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Novel Screen System Improvement Methodology for Flood and Diffuse Pollution Control: Demonstration via a Case Study

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Abstract: Screen systems are often neglected in practice. This can lead to local flooding, pollution of receiving watercourses, blockages of channels by debris, and safety problems for children playing. The aim of this case study is therefore to protect below-ground channels and people, prevent flooding, improve water quality, and save personnel costs through a new screen system maintenance, repair, and upgrade methodology. The results show that repairing or enlarging the screens optimizes their functionality and reduces the risk of flooding. A particular focus is on increasing the screen dimension from one- and two-dimensional to three-dimensional screens. The new variable safety priority and the bar spacing increase with the passage area. Screens at large discharges should therefore be prioritized. Cleaning sand traps reduces the risk of pipe blockages and improves the water quality of receiving waters. Fine particles often have too high nutrient and oxygen demand values. The installation of pre-screens can increase the efficiency of the main screens. Optimization of travel routes for maintenance teams can be achieved by better planning maintenance routes. Adapting and maintaining screens to climate change by applying the novel prioritization method is likely to be successful. This should include prioritized inspections, repairs, and adjustments to screen structures.

Keywords: automated screen cleaning; climate change adaptation; flood protection; pipe clogging; receiving water pollution; sediment trap; surface water runoff; three-dimensional screen; urban water

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1. Introduction and Background

1.1. Local Flooding Due to Heavy Rain

The frequency of flood events has increased and can be explained by climate change [1–3]. Forecasts suggest that the frequency of heavy rainfall events will continue to increase. Whole districts and streets of cities such as Oberursel (Taunus) near Frankfurt am Main are regularly affected by floods. Floods are triggered by heavy rainfall events as in January 2023 (Figure 1), August 2023, and May 2024. Due to climate change, many urban areas such as Oberursel face more frequent and short heavy downpours leading to localized flooding [3], resulting in flooded cellars. Only in the past two years, three rainfall events with a likelihood of occurring only once within 100 years occurred.

However, the sewage system in Germany does not serve a flood protection purpose and therefore quickly reaches its stress maximum during heavy rainfall [4]. Highly sealed urban areas and low grounds allow for flooding [1,2].

Rainwater flows via open ditches, closed pipes, and streams directly into the sewage system or into nearby watercourses. Streams and trenches are important receiving watercourses that also serve urban rainwater drainage. In the event of heavy rain events, these also receive combined sewer overflow water [2]. This resulted in considerable organic pollution of local watercourses [5] in Oberursel in 2023 and 2024.

Figure 1. Example of flooding of a street, path, and private property due to blockage of a screen (screen number 4) and a pipe during heavy rain (January 2023) in Oberstedten, Oberursel (Taunus).

Both trenches and streams as well as separate and mixed water channels flood through too much surface drainage. In addition, screen systems (also called flotsam removal systems) can be clogged due to rubble and organic material such as sticks and leaves. There were also many recent local floods associated with clogged screens in Oberursel (Figure 1).

Climate change leads to an increase in heavy rainfall events and floods [3,6]. These changes require an adaptation of the water infrastructure, including the screen systems (including flotsam screens), to meet the new challenges of more debris and flotsam [1,5]. This was one of the drivers for the study on screen systems in Oberursel.

1.2. Challenges with Existing Screen Systems

The municipality of Oberursel currently (summer 2024) maintains 56 screen systems. There are also two other urban screens in the planning phase. Thirty of the existing screen systems no longer adhere to the state of the art, are damaged, or suffer from inadequate maintenance [7]. These systems are increasingly clogged and quickly reach their stress maximum during more heavy rainfall events as a function of climate change (Figure 2).

(**a**) (**b**)

Figure 2. Examples of (**a**) a two-dimensional screen (screen number 17) with a silt trap; and (**b**) a one-dimensional screen (screen number 21) without silt trap after heavy rain (May 2024) in Oberstedten, Oberursel (Taunus).

Most of the screens in the community are one- and two-dimensional and have no sediment trap. This leads to frequent clogging from stones and sediment [8,9]. The maintenance teams for screens and streams are behind in terms of cleaning of clogged screens for several years due to a lack of workforce. The increased effort to avoid flood events costs time and money. Added to this is the increase in water pollution by fine solids (Figure 2b), which cannot be retained well by screens and sediment traps [10,11]. To address this challenge, the screen systems need to be more frequently maintained, repaired, and/or upgraded. However, this requires prioritization of work based on expert judgement and/or field investigations [12].

1.3. Screen Maintenance

The entire construction, which includes the screen, is viewed as a coherent system. This involves, for example, elements such as the inlet area of the stream or ditch, a deadwood lock, a sediment and stone trap [13], the screen, and the entrance area into the subsequent building element such as a rainwater or mixed-water pipe.

Screen maintenance includes regular cleaning, functional control, and repair [7]. Due to increased heavy rainfall events, the maintenance of screens must be carried out more often. In addition, there are the necessary adjustments to the screen to new boundary conditions. This is a challenge for the maintenance teams and requires more efficient organization, implementation of the cleaning work, and work prioritization particularly during a storm event. The plans for the cleaning work must be time- and personnel-saving. If the screens are thoroughly cleaned, the duration until the next cleaning can be extended. Work equipment for the maintenance work must be suitable and safe [4,14].

1.4. Screen Design Optimization Needs

The standards of the German Institute for Standardization provide the relevant design requirements for screen systems. In the worksheets and reports of the German Association for Water Management, Wastewater, and Waste [15], there are also many specifications on water-related structures. The DIN 19661 standard [16] deals with buildings in, on, above, and among above-ground waters. This norm serves planning, construction, operation, and maintenance [16].

The accessibility of screen systems for maintenance work or rescue of people or animals must be upheld. Poor system accessibility leads to a reduction in the quality of maintenance work [7,17].

