



Irrigation pond at Emmaboda Golf Club. Photo: Michael Bekken.

Irrigation with brackish and wastewater on Swedish golf courses

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As the effects of climate change become more pronounced and summer droughts become more frequent, an increasing number of golf courses in northern Europe may need to transition to lower quality irrigation water sources.

Approximately 70 golf courses in Sweden and Finland are located close to the Baltic Sea, and many of them have looked for alternative water sources in recent years. The Baltic Sea has a salinity of 0.6–1.0 % NaCl, substantially lower than ocean water ($\approx 3.5\%$), but still high enough to create challenges for turfgrass management. Excess salt in irrigation water and in the soil is an issue for turfgrass because high salt concentrations limit water uptake into the plant. Salinity of irrigation water

is measured by the electrical conductivity (EC) of irrigation water (W) and is abbreviated EC_w . Salinity of the soil is measured by the electrical conductivity (EC) of the soil (E) and is abbreviated EC_E . If the salinity of the soil solution is too high, water does not flow into the plant.

In addition to the overall salinity of the soil, the sodicity of the soil is also important. Sodicity is the presence of sodium (Na) in irrigation water and in the soil. Sodicity in irrigation water is measured by the sodium adsorption ratio (SAR) which is the ratio of sodium ions to calcium (Ca) and magnesium (Mg) ions. Sodicity in the soil is measured by the exchangeable sodium percentage (ESP) which is the percentage of sodium ions that occupy

the cation exchange sites in the soil. High percentages of sodium in the soil cause clay minerals to disperse, which greatly reduces macropore space and thus water infiltration and the flow of gases into and out of the soil.

In FAIR WATER II we wanted to learn about the use of low quality irrigation water on seven golf courses along the Baltic coast of Sweden (Figure 1).

At each golf course we tested irrigation water quality and evaluated soil salinity and sodicity levels on putting greens. Preliminary results from October 2024 were presented by Aamlid et al. (2025). Here we continue with results from 2025.

Golf courses in study

- Ljunghusens GK
- Falsterbo GK
- Flommens GK
- Ronneby GK
- Emmaboda GK
- Västerviks GK
- Loftahammars GK

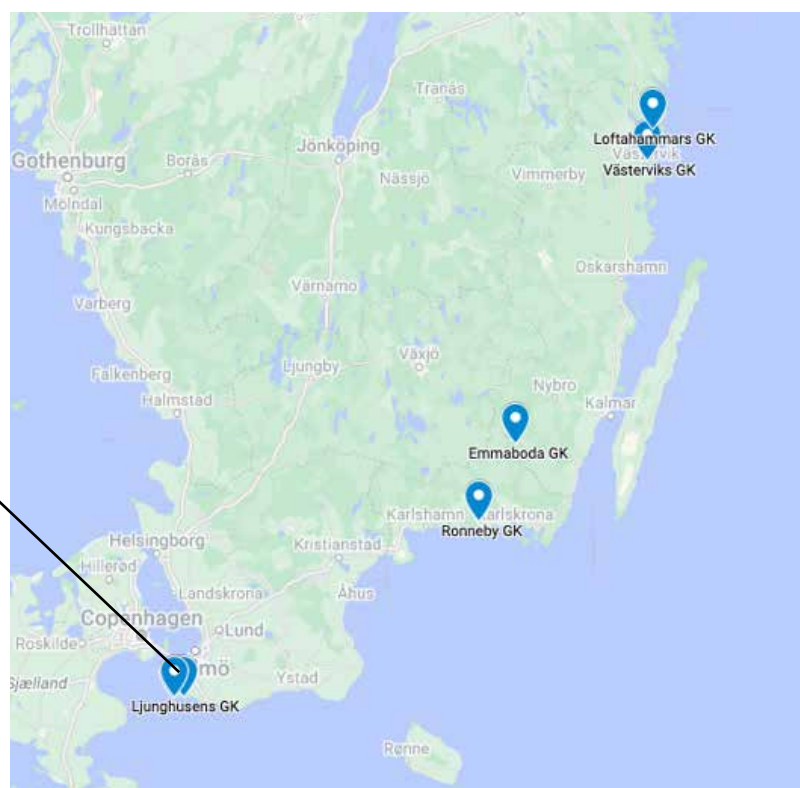
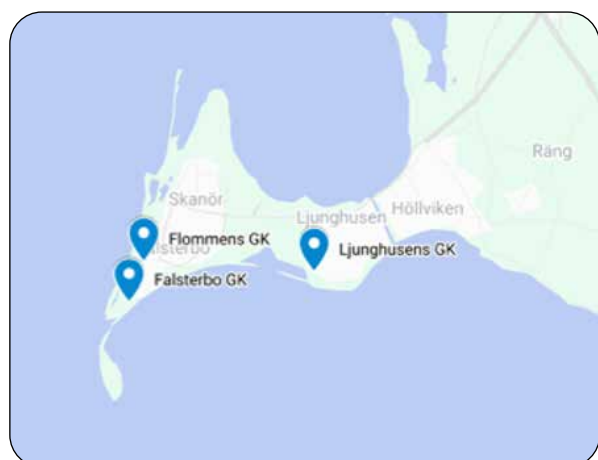


