

Vetiver Floating Rafts for Oil Refinery Effluent, Thanh Hoa, Vietnam

English Summary and Technical Review

Source: OlaFarm, "Bè Vetiver xử lý nước thải lọc dầu tại Thanh Hoá: kinh nghiệm triển khai và kết quả sau hai tháng" (Vetiver rafts treating refinery wastewater in Thanh Hoa: implementation experience and results after two months). Author: Phạm Thị Nhân, MSc, OlaFarm manager. Updated September 7, 2026. olafarm.com

Note on the translation: *This is a close, section-by-section English rendering of the article in condensed form rather than a verbatim word-for-word translation, since the article is [OlaFarm's copyrighted text](#). All technical content, figures, and claims are carried over.*

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Part A. English Summary of the Article

Overview

The article describes vetiver grass planted on floating rafts in an operating wastewater lagoon at a petrochemical refinery in Thanh Hoa Province. The roots and the microbial film on them are presented as taking up or breaking down nitrogen, phosphorus, organic matter, suspended solids, heavy metals, oil and grease, and phenol. The piece covers plant selection, raft construction, and conditions two months after installation. OlaFarm supplied planting material and design advice; a different contractor did the installation.



Photo 1: *Strips of floating rafts planted with vetiver and umbrella sedge on the refinery's lined lagoon. Newly planted vetiver rafts, still yellow, lie next to rafts that have already greened. The project used both species: 60% vetiver, 40% umbrella sedge. Photo: OlaFarm (olafarm.com), used with permission.*

Project data

Item	Details
Work done	Floating rafts planted with vetiver and umbrella sedge (<i>Cyperus alternifolius</i>) placed on part of an operating treatment lagoon
Objective	Lower the pH of lagoon water leaving the upstream physical and chemical treatment stages
Facility	Liner-sealed wastewater lagoon, about 10,000 m ² (1 ha), at a petrochemical refinery
Timeline	Planting material delivered June 11, 2026; rafts launched from June 12; monitored to early August 2026
Scale	108,000 vetiver tillers, planted as about 10,800 clumps (one clump of about 10 tillers per planting point); rafts 4 × 2 m; 20 cm spacing; about 60% of rafts vetiver, 40% umbrella sedge; partial surface cover only
Cultivar	HB06 (OlaFarm selection), bare-root clumps, trimmed, with original soil deliberately left around the roots to bind the tillers together
OlaFarm role	Planting material and design advice; construction by another firm



Photo 2: Vetiver and umbrella sedge rafts side by side on the black-lined lagoon, with railings and pipelines along the bank and port cranes on the horizon. Rafts about six weeks after planting. Photo: OlaFarm (olafarm.com), used with permission.

Why add a stage to the lagoon, and which method

An operating lagoon cannot be drained to build new works. This one follows the plant's physical and chemical treatment and has continuous inflow and outflow. Water leaving those stages has a higher pH than the owner wants, and the owner chose a biological stage on the lagoon surface, using the existing retention time, instead of adding more chemicals. Refinery wastewater differs from domestic sewage: besides nutrients it carries oil and grease, suspended solids, persistent organics, and, after chemical treatment, off-neutral pH. Ordinary aquatic plants tend to die or stagnate in such water.

Three approaches are compared: (a) a constructed wetland on a filter bed, which gives controlled flow and stable performance but needs separate land and new construction and cannot be fitted into a full lagoon; (b) free-floating plants such as water hyacinth, which cost almost nothing but drift, clog the surface, are hard to harvest, and die in strong wastewater (a 2015 Vietnamese piggery-effluent trial is cited in which hyacinth died after 8 days while vetiver survived and reduced BOD); and (c) a constructed floating wetland,

with plants on floating frames and roots hanging free in the water. Option (c) was chosen because it works in a full lagoon, can be placed exactly, and is cheap and fast to install. Its drawbacks are the need for anchoring that follows water level, regular cutting, and a large raft area if the rafts are to carry most of the load.

What vetiver removes: evidence cited

Vetiver is described as removing pollutants in three ways at once: uptake of N, P, and some metals into biomass; trapping of suspended solids by the root curtain; and breakdown of organics, oil, and toxic compounds such as phenol by root-zone microbes. The article tabulates published results, stressing that they come from differing conditions and are a reference range, not a forecast for this lagoon:

Parameter	Reported result	Source cited
N and P (hydroponic)	1 m ² of vetiver removed 30,000 mg N and 3,575 mg P in 8 days	Truong & Danh 2015, p. 18
N and P (pond)	Over 90% reduction, Venezuela	Truong & Danh 2015, p. 20
BOD	Piggery effluent: 40% lower after 32 days; hyacinth control died by day 8	Truong & Danh 2015, p. 21
Crude oil, COD, BOD	1% crude oil in water, 6-plant raft in 25 L tanks: oil –91.39%, COD –84.60%, BOD –84.25% after 4 weeks	Effendi et al. 2017
Oil & grease, TSS (oil industry)	Pilot rafts, Colombian oil company: O&G –73–100%, TSS –29–75%; inflow 0.33–5.23 mg/L and 1.7–18 mg/L	Truong & Danh 2015, p. 59
Phenol	Fully degraded; rate about 32× faster than water without vetiver (Thailand)	Truong & Danh 2015, p. 21
Heavy metals	Pb, Zn, Cd, Cu accumulate mainly in roots, little moves to shoots	Danh et al. 2009
Fluoride (a limitation)	Fell only from 2.72 to 2.22 mg/L, then plateaued	Truong & Danh 2015, p. 20

Why the owner chose vetiver rafts

First, the depth of published research and guidance, both in Vietnam (Can Tho University's vetiver monograph, 2016, and its floating-wetland design handbook, 2023) and internationally (TVNI's water-quality handbook by Truong and Danh, 2015; the Danh et al. 2009 review), which gives the owner data for design and comparison.

