Acknowledgments

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Summary

Many drugs used daily by millions of people end up in the sewer through urine. Because these molecules are small, they are difficult to filter out of sewage. The drug residues thus enter surface water, posing a threat to the water chain.

To address this problem, research was conducted to see if it is possible to develop toilet paper that will bond with the drug residues or also called micropollutants, so that they are better removed from sewage. The main question here is "Can micropollutants in surface water be reduced using lignin incorporated into toilet paper?".

In order to answer this question, three sub-questions were drawn up: "To what extent do micropollutants bond more with lignin than cellulose?", "To what extent do micropollutants bond more with toilet paper with lignin incorporated than with toilet paper without lignin?" and "To what extent is it realistic that toilet paper with lignin can be produced for consumers?".

After research, the following conclusions were drawn: pure lignin absorbs micropollutants 20% more than pure cellulose on average, and lignin incorporated into toilet paper absorbs about 10% less than pure lignin on average. In addition, it seems likely that toilet paper containing lignin can be produced on a large scale for consumers because it is a common substance, and it is currently removed from toilet paper because of its color.

Abbreviations and acronyms

<table>
<thead>
<tr>
<th>OEDC</th>
<th>Organisation for Economic Co-operation and Development</th>
<th>PL</th>
<th>Pure lignine</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTT</td>
<td>CWS maxi 100 toilet paper</td>
<td>WLT</td>
<td>Toilet paper without lignin</td>
</tr>
<tr>
<td>FTT</td>
<td>Floralys toilet paper</td>
<td>SLT</td>
<td>Toilet paper with lignin sprinkled on top</td>
</tr>
<tr>
<td>DTT</td>
<td>Page toilet paper</td>
<td>ELT</td>
<td>Toilet paper with 10 gram processed lignin</td>
</tr>
<tr>
<td>PC</td>
<td>Pure cellulose</td>
<td>DLT</td>
<td>Toilet paper with 20 gram processed lignin</td>
</tr>
</tbody>
</table>
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1.0 Relevance

Most of the medicines used daily by millions of people all over the world end up in the surface water. These medicines can already have a big impact on the environment in small quantities, as pharmaceuticals are designed to interact with a living system and cause a pharmacological reaction even in low concentrations. The emission of pharmaceutical residues has been a problem for many years, but still a lot is unknown about this. Though it is difficult to research the long-term effects of the pollution, it is clear that it is becoming more and more important to find a way to reduce pollution as much as possible. Because of the aging population, the use of pharmaceuticals is expected to increase by 37% between 2011 and 2050 [1], on top of that, the concentration of pharmaceuticals in surface water will also rise due to increasing drought. [2]

Drug residues may affect the purity of drinking water, since 40% of the drinking water in the Netherlands is extracted from surface water. [3] The Vewin, the association of water companies in the Netherlands, expresses that it is extremely important to take measures and calls it an urgent problem. Indeed, producing safe drinking water is becoming increasingly difficult. [4]
There is a lack of knowledge about mixture toxicity, and endocrine disruptors can already have a negative impact on the environment at concentrations lower than the detection limit. Studies have been done in laboratories showing that painkillers cause tissue damage in fish and antidepressants alter the behavior of fish and water crayfish. These effects have already been observed in the wild as well. In addition, estrogenic hormones, female hormones found in contraceptive pills, cause aquatic animals to be affected. For example, a 2003 study found that male bream that lived around a sewage treatment plant discharge point showed female characteristics, such as increased levels of vitellogenin and oocytes in the testes. [5] In 2019, estrogenic hormones were found to cause reduced reproduction of clams and crayfish. These effects of pharmaceutical residues in surface water are just a few of many more examples. [6] The micropollutants have deleterious effects on aquatic organisms, putting pressure on the quality of aquatic life.

Currently, as much as 1382 tons of drug residues enter Dutch wastewater annually. Between 5-10% of drug residues in the sewer come from concentrated emission sources, such as hospitals and health care institutions. They already apply a number of measures that significantly reduce pollution, making the emission from hospitals and health care institutions relatively low. Much of the drug residues in the sewer come from private individuals. Since sewage treatment cannot filter out all the drug residues, 35% of the residues from the sewage system enter surface water. [2] The problem is not only going on in the Netherlands. Recent research shows that many kinds of pharmaceuticals end up in the surface water all over the world, as shown in figure 1.

