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DWA Clear Concepts. Clean Environment.

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Theodor-Heuss-Allee 17, 53773 Hennef, Germany
P. O. Box 11 65, 53758 Hennef, Germany
phone +49 22 42 872-0, fax +49 22 42 872-151
web: www.gfa-news.de, http://en.dwa.de/journals.html

Editor:
Dr. Frank Bringewski
phone +49 22 42 872-190
e-mail: bringewski@dwa.de

Advertising:
Christian Lange B. A., Monika Kramer
phone +49 22 42 872-129
e-mail: anzeigen@dwa.de

Editorial Assistant:
Bianca Jakubowski
phone +49 22 42 872-138
e-mail: jakubowski@dwa.de

Typesetting:
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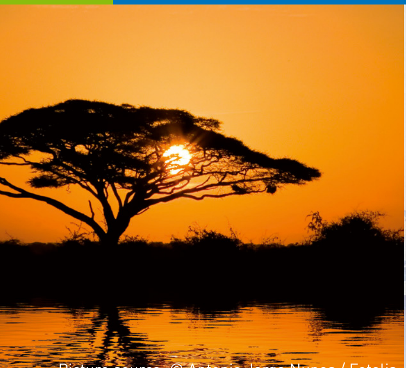
Visit DWA at the international IFAT editions!

DWA participates in IFAT trade fairs worldwide with a diverse program. Firstly, expert lectures within the Technical Scientific Conference. Secondly, Products in Practice (PiP) sessions, which provide a perfect mix of theoretical knowledge and on-site live demonstrations by different companies.

Furthermore, in order to support the international engineers of tomorrow, DWA implemented the University Challenges and Water Skills. Lastly, DWA helps represent the German water sector on behalf of the Federal Ministry for Economic Affairs and Energy at the German Pavilion.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IFAT Africa

IFAT Africa

IFAT Africa takes place every two years in Johannesburg.

dwa.de/ifat-africa

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IE expo China takes place every year in Shanghai.

dwa.de/ie-expo


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IFAT

IFAT Munich

IFAT Munich takes place every two years in Munich.

dwa.de/ifat-en

In 2018 with 3,305 exhibitors spread across 18 halls and the outdoor area, the IFAT Munich was fully booked despite the increase in space and brought together 142,472 visitors and decision makers from 162 countries on the exhibition grounds.


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IFAT Eurasia

IFAT Eurasia

IFAT Eurasia takes place every two years in Istanbul.

dwa.de/ifat-eurasia

IFAT India

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Unexpected, uncertain times

This was unexpected – for all of us. The rapid spread of the Coronavirus not only posed great challenges to health systems, but also to the economy, the educational system, cultural and creative sectors as well as our social life. And here one thing causes another – a vicious circle. The virus forced politicians to take unusual and until recently unimaginable measures. The term "lockdown" used to be a rather unworldly term for many citizens. But it suddenly determined everyday life for many months and now it has taken its firm place in the general vocabulary. And yet the strict measures taken in Germany, Europe and many other countries worldwide will accompany us for a longer, uncertain time. We all have to learn to deal with the new reality that had hit us so unforeseen.

And so, drastic measures require creative coping strategies. Just like other sectors, companies and businesses in the so-called critical infrastructure had to cope with the Corona challenges in the recent months also. For the water industry, for example, the main goal was to maintain the supply structure. While handling the core business, the water sectors international activities were severely hampered. The IFAT in Munich, the worlds leading Trade Fair for Water, Sewage, Waste and Raw Materials Management, which was scheduled for May 2020, was first postponed and finally cancelled. 140,000 professionals from 162 countries and regions (figures from the event in 2018) were not able to meet and exchange ideas. Companies and exhibitors were deprived of new international contacts and had no chance to introduce new products and services to the experts in the way they normally do.

But the Coronavirus is of course not the only challenge mankind faces. Climate change is perhaps our greatest challenge and requires attention and actions, also from water experts. For example, the re-use of water is linked to climate change and is becoming increasingly important. Many regions in Europe, not only the southern ones, deal with higher temperatures in summer time and a different temporal distribution of rainfall than in past years. This causes drought as well as heavy rain and floods. Therefore, the European Union has acted and promote water re-use. A new regulation on minimum requirements for water re-use for agricultural irrigation has entered into force. The new rules will apply from 26th of June 2023 and are expected to stimulate and facilitate water re-use in the EU.

Against this background, the German Association for Water Management, Wastewater and Waste (DWA) has decided to publish an international edition of its journal *KA* ("Correspondence Wastewater and Waste") just like every two years since 2012. This issue of the journal is also intended to spread and share knowledge and experience made in Germany.

One way to achieve the spread of skills are international water operator partnerships. Operator partnerships have been implemented successfully under the description WOP (Water Operator Partnership) for years and are funded worldwide amongst others by the Office for the Global Water Operators' Partnerships Alliance (GWOPA) of UN Habitat. The German Federal Ministry for Economic Cooperation and Development has now launched the pilot project "Operator Platform to Strengthen Partnerships of Municipal Enterprises Worldwide" to implement four pilot partnerships between municipal German operators and international operators over a three-year project period. Details are outlined in an article in this issue.

DWA has recently published an extensive report covering a variety of aspects to be considered within the scope of non-potable water reuse. An article in this issue provides an overview of excerpts of the publication "Non-Potable Water Re-use – Development, Technologies and International Framework Conditions for Agricultural, Urban and Industrial Uses" in the series DWA Topics.

Foto: EG/LV, Klaus Baumers

The standards of wastewater collection and treatment in Germany are among the highest in the world. This is due to thorough engineering and research as well as to the expertise of the operating staff of wastewater treatment plants. Two essays exemplify this: one essay that deals with sewer status detection using 3D imaging data and artificial intelligence. And another essay that evaluates thoroughly the operating data of a large proportion of the nearly 10,000 sewage treatment plants in Germany.

Even after more than half a year, the handling of the Coronavirus still requires a lot of care, strict measures, the making of difficult political and economic decisions, but also requires restrictions in social and private life. Nevertheless, we must not ignore the global issues that are still there, such as climate change. These issues demand a continuing intensive exchange of thoughts and ideas – resulting in actions. An innovative and ecological water management can contribute to fighting climate change.

Best wishes and enjoy reading.

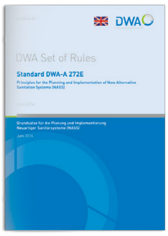
Uli Paetzel

Prof. Dr. Uli Paetzel
President of the German Association for Water Management, Wastewater and Waste (DWA)

Publications

Unit price

☐ Standard
DWA-A 272E



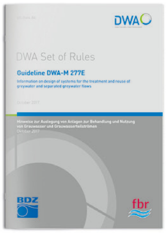
Principles for the Planning and Implementation of New Alternative Sanitation Systems (NASS)

€ 43.50 *

German edition June 2014, May 2019, 38 pages, A4, ISBN Print 978-3-88721-645-0,
ISBN E-Book 978-3-88721-646-7

In addition to the basic principles and the system design of New Alternative Sanitation Systems (NASS), this Standard presents in particular the specific characteristics, which, compared to conventional systems, are to be considered during conception, planning, construction and operation. By a description of the essential aspects and the approach to comparative evaluation of different concepts, including NASS, the effects of the chosen systems on all relevant protection goals and criteria can be considered comprehensively. Target audience of the Standard are actors such as planners, manufacturers and builders who are directly responsible for the implementation of water infrastructure systems, as well as utilities and waste disposal companies, public authorities and urban planners, in whose areas of responsibility could provide opportunities for the implementation of NASS.

