Solution for eutrophication of the lake Årungen by removal of sediments

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Nore Stolte and *Ada Heyerdal Jervell* are students at Ås videregående. The work presented here is part of their research regarding the lake Årungen. Stolte and Heyerdal Jervell were finalists in the 2011 Norwegian Junior Water Prize contest.

Sammendrag

Løsning for forurensningen i innsjøen Årungen ved fjerning av sediment. Vi har undersøkt en metode for å fjerne sedimenter fra innsjøen Årungen, for å forminske graden av forurensingen i vannet. Årungen ligger i Ås, Akershus, Norge. Sedimenter i Årungen inneholder store mengder næringsstoffer som nitrogen og fosfor på grunn av avløpsvann fra omliggende jordbruksområder. Dette bidrar til algeoppblomstring i sjøen. Eksperimenter, som gir et bilde av muligheten for å pumpe opp partikler med en hevert, viser at det kan være mulig å fjerne sedimentene med en hevert. Metoden må likevel overvåkes nøye, siden stein og liknende kan stoppe vannstrømmen. Å bruke en hevert er ønskelig på grunn av lave kostnader og lavt energiforbruk.

Summary

We have explored a method to remove sediments from Årungen, in order to bring an end to the current eutrophication of the lake. Årungen is situated in Ås, Akershus county, Norway. Because of the farmlands surrounding Årungen, sediments the lake contain a large amount of macronutrients, such as nitrogen and phosphorus, contributing to regular occurrence of the algae blooms. Experiments on the functioning of the syphon method and its ability to suck up other particles in the water stream, show that a syphon could be effective for the removal of sediments in the lake. However, it will have to be closely controlled by humans in order for it not to stop due to rocks and other, bigger particles. Applying the syphon method for removal of sediments is a suitable option for the lake because of the low costs and the minimal energy requirements.

Introduction

The goal of our research has been to explore a method that can reduce the level of eutrophication of the lake Årungen. Our proposal is to do this by removing the sediments using the syphon method. We will look at why we find it necessary to remove the sediments, and how this can be done in the most effective way.

Årungen, practical information

Årungen is a eutrophicated lake on the east side of the Oslofjord, situated in Akershus county, Norway. The lake lies at a height of 33 metres above sea level, and has an area of 1.2 km^2. The average depth is 8.1 m, and the maximum depth is 13.3 m, so the lake is relatively shallow. The total water volume of the lake is approximately $9.7 \cdot 10^6$ m^3.

The catchment area of Årungen is 51 km^2. More than half of this area is used for agriculture (with 85 % of this used for cultivation of grain); 18 % is forest, mostly coniferous trees; 2 % is industrial area and approximately 9 % consists of buildings. There is a highway (E6) as close as 50 m from the shore of the lake. About 7000 people live within the catchment area of Årungen, with about 100 living in its direct surroundings.

Årungen has several main inlets, and one main outlet. Syverudbekken comes in on the east side of the lake, transporting water into the lake from Østensjøvannet. Norderåsbekken enters on the southeast side of the lake. Other large inlets are Smedbølbekken and Vollebekken. The main outlet of the lake is Årungenelva on the north side of the lake. It has a length of about 2 km and transports the water northward into the Bunnefjord, which is in direct connection to the Oslofjord.

The importance of the removal of sediments

From earlier studies, we learn that the sediments found in Årungen contain a high rate of eutrophicating matter, which again contains a large amount of macronutrients (such as N, P, K, and Mg). Nitrogen and phosphorus are often found in bonds that are available for organisms (Amundsen, 2003). These easily available nutrients can be brought back into the water; sediment particles are brought back into the water mass by resuspension, through turbulence by wind, at spring and fall turnover, due to animal activity or gas forming in the sediments. The process of resuspension is enhanced especially under anaerobic conditions (Kalff, 2002). The particles will, in general, have a short period as suspended materials in comparison with dissolved bonds, thus becoming an easily available source of nutrients for algae and bacteria (Sanni et al., 1984). This way, the sediments contribute to the algae blooms that occur regularly in Årungen.

