high permeability. Gravel and sand have high permeability, silt and clay a low one. The permeability of bedrock is highly variable, but usually very low. That means that larger amounts of water per unit time can be extracted from gravel and sand but not clay and silt. From bedrock, in some cases high extraction rates are possible, but usually not. Very often very deep wells have to be drilled, which, on an island, includes the risk to find saltwater, not freshwater.

Groundwater recharge is the amount of water that enters the groundwater (coming from precipitation mainly in humid climates). Without groundwater recharge, extraction of groundwater from an aquifer leads to depletion of an aquifer – eventually the aquifer will be empty. A general rule says that extraction must in no case be larger than recharge. In fact, extraction must be much smaller than recharge as "ecological water demands" (plants, groundwater dependent ecosystems, surface water discharge) have also to be taken into account.

Groundwater recharge is much less than precipitation: A large part of precipitation is lost back into the atmosphere through evaporation and transpiration of plants. Another part of precipitation falling on the ground cannot infiltrate in the soil, for example if the soil is already filled with water or if the surface is impermeable (bedrock and sealed surfaces). This part will flow of as surface runoff and eventually flow into the sea. Therefore, in a simplified way, we can say that groundwater recharge is:

Precipitation (P) minus Evapotranspiration (ET) minus Surface runoff (S_R).

This equation can only be applied for long time periods (>10 years) as it does not include changes in storage (soil moisture, groundwater).

To know the groundwater recharge on the entire island is important, but not immediately helpful to answer the question how much groundwater is available. On Koster, most of the groundwater recharge occurs in areas which are far away from the existing wells. Groundwater can theoretically flow over large horizontal distances, but only if large, continuous aquifers exist. This is not the case on Koster. Here, groundwater system on Koster is separated in very small disconnected units. That means, only the groundwater recharge in the areas where wells are located is available for extraction.

[5] The technical term used in hydrogeology is hydraulic conductivity, K [m/s]

To determine the groundwater available on Koster for water supply is an extremely difficult question because:

- Evapotranspiration is very difficult to measure in general, and on Koster, no measurements exist.
- No surface water runoff and discharge measurements exist on Koster
- The aquifers are small and disconnected.

Water shortage and private (local) wells:

It has to be pointed out that water shortages can be both global, or local, both in time and space. There might be plenty of water available on an island in average, and still there may be times and places where at some places water is short. Water shortage can also be a problem of the type of technical installation and how they are build. We just give a few examples:

- The yield of wells in bedrock is extremely variable. If the borehole crosses a fracture zone, the yield may be high, while only 10m away, outside the fracture zone, the yield is low.
- The thickness of soil formations, and their permeability can vary a lot in space. The soil may be 5m thick in one place, but only 1,5 on the neighbouring property. Or the sediments may be sandier in one location and contain more clay in another. This will have strong influences on water availability.
- The main technical factors determining the yield of a dug well are the well depth, the position of the water table with respect to well depth (saturated thickness) and the well diameter. A well with a diameter of 2 m will yield 4 times more water than a well with 1m diameter. A difference in depth of 50cm can determine if water is short in summer or not.

2.3 Comments on the problem description and the project plan

In the course of the project, in particular after retrieving the results from measurements in July and September, it became apparent that salt water intrusion (see section 2.2.1) may not be the most pressing problem on Koster.

Firstly, our summer/autumn measurements did not show very significant increases of salinity in comparison to the measurements in April. We also didn't see a general trend in the position of the saltwater fresh water interface. Measurements in the winter 2016/2017 would be needed to confirm this, but it seems that the current extraction of groundwater does not lead to a general salinization of water. Exceptions with strongly increasing salinity occurred, however. When looking at long term trends we could not observe any significant trends of increasing salinity either. The database for this is rather weak, and a more targeted analysis may be needed.

Secondly, we did not expect that that many wells were dug wells, which do not reach down to the saltwater interface and don't seem to have a big impact on the water balance of the bedrock aquifer (where the drilled wells are installed). The shallow wells tap local, shallow aquifers with a very small area of influence usually. Withdrawal from these wells can in most cases not invoke sea water intrusion. The problem with those wells are more often other water quality problems, partly because they are installed in geological formations rich in organic matter, which may lead to smell, taste and colour, and partly because those wells may not be well protected against contamination from water or other. We are also concerned that some wells may be in need of maintenance and technical installations should be checked.

Our project plan was therefore too much focused on saltwater intrusion, which we considered to be the most pressing problem. We recommend to, in future investigations, have a stronger focus on the shallow aquifers as well.

2.4 Limitations of the present report

This report does not yet include a systematic spatio-temporal analysis of all obtained results in relation to geology, topography and land-use. This is a large effort and will be the topic of the Master's Thesis projects carried out by Maria Granberg, Sebastian Pokorny and Johanna Merisalu which are expected to be submitted in June 2017.

3 Study area

The Koster-islands are a part of the municipality of Strömstad, and a segment of the larger archipelago of Bohuslän situated along the northern part of the Swedish west coast and close to the Norwegian border. The Koster archipelago is separated from the mainland by the Koster fjord, a 200-250-meter-deep fault zone with N-S orientation (Kim Andersson, 2010).

The year round settled population on Koster are estimated to 320 individuals. Tourism has become a large part of the revenue of the islands and the municipality is voicing its interests in further exploitation. Up to 6000 persons visits the islands each day during the summer months according to Kosters företagarförening (Kosters-företagarförening, 2015).

3.1 Geology

The history of Koster is the result of two orogenic periods, the Gothian and the Sveconorwegian, separated by the Kosterperioden. Three main types of rock are present on Koster (Nyström and Wall, 1993):

- Sedimentary gneiss with layers of amphibolite, veined to severely melted (Stora Le-Marstrand Group)
- Tonalite to granodiorite, gneissic (Långegärde tonalite)
- Granite, augen-bearing with bands of even-grained granite (Vättnet granite)

The Vättnet granite is mainly found at Nordkoster while the Långgärde tonalite is found at Sydkoster. Most common is the Stora Le-Marstrand Group sedimentary gneiss that is found to a large extent on both islands. Another typical feature for the Koster islands is the parallel Koster Diabase dikes which cut through older formations. The orientation of the Koster Diabase dikes is typically N330 (Nyström and Wall, 1993). Other types of granite, gabbro and amphibolite are also present.

Past stress fields and the rock type determines the structural features. There are three distinct differences between the bedrock Koster. The granites have a regular fracture pattern compared to the gneisses which fractures are closely linked to its foliation planes. The foliation planes are hard to generalize because the gneisses have been greatly deformed. Granites are thereby generally more favorable for groundwater extraction. The Koster diabase has much less fractures and therefore functions as vertical embankments between surrounding bedrock. (Nyström and Wall, 1993) This feature could be a limitation for large-scale extraction of groundwater from the bedrock. These are just some of the major differences, in addition there are many more local variations.

The large scale lineaments are most commonly in and around N330. Small scale fractures show a larger variation. Results from previous fracture mapping where all fractures on 11 outcrops on Sydkoster was measured show that N330 is the most common fracture orientation (Johansson, 1990). Mapping on Nordkoster showed that the main fracture orientation varies on the island. The northern parts have a high frequency of fractures similar to the lineament orientation while the southern parts have a higher frequency of EW fractures.

Figure 2 shows a simplified geological map of Koster, Figure 4 a more detailed map of the bedrock.

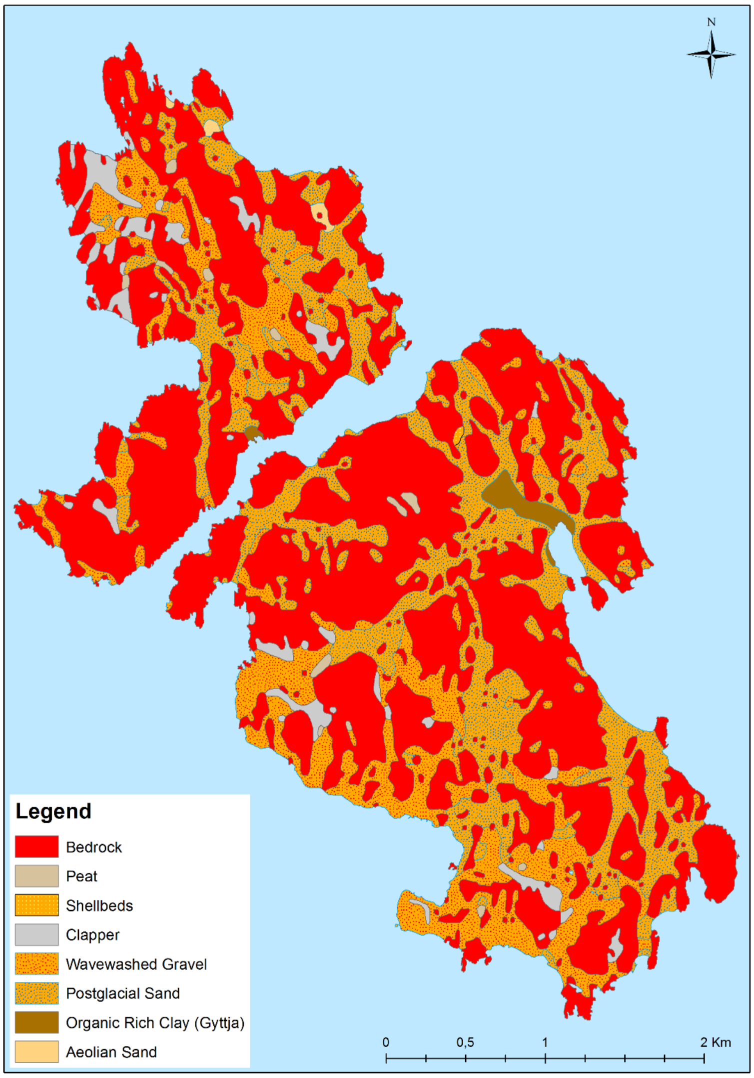

Figure 2: SGU's quaternary deposits map showing the distribution of soil types at or near the soil surface.

3.2 Hydrogeology

Koster's hydrogeology is characterized by small isolated aquifers, both in sediment and in bedrock. In the bedrock, groundwater flow is restricted to fractures and the hydraulic conductivity is dependent on the orientation and width of the fractures. The NW-SE ridges have a large impact on the groundwater flow. These ridges are often filled with rock fragments that contain large volume of water but the hydraulic conductivity in these ridges are low due to a large fraction of fine material. The diabase dykes have few fractures and therefore low hydraulic conductivity resulting in embankment of the flow from surrounding gneisses. The contact zones between the diabase and gneisses do however have high hydraulic conductivity.

The groundwater in bedrock is restricted to the fractures. The groundwater flow is thereby dependent on fractures being connected to make considerable amount groundwater available for extraction. The larger fractures are usually filled with sediments which limits the hydraulic conductivity.

Tension fractures are considered to provide greater amounts of groundwater than shear fractures. The compressive stresses on the Scandinavian crystalline bedrock have mostly been in NS and EW direction. These stresses have resulted in tension fractures with the same orientation. However, the whole area has rotated since formation of the fractures, so those NS tension fracture zones might in fact be N330. The shear fractures are thereby generally in 45 degrees of the tension fractures.

In the quaternary sediments hydraulic conductivity and storage capacity are mainly dependent on the grain size distribution (controlling hydraulic conductivity and specific yield) and the thickness of the sediments (controlling transmissivity). The formations with the highest hydraulic conductivity and specific yield are the postglacial sands and the wave washed gravel formations shown in Figure 2. Larger continuous areas covered by sediments are usually found in lower lying parts of the island.

The groundwater from the different geological formations is usually fresh (EC <1000 µS/cm). However, in drilled wells water becomes salty in a depth of 60-80m, a fact that was both reported by islanders and confirmed by our measurements. Water in the sedimentary formations can be salty in some areas, in particular around Röd.

Figure 3 shows the estimated thickness of unconsolidated quaternarnary materials (“soil”) on Koster (SGU, geodatalagret). The thicknesses shown on the map are thereby not based on measurements but on model calculations (Tore Påsse, SGU, personal communication).

3.3 Climate

The climate on the islands are characterized by mild windy winters and warm sunny summers (see also section 5.3.3). The amount of precipitation is largest in the autumn months closely followed by the summer months. The yearly precipitation is approximately 650 mm[6]. The evapotranspiration is estimated to just about 450 mm and the possible ground water recharge is the remaining 200 mm (Nyström and Wall, 1993).

3.4 Water supply

80 % of the properties on Koster have private wells. On Nordkoster (Kostervatten, 2016) all water supply is based on private wells. On the entire island, about 70% of all wells are shallow dug wells in sediments and 30% are drilled wells in bedrock.

On Sydkoster, the municipal waterworks in Ekenäs supplies 110 out of 367 properties on Sydkoster. This water works uses fresh natural groundwater from a nearby well. In the summer the capacity of this well is often exhausted. In that case the water is mixed with seawater and

[6] We used a value of 726 mm for our groundwater recharge and water balance calculations as this is closer to the average precipitation data of the last 15 years.

desalinized. Major part of treated water comes from seawater, 200 m^3/day of 250 m^3/day in total.

3.5 Waste water

142 out of 198 properties on Nordkoster are connected to the municipally wastewater system and 153 out of 367 on Sydkoster (Kostervatten, 2016).

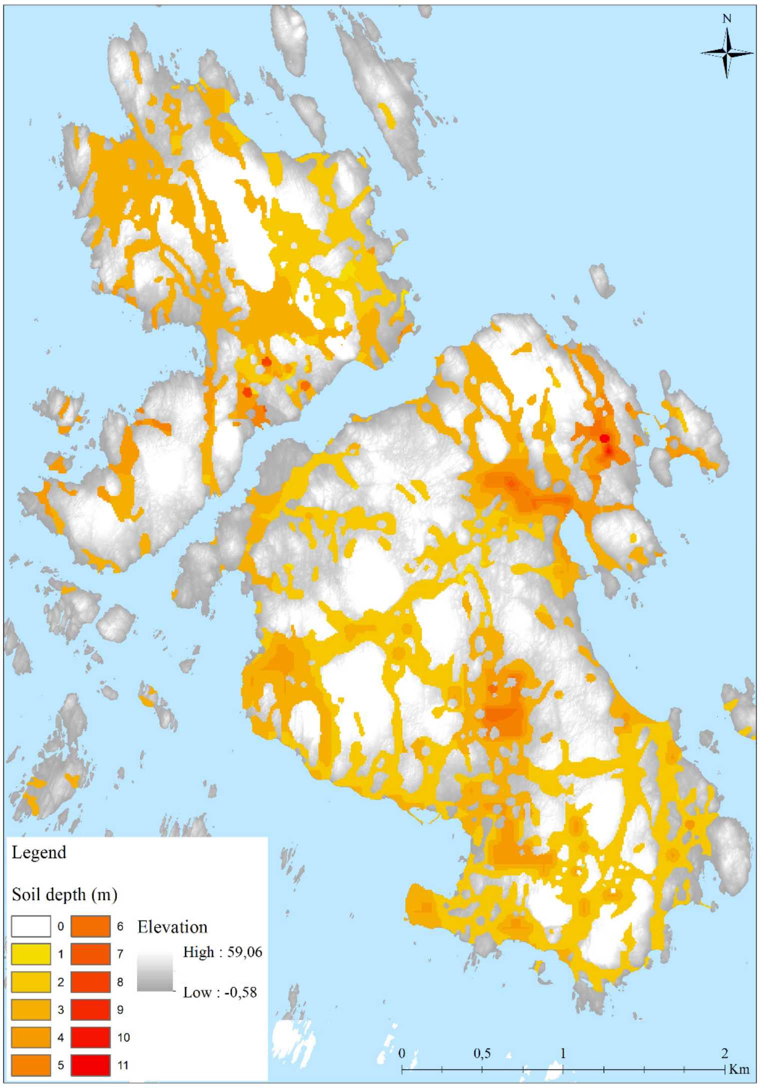

Figure 3: Map of the soil thickness (depth) on Koster, based (source: SGU).

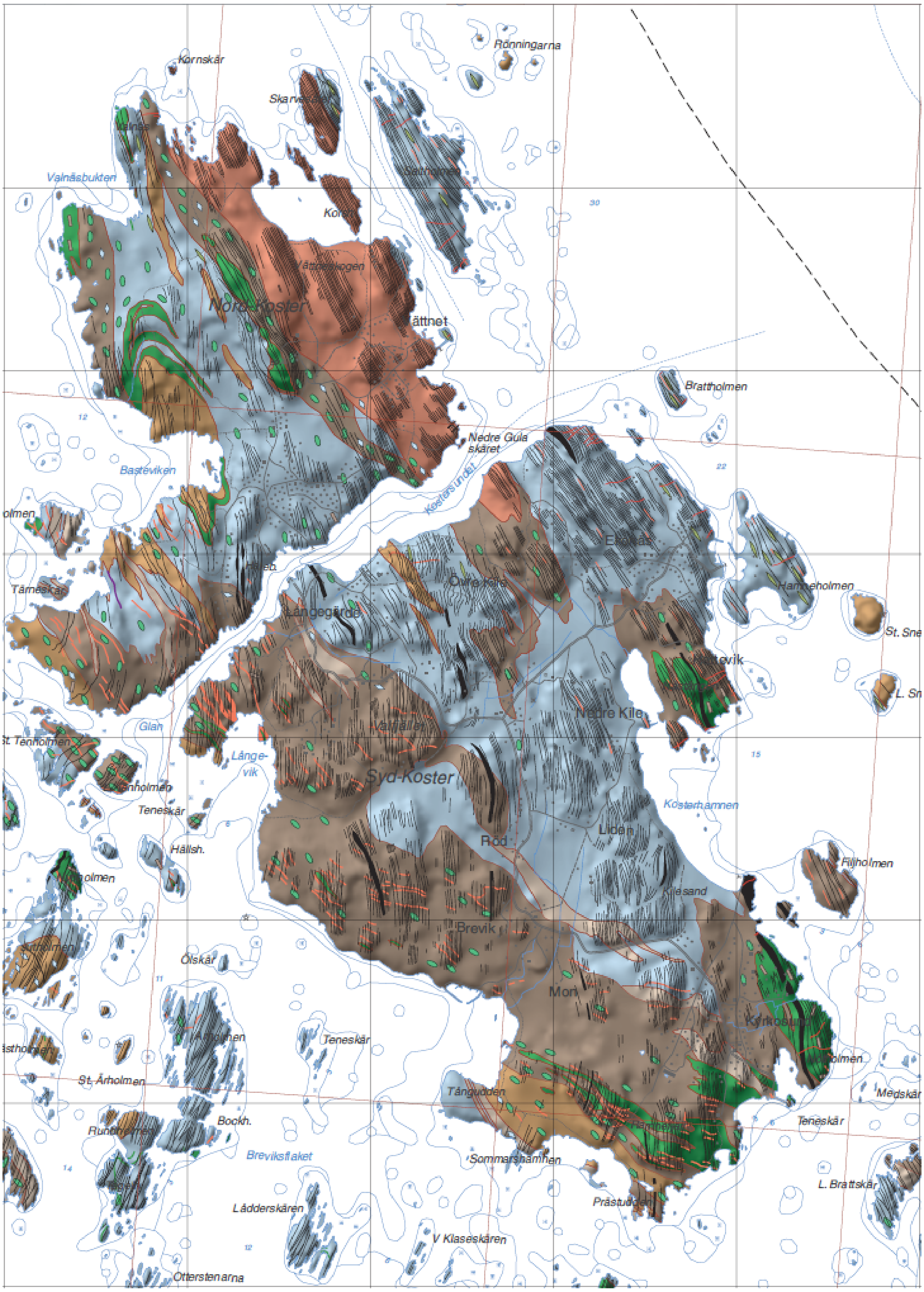

Figure 4: Map of the bedrock on Koster (Eliasson, 2011). For legend see Figure 5.

Figure 5: Legend for the map of the bedrock on Koster shown in Figure 4.

4 Methods and Data

This section describes the data sources used and the methods applied in this investigation.

4.1 Data

Most of the data used in this investigations were generated through own measurements described in the section “Methods”. Other sources of data and information were:

- Chemical water analysis carried out by accredited laboratories collected by Strömstad municipality from private wells, the public water works and several larger facilities.
- Reports from SGU (Sveriges Geologiska Undersökningar), consultants and other sources (listed in Appendix: Literature)
- Weather data and sea level data from SHMI
- Data from SGUs well archive (brunnsarkivet)
- Inventory of potentially contaminated areas on Koster provided by Strömstad municipality
- GIS-data, digital data sets and maps provided by Sveriges Lantbruksuniversitet (SLU).
- Property data (fastighetskartan), property owner addresses and data on public water supply

4.2 Methods

The methods section of this document is divided into four sections:

1. Field measurements and sampling
2. Laboratory analysis
3. Analysis of external data and finally
4. Calculations and analysis based on a synthesis of 1.-3.

The theoretical background and the motivation for applying the individual methods is not described in this report.

4.2.1 Field Measurements and sampling

4.2.1.1 Selection of wells and locations for field measurements and sampling.

From the estimated 600-1000 wells on the island, 207 were included in different field measurement and sampling activities. The criteria for the choice of wells were as follows:

1. To achieve an even geographical distribution we tried to include wells from all parts of the island also representing the spatial density of wells in particular areas.
2. Accessibility of the wells: In many cases it was necessary that well-owners were present during the measurements. In all cases we asked for permission to carry out

measurements. This required that contact details of well-owners were know and in many cases that well owners were present on the island. Many property units could not be contacted or did not respond to our attempts to contact them.

3. Technical prerequisites: Some of our instruments would not fit in drilled wells where a hose/pump is installed and few wells could not be opened.

Finally, when planning the investigation, we had underestimated the difficulties to get around on the island and the time to get from one measurement point to the next. This alone made a reduction of measurement points necessary.

4.2.1.2 Groundwater levels and physico-chemical in situ parameters

Physio-chemical in situ parameters (temperature, pH, electrical conductivity (EC), dissolved oxygen and redox potential) were measured in dug wells (Figure 6) in April, July/August and September 2016 with a multi-parameter water quality meter (*HANNA Instruments, Model HI9829*).

No in in situ physico-chemical measurements were made in drilled wells because the instrument would usually not fit into the boreholes where a hose/pump is installed and measurements in tap water would not yield meaningful results for most of the in-situ physico-chemical parameters.

In addition to the physico-chemical parameters groundwater levels were measured in all wells (including drilled wells, where possible) shown in Figure 6 and Figure 7. In total groundwater levels were measured in 27 (32 at least 2 times) dug- and 26 (42 at least 2 times) drilled wells at least three times.

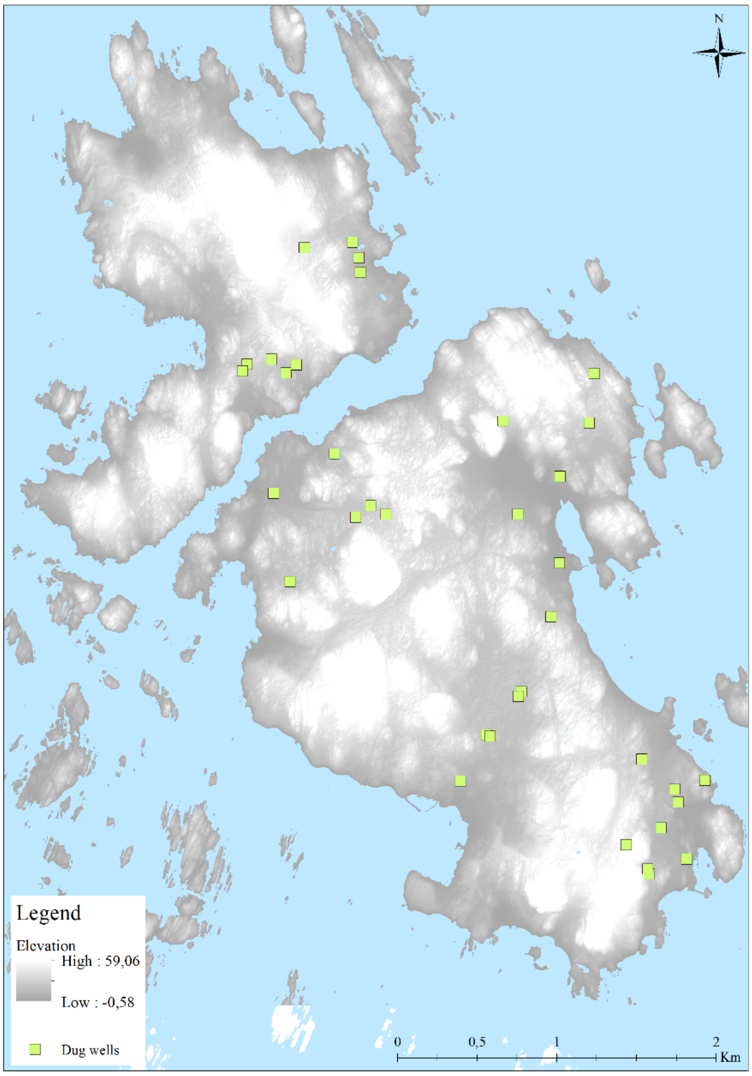

Figure 6: Dug wells where in situ parameters and groundwater water level were measured.

4.2.1.3 Borehole logs of electrical conductivity (EC) and temperature (depth profiles)

Borehole logs were created by measuring EC and temperature at different depths in drilled wells (Figure 7). The measurements took place in April, July/August and September 2016. The purpose was to see which wells that were affected by salty groundwater and to detect changes in salt concentration with depth. Extraction that exceeds local recharge could result in an upward movement of the transition zone between fresh and salt groundwater (repeated measurements allows for detecting such changes.

For the borehole logs, measurements were taken every 1-5 meters with a *Solinst Model 107 TLC Meter*. The instrument was calibrated each day prior to the measurements using a two-point calibration (1,413 and 5,000 µS/cm).

