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RESEARCH ARTICLE

Field test of best management practice pollutant removal efficiencies in Shenzhen, China

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Abstract This paper presents a study on the use of best management practices (BMPs) for controlling nonpoint pollution in the Xikeng Reservoir watershed located in Shenzhen, China. A BMP treatment train design, including a pond, a wetland, and a buffer strip placed in series was implemented at the reservoir location. A separate grass swale was also constructed at the site. Low impact development (LID) BMPs, namely a planter box and bioboxes, were used at the parking lot of the reservoir's Administration Building. Samples were collected during storm events and were analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), and total phosphorus (TP). The removal efficiencies of both BMP systems were evaluated using the Efficiency Ratio (ER) method based on the event mean concentration (EMC) data. In summary, the pond/wetland treatment train removed 70%–90% of TSS, 20%–50% of BOD_5, and 30%–70% of TP and NH_3-N. The swale removed 50%–90% of TSS, 30%–55% of BOD_5, −10%–35% of NH_3-N, and 25%–70% of TP. For the planter box and biobox, the ranges of removal rates were 70%–90%, 20%–50%, and 30%–70% for TSS, BOD_5, and ammonia and phosphorus, respectively.

Keywords nonpoint source (NPS) pollution control, best management practices (BMPs), Xikeng Reservoir, Shenzhen, China, BMP treatment train

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1 Introduction

The Xikeng Reservoir is located in BaoAn District, Shenzhen, China. The reservoir is an off-channel reservoir with a direct drainage area of 5 km^2 and a water surface area of about 2 km^2 at maximum water elevation. The land use in the direct drainage area of the reservoir is about 50% forest, 15% bamboo trees, 15% fruit gardens and terrace crop lands, 10% scattered residential areas, and 10% bare lands. The reservoir has a normal storage capacity of approximately 20×10^6 m^3 and a normal water level of 72 m. The Xikeng Reservoir is one of the major water supply reservoirs in Shenzhen. Currently, the Xikeng Reservoir supplies more than 80×10^6 m^3 of water annually. Until three years ago, the reservoir took in water through a diversion pipeline from the Guanlan River. However, due to serious pollution problems in the Guanlan River water, the authorities discontinued withdrawing from the Guanlan River and constructed a diversion system that takes water from a cleaner source, the Dongjiang River.

The water quality in the Xikeng Reservoir was poor due to the pollution in the Guanlan River. Since the Dongjiang diversion system was implemented, the reservoir water quality has greatly improved. However, several potential problems still exist in the Xikeng Reservoir watershed:

1) Serious soil erosion at a number of "hot" spots;

2) Elevated levels of ammonia, total phosphorus, total nitrogen, and coli form bacteria;

3) Areas that drain directly into the reservoir, but outside the jurisdiction of the reservoir administration, such as some small households, farming, and quarry activities, are still generating pollution impacting the reservoir water quality.

This paper presents a study on the potential application of best management practices (BMPs) for controlling nonpoint pollution in the Xikeng Reservoir watershed. According to the Maryland Department of the Environment [1], stormwater management BMPs are generally classified into six categories:

• Group 1: Stormwater Ponds—Dry or wet detention ponds, extended detention ponds.

• Group 2: Stormwater Wetlands—Constructed surface flow or subsurface flow wetlands.

• Group 3: Infiltration Practices—Infiltration trenches and basins, permeable pavement.

• Group 4: Filter Practices—Buffer strips, sand filters, biofilters.

• Group 5: Open Channel Practices—Grassed swales.

• Group 6: Non-structure Practices—Street sweeping, nutrient management, land use planning.

The Maryland BMP design guidelines [2] suggest that BMPs should be selected from the above six groups according to the following factors: 1) watershed, 2) terrain, 3) stormwater treatment suitability, 4) physical feasibility, 5) community and environmental, and 6) location and permitting. The Xikeng BMP selection was based mainly on the first four factors. In particular, due to the proximity of the pollutant sources to the reservoir's shoreline, it is an appropriate study on BMP treatment train design involving several types of BMPs placed in series.

The use of BMPs as a preferred strategy for nonpoint source (NPS) pollution control in the United States began in the early 1990s. Over those years, a great deal has been learned about the effectiveness of BMPs as a means of mitigating nonpoint or stormwater runoff pollution through numerous laboratory and field studies. For example, the US Environmental Protection Agency (USEPA) [3,4] provided a summary of BMP pollutant removal efficiencies, as shown in Table 1. Other significant lessons learned include the following:

• Since NPS pollution is storm-driven, its characteristics vary significantly from location to location, which suggests that BMP selection and design should be based on local conditions.