Screens are usually made of metal (Figure 2), while deadwood locks are often made of natural materials such as tree trunks (often hardwood; for example, obtained from oak trees). The screen can be one-dimensional (Figure 2b), two-dimensional (Figure 2a), or three-dimensional. Depending on the area, location, and flotsam, it can be decided which screen design is most appropriate. Some of the existing screens are often converted from being one- to three-dimensional, because the screens can thereafter filter a greater capacity of water and then become more effective. The increasing heavy rainfall events require frequent checks of all screens concerning their function (Figure 1). Screen systems may have to be retrofitted by a finer or multi-dimensional screen and a sediment trap [8,13,17].

1.5. Automated Screens as a Future Option

Screen systems can be operated with and without foreign energy to ensure cleaning. The drive mechanism can be operated electrically, hydraulically, pneumatically or through hydropower. Cleaning can be performed automatically, activated, or carried out by maintenance work [18]. However, screen systems for trenches (Figure 2b) and streams are simple and are, therefore, usually cleaned manually.

Automated cleaning requires a delimitation of the screen system from its surroundings to prevent external access and thereby minimize danger. However, since this is not always possible due to its location and the surrounding area, it must be avoided in many cases.

Nevertheless, particularly automated cleaning systems for some larger screens might be an option for the future, if the technology becomes more efficient, cheaper, and safer [18].

1.6. Supporting Structures

There is a need to assess if the effectiveness of screens can be increased by supporting structures. Additional structures such as deadwood locks, pre-screens, as well as sand and sediment trap structures (Figure 2a) support the function of the main screen by holding larger amounts of flotsam and sediment back before they reach the main screen [13]. This relieves the primary screen, which reduces the risk of flooding [1,8,19].

Most of the time, large items such as wooden trunks and shopping baskets are retained by pre-screens to avoid damage and clogging of the main screen. Depending on the location and nature of flotsam, the installation of pre-screens and sediment traps (Figure 2a) is an important step to improve the drain capacity of the streams [19].

Sand and stone traps have the task of holding back solids (mud, sand, and stones) carried by the stream to prevent deposits in stretches further downstream [8,19] and piped sections. However, they can also serve pre-treatment to relieve the main screen [10,11].

Many pollution parameters such as suspended solids, biological oxygen demand, nutrients, and metals correlate well with sediment [20], which can be held back by a sediment trap [13,17]. The federal guidelines for recognizing ecologically critical water pollution by wastewater propose various solutions to improve the water quality of receiving watercourses such as streams [19,21]. It is therefore the responsibility of the municipalities to propose concepts for solutions such as improved screening systems, which the lower water authority and, if necessary, also the regional council must evaluate.

1.7. Objectives

The overarching goal is to optimize screen systems of local drainage systems for flood and diffuse pollution control purposes by proposing a new predominantly qualitative methodology for screen system maintenance, repair, and upgrade prioritization. The following objectives have been addressed: (a) protect pipes from clogging, (b) prevent local floods, (c) improve the water quality, (d) improvement of preparations for storm events, (e) savings of personnel and material resources, (f) get the screens cleaned faster, (g) automation of screen system cleaning and processes, and (h) improved screen monitoring.

2. Methodology

2.1. Locality Data

Oberursel has been selected as a typical and therefore representative small town in Europe facing climate change challenges such as localized flooding [3]. The northwest and west of the catchment is dominated by forest and hills. There is a small belt of agricultural land and grassland surrounding the town in the north, east, and south. The areas behind this belt are dominated by urban areas that are particularly dense in the southeast (Frankfurt am Main). The catchment slopes from the northwest to the southeast. Consequently, screens encounter high flows with debris coming from the forest in the northwest. The screen systems in the northeast collect sediment from flooded fields.

A detailed recording of the screen locations is required to carry out a systematic analysis and optimization (Figure 3). In addition, other information is collected on monitoring and maintenance of the screen system including previously reported damage. Table 1 shows summary statistics of measured and estimated variables for all screen locations in the example municipality of Oberursel near Frankfurt.

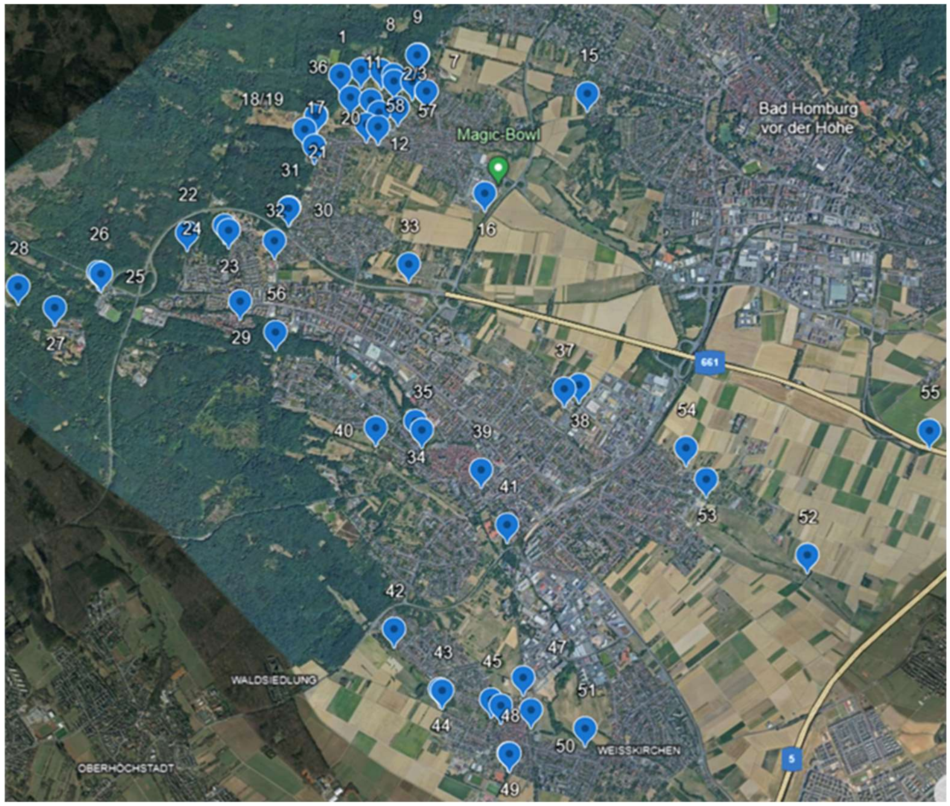

Figure 3. Overview of the 58 screen systems (some with sediment trap) in Oberursel (Taunus).

