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Tree box performance in exfiltrating stormwater runoff

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Abstract

This study determines the exfiltration rates in six tree boxes with embedded sensors and analyzes their hydrologic performance for 2 years to quantify the effect of different parameters (i.e., water depth, temperature, and age) on the exfiltration rate. Each tree box is 1.5 m wide, 1.5 m long, and 1.8 m deep. A 46-cm-diameter shaft was drilled at the bottom of each tree box to reach the underlying permeable soil layer. The water level inside the shaft rose up to 500 cm. Exfiltration rate increased with water level and exfiltration rate in second year decreased significantly by 27%–37% compared with first year. Overall, in the second year, the decrease in geometric mean exfiltration rate was largest for moderate depths of the standing water inside the shaft, ranging between 100 and 130 cm from the bottom of the shaft. The exfiltration rate of the tree boxes was significantly larger for warmer season and significantly smaller for cooler season. The infiltration rate of the underlying soil is a controlling factor of the performance of tree box.

Keywords

sediments; soil; stormwater

Introduction

DURING rainfall or snowmelt, total runoff flow or inputs to the sewer connection system can exceed the capacity of the combined sewer system (CSS) causing the system to overflow to surface water bodies (e.g., lakes, rivers, estuaries, or coastal water). These discharges, which are called combined sewer overflows (CSOs), can be a major source of water pollution in communities served by CSSs (U.S. EPA, 1995). To reduce the CSO volume and the effect of CSOs on water quality, aquatic biota and human health, either the quantity of water reaching the sewer system needs to be reduced or the capacity of the system must be increased. Green infrastructure (GI) stormwater control measures (SCMs) can detain and store stormwater to delay excess runoff, to reduce peak discharge, and to improve water quality. They also

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Disclaimer

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reduce the runoff volume through infiltration and evapotranspiration (Vermont Department of Environmental Conservation, 2019).

Infiltration and exfiltration are controlling factors for most of the SCMs. Infiltration is the process by which water on the ground surface enters the soil. Exfiltration refers to a loss of water from a drainage system as the result of percolation or absorption into the surrounding soil. There are many factors that can affect the exfiltration rate of a SCM including ponding depths and temperature. Warrick, Zerihun, Sanchez, and Furman (2005) computed cumulative infiltration depth as a function of variable ponded water depth using a Green-Ampt analysis. In that study, the input water depths were field-measured values from two irrigation events on superstition sand with a sand fraction of more than 90%. The Superstition sand is a soil series that consists of very deep, somewhat excessively drained soils that formed in sandy eolian deposits. The researchers showed that with a 3.6 cm decrease in ponding depth, the cumulative infiltration decreased by 6.8 cm.

Temperature can also affect the infiltration and exfiltration rate. Gardner (1955) conducted extensive laboratory tests at constant soil moisture content and found that increase in temperature increased the infiltration rate of the soil. In that study, soil moisture tension increased from 50 to 100 kPa with an increase in temperature from 5 to 48°C. It was concluded that due to increase in temperature, there was an increase in the free energy of water molecules. As a result, the soil moisture tension increased which lead the soil profile to drain further increasing the infiltration rate. Whether the infiltration will increase or not depend on the soil moisture content, if the soil water content is large enough, then the hydraulic conductivity allows significant drainage.

Duke measured the temperature of irrigation water flowing in furrows in fields of corn and onions with an infrared thermometer. The temperature increased from 11 to 34°C from inflow to downstream ends of the field during mid-afternoon. The researcher documented that this temperature increase reduced the viscosity of the water which increased the hydraulic conductivity by 70%. Emerson and Traver (2008) developed a regression model based on field data of bioinfiltration traffic island and pervious concrete infiltration basin, showing that increase in temperature increased the hydraulic conductivity of the soil. Clancy and Alba (2011) took 67 infiltration measurements in a park that consists of sand and loamy sand on the month of September, October, and November in 2007 and 2008, with double-ring infiltrometers to look at the effect of temperature, viscosity on infiltration rate and compare the infiltration of 2007 with 2008. The average temperatures in 2007 and 2008 were 14°C and 16°C, respectively, and the average infiltration rates were 0.049 and 0.067 mm/s, respectively. So, they observed a 36% increase in infiltration rate in 2008 compared with 2007, with a temperature increase from 14°C to 16°C. Variation in the hydraulic conductivity of the soil surface due to changes in the water viscosity in response to diurnal temperature changes can cause the infiltration rate to vary throughout the day (Jaynes, 1990).