• Implementation of BMPs requires a sound regulatory framework and practical institutional planning and execution.

• BMPs must be properly maintained in order to be effective for a long period of time.

It can be seen from Table 1 that the pollutant removal efficiency varies widely from BMP to BMP, even for a single BMP. Much of the variation in removal efficiency can be attributed to the fact that storm events are random in nature and the number of samples is usually small due to the complexity in the cost of storm event sampling. Another reason for the variation in efficiency is simply the nature of NPS pollution, i.e., being site-specific. The same BMP might perform well at one location but poorly at another location. A more recent summary of BMP pollutant removal efficiencies was done by the Center for Watershed Protection, as shown in Table 2.

For detailed BMP performance and other pertinent information, the ASCE/USEPA/WEF has jointly developed an international BMP database [7] and has been updating the information periodically.

Under certain situations, the use of a single BMP cannot provide enough treatment to achieve a set water quality or quantity goal. In such cases, the use of two or more BMPs in series may be considered. This approach is sometimes called stormwater "treatment train" for stormwater runoff control. Field data on BMP treatment train applications are few. One example is the laboratory and field demonstration studies on the performance of the multi-chambered treatment train (MCTT) system reported recently by Field et al. [8].

The Shenzhen study was motivated by the fact that although some studies on a few BMPs were reported, there still was very little information available regarding field data on BMP performance in China. It is expected that the results from the Shenzhen study would add to the existing database, especially towards expanding the current limited information on BMP treatment train performances.

The objectives of this study are as follows:

Table 1 Summary of BMP expected pollutant removal efficiency [5]

BMP type	typical pollutant removal/%				
	suspended solids	nitrogen	phosphorus	pathogens	metals
dry detention basins	30–65	15–45	15–45	< 30	15–45
retention basins	50–80	30–65	30–65	< 30	50–80
constructed wetlands	50–80	< 30	15–45	< 30	50–80
infiltration basins	50–80	50–80	50–80	65–100	50–80
infiltration trenches/dry wells	50–80	50–80	15–45	65–10	50–80
porous pavement	65–100	65–100	30–65	65–100	65–100
grassed swales	30–65	15–45	15–45	< 30	15–45
vegetated filter strips	50–80	50–80	50–80	< 30	30–65
surface sand filters	50–80	< 30	50–80	< 30	50–80
other media filters	65–100	15–45	< 30	< 30	50–80

Table 2 Median pollutant removal (%) of stormwater treatment practices [6]

	median pollutant removal/%						
	TSS	TP	Sol P	TN	NO_x	Cu	Zn
stormwater dry ponds	47	19	– 6	25	4	26[a)]	26
stormwater wet ponds	80	51	66	33	43	57	66
stormwater wetlands	76	49	35	30	67	40	44
filtering practices[b)]	86	59	3	38	– 14	49	88
infiltration practices	95[a)]	70	85[a)]	51	82[a)]	N/A	99[a)]
water quality swales[c)]	81	34	38	84[a)]	31	51	71

Notes: a) Fewer than 5 data points; b) Does not include vertical sand filters and filter strips; c) Refers to open channel practices designed for water quality; N/A = data are not available; TSS = total suspended solids; TP = total phosphorus; Sol P = soluble phosphorus; TN = total nitrogen; NO_x= nitrate and nitrite

• To recommend a detailed approach to mitigate the pollution problem on the reservoir. The task includes a thorough review of BMPs, especially those deemed appropriate for implementation in the Xikeng Reservoir watershed.

• To select one or more sub-watersheds in the direct drainage area in which to conduct a demonstration study on watershed BMPs. The purpose is to generate quantitative information on the performance of the selected practice or practices.

• To monitor the pollutant removal effectiveness of the BMP installation. A field-sampling program was devised for monitoring the installed BMPs during storm events. The removal efficiencies were evaluated using the event mean concentration (EMC) approach. The parameters included total suspended solids (TSS), 5-day biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), and total phosphorus (TP).

2 Materials and methods

2.1 Selection of sub-basins for BMP implementation

A thorough field investigation of the Xikeng Reservoir direct drainage area was conducted, leading to the selection of two areas for BMP installation. The following factors were considered in the selection process:

• An adequate drainage area should be selected to generate enough runoff under frequent storm events to satisfy sampling volume requirements.

• Land use should be expected to have relatively high pollutant concentrations.

• The sites should have easy access for sampling, be fit for BMP construction, and satisfy safety and other logistical needs.

