STORAGE AND TRANSPORT OF WATER UNDER WATER
LAGRING OCH TRANSPORT AV VATTEN UNDER VATTEN

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Abstract

Placing water tanks or water pipes under water has the advantage that the walls are subjected to a much lower pressure difference. An underwater tank, where the walls are made from a flexible material like canvas, instead of metal or concrete, can adjust its volume to exactly the volume to be stored inside. Tennis tents are examples of such soft constructions on land. A pipe may economically assume a much larger diameter on the bottom of the sea, as compared to over land. That enables pipes with extremely low pressure drops and that the pipe also may be made of canvas. A common firehose is an example of such a pipe used on land – flat, transportable, cheap, and light when not used. Two examples for sweet water to drought-stricken Gotland are given. The first example is storing 1 million m³ from abundant-water-winters to summer, resulting in an annualised cost of 2–3 SEK/m³ ($0.2 – $0.3/m³). The other example is a 183 km long pipe in canvas transporting 2 m³/s sweet water to Gotland from mainland Sweden. That water is then roughly estimated to cost annually 1 SEK/m³ ($0.1/m³) used on Gotland. Could this be cheaper than desalination?

Key words: Underwater storage, pipe, canvas, Gotland

Sammanfattning

Undervattenstankar och undervattensrör har fördelen att begränsningsytorna utsätts för en mycket lägre tryckdifferens. En undervattenstank som är gjord av ett flexibelt material som duk, istället för av metall eller betong, kan anpassa sin volym till exakt den inneslutna volymen. Tennistält är exempel på sådana mjuka konstruktioner på land. Rör med stor diameter kan mycket enklare förläggas på sjö- eller havsbotten än på land. Det tillåter rör med extremt lågt tryckfall och att röret därigenom också kan konstrueras av tunt material som duk. En vanlig brandslang är ett exempel på ett sådant rör som används på land – platt, transportabel, billig och lätt när den inte används. Två exempel ges för sötvatten till torkdrabbade Gotland. Det första exemplet innefattar lagring av 1 miljon m³ från vinter till sommar där det beräknade årliga kostnaden är 2 – 3 kr/m³. Det andra exemplet är en 183 km lång ledning av duk som transporterar 2 m³/s från fastlandet till Gotland. Vattnet uppskattas då grovt kosta cirka 1 kr/m³ vid Gotland. Kan detta var billigare än avsaltning?

Introduction

Wouldn't it be nice if sweet water could be stored or transported over long distances in large quantities and at a very low cost? The need for this is great all around the world. The alternative is often desalination of seawater, which is both capital-, maintenance- and energy intensive. This article was triggered by the Cementa mining conflict on Gotland. However, there could be many better options outside the courtrooms, alleviating the water situation on Gotland.

It will be necessary to find a larger community that is cooperating with a larger company to first verify the ideas hereunder and later build a prototype somewhere. Maybe Gotland at a later stage could benefit as a full scale demonstration opportunity. This study has been done without any support or funding. No patent has been applied for, and no political or commercial interests are behind it so far.

Storing water in water

Storages and pipes under water, made of thin flexible material like canvas could in many cases drastically reduce the cost of supplying sweet water compared to e.g. desalination processes. We can see such large canvas constructions on land, e.g. blown up tents over tennis courts or larger fire hoses.

When placing a tank of water under water, the pressure from outside will be roughly the same as inside. If the walls of such a submerged tank are also made flexible, like a submerged giant "plastic bag", you could supply or withdraw water from the bag while the walls were flexing. Now imagine such a plastic bag, not for a litre but for 20 000 m^3 using canvas. Canvas would thus separate the water inside the "bag" from the outside water. Canvas is an inexpensive material compared to materials normally used. Let's call this concept an **U**nder **W**ater **R**eservoir (**UWR**). Very rough annualised investment calculations with 5 % real interest and 20 years life length indicate that water can be stored winter to summer at the cost of 2–3 SEK / m^3 (~0.2 -0.3 \$/m^3).

