EVALUATION REPORT
Constructing Wetlands Pilot at Sher Ethiopia PLC
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1 Introduction

Description of the issue
Sher Ethiopia is a private sector entity that produces roses. This happens in large quantities and with much labour being involved (over 10,000 employees). The flower production takes place in large greenhouses, located next to Lake of Ziway in the Ethiopian municipality of Ziway. The municipality of Ziway depends on the lake for her water needs: both drinking water and irrigation water. Next to that, the lake is an important source of food, with fish being an important item on the local menu. In many ways, the optimal quality of the lake water is of concern to everybody.

Sher Ethiopia is among the first to take action, since the management realised that the farm not only consumes a lot of lake water to irrigate the millions of roses it produces, but also because Sher Ethiopia discharged its effluent water to the lake. The company wants to improve this situation and prevent possible pollution of the lake by means of their effluent water, both by studying the present situation and seeking possible solutions.

Already twenty years ago, Sher obtained the MPS certificate for sustainable practice on the highest (A) level (certificate nr. 802685). MPS originates from 1993 under the Dutch name “Milieu Programma Siersteelt” and has grown nowadays to an organisation that certifies growers and traders in the floricultural and horticultural sector worldwide, being active in over 55 countries and around 4000 certified companies. This means that Sher Ethiopia only uses fertilizers and other chemical parameters that are allowed under strict certification. MPS audits this meticulously.

Furthermore, in recent years Sher Ethiopia has changed its rose cultivation practices from the use of chemical pest control towards biological pest control, implemented by Koppert BV (located in the Netherlands), which is the world leading company in this line of crop protection. This means that no substances can be used that might do any harm to the (micro-)biological organisms like nematodes and fungi that are being used for pest control within the Sher Ethiopia greenhouses. The current practices bring Sher Ethiopia above the MPS-A standard.

Additionally to being certified for sustainable management and being active in biological pest control, Sher Ethiopia wants to purify its wastewater to be beyond any doubt for external players when it comes to sustainability. To show that the wastewater coming out of the greenhouses with constructed wetlands is harmless, the company has the desire to take back all effluent water into its own water system. Hence, Sher Ethiopia wants its effluent water to be purified and monitored.

Description of the pilot as an answer towards the solution
From 2008 onwards, the Dutch Ministry of Economic Affairs has been present in the Ziway area, working together with the Horn of Africa Regional Environmental Centre & Network (HoA-REC&N) and many other local stakeholders in a project called “Buffer Zone Ziway”. The Ministry appointed DLG (Government Service for Land and Water Management, an agency of the Ministry of Economic Affairs) and provided a budget through the Embassy of the Kingdom of the Netherlands in Addis (EKN).

During the project, DLG was invited by Sher Ethiopia to give guidance in the quest for a safe water quality for which DLG assembled a small team. With an early input of UNESCO-IHE (the Netherlands), advice was given towards the use of constructed wetlands as a possible solution. Scientific literature indicates the effectiveness of these purification systems for treating residues of crop improving elements (fertilisers, insecticides, fungicides and pesticides). Treating the effluent water with a retention time of five days in a constructed wetland system, under reasonably anaerobic circumstances, was considered to be a promising approach.
After this first step, some drawings were made to explain the set-up. Then, the possible realisation of one or more pilot systems was approved. And when it came to making specific calculations for the more technical parts, Ecofyt was invited. In collaboration between the project leader DLG\(^1\), Ecofyt and the directory and staff of Sher Ethiopia, a first pilot was set up in 2012 to test the effectiveness of the constructed wetlands.

On July 1st, 2014, HoA-REC&N became involved in the constructed wetlands project to ensure the finalization of the pilot at Sher Ethiopia, focusing on a review of the wetland design and make the necessary adjustment, water sampling and analysis, developing manuals and the writing of this report to determine whether the constructed wetland pilot has a positive effect on the treatment of Sher’s wastewater. This report is meant to give solid ground to upscale constructed wetlands to other greenhouses of Sher Ethiopia and ultimately to other companies, and to determine whether it is a cost-effective means to treat wastewater in the continuously expanding horticulture sector.

\(^1\) WUR/Alterra per September 2014 since DLG will cease to exist on December 31th, 2014.
2 Summary

In the constructed wetland system, three components can be distinguished: 1) two wetlands in the greenhouses, 2) the drainage ditch between the greenhouses of about 2.5 km in length and 3) two wetlands outside the greenhouses at the boundary ditch of the site.

From the beginning of the pilot finalization project, weekly contact between users and designers was maintained to observe the current functioning of the wetland and to cure any start-up problems. After about one-and-a-half years, the pilot had become mature enough for proper evaluation.

From week 29 to 41, 2014, water samples were taken at various fixed spots in the system, which were then analysed in accredited laboratories, partly in Ethiopia and partly in the Netherlands. Samples were also taken at a reference drainage ditch to make a comparison with water that is not treated by constructed wetlands. The results of these water samples have been processed by Ecofyt to calculate the effect of the three components in the system.

Before creating a final report, the report and findings were assessed by the RIVM (National Institute for Public Health and Environment in the Netherlands) who took up the role of independent expert.

Different conclusions have been drawn from the data collected, which can be divided into:
- Main conclusions,
- Conclusions regarding the treatment efficiency,
- Related conclusions regarding the design and engineering of the pilot system.

Based on the evaluation, the final conclusions by the creators of the pilot system are:
- One can undoubtedly speak of a successful water treatment system.
- Purification efficiency is high and the costs of investment, management and maintenance are low.

The parameters studied have been divided into several groups and the average final results, (percentage removal from the treated water), when comparing dirtiest influent with final effluent, are as follows:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrients</td>
<td>99.4%</td>
</tr>
<tr>
<td>(Ammonium and Nitrate Nitrogen, Phosphorous)</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>94%</td>
</tr>
<tr>
<td>(Magnesium, Iron, Manganese, Zinc, Boron, Copper, Molybdenum)</td>
<td></td>
</tr>
<tr>
<td>Heavy metals</td>
<td>93%</td>
</tr>
<tr>
<td>(Manganese, Zinc, Boron, Copper, Molybdenum)</td>
<td></td>
</tr>
<tr>
<td>Residues (numbers)</td>
<td>65%</td>
</tr>
<tr>
<td>(from total no. of substances found in system to total found in effluent)</td>
<td></td>
</tr>
<tr>
<td>Residues (total weight)</td>
<td>99.98%</td>
</tr>
<tr>
<td>(from total weight found in influent to total weight found in effluent)</td>
<td></td>
</tr>
</tbody>
</table>

When comparing with the reference ditch, the result on the total weight of residues amounts to 79% in favour of the pilot. Or: in exact data: the final water in the reference ditch contained 47.55 · g of residues per litre where the final effluent from the pilot contained 9.99 · g per litre. This final calculation is of a more hypothetical nature, because the flows in the drainage ditches are approximates. The value is accurate if both ditches provide equal flow and pollution rates.

The system is not able to treat all water in the drainage ditches year-round. There are occasionally local downpours that are so severe that it is impossible to retain that rainwater. In that case, the discharged wastewater will be very highly diluted.

It should also be noted that the treatment system itself is a completely natural system that has been built with local materials, for the greater part, as well with local plants.
3 Objective

Objective of the Agreement (June 16th, 2014)
Ecofyt is assigned by HoA-REC&N and the EKN to finalize the constructed wetlands pilot at Sher Ethiopia. The focus of the finalizing of the project is on a review of the wetland design, water sampling and the writing of an evaluation report, to determine whether the constructed wetlands pilot has a positive effect on the treatment of Sher Ethiopia’s wastewater. The evaluation report is meant to give solid ground to upscale constructed wetlands to other greenhouses of Sher Ethiopia and ultimately to other companies in Ethiopia, being a cost-effective means to treat wastewater in the expanding horticulture sector.

Approach
Early 2014, it proved to be impossible to finalize the pilot within the initial budget. Therefore, HoA-REC&N has taken the role to provide financial resources through its EKN funding to finalize the pilot, with the objective to improve the quality of water resources flowing out, as well as within the greenhouses of Sher Ethiopia, and promote the upscaling of the constructed wetlands in the future.

Independent experts from the RIVM (the Netherlands) have reviewed this evaluation report on the consistency in the given data, the results and the conclusions that are based on these data. The design and engineering of the wetlands themselves were not subject of this assessment.