Second, pH range. Vetiver has been recorded growing on bauxite residue at pH 12 and gold tailings at pH 2.7 in Queensland; OlaFarm's own cultivar sheet gives HB06 a tolerance of pH 3.3–12.5. The mechanism relied on is root and microbial respiration releasing CO₂ and organic acids, pulling root-zone pH toward neutral. The article states that how much and how fast can only be read from the plant's inflow and outflow monitoring.

Third, tolerance of oily water. The 1% crude-oil trial deliberately tested a very high concentration, and the plants not only survived but removed 91% of the oil. The Colombian pilot used real oil-industry water at much lower concentrations, closer to what remains after oil separation. Together these support vetiver's suitability but are not figures for this lagoon. OlaFarm therefore advises treating the literature as a reference range and measuring performance on the lagoon itself, before and after launch, over at least one season to remove rainfall and temperature effects.

Limits are also acknowledged: in Venezuelan soil mixed with 5% heavy crude, vetiver tillered more than controls with no toxicity signs after six months, but biomass, height, and roots were reduced and soil oil

content was not significantly lower than unplanted plots (Brandt et al. 2006). An Australian greenhouse trial found diesel highly toxic (plants died at a 50% diesel mix) while oxidized hydraulic oil was well tolerated. The conclusion drawn: at high oil loads the plant survives but does not clean the oil, and water with concentrated diesel should be avoided.

The owner split the rafts roughly 60:40 between vetiver and umbrella sedge, side by side in the same water, both to have two species working and to compare their adaptation directly on site.

Raft construction

Each raft is 4 × 2 m (8 m²) and has three layers:



Photo 3: OlaFarm workers unloading woven sacks of vetiver clumps beside the lagoon, with stacked raft frames on the right. All 108,000 tillers arrived on one 2.4-tonne truck. Photo: OlaFarm (olafarm.com), used with permission.

- **Outer frame:** sealed plastic pipe described as "phi 10" (see review note on size), forming a rectangle that is both frame and float. It does not rust in wastewater, needs no paint, is widely available, and is cheaper than metal.
- **Support mesh:** green PE netting with 2 cm openings stretched inside the frame, small enough to hold clumps, open enough for roots to pass straight down. UV and water resistant for years; patchable.
- **Top grid:** monofilament netting with 10 × 10 cm cells stretched above, one clump per cell, holding clumps upright in the first weeks before new roots anchor into the lower mesh, and keeping rows neat.

The 4 × 2 m size is long enough to be stable in wind, light enough to lift by sling and tow by hand, and matches stock net widths. Rafts were assembled and planted on the bank under a shade net, lifted into the water as each was finished, and joined end to end into long strips, so work on the water was limited to positioning and tying.



Photo 4: Workers planting trimmed vetiver clumps into pipe-frame rafts lined with green mesh, under a shade net on the lagoon bank. Each raft is launched as soon as it is planted. Photo: OlaFarm (olafarm.com), used with permission.



Photo 5: A planted raft being lowered by sling into the lagoon and joined to the end of a strip of rafts already afloat. Photo: OlaFarm (olafarm.com), used with permission.

Each planting point is one HB06 bare-root clump of about 10 tillers (not 10 separate slips), with leaves cut to about 25 cm and roots trimmed to stimulate new roots. When splitting the clumps, OlaFarm deliberately left some of the original nursery soil around the roots so the tillers stay bound together. Short leaves cut transpiration before new roots form, so new rafts look yellow and bare, which is normal. Bare-root clumps are lighter, faster, and cheaper than potted plants; all 108,000 tillers went in sacks on one 2.4-tonne truck.



Photo 6: HB06 bare-root clumps freshly dug at the OlaFarm nursery: about 10 tillers per clump, leaves cut to about 25 cm, roots trimmed to stimulate new growth, some soil kept at the base. Photo: OlaFarm (olafarm.com), used with permission.



Photo 7: Close-up of trimmed clumps on a raft. The monofilament grid above holds each clump upright; new green shoots are emerging from the still-yellow clumps. Photo: OlaFarm (olafarm.com), used with permission.

Long-term maintenance is limited to periodic leaf cutting to remove biomass, checking ties between rafts and bank moorings, and patching netting. Vetiver regrows and persists for years, and the plastic frame does not rot, so neither plants nor rafts need seasonal replacement.

Sizing and layout

At 20 cm spacing a raft holds 20 clumps × 10 rows = 200 clumps, or about 2,000 tillers. 108,000 tillers (about 10,800 clumps) therefore gives about 54 vetiver rafts, plus about 36 sedge rafts at the 60:40 ratio: about 90 rafts and 720 m² of raft on a roughly 10,000 m² lagoon. These are calculated, not counted, numbers. Cover is thus a small fraction of the surface, chosen because the rafts play a supporting role after

chemical treatment. Rafts were linked into long strips running along the lagoon with channels between, because removal depends on the distance water travels through the root curtain, not on raft numbers.

