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Department of **Primary Industries and Regional Development**

GOVERNMENT OF WESTERN AUSTRALIA

Lower Vasse River water treatment trials 2016–18: synthesis report

Can phosphorus-binding clay reduce algal blooms in the Lower Vasse River?

Revitalising Geographe Waterways

VASSE taskFORCE

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Can phosphorus-binding clay reduce algal blooms in the Lower Vasse River?

Department of Water and Environmental Regulation

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Summary

In the summers of 2016–17 and 2017–18, the Department of Water and Environmental Regulation (DWER) trialled a new phosphorus-binding clay product (HT-clay) in the Lower Vasse River to explore new management options for controlling algal blooms. The project was part of the Revitalising Geographe Waterways strategy and supported by the Regional Estuaries Initiative (REI). This report summarises the trials and makes management recommendations. The trials follow on from a large-scale trial conducted by DWER in the early 2000s which indicated that Phoslock® (now a widely established phosphorus-binding clay) was an excellent management option to reduce algal growth and improve water quality in the Lower Vasse River, where toxic algal blooms occur annually. More technical detail and results from the trials will be published in separate technical reports.

Objectives of the study

The trials were designed to answer the following questions:

1. Is HT-clay a viable alternative to the commercially available Phoslock® and can it be used in the future to reduce algal blooms in the Lower Vasse River?
2. How much HT-clay needs to be added to efficiently control phosphorus concentrations and algal growth?
3. How much phosphorus is released from the sediments without clay treatment? Does the HT-clay layer on top of the sediments efficiently reduce phosphorus release?
4. Does the HT-clay treatment affect invertebrate organisms living in the Lower Vasse River?

Key findings

- HT-clay treatment showed promising results in the Lower Vasse River water treatment trials and was able to efficiently control phosphorus concentrations and algal blooms when applied at a similar dosing rate to Phoslock®.
- Concentrations of phosphate (soluble and bioavailable form of phosphorus) and total phosphorus were reduced substantially within two to three hours of HT-clay application in both trials.
- Phosphate and total phosphorus concentrations remained below the recommended water-management target thresholds of 0.04 and 0.1 mg P/L respectively: this was over the entire monitoring period for both trials when clay doses ≥ 0.75g/L were applied.
- The HT-clay was able to immediately remove an algal bloom within hours of application by binding algae into larger aggregates, causing them to sink to the bottom of the river. This is an advantage compared with the Phoslock® clay, which has to be applied before the onset of an algal bloom.
- The clay treatment reduced algae growth and improved water quality for the entire length of both trials when compared with non-treated control areas. This

was evident using both visual assessment and evaluation of algal growth indicators such as algal cell count (2016–17 trial only) or chlorophyll concentrations.

- A temporary increase of floating algal mats was observed in areas treated with clay. This was likely due to the improved water quality conditions which enabled light penetration to the ground of the river, creating more favourable conditions for benthic algae.
- The HT-clay treatment did not have any negative effects on small invertebrate organisms living in the Lower Vasse River. However, further testing of a more diverse range of organisms will be conducted before large scale HT-clay applications.
- The HT-clay layer on the bottom of the river was able to reduce phosphorus release from the sediments to the overlying water, despite partial burial at some sites. The average estimated phosphate amounts released from the sediments in the surrounding river ranged from 6.16 to 3.74 mg phosphorus/m^2/day in early summer (December) and early autumn (May), whereas only an average of 1.1 mg phosphorus/m^2/day was released from treated mesocosms.
- HT-clay may become a viable alternative to Phoslock® for the treatment of algal growth in the Lower Vasse River depending on the success of further development work (such as improvements in the clay production process), laboratory testing for producing a detailed environmental risk assessment, and testing for clay performance under varying environmental conditions.
- Improved water quality through the use of phosphorus-binding clay is likely to provide conditions for the establishment of a healthier and more diverse ecosystem.

Recommendations

- Use phosphorus-binding clay annually in the Lower Vasse River as a treatment to significantly reduce algal growth and sediment build-up.
- Continue to investigate opportunities to progress HT-clay from an experimental product to one suitable for large-scale application during the next two years through the REI project, by:
  - optimising the clay production method to enable affordable large-scale production and transport
  - developing a detailed environmental risk assessment of HT-clay application, including toxicity studies with invertebrate organisms as well as looking at the behaviour of clay under changing environmental conditions, such as low/high pH or higher salinities.
  - further researching clay dosing rates and clay performance under different conditions, such as high organic matter contents or higher salinities

   - further investigating ways to reduce floating algal mats associated with clay treatment

- Undertake regular treatment of the Lower Vasse River with commercially available Phoslock® clay to immediately improve water quality in the Lower Vasse River. In the future, this treatment might be replaced by or combined with HT-clay application.
   - To efficiently control algal blooms, 40 tonnes of Phoslock® should be applied annually to treat the stretch of the river between the weir boards at the old butter factory and the causeway bridge (20 tonnes in November before algal bloom onset and top-up applications as required). It is anticipated that the total amount of clay applied annually will be able to be reduced significantly after a few years of regular application.
   - Phoslock® is distributed and applied by an Australian company (Phoslock® Water Solutions) at a price of $3000 per tonne (approximately $120 000 for the annual application of 40 tonnes).
- Treat the stretch of the river between the weir boards at the old butter factory and the causeway bridge as a priority. The most severe algal growth is typically seen in this area and algal blooms appear to develop at the downstream end of the Lower Vasse River before spreading further upstream.
- Combine applications of phosphorus-binding clay with other long-term nutrient management strategies such as nutrient reduction from catchment sources (agricultural as well as urban). It may also be combined with *in situ* remediation such as sediment removal or the establishment of beneficial aquatic plants to improve water quality in the Lower Vasse River in the longer-term.

1 Purpose and background

1.1 Toxic algal blooms and sediment build-up in the Lower Vasse River

The Lower Vasse River, which meanders through the Busselton town centre, has regular toxic blue-green algal blooms during summer: this is a result of limited water flow, elevated water temperatures and most importantly, high concentrations of nutrients such as phosphorus. Nutrients that fuel the excessive algal growth not only enter the system from agricultural and urban catchment sources, but are also released from a thick layer of black, muddy sediments on the bed of the river.

The water regime of the Lower Vasse River has been highly altered, effectively turning it into a stagnant pond throughout the summer months. Most of the upstream river flow bypasses the lower stretch of the Vasse River and is diverted directly into the ocean through the Vasse Diversion Drain. In addition, the weir structure near the old butter factory restricts water exchange with the estuary at its downstream end.

Apart from producing nuisance odours and reducing the amenity of the river, the algal blooms also contribute to the rapid accumulation of the nutrient and organic matter-rich sediments when they decay and sink to the bottom of the river. This creates a system of internal nutrient cycling, where nutrients are released from the sediments back to the overlying water under low oxygen conditions. In this situation, algal blooms can develop independently from external nutrient sources.

The Department of Water and Environmental Regulation (DWER) conducted water treatment trials in the Lower Vasse River with a new phosphorus-binding clay product in the summers of 2016–17 and 2017–18. The aim of the trials was to explore management options for improving water quality and reducing sediment build-up. The trials were funded by the Revitalising Geographe Waterways (RGW) program and were also supported by the Regional Estuaries Initiative (REI).

1.2 What is phosphorus-binding clay?

Phosphorus-binding clay is an innovative product for the treatment of surface waters. It works by locking up the nutrient phosphorus, making it unavailable to fuel algal growth. By reducing the amount of algae, the clay also lowers the accumulation rate of organic sediments. The clay is sprayed onto the water surface as a slurry and removes dissolved phosphorus from the water as it settles. Afterwards it forms a protective layer on top of the sediments that captures phosphorus released from them (Figure 1).

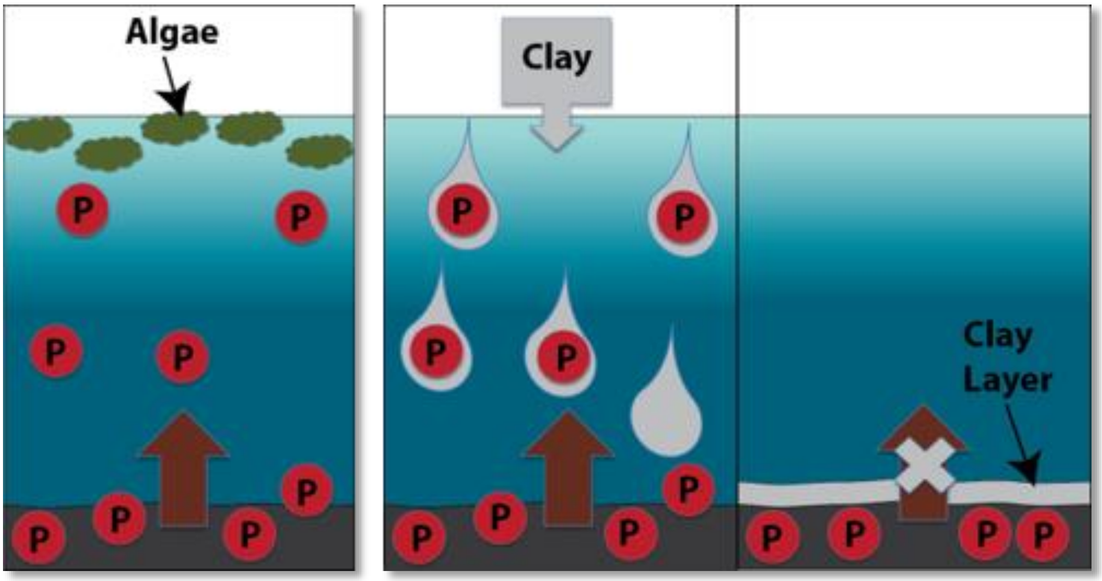

Figure 1: Phosphorus-binding clay products such as Phoslock® or the new HT-clay lock up phosphorus, making it unavailable to algae. Phosphorus is removed as the clay settles through the water and it also forms a protective layer on the sediments – reducing phosphorus release.