Two sites were selected for BMP implementation: the Xikeng Reservoir north site and the administrative parking lot site. The area to the north of the reservoir was considered as an appropriate location for the installation of BMPs. The area was delineated into four sub-watersheds, which drain into three existing ponds and, afterwards, the reservoir. Figure 1 below is a location map of the reservoir showing its sub-watersheds and ponds. The land uses of the sub-watersheds are mostly forest, agriculture (i.e., fruit trees and some crops), a quarry, and a few houses. There are also some bare spots and a dirt road.

The reservoir Administration-Building site is outside southeast of the reservoir watershed (Fig. 1). The parking lot has an area of about 4000 m^2 with a capacity of 20–30 cars. The parking lot has some existing stormwater management features: 1) the use of porous pavers bordering the parking area, 2) the use of grassy areas that act as buffers to the southeast of the parking area, and 3) the use of a stormwater wetland below the pond. However, additional measures can be taken to further improve the management of stormwater from the Administration Building area.

2.2 BMP planning, design, and construction [9]

After making several investigative trips to the reservoir watershed and collecting initial samples of runoff quality, the research team decided to design and construct the following BMPs at the Xikeng site:

• A BMP treatment train, including a pond/wetland system and a separate swale installed at a sub-watershed chosen for the demonstration.

• A planter box and two “bioboxes” similar to a biofilter) were installed at the Xikeng Administration Building parking lot, which, although not located in the reservoir watershed, provides appropriate spaces for testing the selected BMPs.

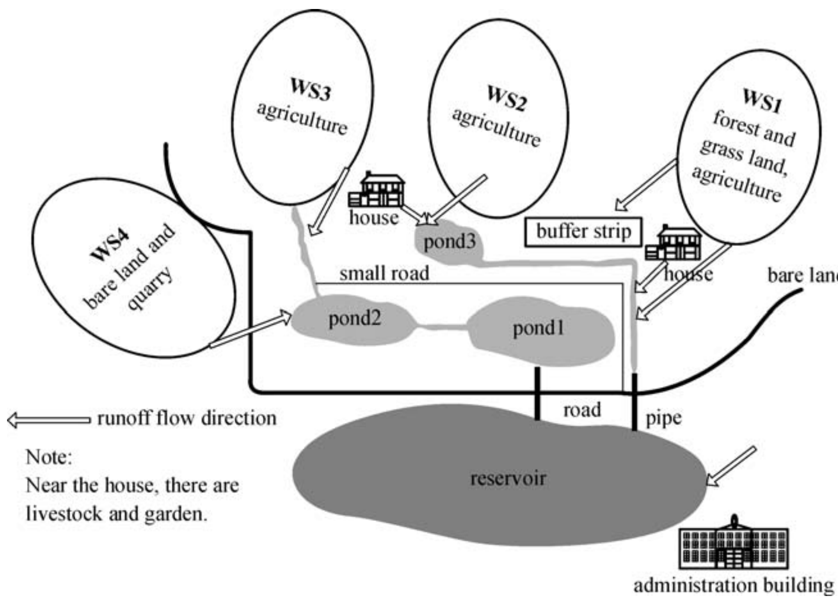

Fig. 1 Potential BMP test site: sub-watersheds at the north of Xikeng Reservoir (not to scale)

2.3 Reservoir site BMP train: the pond/wetland system and the swale

The drainage area of sub-watershed WS-1 (Fig. 1) is approximately 3.6 hectares, and the sub-watershed on its right (including the farm house) is about 1 hectare. The components of the BMP treatment train are shown in Fig. 2.

The water quality volume design for the pond holds 1.27 cm or 0.5 inch of the runoff from the WS-1 watershed, giving a design storage volume of 450 m^3. The maximum water level in the pond was determined using a 2-year storm, and a spillway was provided based on a 5-year storm. These designs were necessarily chosen because of the very tight space available for BMP construction at the site. Some hyacinth plants were placed in the pond to enhance its pollutant removal efficiency.

The wetland design followed mainly the guidelines presented in the Maryland State BMP Guidebook [2,10], many of which were derived from USEPA recommended design considerations [11].

The Pond/Wetland system contains three deepwater cells: the initial deep pool, the forebay, and the micropool. The permanent or deep pool initially receives runoff from the upstream watershed and traps a large portion of the coarse sediments that may have eroded from the drainage area. The deep pool has an area of approximately 160 m^2 (40% of the total Pond/Wetland area) and has an average depth of approximately 2.55 m. The total volume is about 400 m^3, or 60% of the total Pond/Wetland storage volume.