Figure 1: Aus der beek et al. (2016) Number of pharmaceuticals detected in surface waters, groundwater, tap water, and/or drinking water per country
Several actions have been taken to reduce the amount of micropollutants in surface water. For example, the OECD released a report describing a policy to educate people about the dangers associated with surface water pollution and encourage reductions in the inappropriate and excessive consumption of pharmaceuticals. They also mention the importance of encouraging the improvement of wastewater treatment to remove pharmaceutical residues. [7] There are already several filter systems and techniques to filter drug residues from water, but often these ways lead to high costs and are not effective enough yet. This is because the major problem with drug residues is that they are very small molecules, which are difficult to filter.

2.0 Purpose

The goal of this research is to reduce drug residues in surface water by filtering them out of sewage before they are released into nature. The possibility of developing toilet paper to which drug residues from urine will form bonds with will be investigated. After the bonds have been formed, these larger molecules will be easier to filter out of sewage. In addition, toilet paper is a product used by billions of people worldwide. If toilet paper is able to absorb the drug residues, it could be a solution to the problem of drug residues polluting surface water in many countries.

Through literature review, two potentially working substances have emerged for this research: cellulose and lignin. Based on chemical explanations, it can be predicted that drug residues will bond with these substances, as further described in the theoretical framework. Cellulose and lignin occur naturally in trees, from which toilet paper is made. The main question is, "Can micropollutants in surface water be reduced by using lignin incorporated into toilet paper?" This main question will be examined through three sub-questions.

The first sub-question is, "To what extent do micropollutants bond more with lignin than cellulose?". Next, it will be investigated whether there is a big difference in bonding to the drug residues between pure lignin and lignin processed in paper. This will answer the question, "To what extent do micropollutants bond more with toilet paper containing lignin than with toilet paper without lignin?". Finally, this research will look at the applicability of this idea answering the question, "To what extent is it realistic that toilet paper with lignin can be produced for consumers?".
Sub-questions one and two will be answered by conducting experiments in the laboratory at Wetsus. The experiments attempted to mimic the real-life situation in the most measurable way possible. This was done by using synthetic urine and a solution of micropollutants. The synthetic urine and micropollutants were merged with a certain amount of lignin, cellulose or different types of toilet paper, in order to be able to see the difference in concentration of the micropollutants for each substance. In this way it could be determined to what extent the micropollutants were absorbed by the different substances. Sub-question three will be answered by literature review.

3.0 Theoretical framework

3.1 Lignin

Lignin is one of the most abundant organic molecules on earth. It is the wood dust of trees and is found in the cell walls of plants. Lignin functions as a glue substance that strengthens plants and as protection from UV light for trees and plants. It therefore forms many different bonds in the plant. Lignin is a polymer composed of three different monomers: p-coumaryl alcohol (H), coniferyl alcohol (G) and sinapyl alcohol (S), see figure 2. The order of monomers is irregular and varies among plants. Lignin is formed from irregular coupling and addition of the monomers in the form of a network polymer.

![Figure 2: Bos, H.L., Gosselink, R.J.A., Harmsen, P., Van Dam, J.E.G. (2016) The monomers of lignin: sinapyl alcohol (S), coniferyl alcohol (G) en coumaryl alcohol (H)](image)

Lignin has a disordered structure of mainly aromatic rings. Through pi-stacking is lignin able to bond strongly with other molecules containing aromatic rings. A lignin molecule also contains many hydrogen bonds, both intermolecularly and intramolecularly. [8]
The substance lignin has a brown color caused by its multiple conjugated aromatic rings. This is because these rings absorb light of different wavelengths due to the high electron density they exhibit. In the process of making toilet paper, lignin is extracted because of its color. [8]

3.2 Cellulose

Cellulose is the most abundant organic polymer in nature: about 33% of all biological matter consists of cellulose. In addition, it is a main constituent of paper and thus toilet paper as well. It is a polysaccharide, which means that it consists of multiple sugar/glucose groups. Cellulose consists of the linked monomers -(1,4)-D-glucose as shown in figure 3. The monomers are linked together by condensation reactions. [9]

Cellulose has many OH groups, allowing hydrogen bonds to form between these groups. These hydrogen bonds are both intermolecular and intramolecular, making cellulose highly reactive with water. [10]

![Figure 3: Molecular structure of glucose and cellulose](image)

3.3 Overview bonds

In order to make the study as applicable as possible, a list of a wide range of micropollutants was prepared, chosen based on their use in the Netherlands. Table 1 shows which micropollutants contain aromatic rings and how many hydrogen bonds each micropollutant can form on average per molar mass.