Table 1. Summary statistics of measured and estimated variables.

Variable	Unit	Minimum	Median	Average	Standard Deviation	Variance	Maximum
Measured (for 58 screens as shown in Figure 3)							
Area	m^2	0.02	0.15	0.02	0.58	0.27	2.78
Rod distance [1]	cm	3	8.5	3	3.6	12.8	19
Water width	cm	0	156	0	167.3	27,846	1000
Water depth	cm	0	55	0	46.8	2236	200
Passage width [2]	cm	15	43	61.5	57.29	3051	343
Passage height [2]	cm	15	40	48.5	27.99	724	130
Estimated priorities							
Flotsam priority	–	1.0	4.0	3.4	1.3	1.7	5.0
Cleaning priority	–	1.0	3.5	3.0	1.5	2.4	5.0
Area priority	–	2.5	3.0	3.2	0.4	0.2	4.5
Water quality priority	–	1.0	3.0	2.9	1.0	1.1	5.0
Safety priority	–	1.0	3.0	1.2	0.5	0.3	3.0
Renovation priority	–	1.0	1.0	3.2	1.2	1.5	5.0
Screen system renovation priority [3]	–	1.3	2.4	2.5	0.7	0.4	3.8

Notes: [1] Rod distance of the screen area, which is approached by the flow head-on. [2] The passage is the exit opening (e.g., a channel or a built-in stream) of the screen system that is located after the screen. [3] This is a value that is composed of the upper six individual priorities after weighing up interests of stakeholder groups.

Each screen system in Oberursel can be clearly determined by the following entries that were collected in the software Microsoft Excel (Version 2410): screen number, screen name, street and house number, coordinates DD N, and coordinates DD O. In this case study, Google coordinates were utilized. Their accuracy is in the order of several decimeters.

2.2. Subsection Digital Recording and Geo-Systems

The digital recording of the screen locations and pipe systems in the geographical information system CAIGOS [22] offered several advantages such as the spatial analysis of data, which can help to identify and prioritize problematic areas. In addition, digital documentation facilitates long-term monitoring and maintenance of the screens by providing current information about the condition and performance of the screens. The selected geographical information system has an accuracy in the order of several centimeters.

2.3. Data Linked to the Inspection of the Locality

The specific circumstances and boundary conditions of each screen were recorded and documented during local visual inspections. Physical parameters such as the passage width, passage height, shape of the screen, water width, water depth, and floating angle were determined (Table 1). The screens were examined according to the type of flotsam and according to their dimension. The environment of the screen also plays a role to be able to assess the consequences of a local flood in advance and adapt the cleaning priorities accordingly (Figure 1).

2.4. Follow-Up Data Analysis

After cleaning the screen, thorough quality control was crucial to check how well the system works. Outliers in the data were checked. The dimensions of the system were documented. Photos show the placement of the screen and explain its position, as well as the surrounding area before and behind it.

The DWA [15] set of rules was adhered to during laboratory work. Water samples were determined photometrically with tests from Hach Lange.

2.5. New Method Based on Measures of Prioritization

An inexpensive, practical, and rapid, but coarse, methodological approach based on both qualitative, quantitative (expert opinion-based), and practice knowledge is proposed [12]. The strength of this approach is linked to its transparency, effectiveness, and low cost as it does not require detailed on-site investigations, expensive experiments, and data-intensive modeling work.

The new methodology is based on the screen system renovation priority (SSRP) definition. The following parameters were determined by a team of local authority workers (engineers and practitioners such as metal workers, maintenance team, and builders) and the author: flotsam priority, cleaning priority, area priority, water quality priority, safety priority, and renovation priority (Table 1). Each of the priorities mentioned is given a numerical value from 1 (very low) to 5 (very high) by the group of practitioners and experts following an expert opinion methodology [12].

The flotsam priority stands for the size and material nature of the flotsam and how likely it is that it causes clogging of screens and pipes [9]. The cleaning priority indicates how often a screen must be cleaned and which screen should be cleaned first in the event of heavy rainfall. This priority is based on the experience of the local cleaning teams. The area priority indicates how important or vulnerable the area surrounding the screen is in terms of flooding. The water quality priority indicates how important the screen and a possible existing sediment trap is for the water quality of natural waters, which serve as a receiving watercourse [13]. The safety priority indicates how urgent a measure of public safety and health is. The renovation priority represents how much renovation is necessary at the present time to ensure full screen functioning. Subsequently, the SSRP indicates the overall rating based on an interest group weighting of flotsam, cleaning, area, water quality, safety, and renovation priority (Table 2).

Table 2. Example of a stakeholder assessment as a basis for the screen system renovation priority.

Stakeholder Group [1]	Weighing of the SG	Flotsam Priority	Cleaning Priority	Area Priority	Water Quality Priority	Safety Priority	Renovation Priority
Residents	10	2	5	1	2	5	4
Urban drainage	8	5	5	4	4	3	5
Road construction	4	2	3	3	1	4	2
Environment and ecology	5	1	1	1	5	1	3
Public funds [2]	8	3	5	5	4	4	3
Safety and health	15	2	3	5	2	5	2
Screen system renovation priority considering different SGs							
Relative part (Total = 1)		0.13	0.19	0.18	0.14	0.20	0.16

Notes: [1] Stakeholder group = SG. [2] From the point of view of the municipality, which should provide funds for screen system maintenance and renovation work.

