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Robust options to remove nitrate and phosphate from tile drainage

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ABSTRACT. *Diffuse emission from agricultural land is a major, persistent source of nitrogen and phosphorus in surface waters. In this contribution, we present field experiments of a series of robust options to remove nitrate and phosphorus at field drainage level.*
Nitrate removal was enhanced by stimulating naturally occurring denitrification by adding wood chips. The results showed that the initial removal rates were high (between 60 and 80%). Efficiency decreases in case of periodic presence of oxygen. The concentrations of phosphate in the effluent showed peaks during the first year at high temperatures and low water discharge. The emission of nitrous oxide to the surface above the drains was negligible, but was increased at the ends of the drains. It is estimated that the long-term efficiency depends on good control of the water levels and flow rates in the filter beds.
Phosphorus removal was enhanced by using iron-oxide coated sand as filter material. Three methods were tested: drains enveloped with iron oxide coated sand, an edge of field reactor and a slow sand filter reactor at the downstream end of the drainage canal. Results show that up to 95% of the phosphorus can be removed. A reduction of the hydraulic conductivity during the experimental period reduced the efficiency of the edge of field reactor and the slow sand filter reactor. For all phosphorus treatment options tested, high removal efficiencies could be reached and no negative side-effects were found.

Keywords. *engineering technology, nutrients, water quality.*

Introduction

Diffuse emission from agricultural land is a major, persistent source of nitrogen and phosphorus in surface waters in many parts of the world. In the Netherlands, the high intensity of agriculture leads to large emissions of nutrients into the surface waters. At the same time, the goals for nutrients set by the Water Framework Directive are not met for many of these surface

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waters. This urgently calls for options to reduce the emission of nutrients into the surface water by diffuse sources. As approximately half of the agricultural area in the Netherlands contains tile drainage and tile drainage is a major source of nutrients into the surface waters, we have focused on this emission route for nutrient removal options. In this contribution, we discuss field trials with filter systems which can remove nitrogen or phosphorus from tile drainage water before it enters the surface water. For nitrogen, tile drains were enveloped with wood chips to enhance naturally occurring biological denitrification. For phosphorus, iron-oxide coated sand (a side product from drinking water production from groundwater) was used to bind phosphorus. This approach was tested in three designs: by applying the sand around drains, at the outlet of drains before the water enters the surface water, and at the downstream end of the drainage canal.

Nitrogen removal

Materials and methods

On an arable farm in a clay region in the South-West of the Netherlands, three drains were enveloped by wood chips, sand and various amounts of beet pulp to test the removal of nitrate (Figure 1 and Table 1). The plot of approximately 480 by 280 meters was drained by tubes at a mutual distance of about 10 meters and at about 1 meter depth. Three test drains were applied in between the existing drains, over a length of 140 meters. Drain 1 was enveloped with a mixture of sand and wood chips, and was constructed at the same depth as the existing drainage. Drain 2 was enveloped with the same mixture, but placed more deeply (approximately 1.2 meters below ground level). It was expected that at this depth the soil conditions are more favorable for denitrification due to the lower redox potential. Drain 3 was at the same depth as the existing drainage, but the envelope not only contained sand and wood chips, but also beet pulp. This is known to be a highly effective electron donor. The expectation was that even small amounts of this substrate can strongly encourage denitrification. The envelope was deposited around the drain into a slot of about 30 cm width.

Nitrogen removal rates were measured over a two year time span and side effects were determined, such as water permeability, N_2O emissions, and phosphorus emissions.

Figure 1. Construction of drain enveloped with wood chips.

Table 1. Characteristics of enveloped drains for nitrogen removal.