At present Phoslock® is the only commercially available phosphorus-binding clay product. It was developed in the 1990s by a DWER predecessor agency, the Water and Rivers Commission, in collaboration with CSIRO and is now being used around the world. The Lower Vasse River was an important site for field trials during Phoslock® development and for its initial testing. The largest and most successful Phoslock® trial in the Lower Vasse River was conducted by the Water and Rivers Commission in the summer of 2001–02.

Phoslock® does, however, have several limitations: it cannot be applied in marine or brackish environments, it is not produced locally, it contains the rare earth element lanthanum, and it has shown limited efficiency in reducing algal growth once a bloom has already established. A new phosphorus binding clay product, presently referred to as HT-clay, was therefore trialled in this study to address some of these limitations. HT-clay consists of a natural bentonite clay that is modified with a coating of the phosphorus-binding mineral hydrotalcite (HT). HT-clay can be produced from easily accessible and non-harmful materials in a straightforward manufacturing process. It is anticipated that it can be produced locally, potentially even onsite. Although initial laboratory testing of HT-clay has shown promising results, it is still an experimental product. The water treatment trials in the Lower Vasse River were the first larger field trials with this product.

Although algae also depend on other essential nutrients such as nitrogen, limiting phosphorus is often the most efficient strategy to manage algal growth and to control blooms of toxic blue-green algae (cyanobacteria) in particular. Most blue-green algal species are capable of converting and utilising atmospheric nitrogen if required, whereas harmless algal species such as green algae or diatoms depend on dissolved nitrogen species in the water such as nitrate or ammonia. Therefore, blue-green algae have an advantage over other species in a system where the supply of these forms of nitrogen is limited.

1.1 Successful Phoslock® trial in the Lower Vasse River

The Lower Vasse River has been the subject of many water treatment trials conducted by various organisations and agencies. These have ranged from floating islands to enzyme treatments and affected the water quality to varying degrees. The successful Phoslock® trial of summer 2001–02 involved 40 tonnes of Phoslock® being applied to a 650 m stretch of the river – from the weir boards behind the old butter factory to just past the current location of the new council buildings (see Figure 2). Twenty tonnes of clay were applied in October 2001, before the onset of algal blooms, and 10 tonnes each were applied in December and January. Phosphorus concentrations remained low throughout the whole summer and algal blooms were reduced significantly in comparison with a non-treated control area (Robb et al. 2003).

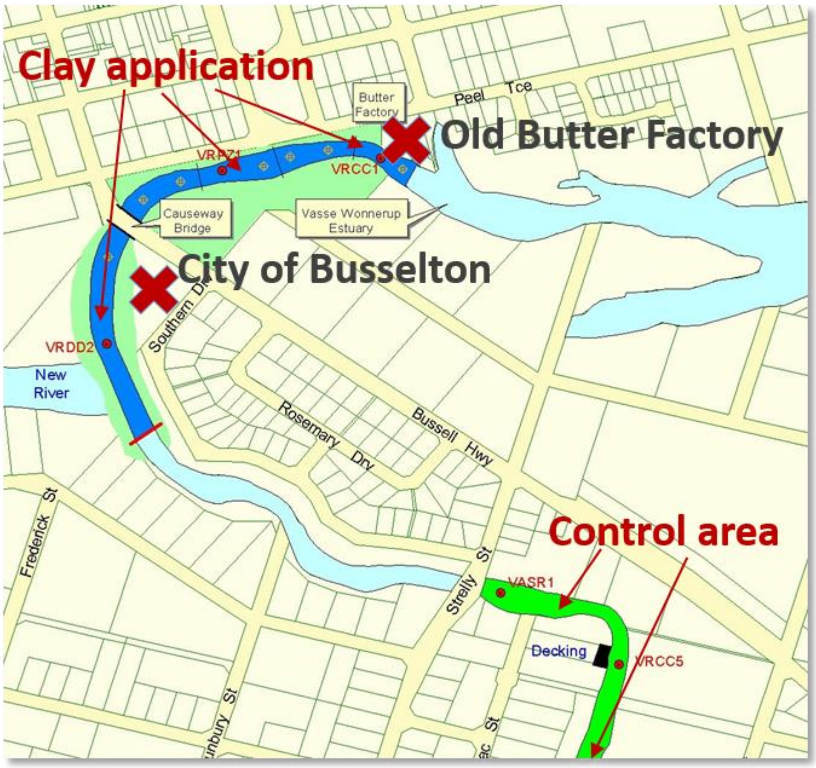

Figure 2: Area of the Lower Vasse River that was successfully treated with Phoslock® in summer 2001–02.

1.2 Aims of the HT-clay trials

These latest Lower Vasse River water treatment trials were the first longer-term field trials with the new HT-clay. They were designed to answer the following questions:

1. Is the HT-clay a viable alternative to Phoslock® and can it be used to reduce algal blooms in the Lower Vasse River?
2. How much clay needs to be added to efficiently control phosphorus concentrations and algal growth?
3. How much phosphorus is released from the sediments without clay treatment? Does the HT-clay layer on top of the sediments efficiently reduce phosphorus release?
4. Does the HT-clay treatment negatively affect invertebrate organisms living in the Lower Vasse River?

2 Methods

DWER tested the new HT-clay product in the Lower Vasse River for two consecutive summers (2016–17 and 2017–18). In both years the trials were set up in front of the new council buildings in an area of the river that typically suffers from severe blue-green algal blooms in summer and was easily accessible by boat (Figure 3).

Figure 3: Location of the HT-clay trial site in front of the council buildings.

2.1 Mesocosm trial summer 2016–17

In summer 2016–17, 15 bottomless plastic tanks (75 cm x 75 cm x 2.3 m) were embedded in the ground of the Lower Vasse River, creating isolated trial areas of water and underlying sediments (mesocosms). In these mesocosms various HT-clay treatments and amounts were tested to determine the most efficient dosing rate (see Figure 4).

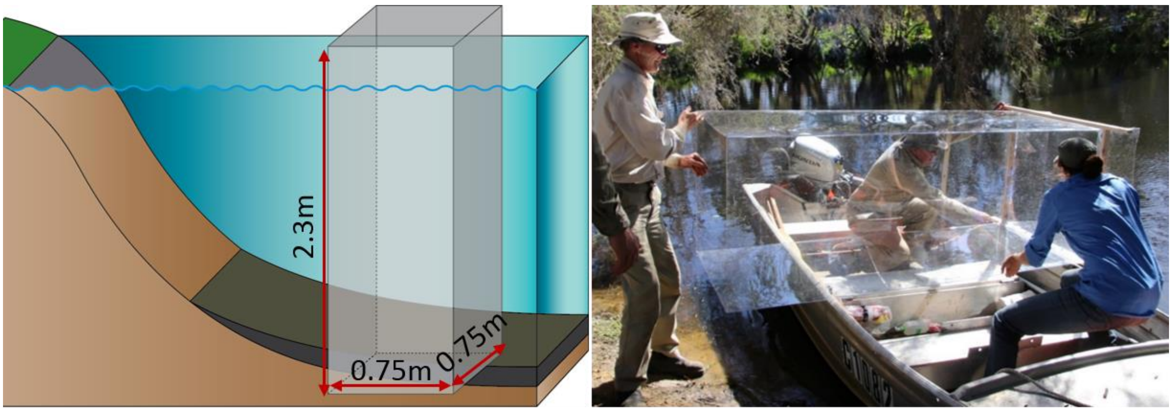

Figure 4: The mesocosm tanks used in this trial were open to the bottom, providing isolated trial areas of river sediments and overlying water.

In early December before the onset of algal blooms, nine randomly selected mesocosm tanks were treated with three different clay doses referred to as 'low', 'medium' and 'high' clay doses in this report (see clay amounts in Table 1). To ensure high quality results and account for natural variability, each clay dose was tested in three different mesocosms to create replicates. Three randomly selected mesocosms were left untreated and served as controls. This approach was taken because the tank structure itself restricts water movement, creating slightly different conditions to the surrounding river, which may also influence algal growth. Hence it is important to compare the water quality conditions in the treated mesocosms with the conditions in the control mesocosms (rather than to the surrounding river) when evaluating the efficiency of the clay treatments.

To test whether HT-clay could still treat algae once a bloom had already established, one of the mesocosm tanks was treated with clay later in summer when an algal bloom was present.

Table 1: Clay amounts added to the mesocosms (given as g dry-weight clay/L).

	Clay amount [g clay /L]
Low clay dose	0.36
Medium clay dose	0.75
High clay dose	1.08
Clay dose added to spare mesocosm in March	1

2.2 Up-scaled trial summer 2017–18

After the successful mesocosm trial, the experiments were further up-scaled in the following summer to larger treatment areas of approximately 455 m^2 each. These were separated by PVC-curtains reaching from the bottom of the river to the water surface (Figure 5). The curtains were held at the water surface with floats and were sealed against the river bed by the weight of a chain and bricks. In addition, sand bags were used to seal small gaps near the banks.

Figure 5: Floating curtains installed in the Lower Vasse River for the 2017–18 HT-clay trial.

Two of the areas (area 1 and area 2) were treated with a total clay amount of nearly 1.5 tonnes. The dose was split and applied at different times throughout the summer (December for area 1 and February for area 2 – see Table 2). A third area was left untreated as a control to mimic the slightly altered conditions between the curtains to provide a baseline for the evaluation of the treatment efficiency.

The clay was evenly sprayed onto the water surface from a moving barge equipped with a 1000 L holding tank, a petrol pump and a spray boom (Figure 6). The tank on the barge was filled directly from the tanker truck that transported the clay to the trial site. To ensure the clay slurry was well-mixed, it was agitated inside the tanker truck by re-circulation with a petrol pump.