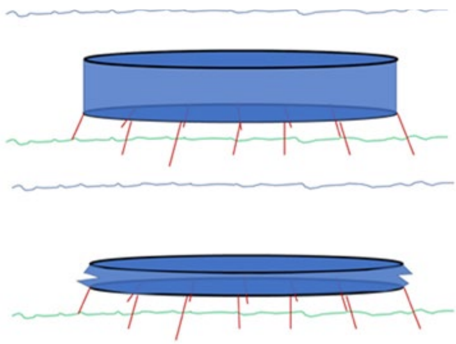

Figure 1. *An UWR of canvass anchored to the bottom (more refined in fig 6).*

When transporting water in water the same canvas material as above can be used, forming a hose/pipe, just like a fire hose. Such a pipe may be manufactured, kept and transported flat, but becomes round by the inner pressure, when used.

The pipe diameter is especially important. With a constant flow, doubling the diameter reduces both the pressure and the energy needed for pumping, by a factor ~32. The circumferential length and the needed pipe material thickness to withstand internal overpressure, must however both be doubled, yielding a factor 4. Combining both the lower pressure needed for the same flow and the increased material needed for the larger diameter, the needed pipe wall material mass will be only 4/32 or just 1/8 to transport the same amount of water. This strongly favours large diameters. Such large pipes can easily be managed under water but normally not above ground or dug down. Let's call this concept an **U**nder **W**ater **P**ipe (**UWP**). Rough investment calculations (5 %, 20 yr) indicate that 1 m^3/s of water can be transported 180 km in a 4 m wide UWP at a cost of 0.5 – 1 SEK/m^3 water.

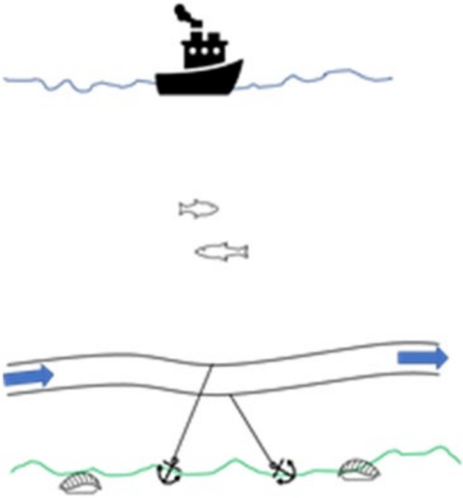

Figure 2. *An UWP of canvas with a lighter medium inside (more refined in fig 8).*

Example Gotland

Gotland is made up of a sequence of sedimentary rocks of limestone and shales spanning 200–500 m deep. There is very little space for groundwater to collect in crevasses, and therefore wells tend to dry out fast, especially during hot summers. The distributed drinking water is presently taken from lakes, a few wells and through desalination of Baltic Sea water. Water for irrigation is often stored in earth-dams from the colder months to summer.

The precipitation on Gotland, not taking evaporation or absorption by vegetation into account, is normal for Sweden i.e., 500–600 mm. This would be enough for both drinking water and irrigation, if the water had accumulated as ground water instead of quickly leaving the island through rivers and creeks into the sea.

The population living permanently on Gotland is around 60 000 but during a few summer months the population is drastically increased. The average needed future water consumption for both drinking water and agriculture, can be roughly estimated to ~1 m^3/s or more than 30 Mm^3/year (M = million). The maximum need occurs in summer months, ~2 m^3/s.

There is often a public drinking water shortage during summer, meaning that restrictions are imposed on the water users: "Don't water your lawn". The earth dams, used for irrigation today, are not being able to cover for the total future need. Thus, more water must either be stored or transported to Gotland. A rough estimation of the need is shown in figure 3.