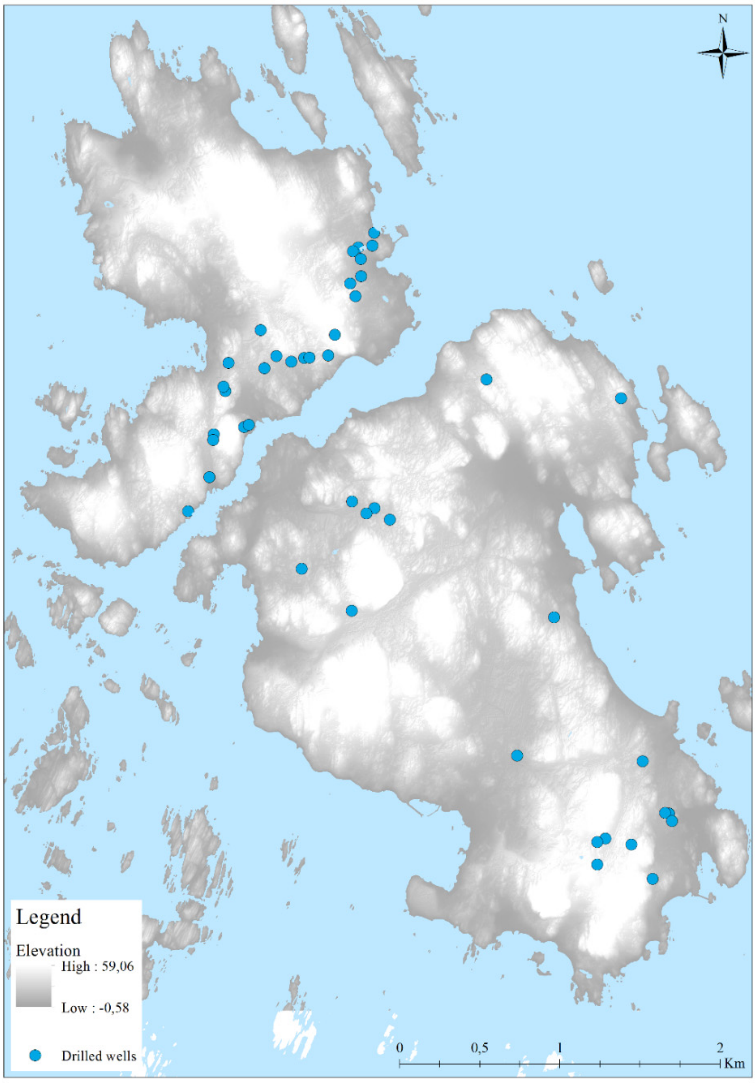

Figure 7. Drilled wells where borehole logs (EC and Temperature) and water level was measured.

4.2.1.4 Continuous measurements of groundwater level, Electrical conductivity (EC), and temperature

Nine wells were selected for continuous measurements of groundwater level, EC, and temperature with LTC Level-loggers. The LTC Level-loggers were set to measure and store pressure level, EC and temperature every 10 minutes. The pressure level is recalculated and corrected for air pressure and shown as water level above the instrument. The Level-loggers were installed in wells on both Nord- and Sydkoster, for a detailed information see Table 1 and Figure 8 for their location.

The decision to place the nine instruments given a choice of several 100 places was a difficult one. An even spatial distribution is desired but it is also interesting to see what the relations between wells in a close distance are. In Vettnet, two instruments were installed very close in a drilled and a dug well. On Sydkoster, two instruments were installed in two drilled wells in a close distanced. Unfortunately, in both cases one of the instruments had to be removed due to technical problems in July.

Table 1: Continuous measurements of groundwater level, EC, and temperature - overview

	Installed				
Well ID	**From**	**To**	**Well type**	**Location**	**Installation depth [m]**
12	2016-03-22		Dug	Nordkoster	2
33	2015-12-16	2016-06-20	Drilled	Nordkoster	28
46	2016-03-22	2016-07-11	Drilled	Nordkoster	27.5
84	2015-12-16		Dug	Sydkoster	4.5
99	2016-03-22		Drilled	Sydkoster	8
124	2015-12-16		Dug	Sydkoster	1.5
151	2016-03-22		Drilled	Sydkoster	28
152	2016-03-22		Drilled	Sydkoster	25
172	2016-03-22		Drilled	Sydkoster	28
161	2016-08-18		Drilled	Sydkoster	19
215	2016-08-18		Drilled	Sydkoster	19

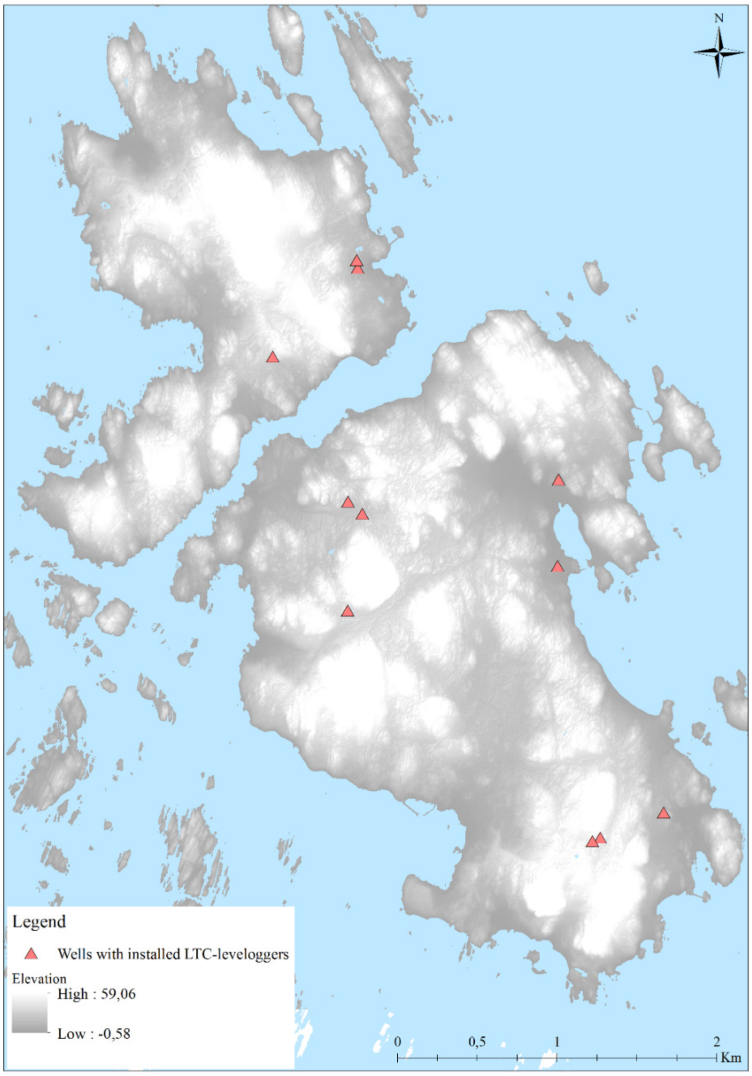

Figure 8: Location of the installed pressure transducers

4.2.1.5 Groundwater sampling

Groundwater samples were taken 3 times: in April (before the summer), at the peak of the summer holiday season in the last week of July, after the summer (September/October[7]) to see how the increased water consumption influences the system, how fast it responds and how fast the values go back to normal. The sampling was done by a selection of well-owners who were provided with sample bottles and an instruction. The samples were then collected by us and transported to the lab for further analysis. The selection of wells was done with help of Torbjörn Stjernberg, Göran Lyth and Göran Larsson and included mainly people who live permanently on the island. This was a necessary requirement as the first sampling took place in April, were mainly permanent residents were present to take samples.

[7] Some of the September measurements had to be repeated in early October because of a calibration problem

Together with the sample bottles a questionnaire was distributed with questions regarding well characteristics and usage of water before the sample was taken.

11 samples were taken for analysis of organic contaminants (see section 4.2.2.3).

4.2.2 Laboratory Measurements

The laboratory measurements were partly performed in our own laboratory, partly samples were sent to an external laboratory (Eurofins) for those chemical parameters we don't have analytical capacities for (organic contaminants). Of the foreseen measurements the Major ion chemistry is not completed for all samples (SmartChem 200, photometric analysis) at the time this report is written.

4.2.2.1 Electrical conductivity (EC) in water samples

Water samples from wells both from North and from South Koster taken by the well owners were collected in April, July 2016 and September (see section 4.2.1.5). In total 114 water samples were obtained in April, 91 in July and 70 in September. Based on the measurements of the EC in water samples from April, 77 wells were selected for further chemical analysis (metals, major ions) and a few more wells were added in July. Hereby, high EC values (indicating a possible risk for inflowing saltwater) and a broad spatial distribution of the sample locations were of special interest. Although the deeper drilled wells were in focus, some dug wells were included in the selection as well.

After arrival at the University of Gothenburg, all water samples were stored cold and the EC in all samples was measured within a couple of days after arrival. The measurements were carried out with an *Ecosan Con 5* handheld device. The instrument was calibrated prior to the measurements using a suitable EC standard 1,413 µS/cm and 5000 µS/cm. Between measurements, the probe was rinsed with distilled water and wiped to avoid cross contamination of the samples.

4.2.2.2 Analysis of metals and major ions (ICP-MS, Smartchem)

The selected water samples (see previous section) were analyzed for selected metals and other ions. Analyses for metals was carried out with an ICP-MS instrument in the lab facilities of the Department of Earth Sciences at the University of Gothenburg. The following metals were analyzed: Li, B, Na, Mg, Al, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Sr, Cd, Ba, Hg, Pb and U. Figure 9 shows all the wells from which water samples were obtained in April and those which were selected for ICP-MS analysis of metals.

Furthermore, the samples were analyzed for selected anions using a SmartChem 200 photo-spectrometer in the lab facilities of the Department of Earth Sciences at the University of Gothenburg. The following anions were so far analyzed: Cl, PO_4, Si, and SO_4. Due to a technical problem with the instrument, the measurements of other parameters had to be postponed.

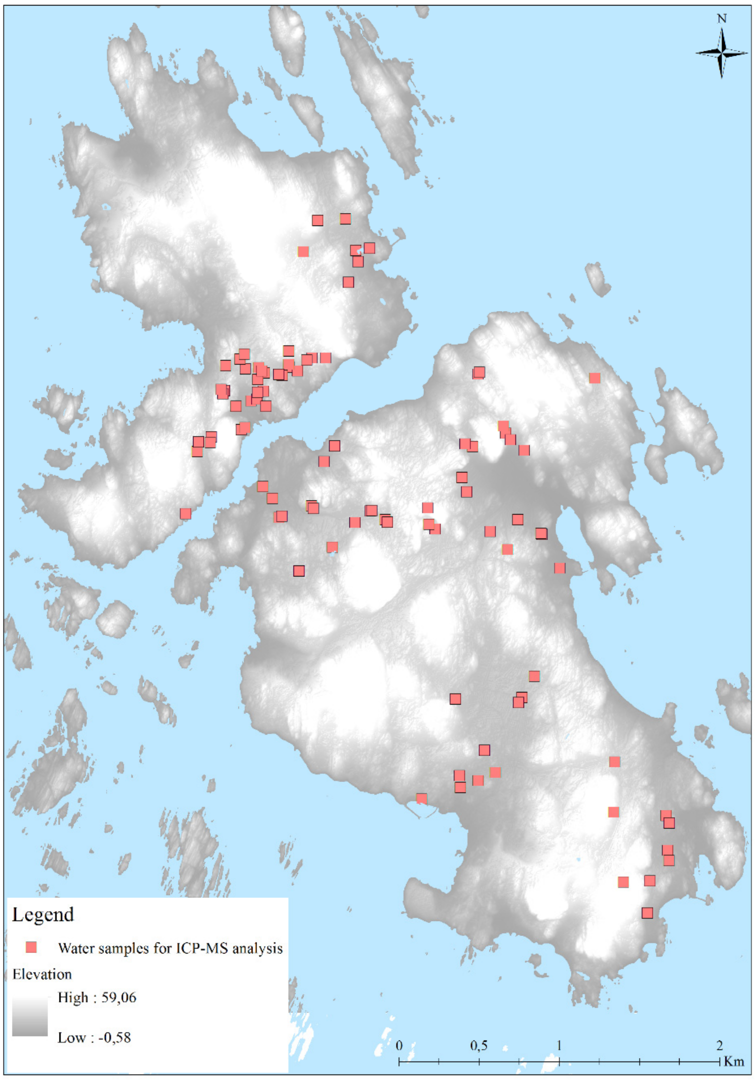

Figure 9: Location of wells from which water samples for ICP-MS analysis (metals) have been obtained.

4.2.2.3 Organic contaminants

A large number of organic contaminants may occur in groundwater due to a large range of different human activities. To be able to estimate the threats that organic contaminants can pose to the groundwater based drinking water supply on Koster we decided to perform a limited sampling campaign. Based on reports from islanders and an inventory of potentially contaminated areas provided by Strömstad municipality (section 5.3.2) we selected several locations to take water samples for analyzing for a selection of typical organic contaminants according to the recommendations of the Swedish environmental protection agency: BTEX (benzene, toluene, ethylbenzene and xylene), aliphatic and aromatic compounds, PAHs (Polycyclic aromatic hydrocarbons), VOC (volatile organic compounds), per-fluorinated substances (PFOA, PFOS).

Due to the high costs of the respective analysis samples could only be taken from 11 locations and only a selection or the aforementioned parameters could be analyzed for each.

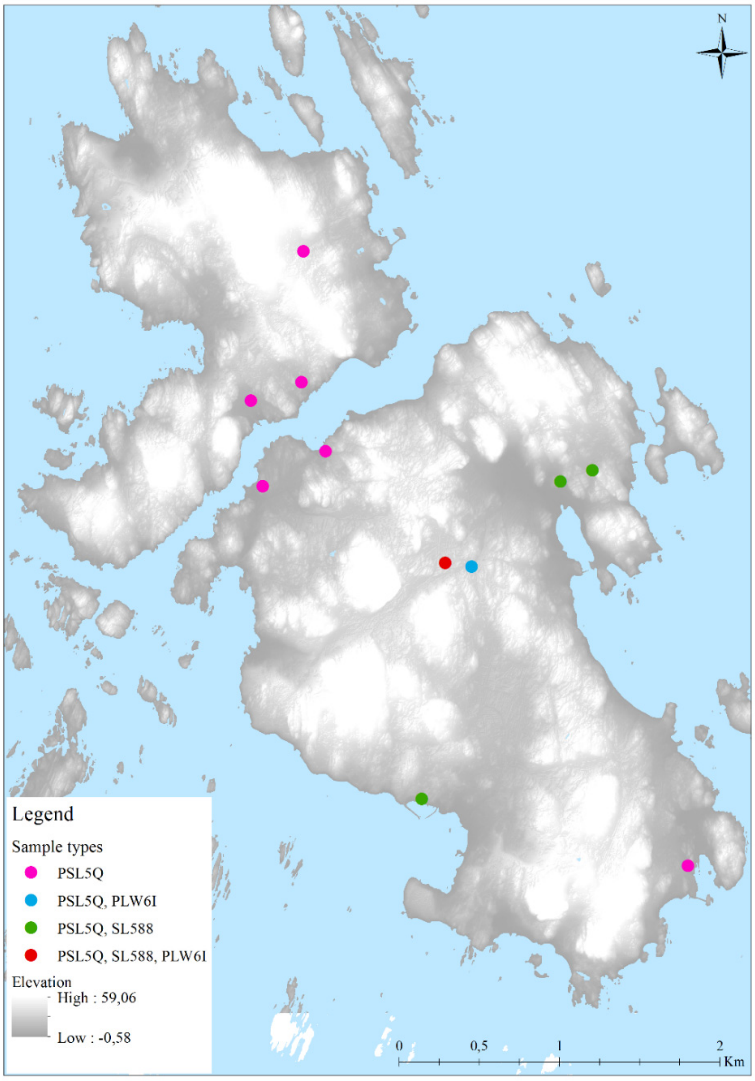

Figure 10: Sampling locations for organic contaminants. The color coding explains which analysis were performed:
PSL5Q: BTEX (benzene, toluene, ethylbenzene and xylene), aliphatic and aromatic compounds, PAHs (Polycyclic aromatic hydrocarbons)
SL588: VOC (volatile organic compounds)
PLW61: per-fluorinated substances (PFOA, PFOS)
The sampling locations were chosen according to the inventory listed in section 5.3.2

4.2.3 Literature and external data

During the time we carried out the investigations described in this report, we received a large number of reports and data sets which were partly provided to us at the project start, partly we got to know about them through targeted research and some we found or received just by chance (for example a report by SGU mentioned to us by one well-owner who happened to have one page of the report with a report number).

It is important to note, that it was impossible to analyze and use all the external information available. Partly, because the information is overwhelming, partly, because the information is only available in paper form (not allowing numerical analysis), and partly because the information is unclear or incomplete.

In addition to information from documents and previous investigations, we received a large number of information by anecdotal evidence. Oral communication, information mentioned in emails, partly in form of facts, partly in form of rumors or assumptions. We have tried to collect and store this information as far as possible, but were not able to analyze it yet.

As example, we list the data sources we obtained indicating well locations:

1. Data from SGUs well archive: 'Brunnsarkivet"
2. Data obtained through our online survey
3. Maps with well locations, provided by Göran Lyth / Göran Larsson in April 2016
4. Wells, contained in the folders with water chemistry analysis provided by Strömstad municipality
5. Wells, contained in a data set with water chemistry analysis provided by Lena Maxe, SGU
6. Wells, we got to know of by personal communication following the letter sent to property owners in April and our letter sent in June

These data sets are partly overlapping, partly contradictory, and have very different content of information. And yet, despite the many different sources, we still have information about 300 wells only.

4.2.3.1 Chemical and microbial water analysis carried out but external laboratories

We strived to collect as many water analysis report from private wells as possible to determine the changes of water quality on the islands in space and time. The major source of analysis protocols was from Strömstad municipality. About 30 folders with paper copies of the protocols for private wells, Ekenäs water works and larger facilities were provided. Of those, we selected all wells on Koster and entered selected analyses[8] values into a database.

[8] The reports contain, depending on laboratory, analysis packages ordered, age, etc., between 10 and 50 values of interest. Of those we have so far entered in our data base: data related to microbiological contamination, Chloride and electrical conductivity, overall assessment as well as descriptive information of the sampling location and time.

Additionally, we received a selection of 22 water analysis reports from SGU and their national supervision project[9]. Finally, analysis protocols were obtained from people on Koster in response to a letter sent out in June 2016 and as an attachment to the water samples taken by selected well-owners (see section 4.2.1.5).

4.2.3.2 Inventory of potentially contaminated areas on Koster provided by Strömstad municipality

On request, the department of environment, Strömstad municipality has provided us a list with potentially contaminated areas on Koster. We used this list to select sample locations for water samples to be analysed for organic contaminants (see section 4.2.2.3).

4.2.3.3 Weather, climate and sea level data from SMHI

We downloaded the respective data from SMHI's homepage and used it to analyse the weather situation in 2016 in comparison to the reference period 1961-1990 and the average of the last ten years. The data was also used to analyse how the groundwater levels and other parameters responded to climate data. Finally, the data were used to calculate water balance terms, such as evapotranspiration and groundwater recharge.

4.2.3.4 Calculations of Groundwater recharge

The groundwater system on the Koster islands is complex and heterogenic. It consists of a large number of small groundwater reservoirs, both consolidated and unconsolidated. This situation leads to large local variations in the groundwater conditions, which also applies for the drinking water supply.

A comparison between groundwater recharge, extraction and water availability was carried out in order to better understand the sustainability degree of the current groundwater management on the islands and also the future potential of a sustainable drinking water supply based on local groundwater.

The use of groundwater as drinking water in coastal areas is constrained by the proximity of salty groundwater below the sea bottom, which also extends under land. On islands the availability of fresh groundwater is thereby strictly limited. If the extraction of fresh groundwater exceeds the amount of groundwater which is renewed by natural groundwater recharge, the fresh groundwater will eventually be replaced by salty groundwater. Therefore, it is important to assess the groundwater recharge. *Groundwater recharge* is water added to the groundwater reservoir by recharging the water table (de Vries and Simmers, 2002). In the present study we estimated groundwater recharge the following equation:

$$R_i = (P - ET) * C_i$$

where R_i is groundwater recharge (mm or m^3), P is precipitation (mm or m^3), ET is evapotranspiration (mm or m^3) and C_i is the infiltration coefficient (dimensionless).

[9] http://www.sgu.se/samhallsplanering/planering-och-markanvandning/grundvatten-i-planeringen/grundvatten-i-oversiktsplanen

Strictly speaking this equation can only be applied for longer periods (>10a) as it does not take into account storage in the unsaturated zone.

The equation above can be modified to yield surface runoff S_r:

$S_r = (P - ET) * (1-C_i)$

Precipitation is water in any forms that condensates from the atmosphere. It is the only directly measurable parameter in the groundwater recharge calculation and is therefore considered the most accurate parameter in the equation. Despite this, it still contains several uncertainties. Precipitation data is point data from specific geographic locations (weather stations). No data is available for locations in between these weather stations. This is problematic because precipitation can show large local variations. Precipitation measurements are known to have error margins of up to 20% in southern Sweden.

Evapotranspiration is the sum of water transpired by plants and water evaporated to the atmosphere from free water and from water stored in soil. Actual evapotranspiration (ET_a) is the amount of water that evapotranspires under field conditions, thus it is limited by soil moisture (Fetter, 2014). If the soil is dry, no evaporation takes place. Plants adjust their activities (growth) to water availability. ET_a is unfortunately difficult to measure and difficult to calculate as it depends on a large number of often unknown parameters. Potential evapotranspiration (ET_p) is the largest possible water loss to the atmosphere. It is the amount of water that would evapotranspire under conditions of fully saturated soil. The ET_p is therefore most often much larger compared to field conditions, in particular in the summer month. ET_p is generally estimated by theoretical or empirical equations using meteorological parameters (Lu et al. 2005). As for precipitation, some of the input parameters can show large local variations and uncertainty.

The term $P - ET$ is often referred to as effective precipitation (the part of P which is available for infiltration in soil or surface runoff.

Infiltration coefficient describes the relation between infiltration of precipitation and surface runoff. The infiltration coefficient is defined by following equation:

$C_i = V_e / V_b$

where V_e is the volume of water infiltrating the ground and V_b is the total volume of effective precipitation in an area (Bonacci, 2001). It is dimensionless and ranges from 0 to 1. No soild type cover is considered to have an infiltration coefficient of 1 because a small part of the precipitation will almost always form surface runoff, due to factors such as high intensity rainfall and topography (Misstear & Brown, 2002). Infiltration coefficients are high for soils with high permeability (gravel, sand) and low for soils with low permeability (silt, clay). For bedrock, they are assumed to be very low.

Accordingly, *surface runoff* S_r is the part of effective precipitation that cannot infiltrate. It is assumed to directly move into the surface runoff system and form stream flow.

The groundwater recharge on the Koster islands was calculated with the assumption that all precipitation infiltrating the ground surface will recharge the water table. This will not be the case in reality since some water will be stored in the unsaturated zone a soil moisture, in particular after longer dry periods. Soil moisture and groundwater recharge are accounted as one in this case, because they are difficult to separate. However, the amount of water added to soil moisture is considered low since the dominating soil types on the islands are sand and gravel with low field capacity.

One disadvantage of the infiltration coefficient approach to estimate groundwater recharge is that it assumes that water, that does not infiltrate directly at the point where precipitation falls, cannot become groundwater recharge. This is however not correct, as water can move at the surface of impermeable materials as surface runoff until it meets materials with better infiltration capacity to infiltrate. Surface runoff from bedrock areas, thus not infiltrated water most often infiltrates soil deposits in lower topographic areas, this process is called "*indirect infiltration*" further on. There are many uncertainties regarding the quantity of indirect infiltration since overland flow is difficult to measure directly in field and can both infiltrate and flow as surface runoff in streams etc. Discharge in streams can be measured directly in field. Unfortunately, no previous studies exist and no measurements was carried out since all streams was dry during the project time. Surface runoff is therefore a large uncertainty. Calculations was therefore carried out for three alternative infiltration quantities: were 25%, 50% and 75% of the overland flow becomes indirect infiltration.

Groundwater recharge is in this case calculated from precipitation, evapotranspiration and infiltration coefficients. The accuracy of the result is entirely dependent on the accuracy of the input parameters.

Groundwater recharge was calculated for bedrock and soil deposits on Koster. The entire groundwater recharge on the islands is unfortunately not interesting when assessing whether the water usage on the islands are sustainable. Extraction of water occurs concentrated in relatively small areas on the islands resulting in local quantity- and quality problems. In order to get a better understanding of the local conditions 12 subareas was created on the islands. These areas were centered around soil deposits and the outlines was determined by topography and flow directions. In other words, catchments were created for larger soil deposits. The catchments were determined by the following process:

- A digital elevation model (DEM) containing topographic data was retrieved from Lantmäteriet together with a soil map from the geological survey of Sweden (SGU).
- The DEM was altered with the tool "Fill" in order to remove depressions in the topographic data (Figure 11).
- The tools "flow Direction" and "flow Accumulation" was used to get new rasters containing data regarding direction of surface water flow and the accumulated flow to each downslope cell.
- Polygons outlining the sand- and gravel deposits in residential areas were created and used as pour points (gauges) when calculating the catchments using the tool "Watershed".

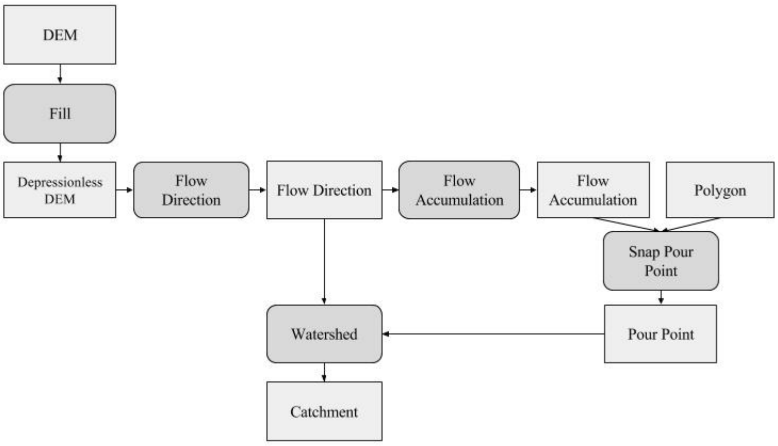

Figure 11. Schematic description of the process resulting in 12 sub-areas on the islands.

The parameters included in the groundwater recharge calculation (precipitation, evapotranspiration and infiltration coefficients) was estimated as follows: Precipitation, Evapotranspiration and infiltrations coefficients were determined for the groundwater recharge calculations by following processes:

Precipitation data was downloaded from The Swedish Meteorological and Hydrological Institute. The data was received from a weather station on Nordkoster (Nordkoster A).

The potential evapotranspiration was calculated using two empirical methods suitable for different temperatures: The Ivanov method for the winter months November to February (Pellicciotti, 2012; Singh and Frevert, 2002). with average air temperatures below 5.6 degrees celsius and the Turc method for the other months with average air temperatures above 5.6 degrees celsius.

- *The Turc method* is one of the most common equations used to calculate daily evapotranspiration for positive air temperatures (Novák, 2012). It has been compared to lysimeter measurements and the results turned out similar for humid climates. Only the complex FAO-56 PM method showed better results (Jensen 1990 cited in (Trajković and Stojnić, 2007)). The following equation was used for the Turc method:

*PET=0.31*C*(Rg+2.094)*(T/T+15)*

C=1 given that RH 50 %

where PET is the daily potential evapotranspiration [mm/day], RG is global radiation [MJ/m2/day], T is the daily average air temperature [^{0}C] and RH is the average air humidity [%] (Pellicciotti, 2012; Singh and Frevert, 2002). The average air humidity was considerably higher than 50 % for all months, which means that C was set to 1 in all calculations. Since groundwater recharge was calculated on a monthly basis the equation above was multiplied with the total number of days for each month.