To test whether the curtains provided a sufficient seal, a bromide salt was added to the trial areas and used as a tracer to monitor any water exchange with the surrounding river.

Figure 6: Clay application from a moving barge equipped with a petrol pump and spray boom.

The trial was cut short due to two unexpected summer rain/storm events in mid-December and mid-January, which led to water movement in the otherwise stagnant river and caused the curtains to leak significantly. The bromide tracer indicated that during and after the storm events, a near-complete water exchange between the trial areas and the surrounding river occurred within 24 to 48 hours. This made it impossible to evaluate the effect on water quality of the first clay application in December. Sediment sampling with a handheld corer in January indicated that most of this clay was flushed out during the second storm event in mid-January.

When weather and flow conditions had normalised, the trial went ahead as planned, with a large clay application in February and a smaller top-up application in March (Table 2). To evaluate the treatment efficiency, water quality was monitored from the clay application in February until the end of the trial on 27 March.

Table 2: Amount and timing of clay application during the up-scaled second HT-clay trial. Clay doses were calculated assuming an average water depth of 1.6 m.

Application date	Clay dose	
	Area 1	**Area 2**
11 Dec 2017	*360kg (0.46 g/L)	–
8 Feb 2018	114kg (0.15 g/L)	606kg (0.83 g/L)
15 Mar 2018	180kg (0.24 g/L)	180kg (0.24 g/L)
Total	654kg (0.88g/L)	786kg (1.07g/L)

*Most of this was likely washed out in the storm on 16 Jan.

2.3 How did we monitor the success of the trials?

Water quality analysis

To evaluate the efficiency of the different clay treatments, the water quality at all trial sites and in the surrounding river was monitored immediately before and after clay application and then weekly throughout the trials. Water quality in the 2016–17 mesocosm trial was monitored for the entire summer from early December until the end of April, whereas the up-scaled trial in 2017–18 was cut short due to unexpected rain events and was monitored from early February until the end of March only.

Water quality variables of particular interest were phosphorus concentrations and algal growth indicators, such as phytoplankton cell counts or the concentration of algal pigments (chlorophyll). However, other water quality indicators that may have interfered with or been influenced by the HT-clay were also monitored (see

Table 3 for a complete list). In addition, weekly photographs were taken at each site to document the visual amenity of the water.

Figure 7: Water quality monitoring at a mesocosm tank.

Table 3: Water quality variables that were monitored as part of the trials.

Variable	Why was this measured?
TP, FRP, TN, NH_3, NO_x, Si	Test clay P-removal efficiency and monitor nutrients relevant for algal growth
Chlorophyll	Quantify algal growth
Phytoplankton species and cell count	Quantify algal growth and determine proportion of potentially harmful species in treated mesocosms versus non-treated controls
Turbidity	Is increased by algal growth and may possibly be altered by clay re-suspension
DO	Is heavily influenced by algal growth and may indicate water column stratification
Temperature	May indicate water column stratification and influences algal growth
pH	May interfere with clay efficiency and could also possibly be influenced by the addition of the alkaline clay slurry in the short term
Alkalinity	Carbonate concentration influences clay efficiency because it is also adsorbed by the clay and competes with phosphorus
DOC	Influences clay efficiency because it is adsorbed by the clay and competes with phosphorus
TSS	Test if it increases by clay application and monitor algal growth

TP: total phosphorus; FRP: filterable reactive phosphorus; TN: total nitrogen; NH3: ammonia; NOx: oxidised inorganic nitrogen species; Si: silica; DO: dissolved oxygen; DOC: dissolved organic carbon; TSS: total suspended solids

Sediment and pore water analysis

Sediments and the water contained within them (pore water) were sampled as part of the first mesocosm trial to:

- gain a better understanding of sediment volumes, accumulation rates and quality
- test if the clay could reduce phosphorus release from the sediments.

Sediment cores were collected with a hand coring device (Figure 8) before the trial was set up in early December and when it ended at the start of May. We sampled the mesocosms that were treated with the high clay dose, the untreated control mesocosms and the surrounding river. Two cores were collected from each location: one core for the analysis of total nutrient and organic matter contents and the other core for pore water analysis.

The sediment cores were accurately sectioned into fine depth intervals with a core slicing apparatus. Pore water was extracted from the sediments with a centrifuge. All steps of pore water sampling (including core slicing) were conducted under a nitrogen atmosphere to exclude air and avoid oxidation and precipitation reactions that would alter nutrient concentrations.

Figure 8: Sediment sampling with a hand coring device.

Macroinvertebrate count and identification

Small invertebrate organisms living within and near the sediments were collected and identified inside and around the trial areas as part of the second clay trial to ensure the clay treatment had no negative effect on these organisms.

Although the clay itself is non-toxic, some concern had arisen about detrimental effects due to increased turbidity and suspended solid content immediately after clay application and upon sediment disturbance. The organisms most affected would be small invertebrates living within and near the sediments. Thus we decided to see which organisms were present in the Lower Vasse River and to test whether the clay treatment had affected their abundance or diversity.

Figure 9: Sampling of invertebrate organisms with a fine sweep net.

Invertebrate organisms were counted and identified in samples that were collected at the end of the trial (late March) from each trial area, as well up and downstream of the floating curtains. Two samples were collected from each location: one sample was collected with a fine sweep net from the area near the banks over a length of 13 m; the other sample consisted of organic sediments and was collected from the middle of the river using an Ekman grab (sediment volume 7 L). In this report the different types of samples will be referred to as ‘channel’ and ‘sediment’ samples respectively.

3 Results

3.1 Did the clay treatment reduce phosphorus concentrations?

Immediate effects after clay application

Concentrations of phosphate (soluble and bioavailable form of phosphorus) and total phosphorus were reduced substantially within two to three hours of clay application in both trials (see figures 10 and 11). The phosphorus uptake took place instantaneously as the clay was settling through the water. In the mesocosm trial, phosphate concentrations were reduced by up to 98% at the highest clay dose. In the up-scaled trial, phosphate was almost completely removed in area 2 (phosphate concentration was below the method detection limit of 0.005 mg P/L) and reduced by 92% in area 1.

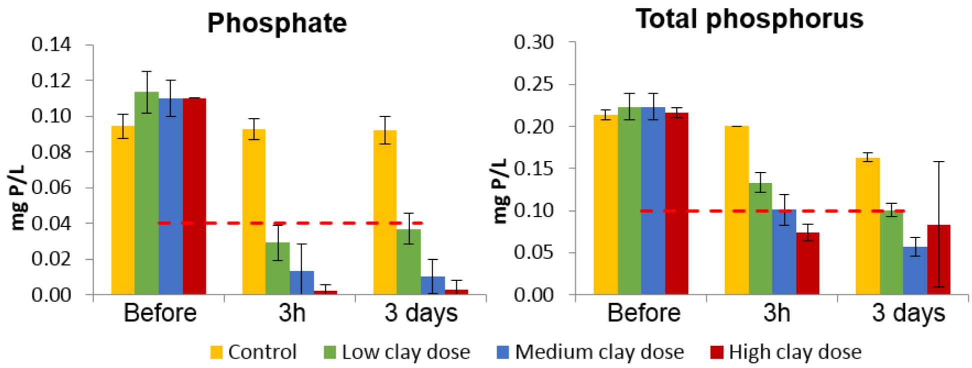

Figure 10: Concentrations of phosphate (soluble and bioavailable form of phosphorus) and total phosphorus before and after HT-clay treatment – mesocosm trial 2016–17. Red lines mark target thresholds, error bars represent standard deviation of three replicate mesocosm tanks.

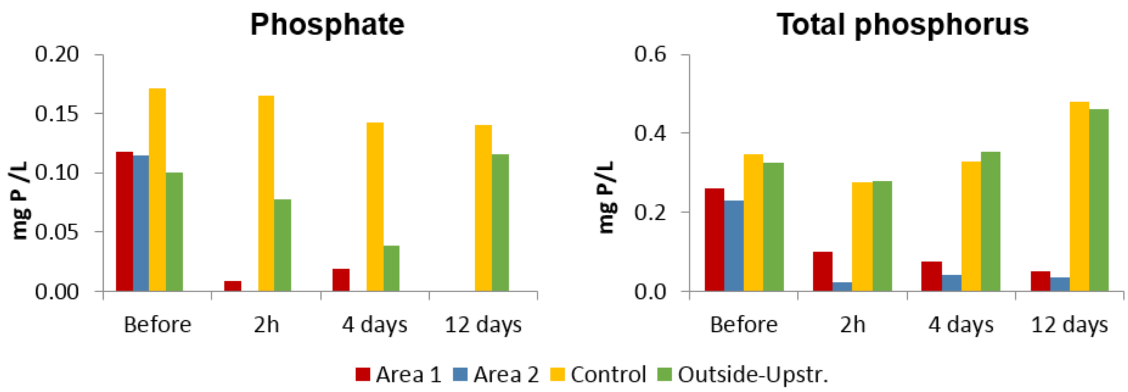

Figure 11: Phosphorus concentrations before and after HT-clay treatment in February 2018 – up-scaled trial 2017–18. (Note: the site downstream of the curtains was analysed from a later date onwards and is therefore not included in this graph.)

To evaluate the efficiency of the clay treatment, phosphate concentrations are more relevant than the concentration of the total phosphorus. Phosphate is the water soluble form of phosphorus which is immediately available to algae (the HT-clay is specifically designed to remove this form of phosphorus). Phosphate is typically analysed as filterable reactive phosphorus (FRP). In contrast, a large fraction of the total phosphorus is bound and contained within the algae. The clay treatment lowers the total phosphorus concentration in the water largely by removing algae and particulates, but it has not been designed for this purpose specifically.