The sediments in Årungen have very specific properties. They have a pH of 6.3, and consist of 23.9 % sand, 56,7 % silt and 19,6 % clay, which gives the sediments the qualities of silty clay (Amundsen, 2003). In table 1 are the specific numbers for some of the chemical substances found in the sediment of Årungen.

Substance	Amount
Organic carbon	2,10%
Nitrogen, total	1230 mg/kg
Ammonium	127 mg/kg
Nitrate	>0,96 mg/kg
Magnesium	5340 mg/kg
Potassium	3140 mg/kg
Phosphorus	771 mg/kg
Sodium	336 mg/kg
Calcium	4160 mg/kg

Table 1. Substances found in the sediments of Årungen (Amundsen, 2003)

Syphon method

The method we want to use to remove the sediments from Årungen is the syphon method, which transfers water from a higher point to a lower point while going over a top, driven by the atmospheric pressure. This method therefore requires minimal energy. The syphon principle is illustrated in figure 1.

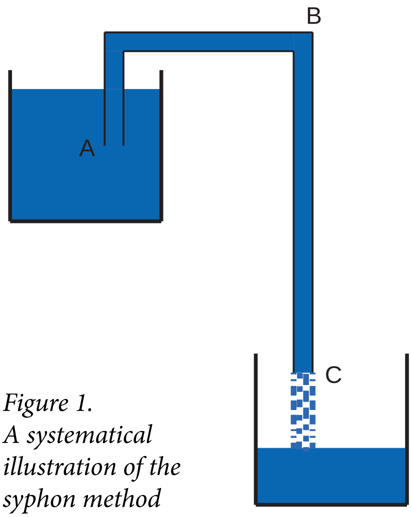

Figure 1.
A systematical illustration of the syphon method

The maximum height that the falling cylinder (from B to C) can have is limited, since at zero pressure a vacuum forms and the liquid will start form bubbles, causing the syphon to stop draining water. The maximum height can be found using Bernoulli's equation, given by, where v is the velocity of the fluid, g is the acceleration due to gravity, y is the elevation in the gravity field, P is the pressure and ρ is the fluid density.

$$\frac{v^2}{2} + gy + \frac{P}{\rho} = constant$$

To find the maximum height, we have to solved the equation for the syphon.

$$BC_{MAX} = \frac{P_{atm}}{\rho g}$$

Hence, we find that the maximum height of fall for water is approximately 10 m.

Theory and experiments

As part of the recovery of the ecosystem, we propose to remove the sediments from the bottom of Årungen using the explained syphon method. Removal of sediments will decrease the percentage of organic material in the lake, as well as nutrients and minerals (Sanni et al., 1984). A lower rate of macronutrients and minerals will potentially cause in a decreasing growth of phytoplankton, resulting in the lake being less eutrophicated. In that way, the original ecosystem can be (partially) restored.

Our experiments show whether a syphon can be used to successfully remove sediment from Årungen. Practical problems will be taken in consideration as well. Finally, some suggestions will be given for possible applications for the sediments removed from Årungen.

Several experiments have been performed in order to test the functioning of the syphon method for the removal of sediments. The first round of experiments was done to provide a greater understanding of the syphon method and its physics. Secondly, the syphon method was tested for its ability to suck "sediment" from a container filled with water.

The physics of a syphon

The first experiments were carried out to give a greater understanding on the functioning of a syphon.

For all these experiments, a container was filled with 1L of water. Tubes of different diameters and lengths were submerged into this container with one end, while the other end was led to another, empty container. By varying the tube parameters and the height difference between the containers and water surfaces, the behaviour of a syphon was easily determined.

Experiment 1

One container filled with water was placed at the same level as another, empty container. A tube of 5 mm in diameter was placed in between the two containers. Upon introducing suction at the end of the tube in the empty container, water started to flow between the containers.