- *The Ivanov method* is a widely used equation to estimate monthly potential evapotranspiration for the winter months, as mentioned before. The following equation was applied for the Ivanov method:

PET=0.0011*(25+T)2*(100-RH)

where PET is the monthly potential evapotranspiration [mm/month], T is the monthly average air temperature [^{0}C] and RH is the monthly average air humidity [%].

Global radiation-, temperature- and relative air humidity data was downloaded from The Swedish Meteorological and Hydrological Institute. The data was received from the same weather station as precipitation, Nordkoster A. Relative air humidity was obtained as hourly data and some hours were missing in the data series. However, this should not have a significant effect on the monthly averages.

Infiltration coefficients was retrieved from literature for 5 soil types and bedrock (Table 2). Values for peat and bedrock was retrieved from Berg & Engelbrektsson (2015), clay from Barkels & Parra (2010) and sand, gravel and clapper was retrieved from Misstear & Brown (2002).

Table 2. Infiltrations coefficients obtained from Barkels & Parra (2010), Misstear & Brown (2002) and Berg & Engelbrektsson (2015).

Land cover	C_i
Clay	0.1
Sand	0.5
Peat	0.05
Bedrock	0.11
Gravel	0.6
Clapper	0.9

4.2.3.5 Calculation of extraction

Extraction of groundwater through pumping occurs on all parts of the islands were households are located. The demands can roughly be estimated based on the number of people in a household at different times of the year and the average daily consumption. Within the framework of the Kostervatten project, the average daily consumption per person was determined through a survey that people on Koster participated in. The results were that people on the Koster islands consume little less than half of the average water demand per capita in Sweden, around 75 l/day compared to 160 l/day (Pleijel, 2016). The number of people in a household (using water from a specific well) varies strongly between the winter and summer months (see section 5.3.6 and Table 15). It needs to be pointed out that the total sum of extraction over the entire island is not really relevant, as the extraction occurs concentrated in relatively small areas on the island. In order to investigate the relation between water availability, groundwater recharge and extraction, the volume water consumed in every sub area must be determined. No absolute figures exist regarding consumption, so the quantity was assessed by following procedure:

- Estimating the number of people using dug respectively drilled wells was carried out by first determining an average number of people per household for both high season (June-August) and low season (September-May). This was done based on a survey sent out to the people on Koster in conjunction with the water samples collected in April, July and September (section 5.3.6).

- The number of households in each area was determined from "Fastighetskartan" in ArcGIS and then multiplied with the number of people per household (see previous step).
- A ratio between dug and drilled wells was determined to be able to get an approximate number of people using water from respectively well type. Several ratios were calculated based on different information sources: the online survey, the water sample-surveys, wells for in-situ measurements and all of this information combined. Finally, a suitable ratio was chosen from these different ones and the number of people using dug respectively drilled wells could be calculated for both seasons.
- The last step in the process of receiving approximate volumes of water extracted from soil respectively bedrock was to multiply the amount of people with the monthly average consumption of water on the Koster islands (0.075 m^3/day, i.e. 2.25 m3/month) and the number of months for the seasons (3 for high- and 9 for low season).

4.2.3.6 Calculations of water availability

Many wells on Koster are drilled wells (in bedrock). Groundwater in crystalline bedrock is restricted to fractures and not to the pores as in unconsolidated material. This makes the bedrock system more complex and harder to predict than an unconsolidated aquifer. An estimation of the water availability in bedrock was therefore calculated for the Koster islands as a whole, thus the islands were not divided into sub areas. The total amount of water in bedrock was calculated for Koster as a whole since it is difficult to divide the fracture system into sub areas. Groundwater in crystalline bedrock are restricted to fractures and not to the pores as in unconsolidated material. The fracture volume or the kinematic porosity of the crystalline bedrock was set to 0.1 % of the total volume (Sundqvist et al, 2009). The fracture volume used in the calculation is not site specific. It is based on typical volumes for crystalline bedrock in Sweden and not on fracture mapping. The total volume of bedrock with fractures containing freshwater was determined by following process:

- Depth of the transition zone between fresh and salt groundwater was defined from the borehole logs. A rapid increase in electrical conductivity with depth indicates a transition from freshwater to saltwater. Some of the borehole logs measured during spring and summer gave indications regarding the depth of the transition zone. However, the depth varied between different sites and an average was calculated and used for both islands. The depth of the transition zone was assumed to be horizontally equal, thus the transition zone was considered a flat, horizontal surface which is a simplification of reality.
- A digital elevation model (DEM) containing topographic data was retrieved from Lantmäteriet together with a raster containing data of soil depth from the geological survey of Sweden (SGU) and was used in order to determine the volume of bedrock on the islands. The first step was to subtract the soil depth from the DEM in order get a new elevation model only containing topography data for the bedrock. This was done using the tool "Raster Calculator" (Figure 12) in ArcGIS.
- A new layer containing the elevation of the transition zone was created with the tool "Create Constant Raster".

- The new raster together with the modified DEM was used to calculate the volume of bedrock above the transition zone using the tool “Surface Volume”.
- The volume of bedrock above the transition zone was multiplied with the kinematic porosity for the crystalline bedrock in order to get the volume of water contained in bedrock.

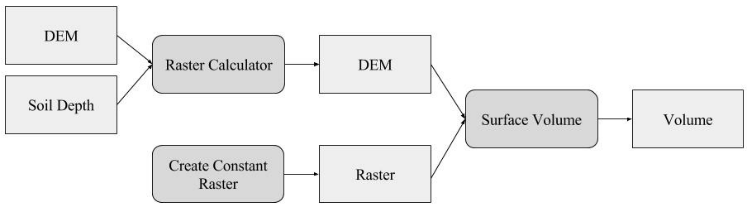

Figure 12. Schematic description of the process determining the total volume of bedrock above the transition zone on Koster.

The total volume of bedrock in the 12 sub areas was also determined using GIS. For this analysis the mean elevation value for bedrock in every area was determined using the tool “zonal statistics”. The elevation was added to the 50-meter transition zone and the total elevation was multiplied with the area for each sub area in order to get the volume of bedrock. The total volume was multiplied with the kinematic porosity which resulted in the volume of water in bedrock for each sub area.

Many wells on Koster are shallow dug wells in thin quaternary sediments. Such wells are restricted to collect infiltrated precipitation from surrounding soils. The volume of water available in these soil deposits depend on the thickness and specific yield of the sediment. The available water in these deposits was determined in order to evaluate if the water stored in sediment is large enough to overcome a period with higher extraction, larger evapotranspiration and no groundwater recharge. Also if the precipitation in autumn winter and spring is large enough to refill the deficits created during the summer months. The volume available water in soil was determined by following process:

- A shape file containing information regarding the unconsolidated materials present on Koster together with a raster containing data of soil depth was retrieved from the geological survey of Sweden (SGU). Both soil type and thickness are considered uncertainties in these calculations.
- The volume of unconsolidated material was calculated using the tool “Raster Calculation” for every cell (Figure 13).
- The shape file containing information regarding soil type on the islands was split into new layers were every layer represented different soil types using the tool “split by attribute”.
- The volume of every soil type present on the islands was calculated using the tool “Clip”. The new raster containing volume of unconsolidated material in every cell together with the polygons for every soil type was used as input. The output generated several rasters with volume of every soil type.
- In order to determine the volume of water stored in soils, the volume of every soil type was multiplied with the specific yield (Table 3). The specific yield values used are

averages from several measurements around the world and unfortunately not site specific.

The volume of available water was also calculated for the twelve sub areas mentioned earlier. Some of the twelve sub areas had connected soil deposits across the borders of the sub areas. The borders cutting the soil deposits are therefore not absolute, some water may flow between sub areas.

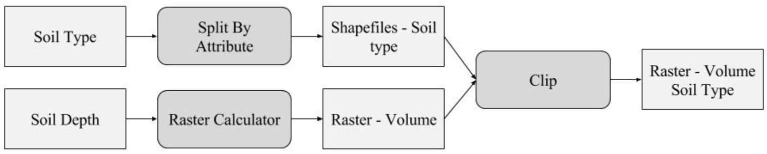

Figure 13. Schematic description of the process determining the total volume of available water in soil deposits on Koster.

Table 3. Specific yield for soils (Johnson, 1967; SGU, 2016)

Soil Type	Specific Yield
Aeolian sand	21
Organic rich clay (Gyttja)	2
Postglacial sand	26
Wave washed gravel	23
Shell beds	26
Peat	44
Clapper	22

4.2.3.7 GIS data sets and maps

Digital maps and spatial databases were partly available through the national geodata service provided through SLU (https://zeus.slu.se/), partly through the municipality of Strömstad (fastighets information).

4.2.3.8 Other reports

We have not yet made a systematic inventory and analysis of all other reports and documents available to us.

4.2.3.9 Questionnaires

To obtain a complete inventory of wells on Koster, the modes of usage of these wells and descriptive data, we prepared an online questionnaire (see Appendix). The link to this questionnaire was sent in a letter addressed to 878 property owners, 165 of which live abroad. About 50 letters (mainly to addresses abroad) were undeliverable.

5 Results

The results are presented here in the same sequence as the respective methods described in the previous section.

5.1 Field measurements and sampling

5.1.1 Groundwater levels and physico-chemical in situ parameters

Groundwater levels in all dug wells have decreased from April to July (Figure 14). 18 of the 27 dug wells where groundwater level measurements have been performed have decreased with 0-1 meters, 8 have decreased with 1-2 meters and 1 have decreased with 2-3 meters. A decrease of water levels can be considered normal during summer months due to the increased evapotranspiration, limited groundwater recharge and groundwater discharge into surface waters on the island and the sea. The decrease on Koster is a result of both natural processes and an increased water demand due to more residents during the summer.

From July to September, most groundwater levels in dug wells did not go back to where they were before the summer. They were generally still low in September (Figure 15). This can be explained by the dry weather in August and September, which did not bring groundwater levels back to normal, but also with the limited capacity of the natural groundwater systems to provide the water needed to refill the reservoirs through horizontal flow. From personal communication, we learned that the groundwater levels remained low even in the beginning of November, due to the dry autumn. This also indicates that the groundwater levels in the soil are more dependent on the weather conditions than on the extraction by consumers.

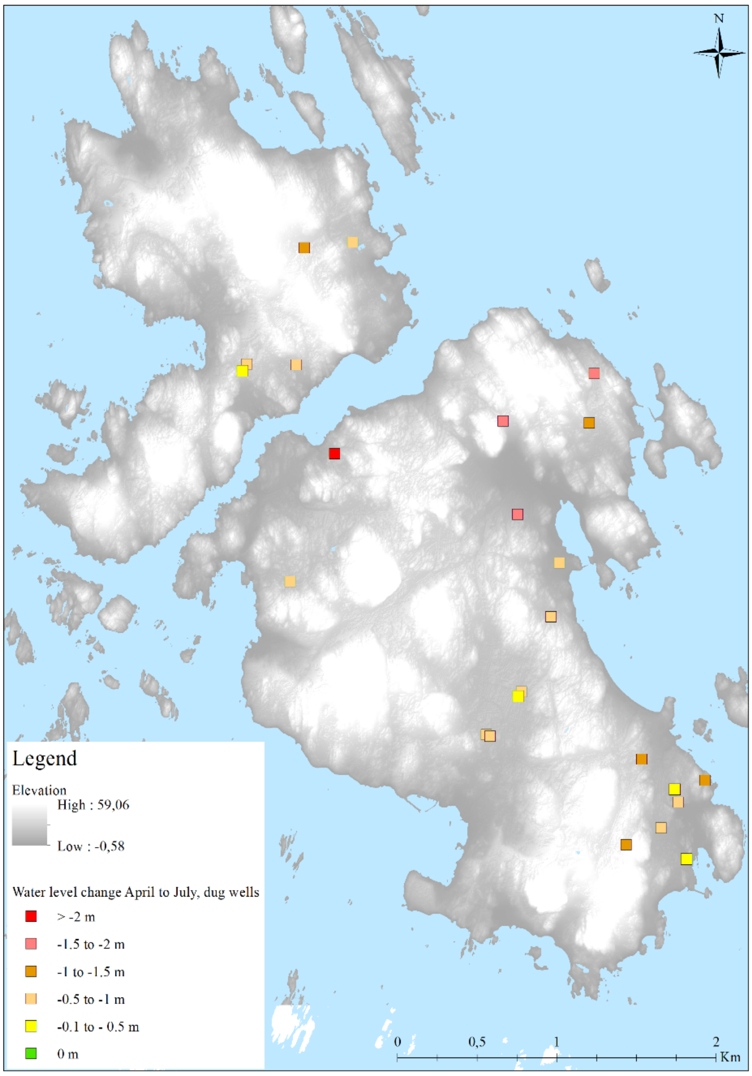

Figure 14: Map showing the change in hydraulic head in dug wells between April and July 2016.

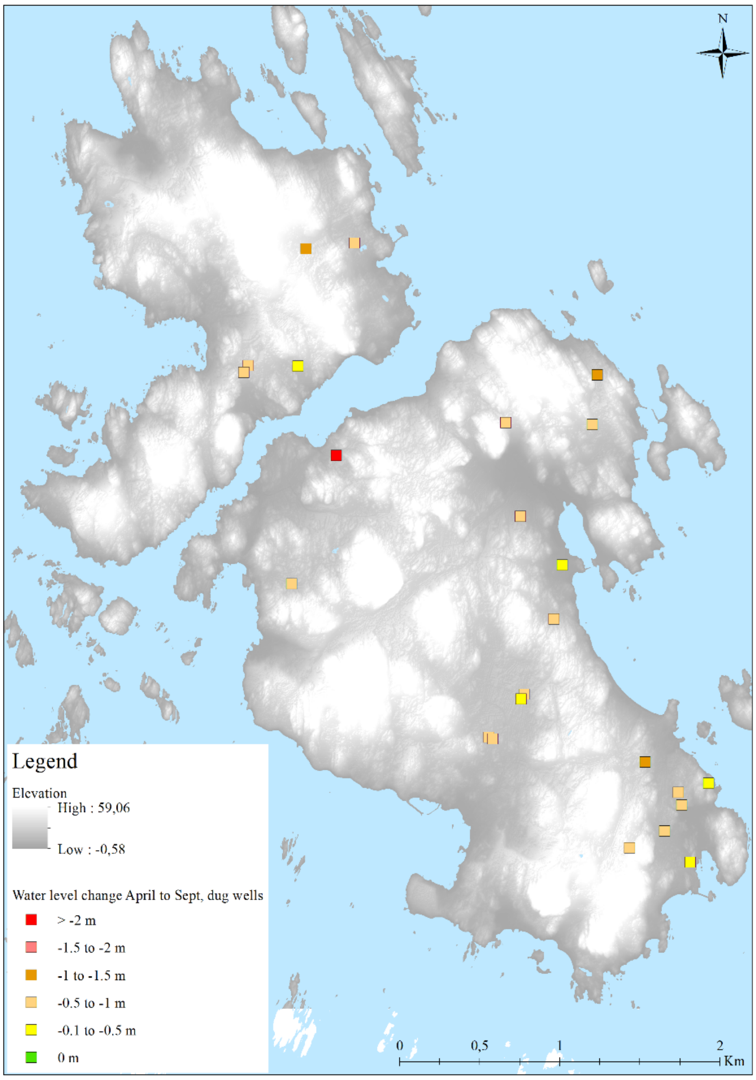

Figure 15: Map showing the change in hydraulic head in dug wells between April and September 2016.

Figure 16 shows the changes in groundwater levels for the drilled wells. Groundwater levels have decreased in 25 of 26 observed wells from April to July. The decreases are strong to very strong in 11, moderate in 15 cases. In one case the water level increased.

From July to September, some groundwater levels in drilled wells did go back to where they were before the summer while others remained rather low (Figure 17). In general, the groundwater levels in the drilled wells recover faster and more completely than those in dug wells, indicating that the drawdowns in the deep wells are very local only. Natural recharge from precipitation seems to play a minor role. Horizontal backflow into the depression cone through the fracture system can replace the deficits even without recharge.

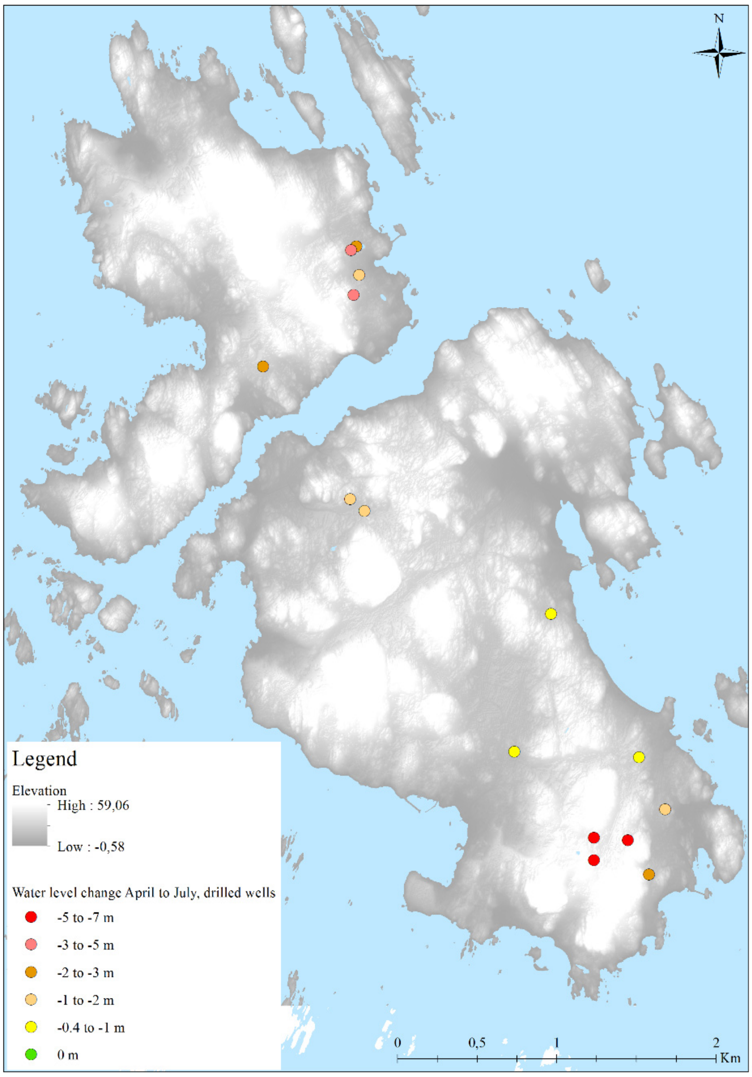

Figure 16: Map showing the change in hydraulic head in drilled wells between April and July 2016.

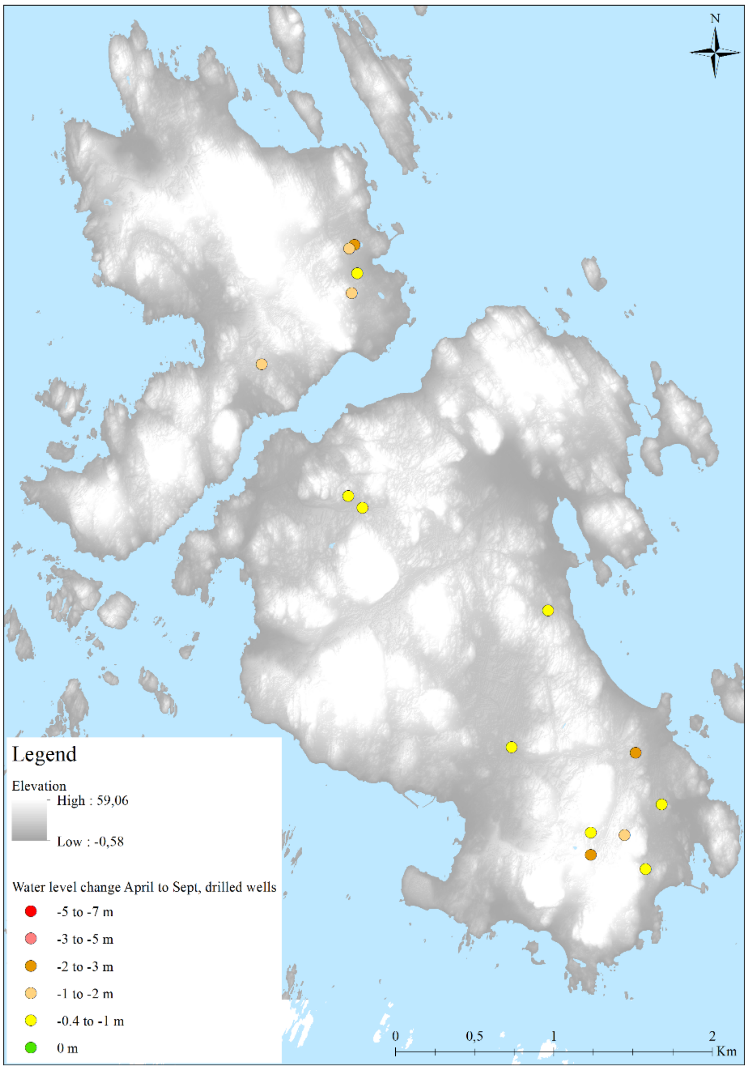

Figure 17: Map showing the change in hydraulic head in drilled wells between April and September 2016.

All groundwater level values and the respective changes should be regarded with some caution: As measurements were all done in pumping wells during operation, values can vary strongly within very short periods (hours/minutes) as shown in section 5.1.3. However, in particular for the dug wells, we are confident that the measurements are representative as daily fluctuations are usually small in dug wells.

5.1.2 Borehole logs of electrical conductivity and temperature (depth profiles)

Electrical conductivity at different depths was measured in 46 drilled wells between December 2015 and September 2016 at 2 - 5 occasions in order to detect seasonal changes of the total salinity and the position of the freshwater/saltwater interface. Three main types of behaviors can be distinguished:

- A 'positive' behavior, where the transition zone between high and low EC is found deeper and/or the electrical conductivity is lower in the summer than during spring and autumn.
- A 'negative' behavior, where the transition zone has migrated upwards and/or the conductivity is significantly higher in the summer than during spring and autumn.
- A 'neutral' behavior, where there is no notable change between the measurements.

A selection of the measured borehole logs is presented in the following. The first example from Kyrkosund (Figure 18) shows a 'positive' behavior. The EC is lower in both July and October compared to April. The transition zone is only clearly visible in July where the EC is almost constant at a low value until 48 m below ground surface where it increases by several thousand within a couple of meters. In April is the transition more diffuse and gradually increases from around 31 meters. The EC is lowest in the October measurement. This behavior can be a result of the well not being in use much before the April measurements resulting in stagnant groundwater with higher EC. The water table lowered from 5.32 m below ground surface in April to 9.17 m in July and recovered to 5.78 in October.

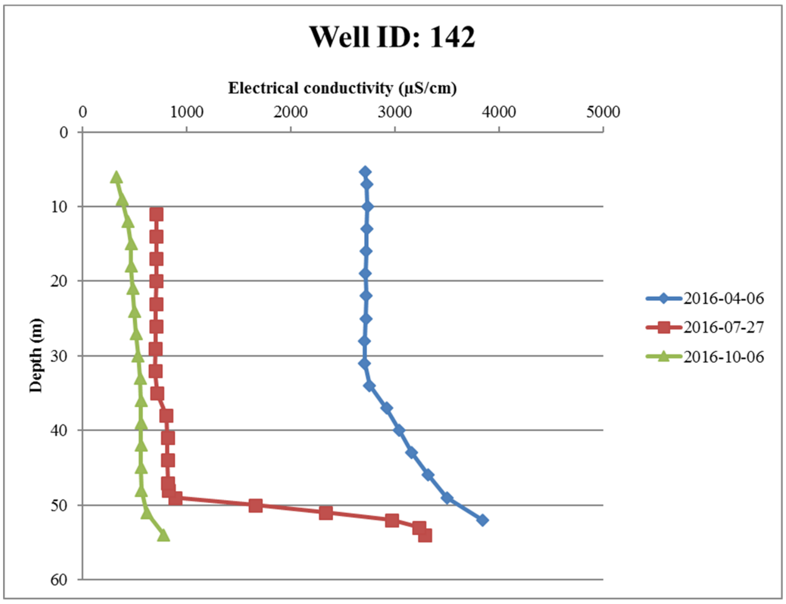

Figure 18: Example of of a borehole log showing EC measurements

The next example, also from Kyrkosund (Figure 19) shows a 'negative' behavior, where the maximum EC increases between the measurements. The maximum values for April is 22000, compared to 28900 for July and 33200 for October. The transition zone is rather sharp for all three measurements, but is located 20 meters deeper in July.

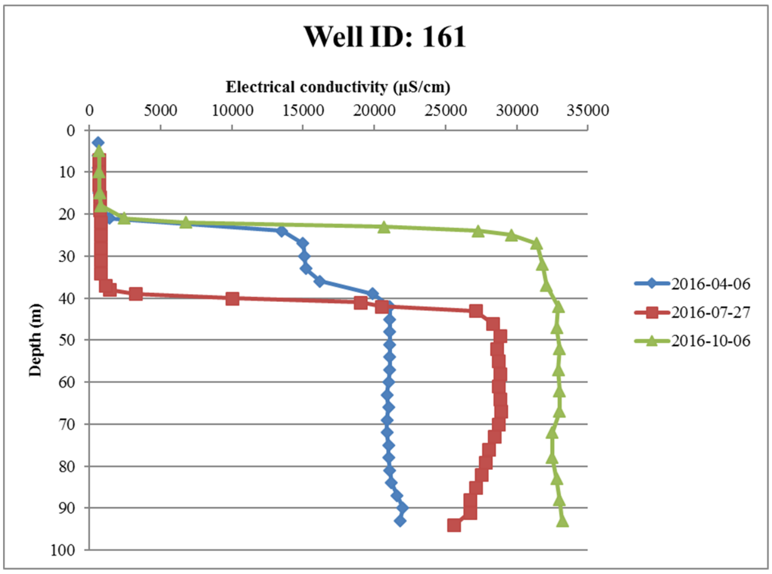

Figure 19: Example of a borehole log showing EC measurements

The next example, also from Kyrkosund (Figure 20) shows a 'negative' behavior, where the maximum EC increases during the summer but rather low in spring and autumn. The maximum values are 489 µS/cm in April, 2227 in July and 358 in October. The transition zone is only visible for the summer measurement where it is located approximately 36 meters below ground surface.