Photo 2 (all pictures © Pieter Boone, Joost van Uum, Frank van Dien)
4 Design of the pilot

The main idea was to design and engineer a water treatment system based on the principles of a natural wetland. Starting in 2011 by assignment of the EKN, the first challenge was to fit in the best wetland type and water system into the existing situation of the Sher Ethiopia compound. The existing context was dominated by the fact that there was no space to make any kind of constructed wetland and that the most optimal set-up (from a technical point of view) would be far too expensive to realize. As a result of this a ‘three step system’ was designed for the pilot set-up (see next page).

Figure 1 Schematic view of water treatment varieties with constructed wetlands. For the pilot the types Horizontal Flow (HF) and Saturated Down Flow (DFS) have been used.
The wastewater treatment pilot at Sher Ethiopia is a water management system for four greenhouses and consists of four constructed wetlands. It also uses an existing open drainage ditch between the greenhouses.

The objective is to purify the following wastewater streams:
- Remnants of fertiliser water (nutrients);
- Remnants of spraying water (including pesticides);
- Bucket water (from the buckets in which the cut roses are brought to the pack houses);
- Refrigerator water from the cold storage at the pack houses.

The pilot project covers four greenhouses, namely the numbers (or lines) 14 and 34, as well as 13 and 33.

As indicated in the diagram, two constructed wetlands (CW1) have been added to the buildings in the greenhouse (known as vocom houses), where fertiliser and pesticides are prepared. All remnants of the water used in these preparations are discharged to a gutter and next in a sedimentation tank. It then flows into a sump from where the wastewater is pumped into the constructed wetland. These wetlands provide the first water purification step.

Subsequently, the water flows into the ditch that runs parallel to the greenhouses. This ditch also receives the water from the pack houses (estimated to give a dilution of at least a factor 2.7 (from 2.5 m³ to 6.8 m³/day). The ditch carries the water to a second set of constructed wetlands, situated between the greenhouses and the boundary ditch. These filters (CW2) are outside the greenhouses. The boundary ditch connects directly to Lake Ziway.
Figure 3

Illustration representing the set-up for the second wetland outside the greenhouses

Source: M. Zapater-Pereyra, UNESCO-IHE, 2011)

Figure 4

Engineered by Ecofyt, showing the technical details of wetland 1, sedimentation tank and pump sump. This inside wetland was situated right next to the vocom house. Rose beds had to make way for this wetland and its feeding system.

Figure 5

Engineered by Ecofyt, the cross-section of the second type of wetland, outside the greenhouses. The adjustable outlet pipe is a very basic solution to control the water level in the wetland. The second wetland had to be built half in the existing bordering ditch because of a lack of space.
Photo 3

Construction of wetland 1 inside the greenhouse and next to the vocom house in 2012. The sedimentation tank and the pump sump can be seen in the front. Of all materials used, only the lining had to be imported (from 2014 on also obtainable in Ethiopia).

Photo 4

The second wetland, outside the greenhouses, is ready to be filled with substrate and plants. Sher Ethiopia personnel built all concrete structures on the spot.

Photo 5

Testing the pump capacity and the feeding water lines of the outside wetland. The basin is filled with a substrate that is obtained in the region.

Photo 6

Although the water system and its management are as basic as possible, the use of electric circuits was inevitable for pumps, timers etc. It appeared very important that within the Sher Ethiopia staff, the responsibility for this was given to one person only and she (!) had weekly contact with Ecofyt.
One of the two indoor wetlands, a few weeks after planting the Phragmites australis in early 2013.

The outdoor wetland in early 2013, planted with different species to experiment. Here: Canna sp. and in the background Arunda sp.

The outdoor wetland in 2014, which has matured for a long period and is now ready to be seriously tested on its efficiency. The Arunda sp. reaches up to four meters.
Some pictures of the steps in the system:

**Photo 10**
The water of every vocom house is first led into a sedimentation tank. In this tank the water can settle and small particles can float or sink, depending their specific weight. The exhaust pipe has been made in such a way that specifically the liquid fraction will continue to the next tank: the pump sump.

**Photo 11**
From the pump sump the pretreated water will be pumped to the constructed wetland. To get the steadiest and thus most reliable results during the entire testing period, this pump is regulated by a electronic timer and a float switch. A bypass is also installed in case the incoming water exceeds the expectations regarding quantity.

**Photo 12**
The indoor constructed wetland (a basin filled with sand, sealed with a watertight liner and finished with a concrete outlining) receives the pumped wastewater of the vocom house. Their beds are planted with reed (Phragmites australis). This type of wetland is called 'Horizontal Subsurface Flow Wetland' in which system the water is pumped in at the top left side and collected at the bottom right side, in a drainage pipe.

**Photo 13**
After the wetland, the water flows in the ditch that runs between the greenhouses. With a regulation pipe, the internal water level of the wetland is managed. That level is set pretty high to obtain a saturated substrate in the system. The ditch itself is also an important part of the purification system as in here the water gets to be exposed to sunlight (UV) and air (oxygen). Also, the water is diluted with 'bucket water' from the pack houses and the condense water from the refrigerator units.
At the end of the ditch, the collected water gets pumped up again and divided over the two wetlands that are outside the greenhouses. Their beds are planted with locally harvested macrophytes (mostly shoots) like Typha sp., Canna sp., Arunda sp., Cyperus sp. From here the water is supposed to be discharged towards Lake Ziway. But during the first pilot year, Sher Ethiopia had already decided to stop discharging the water that came out of the treatment system and take it back into the water reservoirs of the greenhouses. Thus, the effluent water of the pilot is actually already recycled and mixed with water that is pumped from Lake Ziway.

The pilot serves four greenhouses that are exploited by Sher Ethiopia. In case the involved parties consider the pilot as an adequate means to treat wastewater in the horticulture sector, other greenhouses are likely to be equipped with a similar purification system.

**Specifications of the system**

- CW 1 at vocom house line 14 treats a quantity of ca. 1000 litres of waste water per day;
- The surface is: 4.75 x 5.25 meter; 24.9 m²;
- CW 1 in line 34 is identical to line 14 but dimensioned at a quantity of 1500 litres per day;
- The surface is: 4.75 x 7.65 meter; 36.4 m²;
- Used as vegetation: Phragmites australis (locally collected roots and stems);
- CW 2 outside line 33 treats a quantity of 3000 litres per day;
- The surface is 50,00 x 1,00 meter; 50 m²;
- CW 2 outside line 34 is identical and also treats 3000 litres per day;
- The surface is 50,00 x 1,00 meter; 50 m²;
- Used as vegetation: Canna spec., Cyperus sp., Typha sp., Arunda sp. (locally found).

**System in dry and wet season**

The purification system is designed in such a way that it can function both in the dry season (precipitation minor or zero) and in the wet season (precipitation up to 145 mm per month). Precipitation usually comes in the form of a few heavy events. The extremes in the discharge of storm water are therefore large. Hence, the dimensioning has taken place with an eye on the dry season because that relates to the greater part of the year (8 months). The consequence is that during the rainy season water will pass alongside the system – sometimes in very large quantities. During that time also part of the wastewater will escape purification. This will however be in a highly diluted form.

**Climate data**

The figure shows the monthly precipitation per month (source: www.climatedata.eu) with clear peaks in July and August. The regular precipitation and its discharge are also influenced by a considerable evaporation. The lake evaporates ca.1780 mm on a yearly basis (source: Vallet-Coulomb et al. 2000).

![Figure 6 precipitation and temperature in Ziway](image)
Limited 'scope' of the system

During the design of the system, it appeared to be impossible to obtain an exact, reliable insight concerning the quantities of the wastewater to be treated. Therefore, it was decided to dimension the purification system on a fair estimate and to let the water pass in an optimally controlled way. It was quantified how much water would go into the system (stabilisation of the quantity). In case more water would be offered, it would bypass the system and it would be discharged as before. That means that there are two factors that limit the scope of the pilot system and therefore not the full 100 percent of the wastewater will be treated in the pilot phase.