☐ Guideline
DWA-M 277E



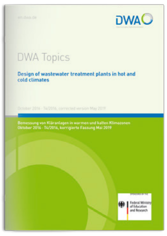
Information on design of systems for the treatment and reuse of greywater and separated greywater flows

€ 46.50 *

German edition October 2017, August 2019, 36 pages, A4, ISBN Print 978-3-88721-647-4,
ISBN E-Book 978-3-88721-648-1

An integral part of NASS according to Standard DWA-A 272 is the treatment and reuse of greywater. Following numerous research projects and long-term scientific studies, greywater reuse systems produced industrially for the treatment of separated greywater flows within the building services engineering are available on the market. However, to date there exist no technical regulations for these systems. The Guideline DWA-M 277 can be applied to systems which process and supply service water from greywater for private as well as public/commercial buildings, or which treat the greywater and discharge it. Moreover, this document can also be applied to systems in the commercial sector such as in hotels, guest houses, sports facilities, camping sites and restaurants. The present Guideline provides information and assistance for the planning, design, construction, operation and maintenance of greywater treatment and reuse systems for different applications.

☐ DWA Topics



Design of wastewater treatment plants in hot and cold climates

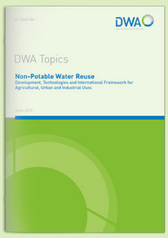
€ 58.00 *

German edition October 2016, corrected version May 2019, 304 pages, A4,
ISBN Print 978-3-88721-615-3, ISBN E-Book 978-3-88721-616-0

The design of wastewater and sludge treatment plants under deviating wastewater and climatic conditions in other countries requires an amendment of existing design rules compliant to the DWA Set of Rules, which have been primarily developed for Central European conditions. This concerns, for example, the consideration of high or low wastewater temperatures, increased salt content or special discharge requirements. Within the framework of the „EXPOVAL" research project funded by the Federal Ministry of Education and Research (BMBF), internationally applicable design approaches have been developed. The results have been prepared for this volume in the form of internationally applicable design approaches and supplement the DWA Set of Rules accordingly.

Non-Potable Water Reuse - Development, Technologies and International Framework for Agricultural, Urban and Industrial Uses

☐ DWA Topics



June 2019, 98 pages, A4, ISBN Print: 978-3-88721-834-8, ISBN E-Book: 978-3-88721-835-5

€ 50.00 *

New

This report is intended to provide general guidance for water utilities, consulting engineers and regulatory agencies for planning and expanding non-potable water reuse as an alternative freshwater supply, in particular for agricultural irrigation, urban landscape irrigation and other urban uses and industrial practices. The report provides an overview regarding relevant regulations and guidelines of water reuse, continues to describe the various aspects of risk management involved in water reuse, and also highlights the various technologies that are applied for water reuse. It does not provide numerical recommendations, which must be derived from site and country specific conditions and assessments. An compilation of case studies provides valuable experiences.

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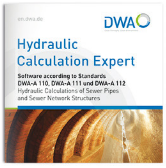

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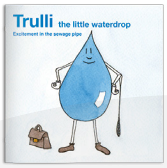
In addition to this "knowledge to go" for trainees, the class set also contains a spiral bound text- and workbook titled 'Fit in Wastewater Technology?' specifically developed for the practical and comprehensive knowledge transfer in the occupational field of wastewater engineering.

Brochure



Trulli the little waterdrop - Excitement in the sewage pipe

€ 1.20

1st edition 2019, 27 pages, 12,5 x 12,5 cm

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07/2020

Sewer Status Detection: Perspectives with Innovative 3D Image Data and with Artificial Intelligence in 2D and 3D Image Analysis Based on the Example of the BMBF Project AUZUKA

Jan Waschnewski, Ralf Hilpert, Daniel Sauter, Peter Eisert, Johannes Künzel, Birgit Schalter, Klaus-Jochen Sympher (Berlin/Germany), UIrich Jöckel (Lindau/Germany), Klemens Kresin (Gleichen/Germany), Karl-Heinz Franke, Daniel Kapusi, René Döhring (Ilmenau/Germany), Philipp Woock (Karlsruhe/Germany), Florian Zimmermann (Sankt Augustin/Germany)

Abstract

The AUZUKA research project, supported by the German Federal Ministry for Education and Research (BMBF), enables to map the status of sewer systems in an automated and more standardised manner by developing modern sensor and image processing technology. This technology is based on mapping sewer damage using artificial intelligence (AI) for both traditional fish-eye technology (2D) and for new 3D image capture technology. Recognition rate results averaging over 80 per cent have been achieved to date by combining AI with existing image analysis algorithms and the heuristics developed here. The software that has been developed assists in detecting the status of sewer systems with efficient ways to determine damage and take stock, including information about their characterisation and identifying the extent. This software and 3D sensor technology can be used as a complete solution or as a component to quickly identify priority areas for action for sewer renovations and thus guide investments in an optimised manner. Automated damage detection and surveying of the extent of damage using an assistance system significantly reduces the high level of subjectivity that has existed to date.

1 Introduction

To ensure the functionality of wastewater collection, sewer networks are inspected and repaired where necessary. There is a need for acceleration of the workflow and higher quality in investigation of sewer condition. The focus of the research lies above all in the development of more intelligent systems within the wastewater infrastructure and sustainable management. The AUZUKA research association is developing a brand-new 3D camera sensor head and methods with which depth information and assistance by neural learning are used for the first time to automatically detect and categorise damage in the sewer network.

As a commercial water management organisation, Berliner Wasserbetriebe (BWB) are both consumers and scientific practice partners in the project. Together with network partners they are working out technical solutions for automated image analysis as an assistance system and an innovative camera sensor head. They are evaluating its use capabilities in the sewer inspection sector.

The current interim results from the AUZUKA project reflect different strategies which have been used to train the neural networks. The method for the provision of training data (labelling) in sufficient quality and quantity plays an important role here. Software architecture was designed for the labelling interface and for artificial intelligence (AI)-assisted damage detection. The generation of 3D image data presents technological challenges, such as adequate lighting for any problem, optimal sharpness and separation of image contents. The aim of the work is to accelerate the objective sewer condition investigation. The feasibility of differentiating between damage requiring repair and damage-free sewer sections and/or negligible sewer damage shall be presented.