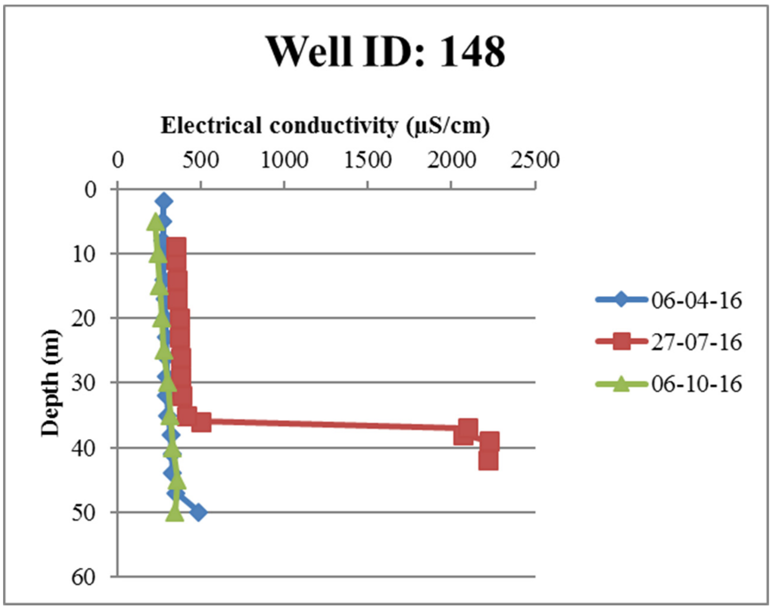

Figure 20: Example of a borehole log showing EC measurements

The last example (Figure 24) is from Nordkoster, and represents a 'neutral' behavior. There are no significant differences between the three days of measurements, not for either EC or the depth of the transition zone. This might be a result of sludge at the bottom of the borehole.

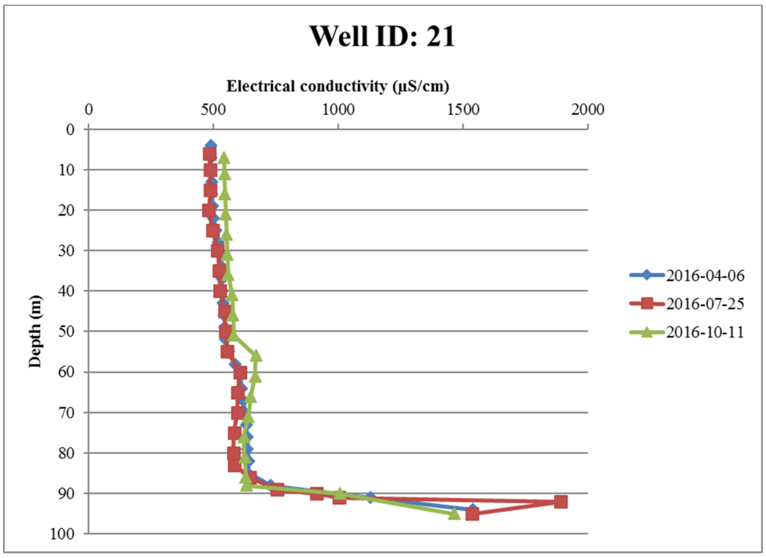

Figure 21: Example of a borehole log showing EC measurements

The last example (Figure 22) is also from Kyrkosund and represents a 'neutral' behavior. The EC is similar between the measurements down to approximately 46 meters below ground surface. Below that level (where there is something blocking the instrument), the instrument only got past the pump two times and the EC significantly increased in both. Since there are only two 'complete measurements' interpretation should be regarded with some caution. In any case this measurement shows a very large and clear increase which can hardly be explained by any other causes than the presence of the interface between fresh and sea water.

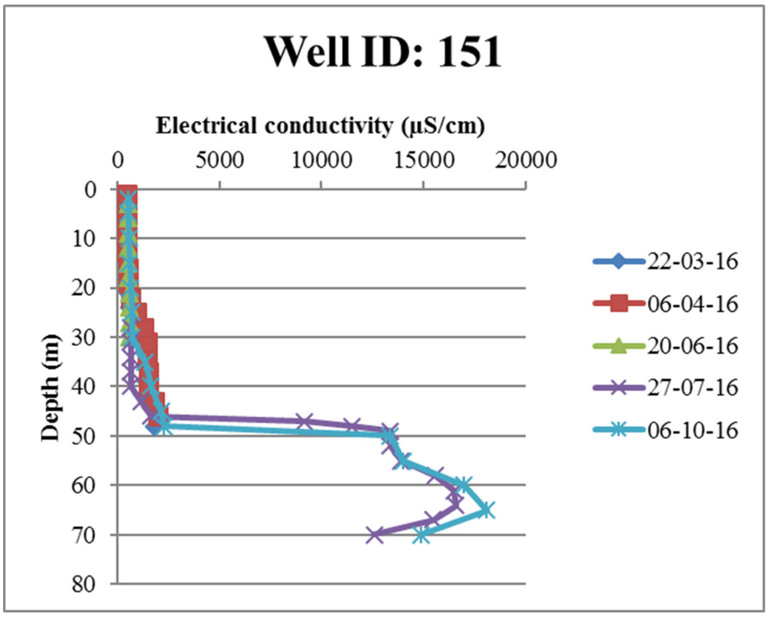

Figure 22: Example of a borehole log showing EC measurements

Figure 23 shows an attempt to summarize the results of the individual borehole logs from the both islands. The measurements were aggregated for the three periods "before" "during" and "after" the summer. The average of minimum of EC (usually the values from shallow depth) the average of the maximum EC (usually from the deeper parts of the well) and the averages of the average EC for each well are shown. Averages, minimum and maximum increase from April to September/October. Interestingly the values seem to be higher in September/October than in July which indicates an increase of salinity due to pumping and/or decreased groundwater recharge.

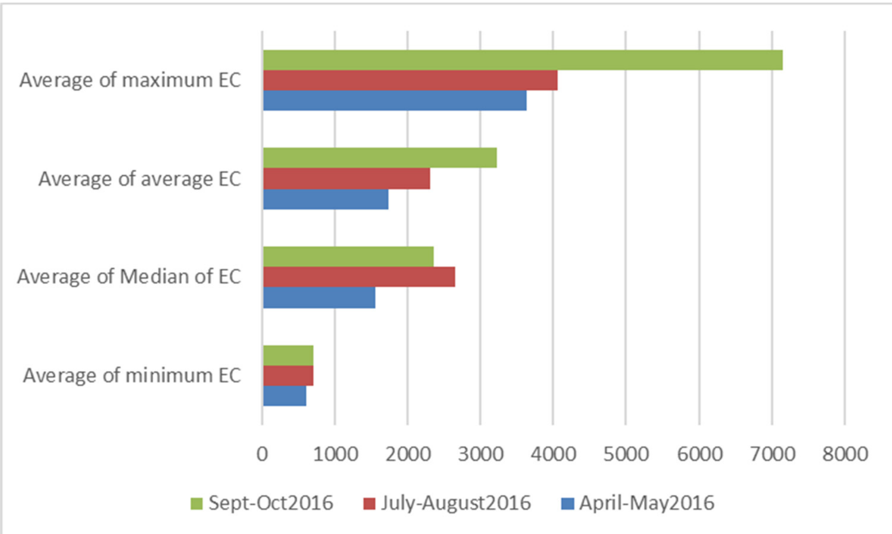

Figure 23: Summary of borehole-log measurements: averages of minimum, maximum, medians and average values for all boreholes and the three different main measurement periods Only borehole that were measured in all three periods are included.

From the borehole logs of EC the following conclusions can be obtained:

- In most cases a relatively sharp boundary from fresh water to saltier water can be detected. This lies typically around 50m below sea level, but varies strongly in different places.
- In some, but not all cases, this boundary is influenced by pumping. It is difficult to say something definitive though, as we had little control if the wells, when the borehole logs were performed, were in use, not used, or not used for a very long time

It should be noted that the borehole logs can be difficult to interpret as:

1. The pumps in some of the wells measured were in use or not in use at the time the measurements took place. In particular, in the spring, many of the wells had not been used for a longer period. In an unused well, water stagnates which can change the chemical properties. In a used well, water from the surroundings replaces the water in the well which leads to more representative values.
2. In many wells, it was not possible to measure all the way down to the well bottom. Very often, it was not possible to get past the pump with the 2 cm wide instrument.

5.1.3 Continuous measurements of pressure, EC, T

Figure 24 shows the results of the continuous measurements of pressure, EC, T in Well 12, a dug well located in Vettnet in the eastern part of Nordkoster. The measurements started March 22 and are ongoing. On Mars 22 was the water level 1 meter above the pressure transducer. The water level decreased throughout the measurement period, except for one quick rise on April 28 and one on May 21 both of which coincide with heavy precipitation events. The water temperature increased from 4.7 °C to 13.7 °C during the measurement period. These relatively strong changes in temperature can be explained by the very shallow groundwater table. The EC increases throughout the period from 248 µS/cm in late March to 507 µS/cm towards the end of July. At the end of the measurement period was the water level below the instrument, indicating that the well was almost empty. Despite the well being shallow, heavy precipitation does not seem to affect temperature, water level or EC greatly. This could indicate that the major part of recharge is not a direct response of local infiltration.

In this specific case, a longer monitoring period is preferred to see how the water level and EC change during the fall / winter.

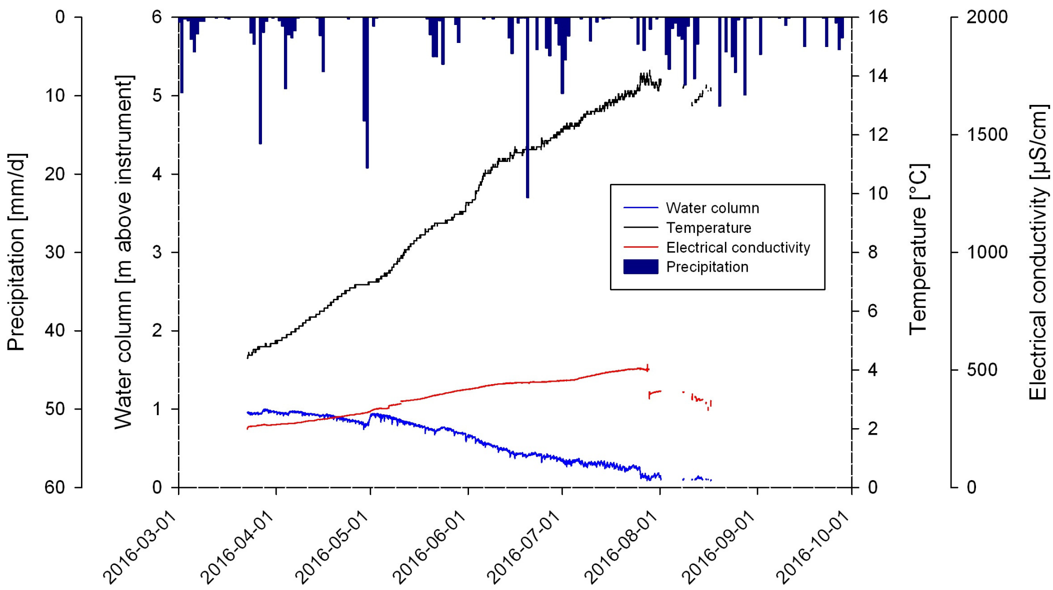

Figure 24: The variations in water level, electrical conductivity and water temperature between Mars 2016 and July 2016 in Well 12, a private dug well located in Vettnet, Nordkoster. The measured parameters are presented together with precipitation data acquired from SMHI (shown as bars).

Figure 25 shows the results of the continuous measurements of pressure, EC, T in well 33, a drilled well located in Duvnäs in the southern part Nordkoster that was in use throughout the entire observation period. The water level fluctuates around a stable value from December to end of May. Starting end of May is the trend a continuous decline. The maximum drop of the water level is around 22 m. A precipitation event is generally followed by an immediate increase in water level and decrease of EC, indicating infiltration of surface water. The EC increases from about 300 µS/cm to 500. These values are within the range of drinking water standards.

The general pattern is that a withdrawal increases EC while precipitation decreases it. This means that the well have a relative quick response and is closely connected to what happens above surface. Absence of precipitation leads to lower water levels and higher EC, so even though the response is quick it seems sensitive to dry periods.

Due to technical problems, the data logger had to be uninstalled in July so there are no data on how the system recovers after summer.

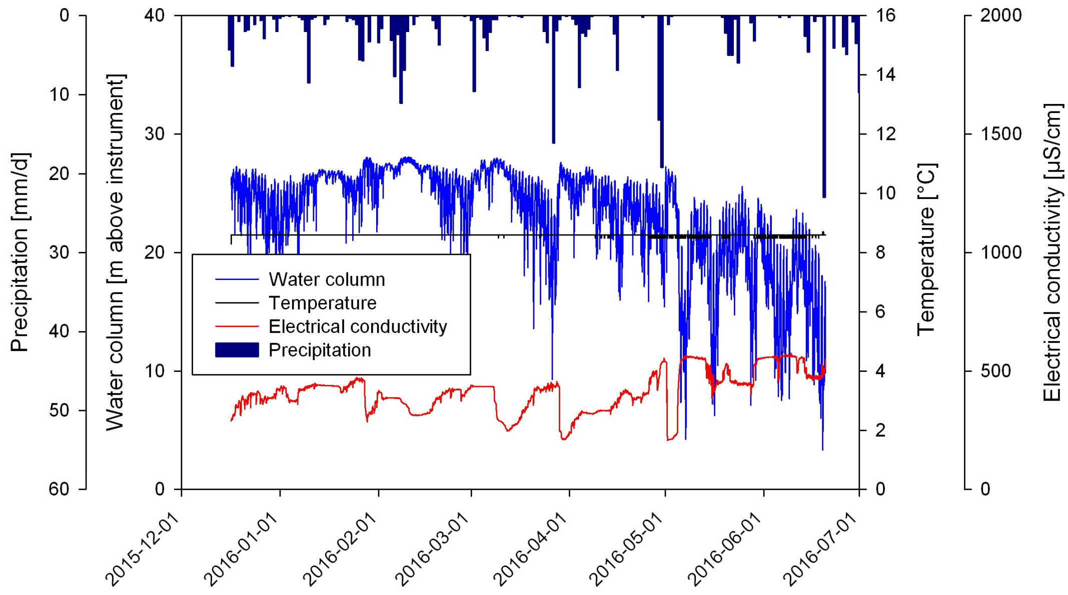

Figure 25: Variations in water level, electrical conductivity and water temperature between December 2015 and July 2016 in Well 33, a private drilled well located in the area of Duvnäs on southern Nordkoster. The measured parameters are compared to precipitation data acquired from SMHI. Measurements in this well could not be continued after July 2016 due to technical problems.

Figure 19 shows the results of the continuous measurements of pressure, EC, T in well 184, a dug well close to the shoreline in Ekenäs on north-eastern Sydkoster. The well is used by the municipal waterworks. The water level dropped by about 4 m from December to July and was unfortunately below the instrument during the last weeks. The electrical conductivity was around 500 µS/cm during the whole period with some small variations. It does not seem to be a clear correlation between pumping and increased electrical conductivity.

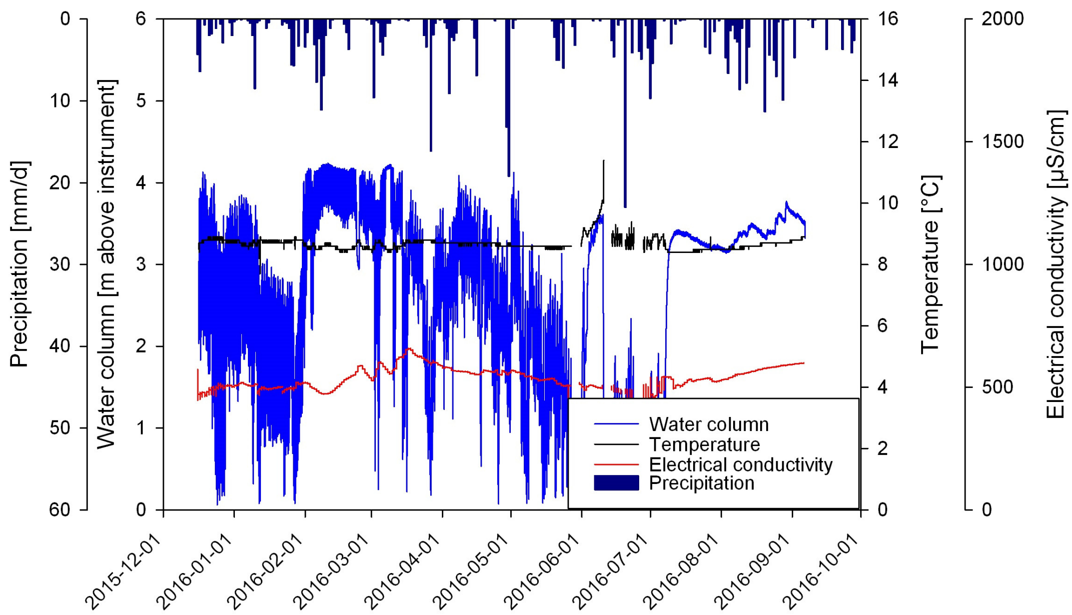

Figure 26: The variations in water level, electrical conductivity and water temperature between December 2015 and July 2016 in Well 84, a dug well located close to the shoreline in Ekenäs on north-eastern Sydkoster. The measured parameters are compared to precipitation data acquired from SMHI.

Figure 27 shows the results for well 151, a drilled well located in Kyrkosund on southern Sydkoster. This well is an example of a well that is only used temporary. Until June is the water level stable and EC is rising (due to stagnant water in the well). As soon as the well is used, both the water level and EC drops quickly. During more regular use in the summer leads to lower water levels and a small increase of EC. After the summer, the water level goes back to "normal" almost immediately. In contrary to well 33 (Figure 25), precipitation events do not result in an immediate rise of groundwater levels or changes in EC, which means that the recharge is not directly connected to precipitation. It is also remarkable that the water level goes down rather quickly and stays low during the peak season but recovers as soon as the extraction stops. It seems like the amount of groundwater is sufficient but that the capacity limits the use.

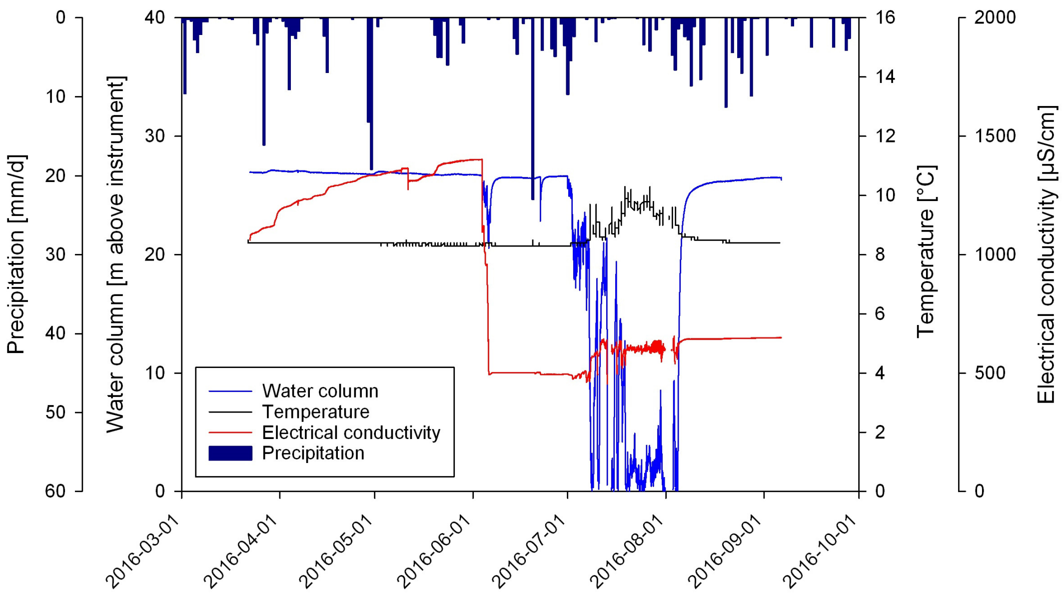

Figure 27: Variations in water level, electrical conductivity and water temperature between Mars 2016 and July 2016 in Well 151, a private drilled well located in the area of Kyrkosund on southern Sydkoster. The measured parameters are compared to precipitation data acquired from SMHI.

Well 152 (Figure 28) is also located in the area of Kyrkosund on southern Sydkoster, close to well 151. Again, heavy precipitation does not immediately influence groundwater levels in the well. In contrary to well 151 (Figure 27) the drawdown occurs much slower with a few spikes that recover rather quickly. Either the owners used less water or the groundwater system behaves very different.

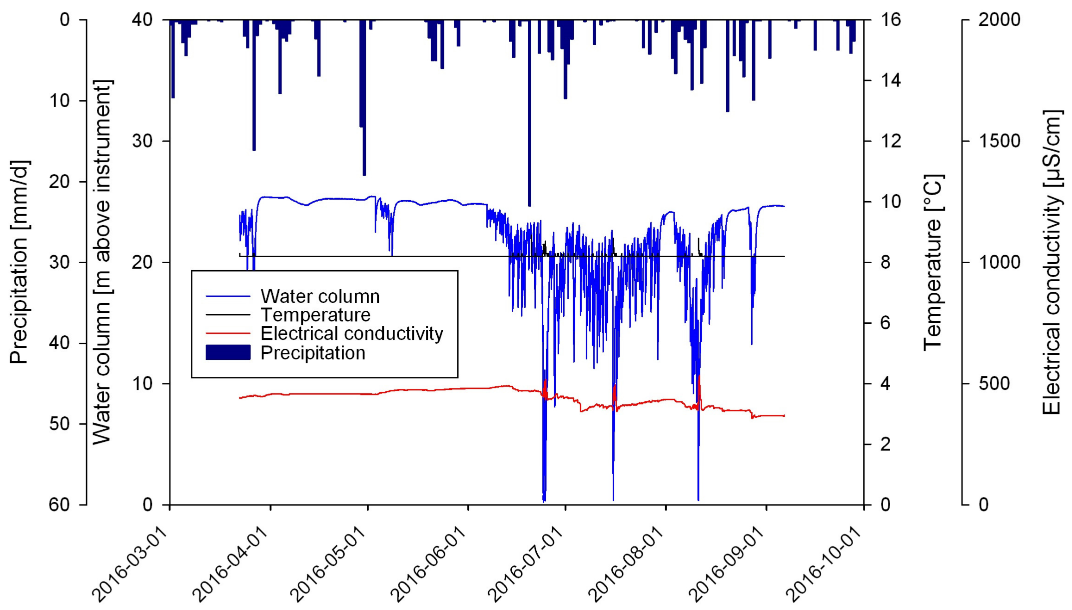

Figure 28: The variations in water level, electrical conductivity and water temperature between March 2016 and July 2016 in Well 152, a private drilled well located in the area of Kyrkosund on southern Sydkoster. The measured parameters are compared to precipitation data acquired from SMHI.

Figure 29 shows a comparison between the variations in water level in well 151 (not in operation) and well 152 (in operation) in the beginning of May 2016. The horizontal distance between these two wells is 60 m. We may see a very weak influence of the larger drawdowns in well 152 (up to 5m) on the water level in well 151 visible through the periodic behavior of groundwater levels in both wells. The influences are however very small (in the range of a few cm) and may be the result of an insufficient correction of barometric pressure changes. However, if the changes in 151 occur due to pumping, they seem to come with a delay of about two days.

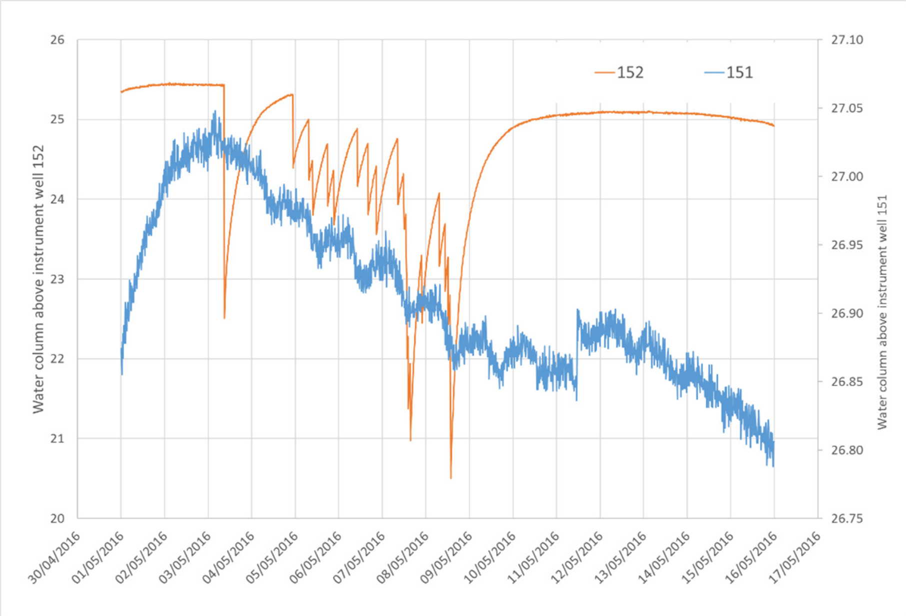

Figure 29: Comparison of the variations in water level between well 151 (not in operation) and well 152 (in operation) in the beginning of May 2016.

5.2 Laboratory Measurements

5.2.1 Electrical conductivity (EC) measurements of collected water sample

The water samples taken by the well owners on Koster in April, July and September 2016 were analyzed for EC in the lab at the University of Gothenburg. Samples from wells with data from both April, July and September were selected in order to detect changes. 65 % of all wells had a higher EC in July compared to April. Of the 22 drilled wells, 68 % had a higher EC in July than in April. Of the 58 dug wells, 61 % had a higher EC in July than in April. Details are shown in Table 4. 40 % off all wells had higher EC in September compared to July. 21 % of the drilled wells and 50 % of the dug wells had higher EC in September compared to July. 52 % of all wells had higher EC in September compared to April, 56 % of the drilled wells and 51 % of the dug wells. Median values were used instead of mean values to reduce the influence of single very high outliers in EC.