Results after two months



Photo 8: Workers wading in the lagoon to tow and tie newly launched vetiver and sedge rafts into neat strips, with the refinery and storage tanks in the distance. Photo: OlaFarm (olafarm.com), used with permission.

Rafts are stable, and vetiver has rooted and greened on the wastewater; pH and water-quality figures await the plant's monitoring cycle and are the plant's unpublished data. Early rafts greened first, so for a time two colors of raft sat side by side. By two months the vetiver was green, upright, and vigorous, with no tilting or drift. Umbrella sedge looked better at first, as it went in as whole leafy plants, but vetiver was clearly ahead after one month, and after two months the sedge was slower and weaker in the same water. The lesson drawn: appearance at planting says nothing about suitability; rooting speed and growth over 4–8 weeks do, and only a trial on the actual water can show it. Claimed results are thus three: the rafts held up for two months; HB06 survives and grows on post-chemical refinery effluent; and it established faster than umbrella sedge. pH performance must come from inflow/outflow data over time.



Photo 9: *Vetiver rafts with long upright leaves beside lower-canopy umbrella sedge rafts, placed together to compare growth in the same water. Refinery tank farm and stack in the background.* Photo: OlaFarm (olafarm.com), used with permission.



Photo 10: *Delivery of planting material, time-stamped 9:42 a.m., June 11, 2026.* Photo: OlaFarm (olafarm.com), used with permission.



Photo 11: Photo taken by the owner on August 3, 2026, 52 days after launch: lush vetiver rafts next to spreading umbrella sedge rafts. Photo: OlaFarm (olafarm.com), used with permission.

Lessons for industrial lagoons

Main lessons: trial the species on the actual water before scaling up, and lay rafts out along the flow path rather than by count. The Can Tho handbook's four weaknesses of floating systems are also listed: (a) oil and herbicides can harm plants and root microbes, so surface oil films need watching and diesel-bearing water should be avoided; (b) plants must be cut or harvested regularly, since pollutants stored in biomass return to the water if plants die in place; (c) falling water levels can ground rafts, so moorings must allow rise and fall (the hollow pipe frame floats with the level); and (d) floating systems need large areas if they are to carry the main load, so define the rafts' role before setting cover.

The article closes with an offer of free advice on sizing, cultivar, density, and monitoring, an FAQ restating the above, a reference list, and a note that OlaFarm is listed in TVNI's Global Vetiver Grass Plant Suppliers directory for Vietnam.

Part B. Technical Review

Overall assessment

This is an unusually good supplier article. It cites real literature with page references, states the limits of vetiver (heavy crude in soil, diesel, fluoride), refuses to publish or invent water-quality results it does not have, and explicitly tells readers to measure on their own lagoon. That candor is exactly what the field needs and is worth encouraging. The main weakness is that the article is titled and framed as treatment "results" when the only results are plant survival and growth; the treatment question it was built to answer, pH reduction, remains open. There are also some technical points in the design logic that deserve attention.

1. pH reduction is a weak and uncertain target for floating vetiver

The stated objective, lowering pH after chemical treatment, is the least well-supported use in the whole article. None of the evidence in its own table concerns pH reduction. The proposed mechanism (root and microbial respiration releasing CO₂ and organic acids) is real but limited in the bulk water:

- At high pH, added CO₂ is converted to bicarbonate and carbonate, so the amount needed to shift pH depends heavily on alkalinity. Lime- or caustic-treated effluent can be strongly buffered, and root respiration may make little difference to the bulk water.
- In an open lagoon, algal photosynthesis often drives daytime pH up. Rafts shade the water beneath them and suppress algae there, which may well be a more significant pH effect than root respiration, but only under the rafts.
- With about 7% surface cover (720 m² of rafts on 10,000 m²), and only about 4% under vetiver, any effect on outflow pH is likely to be modest unless retention time is long and flow is forced through the root curtain.

Recommendation: the plant should monitor inflow and outflow pH at fixed times (early morning and mid-afternoon, to capture the diurnal algal cycle), plus alkalinity, flow rate, and dissolved oxygen, and compare with a pre-raft baseline. If pH compliance with Vietnam's industrial discharge standard (QCVN 40, typically pH 6–9) is a regulatory requirement, the rafts should be treated as a supplementary polishing stage, not a substitute for controlled acid or CO₂ neutralization.

2. The pH tolerance evidence is not directly transferable

The Queensland records of growth at pH 12 and 2.7 were on bauxite residue and gold tailings, in a soil or tailings medium, generally with establishment amendments. On a floating raft the roots are in direct and constant contact with the water, with no buffering medium. The HB06 range of pH 3.3–12.5 is a supplier claim not independently verified in the article. Successful establishment over two months in this lagoon is itself the best evidence that the water is within the plant's tolerance, and should be stated as such.

3. Other refinery constituents not discussed

Refinery effluent commonly contains ammonia and sulfides (from sour water), dissolved salts (from desalter brine), and residual hydrocarbons. At high pH, ammonia shifts to the un-ionized form, which is toxic to plants and microbes. Vetiver is moderately salt tolerant, but salinity and ammonia should be on the monitoring list, and they may explain any future decline in raft vigor.