Ethiopian context

For several reasons, the realised purification system must be able to cope with local circumstances. These vary considerably from e.g. European conditions. The reasons are of several origins and are determining both economics and techniques used in the system:

- In Ethiopia, many materials and tools are not or irregularly available. Also, the quality is not always sufficient;
- Import of materials is however an expensive and time consuming process. Because there is a prerequisite to use materials from within the country (employment, economy), the system should be set up as simple as possible. This also means that by definition the high (European) standards will not always be met. As a starting point it was suggested to take into account that both constructing and maintaining would be done with local materials and that inventory management would be feasible and low cost;
- In the water purification system, submersible pumps, switchboards and timers have been used. Thus there is an electro/electronic component involved. This is both vulnerable and unavoidable. In Ethiopia the electrical supply regularly fails in which case the emergency generators of Sher Ethiopia fall in. This however happens with high starting amplitudes of around 300V. The electric part of the system must be able to survive such conditions. Sensitive electronic equipment should therefore be avoided as much as possible.
- Employees of Sher Ethiopia should be able to follow, judge and maintain the system without help of foreign experts. Therefore training has been given and protocols and manuals have been written. Nevertheless, the entire process should still be as simple and robust as possible. For example, the manual is made with photos and pictograms, as much as possible and the text is short. It was decided to put the text both in English and Amharic.
5 Evaluation method

The evaluation was initiated after the system had been functioning more than 1.5 years (569 days). The system was set in operation on December 22nd, 2012; the start of registration of the technical parameters was January 7th, 2013. Since the start of the system, there has been contact between Sher Ethiopia and Ecofyt on a weekly basis regarding the meter readings and water levels. The reason is obvious: stay up to date and respond quickly to possible fluctuations, conditions or problems as a continuation of the instruction stage.

Evaluation of such a system is more effective and more reliable after a certain maturation time. The purification system is a 'living' system, based on plants and bacterial communities that have to do the work. The plants must grow, produce roots and they need time to be working towards a balanced bacterial community. A second reason to use a long initial period is the fact that after construction many large and small problems can and will arise that require a series of adjustments and changes. Only after some trouble shooting, the system is ready for a reliable evaluation. During the evaluation period (July 2014 - December 2014), no changes to the system have taken place. The water samples were collected by the manager of the relevant greenhouses from Sher Ethiopia, in the presence of a supervisor of HoA-REC&N. Together they stored the samples, where necessary, in the cool house and transported them to Horticoop Ethiopia in Debre Zeyt. From every sample a picture was taken, to follow the process visually and to give "a face" to each dataset. The samples were analysed by certified laboratories:

- Horticoop Ethiopia, Debre Zeyt, Ethiopia
- Altic Dronten, Netherlands, in corporation with Laboratory Zeeuws-Vlaanderen².

Horticoop Ethiopia uses an Inductively Coupled Plasma Spectrometer (ICP). The parameters which were studied are:

- PH (acidity, ISO 10523) and EC (conductivity, ISO 7888)
- Nutrients: Ammonium (NH4, ISO7150-1), Nitrate (NO3, ISO7890-1), Phosphorus (P*), Potassium (K*);
- Metals: Calcium (Ca, *), Magnesium (Mg, *), Sodium (Na, *), Manganese (Mn, *), Iron (Fe, *),
- Heavy metals: Zinc (Zn *), Copper (Cu, *), Molybdenum (Mo, *)
- Other substances: Chloride (Cl, ISO 9297), Silicon (Si *) and
- Compounds: Bicarbonate (HCO3, ISO 9963-2) and Sulphate (SO4, *)

*) Stands for ISO 11885.

Note: the reported concentration Sulphate (SO4²) is measured as a Sulphur (S) with the assumption that the sulphur compounds were present in the form of sulphate.

The samples that were examined in the Netherlands were exported under the responsibility of Horticoop Ethiopia. The Laboratory Zeeuws-Vlaanderen analysed for pesticides and residues. The laboratory uses three methods (GC-MSMS, GC-ECD, and LC-MSMS) with which approximately 600 substances can be distinguished. The full spectrum is applied to the samples sent to them.

The process of the water quality research
- Period of sampling: July 14th, 2014 (week 29) to October 10th, 2014 (Week 41);
- The sampling scheme, including the sampling protocol, can be found in Appendix 4;
- Sampling took place on Mondays and Fridays because the retention time of the water in the first beds of the water treatment system is calculated at five days. It was tried to sample ‘the same litre

² Note: both companies have given official approval for publishing the data of the analysis
of water’ during its flow through the first steps of the treatment system;
- To Horticoop Ethiopia were sent: 5 rounds of 8 samples each. These samples concerned 19 parameters, yielding in total $5 \times 8 \times 19 = 760$ data;
- To Altic B.V. were sent: 2 rounds of 8 samples each. Per sample 633 parameters were to be investigated (some in duplicate) yielding $2 \times 8 \times 633 = 10,128$ data.

The points of sampling have been chosen based on the fact that they are ‘critical points in the path through the system’. Points 1 and 3 make the most polluted samples with the water coming straight from the vocom houses (non-diluted waste water), Points 2 and 4 are the exit pipes from the first wetlands (non-diluted effluent).

Point 5 is at the end of the ditch (diluted with water from the pack houses), forming the influent water for the second and final wetlands.

Point 6 and 7 are the outlet pipes from the second wetlands (again non diluted water).

Point 8 is the reference point, in a ditch from another ‘line’ (greenhouse) where no purification takes place.

Point 9 is the Ziway Lake. Its water quality is not reviewed in this report.

The data reports, coming back from the laboratories, have been placed in spreadsheets for this report.

The data have been brought to a certain level of aggregation to form relevant groups according the interpretation of Ecofyty. The original data reports from the laboratories can be found in Appendix 3.

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**Figure 7** Sampling points in the system.
### 6 Results

**Figure 8** the pictures of the water samples

<table>
<thead>
<tr>
<th>Sample Point 1</th>
<th>Sample Point 2</th>
<th>Sample Point 3</th>
<th>Sample Point 4</th>
<th>Sample Point 5</th>
<th>Sample Point 6</th>
<th>Sample Point 7</th>
<th>Reference Ditch</th>
</tr>
</thead>
<tbody>
<tr>
<td>29th Week, July 14</td>
<td>32nd Week, Aug. 04</td>
<td>32nd Week, Aug. 08</td>
<td>25th Week, Aug. 25</td>
<td>29th Week, Aug. 29</td>
<td>15th Week, Sept. 15</td>
<td>24th Week, Sept. 19</td>
<td>Effluent 33 Out</td>
</tr>
<tr>
<td>29th Week, Sept. 09</td>
<td>32nd Week, Oct. 06</td>
<td>32nd Week, Oct. 10</td>
<td>25th Week, Oct. 03</td>
<td>29th Week, Oct. 06</td>
<td>15th Week, Oct. 19</td>
<td>24th Week, Oct. 29</td>
<td>Effluent 34 Out</td>
</tr>
</tbody>
</table>

**Note on figure 4 (previous page)**
The photos (made by Sher Ethiopia and HoA-REC&N staff, edited by Ecofyt) do not concern the actual samples that were sent to the laboratories. They were however taken at the same time, under the same conditions. The real samples were stored in sterile bottles, provided by Horticoop Ethiopia. The set of photos from week 32 are the samples for both Horticoop Ethiopia and Altic B.V. The samples from week 40 only went to Altic B.V. All the other samples went to Horticoop Ethiopia. In week 35, sampling was done during a rain event.

**Sample points 1 and 3:**
- The water that will be pumped in the first set of wetlands (CW1);
- The water has passed the sediment tank and has lost most of its solids. Samples were taken from the pump sump, not from the sediment tank;
- The red colour of the water is mainly caused by an addition called EDDHA Fe 6%. This is a Ferro chelate forming addition; a micronutrient to treat a lack of iron in plants;
- The set of samples was usually turbid. The coloration varied from pink to almost reddish black.

**Sample points 2 and 4:**
- The water that comes out of the first wetlands in a non-diluted form;
- The water is consistently orange to red and clear, instead of turbid.

**Sample point 5:**
- The water from the end of the ditch, diluted with water from the pack houses; the so-called bucket water (water from the buckets in which the roses are transported to the pack house) and condense water from the refrigerator units;
- The red colour has gone. Again the water is slightly turbid, probably caused by dust and sand coming in this open part of the system.

**Sample points 6 and 7:**
- The water that comes out of the second set of wetlands;
- In almost all samples the water has no colour, is odourless and clear.

**Sample point 8:**
- Water from the end of the ‘reference ditch’, it is comparable with the water at sample point 5, be it without any form of purification.

**Chemical results**
Six samples taken about every 3 weeks give a constant set of data but still remain ‘a snapshot - from a longer movie’. Six points in time can give a representative trend though. It is very well possible that further research will give other results, depending on the season, the kind of roses that are being grown, the growth phase of the crops, etc.