All tested clay doses in both trials were able to drop phosphate concentrations below the recommended ANZECC & ARMCANZ guideline threshold of 0.04 mg P/L for lowland rivers (ANZECC & ARMCANZ 2000). Total phosphorus concentrations were reduced to below the management recommendations target threshold of 0.1 mg P/L to support a shift from phytoplankton to more beneficial macrophytes in Lower Vasse River, which was published by Novak and Chambers (2014).

Longer-term phosphorus reduction

Mesocosm trial 2016–17

The HT-clay treatment reduced total phosphorus and phosphate concentrations to values below the recommended target thresholds of 0.1 and 0.04 mg/L respectively (Novak & Chambers 2014; ANZECC & ARMCANZ 2000) for the entire monitoring period of five months when it was applied in sufficiently high doses (≥0.75 g/L). However, the total phosphorus threshold was slightly exceeded towards the end of summer at the lowest clay dose of 0.36 g/L (see Figure 12).

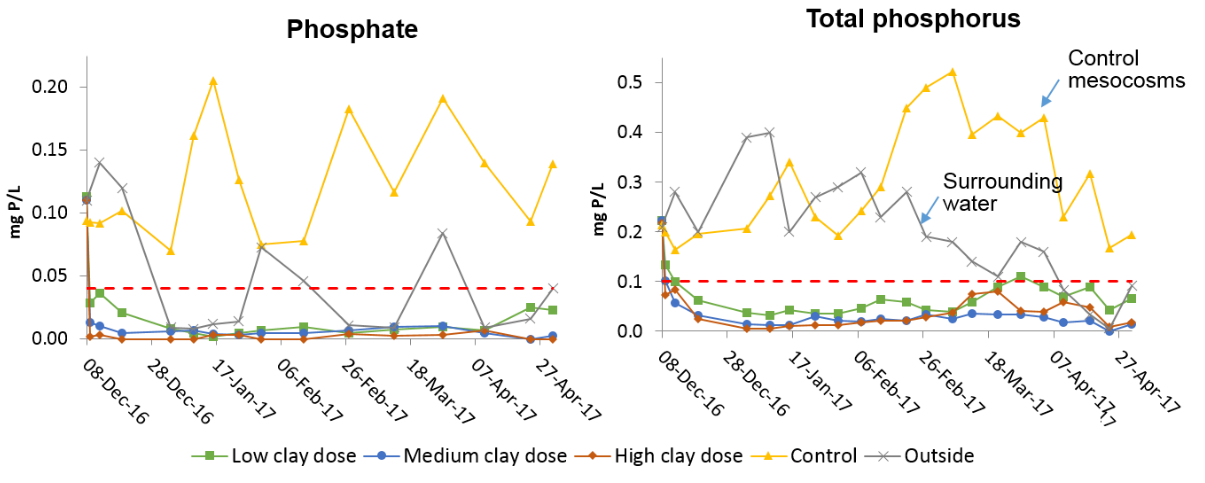

Figure 12: Phosphorus concentrations during the 2016–17 mesocosm trial over the entire monitoring period of five months.

Phosphate concentrations in the treated mesocosms were substantially lower compared with the conditions in the control mesocosms, indicating a high efficiency of the treatment. Phosphate concentrations in the surrounding river fluctuated with algal growth cycles, frequently exceeding the target threshold.

In the last month of the trial water quality conditions in the surrounding river started to improve, whereas algal blooms remained severe in the control mesocosms and also started to develop in some of the treated mesocosms (particularly for the lowest clay dose). This effect was also noticeable in the total phosphorus concentrations which decreased in the surrounding river (Figure 12).

Up-scaled trial 2017–18

Similar to the observations from the previous mesocosm trial, phosphate and total phosphorus concentrations remained low in the treated areas until the end of the trial, proving the efficiency of the clay on a larger scale and under slightly less restricted conditions (Figure 13). However, in the up-scaled trial a top-up clay dose was applied after 34 days, whereas in the mesocosm trial the whole clay amount was applied in a single dosing event in early summer. Top-up clay applications were planned in this trial to treat additional phosphorus input from external sources such as groundwater input or surface runoff, which would not have impacted water quality in the mesocosm trial. Large-scale clay treatment of the Lower Vasse River (with HT-clay as well as Phoslock®) will likely require one to two top-up applications throughout summer to account for this.

Phosphate and total phosphorus concentrations in the treated areas were much lower compared with the untreated control area and in the river upstream of the curtains (Figure 13). However, phosphate concentrations in the river downstream of the curtains were also low, albeit for different reasons.

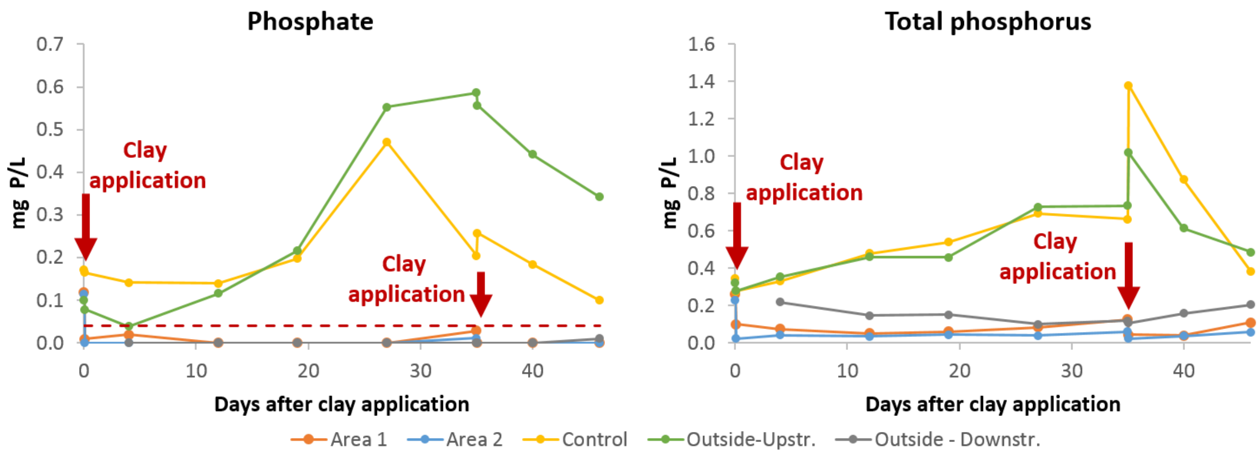

Figure 13: Phosphorus concentrations during the 2017–18 HT-clay trial. Phosphate concentrations were reduced to below the target thresholds (red line) as a result of clay application and remained low until the end of the trial.

We observed that the curtains acted as a barrier to the development of algal blooms. Typically the algal blooms started developing on the downstream side of the curtain setup in the area between the weir boards at the old butter factory and the causeway bridge (Figure 14). The blooms eventually spread to the upstream end of the curtains in late December/early January; however, after the storm event in mid-January – which temporarily cleared most of the algae – the subsequent blooms were largely restricted to the stretch of the river downstream of the curtains, particularly towards the end of the trial. Algal blooms may also temporarily deplete dissolved phosphate in the water until the bloom breaks down and releases the bound phosphorus. This is presumably the reason for the low phosphate concentrations that we measured downstream of the curtains where more severe algal blooms were present. Low phosphate concentrations during algal blooms have previously been observed in the Lower Vasse River during our long-term monitoring program and also to some extend in the mesocosm trial (see section above). Although total phosphorus concentrations at the downstream location were lower compared with the upstream location and in the control areas, they were generally higher than in the treated areas (Figure 13).

In summary, the clay treatment was successful in controlling phosphate concentrations at a larger scale; however, we recommend that the clay application be split into several dosing events throughout summer to account for potential additional phosphate input from runoff or groundwater after the initial clay application.

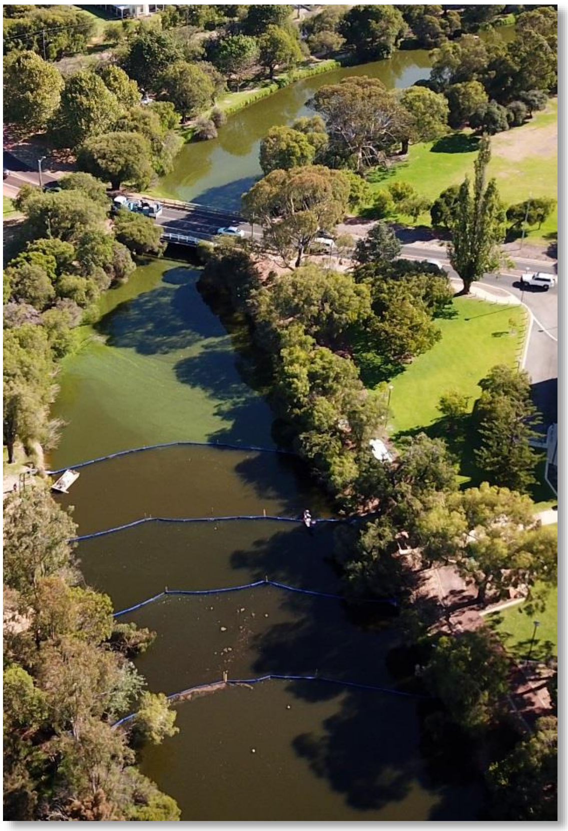

Figure 14: Aerial view before clay application in February 2018. Algal blooms in the Lower Vasse River typically start to develop at the downstream end between the weir boards and the causeway bridge before spreading further upstream.

3.2 Did the clay treatment reduce algal growth?

Immediate removal of algal blooms – flocculation

The HT-clay was able to remove an algal bloom within hours of application. This was shown in the 2016–17 mesocosm trial, the 2017–18 up-scaled trial and in laboratory experiments. The algae bind to the clay and sink to the ground of the river, a process called algal flocculation. The capability of the HT-clay to flocculate algae is a very useful side effect and gives it an advantage over Phoslock® clay, which solely controls algal growth by trapping phosphorus. Phoslock® has to be applied before the onset of an algal bloom (unless combined with a flocculating agent), whereas the new HT-clay still works when algae are already present. This enables more flexibility with timing and type of applications.