Figure 4 shows the spatial distribution of the SSRP values in the case study area. The insert shows a great density of screens with a high renovation priority particularly in the northwest of Oberursel due to high flows coming from forested areas.

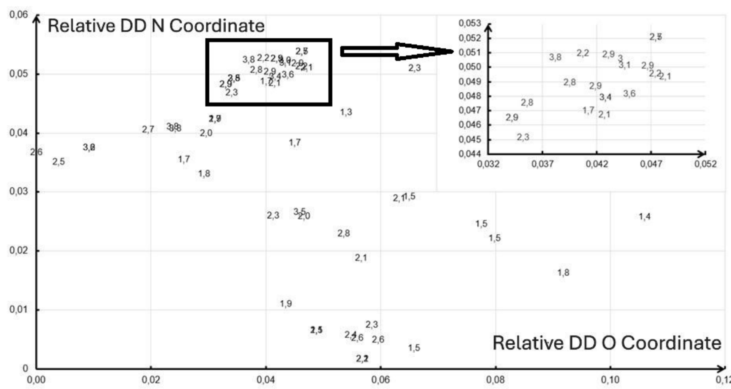

Figure 4. Overview of the screen system renovation priority (SSRP) of 58 screen systems (some with sediment traps) in Oberursel (Taunus) with a separate representation (see insert) of the screens in the Oberstedten district.

The following measures were specified for screen system upgrades: locksmith, concrete, sediment and stones, safety, deadwood, ditch, early warning [23], screen creation, and automatic screen cleaning [12]. Metal processing work (Figure 2) is undertaken by the locksmith. The measures of concrete, sediment and stones, as well as deadwood and ditch are measures for road construction work. Early warning and automatic screen-cleaning measures require external work with a special company for information technology. The measures and their costs should be described in Excel tables. The screens and measures should be sorted according to the SSRP values (Table 1) of the corresponding screens. The higher the SSRP, the more important is the measure (Figure 3). The measures can then be processed from top to bottom by local workers or companies to be commissioned (e.g., locksmith).

One- and two-dimensional screens should be checked for their conversion to three-dimensional screens. This measure should be discussed with the responsible local team for screen construction. First, the individual priorities of the screen should be checked. If screens have a low cleaning priority, their conversion is in most cases superfluous. It must be determined whether a potential screen upgrade would have a benefit. There is the possibility that screens with a low SSRP value will still be upgraded, because this would make a higher contribution to flood protection (Figure 1).

Then, the location of the screen must be considered. A three-dimensional screen may not be installed due to the specific nature of the inlet, stream, or ditch. In this case, it should be checked whether a screen upgrade offers a good solution. The passage or inlet behind the screen must be considered (Table 1). If the inlet is too small, it is usually not worth converting the screen, because the low load capacity of the passage or inlet is not optimized. Since the enlargement of an inlet is linked significantly to more effort and costs, it must be carefully examined whether this is worth it.

In addition, the conversion of screen systems should not lead to any additional difficulties for the cleaning teams. It must be considered which work equipment the teams use so that cleaning is not made more difficult. It is also important that a screen system upgrade (still) ensures the safety of the cleaning teams.

Similar criteria like for the conversion are used to decide on the construction of deadwood locks as well as sediment and stone traps. In addition, however, there is the type of flotsam. In forests, this measure offers a solution for retaining floating tree trunks and large sticks.

Another measure is to install early warning systems such as surveillance sensors [23]. Here, too, a cost–benefit assessment must determine for which screens this measure should be carried out. The weighing takes place based on the priority list and map (Figure 3) as well as the experience made by cleaning teams during heavy rainfall events (Figure 1).

The most complex measure of all is the construction of an automated cleaning system [18]. This measure can only be implemented for very few screens. Automatization is only worthwhile for screens with high cleaning needs and can only be installed if the screens are large enough (cleaning area well above 50 cm in width) and if the surroundings of the screens offer sufficient space to install the system. In addition, the automated screens must be inaccessible to people and animals to prevent dangerous situations leading to accidents. Very few existing screens in the case study meet these criteria.

3. Results and Discussions

3.1. Characteristics of Assessed Screen Systems

The evaluated screens are intended to prevent blocking of pipes, streams, and trenches as well as retain rubble, wood, and plant parts. In the event of heavy rain, a screen is an important structure to prevent flood events and hold back large objects [1]. Without screens, many objects get into the openings of channels and cause blockages. The cleaning of pipes is much more expensive than the maintenance of screens [2,7,13,18]. This was the main motivation for proposing the prioritization methodology.

The screens played an important role in local flood protection by maintaining the optimal water flow rate by preventing blockages. With the increase in heavy rain events, screens are becoming increasingly important for the water infrastructure and for local disaster protection [1]. The construction of deadwood screens is very helpful here because it intercepts much greater material and thereby relieves the primary screen. As a result, this has a lower risk of flooding, because the main screens can ensure the design drainage.

The flow angle influences the efficiency of the screen. Flow-optimized construction can compensate for flow restrictions such as partial clogging [9]. The greater the inclination between the screen and the horizontal, the higher the pressure loss. The hydraulic calculation of these screens is crucial to ensure their efficiency and functionality [14]. However, corresponding data are difficult to obtain in practice for many small screens.

The flow rate is determined by a flow exit coefficient that depends on the construction of the screen and blockage. The rod width and space of the screen determine the size of the flotsam that can be held back. Therefore, these parameters were measured and not estimated.

The inclination of the screen is the angle between the screen and the horizontal. A greater inclination can make cleaning easier but also influences the hydraulic pressure loss. Therefore, a compromise of the design of upgraded screens was required.

The pressure or energy loss caused by the screen can be calculated to understand the effects on the hydraulic performance of the system. However, a correct calculation can only be achieved theoretically, because the loss of pressure differs significantly in reality and changes quickly.