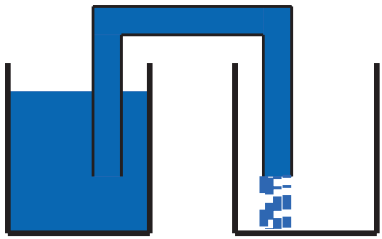

Figure 2. Experiment 1 illustrated

Experiment 2

In the second experiment, also two containers were used, one of them filled with water. The tube was placed between the containers, and the end of the tube in the empty container was after suction placed above the water level of the other container.

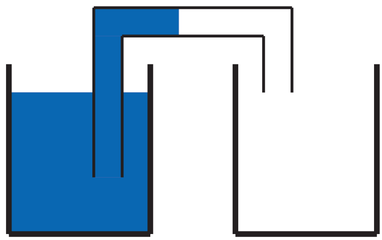

Figure 3. Experiment 2 illustrated

Experiment 3

During the third experiment, the approximate velocity of the water flow was to be found. One container was filled with water and placed at a certain height h from another, empty container. A tube was placed between them, and the syphon was started by suction. By briefly lifting the end of the tube in the water-filled container, air was introduced to the water flow in the form of a bubble. The time for the bubble to pass through the tube was taken using a stopwatch.

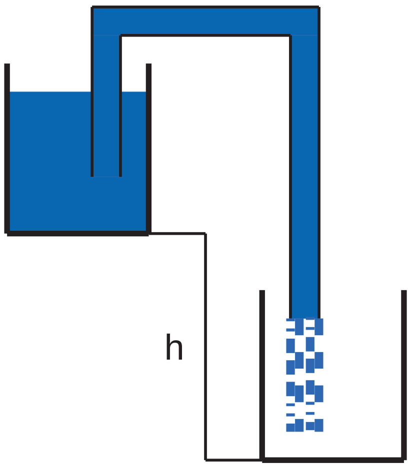

Figure 4. Experiment 3 illustrated

Results and discussion

Experiment 1 and 2 gave some qualitative results on the functioning of a syphon. The syphon works when the water level in the container being emptied is higher than in the container being filled with water. This is due to the pressure difference that results in the water flow through the syphon. The pressure at the end of the tube must be lower than at the start of the tube where the water enters, as this pressure difference causes the water to flow. When the water levels in both containers are equal, the pressure at both tube ends is equal as well. Therefore, the water flows from one container to the other until the water levels are equal. After reaching this critical point, the water in the syphon stops flowing through the tube. Also, we can observe and theoretically confirm that the water moves slower through the syphon as the pressure difference decreases. This is because the speed of the water is depended on the pressure difference. When lifting the end of the tube in the empty container above the water level of the other container, the flow stopped. This is explained by the same principle.

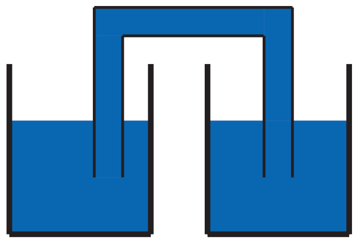

Figure 5. When the water levels and thus the pressure in both containers are equal, the syphon stops.

The results of experiment 3 are shown below in table 2.

Table 2 shows that the higher the elevation, the faster the water flows through the tube, thus the greater the ability of the water to carry particles with it and the greater the sucking force at the bottom of the tube. So, the greatest height difference possible would be desirable

Elevation h (m)	Tube diameter (cm)	Tube length (m)	Time taken (s)	Speed (m/s)
0	0,5	2,5	56,0	0,045
0,30	0,5	2,5	9,0	0,277777778
0,75	0,5	2,5	3,0	0,833333333
0,40	1,3	1,9	2,6	0,730769231

Table 2. Results of experiment 3 and the calculated velocity with each tube length and diameter.

for applications such as in Årungen. Also, a larger tube was able to transport the water faster, so also the use of a tube of a large diameter will give better (and faster) results. This is also backed up by equation for the frictional forces inside tubes – as the radius increases, the frictional force is reduced by the factor of the increase of the radius is to the power of 4. Thus, if the radius of a tube is doubled, the frictional force acting on the water is reduced by a factor of 16.