It will be understood that the total of 10,888 data obtained (and significantly more after making the sheets with average values, yields and comparisons) are not fully described in a few pages. The complete set of data can be found described in Appendix 3 and as attachments to this report. The sheets with the average values (made by Ecofyt) are shown on the following pages. In words and pictures, this report will be limited to the essentials of the analysis of the water samples and focus on the efficiency results of the applied purification.
## Table 1: Analysis of Nutrients and Metals in Water Samples

<table>
<thead>
<tr>
<th>No.</th>
<th>Site Name</th>
<th>Conductivity</th>
<th>pH</th>
<th>Ammonium</th>
<th>NH₄⁺</th>
<th>Nitrate</th>
<th>NO₂⁻</th>
<th>NO₃⁻</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Sodium</th>
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<th>Baricbor</th>
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<th>Copper</th>
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<tbody>
<tr>
<td>1</td>
<td>Pump sump GH-14</td>
<td>3.1</td>
<td>7.7</td>
<td>21.4</td>
<td>17</td>
<td>947</td>
<td>214</td>
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<tr>
<td>2</td>
<td>Outset wetland GH-14</td>
<td>3.1</td>
<td>7.5</td>
<td>6.36</td>
<td>5.0</td>
<td>1219</td>
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<td>0.04</td>
<td>0.96</td>
<td>0.25</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>Pump sump GH-34</td>
<td>4.1</td>
<td>5.7</td>
<td>31.1</td>
<td>24</td>
<td>2138</td>
<td>483</td>
<td>15.9</td>
<td>534</td>
<td>264</td>
<td>91.8</td>
<td>100</td>
<td>369</td>
<td>24.9</td>
<td>258</td>
<td>45.3</td>
<td>17.0</td>
<td>0.73</td>
<td>1.58</td>
<td>0.56</td>
<td>0.80</td>
<td>0.03</td>
</tr>
<tr>
<td>4</td>
<td>Outset wetland GH-34</td>
<td>6.8</td>
<td>7.1</td>
<td>0.57</td>
<td>0.4</td>
<td>2467</td>
<td>191</td>
<td>9.0</td>
<td>&lt;0.01</td>
<td>569</td>
<td>122</td>
<td>6.40</td>
<td>6.40</td>
<td>14.2</td>
<td>597</td>
<td>30.8</td>
<td>5.01</td>
<td>7.68</td>
<td>0.02</td>
<td>3.77</td>
<td>0.23</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>Water basin b/n outside wetlands</td>
<td>0.2</td>
<td>8.8</td>
<td>0.33</td>
<td>0.3</td>
<td>32.2</td>
<td>7.3</td>
<td>&lt;0.01</td>
<td>10.4</td>
<td>5.26</td>
<td>3.02</td>
<td>23.8</td>
<td>5.21</td>
<td>7.02</td>
<td>66.1</td>
<td>6.84</td>
<td>0.74</td>
<td>0.04</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>6</td>
<td>Outlet wetland outside GH 33</td>
<td>0.6</td>
<td>7.8</td>
<td>0.19</td>
<td>0.1</td>
<td>8.57</td>
<td>1.9</td>
<td>&lt;0.01</td>
<td>25.1</td>
<td>3.46</td>
<td>9.16</td>
<td>82.5</td>
<td>3.73</td>
<td>5.55</td>
<td>39.8</td>
<td>18.3</td>
<td>0.20</td>
<td>1.08</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>7</td>
<td>Outlet wetland outside GH 34</td>
<td>0.7</td>
<td>8.0</td>
<td>0.22</td>
<td>0.2</td>
<td>18.1</td>
<td>4.1</td>
<td>&lt;0.01</td>
<td>25.5</td>
<td>6.05</td>
<td>11.8</td>
<td>67.5</td>
<td>4.43</td>
<td>4.98</td>
<td>43.9</td>
<td>22.3</td>
<td>0.07</td>
<td>2.20</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>8</td>
<td>Reference point b/n GH 35&amp;36</td>
<td>0.3</td>
<td>8.1</td>
<td>0.47</td>
<td>0.4</td>
<td>30.4</td>
<td>6.9</td>
<td>&lt;0.78</td>
<td>16.6</td>
<td>14.7</td>
<td>4.36</td>
<td>27.5</td>
<td>9.28</td>
<td>6.34</td>
<td>135</td>
<td>18.2</td>
<td>2.65</td>
<td>0.04</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Note: Values in the table represent the concentration of nutrients and metals in the water samples. The units are in mg/L for most elements, except for pH and conductivity, which are not specified here. The table also includes the results of various analyses and comparisons, such as the percentage of nutrients meeting the criteria, the overall result percentages, and the importance of parameter rankings.
The lab of Horticoo Ethiopian; nutrients and (heavy) metals:

Explanation of table 1:
1. Line 1 to 8 shows the location where the water sample from the system was taken;
2. Lines 1 and 3 concern the wastewater from vocom houses;
3. Lines 2 and 4 relate to the effluent from the first set of filters;
4. Line 5 concerns water at the end of the ditch;
5. Lines 6 and 7 correspond to the effluents from the second set of filters, being the end result of purification;
6. Line 8 form the values of the reference-ditch;
7. The values in the lines 1 to 8 are the averages of five analyses;
8. Lines 9 to 13 give the results of the direct return in each purification step;
9. Lines 14 and 15 focus on the wetlands performance versus the reference ditch;
10. Lines 16 to 18 indicate what steps give positive or negative results;
11. Lines 19 and 20 show the average in- and effluent values (both CW sets are in duplicate after all);
12. Line 21 gives the Dutch discharge standards IBA Class IIIb (according to CIW/CUWVO);
13. Line 22 gives the Dutch regulations regarding Maximum Tolerable Risk (MTR);
14. Line 23 provides per parameter the overall result of the treatment efficiency in percentage;
15. Line 24 indicates whether the results meet the discharge standards;
16. Line 25 indicates the relevance with respect to conventional purification parameters;
17. Line 26 shows (after a “rounding up to 25% rule”) how effective the treatment is. e.g a 11% removal becomes 0% thus zero stars, a 64% removal becomes 75%, thus three stars.

Results based on table 1

1. The removal efficiency of the nutrients amounts in total to 99.4%;
2. The total reduction of metals (through binding and sedimentation) amounts to 94%;
3. For only the heavy metals, the result is 93%;
4. If the final effluent (sample points 6 and 7) is compared to the current Dutch discharge standards then those values can be considered to be easily achieved, e.g. for ammonium-nitrogen by a factor of 25, for total nitrogen by a factor of 19 and for total phosphorus even by a factor of 600;
5. If the same effluent is assessed on the MTR values (Maximum Tolerable Risk), again it can be stated that most standards are generously met: copper by a factor of 7.5, total phosphorus by a factor of 15, chloride by a factor of 20, sulphate sulphur by a factor of 25, molybdenum by a factor of 30, zinc by a factor of 80. Only manganese does not meet the MTR (although there was as much as 80% efficiency achieved). Ammonium-nitrogen is close with 0.16 mg/l, where the MTR is 0.02. (The discharge standards for nitrogen are much higher: 60 mg/l for total nitrogen and 4 mg/l for ammonium-nitrogen);  
6. Compared to the reference situation, there are positive differences on the parameters: pH, ammonium-nitrogen, nitrate-nitrogen, total phosphorus, sulphur-sulphate, chloride, iron, zinc, copper and molybdenum; negative differences were found for conductivity, potassium, calcium, magnesium, sodium, bicarbonate, silicon, manganese and boron.
7. When the purification efficiency is expressed in weight percentages (important parameters; mg/l, ++ to ++++), the pilot system is 48% more effective than the treatment that occurs in ditches that are not connected to a wetland system (see table 1; sum of line 20 is 21.1, sum of line 8 is 40.7).
8. Manganese turns out to be considerably higher in the final effluent of the wetlands than in the reference ditch. Its value in the effluent is high: 2.1 mg/l, which is 70 x the MTR of 0.031 mg/l. Nevertheless, looking at the highest values before and after the first set of filters, an 80% reduction of manganese is achieved in total.

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Thanks to Mr. Amare Haile, HoA-REC&N for the conversion of the pdf-files from Horticoo to Excel format.
### Explanation of tables 2a and b:

Columns 1 t/m 8 (lilac colours) give the sample points in the system.

The values given here are the averages of 2 rounds of samples.