The flow velocity is the speed of the water through the screen. It influences the forces acting on the deadwood lock, the screen, and the drift material. Here, too, calculation is only possible theoretically, because the speed is not constant. Moreover, during heavy rainfall events, taking measurements was not possible.

The classification of the type of screen according to the rod spacing (gap width) is as follows [14]: protective screens (60 to 200 mm), coarse screens (20 to 100 mm), and fine screens (8 to 20 mm). In Oberursel, there are 43 coarse screens (two more in planning) and 13 protective screens. The rod spacing influences the type of drift material that is held back by the screen. A too large distance between the rods can lead to blockage in the further course of the pipe [24]. In comparison, a distance that is too small leads to increased cleaning effort. The rod spacing of each system is adapted to the type of flotsam and the area of the passage behind the screen [2,8,14]. Figure 5 shows that with an increase in screen rod distance, the passage area behind the screen increases as well. However, the correlation indicates only a very weak relationship due to the influence of many other design variables such as velocity, slope, flow approach angle, and local boundary conditions. Nevertheless, Figure 5 should aid other researchers in assessing the findings in various contexts.

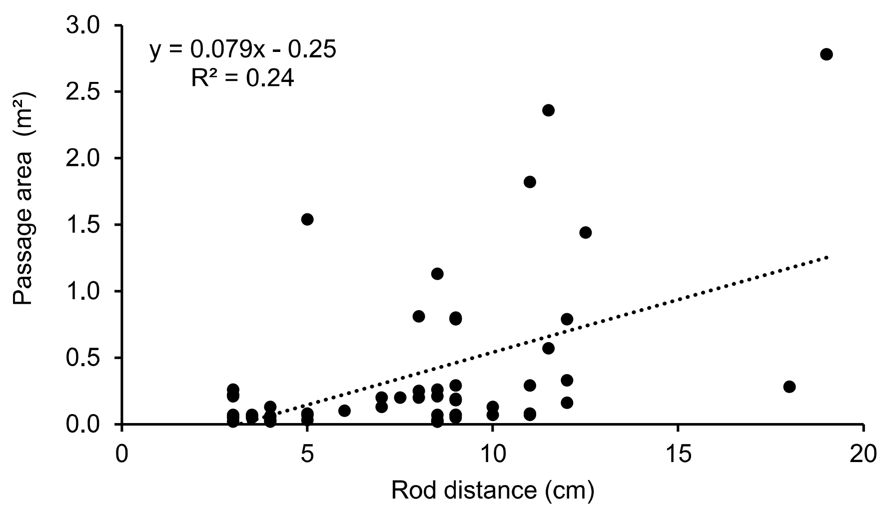

Figure 5. Relationship between the screen bar spacing and the passage area behind the screen.

Pre-screens have a large rod spacing to relieve the main screen by intercepting large items and some of them can be easily maintained via a walkway (Figure 6). Fine screens, on the other hand, have low bar distances, because they are designed to intercept small objects. They are more effective in some cases but have a greater risk of blockage. Therefore, they are not popular with maintenance teams in practice.

With a change in weather conditions, the optimal rod distance of a screen system can change, because the drift material type and size may alter. In the event of heavy rain, much larger material such as wooden trunks and garbage cans may be expected.

A reduction in the flow speed can increase the efficiency of the screen and reduce the risk of clogging [9]. Without a protective pre-screen (Figure 6), screens are exposed to shock loads. Depending on the stability of the screens, it can be helpful to reduce the flow speed through a natural stream design to keep the shock loads low. Personnel costs can be saved with the right flow speed. However, it must be noted that in the case of sand and stone screens, higher velocities are necessary to prevent large amounts of deposits entering and lingering in the screen systems in the case of hydraulic maximum loads causing faults [14,19].

Figure 6. Example of a pre-screen (screen number 26) protecting a main screen (screen number 25) further downstream.

The hydraulic behavior of a screen changes as it becomes clogged. The capacity of the screen decreases, but the behavior cannot be assessed economically in practice for many small screens. The maintenance team visits screens during heavy rainfall events and cleans them if the backwater threatens to cause a local flood. This strategy is only partially successful and could be improved by a monitoring system with sensors and cameras.

In the case of inappropriate screens located within streams, fish passage can be negatively affected. However, fish ladders can help here. A fish protection system can be used to guide fish away from screens. As a consequence, they do not enter the danger zone, so they do not penetrate the main screen, and are guided by the construction arrangement to a bypass. The bypass leads the fish harmlessly to the underwater [19]. In Oberursel, however, the construction of such protective systems is not necessary, because there are no fine screens on flowing waters with fish stock.

In the case of automated cleaning systems [18], a screen is installed. The screen system filters the water and leads the flotsam to a collection unit, which must be tailored to the screen area. In the German case study, there are two automatic screen systems in planning (Figure 7).

(**a**) (**b**)

Figure 7. Examples for locations where an automated screen is suitable: (**a**) screen number 23; and (**b**) screen number 46.

A sole jump is the difference in height for which a screen system can be installed. Depending on where it is, its impact changes on the rake. In principle, the sole jump counteracts deposits and thus prevents clogging [9]. If the sole jump is at the base of the screen or behind it, its positive effects are at their best. Especially behind the screen, the sole jump usually offers the best support against clogging. For the case study in Oberursel, 19 rakes are known, where the sole jump is located behind the screen. For nine other one-dimensional screens, the sole jump is situated directly below the screen.

Often, clogged screen systems can be supplemented by emergency relief. If the amount of water exceeds the resilience of the screen system, the excess water can continue to flow through the emergency relief. The emergency relief must be installed in such a way that water can only flow through sideways from or over the rake in the event of an overload. There is the possibility of a short-term and automatic opening of the screen in the event of an overload, which leads to relief. The screen is often adapted by its height so that the water can continue to flow over the screen if an increase in the water level takes place. This cannot lead to an increase in the backstream level within the canal, ditch, or stream and the flood risk is reduced accordingly [1]. In Oberursel, there are currently six screens with built-in emergency relief options for increased water levels.