Drain nr.	Wood chips (m^3)	Sand (m^3)	Beet pulp (m^3)	Depth (m)	Description
1	11	5	0,5	1,0	Wood chips + beet pulp
2	11	5	0	1,2	Wood chips + deeper
3	11	5	0	1,0	Wood chips

Results

Initial nitrogen removal rates were high (between 60 and 80%) (Figure 2 and 3). The drains installed at a greater depth were most effective in the removal of nitrogen. It was found that the removal rate of total nitrogen by drains enveloped by wood chips greatly decreased during the two-year experimental period. This decrease depended on the application method. The effectiveness when drains were enveloped by a mixture of wood chips and beet pulp decreased to zero. When only wood chips were present, effectiveness dropped to approximately 30%. The effectiveness for drains positioned more deeply dropped to 60%. This decrease in efficiency was accompanied by a decrease in the concentration of dissolved organic carbon and an increase in the redox potential. The results indicate that the decrease in efficiency was caused by the periodic presence of oxygen due to lowering of the water table.

Hydraulic permeability did not change, and thus no clogging is believed to have occurred. The concentrations of phosphate in the effluent, presumably coming from leaching from the woodchips, showed peaks during the first year at high temperatures and low water discharge, but they were not increased during the second year.

The emission of nitrous oxide to the soil surface above the drains was negligible, but was greatly increased at the ends of the drains (Table 3 and 4). With respect to the leaching of total nitrogen, however, these emissions were very low.

On the basis of these results, it is estimated that the long-term efficiency strongly depends on the method of construction and management. When tile drains are laid out in a regular way, the effectiveness can diminish quickly. If the drains are installed deeper, this effectiveness can be maintained much longer. However, with deepened placement, there is a larger chance of increased phosphate concentrations in the effluent.

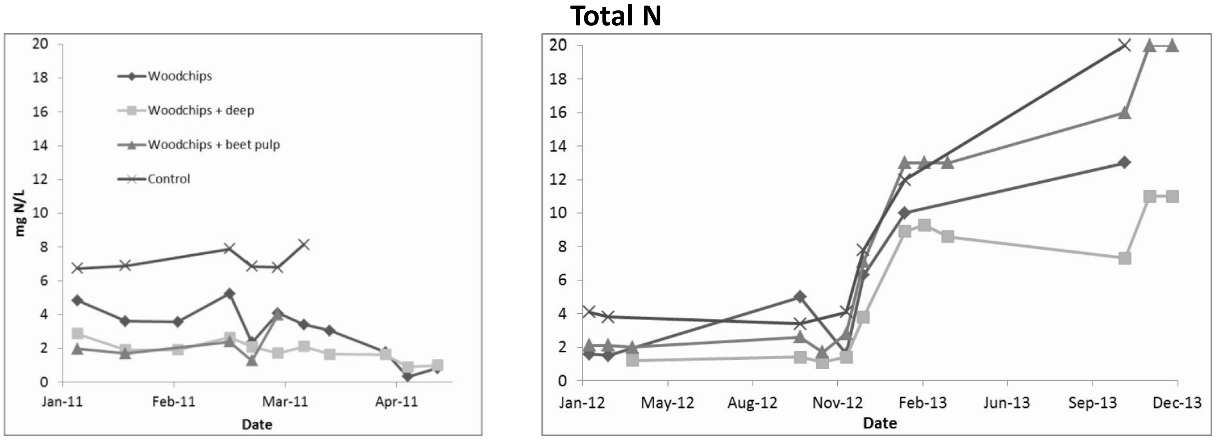

Figure 2. Concentrations of total nitrogen in drainage water effluent under four different conditions (woodchips, wood chips + deeper, woodchips + beet pulp, control).

