



## Supplementary materials

### S1. Composition of wastewater “before”

**Table S1.** Various substances detected in wastewater “before” obtained from local wastewater treatment plant using GC-MS analysis.

| Detected compound  |
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| (Z)-4-Methyl-2-hexene  |
| Azelaic acid   |
| Butane, 2,2,3,3-tetramethyl-   |
| 1-Pentanol, 2-ethyl-4-methyl-  |
| Hexane, 2,5-dimethyl-  |
| Cyclopentane, 1,3-dimethyl-, cis-  |
| Hexane, 2,4-dimethyl-  |
| Cyclohexane, methyl-   |
| Palladium(0), bis(η-2-butadiene) 1,1,4,5,8,8-hexa(tert.-butyl)-1,4,5,8-tetraphosphaooctane |
| Cyclopentane, butyl-   |
| Hexane, 3,3-dimethyl-  |
| Isopropylcyclobutane   |
| Pentane, 2,3,4-trimethyl-  |
| Valeric anhydride  |
| Hexane, 2,3-dimethyl-  |
| Pentane, 3-ethyl-2-methyl-   |
| Heptane, 2-methyl-   |
| Hexane, 3,4-dimethyl-  |
| Heptane, 3-methyl-   |
| Hexane, 3-ethyl-   |
| 1,3,5-Cycloheptatriene   |
| Pentane, 2,2,4-trimethyl-  |
| 1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-                       |

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Cyclopentane, 1-ethyl-3-methyl-, trans-  
Hexane, 2,3,4-trimethyl-  
Hexyl alcohol  
Hexane, 3-ethyl-  
Octane, 3,4-dimethyl-  
Antazoline  
p-Xylene  
Nonane  
Ethylbenzene  
Octane, 2,7-dimethyl-  
Propane, 2-methyl-1-nitro-  
Octane, 3,4-dimethyl-  
Molybdenum, bis[(1,2,3,4,5- $\eta$ )-1,3-bis(1,1-dimethylethyl)-2,4-cyclopentadien-1-yl]di- $\alpha$ -carbonyldicarbonyldi-  
Nonane, 2-methyl-  
2,4,4-Trimethyl-1-pentanol  
Hexane, 3-ethyl-2,5-dimethyl-  
Hematoporphyrin  
1,3-Propanediol, tert-butyldimethylsilyl ether  
2-Butene-1,4-diol  
Decane  
Heptane, 3-ethyl-5-methyl-  
Hexane, 4-ethyl-2-methyl-  
Heptane, 3-ethyl-5-methyl-  
Octane, 2,3,6,7-tetramethyl-  
Decane, 3,7-dimethyl-  
Heptane, 4-ethyl-  
Decane, 2,4-dimethyl-  
Octane, 3,5-dimethyl-  
6-Methyl-2-heptanol  
Octane, 2-methyl-  
Undecane, 2-methyl-  
Octane  
Octane, 2,4,6-trimethyl-  
Tridecane  
Undecane, 2,4-dimethyl-  
Dodecane, 6-methyl-  
Heptane, 3,3-dimethyl-  
Octane, 2,4,6-trimethyl-  
2-Propyl-1-pentanol  
Dodecane, 4,6-dimethyl-  
Benzaldehyde, 2,5-dimethyl-  
Ether, hexyl pentyl  
Benzene, 1,3-bis(1,1-dimethylethyl)-  
Sulfurous acid, 2-ethylhexyl hexyl ester  
1-Octanol  
Hydroxylamine, O-decyl-  
Heptane, 3-ethyl-5-methyl-  
Hexane, 3,3-dimethyl-  
Decane, 6-ethyl-2-methyl-  
Sulfurous acid, 2-propyl undecyl ester  
Decane, 6-ethyl-2-methyl-