After clay application in the up-scaled trial, the water in the treated areas was extremely clear so that structures on the bottom of the river such as wooden debris became visible (see aerial photograph in Figure 15). Nevertheless, the treated areas appeared green, due to the algae that came to rest on the ground of the river together with the clay layer. The difference between the treated areas compared with the non-treated control area – which had thick algal scum on the water surface – was remarkable. These observations were also supported by the concentrations of algal pigments in the water before and after clay application (Figure 16). Similar results were achieved in the mesocosm trial when one of the mesocosms was treated later in summer (figures 18 and 19).

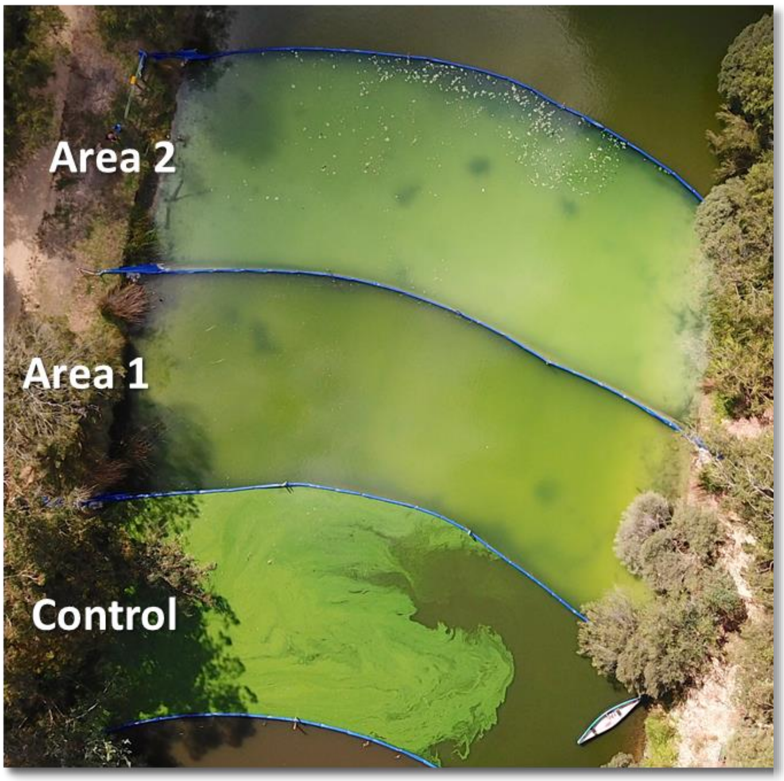

Figure 15: Aerial photo taken immediately after clay application in March 2018. In the treated areas the water is extremely clear, with structures such as wooden debris visible in the middle of the river. The green colour in these areas comes from algae which are now at the ground of the river together with the clay layer. In contrast, there is thick algal scum on the surface of the non-treated control area which is being moved across the trial area by the wind.

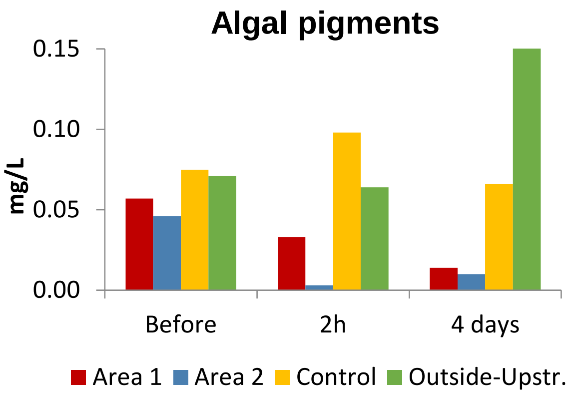

Figure 16: Concentration of algal pigments (chlorophyll and pheophytin) confirm that the clay largely removed an algal bloom within hours of application (up-scaled trial 2017–18, clay application in February).

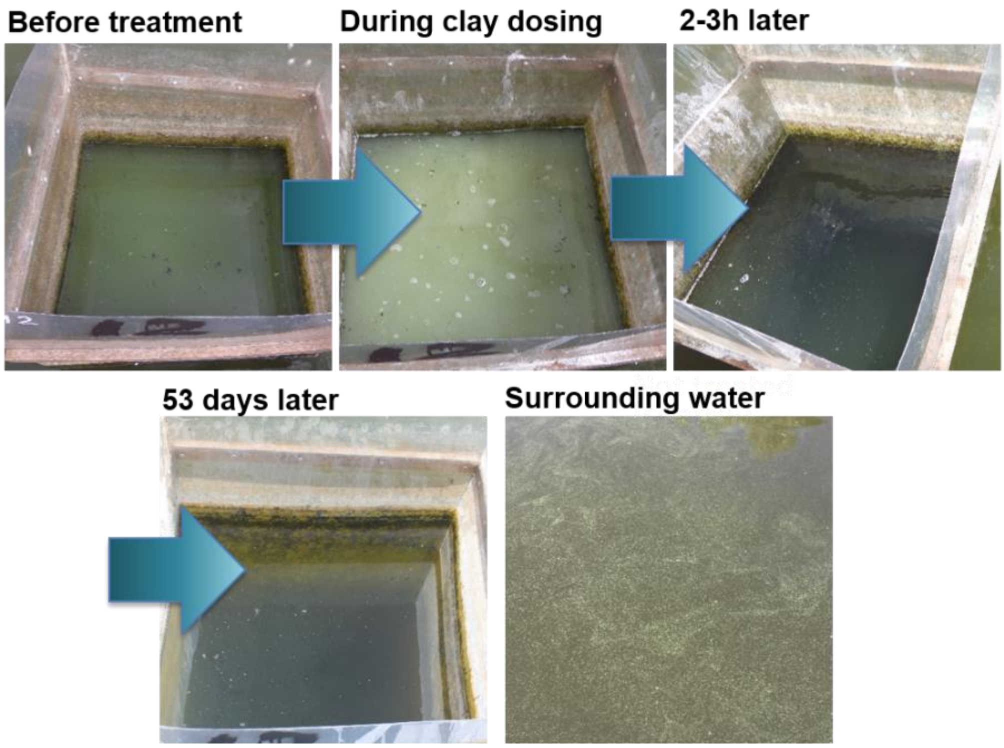

Figure 17: The HT-clay application was able to treat an algal bloom when it was applied to a mesocosm tank later in summer. The difference in visual amenity was immediately noticeable once the clay had settled. The water quality remained improved until the end of the trial 53 days later.

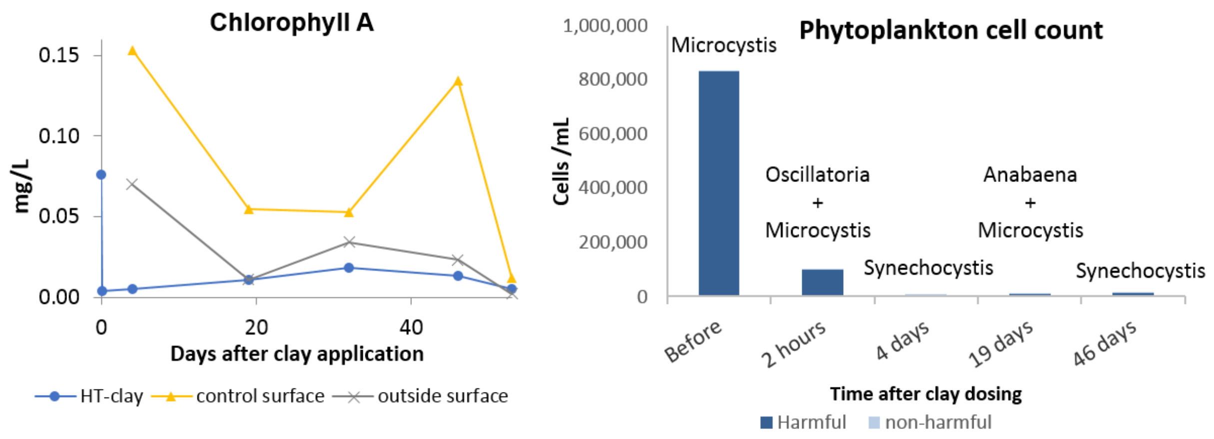

Figure 18: Concentration of chlorophyll A (algal pigment; left) and algal cell count with dominant species (right) in the mesocosm that was treated with clay later in summer when an algal bloom was already present. The algal bloom was largely removed and water quality conditions remained improved until the end of the trial.

Longer-term reduction of algal growth

The clay treatment reduced algal growth and improved water quality during the trial periods in both summers, when compared with the non-treated control area/control mesocosms. This was evident from visual assessment (e.g. Figure 19) and through evaluation of algal growth indicators such as algal cell count or chlorophyll concentration (e.g. figures 21 and 22).

Figure 19: Treated mesocosm versus surrounding water and non-treated control about three months after clay dosing (21 March 2017). The water in many mesocosms treated with the medium and high clay doses was still clear, often with visibility of the river ground. Phytoplankton growth was more severe in control mesocosms compared with the surrounding water towards the end of the trial.

Algal growth remained low in most mesocosms treated with the medium and high clay doses during the entire five-month monitoring period. However, towards the end of the trial when water quality conditions in the surrounding river were starting to improve, severe algal blooms developed in the control mesocosms and also in some of the treated mesocosms, particularly in those that had received the low clay dose (Figure 20). One of the mesocosms that received the high clay dose was presumably contaminated (e.g. by birds) and developed a very significant algal bloom in the second half of the trial. However, there were no algal blooms in the remaining two replicates that received the high clay dose. More detail on the concentration of phytoplankton cells and dominant species is included in Appendix C.