The sediment forebay serves two purposes. First, it initially receives discharge waters from the deep pool and acts as an energy dissipater, reducing the erosive effects of the discharge in the wetland area. Second, it serves to trap any sediment that may have been re-suspended in the deep pool.

The micropool is designed to contain approximately 1.25% of the total Pond/Wetland volume, which comprises approximately 6.25% of the total Pond/Wetland volume when combined with the micropool (see below). This combined volume is slightly less than the generally recommended 10%, while the micropool/plunge pool combination meets topographic constraints and area ratio goals.

The micropool is included in the design to create sufficient depth near the outlet to allow for a reverse sloped pipe, which is highly resistant to clogging, to extend into the normal pool. Organic-rich sediments are deposited below the intake. A design alternative is to use a typical slotted riser pipe with a trash rack. The micropool has a

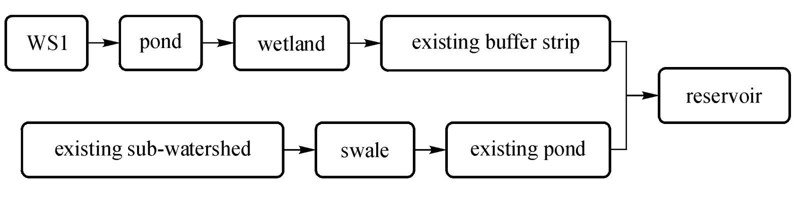

Fig. 2 Flow chart of BMP treatment train design

surface area of 20 m^2 (5% of the total Pond/Wetland area), an average depth of 1.82 m, and a storage volume of approximately 37 m^3.

Stormwater is discharged from the Pond/Wetland system through a reversed slope pipe and riser combination. The outlet is designed so that the intake of the reversed slope pipe remains unclogged and the permanent pool is maintained at water quality volume. The top of the riser is open and was set at a level corresponding to the 2-year recurrence interval storm volume. Water that exceeds that elevation is discharged through the top of the riser, which is fitted with an anti-vortex device and trash rack.

The outlet barrel transports the discharge water through the wetland berm and discharges it through a concrete outlet structure into a 3 m×3 m gravel-filled diaphragm trench. The diaphragm trench serves as a level spreader for the downstream grass buffer strip.

The wetland surface area to volume ratio of the Xikeng Reservoir Pond/Wetland BMP has been maximized by increasing the internal structural complexity of the wetland—adding complex micro-topography, and establishing extensive and dense wetland plant covers. Careful considerations were given in choosing the appropriate vegetation to be planted in the wetland. The following wetland plants were selected: Cannas, Cattail, Reed, and Windmill grass. These plants are all native to Shenzhen and grow very well.

A grassed swale was designed, which drains another sub-watershed roughly 1 hectare in size. The swale parallels the pond/wetland system and has a length of 40 m, a width of 3 m, a depth of 0.4 m, and a slope of 6%. Figures 3 and 4 below depict the pond/wetland system running for a couple of months after completion.

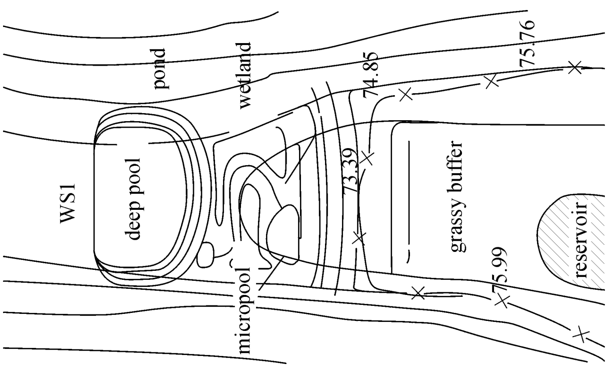

Fig. 3 Schematic diagrams for BMP treatment train design

Fig. 4 BMP treatment train at Xikeng reservoir (looking downstream)

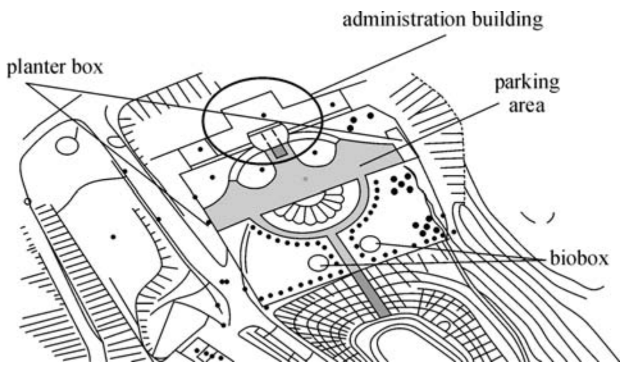

Fig. 5 Schematic of planter box and biobox placement at the administration building

2.4 The Administration Building area BMPs

Stormwater management measures designed for the Administration Building parking lot include: 1) capture, infiltration, and treatment of roof runoff; and 2) management of parking area runoff.