Testing syphon with sediments

In the next series of experiments, a mixture of potato flour and sand was made to simulate the bottom of the lake Årungen, including a layer of organic sediment at the top. The goal with this experiment was to determine if this top layer of dead organic material could be removed using a syphon.

A mixture of potato flour and water was made in a 1 L container. This container was then left for five days in a dark and cool room, so that the potato flour could deposit. This resulted in a layer of approximately 5 mm potato flour at the bottom of the container, with the rest being clear water. Another 1 L container was filled with a mixture of sand and water. The sand used consisted of particles of very different sizes, some larger with diameter about 5 mm, and some small particles (loam). This container was left to deposit for about half an hour. By that time, a large amount of the coarse sand had sunk to the bottom. The top liquid was poured into a third 1 L container and also left for five days, causing all of the (smaller) sand particles to fall to the bottom. The container with the deposited sand was again filled with water, and potato flour was added to the mixture. After the five days of storage, all of the solid parts that were suspended in the water had deposited on the bottom of the container. We tested the syphon method using a transparent tube with 8 mm in diameter.

To test the sucking ability of the syphon, the glass containing the potato flour was emptied first using the syphon method. The potato flour represented the organic matter found at the bottom of Årungen. A successful experiment is reached when as much of the potato flour as possible is removed. Therefore, one end of the tube was put on the bottom of the container, and the syphon was started by introducing suction to the other end. The second container was the one with the smallest amount of sand which had deposited on the bottom. This sand was quite fine, and could be a good scale representation of the silty loam in the lake. Here too, we tried to get as much of the sediment out of the container, using the same method as in the previous experiment. The last container had a thick layer of coarse sand at the bottom, with on top a thinner layer of potato flour. This gave a unique scale model for the organic matter settling on top of sand and rocks. We tried to remove the "organic matter" from the bottom using the same method as in the earlier scale experiments.

Results and discussion

In the first experiment of this series, potato flour representing organic matter was attempted removed from the bottom of a container. The potato flour was being sucked up from the bottom of the container in a pretty fast rate; almost all of it was transported out of the container by the syphon at the time the container was empty for water. The second experiment on the fine sand was also quite successful. A lot of the sand was removed from the bottom by the time the container was emptied, however not as much as in the attempt with the potato flour. In the last experiment, the potato flour was laying on top of a layer of coarse sand. A lot of the potato flour was removed by the syphon. However, the syphon stopped many times due to larger sand particles that got stuck in the tube.

The results imply that it is possible to remove sediments from a filled basin using a syphon. However, as the last

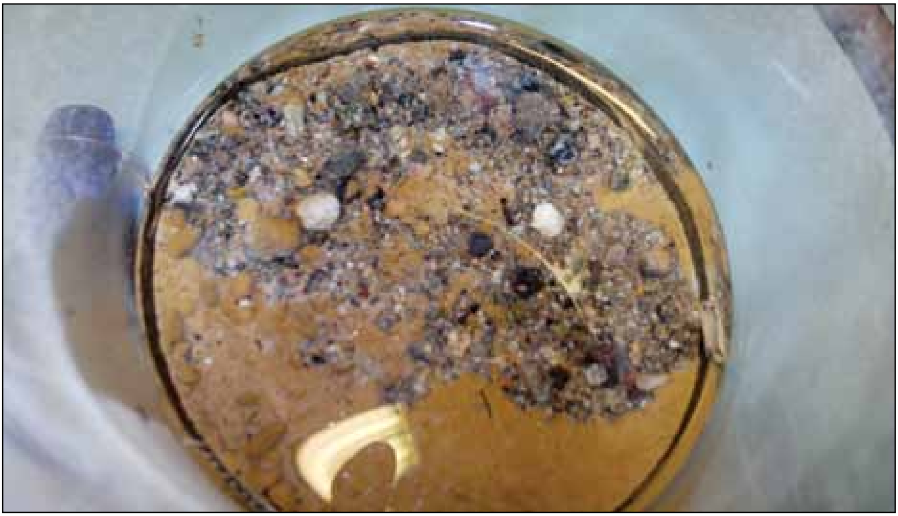

Figure 6. This is what the bottom of the container looked like after removing as much of the potato flour as possible, before the container was emptied for water. The lighter area is the potato flour left.

experiment shows, larger particles can stop the water flow in the syphon. This problem may be solved by simply placing a grid at the opening of the tube, only allowing small particles to enter the syphon.