The colours used (traffic lights) at the right of the table stand for the reduction effect in the parameters found after every step in the purification system. The meaning of the colours is as shown in the legend:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Init. Dil. 1</th>
<th>Init. Dil. 2</th>
<th>Init. Dil. 3</th>
<th>Init. Dil. 4</th>
<th>Final Dil. 1</th>
<th>Final Dil. 2</th>
<th>Final Dil. 3</th>
<th>Final Dil. 4</th>
<th>Total result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter 1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Parameter 2</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 2a the average values of the parameters in the residue analyses, n=2

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4 The conversion of the pdf-files from Altic B.V. to Excel format has been done by Ecofyt
The average values of the parameters in the residue analysis, n=2

Explanations of columns with coloured blocks on the right:
Column no. 1 in this range gives the effect of the first set of wetlands.
Column no. 2 shows the effect of the ditch.
Column no. 3 shows the effect of the second set of wetlands.
Column no. 5 gives the overall result of the system.
Results: pesticides and residues

Based on the analysis by Altic B.V. (laboratory Zeeuws-Vlaanderen) (10,128 data), a number of key issues can be listed:

1) Total number of parameters examined per sample is 633. Some substances were tested in multiple ways, the so-called “duplicates”
2) Total number of distinguishable substances (excluding the duplicates) is 596. This relates to the number of substances that can be found by the laboratory in one sample.
3) Total number of substances found in the pilot is 99. This relates to the number of substances that have been observed anywhere in the system. Some of these substances were observed everywhere, in one or both of the samples. Some were only found once, at any place in the system.

<table>
<thead>
<tr>
<th>total nr. of substances per location:</th>
<th>influent</th>
<th>effluent</th>
<th>ditch</th>
<th>def. effluent</th>
<th>ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>total residu weight (μg/l/ location):</td>
<td>56</td>
<td>57</td>
<td>53</td>
<td>32</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>53</td>
<td>57</td>
<td>32</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>4.661</td>
<td>4.661</td>
<td>4.274</td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>46.468</td>
<td>4.274</td>
<td></td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>5.928</td>
<td>4.661</td>
<td>4.274</td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4) From these 99 substances, 77 different residues were found in the water from the vocom houses, 28 in the final effluent of the pilot and 38 in the reference ditch.
5) The removal percentage of numbers of substances in the pilot amounts to 63.6%.
6) The removal percentage on the total weight of the substance, at the end of the pilot, in comparison to the reference ditch, amounts to 79.0%.

Note: the numbers may seem not in line with the table but they are: the 56 residues of point 1 and the 73 residues of point 3 have many duplicates. In total, the influent has 77 different substances. The same is true for the sample points 6 and 7, 19 residues found in the first, 26 in the second result in 28 different residues, finally.
The purification in three phases: wetland ➔ ditch ➔ wetland:

The fact that there are two sets of wetland systems does not mean that the pilot is a ‘two-stage rocket’ since also the ditch plays an important role in the system. There are two wetlands with reed in the greenhouses: one of 25 m² and one of 36 m². Outside there are two wetlands with other macrophytes of 50 m² each; the total surface of the beds is 161 m². A ditch with a length of 2 km constitutes the connection between these wetlands. This ditch contains (in the dry season) a thin slice of water from an average of about 2 cm deep and circa 1.00 m wide. This results in a surface area of 2.000 m², which is 12.5 times larger than the reed beds. In this ditch two additional important processes are being performed:

- Exposure to sunlight (and thus ultra-violet radiation) and
- Reaction with air (and thus oxygen).

Both processes work optimally because of the thin slice of water. This process has of course always been performed and is therefore also the process that takes place in the lines without a treatment system. It was not possible for Horticoop to examine oxygen levels and UV radiation. Apart from that, as mentioned earlier, in this ditch the water from the pack houses (grading water and bucket water) comes together with the effluent of the vocom houses. Dilution is also an important factor: 2.5 m³ vocom water becomes about 7.0 m³ total flow rate for the filters outside. That is 2.8 times as much. On the other hand, evaporation plays an important role as well. During the pilot this could however not be quantified.

In addition to the treatment efficiency, this result must also be weighed against the ditches where no further purification was applied. Some calculations have been done in comparison to the reference ditch. If the pilot is compared to the reference ditch, there are differences in both positive and negative sense. For the analysis of Horticoop the results are:

<table>
<thead>
<tr>
<th>Pilot ditch cleaner:</th>
<th>Reference ditch cleaner:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorous</td>
<td>Manganese</td>
</tr>
<tr>
<td>Iron</td>
<td>Calcium</td>
</tr>
<tr>
<td>Ammonium</td>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Nitrate</td>
<td>Sodium</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Magnesium</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>conductivity</td>
</tr>
<tr>
<td>Chloride</td>
<td>Boron</td>
</tr>
<tr>
<td>Zinc</td>
<td>Potassium</td>
</tr>
<tr>
<td>Copper</td>
<td>Silicon</td>
</tr>
<tr>
<td></td>
<td>pH</td>
</tr>
<tr>
<td>99%</td>
<td>98%</td>
</tr>
<tr>
<td>95%</td>
<td>69%</td>
</tr>
<tr>
<td>57%</td>
<td>68%</td>
</tr>
<tr>
<td>56%</td>
<td>63%</td>
</tr>
<tr>
<td>56%</td>
<td>58%</td>
</tr>
<tr>
<td>50%</td>
<td>57%</td>
</tr>
<tr>
<td>17%</td>
<td>36%</td>
</tr>
<tr>
<td>29%</td>
<td>34%</td>
</tr>
<tr>
<td>17%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2%</td>
</tr>
</tbody>
</table>

Notes: 1) The parameters in light grey indicate which substances, from a water treatment point of view, are not or less relevant parameters because they are not seen as pollution. 2) The reference calculation is of a more hypothetical nature, because the flows of the drainage ditches are approximates. The value is accurate if both ditches provide equal flow and pollution rates.

For the pesticide analysis of Altic B.V., a comparison was made between the pilot and the reference ditch as well. For 53 of the 99 substances found, the first set of wetlands (near the vocom houses) has a key role in the purification process. The ditch provides a reduction percentage for 58 substances.
For the second set of wetlands a reduction percentage was achieved for 25 parameters\(^6\).

Summarizing, the wetlands deliver \((53 + 25)\) 78 times a certain kind of reduction and the reference ditch is doing so 58 times. In other words, the wetlands pilot contributes to the decomposition of an additional 20 substances.

The purification efficiency of the pilot on the weight of the measured substances amounts to 99.96%. The weight removal in the reference ditch (assuming that the vocom houses would produce the same amounts and sorts of contaminants) is also very high: 99.82%.

The number of parameters on which the pilot outperformed the reference ditch is 33. However, it also happened that the reference ditch outperforms the pilot, the number of cases was 11 times. The number of parameters that have finally been found in the effluent of the pilot is 19 at sample point 6 (the outdoor filter at line 33) and 26 in sample point 7 (outside of the filter at line 34). Of these, there is a number of parameters found on both sides, in total there are 28 different parameters still existing in the purified water. In the water of the vocom houses 77 parameters have been found. The yield is between these two points \((77-28) / 77 = 63.6\%)\. In the reference ditch, 38 substances were detected, making the comparable yield to be 50.6%.

Much more significant are the differences if we look at the weights of the parameters concerned. At the sample points 6 and 7, the total weight of the contaminants at the assumed rate of 6,825 litres per day, divided between the two wetlands amounts to: 68,199 micrograms per day \((10.4 \mu g/l \text{ total weight} \times 6825/2 \text{ for point 6} + 9.58 \mu g/l \text{ total weight} \times 6825/2 \text{ for point 7})\).

At the reference ditch, 38 parameters are found, with a total weight of 423,508 micrograms per day, with an assumed daily flow rate of 6,825 litres \((47.55 \mu g/l \times 6,825 \text{ at point 8})\). If these two values are compared with each other than the efficiency of the pilot versus the reference ditch is 79.0% \([((324,508-68,199)/324,508] \text{ for pesticides cq. residues.}\)

\(^6\) Note: It is possible that a parameter decreased at all three locations. In that case, the substance is counted three times. Similarly, it is possible that a substance had already been broken down completely in a previous stage. In such a case, the next purification step is unable to ‘score’.
7 Conclusions

7.1 Main conclusions

1. The water sample analysis results show that the applied pilot constructed wetlands are a successful method to achieve a high to very high treatment efficiency of the wastewater of Sher Ethiopia. Based on the results, the scaling up of this method of water purification seems to be effective and cost-efficient.

2. The purification efficiency is very high, but not 100%. This means that certain chemical substances after purification are still present in the water. Since Sher Ethiopia captures the purified effluent and brings it back into their internal water system, it can be stated that after purification of the remaining components, a minimal amount of contaminating substances will be spilled into the environment.