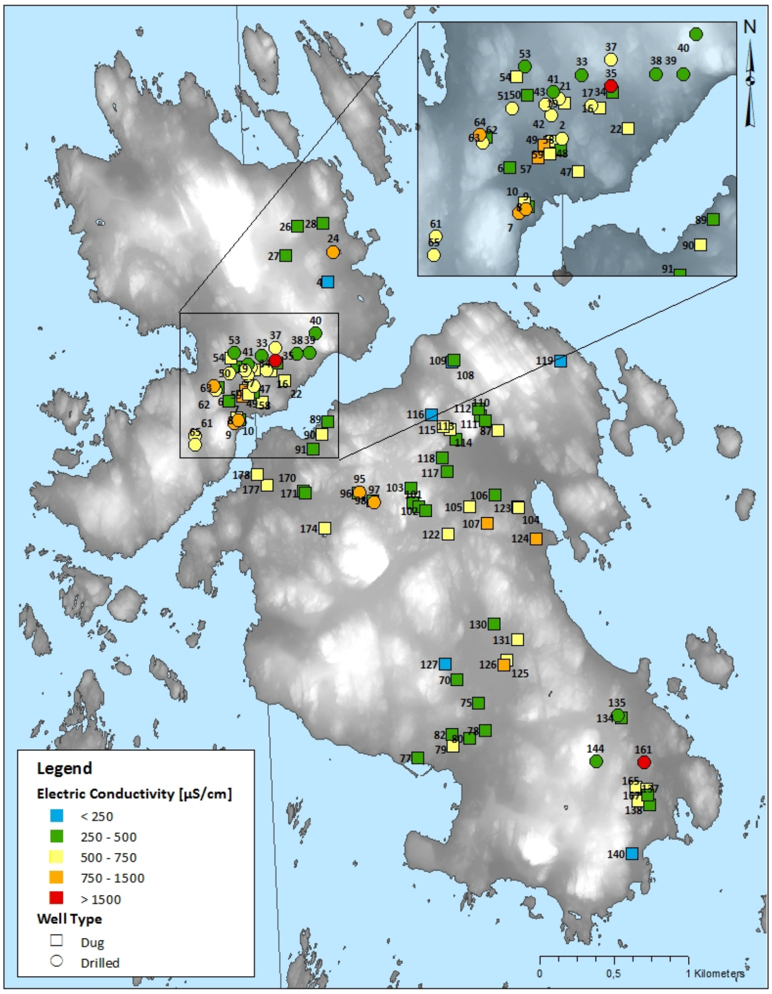

Figure 30: Overview Location and electrical conductivity values of the water samples in April. The intervals are set according to SGU's Bedömningsgrunder för Grundvatten (2013),

Table 4: EC measurements from water samples collected by well owners in April, July and September.

	All Wells	**Drilled wells**	**Dug wells**	**Type unknown**
Number of wells (April)	113	27	83	3
Number of wells (July)	103	37	63	3
Number of wells (September)	67	20	47	0
Median EC April (µS/cm)	492	587	471	502
Median EC July (µS/cm)	554	**740**	507	554
Median EC September (µS/cm)	525.5	629.5	507	
Wells with rising EC April to July	53 (= 65 %)	15 (= 68 %)	35 (= 61 %)	2 (= 67 %)
Wells with rising EC July to September	26 (= 40 %)	4 (=21 %)	22 (=50 %)	
Wells with rising EC April to September	33 (=52 %)	10 (= 56 %)	23 (= 51 %)	
Median rise in EC April to July (µS/cm)	55	87	55	96
Median rise in EC July to September (µS/cm)	20	195	17	
Median rise in EC April to September (µS/cm)	63	59	63	
Wells with falling EC April to July	29 (= 35 %)	7 (= 32 %)	22 (= 39 %)	1 (= 33%)
Wells with falling EC July to September	34 (= 54%)	14 (= 74 %)	20 (= 45%)	
Wells with falling EC April to Septmeber	29 (= 46 %)	8 (= 44 %)	21 (= 47 %)	
Median decline in EC April to July	-41	-92.5	-37	-10
Median decline in EC July to September	-31.5	-48	-15	
Median decline in EC April to September	-28	-23.5	-29	

In general, the drilled wells had a higher EC than the dug wells, both in April, July and September. This is also reflected by the changes in EC: whereas the largest increase in EC in a dug well (Well ID 106) is 310 µS/cm from April to July while the largest increase in a drilled well is 17863 µS/cm from April to September (Well ID 7).

The box plots shown in Figure 31 visualize the data for all wells, drilled and dug, for April, July and September 2016.

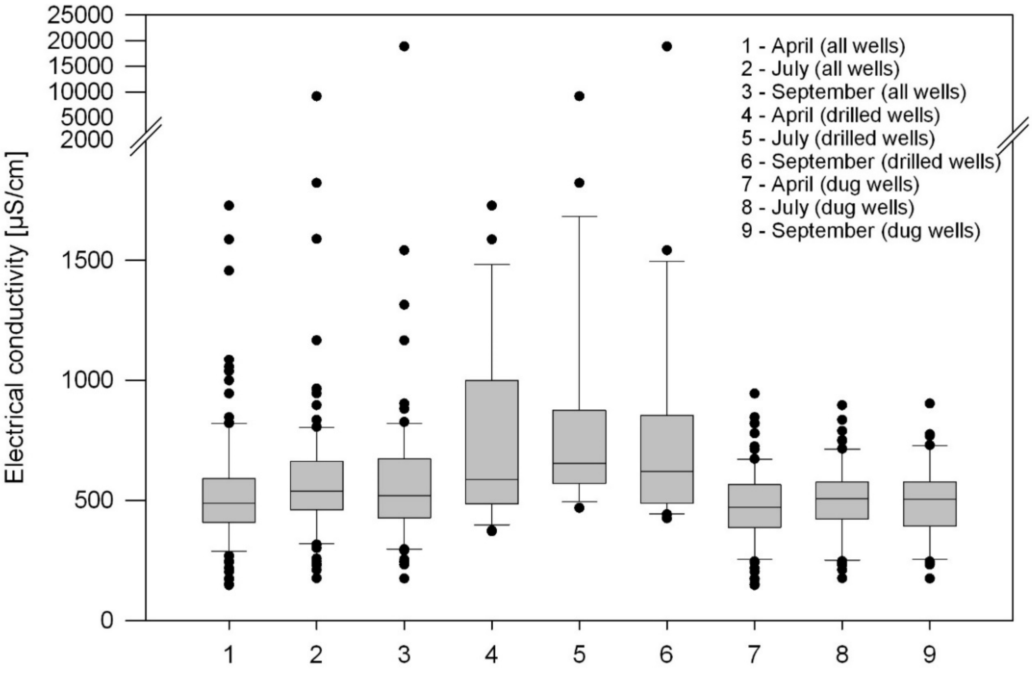

Figure 31: Box plots of EC measurements, grey bars indicating 25/75 percentiles, whiskers indicating 10/90 percentiles, dots indicating outliers, and horizontal lines indicating median values. Note: the scale is logarithmic for better readability.

Figure 32 show the spatial distribution of EC values in samples from all wells in April. No clear general dependency between geographic location and EC can be derived.

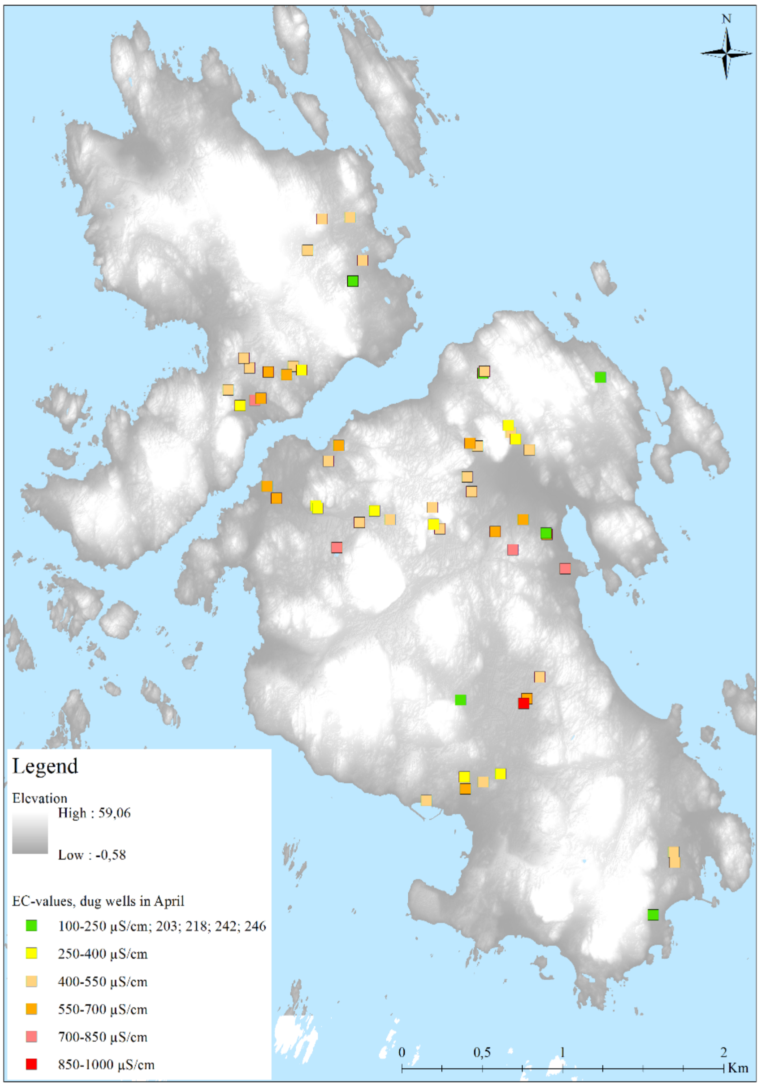

Figure 32: EC in water samples (tap water) collected by well owners in April.

Figure 33 shows the changes of EC between April and July for the dug wells, Figure 34 shows the differences between April and September. It has not been possible to analyze the dependency of direction and magnitude of changes to factors like geology, topography and distance to the shore line – or extraction rates. In any case, a pattern is not clearly visible. It is noteworthy, that in many wells the increases between April and July did not get back to the April values in many wells, in some wells, EC values even continued to increase.

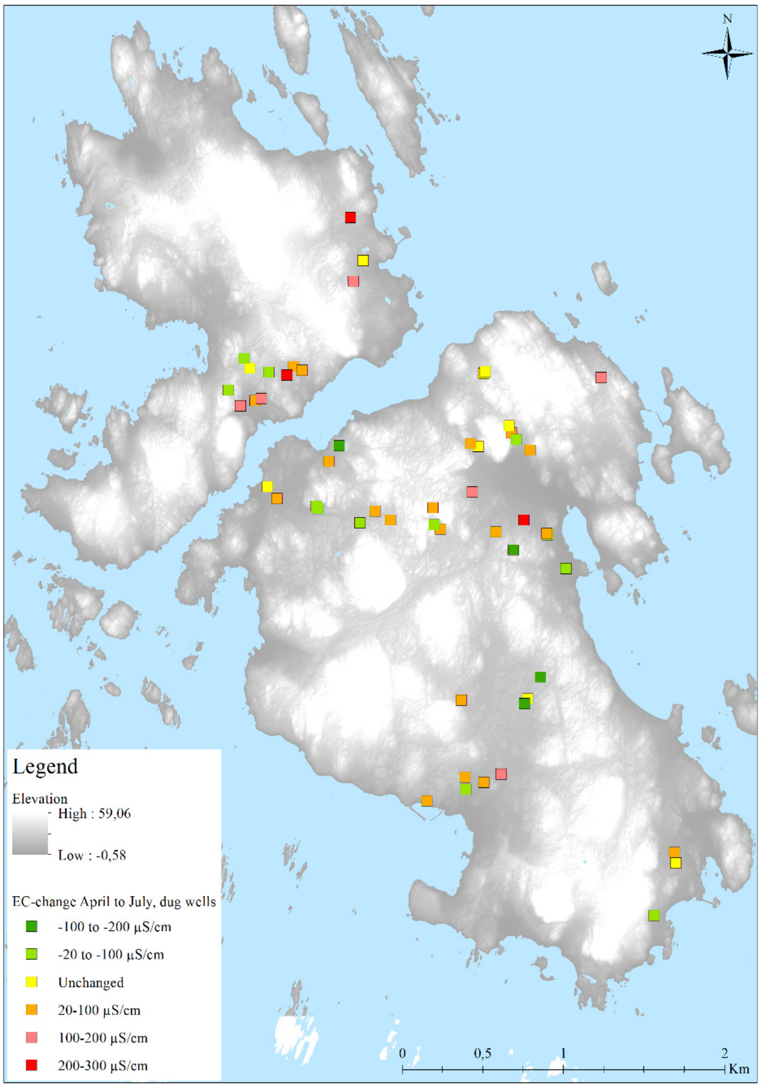

Figure 33: EC in water samples (tap water) collected by well owners, dug wells, changes from April to July.

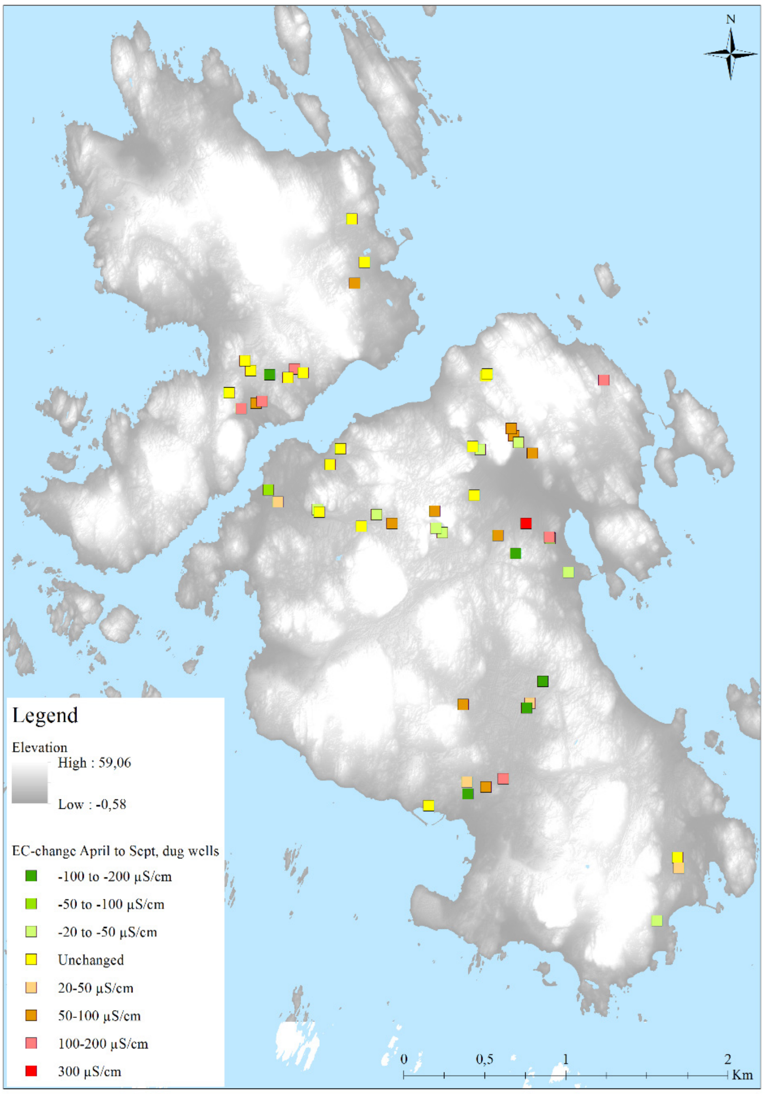

Figure 34: EC in water samples (tap water) collected by well owners, dug wells, changes from April to September.

Figure 35 shows the changes of EC between April and July for the drilled wells, Figure 36 shows the differences between April and September. Again the spatial patterns and factors of influence have not yet been analyzed in detail. In contrary to the dug wells, the EC in September resembles more the EC values measured in April, indicating a faster recovery of drilled wells, similar to the hydraulic heads.

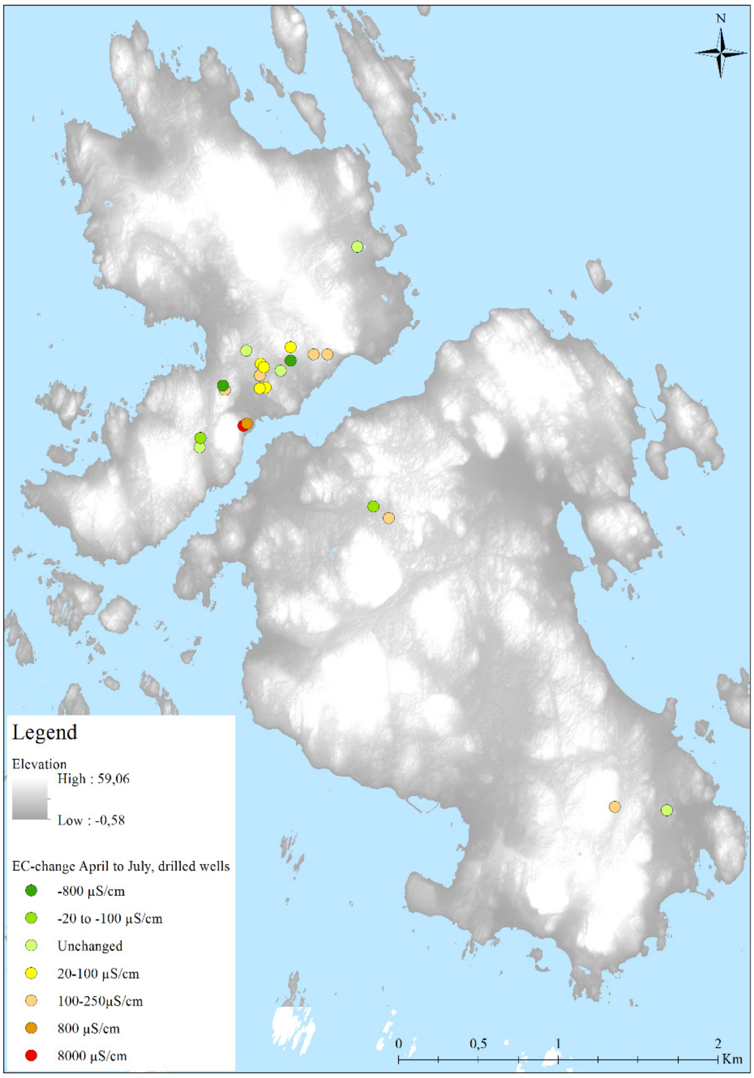

Figure 35: EC in water samples (tap water) collected by well owners, drilled wells, changes from April to July.

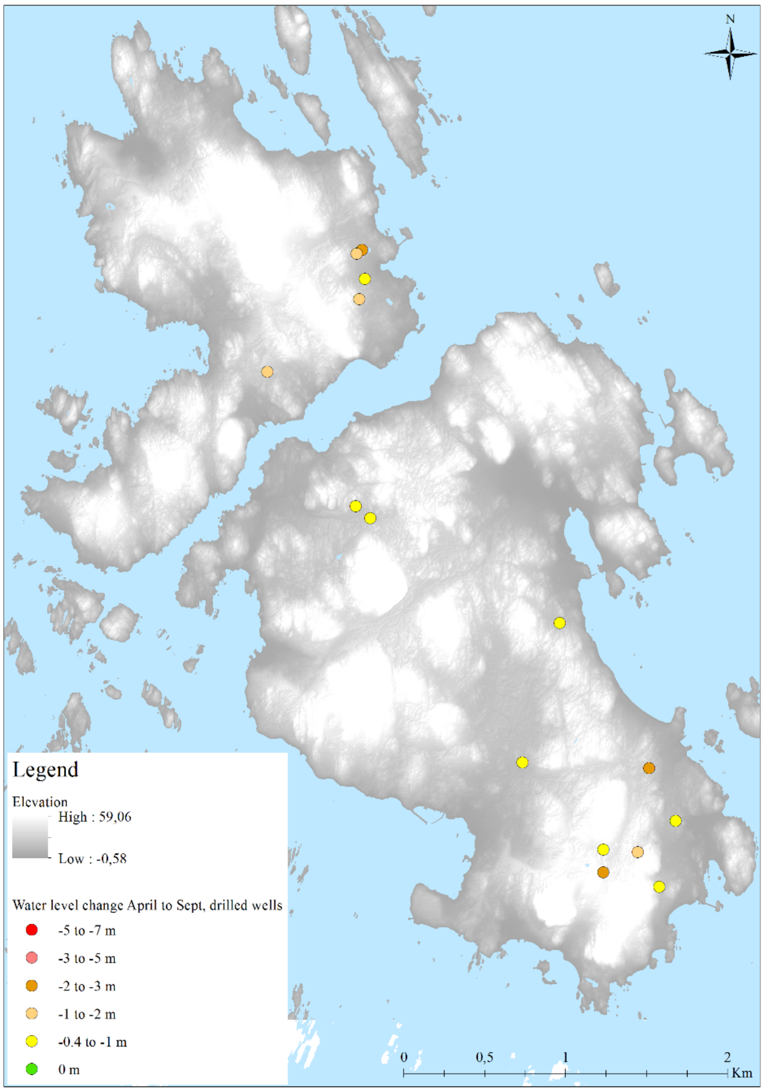

Figure 36: EC in water samples (tap water) collected by well owners, drilled wells, changes from April to September.

Figure 37 shows the geographic distribution decreasing and increasing trend or no significant changes of EC between April and July. Almost all wells with an increased EC, both drilled and dug, are located closer to the shoreline than the ones with a decreased EC on the northern island but not on the southern. A connection between EC-change and topography is visible on both islands. In general, the red squares and circles (increased EC) are located in lower topographic areas (dark grey areas on the map). A change of 40 µS/cm or less was considered within the margin of error of the instrument and these wells was therefore classified as unchanged.

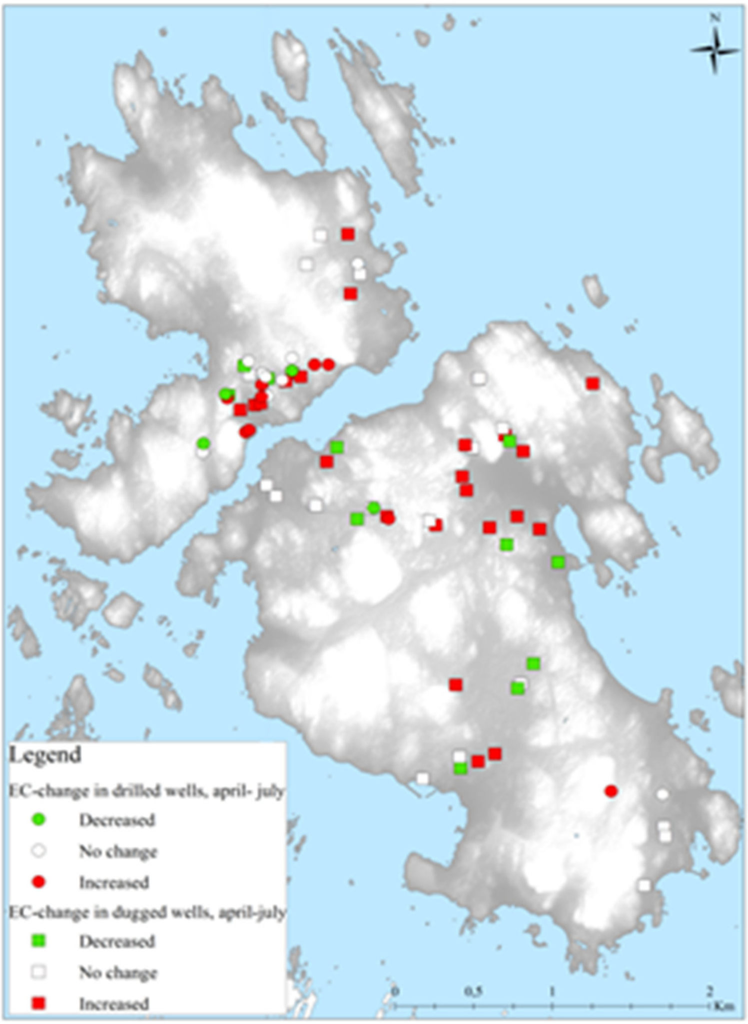

Figure 37: EC in water samples (tap water) collected by well owners in April and July –classified according to trends.

Figure 38 shows correlations of chloride and electrical conductivity for the two sampling campaigns in April and July 2016. There is correlation between the two parameters, indicating that the chloride ion (and with this salt, NaCl) is a main contributor to electrical conductivity. However, there is also some spread in correlation.

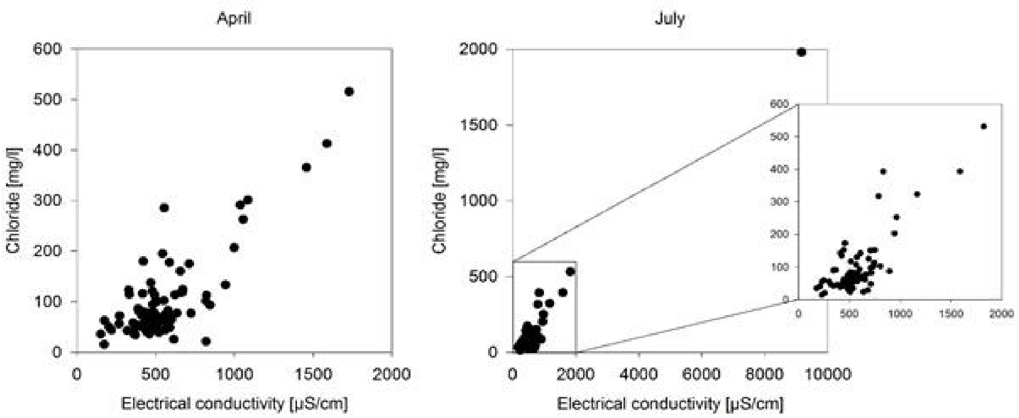

Figure 38: Correlation of chloride concentrations and electrical conductivity for all wells

Overall, the conclusions that can be drawn of the measurements of EC in water samples in April, July and September show that electrical conductivity is generally increasing in times of less groundwater recharge and increased pumping. In some wells, the increase of salinity continues even from July to September. Further monitoring (measurements in December / January) would be required to be sure about the behavior in these cases. It would be very important to know, if all wells go back to "normal" in fall/winter, or if some continue to rise or stay high, indicating salt water intrusion.

However, the results also show that the groundwater systems in different parts of the island behave very differently – which is not entirely unexpected in such a heterogeneous system.

Finally, it should be noted that in many cases, the increases of EC are moderate and not in a range that can be regarded as problematic. Special attention should be given to those wells with very high increases of salinity during the summer.

What the measurements over such a short period cannot reveal, is the status and the trend of the long-term behavior of the groundwater system on the island.

5.2.2 Analysis of metals and major ions

Table 5 and Table 7 show the analysis results of all metal analysis carried out with ICP-MS. The colour codes in the tables indicate the assessment of the metal concentration according to SGUs groundwater quality assessment rules (Table 9).

According to Table 5, 27% of all water samples would receive a classification V (not suitable as drinking water) following SGUs most recent classification because at least one metal exceeds the threshold value for class V. This value lies much higher than the percentage of wells that got a classification "otjänligt" due to chemical parameters in the drinking water analysis that the well owners let do by external laboratories (see section 5.3.1). The reasons for this are that a) the threshold values have become stricter during the years and b) many of the metals we analysed are not included in standard drinking water analysis. According to Table 6 the situation is worst for drilled wells in July, where in 50% of the samples at least one parameter exceeds the threshold value. The drilled wells are in general more problematic with respect to metals and electrical conductivity.

However, the reason for the samples being classified as not suitable are most often EC, sodium and calcium, indicating sea water influence and parameters that could be removed by local treatment. Zinc, nickel and lead could theoretically stem from corroding pipelines. Uranium is of highest concern with about 5% of all samples being not suitable because of concentrations exceeding the thresholds. Iron and manganese can be removed with relatively cheap filters.

In general, the values are typical for Swedish bedrock wells.