The study site for this research is located at Louisville, KY. The U.S. EPA, U.S. Department of Justice, and Kentucky Department for Environmental Protection negotiated a consent decree with the Louisville and Jefferson County Metropolitan Sewer District (MSD; Brown

& Borst, 2013). The City of Louisville, KY decided to incorporate GI to meet the requirements of their order under the consent decree (NRDC, 2011). The consent decree requires green infrastructure (GI) practices to be monitored to assess the effectiveness in reducing combined sewer overflows (CSOs) and achieving consent decree requirements. The Louisville and Jefferson County Metropolitan Sewer District (MSD) committed to monitor the effectiveness of GI in reducing CSOs and achieving consent decree requirements. Continuous monitoring with embedded sensors was performed on several SCMs including six tree boxes to determine the effective surface infiltration and exfiltration into the underlying soils and quantify the relevant hydrologic processes within a stormwater control measure. There are recent studies that focus on continuous monitoring of stormwater control measures. For example, Emerson and Traver (2008) and Emerson, Wadzuk, and Traver (2010) used continuous monitoring data to present the long-term and seasonal changes of the infiltration process of bioinfiltration traffic island and pervious concrete infiltration basin. Another example is that, Jones and Hunt (2009) monitored water temperature and flow rate of inflow and outflow of a bioretention to investigate its effect on runoff temperature. Brown, Borst, and O'Connor (2012) also monitored bioretention practice and permeable pavement and analyzed the data. This paper highlights the continuous long-term monitoring results from six tree boxes.

While temperature, water level depth, and, presumptively, age of the stormwater control are important factors affecting the performance of a SCM, there has been little research on their effect on tree boxes. In this paper, the effect of temperature, water level, and age of the tree boxes on their hydrologic performance are analyzed and presented. The analysis will test the following hypothesis:

1. Based on Emerson and Traver (2008), Clancy and Alba (2011) and Duke (1992)'s findings, the exfiltration rate will increase with temperature.
2. Based on Warrick et al. (2005)'s finding, the exfiltration rate will increase with water level.
3. Based on Clancy and Alba (2011)'s finding, the exfiltration rate in 1st year will be significantly different than 2nd year.

Site Description

In March 2013, MSD installed 29 tree boxes along the side-walk of Story Avenue east of Adams Street and North Spring St. in the Butchertown section of Louisville, KY. The spacing between tree boxes varied from 7.6 to 10.7 m. Each tree box is 1.5 m wide, 1.5 m long, and 1.8 m deep. If the runoff exceeds the tree box capacity (freeboard is full), or the flow exceeds the curb cut capacity; runoff will bypass and flow to the next downgradient tree box. A single tree (*Syringa reticulata*-Ivory silk lilac) was installed in each tree box (Figure 1). Two sets: set A and set B of three tree boxes were selected for monitoring. A single data logger (Campbell Scientific, CR 1000), connected to pressure transducers and time-domain reflectometers, was installed for each set of three tree boxes. Set A was located near the east end of the grouping of tree boxes (Figure 2a). Set A receives street runoff as shown with a blue box in Figure 2a. Set B was located near Adam St. and immediately

downstream of a driveway (Figure 2b). The driveway receives surface runoff from the parking lot located next to it. So, set B receive runoff from the parking lot as shown in the blue box of Figure 2b. Thus, set B was expected to experience larger runoff volumes than set A. Tree boxes within their own set are connected by 0.9-m deep infiltration trenches. It was expected that the exfiltration rate of the tree boxes of set A might differ from set B since they are about 84 m apart, but the exfiltration rate of the tree boxes within each set might not differ because they are 7.6–10.7 m apart and the textural characteristics of the underlying soil are more likely to be uniform within this distance. The tree boxes in each set were numbered sequentially beginning at the upgradient tree box.