2 Starting situation and project preparation

2.1 Goals

In 2016 the BMBF project AUZUKA started under the leadership of the BWB Research and Development team. Project partners are the Humboldt University of Berlin, Dr.Ing. Pecher and Partners, the Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS), JT Electronics, Kappa optronics, Fraunhofer IOSB, Institute for Optronics, System Engineering and Image Analysis, e.sigma Technology. Approx. 9700 kilometres of the total sewer network length in Germany, which measures around 550 000 kilometres, run through Berlin. Like all sewer operators, the BWB inspect this network at regular intervals. This nevertheless only works with extensive image analysis. So far, the documentation of the sewer system is performed with the help of a robot, which provides images about the condition of the sewers. To guarantee a cost-effective system the technology needs to considerably exceed the current state of the art. The specification for this is given by the BWB: Fewer than 10 % relevant damage cases should be manually assigned. The AUZUKA project locates sewer damage and proposes corresponding recording. The image data of the fisheye technology serve as training data for the automatic recording of damage and installation elements in sewer sections. (Partially) automated image recognition with machine learning also takes place in combination with traditional approaches [1].

Project aims are:

- Assistance system for productivity and quality assurance
- Increase of the daily investigation of condition performance by:
  - (highly)-automated image analysis from 2D data pool (fisheye)
  - separation of no-damage/requires repair
  - new sensor technology (from DN 200)/function sample
  - 3D imaging and improved position accuracy
- Identification of relevant damage
- Grouping in accordance with main codes.

2.2 Requirements for optical 3D inspection and image analysis by AUZUKA

Initially, the requirements from the Advisory Guideline DWAM 1495 [2], which correspond to the acknowledged state of the art, are applied for visual inspection using the brand-new 3D camera sensor head. New methods are also developed in the research project (see section 3) in order to enhance the image data quality from former 2D-investigations of sewer condition and thus obtain better starting material for partly-automated damage recognition. For this damage recognition, two aspects of the information processing must be investigated:

1 Damage detection:
In the first step, damage is found in the sewer pipe. The aim is high recall (as much damage as possible is detected automatically) with adequate precision (undamaged structures are detected as damage-free areas).

2 Damage grouping:
In the second step, the damage detected is grouped and damage categories and scales are derived. Taking into consideration the scale (section 4) and further damage in the sections and the technical and local boundary conditions, these form the basis for determining the necessary scope of repair work. The extent of the damage is determined using appropriate image features (e.g. colour, texture and contrast) as well as measurement.

Criteria	Manual	AUZUKA	Measure
abstraction from image to data set	🟢	🟡	number
accuracy of stationing (cm)	🟡	🟢	length
accuracy of dimensions (mm)	🟡	🟢	length
efficiency (outlay)	🔴	🟢	time

Table 1: Comparison of manual and automatic investigation of condition

The image recognition developed in the context of the AUZUKA project is also used on existing 2D images from former investigations of sewer condition for which the damage has not yet been coded. Using partly-automated grouping the process of damage coding is carried out in considerably less time and corresponds to a standard which is of a high and consistent quality.

2.3 Damage detection – comparison of manual and AUZUKA

In Table 1 the current manual damage detection by sewer inspectors is compared to the automatic AUZUKA recording; Table 2 includes the weighting of the criteria.

Experienced sewer inspectors detect relevant damage based on colour, texture and contrast features in a complex and physically demanding sighting of the image material. This task should be carried out by the artificial intelligence as far as possible to minimise the amount of damage needing to be manually detected or corrected to relieve practitioners in this area. The AI is trained before operation with pictures of damage cases. With the quantity, quality and diversity of the training images the AI will become more reliable in its decision-making.

Criteria	Weight
abstraction from image to data set	++
accuracy of stationing (cm)	+
accuracy of dimensions (mm)	+
efficiency (outlay)	+++

Table 2: Weighting of criteria of investigation of condition

In the AUZUKA project, each damage detected is at first assigned to a main group. The likelihood that the damage was correctly assigned is given a percentage, which is a measure for the certainty of the AI. The AUZUKA drive carriage provides increased locating accuracy when determining the damages in the sewer, thanks to improved positioning technology (odometry) in the sensor head. The damage location can be determined with an accuracy in the mm range – unlike current damage detection, where tolerances of up to 1.0 m per section is not uncommon.

The accuracy in the detecting of damage extend (for example crack widths) is increased by automatic segmentation (section 4) and measurement in the image. In the case of the former manual sighting of the image material, the results vary depending on given requirements and personal experience. A further benefit of partially-automated detection is the considerable time saving and thus efficiency compared to manual damage detection without the AUZUKA assistance system, because the AI works very rapidly and with equal accuracy.

Partly-automated damage detection obtains a result of equal quality. The recording person is relieved of the monotonous work and can devote herself to the remaining challenging damage. The required qualification for this kind of quality assurance is considerably higher than formerly.

3 Image data

3.1 Image digitalisation

The image data is recorded cyclically during the travel of the inspection robot. The camera chip used has the latest ultra-low noise CMOS technology with a high dynamic range. With the new 3D sensor head, the actuation of the sensors and lighting is designed to give generous overlap of images, in order to guarantee robust stitching of the individual images in the post processing stages. The necessary position data is supplied by an odometry module. Different lighting modes are required and are cycled sequentially. Homogeneous lighting is used for texture imaging and structured lighting is used for pattern imaging, i.e. the projection of specially encoded samples for detecting depth information (3D).

3.2 Image data processing

From the images taken, both the conventional high-resolution colour images (RGB) as well as depth images (D) are obtained, which are registered together by pixel and output as RGBD images. With the additional depth-channel, which maps the actual height differences on the inside wall of the sewer pipe, the quality of the investigation of condition is reaching a completely new dimension. To achieve the best-possible quality colour images with regard to colour reproduction, illumination and image sharpness, a brand-new process, adapted to the special near field geometry in the sewer pipe, has been developed in order to correct colour cast and lighting inhomogeneity [3]. Software modelling of the image capture process also eliminates the blurring effects resulting from the continuous movement of the sensor head during the image capture.

In the 3D stitching process along the pipe axis, neighbouring measurement regions of an individual camera projector module are respectively registered and fused with one another

Fig. 1: Pipeline DN 400, stoneware, example based on root load in the bottom of the pipe (left individual texture image, right stitched RGB-D pipe section) at travel speed 10 cm/s

(Figure 1). The individual neighbouring RGBD measurement regions overlap so that each depth value is detected redundantly. Duplicated measurement from different measurement positions in the sensor head enable closing any gaps in the depth map.

The high-resolution images from the individual camera modules are fused in conjunction with the measured depth data automatically to form a consistent 3D model of the overall pipe (Figure 2). The generated model enables the technical experts to appraise damage and enables the AI-module to carry out automatic status analysis.

The pipe or sewer section is modelled for this purpose with a simple triangle mesh and deviations from this idealised geometry are stored in order that they can be used later by the AI as an additional information source. This process results in a model which is small enough to be depicted effectively and in a visually legible manner. It also allows straightforward extension of the AUZUKA approach for purely textural data [4] already published by the additional depth data. The image segments are stitched along the pipe circumference, with an iterative matching approach [4] and a non-linear optimisation of the individual positions. The result is strikingly depicted in Figure 2.