3. The pilot project is successful but has nonetheless a limited 'scope'. Both during the rainy season and during occasional rain events in the dry season, wastewater (that has only been treated in the first set of wetlands and in the ditch) flows into the environment. This is inherent to the fact that in case of heavy rainfall the water cannot be stored, and thus neither purified.

4. The costs of the design, construction and management of the water purification system are low, and can largely be realized with locally available materials and knowledge. After overcoming some problems in the beginning of the project - mainly physical problems and struggles in terms of maintenance - the system is now stable and working successfully.

5. It is recommended to apply a number of improvements in the design and engineering of the treatment to improve the 'scope' of the system so that at least during the dry period no water will pass outside the treatment. The measures necessary for this purpose are known (see 7.3 Related conclusions).

7.2 Conclusions regarding treatment efficiency

7.2.1 Horticoop data

1. From the analysis of Horticoop (760 data) not all parameters are equally important from a water purification point of view. In particular, calcium, magnesium, sodium, silica and bicarbonate do not play a role as a parameter in the wastewater treatment. Potassium, boron and sulphate only play a role when they appear in problematic concentrations (there are e.g. no discharge standards), but the nutrients (nitrogen and phosphorus) and metals from this set (see table 1) are of importance.

2. The removal efficiency of the overall system, being the difference between the sample points 1 and 3, and 6 and 7 is 93%. This is when only the first group of significant parameters is counted. The percentage is 76% when the insignificant parameters are included.

3. The removal efficiency of the nutrient amounts to 99.4%.

4. The total reduction of metals (through binding and/or sedimentation) amounts to 94%.

5. Looking only at the heavy metals, the result is 93%.
6. When the final effluent (sample points 6 and 7) is compared to the current Dutch discharge standards than these results are very positive, e.g. for total nitrogen by a factor 19, for ammonium-nitrogen by a factor 25 and for total phosphorus even by a factor 600.

7. If the same effluent is assessed on the MTR values (Maximum Tolerable Risk) than again most standards are generously met: copper by a factor 7.5, total phosphorus by a factor 15, chloride by a factor 20, sulphate sulphur by a factor 25, molybdenum by a factor 30, and zinc by a factor 80.

8. Only manganese does not meet the MTR (although there is as much as 80% efficiency achieved). Ammonium-nitrogen is close, with 0.16 mg/l, where is the MTR is set at 0.02. (The discharge standards (i.e waste water) for nitrogen are much more tolerant than the MTR values: 60 mg/l for total nitrogen and 4 mg/l for ammonium-nitrogen.)

9. Manganese turns out to be considerably higher in the final effluent than in the reference ditch. No chemical analysis was performed on the types of substrate. It seems likely that the chosen material is the origin of the manganese found. Its value in the effluent is high: 2.1 mg/l, which is 70x the MTR of 0.031 mg/l.

10. If it is decided to further scale-up within Sher Ethiopia, it is advisable to perform a chemical analysis on the substrate so the choice of this material would not only be driven by the correct granularity but also by its chemical quality.

11. Compared to the reference ditch, there are positive differences on the parameters pH, ammonium-nitrogen, nitrate-nitrogen, total phosphorus, sulphur-sulphate, chloride, iron, zinc, copper and molybdenum.

12. Expressed in weight percentages (Horticoop Ethiopia analyses, important parameters), the purification efficiency of the pilot system is 48% more effective than the treatment that occurs in ditches that are not connected to the wetlands.

7.2.2 Altic BV data

1. From the analysis of Altic B.V. (10,128 data) the key conclusions are: every sample has been tested in 633 ways, looking for parameters. Here are some duplicates (you can search up to three ways to a specific substance). In total 596 different substances can be distinguished in a single water sample.

2. In total, 99 different substances have been found, of which 77 are in the water from the vocom houses, 32 in the ditch, 28 in the final effluent of the pilot, and 38 in the reference ditch. The removal percentage on the number of substances in the pilot is 63.6%, for the reference ditch this is 50.6%.

3. The removal percentage on the total weight (Altic B.V. analyses) of that substance at the end of the pilot, in comparison to the reference ditch, amounts to 79.0%

7.3 Related conclusions regarding the design and engineering of the pilot system

1. The initial estimations of the flow rate are close to the observed flow rates during operation. It is still not exactly known what the precise, actual flow rates are. Flow rate measurement of wastewater can be problematic, due to particles (parts) that are in the water or because of chemical substances. The pump pulse meter readings and the pump timer meter readings stand at the base of estimations regarding the flow rate.
2. The design of the constructed wetlands itself has proven to meet any flow rate (water discharge) that it was subjected to, taking into account that it is impossible to store and purify the occasional enormous flow in the rainy season. The system kept on working during any circumstance. Over- or under loading has not occurred.

3. The system has - from a constructional point of view - not always been free of problems. The second set of wetlands outside the greenhouses has been hit during heavy rainfall in the spring of 2013. The location, directly adjacent to the boundary ditch, has proved to be vulnerable. If up scaling will be decided to other greenhouses, the recommendation is to design them differently: either not as the dividing line between water and land (but further from the ditch), either on a heavy foundation, uninfluenced by the condition of the ditch or the velocity of the (storm) water.

4. The system also had to withstand typical local conditions such as irregular supply of electricity. From this, a number of improvements emerged:
   a. Electronic timers should be more robust or should be avoided.
   b. Electronics & technical parts must be locked to prevent unauthorized actions.

5. Getting the right sand quality has been a difficult issue, the finer fractions were sometimes more abundant than the material that had been ordered, every truck has to be checked. This is a topic for further research, both for chemical and physical qualities, it is possible that another substrate can be found, of more stable quality

6. The use of locally mined cuttings of the applied plants has proved very feasible.
Appendix 1 Independent review by RIVM

Date 19 January 2015
Subject Review evaluation report Wetland Pilots at SHER, Ethiopia

Dear Mr. Wiegant,

VNG-International has asked the National Institute for Public Health and the Environment (RIVM) to review the evaluation report ‘Wetlands Pilots at SHER, Ethiopia’ and add suggestions to improve the quality of the report where necessary.

We read the report with great interest. In our opinion, SHER Ethiopia is working on a great project to actively contribute to the improvement of water quality with the use of local raw materials (plant cuttings). Much information has been collected to evaluate the system, but addressing more attention to the relation with the environment (as described below) and specifying the different steps of the system may contribute to improvement of the report. It was not clear whether this information was not available or was not included in the report. Our comments are specified below.

Effect on other functions: The introduction states that SHER uses water from Lake Ziway, but the lake has other functions as well, such as drinking water and fisheries. There is no information in the report on the size of the lake, where these other functions are located and the effect (possible threat) of the current discharge of wastewater for these functions and the improvement achieved with the new situation (only discharges of raw wastewater during extreme rainfall).

Sampling: Based on the retention time of the water in the system, the approach (page 14) describes the sampling strategy in which the tested effluent water originates from the tested influent water. Was the retention time of the system checked experimentally or checked based on the results of the analyses? Was this approach also used for sampling pesticides and to calculate the efficiency? The results of the measurements for pesticides seem not to be consistent.

Quality of Lake Ziway and chemicals: In the report, data is missing on the water quality of Lake Ziway and its comparison to water from the system discharged onto Lake Ziway. Furthermore, no data is provided on the chemicals and other substances used in the process by SHER. The pesticide analyses show a large variety of substances, and it is unclear which of these substances are used by SHER. At different sampling points in the system, different substances were detected, suggesting that the quality of the influent process water (Lake Ziway) is an important factor. The long term aim, as described in the report, is to use an extended recirculating system. Therefore, it is of great importance to know the exact contribution of the wetlands, the ditch and the influent process water is (Lake Ziway).
Remarkably, the concentration of a number of pesticides is very high (>1000 µg/L). The report describes that SHEER has substituted chemical for biological control (or is working on this). To what extent the presence of some pesticides in relatively high concentrations are related to the substitution, deserves attention.

Contribution ditch: The report mentions a positive contribution of the ditch as a result of oxygen and UV. Does this mean that the oxygen level is initially low? It is important to check the oxygen level because oxygen levels influence the degree of oxidation of metals such as iron and manganese. In oxygen-free conditions (likely to occur in a filter), these metals may again go into solution. Data on concentrations of oxygen are not shown in the analysis results. The data on ammonium and nitrate suggest that little oxygen is present at some points in the system.