A precast, square concrete structure was placed in the excavated tree box pit to provide structural stability (Figure 3). A 46-cm-diameter shaft was drilled at the bottom of each tree box to allow water to drain into the underlying soil layer with larger hydraulic conductivity. A 41-cm-diameter slotted PVC pipe was inserted into the shaft and filled with American Association of State Highway and Transportation Officials (AASHTO) No. 3 sized aggregate (Figure 4). The annular space between the pipe and the boring wall was filled with coarse sand. The depth of the shafts varied from 4.9 to 6.3 m among the tree boxes. A 30-cm thick layer of AASHTO No. 57 aggregate was placed at the bottom of the tree box. The gravel was covered by about 1.65 m of media prepared from 60% sand, 30% compost, and 10% topsoil. Infiltrating water flows through the media and gravel, then through the shaft into the underlying high permeable soil layer. The tree boxes are built in clayey soil, so the native soil surrounding and under the tree boxes is clayey soil up to the depth of the shaft (Figure 4). The concrete sidewalls of the tree box prevents, and the clayey soil surrounding the shaft limits lateral water exfiltration from the tree box and shaft. Because of the low permeable clayey soil layer at the bottom of the tree box, the water that infiltrated through the media has limited infiltration into the clayey soil and naturally directed towards the shaft. Since the bottom of the shaft was drilled into soil with large hydraulic conductivity, the exfiltration rate of the shaft is controlled by the infiltration rate of the underlying soil.

Infiltration measurements of the underlying soil layer of each tree box were taken. To perform the test, a steel pipe was inserted through the shaft 0.305 m into the underlying soil. A 6.25-mm-diameter hole was made in the pipe at a certain depth (couple inches above the ground), and the pipe was then filled with water up to that depth. A pressure transducer was placed at the bottom of the pipe, and water level was recorded at 1-min intervals. Using the water level and time data, the infiltration rate was calculated. The underlying soil was presoaked for 30 min before performing the test. After presoak, the soil is assumed to be saturated and by calculating the rate of the water level drop, the infiltration rate was calculated. The infiltration test could not be performed on the shaft of the most upgradient tree box of set A because of standing water inside the shaft. For the most downgradient tree box of set B, it is suspected that the bottom of the pipe was blocked because the water level inside the pipe did not decrease during the infiltration test. Soil samples below the shaft were also collected from each tree box, and particle size analyses were performed. Based on particle size distribution, the soil type under the shaft is loamy sand. Some descriptive features of each tree box are shown in Table 1.

Instrumentation

A screened monitoring well with a pressure transducer (Model CS450, Campbell Scientific, Odgen UT) was installed at the bottom of each the shaft. This pressure transducer installed inside the shaft would measure the water level depth (Figures 3 and 4). The bottom of the monitoring well was open while the top was capped so that media could not get into the pipe. Rainfall data were collected using a tipping bucket rain gauge installed near the controls and augmented by nearby gauges in the existing MSD system and RADAR based measurements. Rain depth larger than one tenth of an inch is considered as a rain event. Before installation, a five-point calibration was run on pressure transducers across the operational range provided by the manufacturer. The calibrations were within the specification by the manufacturer.

Analysis Procedure

Exfiltration rate calculation

In this study, the water depth data obtained from each pressure transducer installed at the bottom of the shafts in the six tree boxes were analyzed. The objective was to investigate the effect of water depth and water temperature on the exfiltration rate with time. The pressure transducer monitored and reported the water level depth in the shaft and water temperature every minute. The exfiltration rate of the tree box was calculated by using Continuity Equation (Mays, 2005) which is as follows:

$$Q_{\text{net}} = Q_{\text{in}} - Q_{\text{out}} \quad (1)$$

$$\text{or, } \frac{\Delta h}{\Delta t} A_{\text{shaft}} = f * A_{\text{tree box}} - E_x * A_{\text{shaft}} \quad (2)$$

$$\text{or, } E_x = f * \frac{A_{\text{tree box}}}{A_{\text{shaft}}} - \frac{\Delta h}{\Delta t} \quad (3)$$

$$\text{or } E_x = f * \frac{A_{\text{tree box}}}{A_{\text{shaft}}} - \frac{h_2 - h_1}{t_2 - t_1} \quad (4)$$