Table 5: All water samples classified according to the metal concentrations determined through ICP-MS analysis following classification scheme suggested by SGU (Table 9), where V is "otjänlig" and everything above I is tjänligt med anmärkning. Please not that this table summarizes all measurements (April, July and September) that means up to three samples can stem from the same well.

Groundwater quality classification according to SGU	**II**	**III**	**IV**	**V**
Number of samples where at least one parameter falls in the respective class	243	249	187	67
Percentage of samples where at least one parameter falls in the respective class	97.2%	99.6%	74.8%	26.8%
Number of samples where at least 2 parameters fall in the respective class	229	225	62	13
Percentage of samples where at least 2 parameters fall in the respective class	91.6%	90.0%	24.8%	5.2%
Number of samples where at least 3 parameters fall in the respective class	209	184	19	4
Percentage of samples where at least 3 parameters fall in the respective class	83.6%	73.6%	7.6%	1.6%
Number of samples where at least 4 parameters fall in the respective class	165	112	1	3
Percentage of samples where at least 4 parameters fall in the respective class	66.0%	44.8%	0.4%	1.2%
Number of samples where at least 5 parameters fall in the respective class	108	52	1	1
Percentage of samples where at least 5 parameters fall in the respective class	43.2%	20.8%	0.4%	0.4%

Table 6: Shows the same information as Table 5, yet summarized for the three different sampling periods and with a distinction between dug and drilled wells.

Month	Well type	Number of samples	N: at least 1 III	% at least 1 III	N: at least 1 IV	% at least 1 IV	N: at least 1 V	% at least 1 V
April	Total	90	90	100.0%	62	68.9%	18	20.0%
	Drilled	26	26	100.0%	22	84.6%	9	34.6%
	Dug	61	61	100.0%	38	62.3%	9	14.8%
	Unknown	3	3	100.0%	2	66.7%	0	0.0%
July	Total	95	95	100.0%	72	75.8%	30	31.6%
	Drilled	37	37	100.0%	29	78.4%	19	51.4%
	Dug	55	55	100.0%	41	74.5%	11	20.0%
	Unknown	3	3	100.0%	2	66.7%	0	0.0%
Septem-ber	Total	65	64	98.5%	53	81.5%	19	29.2%
	Drilled	20	19	95.0%	18	90.0%	9	45.0%
	Dug	45	45	100.0%	35	77.8%	10	22.2%
	Grand Total	250	249	99.6%	187	74.8%	67	26.8%

Table 7: Metals responsible for a classification "V" for all water samples according to concentrations of the metals analysed with ICP-MS. Please note than in some samples up to 5 different parameters can be classed "V".

	EC	Na	Mg	Ca	Mn	Fe	Ni	Cu	Zn	Pb	U
Number of samples that were classified as "V" because of:	13	25	4	19	6	4	3	1	4	2	4
Percentage of water samples with a classification "V"	15.3%	29.4%	4.7%	22.4%	7.1%	4.7%	3.5%	1.2%	4.7%	2.4%	4.7%
Percentage of all water samples	5.2%	10.0%	1.6%	7.6%	2.4%	1.6%	1.2%	0.4%	1.6%	0.8%	1.6%

Table 9 shows a comparison of the threshold values and classifications used in SGUs "bedömningsgrunder för grundvatten" and the thresholds defined by Livsmedelverket:

Table 9 gives an overview of all parameters.

Table 8: Comparison of SGUs "bedömningsgrunder för grundvatten" that were used for the classification of samples and the thresholds defined by Livsmedelverket.

		Livsmedelsverket		SGU				
		Tjänligt med anmärkning	Otjänligt	I	II	III	IV	V
Aluminium	mg	0.5		<0,01	0,01–0,05	0,05–0,1	0,1–0,5	≥0,5
Arsenik	µg		10	<1	1–2	2–5	5–10	≥ 10
Bly	µg		10	<0,5	0,5–1	1–2	2–10	≥ 10
Järn	mg	0.5		<0,1	0,1–0,2	0,2–0,5	0,5–1	≥1
Kadmium	µg	1	5	<0,1	0,1–0,5	0,5–1	1–5	≥5
Kalcium	mg	100		<10	10–20	20–60	60–100	≥100
Kalium	mg	12		<3	3–6	6–12	12–50	≥50
Koppar	mg	0.2	2	<0,02	0,02–0,2	0,2–1	1–2	≥2
Krom	µg		50	<0,5	0,5–5	5–10	10–50	≥50
Magnesium	mg	30		<2	2–5	5–10	10–30	≥30
Mangan	mg	0.3		<0,05	0,05–0,1	0,1–0,3	0,3–0,4	≥0,4
Natrium	mg	100-200		<5	5–10	10–50	50–100	≥100
Nickel	µg		20	<0,5	0,5–2	2–10	10–20	≥20
Uran	µg	15		<5	5–10	10–15	15–30	≥30

Table 9: All water samples classified according to the metal concentrations determined through ICP-MS analysis following classification scheme suggested by SGU (SGU, 2013), for each of the parameters for which a classification scheme is provided by SGU

	Absolut numbers								Percentages				
Chemical parameter and month	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**			**Chemical parameter and month**	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**
Conductivity (mS/m)	<10/25	25–50	50–75	75–150	≥150	Total		Conductivity (mS/m)	<10/25	25–50	50–75	75–150	≥150
Total	10	91	106	30	13	250		Total	4.0%	36.4%	42.4%	12.0%	5.2%
April	3	40	34	11	2	90		April	3.3%	44.4%	37.8%	12.2%	2.2%
July	3	29	42	12	9	95		July	3.2%	30.5%	44.2%	12.6%	9.5%
September	4	22	30	7	2	65		September	6.2%	33.8%	46.2%	10.8%	3.1%
Aluminium (mg/l)	<0,01	0,01–0,05	0,05–0,1	0,1–0,5	≥0,5			Aluminium (mg/l)	<0,01	0,01–0,05	0,05–0,1	0,1–0,5	≥0,5
Total	83	55	12	18	0	168		Total	49.4%	32.7%	7.1%	10.7%	0.0%
April	25	16	6	4	0	51		April	49.0%	31.4%	11.8%	7.8%	0.0%
July	41	22	4	10	0	77		July	53.2%	28.6%	5.2%	13.0%	0.0%
September	17	17	2	4	0	40		September	42.5%	42.5%	5.0%	10.0%	0.0%
Iron (mg/l)	<0,1	0,1–0,2	0,2–0,5	0,5–1	≥1			Iron (mg/l)	<0,1	0,1–0,2	0,2–0,5	0,5–1	≥1
Total	200	15	22	9	4	250		Total	80.0%	6.0%	8.8%	3.6%	1.6%
April	49	7	21	9	4	90		April	54.4%	7.8%	23.3%	10.0%	4.4%
July	89	6	0	0	0	95		July	93.7%	6.3%	0.0%	0.0%	0.0%
September	62	2	1	0	0	65		September	95.4%	3.1%	1.5%	0.0%	0.0%
Manganese (mg/l)	<0,05	0,05–0,1	0,1–0,3	0,3–0,4	≥0,4			Manganese (mg/l)	<0,05	0,05–0,1	0,1–0,3	0,3–0,4	≥0,4
Total	189	26	27	1	7	250		Total	75.6%	10.4%	10.8%	0.4%	2.8%
April	75	5	9	0	1	90		April	83.3%	5.6%	10.0%	0.0%	1.1%
July	69	14	8	1	3	95		July	72.6%	14.7%	8.4%	1.1%	3.2%
September	45	7	10	0	3	65		September	69.2%	10.8%	15.4%	0.0%	4.6%

	Absolut numbers								Percentages				
Chemical parameter and month	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**			**Chemical parameter and month**	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**
Arsenic (µg/l)	<1	1–2	2–5	5–10	≥ 10			**Arsenic (µg/l)**	<1	1–2	2–5	5–10	≥ 10
Total	193	4	0	0	0	197		Total	98.0%	2.0%	0.0%	0.0%	0.0%
April	40	0	0	0	0	40		April	100.0 %	0.0%	0.0%	0.0%	0.0%
July	90	2	0	0	0	92		July	97.8%	2.2%	0.0%	0.0%	0.0%
September	63	2	0	0	0	65		September	96.9%	3.1%	0.0%	0.0%	0.0%
Uranium (µg/l)	<5	5–10	10–15	15–30	≥30			Uranium (µg/l)	<5	5–10	10–15	15–30	≥30
Total	222	15	3	4	5	249		Total	89.2%	6.0%	1.2%	1.6%	2.0%
April	84	3	0	2	0	89		April	94.4%	3.4%	0.0%	2.2%	0.0%
July	83	6	1	2	3	95		July	87.4%	6.3%	1.1%	2.1%	3.2%
September	55	6	2	0	2	65		September	84.6%	9.2%	3.1%	0.0%	3.1%
Lead (µg/l)	<0,5	0,5–1	1–2	2–10	≥ 10			Lead (µg/l)	<0,5	0,5–1	1–2	2–10	≥ 10
Total	121	44	24	30	2	221		Total	54.8%	19.9%	10.9%	13.6%	0.9%
April	40	11	7	8	0	66		April	60.6%	16.7%	10.6%	12.1%	0.0%
July	51	19	10	11	2	93		July	54.8%	20.4%	10.8%	11.8%	2.2%
September	30	14	7	11	0	62		September	48.4%	22.6%	11.3%	17.7%	0.0%
Cadmium (µg/l)	<0,1	0,1–0,5	0,5–1	1–5	≥5			Cadmium (µg/l)	<0,1	0,1–0,5	0,5–1	1–5	≥5
Total	198	14	1	0	0	213		Total	93.0%	6.6%	0.5%	0.0%	0.0%
April	48	4	1	0	0	53		April	90.6%	7.5%	1.9%	0.0%	0.0%
July	92	3	0	0	0	95		July	96.8%	3.2%	0.0%	0.0%	0.0%
September	58	7	0	0	0	65		September	89.2%	10.8%	0.0%	0.0%	0.0%
Copper (mg/l)	<0,02	0,02–0,2	0,2–1	1–2	≥2			Copper (mg/l)	<0,02	0,02–0,2	0,2–1	1–2	≥2
Total	109	109	22	2	1	243		Total	44.9%	44.9%	9.1%	0.8%	0.4%
April	39	39	5	0	0	83		April	47.0%	47.0%	6.0%	0.0%	0.0%
July	45	43	7	0	0	95		July	47.4%	45.3%	7.4%	0.0%	0.0%
September	25	27	10	2	1	65		September	38.5%	41.5%	15.4%	3.1%	1.5%

	Absolut numbers								Percentages				
Chemical parameter and month	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**			**Chemical parameter and month**	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**
Chromium (µg/l)	<0,5	0,5–5	5–10	10–50	≥50			Chromium (µg/l)	<0,5	0,5–5	5–10	10–50	≥50
Total	167	33	0	0	0	200		Total	83.5%	16.5%	0.0%	0.0%	0.0%
April	31	9	0	0	0	40		April	77.5%	22.5%	0.0%	0.0%	0.0%
July	79	16	0	0	0	95		July	83.2%	16.8%	0.0%	0.0%	0.0%
September	57	8	0	0	0	65		September	87.7%	12.3%	0.0%	0.0%	0.0%
Nickel (µg/l)	<0,5	0,5–2	2–10	10–20	≥20			Nickel (µg/l)	<0,5	0,5–2	2–10	10–20	≥20
Total	18	115	109	5	3	250		Total	7.2%	46.0%	43.6%	2.0%	1.2%
April	4	46	38	2	0	90		April	4.4%	51.1%	42.2%	2.2%	0.0%
July	8	44	40	1	2	95		July	8.4%	46.3%	42.1%	1.1%	2.1%
September	6	25	31	2	1	65		September	9.2%	38.5%	47.7%	3.1%	1.5%
Zink (mg/l)	<0,005	0,005–0,01	0,01–0,1	0,1–1	≥1			Zink (mg/l)	<0,005	0,005–0,01	0,01–0,1	0,1–1	≥1
Total	35	21	139	42	4	241		Total	14.5%	8.7%	57.7%	17.4%	1.7%
April	10	5	50	14	2	81		April	12.3%	6.2%	61.7%	17.3%	2.5%
July	17	8	59	11	0	95		July	17.9%	8.4%	62.1%	11.6%	0.0%
September	8	8	30	17	2	65		September	12.3%	12.3%	46.2%	26.2%	3.1%
Calcium (mg/l)	<10	10–20	20–60	60–100	≥100			Calcium (mg/l)	<10	10–20	20–60	60–100	≥100
Total	29	40	77	84	20	250		Total	11.6%	16.0%	30.8%	33.6%	8.0%
April	10	12	34	31	3	90		April	11.1%	13.3%	37.8%	34.4%	3.3%
July	12	16	29	30	8	95		July	12.6%	16.8%	30.5%	31.6%	8.4%
September	7	12	14	23	9	65		September	10.8%	18.5%	21.5%	35.4%	13.8%
Potassium (mg/l)	<3	3–6	6–12	12–50	≥50			Potassium (mg/l)	<3	3–6	6–12	12–50	≥50
Total	128	88	33	1	0	250		Total	51.2%	35.2%	13.2%	0.4%	0.0%
April	54	27	9	0	0	90		April	60.0%	30.0%	10.0%	0.0%	0.0%
July	51	32	12	0	0	95		July	53.7%	33.7%	12.6%	0.0%	0.0%
September	23	29	12	1	0	65		September	35.4%	44.6%	18.5%	1.5%	0.0%

	Absolut numbers								Percentages				
Chemical parameter and month	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**			**Chemical parameter and month**	**Class I**	**Class II**	**Class III**	**Class IV**	**Class V**
Magnesium (mg/l)	<2	2–5	5–10	10–30	≥30			Magnesium (mg/l)	<2	2–5	5–10	10–30	≥30
Total	28	166	48	3	4	249		Total	11.2%	66.7%	19.3%	1.2%	1.6%
April	5	62	21	1	0	89		April	5.6%	69.7%	23.6%	1.1%	0.0%
July	16	61	14	1	3	95		July	16.8%	64.2%	14.7%	1.1%	3.2%
September	7	43	13	1	1	65		September	10.8%	66.2%	20.0%	1.5%	1.5%
Sodium (mg/l)	<5	5–10	10–50	50–100	≥100			Sodium (mg/l)	<5	5–10	10–50	50–100	≥100
Total	0	7	162	39	25	233		Total	0.0%	3.0%	69.5%	16.7%	10.7%
April	0	5	63	12	7	87		April	0.0%	5.7%	72.4%	13.8%	8.0%
July	0	1	56	16	11	84		July	0.0%	1.2%	66.7%	19.0%	13.1%
September	0	1	43	11	7	62		September	0.0%	1.6%	69.4%	17.7%	11.3%
Boron (mg/l)	<0,01	0,01–0,1	0,1–0,5	0,5–1	≥1			Boron (mg/l)	<0,01	0,01–0,1	0,1–0,5	0,5–1	≥1
Total	6	178	64	2	0	250		Total	2.4%	71.2%	25.6%	0.8%	0.0%
April	6	70	13	1	0	90		April	6.7%	77.8%	14.4%	1.1%	0.0%
July	0	61	33	1	0	95		July	0.0%	64.2%	34.7%	1.1%	0.0%
September	0	47	18	0	0	65		September	0.0%	72.3%	27.7%	0.0%	0.0%
Total samples	1736	1021	849	270	88	3964							
	43.79%	25.76%	21.42%	6.81%	2.22%								

5.2.3 Organic contaminants

Samples were taken at the locations shown in Figure 10. In all of the samples the concentrations of all the parameters from the group BTEX (benzene, toluene, ethylbenzene and xylene), aliphatic and aromatic compounds, PAHs (Polycyclic aromatic hydrocarbons), VOC (volatile organic compounds) were below detection limit. The suspicious areas as indicated in section therefore seem to be not contaminated. It is however, important to point out that contamination can be local and the small number of sample it is possible to miss. Samples were taken in dug wells only. The results therefore do not confirm that the possibility of organic contamination can be excluded. Also, the chosen parameters, as recommended by the Swedish Environmental Protection Agency are only a small selection of the many possible contaminants.

The latter fact is illustrated by the 2 samples which were analyse for per-fluorinated substances (PFOA, PFOS). As they are often found in relation to firefighting activities (training) it was decided to take the samples close to the fire station. Both samples contain PFAS, one in concentrations close to the threshold values.

Both wells are not used for drinking water supply. In general, the properties in this area are usually connected to the municipal waterworks. However, several wells at properties which do not have municipal water are lying in the direction of GW flow. The values were reported to the environmental department of Strömstad municipality which will investigate the situation further.

5.3 Literature and external data

5.3.1 Chemical and microbial water analysis of drinking water samples carried out but external laboratories

We used reports of water quality analysis performed by external laboratories to see how the water quality on Koster has developed over time. Three different data sets were available to us:

- The folders with analysis reports provided by Strömstad municipality
- A list of chemical analysis made available to use by Lena Maxe, SGU (from the years 2011-2015, collected through an agreement between SGU and different laboratories). 22 analyses altogether.
- Analysis reports sent to us by well-owners in response to our letter in June 2016 and together with the water samples (20).

In the following analysis the data from the folders and the data sent to us directly are analysed as one entity. There data from SGU is analysed separately. Please note that these data sets are huge, and the digitalization of the paper copies alone is a task that would take weeks. So far we have only digitized selected information: Chloride concentrations, electrical conductivity, and the microbiological and chemical assessments.

Through the folders with analysis reports provided by Strömstad municipality and the reports sent to us directly, we got access to 874 individual water analysis from Koster, from 188 properties / locations. The analysis reports stem from the period 1978-2015. From 7 locations we received more than 10 analysis reports (Ekenäs water works: 104), from most properties just 1 (135 with one report, 25 with 2 reports, 12 with 3 reports and 7 with 4 to 10 reports). This confirms the information we got through the questionnaire, that most well owners do not send water analysis to laboratories more than once every 10-30 years. It is unknown how complete the data set by the community is, but it possible that there are several hundred wells on Koster, where the water has never been tested in the last 40 years.

Figure 39 shows the number of analysis reports available to us per year. Some contain only a chemical assessment, others only a microbiological assessment.

Please note, that these values encompass only about 20% of all wells on Koster. Please note also that the values shown here include Ekenäs water works and thus to not show private wells only.

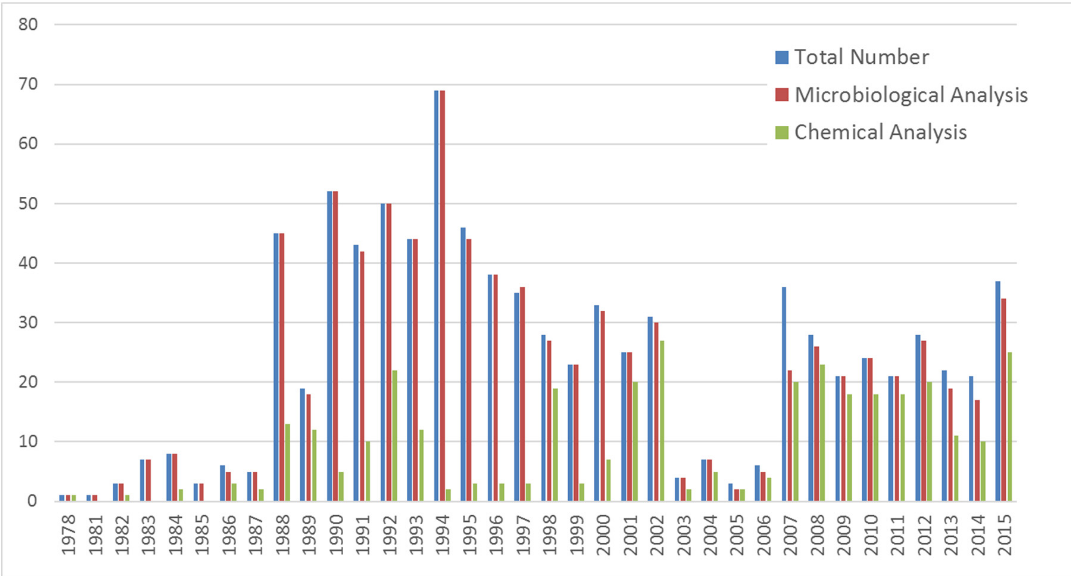

Figure 39: Number of water quality analysis reports available through the folders provided by the municipality of Strömstad and reports sent by well owners. The 22 data sets from SGU (2011-2015) are not included in this diagram.

5.3.1.1 Microbiological analysis

Of the 874 analysis reports, 837 include an assessment of the microbiological status of the water. As Figure 39 shows, the percentage of water analysis reports including a microbiological assessment has decreased slightly in the past few years. We suggest that all analysis should include a microbiological assessment.

Figure 40 shows the percentage of water analysis reports that contain an assessment “not suitable” or “suitable with restrictions” according to microbiological analysis per year. Both numbers have been steadily decreasing in the past years, but “restrictions” still occur in the range of 10-20%. Very few samples are not suitable in the recent years. However, the data provided by SGU shows a higher number of samples which got an assessment "suitable with restrictions" for the years 2011-2015. In the cases where suitable with restrictions was issued, it is usually a high number of coliform bacteria, sometimes also higher numbers of E-coli (which is in other cases a criterion to assess water as not suitable).

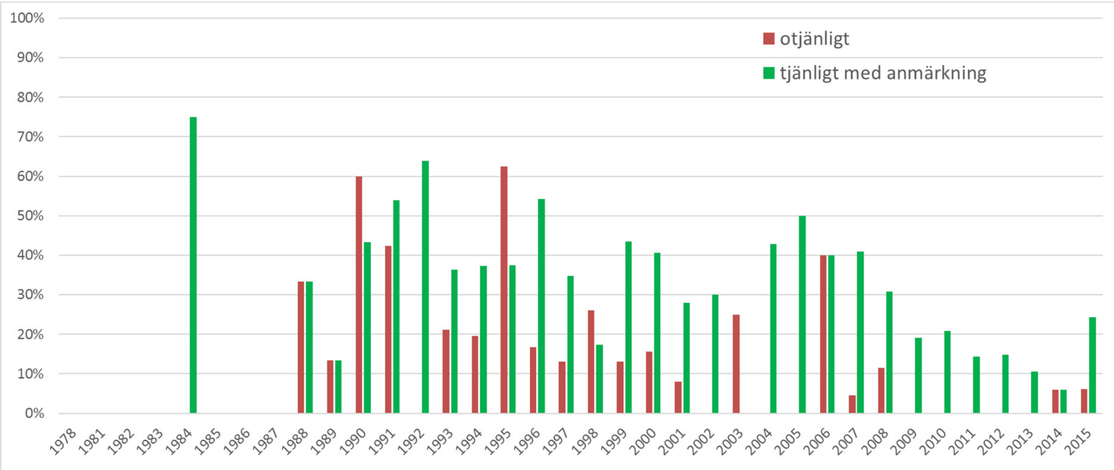

Figure 40: Percentage of water samples that received an assessment "not suitable" or "suitable with restrictions" per year according to microbiological status. Please not that 50% reports received from SGU received the assessment "suitable with restrictions" in the years 2011-2015. This data is not included in this diagram (see Table 10).

5.3.1.2 Chemical analysis

Figure 41 shows the percentage of water analysis reports that contain an assessment "not suitable" or "suitable with restrictions" according to chemical analysis per year. The number of analysis reports with restrictions has been slightly decreasing since 2005 but there might be an increasing trend since 2011. The assessment "with restrictions" still occur in the range of 50% of all samples. Very few samples are not suitable in the recent years. The assessment "with restrictions" was typically made in cases were Iron, Manganese or Chloride (electrical conductivity) were elevated. In some cases, Uranium is the reason for restrictions, in many cases also the low contents of Fluoride. In many cases the comments/restrictions are not worrying and/or concern problems that can be removed through relatively simple treatment.

It should be pointed out, that organic contaminants, heavy metals and other trace elements that can lead to serious health problems are never included in any of the chemical analysis.

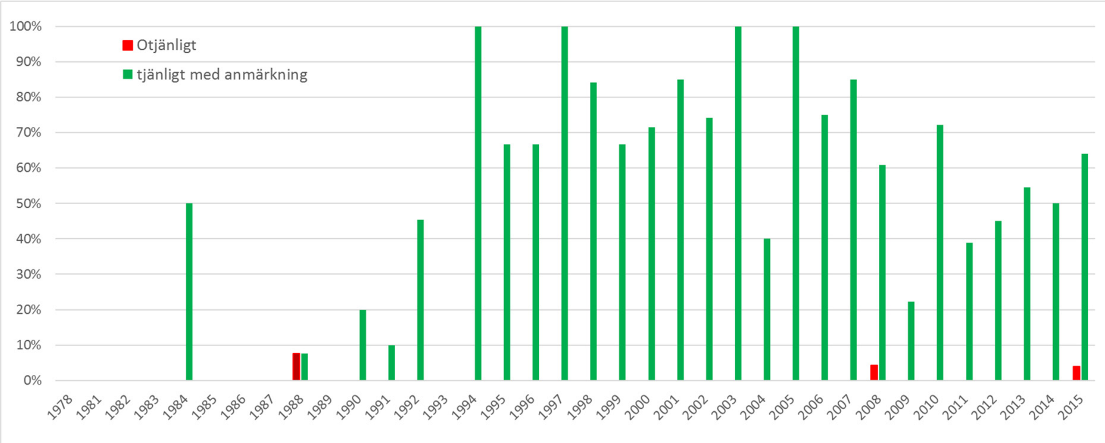

Figure 41: Percentage of water samples that received an assessment "not suitable" or "suitable with restrictions" per year according to chemical status.

The assessment results obtained through the water quality analysis reports from Koster are largely compliant with the conditions found all over Sweden. We quote from the SGU homepage:

En undersökning som gjorts av Socialstyrelsen och SGU visade att kvaliteten på det vatten som används för enskild vattenförsörjning i stor utsträckning inte uppfyller gällande riktvärden. Undersökningen redovisas i "Dricksvatten från enskilda vattentäkter – Ett nationellt tillsynsprojekt 2007". Beroende på om kvalitetsproblem finns kan det finnas anledning för kommunen att överväga om den enskilda vattenförsörjningen i det aktuella området bör ingå i en gemensam lösning för vattenförsörjningen.[10]

It is noteworthy that our own chemical analysis together with the assessment criteria defined in (SGU, 2013) point to a much higher number of not suitable drinking water samples. This may be because we analyzed a higher number of chemical parameters, or because the laboratories applied different criteria.

5.3.1.3 Electrical conductivity and Chloride concentrations

Figure 42 shows the development of the median of electrical conductivity and chloride concentrations from 1982 to 2015. The values, in particular the electrical conductivity for which more values exist, seem to be slightly increasing, in particular in the last 10 years. The significance of the trend is relatively low indicated by a p-value of 0.07.