<table>
<thead>
<tr>
<th>Micropollutant</th>
<th>Aromatic rings</th>
<th>Hydrogen bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atenolol</td>
<td>1</td>
<td>0.0225 per u</td>
</tr>
<tr>
<td>Caffeine</td>
<td>2</td>
<td>0.0309 per u</td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>3</td>
<td>0.01693 per u</td>
</tr>
<tr>
<td>Diclofenac</td>
<td>2</td>
<td>0.0101 per u</td>
</tr>
</tbody>
</table>
3.4 Hypothesis

3.4.1 To what extent do the micropollutants bond more with lignin than with cellulose?
Since many of the micropollutants contain aromatic rings, they are expected to bond more to lignin than to cellulose. This is because the structure of lignin contains many aromatic rings and cellulose contains none. Using Table 1, a hypothesis can be drawn up for each micropollutant.

The order was determined based on the number of aromatic rings and then on the number of hydrogen bonds per molar mass. Indeed, through pi stacking, firmer bonds are formed. This creates the following order, from most bonding micropollutant to lignin to least bonding micropollutant: carbamazepine, caffeine, diclofenac, atenolol, paracetamol, metoprolol, estradiol, ibuprofen, metformin, L-theanine and finally lincomycin.

Between the absorption of metformin, L-theanine and lincomycin by lignin or cellulose will be no difference, because pi stacking does not have an effect on these micropollutants. It is expected that lignin will absorb all the other micropollutants better, because these have aromatic rings.

3.4.2 To what extent do micropollutants bond more with toilet paper containing lignin than with toilet paper without lignin?
From lignin processed in toilet paper is expected that it will absorb the micropollutants better than cellulose. On the other hand, it is not expected that the processed lignin will absorb as much micropollutants as the pure lignin.

### Table 1: Kruisselbrink, F. (2022) Overview of micropollutants with aromatic rings and hydrogen bonds

<table>
<thead>
<tr>
<th>Micropollutant</th>
<th>Aromatic Rings</th>
<th>Hydrogen Bonds per Molar Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estradiol</td>
<td>1</td>
<td>0,0073 per u</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>1</td>
<td>0,0070 per u</td>
</tr>
<tr>
<td>Lincomycin</td>
<td>-</td>
<td>0,0197 per u</td>
</tr>
<tr>
<td>L-theanine</td>
<td>-</td>
<td>0,0344 per u</td>
</tr>
<tr>
<td>Metformin</td>
<td>-</td>
<td>0,0464 per u</td>
</tr>
<tr>
<td>Metoprolol</td>
<td>1</td>
<td>0,0150 per u</td>
</tr>
<tr>
<td>Paracetamol</td>
<td>1</td>
<td>0,0198 per u</td>
</tr>
</tbody>
</table>
Because of the complexity of the lignin molecule, it can form many bonds. When it is processed in toilet paper, lignin will thus form bonds with the toilet paper. This means that less bonds with micropollutants can be formed, and less micropollutants will be absorbed. On top of that is the concentration of lignin a lot lower if it is processed, which causes it to absorb less micropollutants.

The way in which lignin is processed in the toilet paper will have a major influence, because this has an effect on the bonds that lignin forms with the toilet paper. It is also expected that the concentration of lignin will have an impact on the absorption of the micropollutants. Less micropollutants will be absorbed by a lower concentration of lignin.

Furthermore, it is expected that the same order of micropollutants based on their bonds with lignin will emerge as with pure lignin: carbamazepine will be absorbed the most by the processed lignin, followed by caffeine, diclofenac, atenolol, paracetamol, metoprolol, ibuprofen, metformin, L-theanine and finally lincomycin.

4.0 Materials and procedure

All experiments were performed in the laboratories of Wetsus under the supervision of Y. Wang. Nitril gloves were used during every experiment and all safety procedures of the laboratory were followed.