Sediment traps (Figure 2a) relieve screens and prevent functional disorder [19]. They also prevent clogging of pipes and help to save time and staff effort [10,14]. Twenty-one screen systems in Oberursel have a sediment trap. Six more are planned.

Sediment basins also contribute to better water quality and ecology of receiving watercourses. By intercepting sediment and rubble, streams are also relieved ecologically. The water quality priority (Tables 1 and 2) in Oberursel has an average of 3.3 for screen systems with current and future sediment traps. For screen systems with no sediment basin, the average is only 2.7.

The sediment traps investigated are usually dug at a depth between 10 and 100 cm and a length of 100 to 700 cm in front of or behind the screen. Sediment basins form a lowering (often in front of the screen), where stones, sand, and sediments are deposited. The stones and sand are deposited at the bottom of the trap when the water flows through and continues to the screen or pipe (opening). The pool usually consists of concrete or natural stone [8,13,19].

In the case of trenches and streams that run through a forest, a deadwood lock is very effective. A lot of deadwood gets through the forest into ditches and streams. This type of flotsam is mostly large and would clog the channel and possibly damage the screen. It remains in front of the screen and clogs it. In the event of heavy rainfall events, large wood is washed up, and it only takes a few hours for the screen to clog and create a localized flood. This can best be prevented by a deadwood lock. In this way, clogging during heavy rainfall events [9] can be prevented and the cleaning teams are relieved. There are no deadwood locks in Oberursel at the present time, but three are being planned. As expected, the flotsam priority (Tables 1 and 2) for the three screen systems, where a deadwood lock is planned, is 5.0.

The screen systems in Oberursel are in public spaces. Accordingly, they must ensure people's safety. If there is a high risk of falling, railings must be attached. All risks that arise from a screen system must be eliminated. Therefore, two screen systems had to be improved after consulting the regional experts [12] from the Association for Technical Inspection (Technischer Überwachungsverein in German).

In addition, with large pipes and channels, there is a risk that children and animals enter them. For this reason, the channel must be made inaccessible from the outside. The safety priority in connection with the pipe has been assessed (Figure 8). The larger the area, the greater the safety priority is. However, the correlation is weak due to the complexity of the screen system, local boundary conditions, and the estimation method linked to safety priority (see Section 2.5).

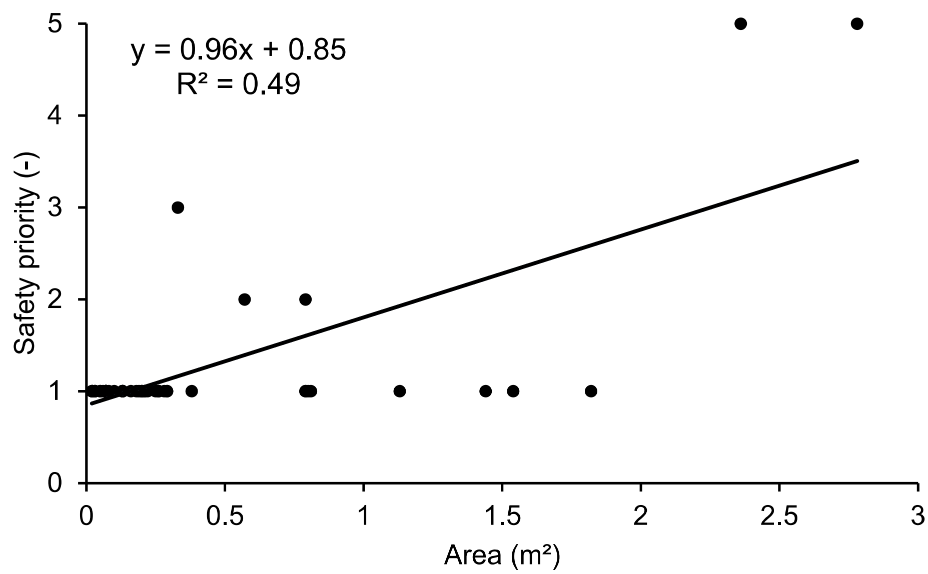

Figure 8. Safety priority as a function of the connection area (pipe).

3.2. Screen System Maintenance Needs

Regular functional controls and cleaning are necessary to ensure the effectiveness of the screen [19]. In the optimal case, small items of flotsam are not removed when cleaning, but they are led to the sewage treatment plant with mixed wastewater. Depending on the screen system, cleaning can also be automated, but mostly an external energy source is required [18].

The following cleaning methods can be used: ejector beam (air–water mixture), rotating stripe comb, broom, cleaning bar, cleaning top spiral, optimized room teeth, cleaning brushes, snail-wear with brush replacement, and fan glands.

If water flows through the entire screen, it must be cleaned in continuous operation. Fine screens must be cleaned more often due to their relatively small rod distances. Cleaning can be automated for fine screens at suitable boundary conditions to save time and effort.

Screen systems are operationally safe and often also low in maintenance (dependent on the weather) [7]. Optical clogging control can often succeed. For this reason, it is worthwhile to apply surveillance sensors in many cases. Much of the control and maintenance can then be performed in the surveillance systems. Together with an automated cleaning system [18], local inspections rarely need be made. This saves time and personnel costs, increases effectiveness, and enables more screens to be cleaned and checked in the same period.

In the event of flood events, the cleaning team must clean the rakes in optimal order based on a priority list, which is a function of both cleaning priority and travel times. The locations of the screens must be included in the planning. This concept for cleaning builds on the analysis of the screen.

Personnel resources play a major role in maintaining and cleaning screens. In the event of heavy rainfall events, many screens must be cleaned quickly due to their high priority rating (Tables 1 and 2; Figure 4). In such cases, a large cleaning team would be very helpful. This would make it possible to divide the team into several groups to clean or free the screen from flotsam and debris more efficiently.