Figure 1. Map of south Sweden showing location of the golf courses.

Methods

Samples of irrigation water and soil from the top 10 cm on three putting greens were analyzed at a commercial soil testing laboratory. Commonly accepted threshold values for cool-season turfgrass are indicated below (Westcot & Ayers 1985, Liu et al. 2023):

- Salinity (Electrical Conductivity) of irrigation water (EC_w):
 - $<0.75 \text{ dS m}^{-1}$: No detrimental effects
 - $0.75\text{-}1.5 \text{ dS m}^{-1}$: Salt stress symptoms can occur
 - $>1.5 \text{ dS m}^{-1}$: Good leaching and drainage required
- Salinity (Electrical Conductivity) of soil (EC_e): $2\text{-}4 \text{ dS m}^{-1}$ (dependent on grass species)
- Sodicity of irrigation water (Sodium Adsorption Ratio, SAR (Na relative to Ca+Mg): 10
- Sodicity of soil (Exchangeable Sodium Percentage, ESP): 15%

Results

The golf courses have come up with different solutions to irrigate with alternative water sources (Table 1).

For example, Västervik Golf Club collects storm water from the housing development around the golf course, mixes it with water from the Baltic Sea, and uses this water on the course. Emmaboda and Loftahammar irrigate with effluent water from wastewater treatment plants. Ljunghusen, Falsterbo, and Flommen source their water from groundwater wells that with rising sea levels suffer from saltwater intrusion from the Baltic Sea. Ronneby irrigates with water from a river near its outlet to the Baltic, meaning that low discharge of the river increases salinity.

The samples of irrigation water from October 2024 indicated that salinity and sodicity levels were generally below thresholds of con-

Table 1. Survey results from interviews with the superintendent at the seven Swedish golf courses involved in the study.

Golf course	Irrigation source	Salinity symptoms	Salinity mitigation measures	Grass species on greens
Ljunghusen	Groundwater with saltwater intrusion	Yellowing of turf on greens	No solutions attempted	Annual bluegrass, red fescue, creeping bentgrass, ryegrass
Falsterbo	Groundwater with saltwater intrusion	Stressed, yellow, and weak turf	Flushing, soil surfactant RePhlex	Red fescue, creeping bentgrass, annual bluegrass
Flommen	Groundwater with saltwater intrusion and stormwater from village	Loss of turgor pressure, spots	Flushing, seaweed product, spray Ca, aeration	Annual bluegrass, red fescue, creeping and browntop bentgrass
Ronneby	River with saltwater intrusion at low discharge	Patches of dead spots, LDS	No solutions attempted	Annual bluegrass, creeping bentgrass
Emmaboda	Effluent water from wastewater treatment plant that is filtered through the course	No symptoms	No solutions attempted	Annual bluegrass, creeping bentgrass, red fescue
Västervik	Greens: stormwater from village. Fairways: stormwater mixed with Baltic Sea water	No symptoms	No solutions attempted	Annual bluegrass
Loftahammar	Effluent water from wastewater treatment plant	No symptoms	No solutions attempted	Annual bluegrass, creeping bentgrass