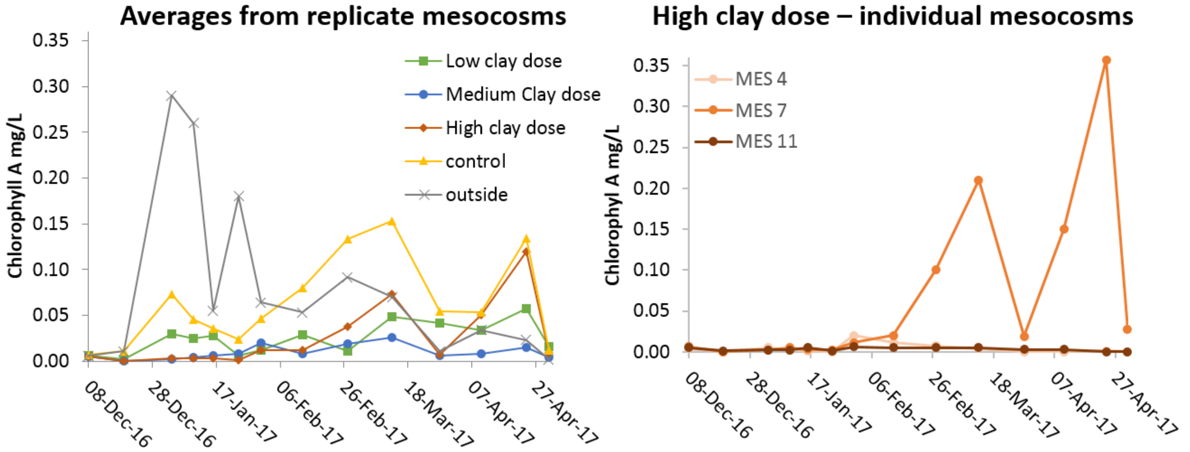

Figure 20: Chlorophyll concentrations during the 2016–17 mesocosm trial. The most significant algal bloom in the surrounding river occurred in late December and January. After that conditions started to improve in the river but algal growth further increased in the control mesocosms. The right figure shows the extremely high chlorophyll concentrations in one of the mesocosms that received the highest clay dose and was presumably contaminated.

Due to the unexpected weather events in summer 2017–18, the algal blooms in the Lower Vasse River followed an unusual pattern that year. Severe algal blooms had established in the river in late December/early January, yet the conditions improved significantly after the mid-January rainfall event. When the clay was applied in early February some algal blooms were present, especially downstream of the trial areas, but these were less severe than before the rain event.

Towards the end of the trial a severe algal bloom had established in the control area, but not in the river outside of the curtains (see concentrations of algal pigments in Figure 21). This shows that the curtains altered the conditions and provided more favourable conditions for algal growth. It is therefore important to compare the algal growth indicators from the treated area with the control area rather than to the surrounding river. Figure 21 indicates that the clay treatment significantly reduced algal growth for the entire trial period compared with the control area.

However, it should be noted that the clay treatment temporarily increased the abundance of floating algal mats associated with clay in both trials. This is presumably due to the improved water quality conditions which enable light penetration to the bottom of the river and support the growth of benthic algae.

Floating mats of benthic algae also developed in the surrounding river, particularly on sunny days, but they were not as abundant as they were in the treated areas.

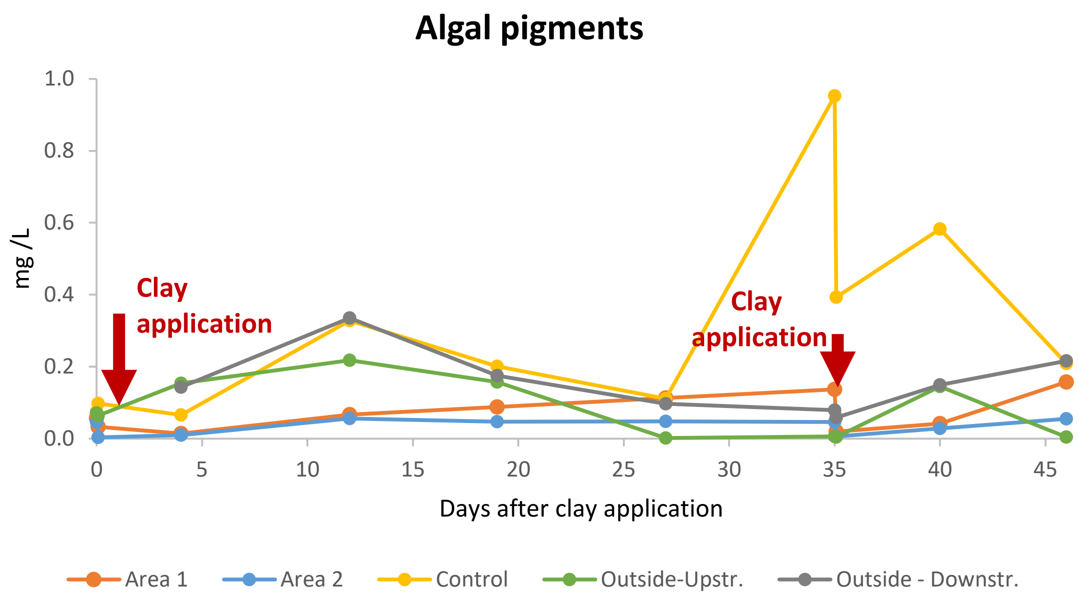

Figure 21: Concentration of algal pigments (chlorophyll and pheophytin) during the up-scaled 2017–18 HT-clay trial in treated and non-treated areas. The most severe algal bloom was present within the non-treated control area. It is important to compare the water quality variables from the treated areas with the control area (rather than to the surrounding river).

3.3 Did the clay treatment affect invertebrate organisms?

Although the clay itself is non-toxic, the presence of the clay layer and a short-term increase in turbidity immediately after application may have adverse effects on small invertebrate organisms living in water and sediments. To assess the impact of the clay on these organisms, the abundance and diversity of invertebrates were studied as part of the second up-scaled trial.

The results indicated no negative influence of the clay application on number and diversity of invertebrates present (Figure 22). However, the general invertebrate diversity in the river (also in non-treated sections) was low and limited to very resilient organisms, as was expected for a degraded environment such as the Lower Vasse River. Organisms found in sediments and water near the banks largely consisted of water boatmen, glass shrimp and larvae of non-biting midges (chironomids). Even fewer organisms were found in the sediments in the middle of the river, being limited to small red worms (oligochaetes) and very low numbers of chironomids. Both species are well-adapted to low oxygen conditions.

Although the present study did not indicate the clay treatment had any negative impacts on the organisms present in the Lower Vasse River, specifically designed laboratory toxicity tests with a higher diversity of invertebrate organisms will need to be conducted before large scale HT-clay applications.

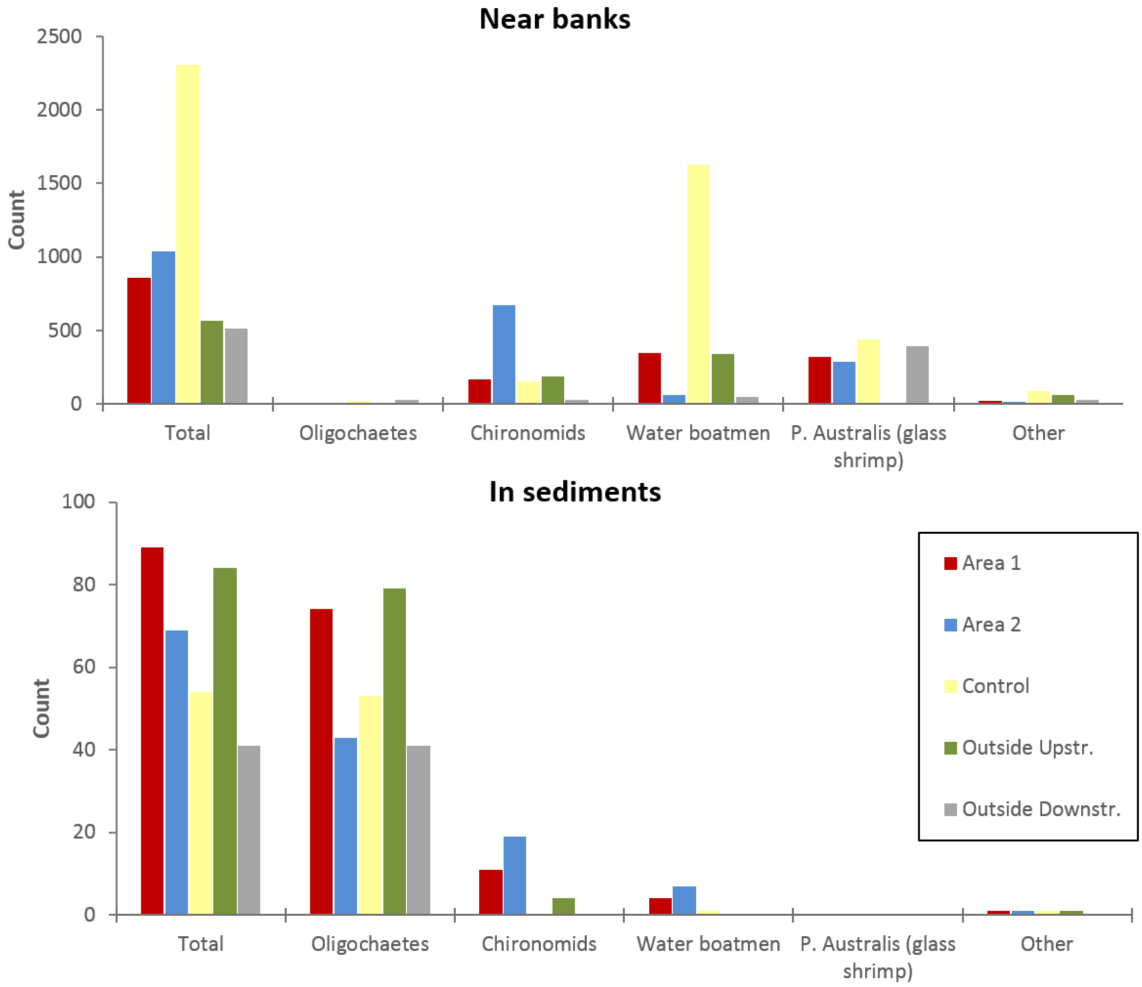

Figure 22: Macroinvertebrate organisms within and around the trial areas in the Lower Vasse River (up-scaled trial summer 2017–18). None of the organisms were negatively influenced by the clay treatment. Water boatmen were extremely abundant in the control area because of the severe algal bloom present in that area, which served as their food source.