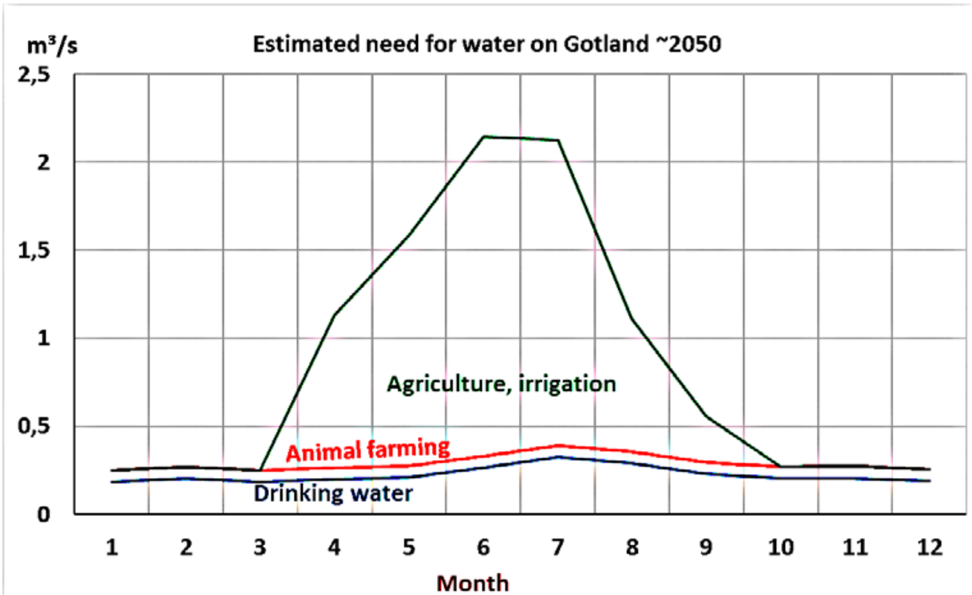

Figure 3. *Whereas the average need for water is 1 m^3/s, the maximum need is 2 m^3/s. (There are 31.5 million seconds in a year to get the yearly need)*

Saving 1 Mm^3 extra for drinking water

A "citizen initiative" has been proposed, to save around 1 Mm^3 more than is used today, for the summer public drinking water production. Saving that amount of water would significantly reduce the drinking water shortage in the summertime. It also seems as if many politicians are in favour of this "citizen initiative". The water proposed to be saved, presently just runs from lake Tingstäde directly into the sea during wintertime and is wasted. An UWR could alternatively store that one Mm^3 outside Irevik, where the creek from Lake Tingstäde enters the sea.

If the same quality of water (VISS, 2022a) as the water exiting Lake Tingstäde is desired, a pipe must be laid down from Lake Tingstäde directly to the UWR to avoid pollution on the way. The first 10 km could be co-located in the creek from Lake Tingstäde to the sea, whereas the last 5 km must be located on the sea bottom. It is advantageous to locate it that far from the shore to find a suitable depth (>60 m). A pipe of common polyethylene (PE-pipe) DN 110 or 125 mm would do fine. The water would then run down by gravity from Lake

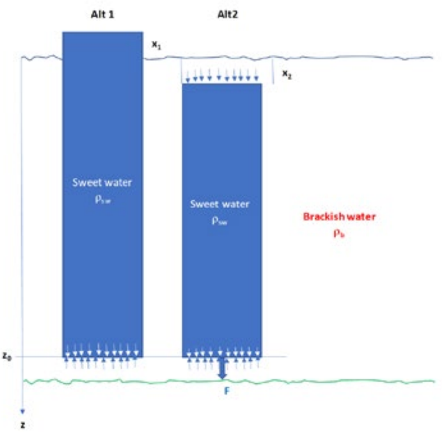

Figure 4. *In alternative 1, the UWR will stick up over the sea surface making it vulnerable to ice and boats. Only alternative 2 is considered feasible in the case of Gotland above. The depth would be set to > 12 m to stay clear of ships.*