Where, A_{shaft} = Cross-sectional area of the shaft, cm^2 ; $A_{\text{tree box}}$ = Cross-sectional area of the tree box, cm^2 ; f = Infiltration rate of the soil media, cm/min ; h_1 = Depth of water level inside the shaft at time t_1 , cm ; h_2 = Depth of water level inside the shaft at time t_2 , cm ; t = Time interval, min ; E_x = Exfiltration rate at water level depth of h_2 , cm/min .

The exfiltration rate from the six tree boxes was calculated for 121 rain events from June 17, 2013 through May 31, 2015. Statistical analysis was performed on these exfiltration rate data using Statistica 9.1 (StatSoft, Tulsa, OK).

The water level in the shaft will rise ($h_2 > h_1$) after periods of intense rainfall when the inflow rate (Q_{in}) through the media is larger than the outflow rate (Q_{out}). During a less

intense rainfall and after the rain stops, the water level drops because the inflow rate is less than outflow rate. A drawdown curve for each rain event was considered for analysis. The infiltration through the media inside the tree box was assumed to be negligible ($f \approx 0$) for the drawdown curve. Therefore, a modification to the Equation (4) which was used in this analysis is as follows:

$$E_x = -\frac{h_2 - h_1}{t_2 - t_1}. \quad (5)$$

Since only the drawdown curve was considered for the analysis, water level h_2 is smaller than water level h_1 , the exfiltration rate is a positive value.

For each tree box, the exfiltration rate for different water levels in 20 to 50 cm increments were calculated. The water level was measured from the bottom of the shaft (the datum is shown in Figure 4). For each rain event, the exfiltration rate was calculated at the water level shown in Table 2. For tree boxes in set A, the water level inside the shaft rose up to 500 cm. For tree boxes in set B, the exfiltration rate was not calculated for water levels larger than 130 cm because either (a) the water level did not rise above 130 cm, or (b) it is suspected that infiltration rate through the soil media was not negligible until the water level drops at 130 cm, so the assumptions used to generate Equation (5) could not be applied. For each water level, the exfiltration rate was calculated from the three-point slope of the drawdown curve at that water level. Based on available data and the highest water level in the shaft, the exfiltration rates for tree box 1 and 2 of set B were calculated for a water levels up to 130 cm, for tree box 3 it was calculated for a water levels up to 50 cm. For the three tree boxes in set A, the exfiltration rates were calculated for depths up to 500 cm.

A typical hydrograph of pressure transducer data (water level) in the shaft shows multiple peaks (shown in Figure 5). Since the infiltration rate of the media during rain is not known, only the drawdown water level data were considered for analysis (i.e., ab, cd, ef, gh, ij sections in Figure 5). The drawdown curve for each rain event was considered for analysis. If there were multiple peaks in one rain event, then the drawdown after each peak was analyzed separately.

Statistical analysis

A two-way Analysis of Variance (ANOVA) test was performed on the exfiltration rates data using Statistica 9.1 (StatSoft, Tulsa, OK). To avoid missing cells in the ANOVA matrix and incomplete analysis, the exfiltration data were divided into groups. Group 1 included exfiltration rate data for water level up to 50 cm, group 2 included data for depth from 100 to 130 cm and group 3 included data for water levels deeper than 130 cm. The pressure transducers also measured the temperature along with water level. The water temperature inside the shaft varied from 5 to 25°C. The exfiltration rate data of each group were again divided into four temperature ranges when analyzing for temperature effect. The ranges were 5–9°C, 10–14°C, 15–19°C, and 20–25°C.

Data groups from all tree boxes were combined and analyzed by group. The Shapiro–Wilks normality test was performed on each group. The exfiltration rate data were log-normally distributed. Therefore, a two-way ANOVA test was performed on the log-transformed data where the categorical independent variables were water level group, temperature group, and year (1 or 2) of the tree box with a significance level of 0.05. From this test, a significant interaction between water level and year, and temperature and year of the tree boxes for each group was observed.