Irrigation pond for mixing of storm water from village with brackish water from the Baltic Sea. Photo: Lars Delborn.

cern for cool season grasses. Only Ljunghusen had an EC_w clearly above 0.75 dS m⁻¹ (Table 2).

However, the summer samplings at the three golf courses on the Falsterbo peninsula in 2025 revealed substantially higher levels. In June 2025, Ljunghusen and Falsterbo had salinity levels at or above the EC_w threshold of 0.75 dS m⁻¹. In addition, the SAR threshold of 10 for irrigation was exceeded at Ljunghusen, but not a Flommen or Falsterbo (Table 2).

Conversely, the salinity of the soil at the time of testing at the time of testing in these three golf courses did not exceed commonly accepted thresholds (Table 3). Ljunghusen, Falsterbo, and Flommen all had soil salinity levels at all three dates of testing that did not exceed an EC_e of 1.2 dS m⁻¹. Thus, even though the irrigation water at these three courses exceeded salinity thresholds, there was still enough water from rainfall or irrigation leaching through the profile to keep soil salinity from exceeding thresholds. Hence, we also found no salinity symptoms when visiting the courses during the summer of 2025. As for sodicity, the ESP of the soil on the putting greens were elevated in June and August 2025 in comparison to October 2024, but none of them exceeded 15%. That said, sodicity is typically not an issue on sand-based putting greens because of the low clay content. In the future, conducting sodicity soil tests on fairways of golf courses that have high SAR values in their irrigation water would be warranted as the native and finer textured soils of the golf course are at higher risk.

At Ronneby the EC_w of the irrigation water was 4.6 dS m⁻¹ in June 2025 and 5.0 dS m⁻¹ in August 2025 which is highly saline water for turfgrass irrigation. The sodicity of the irrigation water was also high in summer 2025 with SAR values of 21 and 28, respectively, far above the recommended SAR threshold of 10. The high sodicity of the irrigation water was reflected



Loftahammar GC irrigate with effluent water from wastewater treatment plants. Photo: Anders Karlson.

Table 2. Salinity and sodicity (SAR: Sodium relative to Calcium + Magnesium) in irrigation water samples taken in October 2024, June 2025 and August 2025 on the seven golf courses. Values above critical limits are indicated in red.

Water samples	Salinity: EC _w (ds m.1) (Threshold: 0.75)			Sodicity: SAR (Threshold: 10)		
	Oct-24	Jun-25	Aug-25	Oct-24	Jun-25	Aug-25
Ljunghusen (new)	2.5	2.0	1.7	5.7	19	16
Ljunghusen (old)		1.6	2.1		14	24
Flommen	0.40	0.74	0.47	1.6	3.7	2.9
Falsterbo		1.2	1.1		6.4	6.0
Ronneby	0.19	4.6	5.0	1.2	21	28
Emmaboda	0.21	0.16	0.3	1.3	0.21	0.99
Västervik	0.31	0.25	0.22	2.6	0.70	0.61
Loftahammar	0.53	0.84	0.80	2.2	4.3	3.4

in the soil sodicity tests at Ronneby where the ESP was nearly 30% in August 2025, again far above the recommended threshold of 15%.

Of the seven golf courses, Ronneby was the one that had the most critical results of the water and soil analyses, although even here, we did not see visual salt damage in 2025.