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Valproic Acid  
2-Propyl-1-pentanol  
Tetradecane  
Oxalic acid, allyl tridecyl ester  
Heptane, 2,2,3,3,5,6,6-heptamethyl-  
Octane, 3,3-dimethyl-  
3-Hexanone, 2,4-dimethyl-  
Undecane, 4,7-dimethyl-  
Undecane, 2,4-dimethyl-  
Pentane, 1-butoxy-  
Tetratetracontane  
Tetracycline  
Hexadecane  
Decane, 6-ethyl-2-methyl-  
Phenol, 3,5-bis(1,1-dimethylethyl)-  
3-Ethyl-3-methylheptane  
17 $\alpha$ -Ethinylestradiol  
2-Decanol  
Octane, 2,4,6-trimethyl-  
2-Ethyl-1-hexanol  
tert-Amyl alcohol  
Sulfurous acid, 2-ethylhexyl hexyl ester  
Dodecane, 2,6,11-trimethyl-  
Hexane, 3,3-dimethyl-  
Octane, 2,4,6-trimethyl-  
Sulfurous acid, 2-ethylhexyl hexyl ester  
Heptadecane  
3-Ethyl-3-methylheptane  
Monopalmitin  
Propanoic acid, 2-methyl-, 2-ethyl-1-propyl-1,3-propanediyl ester  
Pentadecanal-  
2-Decanol  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
Decane, 2,4,6-trimethyl-  
Dodecane, 2,7,10-trimethyl-  
Pentacontanoic acid, ethyl ester  
Decane, 2,9-dimethyl-  
Decane, 6-ethyl-2-methyl-  
1-(2-Methoxyethoxy)-2-methyl-2-propanol  
Ketoprofen methyl ester  
Pentadecanal-  
Tridecane, 1-iodo-  
Hexadecane  
1-Decanol, 2-hexyl-  
Acetic acid, hydrazide  
Phytol  
Sulfurous acid, 2-ethylhexyl hexyl ester  
2-Hydroxy-2,4-dimethyl-3-pentanone  
(2,4-Dichlorophenoxy)acetic acid  
Tetratetracontane

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## S2. Composition of wastewater “after”

**Table S2.** Various substances detected in wastewater “before” obtained from local wastewater treatment plant using GC-MS analysis.

| Detected compound                              |
|--|
| Butane, 2,2,3,3-tetramethyl-                   |
| Hexane, 2,5-dimethyl-                          |
| Cyclopentane, 1,2-dimethyl-, cis-              |
| Hexane, 2,4-dimethyl-                          |
| 4-Hexen-1-ol                                   |
| Cyclohexane, methyl-                           |
| Propane, 2-methyl-1-nitro-                     |
| Cyclopentane, ethyl-                           |
| Hexane, 3,3-dimethyl-                          |
| Cyclopropane, 1,2-dimethyl-, trans-            |
| Pentane, 2,3,4-trimethyl-                      |
| 1-Hexene, 4-methyl-                            |
| Hexane, 2,3-dimethyl-                          |
| Heptane, 2-methyl-                             |
| Pentane, 3-ethyl-                              |
| Hexane, 3,4-dimethyl-                          |
| Heptane, 3-methyl-                             |
| Toluene  |
| Pentane, 2,2,4-trimethyl-                      |
| Cyclopentane, 1-ethyl-3-methyl-, trans-        |
| Octane   |
| Hexane, 2,3,5-trimethyl-                       |
| Heptane, 2,4-dimethyl-                         |
| Valproic Acid                                  |
| Octane, 4-methyl-                              |
| Ethylbenzene                                   |
| p-Xylene                                       |
| Nonane   |
| Ethylbenzene                                   |
| Octane, 2,7-dimethyl-                          |
| Hematoporphyrin                                |
| Pentane, 3-ethyl-2,4-dimethyl-                 |
| Heptane, 3-ethyl-                              |
| Hexane, 3-ethyl-2,5-dimethyl-                  |
| 2-Propyl-1-pentanol                            |
| Decane   |
| 1,3-Propanediol, tert-butyldimethylsilyl ether |
| Heptane, 3,3,4-trimethyl-                      |
| Decane, 2,4-dimethyl-                          |
| Hexane, 4-ethyl-2-methyl-                      |
| Nonane, 2,6-dimethyl-                          |
| Decane, 3,7-dimethyl-                          |
| Heptane, 4-ethyl-                              |
| Octane, 2-methyl-                              |
| Octane, 2,7-dimethyl-                          |
| Citraconic acid                                |