3.3 Image data visualisation

The AUZUKA Viewer can be used to inspect sewers manually and automatically and to identify, mark and determine the size of damage. Certain 2D data formats also allow 3D visualisation of sewers for more precise and optimised illustration of the data (Figure 3). For 3D sewers or for those which can be converted into 3D format, damage can be identified and grouped automatically by the AI using predefined criteria. With its service-orientated different screens and tools the Viewer provides the basic functions for AI-based image analysis (labelling and assisted marking) and the training of the neural networks. The Viewer can integrate different geographical information systems (GIS) so that damage cases can be directly displayed and selected geo-specifically.

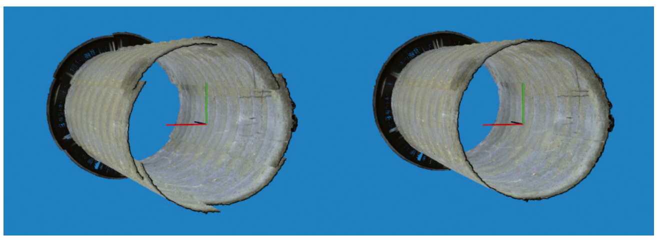

Fig. 2: Model of a concrete pipe (DN 400). Left, unregistered and right, after registration

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European Water Association

Autumn Activities 2020

September

- 9 September 2020 at 12:00 CET
  'A1: WorldSkills Basics for Beginners'
  Free online introduction to WorldSkills and Water Technology competition for all persons interested.

- September 2020 (date and time tbc)
  'Water Utility Asset Management'
  A follow up on the web-seminar in May presenting results and challenges from a Survey conducted by the EWA WG on Economics.

- 16 September 2020 at 16:00 CET
  'Water Reuse', will guide the participants through the new EU water reuse regulation and give them an overview of already available and practically verified technologies for production of reclaimed water.

Registration

Information about content, presenters, date, time and registration is available on **www.EWA-online.eu**

October

- 6 + 7 October 2020 at 12:00 CET
  'EU Policy and Legislation'
  Online course in 2 sessions, which introduces you to EU water politics. An EWA certificate will be issued to participants completing the course.

- 21 October 2020 at 12:00 CET
  'A2: Skill #55 "Water Technology" – Learning from WorldSkills 2019 in Kazan, Russia'.

- 27 October 2020 at 14:30 CET
  'The European Green Deal and Blue Challenges'
  The 1st web-seminar in the Brussels online series 'The EU Green Deal and Blue Challenges'.

November

- 10 November 2020 at 14:30 CET
  'Research and Developments for the Water Environment'
  The 2nd web-seminar in the Brussels online series 'The EU Green Deal and Blue Challenges'.

- 24 November 2020 at 14:30 CET
  The 'Water Framework Directive beyond 2027'
  The 3rd web-seminar in the Brussels online series 'The EU Green Deal and Blue Challenges'

- 25 November at 12:00 CET
  'A3: Insight 1: How to Build Up a National Structure for WorldSkills Competition'
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December

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  The 'Future Challenges of the Water Framework Directive'.
  The 4th web-seminar in the Brussels online series 'The EU Green Deal and Blue Challenges'.

EWA
EUROPEAN WATER ASSOCIATION

European Water Association
Theodor-Heuss-Allee 17
D-53773 Hennef
Phone: +49 2242 872-189
Fax: +49 2242 872-135
E-Mail: info@ewa-online.eu
Internet: www.EWA-online.eu

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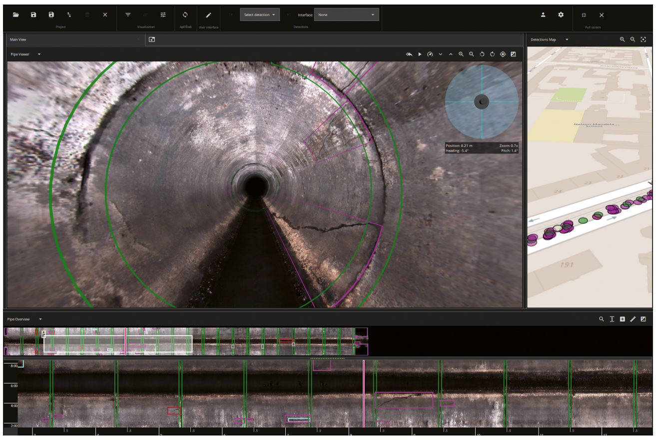

Fig. 3: View of working surface – via AI-marked damage

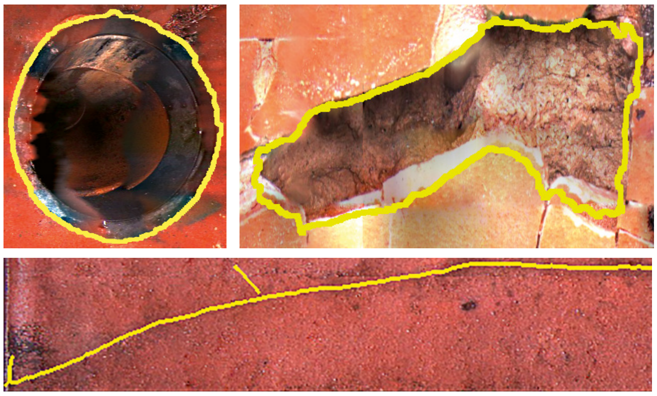

Fig. 4: Automatically masked objects for subsequent automatic measurement (top left: pipe connection, top right: fracture, bottom: crack)

4 Image analysis with AI

The image data are analysed with a special neural network, called “Retina Net”. This is a state-of-the-art one-stage object detector from 2017, whose performance exceeds even the latest two-stage detectors, such as Faster RCNN [5]. In order to train the AI, however, it must first be told what the damage to be classified actually looks like. For this purpose, damage is labelled and used as input for the “training data”. The neural network learns to recognise relationships by repeated similarities in the data. It then extrapolates this machine recognition (learning) to new untrained images, in order to detect damage.

To achieve greater accuracy in damage classification, the first step was to mark damage pixel by pixel. However, as this process is impractical for the vast quantities of training data required, a network is additionally trained to roughly frame the damage. This frame is called a Bounding Box. Inventory data from the manual evaluation can thus be used and new data generated considerably more rapidly.

Image material obtained via the new camera sensor head (3D) and from scans with existing fisheye technology (2D) [4] is used for damage recognition. The latest results of this technology are illustrated in Figure 4.

Damage and/or object classes such as, for example, pipe connections, breaks and cracks (Figure 4) are automatically masked and determined in size in image regions pre-detected by the neural network. The challenge is to link all approaches to form a hybrid system which will enable efficient and simultaneously detailed detection.

5 Training and testing of AI strategies and models

5.1 Assessment of strategies and models

The model quality was assessed against different assessment indicators, which were designed to reveal the strengths and weaknesses of the respective AI strategy. This was followed by selection of appropriate training and analysis strategies.