4. Raft design points

- **Pipe size.** "Phi 10" is ambiguous; it almost certainly means about 10 cm (100 mm) diameter, since 10 mm pipe could not float the raft. A 12 m perimeter of 100 mm pipe displaces roughly 94 L, giving perhaps 75 kg of net buoyancy after pipe weight. That is ample at planting but may become tight as the stand matures, since shoot biomass above water on 8 m² at full height can be substantial. Freeboard should be checked as the grass grows, and regular cutting to about 40–50 cm will keep both load and wind loading down.
- **Wind loading.** Mature vetiver 1.5–2 m tall on light rafts creates significant windage. Linking rafts into strips helps, but moorings on a lined lagoon must be tied to the bank or fixed structures; anchors that could puncture the liner must be avoided. The article's shore-tied approach is correct.
- **Planting density.** 200 clumps per 8 m² (25 clumps/m², about 250 tillers/m²) at 20 cm spacing is dense and appropriate for a fast root curtain.
- **Soil on the clumps.** OlaFarm confirms the soil was left deliberately to keep the tillers bound. It adds a small sediment and nutrient load at launch, which is not significant at this scale, and it may carry mycorrhizal fungi (see point 9).
- **Flow path.** The strip layout is sound in principle, but water will short-circuit around and beneath rafts. Root depth versus lagoon depth matters: if the lagoon is much deeper than the root curtain, most

water passes underneath. Baffles or curtains that direct flow through the root zone would improve contact.

5. Biomass disposal

The article rightly stresses harvesting, but says nothing about what to do with the cuttings. Biomass grown on refinery effluent may carry hydrocarbons and metals, and should not be used as fodder, mulch, or handicraft material without testing. Most metals stay in the roots, so leaf harvesting removes little metal; periodic root trimming or replacement of old clumps would be needed if metal removal were a goal.

6. Season and duration

Two months over the hot season (June–August) is the most favorable window. Thanh Hoa winters are cool, and vetiver growth slows markedly below about 15°C, so uptake and root-zone activity will fall in December–February. The article's call for monitoring over at least one season is right; a full year would be better.

7. The vetiver versus umbrella sedge comparison

This is a useful field observation, and the article honestly notes the confounding factor: sedge went in as whole leafy plants and vetiver as trimmed clumps. It is a visual comparison over two months, not a measured one. Root length and biomass measurements on sample clumps of each species would turn it into real evidence.

8. Minor points

- "Truong và Lưu Thái Danh (2015)" and "Danh et al. (2009)" refer to the same co-author (Luu Thai Danh) in different name orders; harmless but could confuse readers.
- The Effendi et al. (2017) result was in small 25 L tanks with a single oil dose; oil loss in such systems includes volatilization and adsorption onto roots, not only plant or microbial degradation. The article describes it correctly as a tolerance test.

9. Soil on the clumps and a mycorrhiza hypothesis

Vetiver is strongly mycorrhizal, and the nursery soil retained on each clump very likely carries arbuscular mycorrhizal fungi (AMF). The crown and its soil sit at the water surface, the one aerobic zone of a raft, so some early colonization and benefit is plausible. Umbrella sedge belongs to a largely non-mycorrhizal family, so AMF may be part of why vetiver outgrew it. This is a hypothesis [!], not evidence. Two limits apply: AMF need oxygen, so deep roots in the water column are unlikely to be heavily colonized, and phosphorus-rich water tends to suppress the association. OlaFarm has not yet checked for AMF and has offered to test at about 90 days; the Annex gives the root-staining protocol and a paired trial that would test cause rather than association.

Suggested follow-up

- Encourage OlaFarm and the refinery to release even summary monitoring data (inflow/outflow pH, O&G, COD, TSS, before and after rafts). With real data this would be one of the few documented industrial-scale vetiver floating wetlands on refinery effluent anywhere, and a strong candidate for a TVNI case study, including the ICV-8 awards.
- Suggest the additional parameters above (alkalinity, flow, DO, ammonia, salinity, diurnal pH) and root depth measurements.
- Commend the article's candor publicly; it is a good model for other suppliers.

- OlaFarm has asked for consistent monitoring protocols. These are set out in the Annex: water sampling, plant growth, raft buoyancy, biomass harvest, AMF root staining and an optional paired trial.

Glossary of Vietnamese Terms

Vietnamese	English
bè / bè nổi	raft / floating raft
đất ngập nước nổi nhân tạo	constructed floating wetland
hồ lót bạt	lined lagoon (plastic/HDPE liner)
tép (giống)	slip, tiller
cụm rễ trần	bare-root clump
thuỷ trúc	umbrella sedge, <i>Cyperus alternifolius</i>
lục bình	water hyacinth
lưới PE / lưới cước	polyethylene netting / monofilament netting
bao dứa	woven polypropylene sack
nước thải lọc hoá dầu	petrochemical refinery wastewater
quan trắc	(environmental) monitoring

Annex. Data Collection Protocols: Thanh Hoa Refinery Lagoon Vetiver Rafts

Prepared by TVNI for OlaFarm and the refinery owner, September 25, 2026. Version 1.0.