Stormwater runoff from the roof of the Administration Building was discharged from roof leaders on the east and west sides of the building into concrete open channels. These channels transported the runoff to inlets, and from there, to underground pipes. The two downspouts (white) were clearly seen. The concrete channel was not visible, but it flowed along the building until it reached the front wall. The channel then turned 90° west and flowed between the two rows of hedges. A small grating could be seen where the channel turned southward.

The concrete channel efficiently collected and transported the roof runoff but did not allow infiltration nor improve the quality of the runoff water being discharged. This system could be improved by replacing the concrete channel with a flow-through planter box, which was considered as a type of low-impact developmental (LID) BMP.

The flow-through planter box did not allow infiltration of stormwater runoff to flow into the underlying soils; however, it did improve the quality of the runoff waters. The flow-through planter box contained two layers of media, the upper soil (planting) layer and the lower gravel (drainage) layer. Stormwater entered the flow-through planter box through the downspouts and flowed through the upper planting layer and into the lower drainage layer. The drainage layer contained a perforated discharge pipe that drained into a conveyance system. Large-volume rainfalls that exceeded the flow rate caused ponding in the planter box. If the ponded water exceeded a certain depth, then they would enter an overflow pipe. The overflow pipe was also connected to the conveyance system. The conveyance system could be either an underground pipe or, for the Administration Building, could be the downstream portions of the existing concrete channel.

The planter box installed at the Administration Building was designed to treat the first 12.7 mm of rainfall. The bypass design was based on a 50-year rainfall event. The box has a surface area of 10.3 m^2 and a depth of 0.4 m. The dimensions determined for the planter box were checked by using the Hydro CAD simulation package to verify the safe passage of the 50-year stormwater runoff peak discharge. Figure 6 below shows the completed planter box (with two input pipes and four vertical overflow riser pipes) on the west side of the building.

Fig. 6 Planter box at the administration building site

The parking lot at the Administration Building has an area of 0.61 hectare and contains a permeable pavement, giving it an imperiousness of approximately 0.4.

The drop-inlet biobox was chosen to treat the stormwater runoff from the parking lot. Figure 7 shows an elevation drawing of a typical drop-inlet biobox. Runoff dropped through the grated inlet onto a concrete slab or box that acted as a flow splitter. Low-flow runoff entered the planting chamber through a series of orifices. The orifices were set at an angle so that water entering the planting chamber flowed in a circular motion. As high-flow water built up in the flow splitter, it overtopped the orifices and began to flow down into the overflow chamber through an overflow weir. Water was removed from the overflow chamber by an 18″ (or appropriately sized) pipe. The planting chamber was filled with gravel, geotextile, planting soil, and mulch. An 8″ perforated PVC pipe was used to drain the gravel layer.

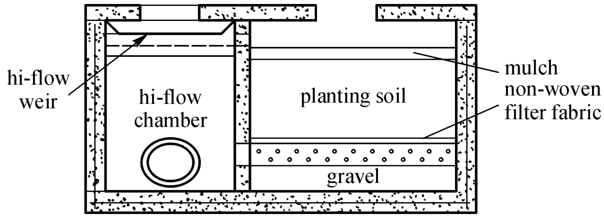

Fig. 7 Drop-inlet biobox—elevation

Two drop-inlet bioboxes were constructed and placed at existing locations of the grated drop inlets. Figure 8 below shows an installed biobox with its cover open.

Fig. 8 Biobox at the administration building parking lot

2.5 Sampling and analytical methods

Before the monitoring and analytical work began, a quality assurance and quality control (QA/QC) plan was devised. The main references for field monitoring and analytical work were the following:

- USEPA/ASCE [12]—Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements.
- The Technology Acceptance Reciprocity Partnership (TARP) [13]—Protocol for Stormwater Best Management Practice Demonstrations.
- University of Virginia [14]—Stormwater Management Laboratory Manual

The sampling and analyses conducted in this study followed mostly the TARP protocol. Manual samples were collected and time composites were analyzed for selected water quality parameters. During the period of September 2006 to June 2007, a total of eight storm events were monitored. Sampling was done manually, and the following water quality parameters were analyzed [15,16]: TSS, BOD_5, TP, and NH_3-N.