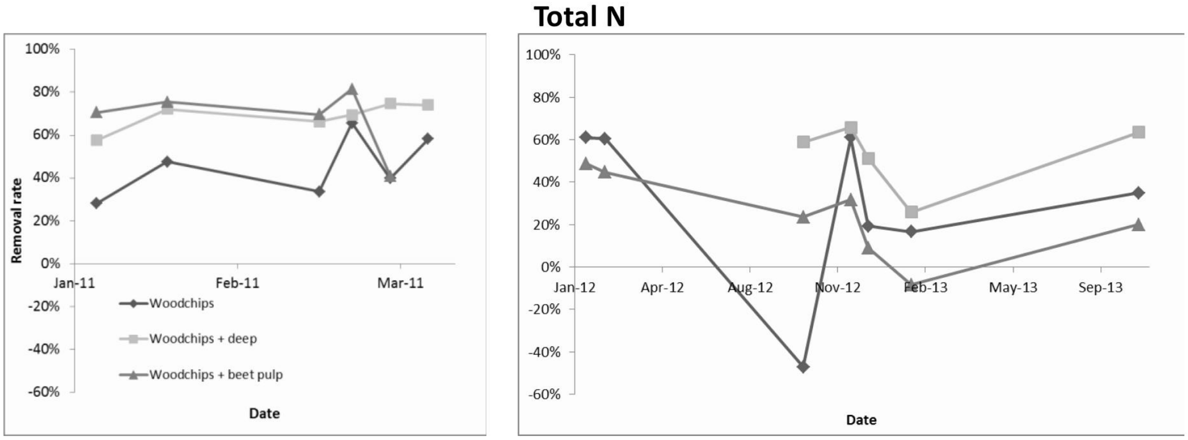

Figure 3. Removal rate (%) for total N.

Table 2. Calculated average removal rate for nitrate and total N during first months after installation (January-April).

	Removal rate (%)	
	Nitrate	Total N-total
Woodchips	59 ± 19	45 ± 6
Woodchips, deep	85 ± 9	69 ± 6
Wood chips + beet pulp	89 ± 7	68 ± 16

Table 3. N_2O emissions at the soil surface for five dates in 2011.

Date	N_2O emission (µg N_2O-N per m^2 per hour) (average ± standard deviation)			
	Woodchips with beet pulp	*Deeper drain with woodchips*	*Normal drain with woodchips*	*Control*
8 February 2011	5 ± 3	6 ± 3	4 ± 5	10 ± 8
25 February 2011	3 ± 3	5 ± 5	4 ± 4	5 ± 5
8 March 2011	2 ± 3	7 ± 14	5 ± 7	3 ± 3
10 May 2011	12 ± 9	9 ± 8	8 ± 8	5 ± 6
30 June 2011	4 ± 5	1 ± 3	-61 ± 94	36 ± 82

Table 4. N_2O emissions at drain outlets in 2013.

Date	Drain	N_2O emission (µg N_2O-N per drain outlet per hour)
23 April 2013	Normal drain with woodchips	803
	Deeper drain with woodchips	Not measurable
	Woodchips with beet pulp	Not measurable
	Control	Not measurable
25 June 2013	Normal drain with woodchips	30
	Deeper drain with woodchips	86
	Woodchips with beet pulp	364
	Control	6
25 June 2013	Normal drain with woodchips	1482
	Deeper drain with woodchips	1869
	Woodchips with beet pulp	3866
	Control	400

Discussion

Based on literature data, the long-term effectiveness of a woodchips enveloped drain is expected to be 10 to 15 years (Moorman et al., 2010). However, certain management practices may decrease the effectiveness significantly within a few years. A likely cause of this decrease is attributed to the breakdown of woodchips due to the presence of aerobic conditions around the drain during periods with a low water table. It is therefore very important that the water levels and flow rates in the filter beds are controlled. For example, this can be done by means of a woodchip bioreactor at the end of the plot and/or the drains. In combination with controlled drainage, this is a very promising possibility: the nitrate removal and the management of side-effects can be optimized, and by using a form of controlled drainage, water storage and crop production can be optimized.

Phosphorus removal

Materials and methods

Three phosphorus removal techniques were tested in a sandy region in the western part of the Netherlands. The experiments were carried out at a 6 ha drained bulb field, draining to a central, isolated drainage ditch. The water level in the drainage ditch was kept lower than in the surrounding surface water areas, and excess water was pumped out. Drain flow and the outflow of the ditch were continuously measured to assess the complete water balance of the area. Figure 4 shows the location where the methods were tested and an impression of the experimental set-up.