Purpose and principles

These protocols let the OlaFarm team and the refinery collect one year of data in a consistent, comparable way, so that results can be read alongside other installations and used to review TVNI's floating-island guidance. They cover six areas: (1) water quality and flow, (2) plant establishment and growth, (3) raft structure and buoyancy, (4) biomass harvest, (5) mycorrhizal (AMF) root staining, and (6) an optional paired trial.

- **Consistency matters more than precision.** Use the same stations, times of day, depths, methods and people wherever possible. A simple measurement taken the same way every month is worth more than a sophisticated one taken occasionally.
- **Use what the refinery already measures.** The plant's permit monitoring probably already covers pH, COD, oil and grease and flow. Ask for those records, including records from before June 2026, which are the only pre-raft baseline available.
- **Record the day number.** Day 0 is June 12, 2026, when rafts were first launched. Day 90 fell on about September 10, 2026, so the first root and AMF sampling should be done as soon as possible and recorded at its actual day (for example, day 105). Later rounds: day 180 (about December 9, 2026) and day 365 (about June 12, 2027).
- **Photograph everything** with a slate or card showing raft or station ID and date in the frame.

Master schedule

What	Where	How often	Section
Field readings: pH, temperature, DO, conductivity	Stations S1–S5	Weekly, morning and afternoon	1.3
24-hour pH and DO profile	S1, S4, S5	Quarterly	1.3
Laboratory analysis	S1 and S5 monthly; S2–S4 quarterly	Monthly	1.4
Flow, water level, lagoon depth	Inlet, outlet, gauge	Daily flow; weekly level; depth once	1.2
Survival census	Sample rafts (all clumps)	Day 30, 90, 180, 365	2.2
Tillers, height, vigor	Tagged clumps	Monthly	2.3
Root length and weights	Sacrificial clumps	Day 90, 180, 365	2.4
Fixed-point photographs	Photo points P1–P4	Monthly	2.5
Freeboard and raft condition	Sample rafts	Monthly	3
Harvest weights	Sample rafts	Every cut	4
AMF root staining	Sacrificial clumps plus nursery control	Day 90, 180, 365	5

1. Water quality and flow

1.1 Monitoring stations

Mark each station with a numbered stake on the bank or a small buoy, record its GPS position, and mark all stations on a sketch map of the lagoon showing the inlet, outlet and raft strips. Sample at 0.3 m below the surface unless stated otherwise.

Code	Station	Location and notes
S1	Inlet	Water entering the lagoon, upstream of any raft. If the inlet is a pipe, sample the pipe discharge.
S2	Vetiver root zone	Inside a vetiver raft strip, in a gap between two rafts, at 0.3 m depth. Use the same gap each time, about midway along the lagoon.
S3	Sedge root zone	As S2, inside an umbrella sedge strip at a similar distance along the flow.
S4	Open water control	Open water at about the same distance along the flow as S2, at least 20 m from any raft.
S5	Outlet	Water leaving the lagoon.

1.2 Flow, water level and lagoon depth

- **Flow:** record daily inflow and outflow volumes (m³/day) from the plant's flow meters.
- **Water level:** install a staff gauge (a graduated post) near the outlet and read it weekly, and after heavy rain.
- **Depth survey (once):** from a boat, measure depth with a weighted, graduated line or pole on a grid of about 20 points, plus under at least three rafts. Record the distance between the root tips and the bottom under those rafts. From area and mean depth, calculate lagoon volume; hydraulic retention time (days) = volume ÷ daily flow.

1.3 Field readings with handheld meters

- **Parameters:** pH, water temperature, dissolved oxygen (DO, mg/L) and electrical conductivity (EC, µS/cm or mS/cm). Turbidity if a meter is available.
- **Timing:** weekly at S1–S5, twice on the same day: early morning (06:00–07:30) and mid-afternoon (14:00–15:30). Algae raise pH and DO during the day and lower them at night, so single readings at random times cannot be compared.
- **24-hour profile (quarterly):** readings every 3 hours for 24 hours at S1, S4 and S5.
- **Calibration:** calibrate pH each day before use with two buffers bracketing the expected range (pH 7 and 10 for alkaline water); calibrate DO and EC as the manufacturer directs. Record every calibration in the meter log.
- **Method:** hold the probe at 0.3 m depth, let the reading stabilize (about 1 minute), and record the value with time and weather (sun, cloud, rain, wind).

1.4 Laboratory analysis

Use an accredited laboratory (VILAS in Vietnam) or the refinery's permitted monitoring laboratory, and ask it to state the method used for each parameter (TCVN, ISO or Standard Methods). Collect grab samples monthly at S1 and S5, and quarterly at S2, S3 and S4. Keep the same laboratory for the whole year.

Parameter	Container	Preservation	Maximum holding time
Total alkalinity (and carbonate/bicarbonate)	Plastic, filled to the brim, no air	Cool to ≤6°C	14 days
BOD5	Plastic, 1 L	Cool to ≤6°C	48 hours
COD	Plastic or glass	H ₂ SO ₄ to pH <2; cool	28 days
TSS	Plastic, 1 L	Cool to ≤6°C	7 days
NH ₄ -N, total N, total P	Plastic	H ₂ SO ₄ to pH <2; cool	28 days

Parameter	Container	Preservation	Maximum holding time
NO ₃ -N	Plastic	Cool to ≤6°C, no acid	48 hours
Oil and grease	Wide-mouth glass, 1 L, PTFE-lined cap	HCl or H ₂ SO ₄ to pH <2; cool	28 days
Phenols	Glass	H ₂ SO ₄ to pH <2; cool	28 days
Sulfide (if present in refinery effluent)	Plastic or glass, no air	Zinc acetate + NaOH to pH >9	7 days
Metals (only if the permit lists them)	Plastic	HNO ₃ to pH <2	6 months

These are standard holding times; where the laboratory gives different instructions, follow the laboratory.