3.4 Results from sediment studies

Did the clay layer reduce phosphorus release from sediments?

Pore water studies (conducted as part of the mesocosm trial) indicated that the clay layer capped the sediments and reduced phosphorus release (Figure 23; Appendix B). The estimated amount of phosphorus released from the sediments within the treated mesocosms during the entire trial period was 89 ±15 mg, which was lower compared with the phosphorus amount released from the same-sized sediment area in the surrounding river (301 ±151 mg) or from the control mesocosms (172 ±86 mg). In contrast, there were no statistically significant differences when comparing the release of ammonia and reactive silica between the treated and untreated mesocosms.

Nutrient release from the sediments to the overlying water can be estimated from nutrient concentrations in the pore water contained within sediments using finely sliced core intervals near the sediment/water interface. This is based on the assumption that in a stagnant system with fine-grained muddy sediments such as the Lower Vasse River during summer, nutrients are predominantly released from sediments to the overlying water by diffusion. Nevertheless, some nutrient release by sediment disturbance likely occurred at least in some of the mesocosms, which has not been considered in the calculations. Visual inspection and chemical analyses of the sediment cores indicated some sediment movement and burial of the clay layer (by up to 5 cm in one of the mesocosms). Despite this movement of the clay layer, phosphorus release from the sediments was still reduced in the treated mesocosms.

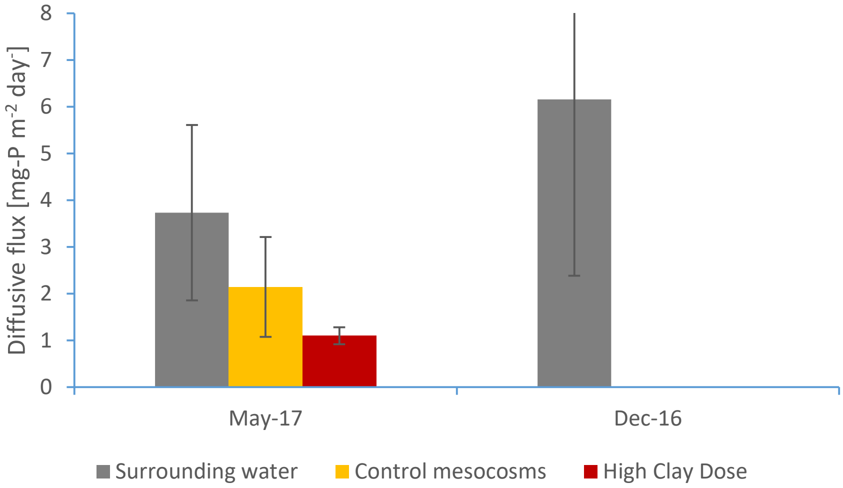

Figure 23: Daily diffusive phosphate release from sediments immediately before and after the HT-clay trial. The results show that the clay layer capped the sediments and reduced P-release. P-release from sediments in the control mesocosms was lower (despite much higher phosphate concentrations in the pore water) presumably due to higher phosphate concentration in the overlying water, which slows diffusive release. Error bars represent standard deviations from three replicate cores. Whereas the replicate cores from the treated mesocosms showed consistent results, there was some variation between the replicates in the control mesocosm and the surrounding area.

How fast do sediments in the Lower Vasse River accumulate?

Nutrient and organic matter-rich sediments often build up rapidly in aquatic systems of poor environmental health such as the Lower Vasse River.

The sediments covering the river bottom at the trial area consisted of an approximately 50 cm thick layer of fine-grained black mud overlying a riverbed of coarse sand. Most of the black sediment must have accumulated rapidly within 17 years because the sediments at this location were largely removed in March 2001 in an attempt to improve water quality.

To more accurately estimate the sediment accumulation rate we analysed lanthanum concentrations in sediment cores. Lanthanum is a major element in Phoslock® clay which was applied to the area in 2001–02. Based on a lanthanum spike in the sediment depth profiles, an accumulation rate of about 13– 17 mm per year was estimated. This is very high compared with typical rates for both lakes and estuaries.

4 Is the new HT-clay a viable alternative to Phoslock®?

Phoslock® and HT-clay each have advantages and disadvantages; thus the specific environment or particular situation for intended application will determine which clay may be more suitable. Both clays have shown promising results in the treatment of algal blooms in the Lower Vasse River. Table 4 lists the most important points in a direct comparison between both clays. However, it should be noted that while Phoslock® is a commercial product that is readily available, the HT-clay is still an experimental product that requires further testing and product development work (see following section).

Table 4: Comparison HT-clay versus Phoslock®

Phoslock®	New HT-clay
Tested dosing rate in the Lower Vasse River ➔1.2 g clay/L	Required dosing rate in the Lower Vasse River ➔ca. 1 g clay/L
Commercial product, readily available	Experimental product, requires further research and optimisation
Does not work in brackish or marine environments	Application may be possible but requires further research
Has to be applied before an algal bloom starts	Removes algal bloom when it has already established
Includes rare earth element lanthanum; is produced in China	Straightforward production process; potentially more economic starting materials; can likely be produced locally

4.1 What's next? – further HT-clay development

Although the HT-clay has shown promising results in first field trials, it is still an experimental product and requires further research and development work before large-scale application may become possible in the Lower Vasse River and at other locations. Current activities in the REI component of the project include:

1. Optimisation of the clay production method to enable affordable large-scale production and transport
2. Development of a detailed environmental risk assessment of HT-clay application, including toxicity studies with invertebrate organisms as well as looking at the behaviour of clay under changing environmental conditions, such as low/high pH or higher salinities.
3. Further research of clay dosing rates and clay performance under different conditions, such as high organic matter contents or higher salinities.

These experiments will be conducted in the next one to two years. If successful, it is anticipated that large-scale HT-clay treatment may become available in the next three to five years.

5 Conclusions - what treatment do we recommend for the Lower Vasse River?

Regular application of phosphorus-binding clay in the Lower Vasse River will reduce algal growth, sediment build-up and phosphorus release from sediments. Over time this will provide conditions for the establishment of a healthier and more diverse ecosystem (e.g. enable growth of macrophytes or aquatic plants).

- We recommend regular Phoslock® treatment for the Lower Vasse River as an immediately available and affordable measure to improve water quality and reduce sediment build-up.
- If the current testing and development of HT-clay is successful, HT-clay may replace or be combined with Phoslock® treatment of the Lower Vasse River in the future. We aim to improve the clay manufacturing process for HT-clay and intend to conduct laboratory testing to develop a detailed environmental risk assessment.
- Annual treatment would involve an estimated 40 tonnes of Phoslock® being split into three to four separate applications during summer (20 tonnes in November before the onset of algal blooms and smaller top-up applications throughout summer when required). It is anticipated that the total annual clay amount could be reduced significantly after a few years of regular application.
- Algal blooms in the Lower Vasse River develop at the downstream end in the area between the weir boards at the old butter factory and the causeway bridge before they spread further upstream. We therefore recommend treatment of this area.
- Phoslock® is a commercially available product that is distributed and applied by the Australian company Phoslock® Water Solutions at a price of $3000 per tonne. A 40 tonne application would therefore cost about $120 000 annually.

Appendices

Appendix A — How did we ensure the trial setup was working?

Bromide tracer

To obtain accurate results for this trial it was important that mixing of the water between the mesocosm tanks or trial areas separated by curtains and the surrounding river was kept at a minimum. To test this, a bromide salt was added to the trial areas and used as a tracer to monitor water exchange. Bromide is an established tracer used in many environmental applications. It is non-harmful with a low natural abundance: its concentrations typically do not change due to natural processes such as adsorption to particles or uptake by organisms.

Bromide loss from the mesocosm tanks was minimal during a monitoring period of almost two months, indicating only minor water exchange with the surrounding river (Figure 24). There was some water exchange with the surrounding areas during the 2017–18 up-scaled trial, particularly towards the end of the trial (Figure 25).

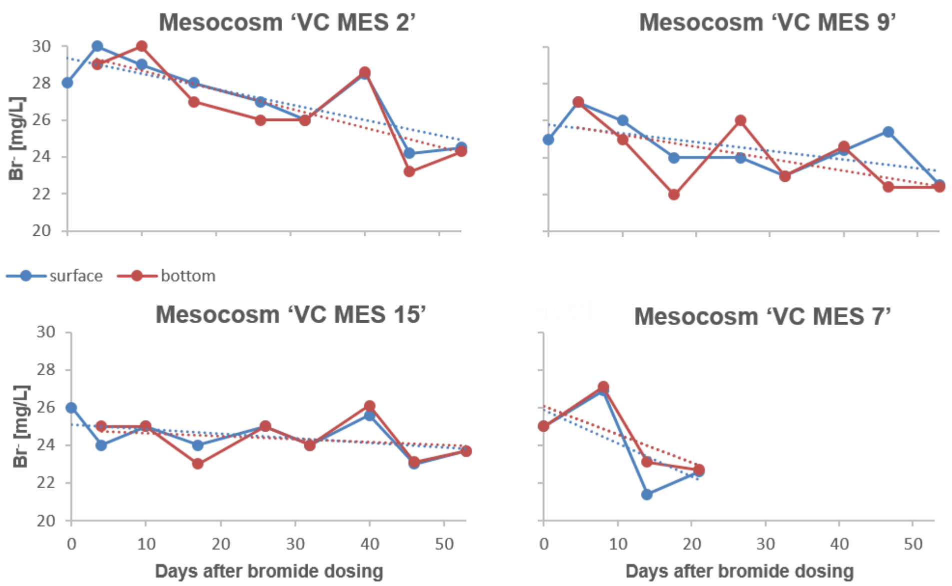

Figure 24: Concentrations of a bromide tracer added to selected mesocosms indicate no or only little water exchange with the surrounding river. Blue and red graphs represent concentration in surface and bottom water samples respectively.