At location 1, three new artificial tile drains were installed. The drains were enveloped by a 10 cm layer of iron-coated sand. The enveloped drains were placed at a distance of 2 m from the existing drains, and three existing drains served as a reference. The drain water was collected in a central pipe. Drain flow was measured continuously and quality was measured using flow-proportional sampling.

At location 2, a strip of the canal bank was set up as a porous filter containing iron-oxide coated sand. Water discharged from three drains was lead through the filter. In addition, flow and water quality were measured continuously using automated equipment.

At the end of the drainage canal (location 3), a reactor was built to test the treatment of the total runoff from the 6 ha bulb field. The slow sand filter was filled with iron-oxide coated sand to bind phosphorus. In order to prevent clogging, two pre-filters were installed to remove coarse debris and finer material. In- and outflow of the reactor was also measured continuously.

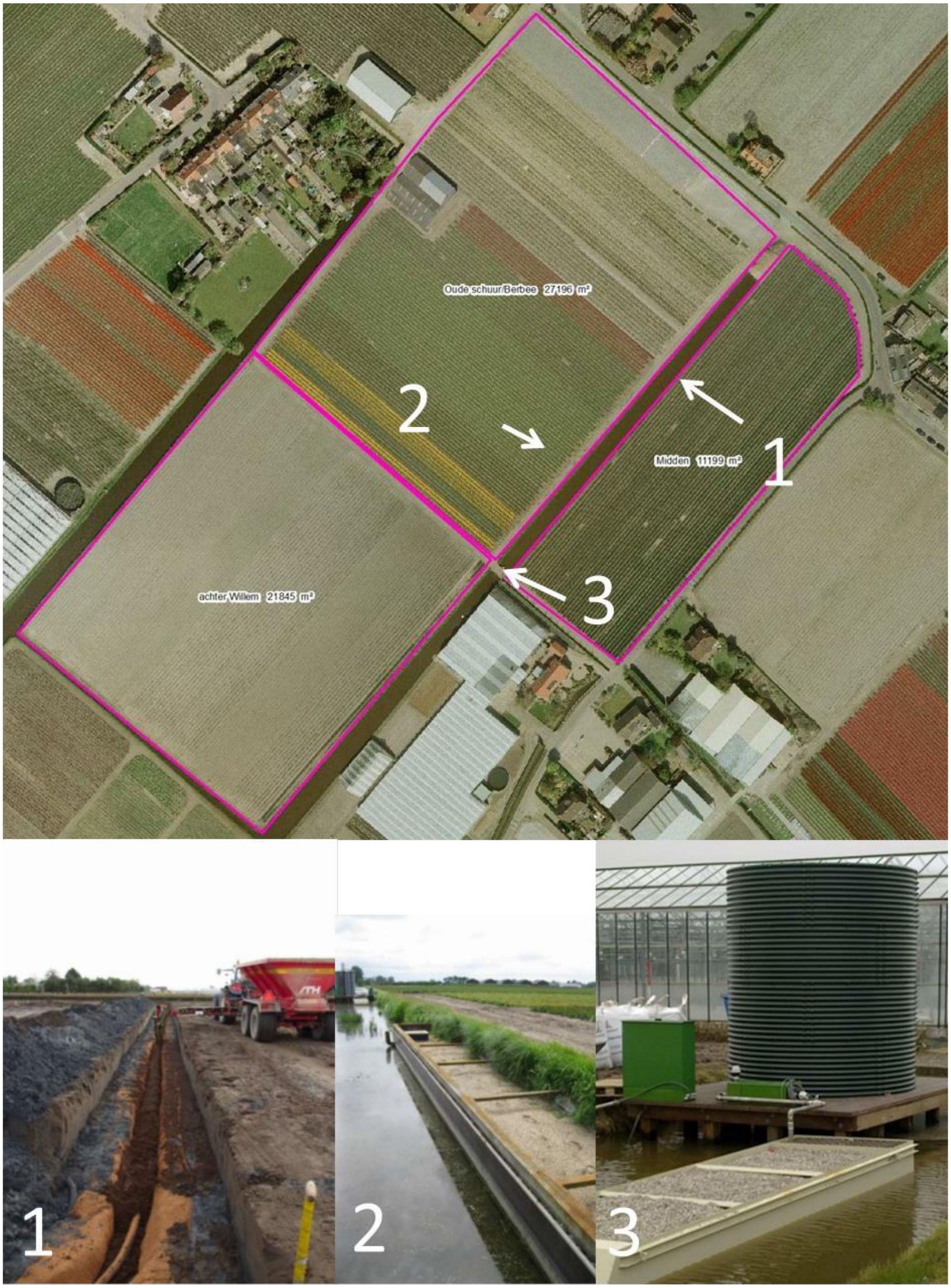

Figure 4. Experimental area. The locations of the field experiments are as follows: (1) Iron-oxide coated sand drains; (2) Canal bank reactor; and (3) Slow sand filter at the end of the drainage canal.

Results

Measurements started early 2013 and continued until the summer of 2014. Both the canal bank reactor and the slow sand filter at the end of the drainage canal showed high efficiencies for phosphorus removal (up to 95 % for the slow sand filter). The removal efficiency of the enveloped drains was somewhat lower: 75 % during the whole period, but gradually increased to > 90 % near the end of the period. Earlier experiments at a different site also showed that for this method, removal efficiency of up to 95 % can be obtained (Groenenberg et al., 2013). Thus, a substantial part of the phosphorus load from the area can be removed using the techniques tested.

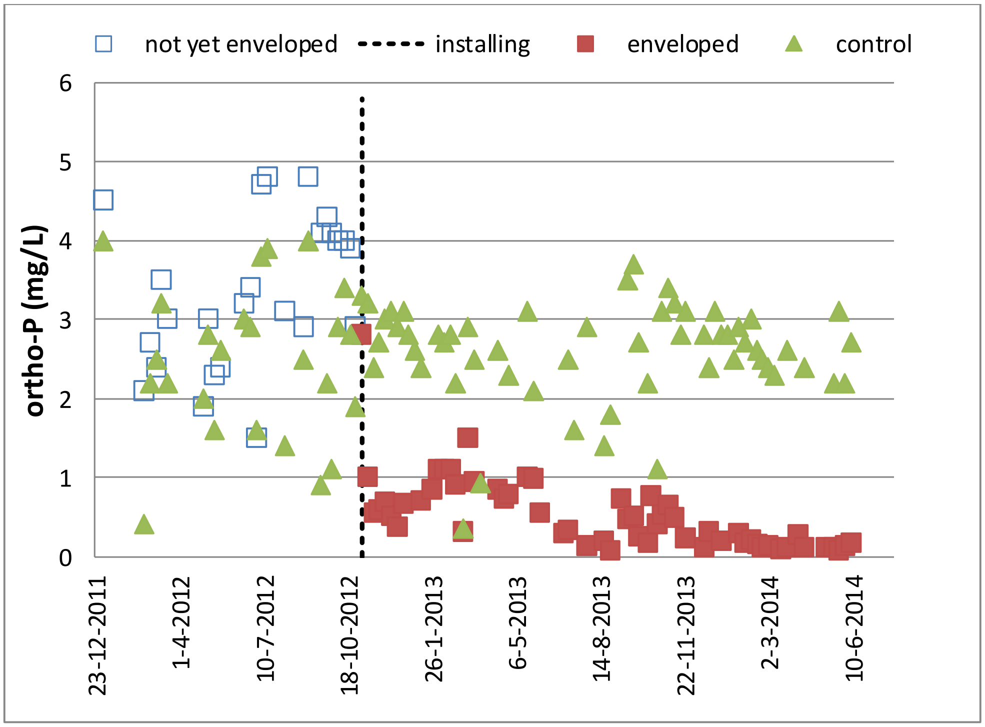

Figure 5. Concentrations of ortho-P in drainage water of drains enveloped with iron-oxide coated sand and control drains.