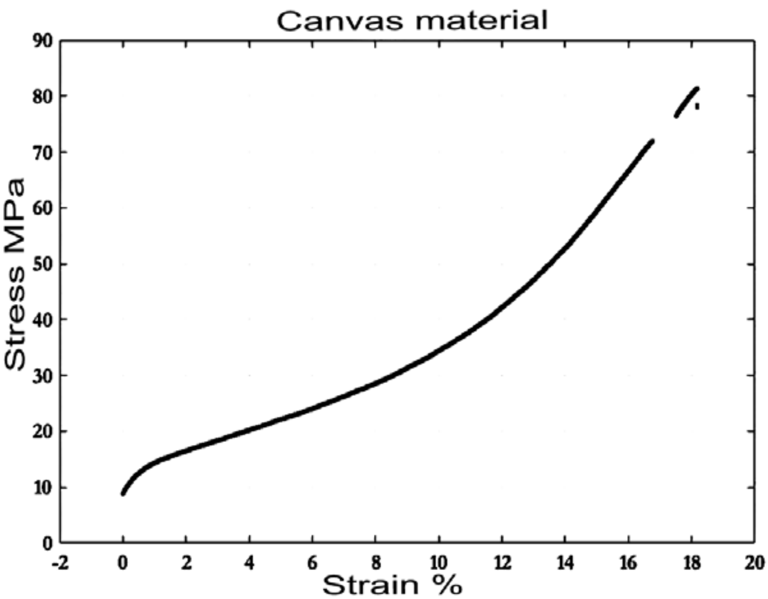

Figure 5. *Stress as a function of the strain of the tested canvas material.*

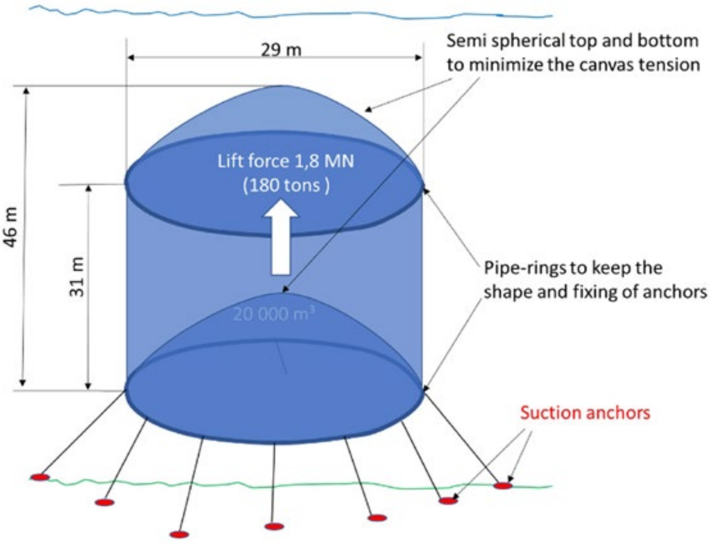

Figure 6. *A more detailed suggestion for an UWR. Suction anchors are frequently used for wind power stations and drill rigs e.g. in the North Sea, but gravity (concrete) or helix (screw) anchors could also be used.*

Tingstäde through the pipe to the UWR wintertime but must then be pumped back up summertime. Today more than 1 Mm^3 water for public water consumption is taken from lake Tingstäde (Region Gotland, 2022).

There are at least two different principles for constructing an UWR. The UWR would also be restricted to a limited size, depending mainly on the density difference between the water inside and outside, and the strength of the canvas.

The density of the seawater at the location is ~1008 kg/m^3 and the density of water inside the UWR is ~999 kg/m^3. According to Archimedes law and for 1 Mm^3 that means a total lifting force of 90 MN (= $V \cdot \Delta\rho \cdot g$). One type of canvas was tested at the Royal Institute of Technology (In Figure 5 below, the gap between 72 and 75 MPa is a measurement error).