- **Sampling:** rinse the sampler (not the sample bottle) with lagoon water, take water at 0.3 m depth, and fill bottles directly. For oil and grease, fill the glass bottle directly from the surface layer, do not rinse it first, and do not combine or transfer samples; floating oil sticks to the container.
- **Handling:** label each bottle with a sample ID (for example TH-S1-20261015-W: site, station, date, water), keep in an ice box, and deliver to the laboratory the same day with a signed sample list.
- **Quality control:** take a duplicate sample at one station in every ten samples, under a different ID, to check laboratory repeatability.

2. Plant establishment and growth

2.1 Sample rafts and tagged clumps

- Number every raft (V01–V54 for vetiver, C01–C36 for sedge) with a durable tag.
- Select 10 vetiver and 6 sedge sample rafts spread evenly from the inlet end to the outlet end (for example every fifth raft). Keep the same rafts for the whole year.
- On each sample raft, tag 10 monitoring clumps with numbered plastic ties at fixed positions away from the edges (for example rows 3, 5 and 7, positions 4, 8, 12 and 16). Record each by position code: row and position, for example R5P8. Tagged clumps are never dug up.
- Designate the outer rows (rows 1 and 10) as sacrificial rows for root and AMF sampling (section 2.4 and section 5). When a clump is removed, replace it with a fresh clump marked with a red tie, and never measure red-tied clumps.

2.2 Survival census

On day 30, 90, 180 and 365, count live and dead clumps on every sample raft. A clump is live if it has at least one green tiller. Survival (%) = live clumps ÷ clumps planted × 100. Record also any gaps that were replanted.

2.3 Monthly growth on tagged clumps

- **Tillers:** count all live tillers (green shoots arising from the crown) on each tagged clump. At planting there were about 10.
- **Height:** measure the natural standing height of the tallest leaf from the crown, in cm, before any cutting. Record cutting dates.
- **Vigor score:** 1 = dead; 2 = mostly yellow, poor; 3 = mixed green and yellow; 4 = green, growing; 5 = dark green, vigorous. Note pests, disease, leaf burn, or purple coloring in cool weather.
- **Sedge:** on sedge rafts, count stems instead of tillers and use the same height and vigor methods.

- **Cool season (December–February):** continue monthly measurements without fail; winter performance is one of the main unknowns. Record daily water temperature at S2 if the plant logs it.

2.4 Root length and biomass (sacrificial clumps)

On day 90 (now overdue, so as soon as possible), day 180 and day 365, remove 2 clumps from the sacrificial rows of 5 vetiver sample rafts and 3 sedge sample rafts (16 clumps per round). Lift each clump slowly and vertically so the roots hang freely.

1. Hang the clump from a hook or hold it up against a measuring board or tape.
2. Record the longest root: length from the base of the crown to the tip of the longest root, in cm.
3. Record the curtain depth: the length at which the root mass visibly thins out (where most roots end), in cm.
4. Record whether new white roots are present (yes/no) and whether nursery soil is still present at the crown.
5. Photograph the clump against the board with its ID.
6. Before cutting anything, take the AMF root samples (section 5).
7. Cut shoots from roots at the crown. Weigh shoots and roots fresh (after draining roots for 5 minutes). Dry at 65–70°C for 48 hours (or sun-dry to constant weight, recording the method) and weigh again.

For comparison, TVNI's floating-island guide uses a Chinese field range of 18–45 cm of root at 90 days.

2.5 Fixed-point photographs

Set 4 photo points (P1–P4) on the bank with marked stakes, covering the inlet end, middle and outlet end. Photograph monthly from the same stake, in the same compass direction and at about the same time of day. Also photograph each sample raft monthly from the same side.

3. Raft structure and buoyancy

- **Once:** record the pipe outside diameter (measure circumference with a tape and divide by 3.14), wall thickness and any pressure rating printed on the pipe, the total pipe length per raft, how the ends are sealed, and mesh specifications. If possible, weigh one empty raft frame with mesh, and the average fresh weight of 20 planting clumps.
- **Monthly on sample rafts:** measure freeboard (height from the water surface to the top of the pipe, in cm) at the four corners and the middle of each long side. Record any tilt, water on the mesh, damaged ties or mooring lines, and punctured or leaking pipe.
- **Action level:** if freeboard at any point falls below half its value at launch, report it to TVNI with a photograph.

4. Biomass harvest

- At every cut, record the date and the cutting height. For each sample raft, collect all cut material in sacks (none may fall into the water) and weigh it fresh with a hanging scale.
- Take a 1 kg fresh subsample per raft, dry it (65–70°C for 48 hours, or sun-dry to constant weight), and weigh it to obtain dry-matter percentage.
- At the first major harvest, send dried subsamples of vetiver shoots to the laboratory for total N and P and, because this is refinery water, for total petroleum hydrocarbons and any metals in the discharge permit. Until results are available, do not use the cut grass as forage or as mulch on food crops.
- Record where the harvested biomass went.