[10] http://www.sgu.se/samhallsplanering/planering-och-markanvandning/grundvatten-i-planeringen/grundvatten-i-oversiktsplanen/

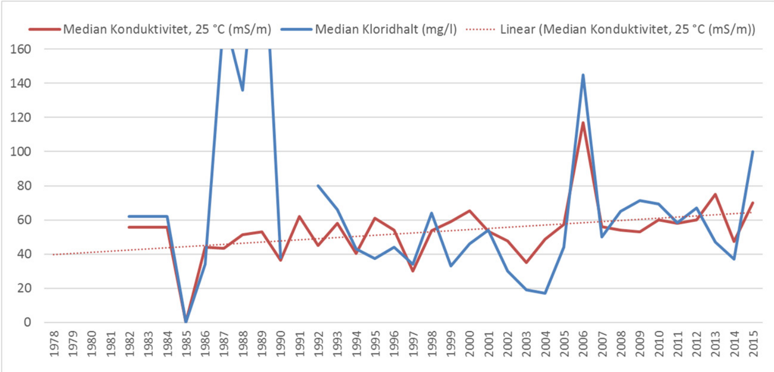

Figure 42: Development of electrical conductivity and Chloride concentration in water samples since 1981 (medians).

Unfortunately, the information whether the wells are drilled or dug, and information on well depth is so incomplete in the analysis reports that an analysis of these aspects and their relation to the chemical status is not possible. It is also not always known where the samples were taken; from tap or the well directly. Also, the data as shown in Figure 42 mixes private wells, water works and other larger facilities.

To illustrate how sensitive the analysis is to selections of sub-sets of data, Figure 43 shows the average electrical conductivity of water for all analysis reports without Ekenäs water works and for Ekenäs water works only. Values for Ekenäs were only available for 2007 to 2015. The values are slightly higher than the averages from all analysis from Koster. As much more values (104) are available from Ekenäs, they lift the overall average and indicate an overall trend that might not be representative (Figure 42).

It is strongly recommended to complete the data set and perform a much more detailed analysis than was possible in the short time span of this project.

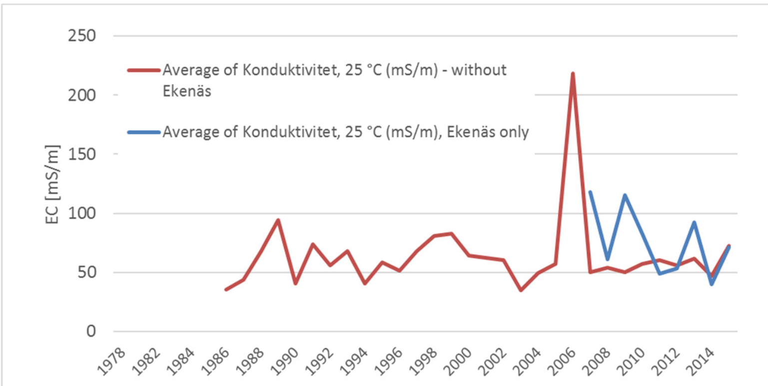

Figure 43: Averages of electrical conductivity, excluding all measurements from Ekenäs water works

5.3.1.4 Analysis of the data provided by SGU (2011-2015)

Table 10 shows a summary of the 22 samples provided by SGU. Only one of the samples was not suitable as drinking water because of chemical status, in the specific case because of lead (Pb). As the well is a dug well, the origin of lead may be from technical installations rather than from natural, geogenic origin. The reasons for an assessment “suitable with restrictions” are in most case iron, chloride (salt) and turbidity. It should be pointed out that very few data sets / samples contain information on metals, radon, etc..

50% of the samples received a classification “suitable with restrictions” because of microbiological factors. The reasons are high concentrations of coliform bacteria and in 2 cases E.coli. All the wells with microbiological problems are dug wells.

Table 10: Chemical and microbiological assessment of 22 drinking water samples from private wells on Koster provided by SGU.

Kemisk bedömning	Otjänligt	Tjänligt	Tjänligt med anmärkning	ingen kemisk bedömning	Total
2011			1		1
2012			6	1	7
2013			4		4
2014	1	1	3	2	7
2015		1	2		3
Total	1	2	16	3	22

Mikrobiologisk bedömning	Otjänligt	Tjänligt	Tjänligt med anmärkning	ingen mikrobiologisk bedömning	Total
2011			1		1
2012		3	4		7
2013		2	2		4
2014		3	3	1	7
2015		2	1		3
Total		10	11	1	22

5.3.2 Inventory of potentially contaminated areas on Koster provided by Strömstad municipality

Contamination of groundwater with organic contaminants is a common problem related to all kinds of human activities, in particular handling of fuels, organic solvents, plant and wood protection products, etc. Production and maintenance of boats is known to have contaminated many locations along the Swedish coast (Bighiu et al., 2016; Eklund and Eklund, 2014; Lagerström et al., 2016). More recently, per-fluorinated compounds were detected in many places related to firefighting activities and training (Banzhaf et al., 2016; Herzke et al., 2012). To evaluate, whether potentially contaminated areas may exist on Koster, we asked the department of environment at the municipality of Strömstad if any suspicions existed.

The following list was provided to us on October 3, 2016:

- Kile 4:2 – ICA-affären vid Torget på Sydkoster. Bensinpump står där och har funnits många år. Bakom affären brändes sopor förr i tiden. Ett lyftbord har läckt hydraulolja vid affären.
- Kile 1:140 – Brandstationen, övningar och test av utrustning har gjorts kring själva brandstationen.
- Kile 1:99 – Mellanlagring av farligt avfall – Tekniska förvaltningen samlar upp Kosterbornas farliga avfall vid några få tillfällen per år.
- Kile 1:9 – Fastighet där mycket skrot och skräp grävts ner under åren.
- Det har funnits en bränslepump i Korsnäshamn för länge sedan.

Båtupptag och hamnverksamhet finns inom följande fastigheter

1. Korshamn/Ekenäs
   a. Kile 5:1
   b. Kile 1:110
2. Kyrkosund
   a. Långagärde 1:11
   b. Långagärde 1:23
   c. Långagärde 1:14
   d. Långagärde 1:12
   e. Kile 2:52
3. Brevik
   a. Brevik 2:1
4. Bodpallen
   a. S:9
5. Vettnet
   a. Nord-koster 1:157

In addition, we received oral / email reports from different people on Koster indicating other possible sources of contamination which we are not listing here.

Following the hints obtained we selected 11 locations to collect water samples and sent them for analysis to Eurofins. The results of the analysis are presented in section 5.2.3.

5.3.3 Weather, climate and sea level data from SMHI

Weather, climate and sea level data from SMHI was used to analysis possible correlations between groundwater levels, precipitation and sea level. Examples are shown in section 5.1.1. The sea level data has not been systematically evaluated yet, but in general, few dependencies became apparent.

Figure 44 shows the results of a comparison of the monthly averages of the mean temperature between 2016, the long-term average reference period 1961-1990 and the averages from the last 11 years (2005-2015). It shows, that the mean air temperatures in each month in 2016 were higher than those of long term averages in 1961-1990. In average, each month in 2016 was 1.7 °C warmer than the reference period. The diagram also shows that the previous 11 years were in average warmer than the long term reference. 2016 was so far slightly warmer than the previous 11 years (0.4 °C). Finally, we show a comparison to 2014, one of the warmest years in the last decade. 2014 was also one of the years that was mentioned in our online-survey as a summer where problems with the water quantity occurred. Compared to 2014, 2016 was about 0.9 °C colder. In particular July 2014 was particular hot with almost 5 °C above the long term average and 4 °C above the 2016 average value.

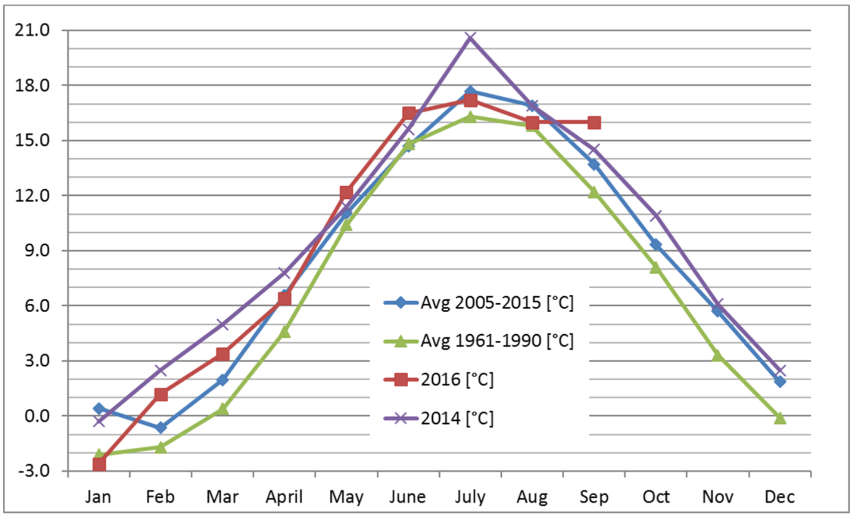

Figure 44: Monthly averages of the mean daily air temperature at Nordkoster weather station (SMHI).

Figure 45 shows the results of a comparison of the monthly sum of precipitation and between 2016, the long-term average reference period 1961-1990 and the averages from the last 11 years (2005-2015). As the variability of precipitation is much higher than the variability of temperature, the picture is less clear here. First, it can be noted that the total annual precipitation in 2005-2015 was higher than in the reference period (2005-2015: 714 mm, 1961-1990: 627 mm). What is interesting, while IPCC and SMHI predict wetter winters and dryer summers on the Northern hemisphere, the development on Nordkoster since 1961 seems to be the other way round: more precipitation in the summer month and equal or less precipitation in the spring, winter and fall. From a groundwater perspective this is unfavorable, as this means less precipitation in the month where groundwater recharge takes place. The additional precipitation in the summer is consumed through evapotranspiration, which will increase with higher temperatures (see above).

2016 was characterized by a relatively wet spring and a relatively dry summer and fall. This has probably led to a good refill of the groundwater reservoir before the summer.

2014, in comparison was extremely dry in June and July, but relatively wet in the spring, fall and winter.

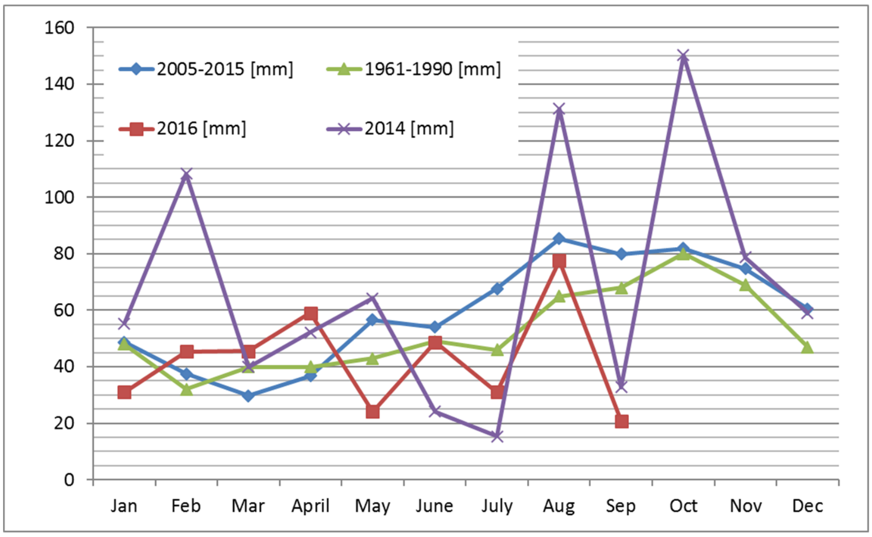

Figure 45: Averages of the monthly sum of precipitation at the Nordkoster weather station (SMHI).

Figure 46 shows a cumulative plot of the average monthly sum of precipitation for 2016, the long-term average reference period 1961-1990 and the averages from the last 11 years (2005-2015). From a water balance perspective looking at precipitation input only, this shows that 2016 was similar to the long term averages 1961-1990 and 2005-2015 but became drier in the summer and fall. In 2014, despite the extremely hot and dry summer, the total availability of precipitation was high throughout the year.

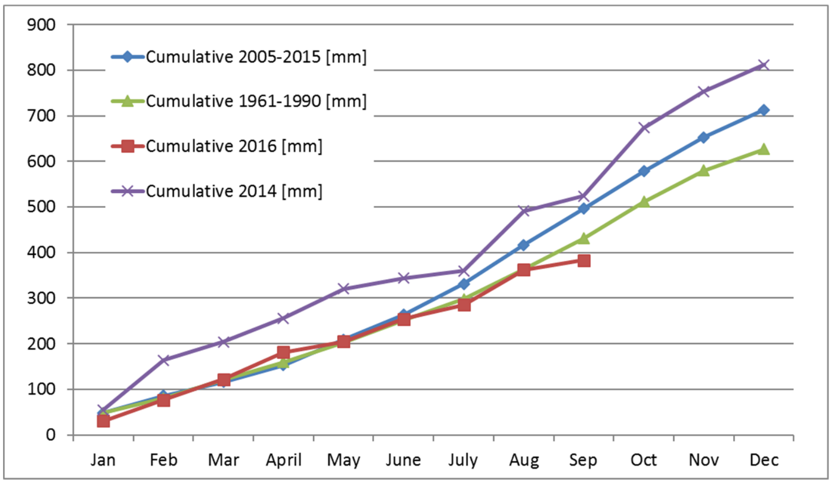

Figure 46: Cumulative plot of the monthly sum of precipitation at the Nordkoster weather station (SMHI).

From the analysis of climatic data presented here the following conclusions can be drawn:

Temperatures on Koster seem to be steadily increasing. This is in line with observations of IPCC/SMHI and the assumption that temperatures will continue to increase seems to be justified. 2016 was a normal year compared to the last 11 years, but abnormally warm with respect to the long term reference period.

Precipitation is also increasing. The variability of precipitation, however, is so strong and the predictions for the future so weak that it is difficult to draw clear conclusions. The observations from Nordkoster seem to indicate, that summers have become wetter, while winters remain approximately at the long term averages from the past. This would be unfavorable for groundwater recharge. 2016 was a relatively dry year in comparison to all past periods evaluated, but the spring was wet, which means good condition for groundwater recharge.

2014 was an interesting year as it was both exceptionally warm and wet. The hot and dry summer preceded a very wet spring. Again, groundwater reservoirs were probably well filled at the start of the dry summer.

In general, it should be noted that the analysis presented here is simplistic and needs to be complemented with model calculations. The relation between precipitation, temperature and groundwater recharge is not at all straightforward and linear. For example, it is not possible to draw conclusions from annual averages and sums or even monthly values. It makes a huge difference if precipitation is evenly distributed over a month or if it falls on a few days only. How precipitation and temperature are related to human water demand is largely unknown. We suggest further investigations in this direction, coupled with analysis of scenarios of future climate.

5.3.4 Groundwater recharge and water availability

5.3.4.1 Groundwater recharge

Groundwater recharge is the most relevant variable quantity for the assessment of groundwater availability. It determines the extractable amount of water over longer periods to guarantee groundwater sustainability, to avoid ecological damages and to avoid seawater intrusion. Groundwater recharge can be conceptualized as precipitation minus evapotranspiration minus surface water runoff, if averaged over a long period of time >>1year. Yearly groundwater recharge was determined for the Koster islands as whole and for 12 sub areas (Figure 47, Table 11), with the purpose to compare these results with the amount of extracted water. These calculations are based on infiltration coefficients which are estimated from literature and not directly measured. Precipitation data together with climatic data needed in the evapotranspiration calculations was retrieved from the weather station located on Nordkoster.

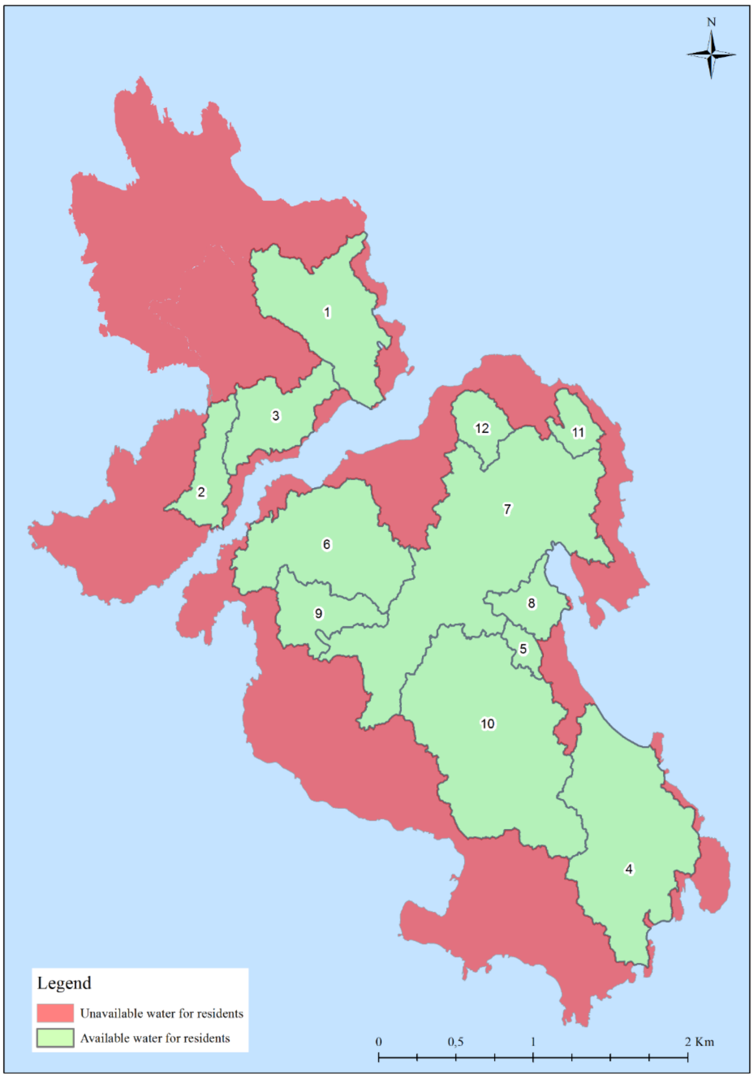

Figure 47. Map showing 12 subareas (green) on the islands where precipitation flows towards soil deposits and is accessible for pumping. Precipitation in red areas are considered to become surface runoff or flow to deposits where no wells are located.

Groundwater recharge was calculated for both soil and bedrock for the entire islands as well as for all sub-areas. To quantift indirect infiltration to soil from surface runoff from bedrock we assumed that:

- On areas where a high percentage of the area is covered by soil, 75% of the surface runoff from bedrock areas infiltrates in adjacent soil areas.
- On areas where a medium percentage of the area is covered by soil, 50% of the surface runoff from bedrock areas infiltrates in adjacent soil areas.
- On areas where a low percentage of the area is covered by soil, 25% of the surface runoff from bedrock areas infiltrates in adjacent soil areas.

The results from the groundwater recharge calculations in Table 12 provide an estimation of the relation between groundwater recharge and extraction on the islands. The extraction does not exceed the calculated groundwater recharge in any of the subareas. Sub-area 3 and 9 are the areas with highest risk for water shortages. Sub-area 3 is located in Duvnäs on Nordkoster and although it has a larger sand- and gravel deposit, the catchment area is relatively small. There is also a large number of residents living in this area. Sub-area 9 is located in western Sydkoster (Vitoxelvägen) and a small sand deposit from which all dug wells extract water. Even though the sand deposit is small, it has a large catchment area, thus a large area contributing to indirect infiltration. This small sand deposit is at high risk for water shortage during longer period with low or no precipitation. It is important to notice that even though these results indicate a high groundwater recharge compared to extraction over the islands, most extraction is concentrated in small parts of these sub-areas which may lead to water shortage locally.

Table 11: Overview of sub-areas used for the water balance calcultions, along with the soil/bedrock ratio and average soil depth.

Sub area		**Surface area soil to surface area bedrock ratio**	**Average soil depth [m]**
	Both islands	41%	1.1
Area ID	All sub areas	47%	1.1
1	Vettnet	67%	1.4
2	Duvnäs	30%	1.5
3	Åleviksvägen	51%	1.0
4	Långegärde	52%	0.74
5	Kyrkosund	19%	1.1
6	Ekenäs	35%	1.5
7	Vitoxevägen	50%	0.18
8	Brevik/röd	41%	1.4
9	Ekenäs-norra	8.5%	1.8
10	Ekenäs-kyrkogård	48%	1.5
11	Bergdalen	46%	0.52
12	Pensionat bergdalen	49%	1.1

Table 12: Extraction and groundwater recharge in mm for 12 subareas. Please note that these values cannot be used to determine extractable volumes at specific locations.

Sub area	Extraction soil [mm/year]*	Extraction bedrock [mm/year]*	Total extraction [mm/year]*	Groundwater recharge soil [mm/year] direct and indirect	Ground-water recharge bedrock [mm/year]*	Volume water in soil [mm]*
Both islands	7.8	4	12	420	31	630
All sub areas	14	9.3	24	280	31	340
1	15	21	36	240	31	380
2	28	18	46	580	31	310
3	43	66	110	280	31	720
4	26	8.5	34	320	31	210
5	8.4	0.66	9.1	400	31	350
6	23	4.1	27	140	31	310
7	25	6.7	32	260	31	230
8	13	0.25	13	410	31	450
9	90	2.8	93	140	31	880
10	10	3.1	13	350	31	560
11	12	3.5	16	360	31	530
12	8.9	2.8	12	340	31	550

* These values express the extraction normalized with the area for the individual sub-areas. They can be used to compare extraction, recharge and storage independent from the area. The annual precipitation assumed for all areas is 726 mm.

We would like to point out that many other factors could/should be included in the recharge calculations, for example soil above bedrock thickness. Low thickness can significantly decrease infiltration rates and thus recharge.

5.3.4.2 Water availability

The maximum amount of water possibly stored in soil and bedrock was calculated, with the purpose to compare these results with the amount of extracted fresh water and the results from the groundwater recharge-calculations. The calculation was carried out for the whole islands and for the twelve sub-areas. The calculations did not contain any measured parameters, only estimated ones.

The volume of fresh groundwater stored in bedrock is conceptualized as the bedrock volume above the transition zone between salty and fresh groundwater and below the water table in the fractured bedrock, times the fractures volume of the bedrock. The following assumptions and simplifications were made:

- The depth of the transition zone was assumed to be a flat, horizontal plane
- The fracture volume used is based on typical volumes for crystalline bedrock in Sweden which may differ from the conditions on Koster.
- It was assumed that the fracture volume (fracture density times aperture) is constant over the entire island

These assumptions and simplifications are necessary as any more realistic representation a) would have resulted in extremely complicated calculations or required a numerical groundwater flow model, and b) would have required data that is not available for most parts of the island.

The volume of fresh groundwater in sediments was estimated as the sediment volume between the bedrock surface and the water table in the sediments, times the specific yield of the sediments. The thickness of the sediments was obtained from a map of soil depth by the Geological Survey of Sweden. The specific yield values are averages from several measurements around the world and not site specific.

Table 13 shows the calculated volumes of fresh groundwater stored in soil and bedrock on the islands. The volumes stated in Table 13 characterize the reservoirs on Koster in general but are of very little practical use. They do not describe extractable volumes. Extractable volumes are defined by groundwater recharge and the local hydrogeological conditions. What is most interesting with these numbers are the quantity of water stored in soil deposits compared to bedrock.

Table 13. Estimated volumes of groundwater stored in the different quaternary geological formations on the island. Please note that the volumes stated here are not extractable volumes. The actual extractable volumes are much smaller and are determined by groundwater recharge and the local hydrogeological conditions at the site of extraction!

Land cover/Land use	**Volume Water (1000 m3)**
Aeolian sand	11
Organic rich clay (Gyttja)	8
Postglacial sand	1689
Wave washed gravel	1115
Shell beds	4
Peat	5
Clapper	207
Bedrock	718

Table 14.Maximum volume of water possibly stored in soil and bedrock together with extraction and groundwater recharge in m^3. Please note that these values cannot be used to determine extractable volumes at specific locations. Also, they describe an overall budget. At a specific location groundwater extraction possibility may be low despite an overall good availability.

Sub Area	**Volume water in soil [1000 m³]**	**Volume water in bedrock [1000 m³]**	**Total volume water [1000 m³]**	**Extraction soil [1000 m³/Year]**	**Extraction bedrock [1000 m³/Year]**	**Extraction Total [1000 m³]**
Both islands	3000	720	3800	38	28	66
All Sub areas	870	310	1200	37	28	65
1	130	30	160	5.1	3.6	8.8
2	39	10	50	1.5	2.3	3.8
3	42	15	57	5.9	8.8	15
4	160	49	210	12	3.6	15
5	5.5	3.2	8.7	0.087	0.029	0.12
6	45	33	78	4.9	1.6	6.5
7	210	75	290	17	4.5	21
8	31	6.8	38	0.74	0.02	0.76
9	4.2	13	17	1.7	0.55	2.2
10	240	63	300	5.5	1.8	7.3
11	38	5.2	43	0.52	0.17	0.7
12	33	7.2	40	0.52	0.17	0.7

5.3.4.3 Summary groundwater recharge and water availability

The water availability calculations provide an indication regarding the amount of groundwater available on the islands and in the respective sub-areas. It can be concluded that groundwater recharge is larger than the maximum possibly stored groundwater some sub-areas 5, 6 and 8 and at least in the same order of magnitude in the others(Table 14). That means that strong changes in recharge (e.g. one or two very dry years) will influence the water availability drastically and there is little storage for making up for missing recharge. The total extraction of groundwater is smaller than both the storage and groundwater recharge in all areas. That indicates that the current groundwater extraction is sustainable, looking at the islands as a whole. However, this does not mean that local water shortages cannot occur. As mentioned earlier, most pumping occurs concentrated in smaller areas. Water, even if available in the vicinity cannot be delivered fast enough horizontally to compensate for a local deficit.

Please notice that all the calculations presented are based on estimates and assumptions and should thus only be used as an indication rather than actual extractable volumes.

5.3.5 Radon

In this investigation, we have not specifically looked at Radon in groundwater. There are several indications that radon may not form a large problem on Koster islands. We suggest to perform a study to be able to quantify the remaining risk.

5.3.6 Results of the online survey

One main purpose of the survey was to determine the number of wells on the island. With only 153 answers to the letters sent to 865 property owners who own 565 properties, this objective could not be reached. We were also surprised that only 16 permanent residents answered. Sending the link to the online survey in a letter is probably not the best but the only feasible approach. Sending out and processing a paper survey with 18 pages to 865 respondents would have required several weeks of processing time.

5.3.6.1 Respondents

The letter with link to questionnaire was sent to 865 addresses. Some recipients own more than one property on Koster, some properties have up to six owners. About 50 letters were undeliverable.

The survey was answered by 153 respondents, whereof two may have answered twice. Of the 153 (151) respondents, 16 live on Koster all year round, 34 own a property there but never live there.