The number of exfiltration rates for each water level varied from 9 to 319 during the first year (June 2013 to May 2014) and 5 to 177 during the second year (June 2014 to May 2015). Less data were obtained for deeper water levels. For a given water level, if there was only one exfiltration data point obtained, it was excluded from the analysis. The number of data for each water level is shown in Table 3.

Results and Discussion

Effect of the water level depth and age on the exfiltration rate of the tree boxes

The exfiltration rate versus water level graph for the tree boxes showed (Figure 6) two curves representing the exfiltration rate versus water level relationship, such that, the exfiltration rate increased with increased depth in the shaft except for the 500 cm water level for year 1. In year 1, the exfiltration rate for the 500 cm water level was smaller than the exfiltration rate at 400 cm. In the second year, the exfiltration rate was generally smaller than the exfiltration rate in first year.

The statistical analysis showed that the exfiltration rate varied with water level and year for each water level group. Exfiltration rates in the first year are significantly larger than the second year. Interaction between the water level and year showed that the variation of exfiltration rate with water level did not change significantly. Overall, the geometric mean exfiltration rate for group 1, group 2, and group 3 decreased by 27%, 37%, and 32%, respectively, in second year. The results from the ANOVA test are shown in Table 4.

Our observations indicate that the pressure head of the water depth is the main driving force of the exfiltration mechanism of the shaft. So if the pressure head increases, the exfiltration rate also increases as shown in Figure 6 (except 500 cm in year 1). The soil particles from the media layer of the tree box might get partially washed out and accumulate in the gravel layer of the shaft or at the bottom of the shaft. This can reduce the exfiltration rate of the shaft over time. From Figure 6, it can be seen that the exfiltration rate in year 2 is smaller than year 1.

For all tree boxes, the water level reached at least 50 cm, so to compare the mean exfiltration rate of all six tree boxes, only the data for water level depth of 20, 30, and 50 cm were included. As mentioned earlier, infiltration measurement of the underlying soil was performed at each tree box except one from set A and at one box from set B. The average measured infiltration rate of the underlying soil for the tree boxes from set A is smaller (0.14 cm/min) than that for the tree boxes from set B (0.23 cm/min). The ANOVA test on the exfiltration rate data shows similar result, that is the mean exfiltration rate of the tree boxes

from set A is different than the exfiltration rate from tree boxes in set B. The mean exfiltration rate for tree boxes from set A is 0.37 cm/min while that from set B is 0.50 cm/min for water level depth 20 to 50 cm. For a given inflow, the lower exfiltration rate leads to a larger water level in the shaft of the tree boxes from set A. This might be the reason that the tree boxes of set A has larger water level depth (500 cm) than the tree boxes of set B (130 cm). The average d_{85} particle size of the underlying soil of set A tree boxes is 13.3 mm (16, 5, and 19 mm) and of set B tree boxes is 13.7 mm (13, 8, and 20 mm). There is no significant difference between average d_{85} of set A and set B.

Figure 7 shows a comparison among the geometric mean exfiltration rates of all tree boxes for water levels 20, 30, and 50 cm. The most upstream, middle, and downstream tree box for set A is designated as “A1”, “A2”, and “A3,” and for set B is designated as “B1”, B2”, and “B3”, respectively. From Figure 7, it can be observed that the exfiltration rate of tree box 1 of set A is the lowest among all tree boxes. At this tree box, when the water level inside the shaft is below 100 cm, the exfiltration rate is low. During construction, standing water was observed inside the shaft, which did not allow us to perform infiltration test of the underlying soil. Fisher LSD Posthoc testing showed that there was no significant difference among the geometric mean exfiltration rates of tree boxes A2, A3, B2, and B3 for water levels less than 100 cm. But the exfiltration rates of A1 and B1 were different from the rest. This variability in exfiltration rate among tree boxes highlight the challenge of installing tree boxes and other SCMs in urban environment. This challenge aggravates when there is a low permeable soil lying below the underlying soil. Layering with finer soil can hinder the exfiltration once the underlying soil reach saturation. But the prospect of the tree boxes in this study is that, they were able to remove the street runoff from the entire drainage area with the hydraulic loading ratio varying among 10–30.