Solutions to excess salinity

When irrigating golf courses with high salinity, a leaching fraction can be included to keep soil salinity at a tolerable level. The leaching fraction can be calculated as:

$$\text{Leaching fraction} = \frac{\text{ECw}}{(5\text{ECe (threshold)} - \text{ECw})}$$

where ECw is the salinity of irrigation water, and the ECe value is the maximal salinity of the soil that can be tolerated by the turfgrass. We recommend testing the salinity levels of your soil just as salinity symptoms start to appear. The threshold will likely be between 2 and 4 ds m⁻¹, lower for annual bluegrass and browntop (colonial) bentgrass than for creeping bentgrass and red fescue, and lower for establishment than for mature grass. (Carrow & Duncan 1998, Aamlid & Landschoot 2007).

If a leaching fraction of 0.5 is calculated it means that approximately 50% more water is required to leach salts through the profile in addition to that needed to replace evapotranspiration. Applying a leaching fraction will only work in soils that are relatively well drained, because the method relies on moving water down through the soil profile to remove excess salts from the rootzone.

Taking as an example the high salinity (4.6 ds m⁻¹) of irrigation water at Ronneby GC in June 2025 and assuming that we do not want soil salinity to exceed the value of 2.3 ds m⁻¹ that was measured at the same time.

Table 3. Salinity (electrical conductivity) and sodicity (ESP = Sodium as percent of cation exchange capacity) in soil samples taken in October 2024, June 2025 and August 2025 from the top 10 cm of the rootzone. Means of three greens per golf course. Values above critical limits are indicated in red.

Soil samples	Salinity ECe (ds m ⁻¹). Threshold: 2.0			Sodicity: ESP (%). Threshold: 15		
	Oct-24	Jun-25	Aug-25	Oct-24	Jun-25	Aug-25
Ljunghusen	1.0	1.1	1.0	4.8	11	12
Flommen	0.5	0.8	0.9	2.0	9.0	6.8
Falsterbo	0.4	1.2	0.9	2.6	6.3	5.8
Ronneby	0.6	2.3	2.0	3.7	3.9	29
Emmaboda	0.5	0.5	0.6	1.1	4.0	2.4
Västervik	0.7	1.4	0.8	1.3	4.6	2.5
Västervik (fairway)	0.8	1.0	0.8	1.3	2.6	1.9
Loftahammar	0.4	0.9	1.0	1.9	5.1	8.4

The leaching fraction is :

$$\frac{4.6}{(5 \times 2.3 - 4.6)} = 0.67$$

If you know the evapotranspiration (ET) rate at your golf course on any given day, you can then calculate the water requirement in millimeters.

$$\text{Water requirement} = \frac{(\text{Evapotranspiration (mm)})}{(1 - \text{Leaching fraction})}$$

In the example from Ronneby GC and assuming a daily ET of 4 mm, the daily water requirement would be

$$\frac{(4 \text{ mm})}{(1 - 0.67)} = 12 \text{ mm.}$$

See Woods (2022) for further information about leaching requirements.

Solutions to excess sodicity

On fine textured soils such as clay, adding gypsum (calcium sulfate) will allow calcium to displace sodium on the exchange sites. The quantity of calcium that needs to be added depends on the current and the target ESP, the soil's cation exchange capacity and bulk density, and how deep you want calcium to displace sodium. See Woods (2022) for details.

Conclusion

The alternative water sources used in this study show a variety of solutions for golf courses in water scarce areas. Overall, our impression is that the courses in the study have learned to manage the challenge imposed by high salinity and/or sodicity. At Ljunghusen, Falsterbo, Flommen and Ronneby there are, however, periods in the summer where the turfgrass quality on greens, tees and fairways may benefit from including a leaching fraction when calculating irrigation amount, and where the fairway quality on clay soils may benefit from the application of calcium sulfate (gypsum).



A photo from the work of collecting soil and water samples at Ljunghusen Golf Club in October. This course has issues with excessive salt in the irrigation water. Photo: Michael Bekken.

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