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N-Isovaleroylglycine  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
Dodecane  
Undecane, 2,4-dimethyl-  
Heptane, 4-propyl-  
Undecane, 2,8-dimethyl-  
Octane, 2,4,6-trimethyl-  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
Decane, 2,5,9-trimethyl-  
Benzaldehyde, 2,5-dimethyl-  
Ether, hexyl pentyl  
Benzene, 1,3-bis(1,1-dimethylethyl)-  
10-Methylnonadecane  
Hexadecane  
Isobutyl 3-methylbutyl disulfide  
1,3-Hexanediol, 2-ethyl-  
(2,4-Dichlorophenoxy)acetic acid  
Oxalic acid, isohexyl neopentyl ester  
Octane  
2,6-Dimethyldecane  
Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)-  
Tetradecane  
Oxalic acid, allyl decyl ester  
Oxalic acid, allyl nonyl ester  
Heptane, 3,3-dimethyl-  
Octane, 2,4,6-trimethyl-  
Decane, 6-ethyl-2-methyl-  
Sulfurous acid, decyl 2-propyl ester  
Decane, 2,4-dimethyl-  
Hexadecane  
Octane, 2,4,6-trimethyl-  
tert-Amyl alcohol  
2,2,4-Trimethyl-3-pentanone  
Phenol, 2,4-bis(1,1-dimethylethyl)-  
Hexane, 3,3-dimethyl-  
9-methylheptadecane  
Sulfurous acid, 2-ethylhexyl hexyl ester  
Sulfurous acid, butyl isohexyl ester  
Undecane, 2-methyl-  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
2-Heptadecenal  
17 $\alpha$ -Ethinylestradiol  
Decane, 6-ethyl-2-methyl-  
Sulfurous acid, 2-ethylhexyl hexyl ester  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
3-Hepten-1-ol  
Sulfurous acid, 2-ethylhexyl hexyl ester  
2-Propyl-1-pentanol  
Decane, 3-ethyl-3-methyl-  
Octadecane, 2-methyl-  
Tetracycline

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Oxalic acid, isohexyl pentyl ester  
Molybdenum, bis[(1,2,3,4,5-ü)-1,3-bis(1,1-dimethylethyl)-2,4-cyclopentadien-1-yl]di-æ-carbonyldicarbonyldi-  
Pentadecanal-  
Undecane, 2,6-dimethyl-  
Sulfurous acid, 2-ethylhexyl hexyl ester  
Ketoprofen methyl ester  
Decane, 3-ethyl-3-methyl-  
1,1':3',1''-Terphenyl, 3,3'',5,5''-tetrabromo-5-(3,5-dibromophenyl)-  
á-Hydroxyisovaleric acid  
Propanoic acid, 2-oxo-, trimethylsilyl ester  
3-Hexanone  
Heptacosane  
Malonamic acid  
Oxalic acid, allyl nonyl ester  
Sulfurous acid, 2-ethylhexyl isohexyl ester

**Table S3.** Removal efficiency of hematoporphyrin, (2,4-dichlorophenoxy)acetic acid (2,4-D), 17 $\alpha$ -ethynylestradiol (EE2), tetracycline, tert-amyl alcohol and ketoprofen methyl ester after treatment of wastewater “before” by various biocatalytic membranes. **1** denotes rejection by pristine membrane, **2** denotes removal rate by membrane with inactivated enzyme, **3** denotes removal rate by catalytic conversion, **4** denotes total removal rate of micropollutant.