Effect of the temperature and age on the exfiltration rate of the tree boxes

The exfiltration rate versus temperature graph for the tree boxes for water level below 100 cm is presented in Figure 8. In the graph, there are two curves showing the exfiltration rate versus temperature relation. For this graph, the exfiltration rate data for water level below 100 cm were combined and then for each temperature range, the geometric mean exfiltration rate was calculated. Exfiltration rate data at water level 100 cm and above were not included in this graph because Statistica software was able to run an ANOVA test for both independent variables (year and temperature) only when water level was below 100 cm due to missing data in the 5–9°C temperature range for water level at 100 cm and above. From the graph, we can observe that, for the first year, the exfiltration rate for temperature 20–25°C was the largest and for other temperature range, there was not much difference in the geometric mean exfiltration rate. For the second year, the exfiltration rate for 15–19 and 20–25°C was larger than rest of the temperature range.

The statistical analysis that was performed on each group showed that for first and second groups, the exfiltration rate of the tree boxes was significantly larger for temperature ranges from 20 to 25 and small during 5–9°C temperature ranges, but no difference was observed between 10–14°C and 15–19°C. The interaction between temperature and year concludes that, for the first group, the variation of the exfiltration rate with year is different for different

temperature ranges. For this group, the exfiltration rate decreased in the second year for 20–25°C and 10–14°C, but no significant difference was observed for other temperature ranges. For the second group, the exfiltration rate did not change with year for the different temperature ranges. Statistica software was not able to perform a two-way ANOVA test for third group due to missing data from one of the temperature ranges. The results from the ANOVA test are shown in Table 5.

Dynamic viscosity of water decreases with the increase in temperature, which can change flow dynamics (Emerson & Traver, 2008). This might be a reason for having higher exfiltration rate with higher temperature ranges. Duke (1992) and Emerson and Traver (2008) observed similar results. They showed that an increase in temperature increased the hydraulic conductivity of the soil. For our study, no trend was evident between temperature and exfiltration rates but the largest exfiltration was observed during the warmest period (20–25°C) and the smallest exfiltration was observed during the coolest period (5–9°C).

Conclusion

The exfiltration rates from six tree boxes were monitored in Louisville, KY, to demonstrate the effect of water level, temperature range and to compare the data from 1st and 2nd year. From the study, it was observed that the exfiltration rate increased with the increase in the water level in the shaft. Among the six tree boxes, “A1” was different; because when water level reached below 50 cm in the shaft the exfiltration rate was negligible. For both sets of tree boxes, tree box 2 has smaller d_{85} size and tree box 3 has larger d_{85} size for that set, but the exfiltration rate of tree box 2 and tree box 3 were not significantly different from each other for both sets.

The exfiltration rate in the second year decreased compared with the first year. The geometric mean exfiltration rate for group 1, group 2, and group 3 decreased by 27%, 37%, and 32%, respectively, in second year. However, the variation of exfiltration rate with water level did not change significantly with year. The data set analyzed in this study is short compared with the expected life span of a tree box. Other than group 1, no trend between exfiltration rate and year was observed for different temperature. The exfiltration rate might decrease over time because of accumulation of soil particles from the top media into the gravel filling of the shaft. Analyzing the monitored data for an extended period will provide more knowledge about the performance of tree boxes over time.

This study showed that one of the factors affecting the exfiltration rate of tree boxes that should be considered during design is the infiltration rate of the underlying soil. Low infiltration rate or layering of the underlying soil can lead to having high water levels in the shaft, but the higher water level in the shaft may impact the exfiltration rate enough to offset the effect of having a low infiltration rate of underlying soil.

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• Practitioner points

- The study determines the exfiltration rates in six tree boxes and analyzes their performance over time.
- Exfiltration rate in second year decreased significantly by 27%–37% compared to first year.
- The exfiltration rate of the tree boxes was larger for warmer rain events and smaller for cooler rain events.
- Tree boxes with lower permeable underlying soil developed higher water level in the shaft.