Assuming a safety factor of at least two, about 40 MPa tension force could be allowed in the canvas above. To withstand the total lifting force of 90 MN thus the total force absorbing area of the canvas must at least be 2.25 m^2. The tested canvas is 1 mm thick and therefore a total length of at least 2.25 km of canvas is required. The canvas strength required, thus precludes using one single UWR for 1 Mm^3. It is rather optimal, to split it into 50 UWR:s, containing 20 000 m^3 each. That would increase the safety factor to 4. Under water storages like these are planned for oil storage in the North Sea, in that case having a volume of ~10 000 m^3. A very rough estimation of the annualised investment cost is 2 - 3 SEK/($m^3 \cdot yr$) stored water (\$0.2 – 0.3/($m^3 \cdot yr$) - while storing from winter to summer.

Figure 7 – *two main alternative sources for Gotland (map from Eniro).*

Sending 2 m³/s in an under-water "river" to Gotland - an Under Water Pipe (UWP)

Creating a flow of 2 m³/s to Gotland from mainland Sweden would mean that the demands for both agriculture and drinking water would be solved permanently. The water should be taken from an unpolluted river that also has a sufficient minimum flow (SMHI, 2022). When looking at the map there are two main alternatives: Motala Ström coming from Lake Vättern, and Emån originating from several smaller lakes.

To totally avoid pumping power for such a large amount of water all the way, the water could be taken at a higher vertical level in the source or with a corresponding inlet velocity of the water to the entrance of the UWP. A large UWP diameter will result in a low pressure drop of the entire UWP, meaning that the water then can be taken at a low altitude relative to the Baltic level to totally avoid power for pumping. A low pressure drop will also allow a thin-walled UWP canvas. Due to the risk of tearing from e.g. fishing, a thinner wall thickness than 1 mm is deemed too risky. However, a larger pipe will mean a higher lifting force in the brackish Baltic water and must then be anchored more firmly.

The pipe will run between the anchoring points in a sinusoidal way. The amplitude of this sinusoidal line results in an optimal distance between the anchor points. The pipe should not be allowed to rise too high above the sea floor. The anchor points must also have a certain safety factor, so that losing one anchor point does not result in mishap. Using a 4 m diameter UWP in Baltic water, a distance (s in fig 7) of 25 m between the anchor points seems reasonable. Each anchor should then take a load of 36 000 N (3.6 tons). The anchors could either be of concrete - using gravity, suction anchors - sucking into a bottom of clay or drilled helix anchors.

Choosing the best diameter, d, of such an UWP is of course particularly important. The sum of the annualised costs for the pipe, the anchoring and yearly energy costs for pumping of water (if needed) should be as low as possible.

In figure 9 the real interest rate has been set to 5 % and the depreciation time has been set to 20 years, yielding an annuity factor of 8 %. Investment in the canvas material, ready and shaped into a spiral welded tube, is estimated to be 50 SEK/kg. The anchoring cost investment is estimated to 3 SEK/N using concrete weight anchors. Cost of electricity, when needed, is assumed to be 2 SEK/kWh. The amount of useful water transported to Gotland is assumed to be 1 m³/s. The UWP, though, is dimensioned for 2 m³/s, to also cover future agricultural needs (see fig 3).