The most important indicator here is the detection rate (true positive rate), which was analysed specifically for the different types and severity of damage. For this the ratio of correct detection to all present damage is determined. A TPR of 90 % means that nine out of ten damage cases were detected.

The mis-detection rate (false positive rate) is also important. Here, the number of detections which did not coincide with an existing damage was determined first. To put this number in relation to a total number, the damage-free running metres of the canal were used. A discretisation of 1 m was selected for this. An FPR of 10 % means that in 10 m damage-free sewer, damage was detected incorrectly in one meter.

By fine-tuning the detection sensitivity, an optimal weighting of the two ratios can be set [6]. This is the ROC curve.

A range of strategies can be considered for training neural networks (AI). So far, six different procedures have been used for implementing. Figure 5 shows that the detection rates can be increased not only by the quantity of training data, but also by the approach of respective AI strategies. Strategies have previously taken into consideration a range of different approaches: pixel-accurate labelling (1), mixed and separately trained networks (2/3) including box labelling, differently labelled training data (4), training using qualitatively-adapted labels (5) and focus on damage classes 1–3 plus the combination of AI with previous heuristics (6). Current results for the latter strategy now show detection rates of up to 100 %. In the next step, extended heuristics are added.

ROC curves (Figure 6) also indicate the classification ability. The area underneath a ROC curve is the measure for the quality of a classifier. As the figure on the left shows, the pipe connection which is easy to detect yields a maximum area below the ROC curve and therefore a high hit rate (“correct positive classification”).

5.2 Neural reasoning errors

There has been a burgeoning interest in artificial intelligence, which is increasing steadily with the increasing application areas. AI is above all pattern-recognition and this offers the po-

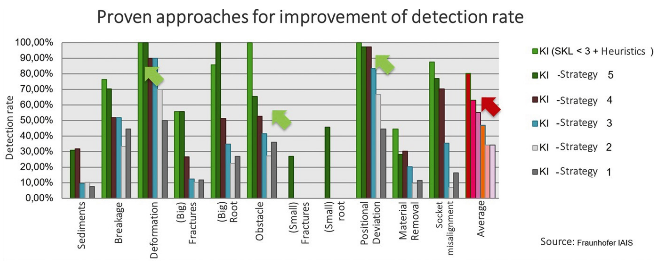

Fig. 5: Development of detection rates based on different strategies with 2D image data

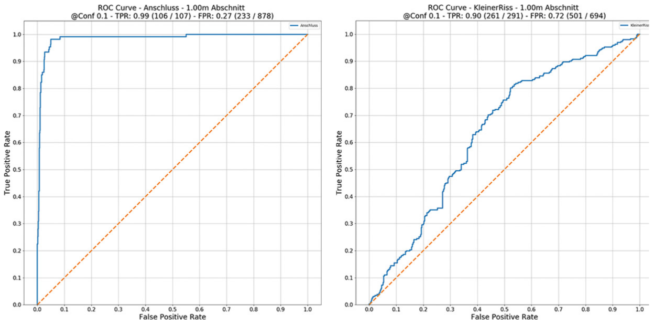

Fig. 6: Illustration of the dependence of true-positive rate and false-positive rate based on an easy-to-detect pipe connection (left) and a hard-to-detect small crack (right) in a ROC diagram

tential to optimise damage detection wherever there are adequate quantities of labelled training data of adequate quality. In this case both the image and label quality are relevant as is the representativeness of the training data. The findings obtained in the BMBF project so far confirm these conditions. Therefore, neural networks, which were specifically trained with images of one sewer material, e.g. stoneware – give higher detection rates on these than networks trained in "mixed" systems. The potential of synthetic training data must also be considered here. Data Augmentation by rotating or mirroring known damage may increase the amount of training data, but it can also generate unrealistic image effects The potential of AI is clear. Particularly the "relearning" of neural networks by additional image examples (i.e.: new training data) delivers a considerable increase in the detection rates.

The results of the AUZUKA project enable an inter-municipal cooperation of sewer operators, in which training data is provided in accordance with standardised specifications: The quality of the AI results can then be increased considerably in a short time.

5.3 Travel and annotation

With the selected journeys all main damage groups and relative damage extent are represented with sufficient frequency. First, the frequently-occurring pipe materials stoneware and concrete with the diameter DN 200 up to DN 400 are selected. In the sections there should be adequate damaged and undamaged areas.

In the context of the research project, the extent to which the training materials selected for the AI depended on individual experts was investigated:

Three experts independently marked damage in the image material of the pipe travel sections with "boxes" and "damage groups" (box labelling). The damage cases including location and damage group (for example root, crack, confluence) were thus detected on an unwind. For this, the image of the sewer interior wall is divided lengthwise at the apex and "unrolled" as a 2D image.

The results were very different because the experts had different foci depending on their roles within their companies. The damage detection spectrum ranged from pure damage detection and inventory to determining the repair requirement:

Expert 1 placed high value on the quality assurance of the investigation of condition and marked each damage case with a box. The second expert was looking for the risk potential and collated several damage cases correspondingly within one box. The third expert focused on determining the repair requirement, and the box enclosed for example half of the section. The box selections of the three experts were then stitched and marked with different colours (Figure 7).

Example corrosion: In the case of concrete corrosion in the base not globally the whole of the section base is marked. Neither every single corrosion hole is labelled, but only the areas of the base which exhibit distinct corrosion are marked.

This comparison example shows that "feeding" an AI with bulk data of very different qualities leads to correspondingly unreliable results. The AI did not supply satisfactory detection rates because of the very different box labelling of the three experts (see also Figure 5, Strategy 4). In the result, emphasis is placed on that the training images transferred to the AI are produced to the same requirements. The AI results are thus far more dependable.

5.4 Reflection on the interim results of the AI by sewer experts

Training results for the AI based on 2D image data were made available. The sewer experts from the research association made the following comments:

1 A higher resolution of the image material means that higher damage detection rates are possible because the AI can detect smaller damage cases. Especially in concrete sewers, due to the open pored structure, many details are visible which can be mistaken for damage. Therefore, the areas detected as damage-free are smaller. The optimal procedure for damage detection in this case is yet to be devised.

2 A spatial view (3D) is also absolutely necessary in order to clearly record all damage and the inventory in the sewer qualitatively and quantitatively. Currently the AI analysis is only based of 2D sewer unwinds. In addition to the images, the AUZUKA camera also captures the sewer area in 3D with structured light (see point 3). This allows detection of damage which projects from or is recessed into the sewer wall (deformations, protruding connections, displaced connections, concrete spalling, roots, caked-on materials and accumulations).

Damage detected by the AI can be verified against the 3D view and the spatial dimensions determined. In the event of uncertainty in the damage detection the quality assurance of the sewer operator makes the decision with the AUZUKA Viewer – the AUZUKA Viewer acts as an assistance system.