Before starting with the experiments two solutions were made. First a solution with micropollutants using the method 4.1 Oplossing met micropolluenten described in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 7 and 8. This solution contained the following micropollutants: atenolol, caffeine, carbamazepine, diclofenac, estradiol, ibuprofen, lincomycin, L-theanine, metformin, metoprolol and paracetamol. The second solution was synthetic urine, this was made using the method 4.2 Synthetische urine described in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 8, 9 and 10. For the second experiment handcrafted toilet paper was made, following the method 4.4 Toiletpapier maken met en zonder lignine described in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 11 and 12. When all experiments were executed and samples were analyzed, data were processed using the method 4.6 Verwerking van resultaten described in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 14 and 15.
4.1 Experiment one: bonds between micropollutants and cellulose/lignin

4.1.1 Materials

The materials used for experiment one can be found in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 10.

4.1.2 Procedure

First, all abbreviations from the types of toilet paper, pure lignin, pure cellulose and blank sample were labeled on the laboratory flasks with a marker. All flasks contained a magnetic stirring bar. The different kinds of toilet paper were weighed, and the pure lignin and cellulose were weighed in plastic medicine cups. The right amount of toilet paper was cut in strokes of 0.5 cm. The toilet paper, pure lignin, pure cellulose were placed in their respective flasks. The medicine cups were flushed with Milli-Q water and this water was also put in the respective flask. 1.3 mL solution with micropollutants was added to every flask with a mechanical pipet. The flasks were filled up to 250 mL with synthetic urine, using a Pasteur pipette. On every flask, a cap was attached, and the flasks were shaken a few times. The flasks were put on the magnetic stirring plate. The magnetic stirring plate was set at a velocity of 270 rpm, such that the stirring bar did not get stuck in the toilet paper, but also did not go too fast.

In the next part, the number of the sample was written on the centrifuge tube. The flask with FTT was taken from the stirring plate and was shaken a few times. The cap had been twisted off and around 3 mL was taken from the flask with a syringe. The content of the syringe was filtered through the syringe filter and put into the centrifuge tube. The number of the sample was written on the glass vial. With a mechanical pipette 1 mL of the sample was put into the vial. The cap was attached to the vial. All steps of this part of the procedure were repeated with the other flasks and also after 1 hour, 3 days and a week. After collecting all samples, they were analyzed using targeted LC-MS.

4.2 Experiment two: bonds between micropollutants and handcrafted toilet paper

4.2.1 Materials

The materials used for experiment two can be found in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater on page 13.
4.2.2 Procedure
First, all abbreviations from the types of handcrafted toilet paper, pure lignin and blank sample were written on the laboratory flasks with a marker. All flasks contained a magnetic stirring bar. The different kinds of toilet paper were weighed, and the pure lignin was weighed in a plastic medicine cup. The right amount of toilet paper was cut in strokes of 0.5 cm. The toilet paper and pure lignin were placed in their respective flasks. The medicine cup was flushed with Milli-Q water and this water was also put in the respective flask. The flasks were filled with about 200 mL synthetic urine. 1.3 mL solution with micropollutants was added to every flask with a mechanical pipet. The flasks were filled up to 250 mL with synthetic urine, using a Pasteur pipette. On every flask the cap was attached, and the flasks were shaken a few times. The flasks were put on the magnetic stirring plate. The magnetic stirring plate is set at a velocity of 270 rpm, such that the stirring bar did not get stuck in the toilet paper, but also did not go too fast.

In the next part the number of the sample was written on the centrifuge tube. The flask with DLT was taken from the stirring plate and was shaken a few times. The cap had been twisted off and around 3 mL was taken from the flask with a syringe. The content of the syringe was filtered through the syringe filter and put into the centrifuge tube. The cap of the centrifuge tube was attached. All steps of this part of the procedure were repeated with the other flasks and the tubes were put into the freezer at a temperature of -18 ºC. These samples were taken from all the flasks directly after filling them and also after 1 hour, 3 days and a week on the magnetic stirring plate. All 24 centrifuge tubes were taken out of the freezer. When all samples were thawed, the number of the sample was written on the glass vial. With a mechanical pipette 1 mL of the sample was put into the vial. The cap was attached to the vial. After collecting all samples, they were analyzed using targeted LC-MS.

5.0 Results
The unedited data of all experiments can be found in Dutch Junior Water Prize Medicijnresten in het oppervlaktewater chapter 9.0 on page 20 to 30. To show the differences in absorption of the micropollutants, bar graphs were made of the results of the experiments. The data of estradiol are unfortunately unknown, because it is not detected anymore by the targeted LC-MS used in the laboratory at Wetsus.
5.1 Results experiment one

Three different kinds of toilet paper were used during this experiment to discover the differences in absorption between them. These results are shown in figure 4.