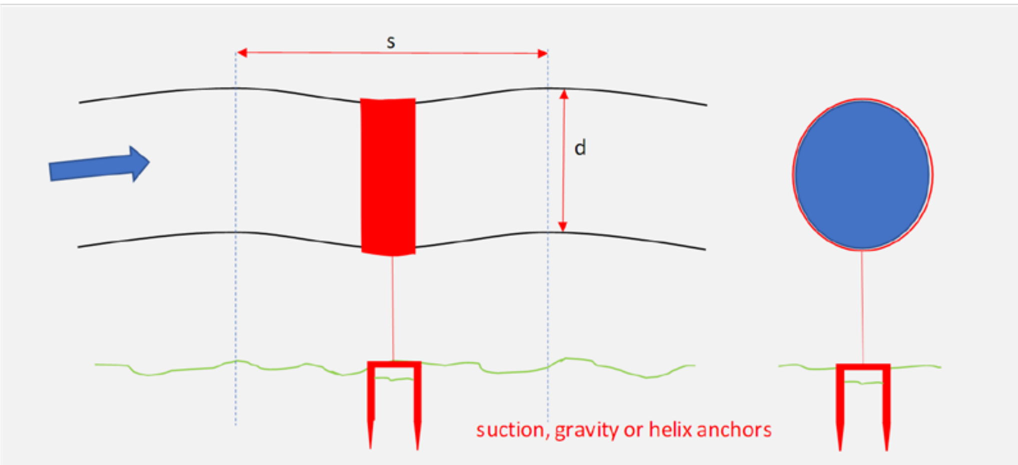

Figure 8 – *Fixing the UWP to the sea floor.*

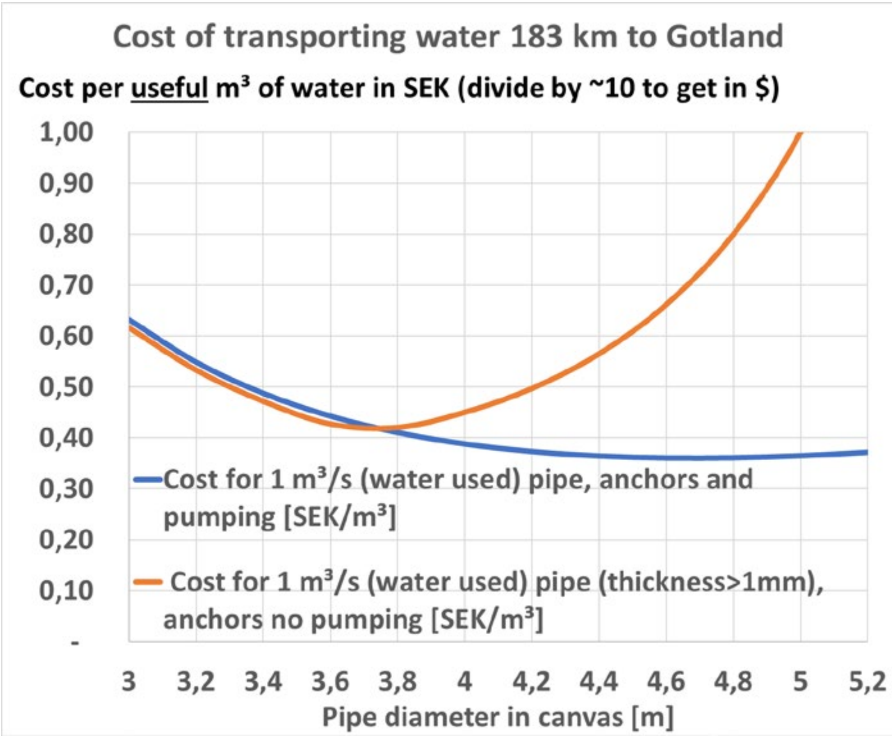

Figure 9. *The blue curve in the figure shows the annualised cost of pumping energy + an adapted, variable thickness of UWP canvas + the anchoring costs. The red curve assumes that the flow can be taken 1 m upstream, meaning saved electricity for pumping, and that the canvas cannot be made thinner than 1 mm.*

Costs for setting the anchors, installing the canvas UWP and detailed inlet and outlet constructions of the UWP are not included. There are huge difficulties getting a quote for building and installation, without an explicit interest from Gotland. It is reasonable though, that including the cost on Gotland in e.g. Storugns (see fig 6) and at the intake, would wind up below 1 SEK/m³. The Storugns bay would then be converted to a "sweet water bay" like the outlet of the river where the water once originated. Including installation, the total investment is roughly estimated to 300 MSEK (30 M$). This investment for "free water" would be ~50 % higher than a newly built desalination plant on Gotland delivering less than 10 % of the water of what the UWP would deliver. The energy needed for desalination amounts to around 3 kWh/m³ (VISS, 2022b). 300 MSEK means roughly an investment of 5 000 SEK per inhabitant or 250 SEK/yr over 20 years.

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