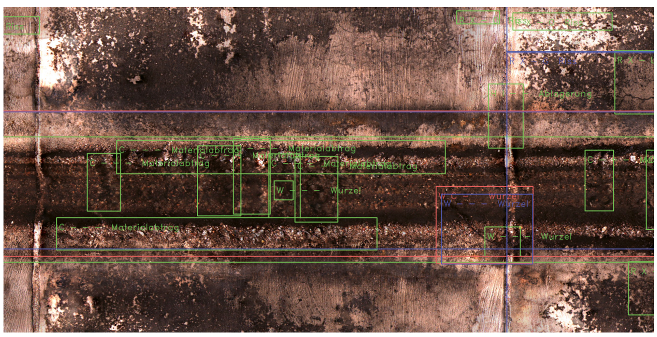

Fig. 7: Example of the different focus of three experts: Expert 1 = Green, Expert 2 = Blue, Expert 3 = Red – accumulation, material removal and roots were detected differently.

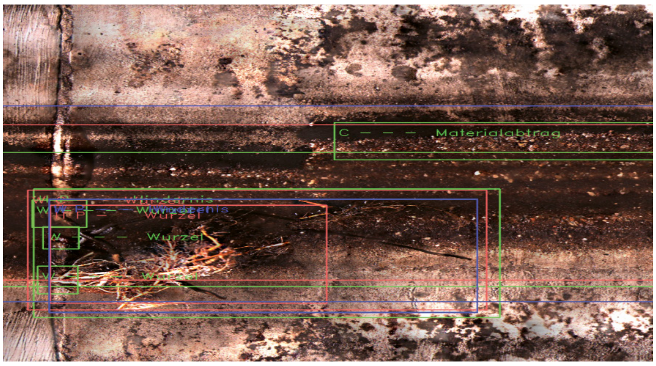

*Fig. 8: Taking heuristics into consideration: for example, in the Berliner Wasserbetriebe damage catalogue the following applies: HP** – "Root ball obstacle" is combined only with W** – root*

3 The AI is supported by a heuristic, with which boundary conditions are specified for certain damage groups, here are a few examples:
- Fine roots are only captured in direct vicinity to sockets and connections.
- Cracks in the glaze in the socket area of stoneware pipes are shrinkage cracks caused by the baking process.
- Flow tracks in the bottom of the sewer are conspicuous, but are only an insignificant discoloration of the sewer wall.
- Unglazed areas on stoneware sockets are insignificant.

The aim is to achieve high reliability in the data capture, classification and determination of the extent of serious damages. Areas without or with slight damage should be dependably (100 %) recognised as such.

The results of the AI are further improved by providing an enhanced and processed data basis and by creating a more precise assignment by means of a heuristic (Figure 8 shows one example).

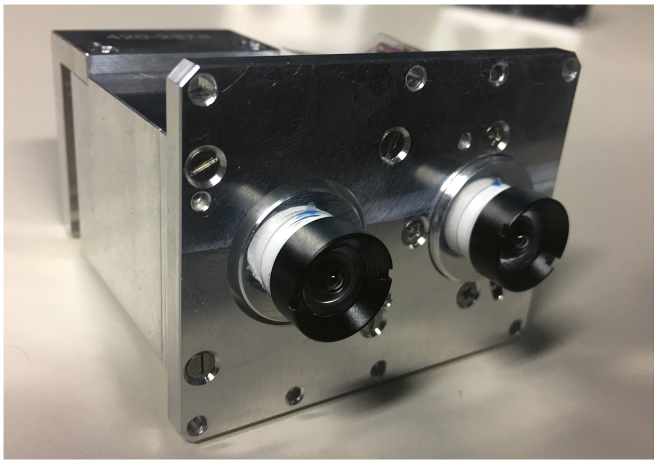

Fig. 9: Laboratory sample: 3D camera-projector module

6 New type of 3D-sensor head

6.1 Sensor head

Concepts for image recording systems of which fields of vision are traditionally forwards or backwards along the pipe axis are at a major disadvantage by their design principle: The relevant image content, which depicts the pipe interior wall, is found in this case at the edge of the images where the optical mapping quality however is most limited. In the central image regions where the best optical mapping qualities are located, only the dark void of the sewer is visible. Only a small proportion of the available camera pixels carry any relevant image information.

To really make full use of the camera resolution and image quality of the lenses used, a new 3D sensor head concept was developed in which the fields of vision of the image recording system are directed from the central pipe axis towards the internal pipe wall. The basic elements of the measurement head

Fig. 10: Evaluation sample: 3D sensor head with multiple camera-projector modules

for the damage detection, recording and measurement in the wastewater sewer are camera-projector modules, which were designed especially for close-ups and wide field angles (Figures 9 and 10). Such a module primarily comprises a projection and a 3K camera unit for 3D surface capture in accordance with the active stereoscopy principle. Additional LEDs on the front of the module produce a diffuse light source for taking the usual high-resolution colour images of the surface (texture images). The use of polarisation filters minimises unwanted reflections. Several modules arranged twisted against each other are integrated into one measuring head so that overall, the fields of vision of the modules map a complete and overlapping image of the pipe circumference with adjacent images, which can be registered and stitched. All of the measurement head camera-projector modules are respectively separately geometrically calibrated with a planar calibration target using the 3DEasyCalib™ [7] Toolkit from the Zentrum for Bild and Signalverarbeitung e.V. (ZBS, Ilmenau).

6.2 Robot drive carriage

Network partner JT electronics GmbH took on an important part of the overall package in the "robot development and system integration".

The carrier vehicle is a wheel-guided carriage unit which integrates the sensor/camera equipment. It completes the path distance measurement of the developed and detailed odometry produced by the IOSB institute, which is part of the Fraunhofer organisation (section 3.2). The development and production of the functional model of the camera was based on several processes in which the type of camera module integrated different functions.

The task was to provide transport and power supply for the camera module and to develop a new and robust optical fibre cable system, which guarantees high-powered digital data transfer along with precise control of the unit in the sewer. According to an optimised performance calculation and implementation, it is possible to carry out 300 m journeys along sewers within a range of 3–20 cm/s. The inclusion of an office workspace in the transport vehicle and the ergonomic design of the high quality workstation met further requirements in the joint project.

A high-traction carrier vehicle with an integrated height adjustment mechanism was developed to guide the camera module along the sewer in the centre of the pipe (Figure 11). This has the benefit of symmetrical clearances to the pipe wall and

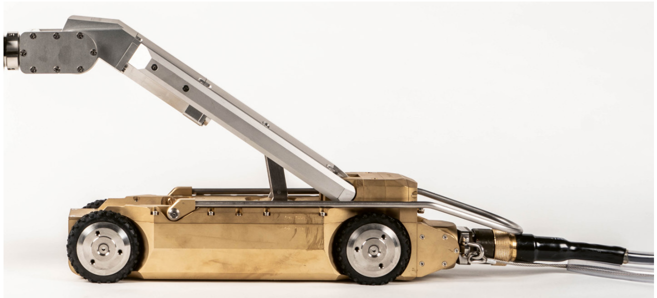

Fig. 11: Wheel-guided carriage unit transports the camera-sensor module with integrated height adjustment

therefore far better preconditions for the image quality for AI. A further optimisation concept is the decoupling of the driving motors for the return journey, so the entire unit is drawn back out of the sewer by the cable. With the latest final function samples, top quality image data can be obtained from DN 200 up to DN 300 sewers.