![Absorption by toilet paper after one week](image)

Figure 4: Kruisselbrink, F. (2022). Bar chart of the absorption of micropollutants FTT, DTT and WTT after one week.

The absorption of the micropollutants by cellulose and lignin was also tested, the results are shown in figure 5.

![Absorption of micropollutants after one week](image)

Figure 5: Kruisselbrink, F. (2022). Bar chart of the absorption of micropollutants by cellulose and lignin after one week.
Tests were also taken at different times to research the difference in absorption. The results of the absorption of carbamazepine are shown in figure 6.

![Absorption of Carbamazepine](image)

**Figure 6:** Kruisselbrink, F. (2022). Bar chart of the absorption of Carbamazepine by cellulose and lignin along with one type of toilet paper (WTT) after one week.

### 5.2 Results experiment two

All handcrafted toilet paper was tested during this experiment to discover the differences between them. The results are shown in figure 7.

![Absorption after a week](image)

**Figure 7:** Kruisselbrink, F. (2022). Bar chart of the absorption of micropollutants by SLT, ELT, DLT and WLT after one week.
The results of SLT and DLT are also shown in figure 8 in comparison to the results of lignin in this experiment.

![Absorption micropollutants after a week](figure8.png)

*Figure 8: Kruisselbrink, F. (2022). Bar chart of the absorption of micropollutants by lignin, SLT and DLT after one week.*

6.0 Answering sub-questions

6.1 To what extent do micropollutants bond more with lignin than with cellulose?

Since it was found that there was hardly any difference between absorption after an hour and one week (figure 6), the graphs are shown only with the absorption after one week.

![Absorption micropollutants after a week](figure9.png)

*Figure 9: Kruisselbrink, F. (2022). Bar chart of the absorption of micropollutants by cellulose and lignin along with one type of toilet paper (WTT) after one week.*
The results in figure 9 show that pure cellulose absorbed on average 48% of the micropollutants and pure lignin absorbed on average 68% of the micropollutants. This is a big difference. Pure lignin absorbed 20% micropollutants more than pure cellulose did. The hypothesis mentioned that three substances were expected to be absorbed equally well by both lignin and cellulose and the rest of the micropollutants better by lignin. Following this, it is not unexpected that a 20% difference occurred.

All micropollutants were better absorbed by pure lignin. Not in each of these micropollutants this difference was equally large, which can largely be explained by pi stacking: micropollutants that contain aromatic rings were much better absorbed than the micropollutants that can only form hydrogen bonds. This is as predicted in the hypothesis, but the expected order did not appear in reality. The other type of bonds, such as hydrogen bonds and Van der Waals forces, had more influence on the absorption than expected.

6.2 To what extent do micropollutants bond more with toilet paper containing lignin than with toilet paper without lignin?

Figure 10 shows the concentration of micropollutants after one week in the flask with pure lignin, the handcrafted toilet paper with sprinkled lignin (SLT), the handcrafted toilet paper with incorporated lignin (DLT) and the toilet paper without lignin (WLT).
The average absorption of micropollutants by pure lignin in this experiment was 64%. The results show that when lignin was processed in toilet paper this percentage dropped with approximately 10%. The toilet paper sprinkled with lignin (SLT) had an average absorption of 53%, the toilet paper with incorporated lignin (DLT) had an average of 51% and the toilet paper without lignin (WLT) 45%.

The results also show that the way of processing lignin in toilet paper did not have major impact on the absorption, because the concentration of micropollutants of SLT and DLT were close. This is shown in figure 5. The results do not correlate with the hypothesis, because the expectation was that the way lignin was processed in toilet paper could be related to the bonds lignin formed in the toilet paper and thus the absorption of the pharmaceuticals would be different between the different ways of processing lignin.

The concentration of lignin in the toilet paper did influence the absorption. Because of the differences in the results of DLT and the toilet paper with less build in lignin (ELT), it appeared that a higher concentration of lignin resulted in more absorption. This corresponds with the hypothesis.