The report does not describe exactly the positive contribution expected of oxygen and UV. Due to the low flow velocities in the ditch there will often be a laminar flow, whereby the oxygen transfer is limited to the upper water layer (but maybe the water level in the ditch is low as well). Due to the low flow velocities, sedimentation will also make a significant contribution to the removal of substances in the ditch. Did the research investigate whether sludge stays behind, and what its quality is? The chemical analyses show that mainly manganese decreases in the ditch, suggesting sedimentation, possibly preceded by oxidation.

Is information available on the levels of suspended matter and organic matter?
In addition, other water (bucket and refrigerator water) flows into the ditch, resulting in dilution of concentration of the substances. This may be another explanation for the reduction in concentrations of the chemical parameters.

For better estimation of the effect of the ditch, it is important to gather more information (data) on the size of the different water streams, including a water- and/or dust balance.

Analysis results: instead of individual results of the analyses, this report shows the average value of five samples taken at the same location. The value of the conclusions will increase by including the bandwidth of the results, since this gives an indication of the consistency of the results, and, for example, seasonal influences.

Table 1 shows the removal calculated in percentages, which also come back in the conclusions (p. 24). The conclusion indicates that the overall removal efficiency is 93%. In addition, a number of parameters are not included. It is not clear why this has been done when calculating the total removal efficiency.

The mechanisms of removal may vary by substance; therefore, averaging percentages of various substances is not suitable when determining the efficiency of constructed wetlands. It is better to take a number of (indicator) parameters and to identify their efficiency. Thus, the removal of nutrients (nitrogen and phosphorus compounds) is very high. The emphasis in the conclusion should focus on this, and it should also indicate that a more mixed picture applies for other inorganic parameters and pesticides.

Calculation of removal efficiency: The calculation of the efficiency is described very compactly. Data indicates that differences are present between the first two wetlands in terms of removal. Nevertheless, in this report no further analyses on these differences are done (see also the comments on analysis results).

Calculating the individual removals provides more information and a better insight into:
- The relation between removal and size of the wetland
- The performance of the individual filters, do all filters function equally well?
- Removal in the time, is the removal by wetlands and the ditch equal during all sampling dates, or are other factors present contributing to differences in removal, such as the weather (wet and dry season, rain or no rain).

Seasonal influence: The report describes a difference in dry and wet season; however, the results do not indicate what effect this has. Depending on the amount of rainwater entering the ditch, the concentration of various substances will be diluted. Is the amount of water in the ditch and/or the amount
of rain measured during sampling? This data is very relevant for conclusions on the effect of the weather. Furthermore, during heavy rainfall more sludge will be discharged to Lake Ziway, because it is stirred up by increasing flow velocity.

**Reference ditch:** Before starting the project, was it considered which substances would be removed by the filters?

A comparison (wetlands 33 and 34) was performed with a reference ditch. For approximately half of the parameters (in particular nutrients), the quality of the effluent water is better than that of the reference ditch. It might be considered whether the improved water quality can be explained solely by the performance of the wetlands, because the water discharged into the reference ditch comes from greenhouses without treatment (constructed wetlands). Furthermore, it is unclear whether similar processes (including raw materials) were used in the greenhouses of the reference ditch?

The influence of the weather could be derived by comparing the reference ditch and the researched ditch, because then the values may be closer together because of dilution. The quality of the water in the reference ditch is closely associated with discharges from other greenhouses and rainfall. The way in which the discharge of the wastewater takes place (continuous or intermittent) can have a major impact on water quality, during sampling, and hence on the analysis results.

**Microbiological parameters:** The evaluation only included chemical parameters for the evaluation of the constructed wetland. However, it would also be very interesting to investigate the microbiological removal by the constructed wetland, especially because of the plans to reuse the purified water. This might be done by the detection of fecal contamination, for example, the presence of E. coli. However, investigation of the removal of fecal contamination requires additional information, such as the addition of fertilizers.

I hope that our response supports you in the further completion of the evaluation and finalization of the report.

Yours sincerely,

Prof. dr. A.M. de Roda Husman
Head dept. Environment at Laboratory for Zoonoses and Environmental Microbiology
Appendix 2 Addressing the issues raised by RIVM

Response from the authors on the review by Prof. Dr. A.M. de Roda Husman of RIVM (National Institute for Public Health and the Environment – Ministry of Health, Welfare and Sport, NL)

First of all, we are very pleased with the review made by RIVM. Not only because the conclusion of RIVM concerning the results of the pilot system is very positive: “Sher Ethiopia is working on a great project to actively contribute to the improvement of water quality with the use of local raw materials”, but also because many suggestions have been made to improve the report itself and to continue research on certain aspects of the pilot and constructed wetlands in general.

We think that the suggestions that are raised are of high interest but most of them go (far) beyond the framework of the assignment of the pilot and its evaluation. For instance: it would be very interesting – maybe even necessary – to compare the results of this pilot with data on the quality of Lake Ziway itself. HoA-REC&N has taken samples from the lake water but these are not yet public. Just like RIVM we strongly encourage further research on lake Ziway’s water quality and the impact on the surroundings. Whether it be in relation to Sher, to the sewerage of the village or to the small-scale horticulture, north of Ziway. Our assignment however was to try to enhance Sher’s wastewater quality and evaluate the effects of our attempt. We will respond to the review by RIVM, chronologically.

Effect on other functions:
The questions in the review are interesting and relevant but go beyond the scope of the pilot. In the introduction some information is added concerning the direct environment of the village of Ziway and the farm of Sher Ethiopia.

Sampling:
The hydraulic retention time (HRT) is a calculated value. With the designed pump regime we assured that it would not be surpassed. There has been no research on the effective HRT, knowing that it is a costly and time-consuming procedure with trace materials. Besides it could harm the real function of the system: to purify wastewater. Inconsistencies in the pesticide data are to be expected, as mentioned in the report, for several reasons.

Quality of lake Ziway and chemicals:
The pilot was about measuring the water purification efficiency of the designed system. The pilot was not about giving full insight in the origin and whereabouts of the chemical parameters, nutrients and metals in the water. Nevertheless the issue raised in the review by RIVM is without doubt both obvious and necessary. It certainly would be interesting to have further research on this matter. As said above, HoA-REC&N will publish their results on the water quality of the lake. This will be around mid-2015. We strongly recommend further research when this has been done.

The use of pesticides on the Sher Ethiopia farm is under the code of conduct of MPS (besides Fair Trade and FFFP). The use of any kind of pesticide (in any concentration) in relation to biological pest control at the same time was not the subject of our research.

Contribution of the ditch:
The oxygen level may indeed be assumed to be low, we designed a saturated constructed wetland that receives exclusively waste water. Oxygen levels could not be measured by Horticoop and on site equipment to do measurements by Sher personnel was decided to be too complicated in relation to the information value. The observations regarding oxygen and manganese are correct. The report however clearly states that the ditch usually contains just one cm of water which makes the
observations on laminar flow otiose. Had suspended solids or organic matter been part of the analyses Horticoop could deliver, we would certainly have had that added to the research. The dilution has been mentioned in the report, complete with data.

**Analysis results:**
Concerning the bandwidth: the report is delivered with the water sample analyses of both Horticoop Ethiopia and Altic B.V. (appendix 7). We are convinced that the bandwidth is totally clear for the reader who wants to go deeper in the material. The report has the scope to inform the reader with more condensed data and results. The report also states clearly which parameters were valued of higher and lesser importance and why.

We agree that the mechanisms of removal vary by substance. For that reason we grouped nutrients, metals, pesticides and gave for each of them the results. This data is to be found in the tables. We did not put extra emphasis on nutrients (however beautiful the result), our greatest interest were the pesticides.

**Calculation of removal efficiency:**
We agree that the calculation is compact. We had 10,880 data to explain to the participants. Most of them would like to have that condensed into a few figures. The leading question was and is: “are we on the right way with this system, yes or no?” The report comes to the conclusion that we are. The dimensioning of the wetlands was based on assumptions. In the pilot we learned many aspects. And yes, there are reasons to design the next wetlands somewhat bigger and also some other improvements in the design and maintenance (appendix 6). But although much was said about the dimensioning of the various systems, the result was the scope of the report, not the design itself.

**Seasonal influence:**
This was indeed only slightly addressed in the former version of the report and has been adapted.