3 Results and discussion

The rainfall amount for the eight storm events ranged from 17.5 to 54 mm. Inflow to and outflow from each BMP were measured. Composite inflow and outflow samples were obtained from individual time samples for each storm event. Removal efficiency was determined by using the Efficiency Ratio (ER) method, which is based on comparing the event mean concentrations (EMC) of the inflow and outflow samples [17].

Tables 3 and 4 below list the complete data set including rainfall, EMCs, and the computed removal efficiencies for each BMP and for the BMP-in-series (pond/wetland) for storm events 04/02/2007 and 05/19/2007, respectively.

Box plots were made from the range and the average removal efficiencies for each water quality parameter over the entire monitoring period. It should be noted that data for the first storm on 09/11/2006 were not included in the average removal computation. The reason was that the BMPs were just recently completed, and the vegetation had not matured and the soil was still loose in the BMPs, which contributed to very low removal rates under little rain. For the last storm on 06/14/2007, only TSS was analyzed due to resource limitations.

Figures 9 and 10 present the box plot of BMP removal efficiencies for TSS and TP, respectively. It can be seen in Fig. 9 that the treatment train of pond/wetland provides excellent (80%) removal of TSS, whereas the pond alone only removed 68%. The planter box and the biobox provide excellent TSS removal due in part to the small areas these BMPs control and also to the fact that both were "over-designed" and therefore over-sized. As shown in Fig. 8, the treatment train of pond/wetland provides adequate (60%) removal of TP. As expected, the pond alone removes only about 30% of TP. The swale is not very effective in removing TP (42%). The high removal rate for the planter box could again be due to its large size.

In summary, the pond/wetland treatment train removed between 70%–90% of TSS, 20%–50% of BOD_5, and 30%–70% of TP and NH_3-N. The swale removed 50%–90% of TSS, 30%–55% of BOD_5, −10%–35% of NH_3-N, and 25%–70% of TP. For the planter box and the biobox, the ranges of removal rates were 70%–90%, 20%–50%,

Table 3 Data and removal results for storm event 04/02/2007

		pollutant concentration/($mg \cdot L^{-1}$)				BMP efficiency/%			
		TSS	BOD_5	NH_3-N	TP	TSS	BOD_5	NH_3-N	TP
pond	pond inflow	406	16.6	2.88	0.63	62.5	7.8	25.7	19.0
wetland	pond outflow/ wetland inflow	152.3	15.3	2.14	0.51	4.6	38.6	24.3	39.2
pond + wetland	wetland outflow	145.3	9.4	1.62	0.31	64.2	43.4	43.8	50.8
swale	swale inflow	323.5	15.2	1.75	0.42	55.1	38.2	7.4	26.2
	swale outflow	145.3	9.4	1.62	0.31				
planter box	planter box in	41	5.6	0.31	0.11	75.6	75.9	58.1	63.6
	planter box out	10	1.35	0.13	0.04				
biobox	biobox in	181	12.8	1.34	0.45	53.0	19.5	22.4	26.7
	biobox out	85	10.3	1.04	0.33				

Notes: the date is 04/02/2007; the rainfall is 54 mm

Table 4 Data and removal results for storm event 05/19/2007

		pollutant concentration/($mg \cdot L^{-1}$)				BMP efficiency/%			
		TSS	BOD_5	NH_3-N	TP	TSS	BOD_5	NH_3-N	TP
pond	pond inflow	525.5	16.7	2.83	0.79	77.7	25.7	32.2	30.4
wetland	pond outflow/ wetland inflow	117	12.4	1.92	0.55	13.7	14.5	34.9	56.4
pond + wetland	wetland outflow	101	10.6	1.25	0.24	80.8	36.5	55.8	69.6
swale	swale inflow	401	15.9	1.62	0.57	74.8	33.3	22.8	57.9
	swale outflow	101	10.6	1.25	0.24				
planter box	planter box in	30	3.8	0.2	0.1	80.0	60.5	45.0	70.0
	planter box out	6	1.5	0.11	0.03				
biobox	biobox in	159	11.7	1.5	0.55	91.2	41.9	38.7	49.1
	biobox out	14	6.8	0.92	0.28				