5. Mycorrhizal (AMF) root staining: ink and vinegar method

5.1 Purpose

To test whether the nursery soil left on each clump carries AMF into the rafts, and how far colonization extends. The questions are: are vetiver roots near the crown colonized? Are deep water-column roots colonized? How does vetiver compare with umbrella sedge? Does colonization change over time? The method is the ink-and-vinegar stain of Vierheilig et al. (1998), which uses household materials and gives results comparable to laboratory stains.

5.2 Materials

- Potassium hydroxide (KOH) pellets to make a 10% solution: 100 g KOH per liter of water.
- White vinegar (about 5% acetic acid).
- Black fountain-pen ink. Sheaffer black ink was used in the original method, and other black inks usually work too. Test the ink first on nursery roots (section 5.3), since some inks do not stain fungi.
- Heat-resistant glass beakers or jars, a hot plate or water bath and a thermometer, a tea strainer or fine sieve, forceps, fine scissors, labeled small vials, 50% ethanol or glycerol for storage.
- Microscope slides and cover slips; a compound microscope with 100× and 400× magnification (a stereo microscope at 20–40× is useful for sorting). A phone camera adapter for photographs.
- Safety equipment: gloves and goggles. KOH is caustic. Always add KOH slowly to water, never water to KOH, and work with hot liquids carefully.

5.3 Samples

- **Per round (day 90, 180, 365):** from each sacrificial clump in section 2.4 take two root samples: (a) crown zone, fine roots within the top 5 cm, including roots inside any remaining nursery soil; (b) water-column zone, fine roots at 20 cm or more below the raft. That gives 20 vetiver samples and 12 sedge samples per round.
- **Positive control:** 3 samples of fine roots from soil-grown HB06 at the OlaFarm nursery, from the same beds that supplied the clumps. These show what colonized vetiver roots look like and confirm the stain is working.
- **Root selection:** take young fine roots (less than about 1 mm thick, white or light-colored), about 0.5–1 g fresh per sample. Old dark roots are hard to clear and rarely show active colonization.
- **Coding for blind scoring:** give each sample a neutral code (for example A01, A02...) and keep the key separately, so the person scoring does not know the source.
- **Storage:** wash off soil gently in tap water, cut into 1 cm pieces, and process within 2 days, or store in 50% ethanol.

5.4 Staining procedure

1. **Clear.** Place root pieces in 10% KOH and heat at about 90°C for 30–60 minutes. Vetiver roots are tough; test times on nursery roots first and use the shortest time that makes roots translucent (pale, see-through). If roots remain dark, rinse and soak them for 10–20 minutes in 3% hydrogen peroxide with a few drops of household ammonia, then rinse.
2. **Rinse.** Pour the roots into the strainer and rinse several times with tap water until no more color comes out.
3. **Stain.** Make the stain: 5 mL ink in 95 mL vinegar (5% ink). Heat the roots in the stain at about 90°C for 3–5 minutes (or bring to a boil for 3 minutes).

4. **Destain.** Rinse in tap water with a few drops of vinegar added, and leave in fresh acidified water for 20 minutes to overnight. The root tissue becomes pale while fungal structures stay blue-black.
5. **Mount.** Place 10 root pieces side by side on a slide in a drop of glycerol (or acidified water), add a cover slip, and press gently. Make 3 slides per sample (30 pieces). Stained roots keep for weeks in glycerol with a few drops of vinegar.

5.5 What to look for

- **AMF hyphae:** blue-black threads, irregular in width, without cross-walls, running along or between the cells of the root cortex.
- **Arbuscules:** fine, much-branched, tree-like structures filling individual cortex cells. These show an active, working partnership.
- **Vesicles:** oval or round swellings, often dark-stained, between or inside cells. These are storage structures.
- **Not AMF:** brown hyphae with regular cross-walls (dark septate endophytes); fungi only on the root surface; root hairs; debris. Record these separately if common, but do not count them as AMF.

Photograph typical examples of each structure from the nursery control first, and use them, together with the reference plate in section 5.5a, as the team's reference set.

5.5a Reference images: Vierheilig et al. (1998), Figure 1

The original ink-and-vinegar paper has one plate of six micrographs (panels a–f) of roots colonized by the AMF species *Glomus mosseae* (now named *Funneliformis mosseae*). The plate is copyright of the American Society for Microbiology, so it is linked here rather than reproduced; it is free [to view online](#). Print it or keep it open beside the microscope. Notes on each panel for the vetiver work:

Panel	What it shows	Notes for scoring vetiver roots
a	Ryegrass roots at low magnification: a colonized root (dark) beside an uncolonized one (pale). Black ink.	The quick first screen. Under a stereo microscope, colonized pieces look darker and speckled. Darkness alone is not proof: confirm under higher magnification before scoring, because tough, incompletely cleared vetiver roots can also look dark.
b	Bean root with heavily and partially colonized sections, individual hyphae visible.	Colonization is patchy along a root. Score a piece as colonized if any AMF structure is present anywhere in it, even a short stretch.
c	Arbuscules in ryegrass root tissue.	The most relevant panel: ryegrass is a grass like vetiver. Arbuscules appear as dense, finely stippled masses filling single cortex cells. They show an active partnership, so record them separately.
d	Vesicles and internal hyphae in ryegrass root tissue.	Vesicles are the oval or round, darker bodies along the hyphae. They tend to be more common in older roots, so expect more at day 180 and 365 than at day 90.
e	Arbuscules and internal hyphae in bean root at high magnification.	Shows the branching: a trunk hypha dividing repeatedly into a tree-like arbuscule. This detail needs 400× or more; at the 100–200× used for routine scoring, arbuscules look like a fuzzy cluster instead.
f	A penetration unit (the point where a hypha enters the root) in ryegrass, stained with blue ink.	Entry points often show a swelling on the root surface with a hypha running into the cortex. This panel also shows that blue ink works if black ink is not available.