The 153 (151) respondents own 174 properties on Koster (38 own two, six own three properties). 139 respondents have an own well. 117 use the water from this well for drinking water. On the 174 properties, a total of 175[11] wells are located. 112 properties have one well, 29 properties have two wells, two properties have three wells, and 14 properties are without any well. Of these 175 (173) wells, 51 are drilled in bedrock, 119 are dug wells and for five wells no information on the type was provided.

[11] In two cases answers are unclear or contradictory so that some results show a total number of 173 wells only.

5.3.6.2 Wells and water usage

Table 15 shows an overview of characteristics of private wells.

Table 15: Overview statistics of well depth, well capacities and users in winter and summer (see also sections 4.2.3.9 and 5.3.5). N is the number of respondents who filled in values in the respective question. The total number of respondents in the survey was 153, the analysis here is only based on the first well on each property (n= 139). The camping ground was removed from the calculation of the number of users (max. users in summer: 350).

Well type	number of wells	Depth average [m]	Depth minimum [m]	Depth maximum [m]
Borrad	26	65	3	150
Grävd	74	4	2	9

Well type	N	Capacity average [l/h]	Capacity minimum [l/h]	Capacity maximum [l/h]
Borrad	6	605	100	1500
Grävd	3	1567	100	4000

Well type	N	Winter users average	Winter users minimum	Winter users maximum
Borrad	31	2	0	10
Grävd	96	2	0	10

Well type	N	Summer users average	Summer users minimum	Summer users maximum
Borrad	32	7	3	20
Grävd	97	7	0	35

The ratio between dug and drilled wells is roughly 3:1, this corresponds well to other observations. Dug wells are shallow, with an average of 4m. The average depth of drilled wells lies around 65m. Only 3 wells in the sample are deeper than 80 m. Of those, only one is used for drinking water supply.

Unfortunately, very few well capacity measurements exist, but the bandwidth of 100-1500 l/h for drilled wells and 100-4000 l/h for dug wells, matches well with the values found in other parts of Sweden. We recommend to use such values with great care, as the capacity of a well cannot be determined independently of the season, the usage of the well prior to the test and the length of duration of the test. A well can very well produce 4 m^3/h for 24 hours but be dry (water level falls below pump) after 25. Well performances can be tested with specific pumping tests, e.g. step drawdown tests over at least 24 (better 72) hourse.

The average number of users per well in the winter is 2 and 7 in the summer. No differences between dug and drilled wells. In the summer the number of users can be 10 times or more the average number of winter users.

5.3.6.3 Self-control of water quality

In our survey, we asked several questions related to the frequency of sending water samples to certified labs. Having water analyzed in certified laboratories is recommended by the national food agency (Livsmedelverket) at least every third year. 143 respondents (90%) answered this question. Figure 48 shows the respective results. Roughly 50% of the respondents have either never sent samples to a laboratory, or only once within the last 30 years. Another 14% does not know if samples have ever been sent to a laboratory. This means that almost two thirds of the well owners on Koster may not have a recent water quality analysis by a certified laboratory from the last 5-10 years, and only about 10% of the well-owners seem to follow the recommendations by Livsmedelverket to send in a sample for analysis every 3 years.

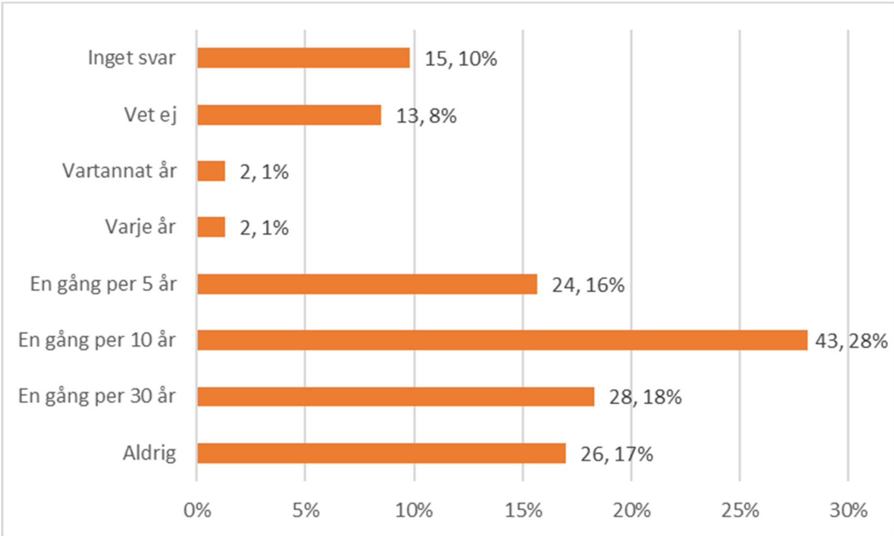

Figure 48: Answers to the question: Hur ofta har ni hittills skickat vattenprover från egen brunn till ett certifierat labb (ALcontrol, Eurofins eller liknande) för att analysera vattenkvalitet?

We also asked about the results obtained from the lab analysis, in particular if the well-owners had received the result "otjänlig" (not suitable) or tjänlig med anmärkning (suitable with restrictions). To evaluate whether the results of the analysis had any influence[12] on the frequency water samples are sent, we looked at the correlation between evaluation results and frequency of sampling. The results shown in Table 16 do not clearly show a respective dependency: About 16% of respondents have gotten a result "otjänlig" or tjänligt med anmärkning" every time or sometimes, while 53% have never gotten such a result. That means also that 30% of well owners may not be aware of their water's quality as the either don't know the results of the analysis or don't know if a sample has been send (inget svar + vet ej).

[12] assuming that people who always get the answer that their water is good tend to send in samples less frequent

Table 16: Correlation between the obtained assessment of drinking water quality and the frequency of sending water samples to the lab

	Har ni någonsin fått ett resultat där vattenprovet erhållit status "otjänlig" eller "tjänligt med anmärkning"?					
Hur ofta har ni hittills skickat vattenprover	Inget svar	Ibland	Ja, varje gång	Nej, aldrig	Vet ej	Grand Total
Inget svar	15 (9.8 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	15 (9.8 %)
Aldrig	8 (5.2 %)	0 (0 %)	0 (0 %)	12 (7.8 %)	6 (3.9 %)	26 (17 %)
En gång per 10 år	1 (0.7 %)	1 (0.7 %)	10 (6.5 %)	29 (19 %)	2 (1.3 %)	43 (28.1 %)
En gång per 30 år	0 (0 %)	1 (0.7 %)	5 (3.3 %)	17 (11.1 %)	5 (3.3 %)	28 (18.3 %)
En gång per 5 år	0 (0 %)	5 (3.3 %)	2 (1.3 %)	16 (10.5 %)	1 (0.7 %)	24 (15.7 %)
Varje år	0 (0 %)	1 (0.7 %)	0 (0 %)	1 (0.7 %)	0 (0 %)	2 (1.3 %)
Vartannat år	0 (0 %)	0 (0 %)	0 (0 %)	1 (0.7 %)	1 (0.7 %)	2 (1.3 %)
Vet ej	0 (0 %)	0 (0 %)	0 (0 %)	5 (3.3 %)	8 (5.2 %)	13 (8.5 %)
Grand Total	24 (15.7 %)	8 (5.2 %)	17 (11.1 %)	81 (52.9 %)	23 (15 %)	153

As there is the possibility that the values shown in Figure 48 do include wells that are not used for drinking water at all we looked at the correlation between the answers to the question if the water is used as drinking water and the results of the analysis provided by the laboratories. As can be seen from Table 17, 21 well owners do not use the water from their wells as drinking waters. 17 seem to use the water as drinking water despite a result "not suitable" or "suitable with restrictions", and 18 use it despite they don't know the result or if water was tested at all. It can be assumed that the seven respondents who did not answer this question most likely don't know the status of their water either.

Table 17: Correlation between the obtained assessment of drinking water quality and the usage as drinking water

	Har ni någonsin fått ett resultat där vattenprovet erhållit status "otjänlig" eller "tjänligt med anmärkning"?					
Används vatten från brunnen som dricksvatten	Inget svar	Ibland	Ja, varje gång	Nej, aldrig	Vet ej	Grand Total
Inget svar	15					15
Ja	7	6	11	75	18	117
Nej	2	2	6	6	5	21
Grand Total	24	8	17	81	23	153

Table 18 shows the result of the cross-correlation between the usage as drinking water and the frequency of sending samples to a lab. It is not possible to conclude that well owners using their water as drinking water send it more often for analysis.

Table 18: Correlation between the frequency of sending water samples to a lab and the usage as drinking water

	Hur ofta har ni hittills skickat vattenprover								
Används vatten från brunnen som dricksvatten	Inget svar	Aldrig	En gång per 10 år	En gång per 30 år	En gång per 5 år	Varje år	Vartannat år	Vet ej	Grand Total
Inget svar	15								15
Ja		19	36	27	22	1	2	10	117
Nej		7	7	1	2	1		3	21
Grand Total	15	26	43	28	24	2	2	13	153

Table 19 shows the results of a cross correlation of the obtained analysis result and measures to improve the water quality. Of the 130 well owners that could answer the question of measures that have been taken with yes or no, 41 have taken measures, but interestingly not predominantly those with a result showing problems with water quality.

Table 19: Correlation between the obtained assessment of drinking water quality and measures to improve water quality

	Har ni någonsin fått ett resultat där vattenprovet erhållit status "otjänlig" eller "tjänligt med anmärkning"?					
Har ni vidtagit några åtgärder i syfte att förbättra vattenkvaliteten?	Inget svar	Ibland	Ja, varje gång	Nej, aldrig	Vet ej	Grand Total
Inget svar	17					17
Ja	1	5	7	27	1	41
Nej	6	3	10	54	16	89
Vet ej					6	6
Grand Total	24	8	17	81	23	153

5.3.6.4 Subjective assessment of problems with water quality and quantity

We also asked the question if well owners had problems with water quality and quantity. According to Table 20, 50% had never had any problems with the quality and 70% did not experience water quantity problems.

Table 20: Summary of answers to the questions about problems with water from the wells.

Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)	Brunn 1	Brunn 2	Brunn 3	Brunn 4	Alla brunnar	%
Brunn finns ej	15	124	149	152		
Ja	62	12	1	0	75	43.6%
Nej	71	11	3	0	85	49.4%
Vet ej	5	6	0	1	12	7.0%
Grand Total	138	29	4	1	172	

Har ni haft problem med vattentillgången (t.ex. försämrad kapacitet)?	Brunn 1	Brunn 2	Brunn 3	Brunn 4	Alla brunnar	%
Brunn finns ej	15	123	149	152		
Ja	38	6	0	0	44	25.4%
Nej	95	21	4	0	120	69.4%
Vet ej	5	3	0	1	9	5.2%
Grand Total	**138**	**30**	**4**	**1**	**173**	

The most common problem with the subjectively experienced water quality is color (32 of 62[13]), followed by smell (21/62) and taste (19/62). In 13 cases (13/62) problems were others, like hardness, or unspecified problems. Salt was only mentioned in 2 cases in the questionnaire. Which is somewhat surprising, as our samples show a higher number of wells with high salinity.

Table 21 shows the relation between problems with groundwater quality and quantity experienced by well owners and the type of the well (drilled, dug). The ratio between problems experienced in either drilled or dug is about the same ratio as the total number of drilled/dug wells for the quality assessment. From the subjective assessment, it is thus not possible to say that drilled wells are better than dug ones or vice versa with respect to water quality. When it comes to water quantity, 84% of the wells experiencing problems are dug wells, thus considerably more than the dug/drilled ratio of the total number of wells.

[13] These numbers are based on the first well on each property only.

Table 21: Problems experienced by well owners with water quality or quantity according to an online survey. Please note, the answers refer to the first well on a property only. Please note: Even people who answered "No" to the question if they experienced problems, described problems in their comments.

	Brunn 1: Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt?				
Brunn 1 är:	Inget svar	Ja	Nej	Vet ej	Grand Total
Brunn finns ej	14				14
Borrad		17	15	2	34
Grävd		43	54	3	100
Vet ej	1	2	2		5
Grand Total	15	62	71	5	153

	Brunn 1: Har ni haft problem med vattentillgången (t.ex. försämrad kapacitet)?				
Brunn 1 är:	Inget svar	Ja	Nej	Vet ej	Grand Total
Brunn finns ej	14				14
Borrad		6	27	1	34
Grävd		31	65	4	100
Vet ej	1	1	3		5
Grand Total	15	38	95	5	153

In summary, it can be concluded that according to the answers of the respondents, 61 out of 173 wells (35%) never had any problems with either quality or quantity. Two thirds of the wells with problems are dug wells, one third drilled – about the same ratio as the total number of dug/drilled wells.

Regarding the problems mentioned by the well owners it should be mentioned that a considerable number of respondents answered "no" to the questions if they have experienced problems with quality or quantity, but nevertheless described respective problems in the comments to this question. Some stated, for example, that the water had color, taste or smell, but they would not regard this as a problem. With respect to water quantity, only two respondents answered " no" to the question if they had any problems, but mentioned respective problems in the comments. In the comments, it was also mentioned that the own well delivered water, while the neighboring wells went dry.

Table 22 list the answer regarding problems reported with water quantity (38 of 139 wells). Please note that some well-owners answered "No" to the question if they had problems, but described problems anyway. Please note also that the answers listed here only refer to the first well on each property (139 wells).

Table 22: Text answers to the question regarding problems with water quantity (answer refer to the first well on a property only)

Brunn 1 är:	Problem med vattentillgången	Brunn 1: Har ni haft problem med vattentillgången (t.ex. försämrad kapacitet)? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)
Grävd	Ja	Ja under torra somrar och stor familj boende
Grävd	Ja	tar slut när många är på plats på sommaren
Borrad	Ja	Regn fattiga sommrar
Borrad	Ja	Om för mycket vatten används måste man vänta ett tag.
Grävd	Ja	Vissa år, vid långvarig torka,ett par veckor i slutet av juli.
Grävd	Ja	Den var jättedålig när den användes och sinade varje sommmar det är därför vi nu bara använder brunns 2 som är djupborrad.
Grävd	Ja	Under sommar månader vid torr väderlek
Grävd	Ja	Kopplar över till brunn 2 vid torra somrar, precis gjort det denna sommar men aldrig förra sommaren (skall nu gå tillbaka till brunn 1 eftersom tillgången är god igen)
Grävd	Ja	I slutet på varma somrar har vi haft väldigt litet vatten och det har sjunkit 6 cm om dagen, trots snål användning. Som värst har vi varit nere på 16 cm vatten ovan hinkkant (en hink sitter runt bottenventilen för att vi ska få in mindre sand), då gav vi upp och åkte hem. På våren (april) kan vi ha c:a 3,5 m.
Grävd	Ja	Vi har ej spoltoalett, diskmaskin eller tvättmaskin. Duschar sparsamt (tvättar oss i havet). Ändå kan nivån sommartid bli oroväckande låg. Vi har aldrig pressat brunnen. Önskemålet är naturligtvis ngt mer bekvämligheter
Grävd	Ja	Extrem torra somrar t.ex. 2014 med 10 mm regn 10 maj - 3 aug sinar brunnen. Ev. var även 1976 ett sådant år då brunnen sinade.
Borrad	Ja	En gång sommaren vattnades gräsmattan varvid inget vatten kom under en kort stund, max 10 minuter.
Borrad	Ja	Mycket dåligt tillflöde som har försämrats de senaste åren
Grävd	Ja	Vi är fem fastigheter som använder brunnen. Regnfattiga somrar får vi knappt kaffevatten-
Grävd	Ja	Ca 10 år siden, etter tørr og varm sommer.
Grävd	Ja	sinade ett par somrar på 60-70-talet
Grävd	Ja	Vi ransonerar vissa somrar under 1-2 mån
Grävd	Ja	Vi måste vara sparsamma med vattnet ej duscha varje dag och tvätta i tvättmaskin.
Grävd	Ja	Sinar under en varm sommar
Borrad	Ja	Juli/August 2014 var kapasiteten til tider dårlig. Ellers har den vært god.
Grävd	Ja	Några dagar vid extremt torra somrar
Grävd	Ja	Vid nyttjande av brunn under sommaren sinar den (vid torrt väder)
Grävd	Ja	Vid ett tillfälle vid en speciellt torr sommar innan vi låtit djupborra en brunn.
Grävd	Ja	Torra somrar var det risk att brunnen sinade
Grävd	Ja	Under torra somrar ransonerar vi vattenuttaget.
Grävd	Ja	varma somrar är vi mycket sparsamma
Grävd	Ja	Jag har alltid uppfattat vattentillgången som dålig och snålar med vatten så att det inte ska ta slut.

Brunn 1 är:	Problem med vattentillgången	Brunn 1: Har ni haft problem med vattentillgången (t.ex. försämrad kapacitet)? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)
Grävd	Ja	Vi har problem under vissa perioder (juli-augusti)särskilt torra år. Andra delar av året är vattentillgången mycket god. OBSERVERA också att brunnen bara är ca 3 m djup (sen kommer berg).
Grävd	Ja	Under torra somrar kan vattnet ta slut.
Grävd	Ja	Vi får snåla på vattnet torra somrar. Särskilt dålig tillgång var det sommaren 2014 då brunnen mer eller mindre sinade.
Grävd	Ja	Om fler än 6 personer i fastigheten sjunker vattennivån från markytan från 0,5 till 4,5 m. Något år som varit regnfattigt har brunnen sinat. Vi kompletterar brunnsvatten med regnvatten för spolning av toaletten.
Borrad	Ja	Efter 40 år något igenslammad.Löstes i maj 2016 med högtrycksspolning av vatten.Fungerar nu utmärkt igen.
Vet ej	Ja	Vid torrperioder sinar brunnen utan att något vatten används. "Brunnen" läcker vad jag kan förstå.
Grävd	Ja	Vid långa torkperioder har vattennivån varit mycket låg, men aldrig helt slut
Grävd	Ja	En torr sommar under 10 år Vatten rann till men vi var många i hushållet och en viss brist uppstod
Grävd	Ja	Vid extrem torka. Vi är alltid mycket nogranna med hur vi nyttjar vattnet.
Grävd	Ja	Kun I torke perioder og mange mennesker
Grävd	Ja	Ja när det är torr sommar sinar brunnen nästan. Just nu är det ca 45 cm vattendjup.

Table 23 list the answers to the question about problems with water quality (62 of 139 wells). Please note that some well-owners answered “No” to the question if they had problems, but described problems anyway. Please note also that the answers listed here only refer to the first well on each property (139 wells).

Table 23: Text answers to the question regarding problems with water quantity (answer refer to the first well on a property only)

Brunn 1 är:	Problem med kvaliten	Brunn 1: Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)
Borrad	Ja	Efter kraftiga regn blir vattnet gult. Det försvinner efter någon veckas användning. Det blir dock inget fel på vare sig smak eller lukt eller drickbarhet.
Grävd	Ja	Tidigare kunde vattnet vara lite humusfärgat på våren men inte de senaste 5 åren. men vi har inte tidigare varit boende i huset så mycket vinter som de sista åren
Grävd	Ja	Litet dysmak vid säsongsmörjan Litet instängd doft sommartid
Grävd	Nej	Kalkhaltigt vatten
Grävd	Ja	Lätt järnfärgat, smakar järn
Grävd	Ja	Bara sommarbostad. Vattnet kan vara lite missfärgat inledningsvis (någon dag) då vi startat upp vattenpumparna.
Grävd	Ja	gulaktig färg, sediment

Brunn 1 är:	**Problem med kvaliten**	**Brunn 1: Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)**
Borrad	Ja	Tidigare luktade det lite svavel
Grävd	Ja	Lite gulaktigt i färgen, men smakar inte något.
Grävd	Ja	Ovanligt, nej, men i jämförelse med kommunalt dricksvatten så har vattnet en viss gulfärg och vissa känsliga personer tycker det inte smakar gott, andra dricker det utan problem.
Vet ej	Nej	Vattnet har lite färg men det uppfattar vi inte som ovanligt.
Grävd	Nej	Brunnen används ej som hushållsvatten, enbart som komplement för WC.
Borrad	Ja	tidvis lätt brunfärgat
Grävd	Ja	Smakar ej bra lite gulaktig färg
Borrad	Ja	Om vatten tas ut i stor mängd, och på förhållandevis kort tid, uppstår en "unken" lukt som försvinner efter 2-4 h (när vattnet fått rinna till i egen takt?)
Borrad	Ja	Då den "knackade" djupborrade brunnen gjordes i slutet av 1950-talet fick man en liten saltvatteninträngning. På 1980-talet cementerade en brunnsborrningsfirma igen ca 20 meter av de ursprungliga ca 50 m. Detta resulterade i försumbar saltvatteninträngning. Brunnen ligger på strandfastighet, ca 25 meter från havet.
Grävd	Ja	När nivån stigit efter kraftigt regn har min fru uppfattat vattnet som mindre bra.
Grävd	Ja	humusdoft, färg och smak. Varierar över året. Järnutfällningar i porlinet. Oljig/fet karaktär på vattnet.
Grävd	Ja	smakar inte särskilt gott. vi använder det i kokt form till the och kaffe men dricker det f.ö. inte
Grävd	Ja	Vissa somrar ibland gulfärgat. Järn fälls ut i brunnen men inte i huset.
Borrad	Ja	Salt, kalk
Borrad	Ja	Svavelväte de första åren från 2002 därefter avtagande men återkommande på försommaren.
Borrad	Ja	Salt smak
Grävd	Ja	Har haft gulaktig fär i flera år.
Grävd	Nej	färg
Grävd	Ja	Brun Missfärgning, har alltid varit så
Borrad	Ja	Ljusbrun färg vid regn
Grävd	Ja	Något brunt emellanåt.
Grävd	Ja	På sensommaren kan ibland upplevas lukt och smak av metangas. Av hjälps med tryckluft.
Grävd	Nej	Vannet har både smak, lukt og farge, men det oppfattes ikke som uvanlig.
Borrad	Vet ej	Har litt brunfarge.
Grävd	Ja	Ved høyt forbruk og lite nedbør kan vannet bli brunt. Kan da ikke brukes som drikkevann
Borrad	Ja	Lukter i perioder, svovel lukt
Grävd	Ja	lätt brunfärgat, blir en brunaktig beläggning på insidan av koppar etc.
Grävd	Ja	Har luktet svovel, og smakt litt dårlig, selv om det er rent. Se det jeg skrev om vannrensing.
Borrad	Ja	Lukt og farge

Brunn 1 är:	Problem med kvaliten	Brunn 1: Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)
Grävd	Ja	Svag järnsmak. Svag brun färg förekommer
Grävd	Ja	Dysmak
Grävd	Ja	Vattnet är gult och kan ibland lukta svavel.
Grävd	Ja	gul-brun färg har alltid funnits och minskar efter rengöring av brunnen, vilket görs var tredje-fjärde år. Ingen konstig smak eller lukt.
Grävd	Ja	Svavellukt och bubbel nær inter ær anvænd på en stund.
Grävd	Ja	Missfärgning (förhöjd järnhalt) Tillfälliga föhöjnigar av bakterihalt
Grävd	Ja	Missfärgat pga järn/humus
Grävd	Ja	Viss humussmak under högsommar allt sedan brunnen grävdes. Helt ok smak vår, försommar och höst
Borrad	Ja	Vattnet har en viss lukt och från början var vattnet grumligt men nu är det mycket bättre.
Grävd	Ja	Lätt brunfärgat vatten
Grävd	Nej	inte så gott använder det ffa till the och kaffe d.v.s. kokt förutom disk, toa, dusch etc
Grävd	Ja	Litt smak av järn
Grävd	Ja	Vattnet blir ibland missfärgat. Det smakar inte alltid så bra.
Grävd	Ja	Vid kraftiga regn kan vattnet vara av sämre kvalitet. Lite grumligt, sumpaktig lukt och dålig smak.
Grävd	Ja	"brunt" vatten (ytvatten tränger in regniga somrar)
Grävd	Ja	Ofta mot slutet av sommaren. Lite svavelvätedoft och unken smak. Något gul-färgat.
Borrad	Ja	När brunnen inte använts på några veckor kan det lukta lite svavel innan det spolats en stund. En maskin tvätt o sedan är vattnet ok igen.
Grävd	Nej	Litt humus og gulaktig vann, men det er helt okay
Borrad	Ja	Har haft lukt och färg
Grävd	Ja	Enstaka tillfällen har vattnet luktat lite dåligt(detta har hänt när vi tagit ut mycket vatten tidig vår och nivån har varit väldigt hög blir bra efter någon vecka när nivå stabiliseras sig)
Borrad	Ja	Vid kraftiga regn har tidigare ytvatten runnit ner i borrhållet , detta är nu åtgärdat
Grävd	Ja	Vattnet har alltid varit hårt, så det har behövts mkt diskmedel och tvättmedel. De sista åren blev det en gul beläggning på glas och plast.
Grävd	Ja	Smakar lite mossa, färgar brunt på sanitetsporslin etc
Grävd	Ja	Smak av mylla vid långvarig nederbörd eller snösmältning, främst vår.
Vet ej	Ja	Vattnet är "regnvatten" och kan vara grumligt samt viss unken doft.
Grävd	Ja	Innan installation av filter lukt och smak av rötgas eller likv. men lukt och smak försvann med filtrering. Lätt brunfärgat vilket inte försvann trots filter
Grävd	Ja	Lite missfärgning humus?
Grävd	Ja	svagt guldfärgat vatten. Vattnet är hårt (skalgruslager i marken) och innehåller en del järn och möjligen lite mangan

Brunn 1 är:	**Problem med kvaliten**	**Brunn 1: Har ni haft några problem med att vattnet har någon smak, lukt eller färg som ni uppfattar som ovanligt? - Om ja, vänligen specificera nedan. (vad, hur, när, hur länge, etc.?)**
Grävd	Ja	Lukt (ruttet ägg), försvinner allteftersom vi använder. Är sommarboende ich kommer hit på helger. Färg, som mycket ljust te
Grävd	Ja	dålig smak och lukt.
Vet ej	Ja	Se tidligere kommentarer
Borrad	Ja	Från start 2003 och under 8-9 år tydlig lukt av svavelväte. Detta problem finns ej längre.
Borrad	Ja	Brunnen borrades år 1964. Tillgänglig vattenvolym kunde inte fastställas, eftersom den översteg max kapacitet för den mätutrustning som fanns. Vattenprov skickades för analys, utan anmärkning. Från början var vattnet kristallklart och helt utan bismak. Med åren blev vattnet något brunfärgat, särskilt på våren, troligen humus och/eller rost. Aldrig någon besvärande bismak. Efter byte 2016 till dränkt pump är vattnet åter klart och färglöst.

5.3.7 Information retrieved through personal communication

In the course of the project, we had many exchanges with people living permanently or temporarily on Koster through direct communication, on the phone or by email. We took notes of some of the telephone conversation and saved all emails for further evaluation. We do not report on those answers here specifically, but would like to point out that both water quantity and water quality from private wells are perceived very differently by different users.

6 Discussion, conclusions and recommendations

Please refer to the Swedish summary at the beginning of this report (section 1) for discussion, conclusions and recommendations.

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