Notes: the date is 05/19/2007; the rainfall is 26.2 mm

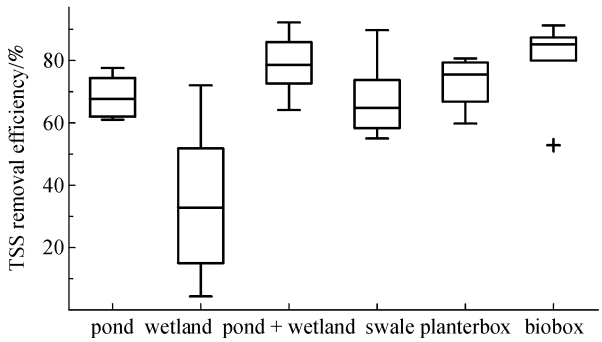

Fig. 9 Box plots of range and average of TSS removal efficiency for various BMPs

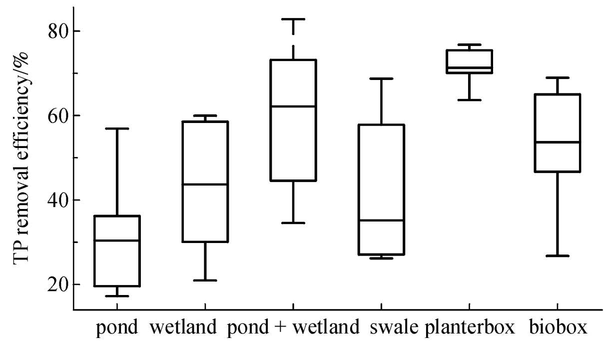

Fig. 11 Box plots of range and average of TP removal efficiency for various BMPs

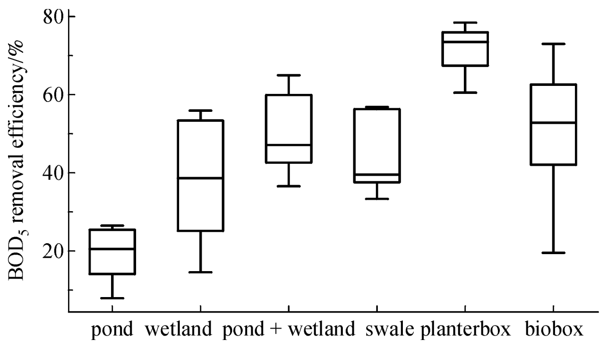

Fig. 10 Box plots of range and average of BOD_5 removal efficiency for various BMPs

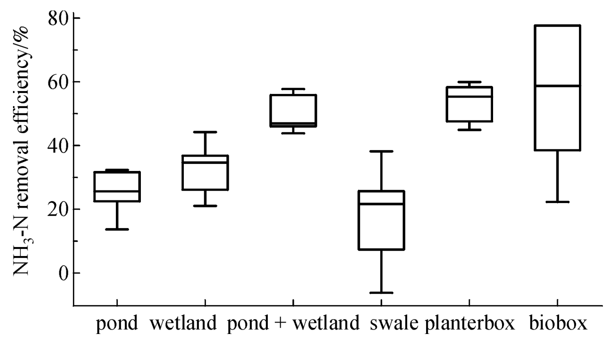

Fig. 12 Box plots of range and average of NH_3-N removal efficiency for various BMPs

and 30%–70% for TSS, BOD_5, and ammonia and phosphorus, respectively.

The results obtained at the Xikeng Reservoir site indicate that the use of BMPs in series such as the pond/wetland combination would significantly enhance pollutant removal compared to a single BMP. For example, as shown in Fig. 9, with the pond only, the TSS removal rate averaged about 68%, while for the pond-wetland in series, the TSS removal increased to almost 80%. The low efficiency (25%) for wetland alone can be explained by the fact that the second BMP in a BMP-series always will have a lower removal rate than a single BMP, especially for particulate pollutants such as TSS.

For dissolved pollutants such as TP, wetlands are known to be an efficient BMP treatment. As shown in Fig. 11, the wetland alone is more effective in removing TP than the pond, and the pond-wetland in series removes more than 60% of TP, which is considered to be highly efficient among all the BMPs.

As mentioned earlier in this paper, very little field monitoring data are reported in the literature on BMP treatment train performance. One such study was recently completed on the use of MCTT for treating stormwater runoff from a parking lot of a vehicle maintenance facility [7]. A comparison of the pollutant removal efficiency of the pond-wetland system in Shenzhen with the results from the MCTT study is given below in Table 5.

From Table 5, it can be seen that the pond-wetland system is more effective in removing dissolved type of pollutants such as ammonia and TP. Results from the grassed swale were compared with literature data, as shown in Table 6 below.