Conclusion

The achieved results imply that it might be possible to remove sediments in the lake Årungen by using a syphon. However, as we have seen in one of the experiments, there are some troubles connected to this process. Since the syphon was blocked several times by sand particles, we can expect this to happen in a full-scale project in Årungen as well.

This problem requires some more research, but there are many possibilities. We can simply attach a grid to the end of the tube, to make sure that there are no large particles sucked into the tube, stopping the syphon. However, this method could make the syphon less effective since there then could be smaller particles stopping the flow through the grid. Another possibility is to only use the syphon when the boundary between the sediments and water is not that distinct, during the spring- and fall-turnover for instance. In order to remove the nutrients and organic material then, we would not need to have the syphon lying on the bottom of the lake, and therefore we will not have the problem of the syphon being stopped by larger particles.

An appropriate place for the syphon must be found, both in the water and on shore. The syphon's end that is lying on or hanging above the bottom of Årungen should be in a place where we find a large amount of sediments. Any other place will be a waste of money and resources. From earlier research we know that the sediments in the middle of the lake are 20-30 cm deeper than closer to shore (Amundsen, 2003). It would therefore be logical to place the sucking part of the syphon there.

As seen in our experiments, the height the fluid falls must be larger than what it travels up from the lake's surface. The larger this elevation is, the faster the flow. Thus, a possibility is to place the syphon close to the main outlet, Årungenelva, since this is the place where the elevation is most rapidly decreased. The flow rate also depends on the tube diameter as seen in our experiments (which test with approximately the same elevation, but different tube diameters). The larger the diameter, the faster the flow, hence larger particles can be lifted into the syphon without stopping it.

From Bernoulli's equation, we know that the maximum fall height of water in a syphon is 10 meters. In other words, we should be aware of that the difference in height between the end of the syphon tube and the highest point of the syphon cannot be larger than 10 m.

What can be done with the sediments?

We have seen that there is a possibility to remove the sediments from the bottom of Årungen. This raises a new question, what to do with the sediments? Once we get them out of the lake, we need a place to store them or to spread them. The sediments contain nutrients, and if stored under anaerobic conditions, methane will be formed, as shown in the reaction $C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2$.

Methane is a strong greenhouse gas, much worse than carbon dioxide when considering the global warming issue, but it also releases a considerable amount of energy during combustion: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. This could, if done right, become a potential energy source for local farmers and households. A way to extract methane from the sediments is to store them in a big container without oxygen, much like a huge silo. The methane gas formed can easily be lead to a separate container, although there are of course many difficulties involved in this method as well. This requires more research, but can be worth a consideration.

As mentioned above, the sediments contain nutrients, and a lot of these are vital for plants. Most of the nutrients found in the sediments are most likel y not available for plants. However, there are processes which make such nutrients available for plants (e.g. in the form NH_4NO_3), but these processes require energy. A possibility is to use the energy provided by the combustion of methane for this purpose. The sediments can then be used as fertilizers on farming land nearby.

By using the nutrients from the sediments, which once were applied as fertilizer, we reduce the necessity of new artificial fertilizers on the farming land to a great extent. This especially is of vital importance for the decrease in available phosphorus amount in the world. In addition, we reduce the current content of nutrients in Årungen, hence the eutrophication, as well as the supply of new nutrients.

A global perspective

Årungen is only one out of many eutrophicated lakes in Norway and, in fact, in the rest of the world. The suggested method found from our research, can be used on a scale of different lakes, as sediments often are present as a part of the problem. Properties that are important for this method to work, is that the sediments are not too firm. There should also be a significant elevation difference nearby, making it possible for the syphon to perform optimally.

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