6.3 To what extent is it realistic that toilet paper with lignin can be produced for consumers?

The first option in producing toilet paper with lignin is by adding it in the production process. The results of the experiments showed that adding lignin to toilet paper could be done. However, the question is whether enough lignin is available to provide everyone with toilet paper containing lignin. Lignin is naturally already present in trees and plants and it is one of the three main components. Nowadays most of the produced lignin gets burned as residual product and only a small portion is available to be processed. [11]

Another option for the production of toilet paper with lignin is to stop removing lignin in the process of making toilet paper. Normally lignin is removed, because it gives the paper an unwanted brown color. So it would even save time and energy to stop removing lignin in the process of making toilet paper. The only thing would be needed is that the consumer gets used to the light brown color of the toilet paper. The expectation is that toilet paper with lignin definitely has potential to be used on a daily basis.
Not in every country people are allowed to flush toilet paper, nor do the people use toilet paper in the first place. In that case, the absorptive qualities of lignin can still be used by for example adding lignin to toilet blocks, so it will still be flushed through the toilet with the urine, or adding lignin in the sewage.

7.0 Conclusion

In this research, an answer was sought to the question: “Can micropollutants in surface water be reduced by using lignin incorporated into toilet paper?” Experiments have been carried out in Wetsus’ laboratory to answer this question, from which the following conclusions can be drawn.

All micropollutants appeared to be absorbed better or equally well by pure lignin than by pure cellulose and normal toilet paper. On average, pure lignin absorbed the micropollutants 20% more than pure cellulose. However, the degree of absorption differed per micropollutant. Lincomycin was better absorbed by lignin than expected and paracetamol was absorbed worse than expected. In addition, caffeine was better absorbed by lignin than carbamazepine, which was also contrary to expectations. For these reasons, the hypothesis is rejected.

Every kind of handcrafted toilet paper with incorporated lignin absorbed the micropollutants on average more than the handcrafted toilet paper without lignin. The lignin processed in the toilet paper absorbed the micropollutants about 10% less on average than pure lignin. On average, toilet paper sprinkled with lignin (SLT) absorbed more micropollutants than toilet paper with lignin (DLT): 53% compared to 51%. This difference is however minimal, which means that the way in which lignin is processed in toilet paper has no influence on the absorption. This was not as expected and thereby this hypothesis is also rejected.

In conclusion, lignin absorbed micropollutants better than cellulose, and lignin processed in different ways in handcrafted toilet paper also absorbed micropollutants better than handcrafted toilet paper without lignin. With these results it is possible to reduce micropollutants in surface water using lignin incorporated into toilet paper. However, to see whether toilet paper with lignin has enough effect on a large scale to reduce environmental impact of micropollutants, more research will have to be carried out in the future.
8.0 Discussion

For this study, two experiments were performed and accurately described in the procedure. The concentrations were measured using Targeted LCMS, which is one of the most precise methods to measure concentrations. The probability that micropollutants reacted with each other and thus were not detected properly is very small, because micropollutants have great stability. The experiments were conducted under the supervision of Y. Wang; she ensured that no mistakes were made in this process. However, during the research some things happened that did not go according to expectations, which will now be highlighted.

In experiment one and two, samples were taken from the synthetic urine with the micropollutant solution for control. In experiment two, the values of this sample were not as expected, because when compared with the sample of the flask with lignin, the concentrations of micropollutants were higher in the flask with lignin. In experiment one it was proved that lignin absorbed micropollutants, so the blank sample of experiment two cannot be correct. Therefore, when processing the results, we chose to use the blank sample from experiment one as a benchmark.

In the way experiment two was done, it is not possible to precisely determine the amount of lignin in the ELT and DLT. Therefore, it is not exactly clear what the difference in absorption by lignin caused between the paper with the sprinkled lignin and the paper with the incorporated lignin. For these reasons, it is important that more research is done on manufacturing toilet paper with lignin.

It must be looked at which steps are needed to add lignin in the current manufacturing process. Another possibility is not to remove lignin in the first place, after which can be investigated whether lignin still absorbs micropollutants as well as in its pure form. When there is more clarity on these possibilities, the costs of adding or incorporating lignin into toilet paper can be considered and then can be decided whether this outweighs the already existing ways of reducing micropollutants in surface water. It is also important to investigate whether the pharmaceuticals absorbed by lignin are not the same pharmaceuticals that are already filtered out of wastewater by the sewage treatment plants.
9.0 References


10.0 Bibliography

Bos, H.L., Gosselink, R.J.A., Harmsen, P., Van Dam, J.E.G. (2016) De basisbouwstenen van lignine: sinapyl alcohol (S), coniferyl alcohol (G) en coumaryl alcohol (H)