Objective documentation and log data are guaranteed. Post-processing is carried out using the criterion of substance preservation, with hydraulic calculations for repairs and further engineering, and stock depreciation and requirements.

6.3 Vehicle control

The software module for vehicle control is adaptive and platform-independent control and monitoring software, which can control and monitor a variety of carrier vehicles (Figure 12). The benefit lies in the fact that no additional hardware (for example joystick, control console etc.) is needed. An "intuitive" modular assembly system can show the user different control and display elements permanently or temporarily as required. Several sensor sources can be connected to the carrier vehicle and analysed, for example speed, manometer, temperature, warnings etc. All control commands are communicated via a CANBus.

Real-time visualisation (Digital Twin) in the form of a 3D-model of the carrier vehicle gives useful insights into the operating status of the vehicle during use (Figure 13). For example, the required stroke of the sensor head arm can be visualised for different nominal diameters. The software offers different expansion options for customer-specific requirements.

7 Conclusion

Artificial Intelligence offers the potential to considerably increase the workflow efficiency for damage analysis in the in-

Fig. 12: Universal vehicle control

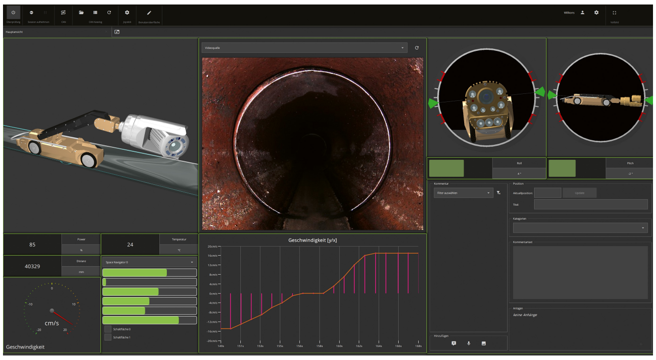

Fig. 13: Realtime visualisation of the vehicle during operation

vestigation of condition of sewer network. The use of (partly-) automated assistance can release the recording staff to devote them to other more technically demanding damage types.

To achieve the ideal of error-free damage detection of consistent quality it is worth using image data processing to create an improved 2D-data basis with which the AI can be trained. The quality of appropriate 2D and also 3D training data is of great importance in this case. Measurement data which has not been qualitatively pre-sorted lead to correspondingly unreliable results. Therefore, there is a need for development to achieve greater reliability in the capture, classification and extent determination of serious damage.

The potential of AI is clear, so its further development will pay off. Inter-municipal cooperation in this case should considerably accelerate investigation of sewer condition and stabilise its quality.

8 Prospects

By the end of the project in December 2020 hybrid processes will be used for automated image capture. Besides, neural networks heuristics in combination with traditional approaches are used as well. The AI offers assistance for expert appraisals when damage detection with high hit rates is provided, respectively marked in accordance with type and extent. In the medium term, AUZUKA can be the foundation for automatic assisted and reliable monitoring of what is the most important urban infrastructure. A further added value of the AUZUKA assistance system is in the shorter time interval between the camera inspection and the result of the actual investigation of condition.

Acknowledgement

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Authors

Dipl.-Ing. Jan Waschnewski, Dipl.-Ing Ralf Hilpert,
Dipl.-Ing. Daniel Sauter
Berliner Wasserbetriebe
Cicerostraße 24, 10864 Berlin, Germany

E-Mail: jan.waschnewski@bwb.de

Dipl.-Ing. René Döhring
e.sigma Technology GmbH
Langewiesener Straße 16, 98693 Ilmenau, Germany

Prof. Peter Eisert, M. Sc. Johannes Künzel
Humboldt-Universität zu Berlin
Visual Computing
Unter den Linden 6, 10099 Berlin, Germany

Dipl.-Ing. (FH) Ulrich Jöckel
JT-elektronik GmbH
Robert-Bosch-Straße 26, 88131 Lindau, Germany

Dr.-Ing. habil. Karl-Heinz Franke, Dipl.-Ing. Daniel Kapusi
Zentrum für Bild- und Signalverarbeitung (ZBS) e. V.
Werner-von-Siemens-Straße 10, 98693 Ilmenau, Germany

Dipl.-Phys. Klemens Kresin
Kappa optronics GmbH
Kleines Feld 6, 37130 Gleichen, Germany

Dipl.-Ing. Klaus-Jochen Sympher, Dipl.-Ing. Birgit Schalter
Dr.-Ing. Pecher und Partner Ingenieurgesellschaft mbH
Sachsendamm 93 – Aufgang B, 10829 Berlin, Germany

Dr.-Ing. Philipp Woock
Fraunhofer IOSB, Institut für Optronik, Systemtechnik und Bildauswertung
Fraunhoferstraße 1, 76131 Karlsruhe, Germany

Dr. Florian Zimmermann
Fraunhofer Institut für Intelligente Analyse- und Informationssysteme (IAIS)
Schloss Birlinghoven, 53757 Sankt Augustin, Germany

31st Performance Verification for Municipal Wastewater Treatment Plants

Comparison of Nitrogen Removal Processes

DWA Working group BIZ-1.1 "Wastewater treatment plant neighbourhoods"

Abstract

The DWA Performance Verification for Municipal Wastewater Treatment Plants paints a representative picture of the treatment performance of wastewater treatment plants in Germany. Data for Austria and South Tyrol is also included for comparative purposes. All told, the requirements of the EU Urban Waste Water Treatment Directive were met or far surpassed in a nationwide average during the reporting year of 2018. While there are no major variations between the different size categories of wastewater treatment plants when it comes to their degradation of chemical oxygen demand and nitrogen, wastewater treatment plants designed to serve fewer than 10,000 residents do much worse at eliminating phosphorous. Particular attention was paid to nitrogen elimination this year. Plants with intermittent denitrification fared the best. However, this success is tied to somewhat higher ammonium discharge values. A decision must be made on a case-by-case basis about which parameter must be accorded the higher priority

Key words: wastewater treatment, municipal, Germany, Austria, South Tyrol, wastewater treatment plant, performance verification, nitrogen elimination

1 Aims, principles and limits of national performance verification

More than 30 years ago, the term "benchmarking" was introduced. The growing scope of data and national analysis of results have steadily developed so that in today's terminology, the more general description "performance verification" appears more appropriate. Therefore this new term will be used henceforth.

The DWA (German Association for Water Management, Wastewater and Waste) performance verification is an indicator of the quality of wastewater cleaning and the related energy consumption. The performance verification is the outcome of the skilled work of the operating personnel, which is acknowledged here. The data of the performance verification has been gathered and analysed by the DWA regional groups and the ÖWAV (Austrian Water and Waste Management Association).