Scale: the scale bars in the plate are 5–25 μm , so these are close-up views. A routine scoring field at 100–200× covers a much wider area, so structures will look smaller than in the plate. The plate shows ryegrass and bean roots, which are thinner than vetiver roots and clear more easily, so expect vetiver preparations to look somewhat darker and less crisp.

5.6 Scoring

Use the root-segment method. At 100–200× magnification, examine each of the 30 root pieces per sample and record for each piece whether AMF hyphae, arbuscules and vesicles are present. Then calculate:

- Colonization (%) = pieces with any AMF structure ÷ pieces examined × 100.
- Arbuscule frequency (%) = pieces with arbuscules ÷ pieces examined × 100, and the same for vesicles.

Laboratories with more experience may use the gridline-intersect method (Giovannetti and Mosse 1980) or the magnified-intersections method (McGonigle et al. 1990) instead; if so, use one method for the whole year. For quality control, have a second person score 1 sample in 10, and record both scores.

5.7 Reading the results

If the hypothesis is right, crown-zone vetiver roots will be colonized much more than deep water-column roots, vetiver more than sedge, and the nursery control most of all. Low colonization in deep roots is expected, because AMF need oxygen, and is a useful result, not a failure. Colonization alone shows association, not cause; the paired trial in section 6 tests cause.

6. Optional paired trial: does the nursery soil matter?

This small trial would test whether retained soil (and the AMF it may carry) improves establishment, and would also answer the open question in TVNI's floating-island guide about bare-root versus pre-grown plants.

- **Treatments:** T1, clumps of about 10 tillers with nursery soil retained (current practice); T2, identical clumps with the soil washed off; T3, container-grown plants, if available. All from the same HB06 batch, trimmed the same way.
- **Layout:** 4 new rafts, each divided into blocks of rows (for example rows 1–3, 4–6, 7–9), with each treatment in one block and the order of blocks changed on each raft. Place the 4 rafts side by side at the same position in the flow. Putting all treatments on every raft means they share the same water.
- **Measurements:** days until new green shoots appear; survival, tillers, height and vigor at 30, 60, 90 and 180 days; root length and AMF at 90 and 180 days, using sections 2 and 5.
- **Timing:** starting now means establishment in the cool season, which is a harder test. Starting in March 2027 gives warm-season conditions like the main installation. Either is useful, but record which.

7. Data management, safety and reporting

- **Recording:** fill in the field forms below on paper at the site, then enter them into a spreadsheet each week. Keep the paper originals. Record who took each measurement.
- **Reporting:** send the spreadsheet, laboratory reports and a selection of photographs to TVNI every three months, with a short note of anything unusual (storms, plant shutdowns, spills, pest attacks, changes in treatment upstream).
- **Safety:** follow all refinery site rules and permits. Wear a life jacket on or near the water and never work on the lagoon alone. Wear gloves when handling wastewater and wash hands afterward. Use goggles and gloves with KOH and hot liquids.

8. Field forms

Form 1. Water field readings

Date	Time	Station	pH	Temp °C	DO mg/L	EC	Weather	Initials

Form 2. Tagged clump growth (one sheet per raft per month)

Raft ID	Position	Tillers	Height cm	Vigor 1–5	Notes

Form 3. Root sampling (sacrificial clumps)

Date / day	Raft	Position	Longest root cm	Curtain depth cm	White roots Y/N	Soil at crown Y/N	Shoot / root fresh g	Shoot / root dry g

Form 4. Freeboard and raft condition

Date	Raft	C1 cm	C2 cm	C3 cm	C4 cm	Side A cm	Side B cm	Condition, ties, damage

Date	Raft	C1 cm	C2 cm	C3 cm	C4 cm	Side A cm	Side B cm	Condition, ties, damage

Form 5. Harvest

Date	Raft	Cut height cm	Fresh weight kg	Dry matter %	Destination of biomass

Form 6. AMF scoring (one row per sample)

Code	Pieces examined	With hyphae	With arbuscules	With vesicles	Colonization %	Scorer, notes

References for the protocols

Giovannetti, M., and B. Mosse. 1980. "An Evaluation of Techniques for Measuring Vesicular Arbuscular Mycorrhizal Infection in Roots." *New Phytologist* 84: 489–500.

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Vierheilig, H., A. P. Coughlan, U. Wyss, and Y. Piché. 1998. "[Ink and Vinegar, a Simple Staining Technique for Arbuscular-Mycorrhizal Fungi.](#)" *Applied and Environmental Microbiology* 64 (12): 5004–5007.

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