Figure 1.
Tree boxes installed in Louisville, KY.

Figure 2.
Runoff contributing area of tree boxes of (a) set A and (b) set B (Source: Google earth).

Figure 3.
Plan view of the tree boxes showing the locations of pressure transducer.

Figure 4. Cross section (Section A-A) of the tree boxes of each set showing the location of pressure transducer (the annular space between the PVC pipe and the boring wall was filled with coarse sand).

Figure 5.
Illustrative Hydrograph of water level depth inside the shaft of a tree box during the rain event on 7/21/13.

Figure 6. Effect of water level depth on the exfiltration rate for all tree boxes and all temperature range. Each point in the graph indicates geometric mean exfiltration rate and 95% confidence interval around the mean or $10^{\text{mean}(\log_{10}(\text{exfiltration rate})) \pm 95\% \text{ confidence interval}}$.

Figure 7.
Mean exfiltration rate of all tree boxes for water level depth less than 100 cm.

Figure 8.

Effect of temperature on the exfiltration rate for water level below 100 cm for all tree boxes.

Each point in the graph indicates geometric mean exfiltration rate and 95% confidence interval around the mean or $10^{\text{mean}(\log_{10}(\text{exfiltration rate})) \pm 95\% \text{ confidence interval}}$.

Table 1.

Descriptive features of each tree boxes

TREE BOX NUMBER	SET	ESTIMATED DRAINAGE AREA ^a (M ²)	SHAFT DEPTH (M)	MEASURED INFILTRATION RATE AT THE BOTTOM OF THE SHAFT (CM/MIN)	SOIL CHARACTERISTICS AT THE BOTTOM OF THE SHAFT
#1	A	75	5.7	0.23	84% sand, 10% silt, 6% clay
#2		69	4.9	0.06	80% sand, 14% silt, 6% clay
#3		69	5–6 m (estimated)	not measured	84% sand, 10% silt, 6% clay
#1	B	684	6.3	0.26	81% sand, 11% silt, 8% clay
#2		46	5.9	0.20	74% sand, 19% silt, 7% clay
#3		78	5 ~ 6 m (estimated)	Excluded because of no drawdown of water level	83% sand, 10% silt, 6% clay

^a Drainage area is estimated from google earth.

Table 2.

Water level depth for exfiltration rate analysis for tree boxes

Water level depth (cm) for tree boxes of set A	500, 400, 350, 300, 250, 200, 130, 100, 50, 30, 20
Water level depth (cm) for tree box 1 and 2 of set B	130, 100, 50, 30, 20
Water level depth (cm) for tree box 3 of set B	50, 30, 20

Table 3.

Number of data for each water level depth

WATER LEVEL (CM)	500	400	350	300	250	200	130	100	50	30	20
Number of data in 1st year	9	28	38	53	58	75	118	167	304	319	289
Number of data in 2nd year	5	7	17	29	26	29	61	79	162	177	172

Table 4.

Results from Two-way ANOVA test

GROUP	PARAMETER	<i>F</i>	<i>P</i>
1 (Water level < 100 cm)	Water level	194.50	<0.001
	Year	037.20	<0.001
	Water level + Year	002.40	0.088
2 (Water level = 100 or 130 cm)	Water level	017.69	<0.001
	Year	033.84	<0.001
	Water level + Year	000.11	0.743
3 (Water level > 130 cm)	Water level	025.24	<0.001
	Year	012.62	<0.001
	Water level + Year	001.65	0.145

Note. Bold font represents statistically significant values.

Table 5.

Results from Two-way ANOVA test

GROUP	PARAMETER	F	P
1 (Water level < 100 cm)	Temperature	28.75	<0.001
	Year	11.27	<0.001
	Temperature + Year	04.11	0.006
2 (Water level = 100 or 130 cm)	Temperature	55.62	<0.001
	Year	n/a	n/a
	Temperature + Year	02.38	0.093
3 (Water level > 130 cm)	Temperature	n/a	n/a
	Year	n/a	n/a
	Temperature + Year	n/a	n/a

Note. Bold font represents statistically significant. n/a represents result not available. ANOVA test was not performed due to missing data.