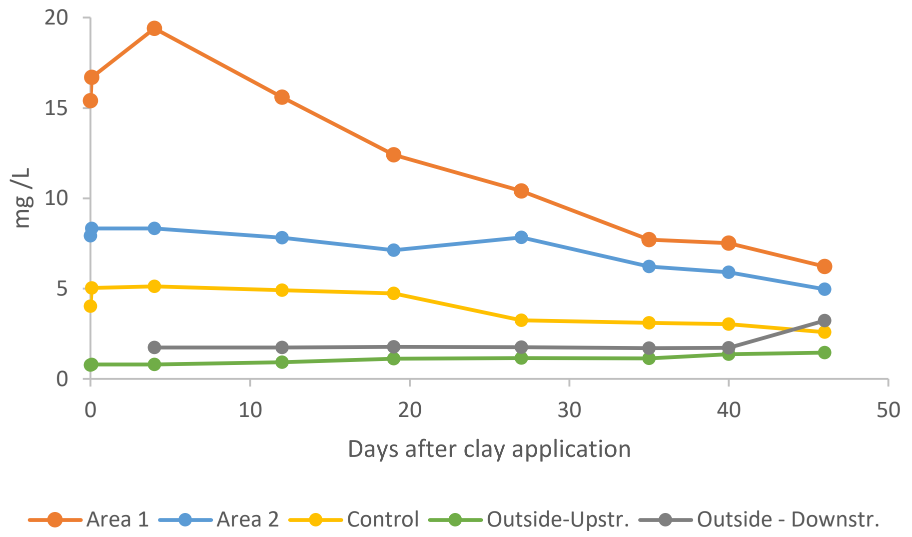

Figure 25: Bromide concentrations during the 2017–18 up-scaled HT-clay trial. Sodium bromide was applied to trial areas 1 and 2 before clay application. The loss of bromide from area 1 during the trial indicates some water exchange with the surrounding areas. Bromide concentrations in the non-treated control area were elevated compared with the surrounding river due to some water exchange with the treated areas, presumably this largely happened before clay application when there was still some water movement after the storm event.

Appendix B — Diffusive nutrient fluxes from the sediments to the overlying water

For this study the diffusive nutrient release was estimated from concentration gradients in pore water within the top three centimetres of the sediment cores that were collected in May 2017 and December 2016. Daily nutrient fluxes per square metre, as well as total nutrient release per mesocosm area over the whole trial duration are summarised in Table 5. All nutrient fluxes were generally very high, which can be expected from a system like the Lower Vasse River.

Table 5: Average diffusive nutrient fluxes (± standard deviation) determined immediately before and after the HT-clay trial in December 2016 and May 2017 respectively.

Sampling date	**Nutrient**	**Clay treatment**	**Flux (F)** [mg $m^{-2}day^{-1}$]	**Estimated amount released during trial per mesocosm area**
May 2017 (after trial)	Filterable reactive phosphorus (FRP)	Surrounding river (no clay)	3.74 ±*1.88*	301 ±*151* mg-P
May 2017 (after trial)	Filterable reactive phosphorus (FRP)	Control mesocosms (no clay)	2.14 ±*1.07*	172 ±*86* mg-P
May 2017 (after trial)	Filterable reactive phosphorus (FRP)	High clay dose	1.10 ±*0.18*	89 ±*15* mg-P
May 2017 (after trial)	Ammonia (NH_3)	Surrounding river (no clay)	45.4 ±*5.2*	3653 ±*417* mg-N
May 2017 (after trial)	Ammonia (NH_3)	Control mesocosms (no clay)	38.5 ±*19.7*	3098 ±*1586* mg-N
May 2017 (after trial)	Ammonia (NH_3)	High clay dose	36.0 ±*7.2*	2896 ±*582* mg-N
May 2017 (after trial)	Reactive silica	Surrounding river (no clay)	25.1 ±*2.7*	2018 ±*220* mg-Si
May 2017 (after trial)	Reactive silica	Control mesocosms (no clay)	12.5 ±*9.5*	1006 ±*765* mg-Si
May 2017 (after trial)	Reactive silica	High clay dose	19.3 ±*5.7*	1551 ±*459* mg-Si
December 2016 (before trial)	Filterable reactive phosphorus (FRP)	Surrounding river (no clay)	*6.16 ±*3.77*	*495 ±*303* mg-P
December 2016 (before trial)	Ammonia (NH_3)	Surrounding river (no clay)	30.5 ±*23.2*	2452 ±*1862* mg-N
December 2016 (before trial)	Reactive silica	Surrounding river (no clay)	11.4 ±*2.4*	918 ±*190* mg-Si

*Only determined from concentrations in top 2 cm sediment layers (all other fluxes calculated from top 3 cm)

Appendix C — Phytoplankton species analysis during the 2016–17 mesocosm trial

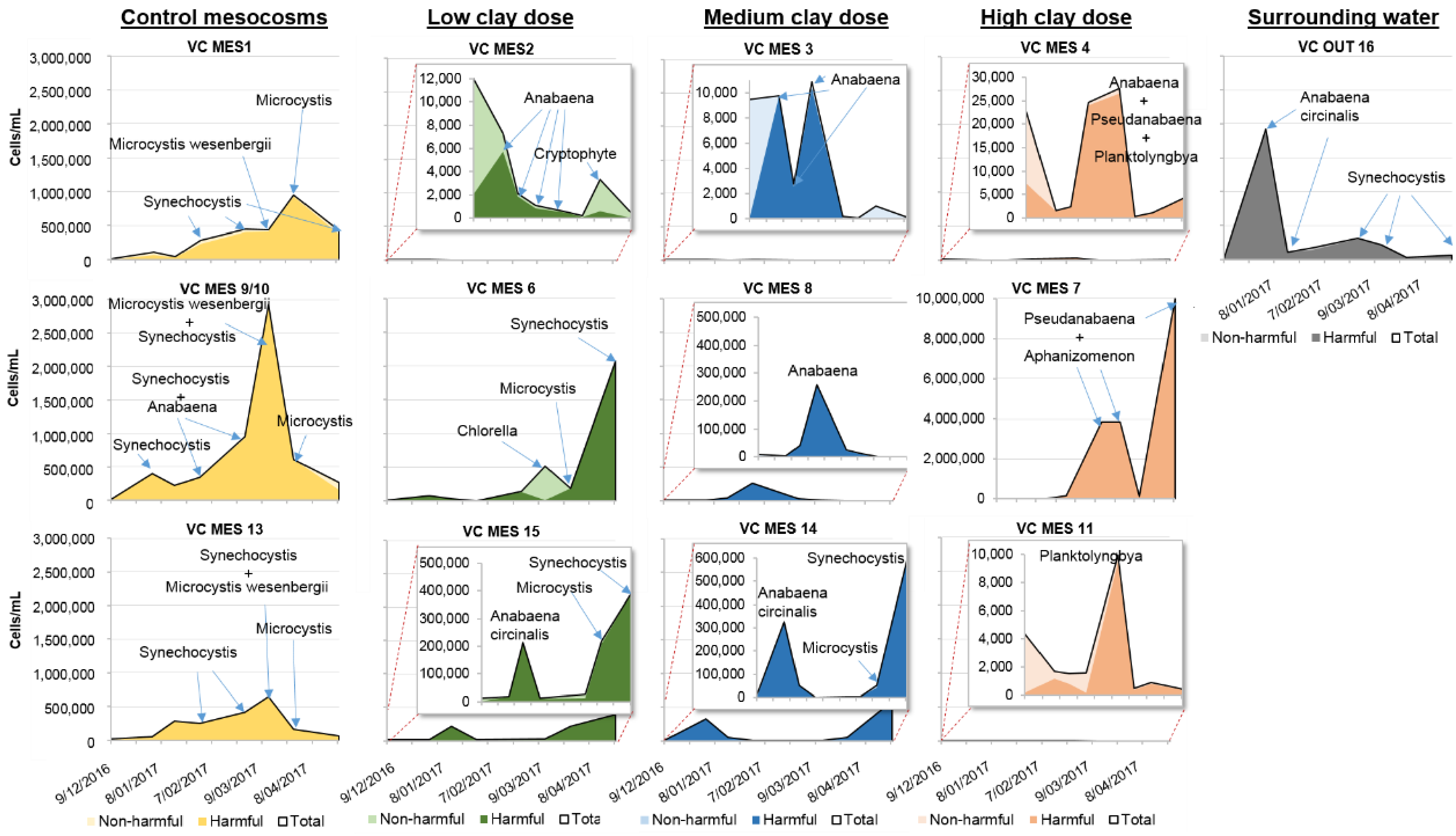

Figure 26: Phytoplankton cell counts and dominant species in the mesocosms and surrounding river throughout the 2016–17 trial.

Shortened forms

DO	Dissolved oxygen
DOC	Dissolved organic carbon
DWER	Department of Water and Environmental Regulation
FRP	Filterable reactive phosphorus
HT	Hydrotalcite
P	Phosphorus
REI	Regional Estuaries Initiative
RGW	Revitalising Geographe Waterways
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids

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