| Analyzed compound                | Membrane-laccase |     |     |            | Membrane-tyrosinase |     |     |            | Membrane-HRP |    |    |            |
|----------------------------------|------------------|-----|-----|------------|---------------------|-----|-----|------------|--------------|----|----|------------|
|                                  | 1                | 2   | 3   | 4          | 1                   | 2   | 3   | 4          | 1            | 2  | 3  | 4          |
| Hematoporphyrin                  | 3%               | 5%  | 13% | <b>21%</b> | 3%                  | 4%  | 3%  | <b>10%</b> | 3%           | 3% | 5% | <b>11%</b> |
| (2,4-Dichlorophenoxy)acetic acid | 10%              | 11% | 30% | <b>51%</b> | 10%                 | 12% | 23% | <b>45%</b> | 10%          | 8% | 2% | <b>20%</b> |
| 17 $\alpha$ -Ethynylestradiol    | 7%               | 5%  | 30% | <b>42%</b> | 7%                  | 3%  | 30% | <b>40%</b> | 7%           | 4% | 4% | <b>15%</b> |
| Tetracycline                     | 6%               | 14% | 28% | <b>48%</b> | 6%                  | 9%  | 21% | <b>36%</b> | 6%           | 7% | 8% | <b>21%</b> |
| tert-Amyl alcohol                | 4%               | 2%  | 23% | <b>29%</b> | 4%                  | 3%  | 14% | <b>21%</b> | 4%           | 2% | 3% | <b>9%</b>  |
| Ketoprofen methyl ester          | 8%               | 9%  | 20% | <b>37%</b> | 8%                  | 8%  | 11% | <b>27%</b> | 8%           | 5% | 5% | <b>18%</b> |

**Table S4.** Removal efficiency of hematoporphyrin, (2,4-dichlorophenoxy)acetic acid (2,4-D), 17 $\alpha$ -ethynylestradiol (EE2), tetracycline, tert-amyl alcohol and ketoprofen methyl ester after treatment of wastewater “after” by various biocatalytic membranes. **1** denotes rejection by pristine membrane, **2** denotes removal rate by membrane with inactivated enzyme, **3** denotes removal rate by catalytic conversion, **4** denotes total removal rate of micropollutant.

| Analyzed compound                | Membrane-laccase |     |     |            | Membrane-tyrosinase |     |     |            | Membrane-HRP |     |     |            |
|----------------------------------|------------------|-----|-----|------------|---------------------|-----|-----|------------|--------------|-----|-----|------------|
|                                  | 1                | 2   | 3   | 4          | 1                   | 2   | 3   | 4          | 1            | 2   | 3   | 4          |
| Hematoporphyrin                  | 3%               | 8%  | 15% | <b>26%</b> | 3%                  | 6%  | 4%  | <b>13%</b> | 3%           | 3%  | 5%  | <b>11%</b> |
| (2,4-Dichlorophenoxy)acetic acid | 10%              | 13% | 38% | <b>61%</b> | 10%                 | 17% | 22% | <b>49%</b> | 10%          | 10% | 4%  | <b>24%</b> |
| 17 $\alpha$ -Ethynylestradiol    | 7%               | 6%  | 36% | <b>49%</b> | 7%                  | 6%  | 33% | <b>46%</b> | 7%           | 6%  | 4%  | <b>17%</b> |
| Tetracycline                     | 6%               | 18% | 32% | <b>56%</b> | 6%                  | 12% | 20% | <b>38%</b> | 6%           | 8%  | 12% | <b>26%</b> |
| tert-Amyl alcohol                | 4%               | 4%  | 22% | <b>30%</b> | 4%                  | 5%  | 18% | <b>27%</b> | 4%           | 4%  | 5%  | <b>13%</b> |
| Ketoprofen methyl ester          | 8%               | 13% | 19% | <b>40%</b> | 8%                  | 11% | 13% | <b>32%</b> | 8%           | 8%  | 3%  | <b>19%</b> |