**Reference ditch:**
The project was initiated with the focus on pesticide removal. There was no specific knowledge of what we would find. The reference ditch did indeed tell us the difference between greenhouses with (wastewater) treatment and greenhouses without treatment. It is not possible to say in which degree the diverse greenhouses are alike: different roses call for different (pest control) treatment, and different stages of the plants (from shoots to full grown, highly yielding roses) will only complicate the comparison. And yes, even the dilution factor will vary. But, with the help of Sher Ethiopia staff, we tried to keep these differences to a minimum: the comparison will be the best we can expect. The research learned us much about the dynamics of floriculture. And this was only at Sher Ethiopia, a company with the highest certificates and environmental interest and awareness.

**Microbiological parameters:**
Had it been in the package of Horticoop Ethiopia, it would have been part of the research. It is very true. Indeed, this makes part of the data we want to know. Fortunately we have plenty data that constructed wetlands may perform up to 99.98% of removal, we would however appreciate to know if that result was acknowledged in this project, too.

We like to thank Prof. Dr. A.M. de Roda Husman of RIVM for her role in this research and we trust that her remarks will have improved the quality of our report and will enforce further research.

Alterra, Wageningen
Ir. P. Boone
Ecofyt, Oirschot
F. van Dien
Appendix 3 Sampling protocol

Protocol of sampling for the final evaluation of wetlands
- Sampling will be done in 5 rounds every three weeks (see schedule below);
- Each round contains 8 samples;
- Sampling will be done on Mondays and Fridays of the same week;
- All samples will be transported to Horticoop in Debre Zeyt after the sampling on Friday;
- Samples will be taken by Kifle (Sher) and Amare (HoA-REC);
- Samples will be taken in sterile bottles that have no air bubbles enclosed;
- On Monday: sample at point 1 & 3 (description of points: see below);
- The bottles will be coded e.g. “34-3 dd-mm- yyyy”. (greenhouse nr - sampling point – date);
- Codes are written on the white bottles with permanent marker;
- After the sample in the white bottle another sample is taken in the glass pot;
- Use the same code on the black label of this pot with a white chalk;
- Make a picture of this sample with the water surface visible;
- Store the white bottles for Horticoop in cool house at 4°C;
- On Friday take samples at points 7, 6, 5 & 8, then 4 and 2. (in this order, from clean to dirty);
- Same protocols on filling, codes and pictures;
- Don’t store sample bottles in warm places, keep them out of sunlight, if there is time between sampling and transportation to Horticoop: store them at cool house at 4°C;
- Transport all samples (Monday and Friday) by car, in a cool box;
- Before transport, check if every bottle is coded;
- All 8 samples are to be handed over to Horticoop personnel and placed cool on the same Friday;
- Apart from the above samples we will have samples that will be sent to Holland, by Horticoop;
- These samples are taken in two rounds (see schedule below, “+ NL samples”);
- These bottles are labelled e.g. “13-1 dd-mm- yyyy NL”;
- HoA-REC&N will contact Horticoop on the size of these bottles and will take care of delivery at the Sher Ethiopia.

Schedule of water samples:
Round 1: week 29 Monday, July 14 and Friday July 18
Round 2: week 32 Monday August 4 and Friday August 8 + NL samples
Round 3: week 35 Monday August 25 and Friday August 29
Round 4: week 38 Monday September 15 and Friday September 19
Round 5: week 41 Monday October 6 and Friday October 10 + NL samples

NB: the last NL samples have been taken a week earlier, in week 40. This was because the results of the first set did not come through for a while. Week 40 was then added to be able to obtain two samples in the research period. But then the data came through anyway (they had been ‘misplaced’) so we dropped the NL analyses of week 41.

List of sampling points:
Point 1: pump sump in greenhouse 14
Point 2: outlet wetland of greenhouse 14
Point 3: pump sump of greenhouse 34
Point 4: outlet wetland of greenhouse 34
Point 5: water basin between the two wetlands outside
Point 6: outlet wetland outside greenhouse 33
Point 7: outlet wetland outside greenhouse 34
Point 8: reference point at end of another channel without any treatment
Appendix 4 Terms of Reference Ecofyt

1. Objective of the Agreement

1.1 The objective for signing this agreement is to finalize the constructed wetlands pilot at Sher Ethiopia, focusing on a review of the wetland design and make the necessary adjustment, water sampling and analysis, developing manuals and the writing of a report to determine whether the constructed wetland pilot has a positive effect on the treatment of Sher's wastewater. This report is meant to give solid ground to upscale constructed wetlands to other greenhouses of Sher Ethiopia and ultimately to other companies, and to determine whether it is a cost-effective means to treat wastewater in the continuously expanding horticulture sector.

1.2 Ecofyt and HoA-REC&N understand and agree that they are duty bound to closely collaborate on works related to the project and exchange all relevant information thereon.

2. Approach

The project began as collaboration among DLG, Sher Ethiopia, HoA-REC&N and Ecofyt to finalize a pilot constructed wetland, which was started with the aim to treat wastewater at Sher Ethiopia’s greenhouses. To finalize the pilot, HoA-REC&N shall provide financial resources through its EKN funding, with the objective to improve the quality of water resources flowing out, as well as within the greenhouses of Sher Ethiopia, and promote the upscaling of the constructed wetlands in the future. HoA-REC&N provides funding, so that Ecofyt can do the needed water analysis, wetland design testing, facilitation of stakeholder meetings and writing of a report that determines the functioning of the constructed wetlands pilot. Ecofyt will allocate 21 man-days in Ethiopia, besides which 5 man-days are spent in the Netherlands as well. Travel days are not counted as workdays.

3. Validity of the agreement

3.1 The agreement takes effect from July 1st, 2014 and ends on December 31st, 2014. Ecofyt will implement the project within this period.

4. Duties and responsibilities of the parties to this agreement

4.1 Within this agreement, Ecofyt shall:

4.1.1 come up with a report for adjustments/improvements for the constructed wetlands. The water recycling system will be discussed and integrated in the current design;
4.1.2 train personnel from Sher Ethiopia to properly operate the wetlands, and develop an illustrated manual/guideline for operational use of the wetlands;
4.1.3 be responsible for the scientifically-sound collection of water samples by trained personnel of Sher Ethiopia. To reduce risk that water samples are not taken adequately, more energy will be invested to train personnel on this matter, and HoA-REC&N staff is present every time that samples for the report are taken;
4.1.4 write a report, verified by an independent party (provided by the EKN), which provides a decisive answer regarding the functioning of the constructed wetlands and implications for upscaling;
4.1.5 communicate on the progress and results of the project towards Sher Ethiopia, EKN and HoA-REC&N;
4.1.6 write an overall evaluation report with recommendations for the constructed wetlands at Sher Ethiopia.

4.2 Within this agreement, HoA-REC&N shall:

4.2.1 cover the following costs: expert fee, and travel & accommodation.

The total fund excludes the costs for water samples analysis and the hiring of the independent
expert, which will be hired by the Dutch Sustainability Unit, through the EKN;
4.2.2 organise a meeting with the EKN, Sher Ethiopia, Ecofyt and HoA-REC&N;
4.2.3 organise transportation for Ecofyt from Ziway to Addis Ababa on appointment;
4.2.4 provide arrangements for the water samples to be transported to Horticoop (in Debre Zeit) for analysis, and provide Horticoop with the financial resources to do so.

No information about the project will be disseminated outside the four partite group (Sher Ethiopia, EKN, HoA-REC&N, Ecofyt). Any information sharing with third parties happens in such a way that all four parties agree with the message.
Appendix 5 Improvements in the design and engineering

- When scaling up the system in order to prevent water flowing out without being purified, the water collecting basin between the outer constructed wetlands will get a larger capacity so that after a light to moderate (incidental) rainfall no significant amounts of water will flush over the wall of the basin.

- Just before the collecting basin between the outer constructed wetlands a sand trap will be made. By doing this less cleaning of the collecting basin itself will be necessary. Also less sand will be pumped up into the pipe lines.

- All the adjustable outlet pipes from the constructed wetlands will be properly fixed and will get a scale board that indicates the right positions. The applied technique in the pilot is not robust enough.

- The outer constructed wetlands will be built outside the existing profile of the bordering ditch if there is enough space to do so. This is to prevent damage in the rainy season and extra costs in maintenance.

- The substrate used for the constructed wetlands will be tested before transport for its percentage of silt and its organic and chemical parameters.
Appendix 6 Data of analyses

The original pdf-files from the laboratories will be attached to this document:

Appendix 6 - Horticoop Ethiopia and Altic B.V. water sample analyses.pdf (244 pages)
Also the two excel files derived from this data can be found here.
Appendix 7 Manual

as attachment: appendix 7 - manual pilot.compressed.pdf