The results in Table 6 show that the Shenzhen grassed swale performed similarly to those reported in the literature and that the length of the swale is an important parameter affecting the swale removal efficiency.

This study also examined the relationship between

Table 5 Comparison of MCTT and pond/wetland pollutant removal efficiency

study site parameter	TSS	COD	NH_3-N	TP	Cu	Pb	Zn	BOD_5
pond wetland, Shenzhen	80	N/A	55	60	N/A	N/A	N/A	42
MCTT, Taipei	81	24	30	42	51	50	65	N/A

Note: N/A = data are not available

Table 6 Pollutant removal efficiencies for grassed swales (modified from [18])

design	pollutant removal efficiencies/%					reference
	TSS	metals	nutrients			
			TN	NO_3	TP	
grassed channel	68		23	−2	43	[19][a)]
vegetated swale (61 m)	21–95	—	—	—	32-85	[20][b)]
vegetated swale (30 m)	49	13	—	—	33	[21][b)]
grassed swale	30	11	—	—	N/A	[22][a)]
grassed swale, Shenzhen (40 m)	60	N/A	N/A	N/A	35	[23]
grassed swale (61 m)	83	30–72	—	—	29	[24][b)]

Notes: a) removal efficiencies based on concentrations; b) removal efficiencies based on mass loading

pollutant removal and amount of rainfall for the various BMPs. Theoretically, the removal efficiencies of the planter box and biobox would decrease rapidly with the increase in rainfall volume because their small sizes require a bypass of large flows. On the other hand, the efficiency of the pond/wetland system should decrease at a slower rate due to its large storage volume. These trends are confirmed in Figs. 13 and 14 below.

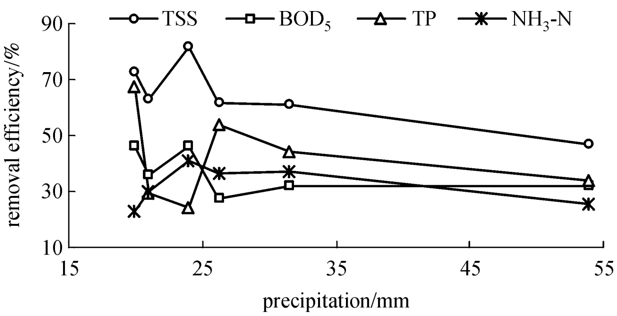

Fig. 13 Relationship between removal rate and rainfall volume for the BMP treatment train

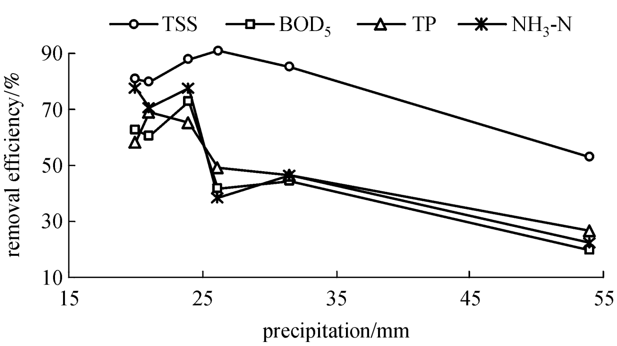

Fig. 14 Relationship between removal rate and rainfall volume for the biobox system

4 Conclusions

When BMPs are installed in series for monitoring the BMP treatment train at the Xikeng Reservoir in Shenzhen, China, the removal of pollutants such as sediment and nutrients can be significantly enhanced. The planter box and the biobox were also found to be effective, especially during little rainfall.

In summary, the pond/wetland treatment train removed 70%–90% of TSS, 20%–50% of BOD_5, and 30%–70% of TP and NH_3-N. The swale removed 50%–90% of TSS, 30%–55% of BOD_5, −10%–35% of NH_3-N, and 25%–70% of TP. For the planter box and the biobox, the ranges of removal rates were 70%–90%, 20%–50%, and 30%–70% for TSS, BOD_5, and ammonia and phosphorus, respectively.

The significance of NPS pollution is increasingly gaining recognition in China. Currently, there is no regulatory requirement on BMP implementation in China. However, studies such as this would contribute towards making available the information needed on the characteristics and impact of nonpoint pollution, and the appropriate technologies for controlling such pollution. The proliferation of this information would form the basis on which a regulatory framework can be established at the local, provincial, or national level. BMP implementation can also be achieved voluntarily, especially for those BMPs that can be integrated into the landscape, such as the planter boxes and bioboxes described in this paper.

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