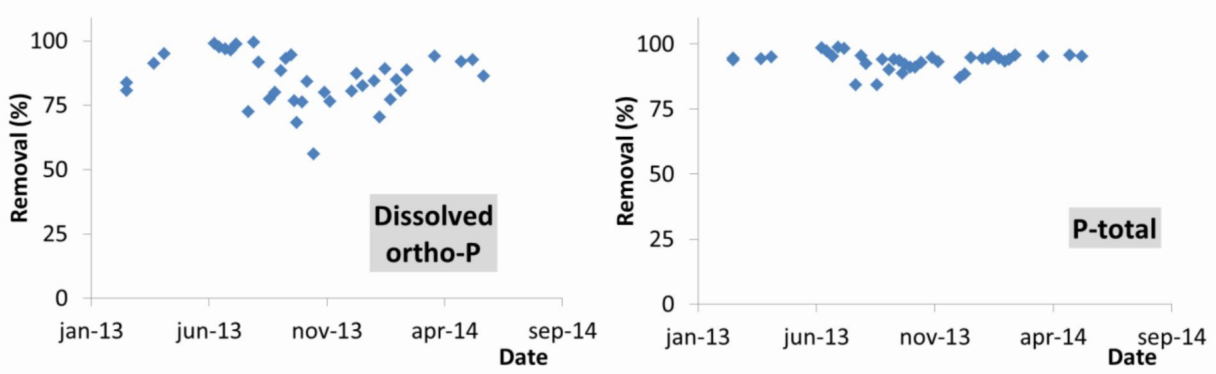

Figure 6. Removal rate of dissolved ortho-P and P-total.

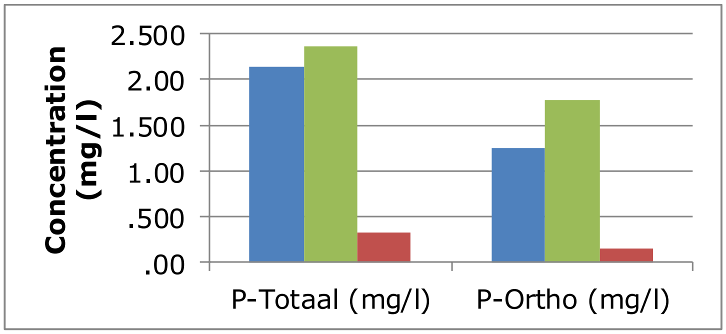

Figure 7. Average concentration of total P and ortho P in canal and in- and effluent of slow sand filter. Blue: canal surface water; green: influent; red: effluent.

Table 3. Removal efficiencies for ortho- and total phosphorus, based on the measurement period from instalment in March 2013 (Bank reactor and Slow sand filter) or November 2012 (Iron-oxide coated drains) until July 2014.

	Removal Efficiency for Ortho-P	Removal Efficiency for Total P
Iron-oxide coated sand drains	75%	-
Canal bank Reactor	86%	92%
Slow sand filter	95%	86%

Conclusion

The field data presented here demonstrate that robust, in field treatment options for nitrogen and phosphorus are able to remove substantial amounts of nitrate and phosphate from drainage water (up to 60-80% of nitrate, up to 95% of phosphate). The use of low cost materials (woodchips, iron-oxide coated sand) and installation with a minimum of technological modules such as pumps makes the options robust and potentially cost-effective.

Still, many aspects deserve further improvement to make these options really fit for widespread application. For the use of woodchips for nitrogen removal, the optimization of residence time to control nitrogen removal, redox potential and side effects such as N_2O emissions deserve attention. For the use of iron-oxide coated sand filters to remove phosphorus, hydraulic permeability needs attention For all options, further improvement of connection to agricultural practices is needed. By smart connection of water quantity and water quality management, eutrophication could be minimized and agricultural production could be optimized.

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