In addition to maintaining the screen system, there is also the treatment of the collected flotsam. Before this is removed, it must be pressed to save space during transport. Piston presses, roller presses, and snail presses are three relevant press systems with different functions. In addition, the weight and volume of the screen is reduced by drainage. Before transportation, the flotsam is temporarily stored in collecting containers. The collected waste is often disposed of by landfill, combustion, or composting.

When it comes to screen maintenance, the screen must be protected in winter from freezing. This may best be realized by total enclosure, which is, however, costly. Therefore, none of the current screens in Oberursel had an enclosure.

The sediment basin is cleaned by removal of the rubble between major storm events based on experience currently not supported by a sediment transport analysis, which only works as long as experienced personnel are available. Cleaning is part of the screen plant care. Regular cleaning by the maintenance team is important to ensure the function of the silt trap. Due to the weight of the sediment and rubble, cleaning is often carried out by an excavator. Since the width of the sediment trap usually does not exceed one meter and the height usually does not exceed half a meter, the excavation of the trap must be performed carefully to prevent damage to the concrete or stone of the structure. Cleaning causes high effort and costs, but it is essential to ensure the function of the sediment trap and thereby also the task of the screen system. The developed prioritization scores should help optimize maintenance and repair work [7].

Sediment and rubble pools can also be placed behind the screen. As a result, cleaning can often only succeed manually. In this case, the system comprises mostly a coarse screen. The bar distances are then large enough that rubble and sediment can flow through. So that rubble and sediment do not clog the entrance area of the pipe, but are deposited in the sediment trap [8].

Table 3 shows an overview of the water quality parameters of representative sediment traps. Sediment tanks with and without many fine components contribute to water pollution of receiving watercourses due to their high chemical oxygen demand. Fine materials such as organic silt often also have an increased nutrient value [5,13]. As a consequence, many more silt traps are currently in the planning stage.

Table 3. Overview of quality parameters (after filtering) of representative sediment traps on 16 September 2024: screen 17 (Figure 2a) with a high content of fines (99% of the sample below 63 μm) and screen 21 (Figure 2b) with a normal sieve-size distribution.

Variable	Unit	Number 17	Number 21	Threshold
pH value	–	7.7	7.6	–
Chemical oxygen demand	mg/L	66.2	68.1	35
Ammonium nitrogen	mg/L	0.243	0.694	1.2
Nitrate nitrogen	mg/L	11.80	3.06	–
Total nitrogen	mg/L	16.50	6.48	12
Orthophosphate phosphorus	mg/L	0.434	0.099	–
Phosphate	mg/L	1.11	0.584	0.7
Organic compounds (according to weight share)	%	25	3	–

Notes: Remarks: Two liters of tap water were added to each sediment test of 4 L to obtain a water sample after 1 min of stirring. Threshold values refer to the discharge of cleaned sewage water directly into the Urselbach (receiving watercourse).

Generally, damage to concrete supporting structures of screens is rather common (Figure 9), but the screens themselves need to be repaired rather rarely. The rods of screens are mostly made of metal and are, therefore, difficult to break or bend. Damage is rarely caused by drift material or impact load. Much damage is caused by humans, either by the maintenance teams or by vandalism. By acting heavily from the outside, screens can become loose in their installation place or obtain fractures in some places, which affects their function.

(**a**) (**b**)

Figure 9. Examples of predominantly damage to concrete-based supporting structures: (**a**) screen number 23; and (**b**) screen number 40.

Damaged screens must be repaired promptly to maintain their functionality. If the same defect is independent of humans and occurs repeatedly, optimization of the screens must be considered. As part of the repair, an optimization or expansion of the system (for example, by a pre-screen, a deadwood lock, or a rubble collection trap) can also be carried out to save time. Figure 10 shows a successful screen renewal in the case study.

(**a**) (**b**)

Figure 10. Representative example: screen number 28 (**a**) before and (**b**) after renewal.

Table 4 provides an overview of the most common options of original and future compositions of screen systems. A future composition is based on the recommendations for action by a local team of experts in this case study following an expert opinion methodology [12]. Clear developments (trends) can be seen for options 1 to 5. These options contain at least 69% of the group members (specific type of screen system).

Table 4. Overview of the original and future screen system composition. Number of systems: 58.

Option	Screen				Ditch	Sediment Trap (Old)	Sediment Trap (New)	Early Warning System	Number of Group Members
	None	1-D	2-D	3-D					
Current situation (no individual cases)									
1			✓		✓				18
2			✓		✓	✓			17
3		✓			✓				12
4		✓			✓	✓			4
5				✓	✓				3
6	✓				✓				2
7			✓						2
Future situation (plus eight individual cases)									
1			✓		✓				13
2			✓		✓	✓			13
3		✓			✓				6
4		✓			✓	✓			2
5				✓	✓				6
8			✓		✓	✓	✓		3
9				✓	✓		✓		3
10			✓		✓		✓		2
11				✓	✓			✓	2

Option 1 shows a change by five group members, which can be justified by optimizing the screen systems with a sediment trap or upgrading the screen dimension. Some of the group members of options 1 and 5 in the state of the future are in the actual state in option 3. The number of group members for option 2 is also reduced, because a new sediment trap is planned, or the screen dimension is increased.

Option 3 shows a noticeable decline in the number of group members by 50%. These are screen systems that consist only of a one-dimensional screen. This means that there are many optimization options or that they are essential. The compensation dimension is mainly optimized, which supports options 1 and 5 in the state of the future.

The only option that shows a significant increase in group members is option 5. The members of this option increase by 100% to six members in the future scenario. Most group members of the screen systems of options 8 to 11 differ from the other screen systems by their relatively high SSRP value. The individual cases can be attributed to installations of deadwood locks, early warning systems [23], and automated cleaning systems [18].

Protective walls or flood relief structures for some screen structures may be necessary to improve their stability and efficiency. Protective walls could make sense to achieve a more efficient functioning of the screen. Furthermore, flood relief structures are sometimes necessary to prevent blockages.

If a data analysis indicates that some geometric conditions between the screen system and the water flow direction are inappropriate, a protective wall can be the solution. Especially due to heavy rainfall events, some screens are no longer suitable for the current situation. In addition, increasing technical advances result in more efficient screen systems and methods, which means that older screens will have to be modified or replaced. Through systematic before-and-after comparisons (before and after installation of the screen or before and after the screen wall change), someone can make statements about the effectiveness of the system and make recommendations for future renovations. By observing the screen usage and functioning under different conditions, someone can determine whether a screen system is dimensioned too small. From a flotsam cover of well over 60%, an increase in the screen dimensioning must be considered. For example, a one-dimensional screen could be replaced by a multi-dimensional one.

The distance between the deadwood lock and the screen must not be too long to prevent deadwood (Figure 11) from causing clogging of the screen from damaged trees between the deadwood lock and the screen. Depending on the location and environment, it must be decided to which side the deadwood should be guided by the deadwood lock. Ideally, there is a meadow, field, or forest on one side of the lock. The deadwood does not cause any major problems at such locations. In some cases, the deadwood must be redirected to a path or a small road because the other side is blocked or inaccessible.

(**a**) (**b**) (**c**)

Figure 11. (**a**) Functioning of a deadwood lock as well as examples of typical stream locations within a forest where a deadwood lock would be suitable to protect a downstream screen from damage: (**b**) screen number 24; and (**c**) screen number 28.

In general, and especially for deadwood locks, the total height must be significantly higher than that of the nearby area to avoid the drifting away of the already-collected flotsam. The static stress on the structure must also be considered. This very simple type of coarse screen used as a pre-screen is particularly helpful during heavy rainfall events, because it intercepts deadwood from trees and thereby relieves the main screen. However, cleaning must be carried out extensively with suitable equipment. To achieve this safely during a storm is seen as a great challenge by the maintenance team in this case study.

3.3. Recommendations for Action and Future Studies

The proposed prioritization method to maintain, repair, and upgrade screen systems is mainly based on qualitative data linked to practice knowledge. To increase its reliability, findings can be improved by adding more detailed expert judgement [12] and quantitative data. For larger structures, additional modeling work can also help with decision-making. However, this leads to higher costs linked to personnel, consumables, and field investigations.

In view of the challenges of climate change and the increasing heavy rain events, it is essential to create a comprehensive database of all screen locations and to maintain it continuously [3].

The load stress and the stress intensity of individual screen systems should be examined. To make decisions, functional analyses of screens must be made regularly.

The construction of a new screen, the conversion of an existing one, or the relocation of a screen to a more suitable nearby area should be considered. For example, screen number 4 should be relocated to a location just before a nearby footbridge (Figure 1). The installation of sedimentation traps and rubble catches as well as deadwood locks at suitable locations should be checked. Screening automation in terms of cleaning should also be considered.

It is necessary to create sensible maintenance and cleaning plans, which are both time- and personnel-saving as well as effective. It must be determined which screen can be maintained and/or repaired and where external help should be used. Locations, where the use of sensors is worthwhile in connection with an early warning system, should be identified. A further study on implementation feasibility and (financial) limitations would be helpful.

A cost–benefit analysis of the status quo compared with proposed measures for representative screen system sites for different case studies could enhance the recommendations. Assessing potential cost savings should also enhance the study's practical relevance.

State funds can often be applied for to comprehensively renovate or expand screens to control flooding and diffuse pollution. There are also funding programs on different administrative levels in Germany.

The proposed methodology is based on results linked to only one case study. To address this limitation, the method could be improved by applying it to more case studies that are very different from one another, making it robust towards high data variability. This should also lead to the uptake of the proposed prioritization method by urban water guidelines.

4. Conclusions

A new methodology of prioritizing screen system maintenance, repair, and upgrading has been proposed. The basis of the method is judgment based on practitioners and engineers supported by a limited physical data set. This cheap but rough approach is justified for a complex hydraulic system of many small screens and should help to reduce costs and effort. In addition, more traditional methods based on field experiments and modeling tools may support case studies with fewer and more substantial constructions requiring detailed knowledge on specific system behavior.

Repairing or enlarging screens often optimizes their functionality and reduces the local flood risk. Screens should be provided with additional structures such as sand and debris traps. A special focus should also be placed on increasing the screen dimension and positioning.

The safety priority increases with the passage area (often a pipe) behind the screen. This also applies to the bar spacing of the screen. These screens should therefore be prioritized during maintenance.

Regular cleaning of sediment traps reduces the risk of pipe blockages and improves the water quality of receiving waters that are polluted by stormwater pipes. Fine particles in the sediment often have too high nutrient and oxygen demand values.

The installation of remote monitoring systems can significantly improve the efficiency of maintenance teams. Real-time monitoring of the screens allows problems to be identified early and quickly resolved. This reduces personnel costs and enables a faster response time in the event of blockages or damage. Such systems can make maintenance much easier, especially in hard-to-reach or remote areas.

Installing pre-screens can also increase the efficiency of the main screens. Pre-screens catch larger debris before they reach the main screens, thus reducing the load on the main screens. This leads to a reduction in cleaning intervals and higher functionality of the entire screen structure.

Optimizing travel routes for maintenance teams can be achieved by analyzing locations and strategically planning maintenance routes. This saves time and resources and ensures that the screens are regularly and efficiently maintained. The combination of digital recording, remote monitoring, and optimized travel routes forms the basis for effective and sustainable screen maintenance.

A long-term strategy for adapting and maintaining debris screens to climate change is essential. This should include regular inspections, timely repairs and adjustments to the screen structures, and continuous training of maintenance teams.

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