According to the German Federal Statistical Office, the level of connection of the inhabitants to municipal wastewater treatment plants was 97.1 %. Of the total of 9105 municipal wastewater treatment plants in Germany with a design capacity of 151.8 million residents, 5462 wastewater treatment plants with a design capacity of 132.2 million residents participated in the 31st DWA performance verification. With a participation rate of 87.1 %, the results for 2018 can be considered representative for Germany. The more than 3.6 million spot measurements taken by operating personnel in the context of self-monitoring, and which are incorporated in the evaluation as mean annual values, provide the foundation.

As in the past, the evaluation is grouped by DWA regional groups and size range (SR) of the wastewater treatment plants. The distribution of wastewater treatment plants with respect to design capacity and number is shown in figure 1. While only 4 % of the wastewater treatment plants have a design capacity greater than 100,000 PE (population equivalent) (SR 5), these plants represent 52 % of the total design capacity. The rows about energy in table 1 show the overall energy consumption of the municipal wastewater treatment plants in Germany cov-

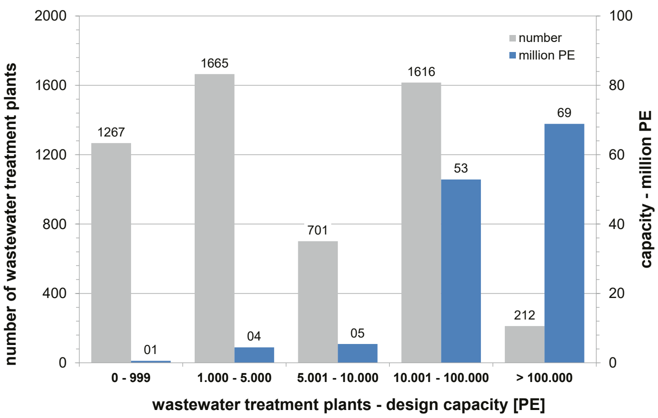

Fig. 1: Number and design capacities of the wastewater treatment plants taking part in the DWA performance verification in 2018 per plant size

ered by the performance verification (coverage 87.1 %) at 3139 GWh/a. This lies within the order of magnitude of approximately 2.4 % of the domestic current consumption [129 TeraWh, source: German Environment Agency (Umweltbundesamt) 2018]. It is also clear that in regional groups with predominantly large wastewater treatment plants such as, for example: North RhineWestfalia, the energy generation is over 50 %, while in a regional group such as Hesse/Rhineland-Palatinate/Saarland with lots of small plants with no fouling, less than 29 % of energy used is generated by sewage treatment plants.

2 Results

Table 1 shows the collated results of the in and outflow measurements (freight-weighted mean values), the elimination performances, further parameters and details about participation.

As in previous years, the results of the performance verification of the ÖWAV wastewater treatment neighbourhoods for facilities in Austria and South Tyrol were also shown.

Compared to the previous year, the degree of contamination in the intake increased slightly due to the reduced wastewater quantity because of the longer dry weather periods. The out-

DWA Federal State Association / parameter		Baden-Württem-berg	Bavaria	Hesse/ Rhineland-Palatinate/ Saarland	North	North-East	North-rhine-West-falia	Sachsen/ Thu-ringia	DWA	ÖWAV**)
wastewater treatment plant (number)		898	1585	1190	521	289	476	503	5462	775
annual sewage amount (millon m³)		1454	1396	1178	808	493	2007	408	7744	1090
installed volume PE (million residents)		21,4	24,7	15,2	20,7	12,7	29,5	8,0	132,2	22,2
mean PE loading (million residents)		15,7	17,5	12,9	16,3	12,0	19,7	6,5	100,7	15,5
installed PE/mean PE loading		1,37	1,40	1,18	1,27	1,06	1,50	1,23	1,31	1,43
specific resultant wastewater [m³/(PE · a)]		93	80	91	50	41	102	63	82	70
specific energy consumption [kWh/(PE · a)]		33,7	30,4	31,6	30,6	28,7	34,3	31,8	31,7	27,3
total electricity consumption [GWh/a]		520	518	397	489	342	672	203	3139	401
wastewater treatment plants taken into consideration (number)		873	1332	1145	432	270	465	463	4980	775
total energy generation [GWh/a]		201	n. e.	114	208	153	356	81	1112	155
wastewater treatment plants taken into consideration (number)		255	n. e.	185	116	57	204	56	873	138
COD	inflow (m/L)	472	579	483	884	1068	459	698	582	624
	effluent (mg/L)	20	27	23	39	41	27	29	27	31
	elimination (%)	95,8	95,4	95,2	95,6	96,1	94,2	95,8	95,3	95,1
total N*)	inflow (m/L)	43,9	56,0	47,8	75,2	89,0	44,5	63,8	54,0	50,6
	effluent (mg/L)	9,5	9,9	8,8	9,1	11,4	7,3	10,0	9,0	9,2
	elimination (%)	78,3	82,3	81,6	87,9	87,2	83,6	84,4	83,3	81,8
total P	inflow (m/L)	6,2	7,9	6,4	10,7	13,1	6,2	9,1	7,6	7,2
	effluent (mg/L)	0,42	0,78	0,61	0,54	0,53	0,42	0,86	0,56	0,58
	elimination (%)	93,2	90,1	90,5	95,0	96,0	93,2	90,5	92,7	91,9
NH_4-N	effluent (mg/L)	0,66	1,60	1,73	1,29	0,94	0,94	1,35	1,18	1,30
NO_3-N	effluent (mg/L)	7,3	6,5	5,3	6,0	8,4	5,0	6,5	6,2	6,2
N_{inorg}	effluent (mg/L)	8,0	8,1	7,1	7,2	9,3	5,9	7,9	7,3	7,5

*) total N = N_{inorg} + N_{org}
**) Austria and South Tyrol (without industrial wastewater facilities)
n. r.: not recorded

Table 1: Average intake and discharge values, elimination performances and characteristics

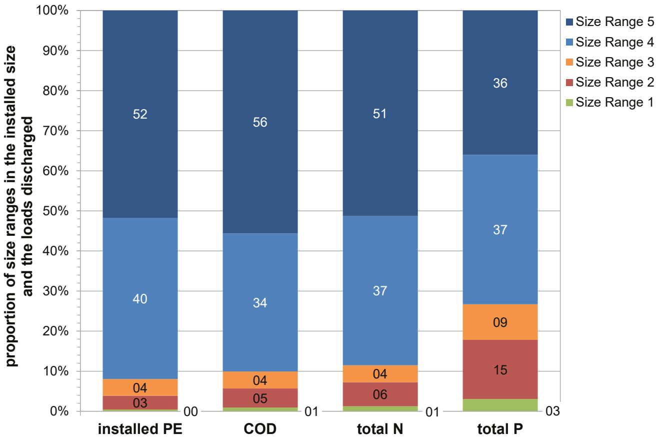

Fig. 2: Percentage proportions of capacity (PE) and introduced load by size of wastewater treatment plant

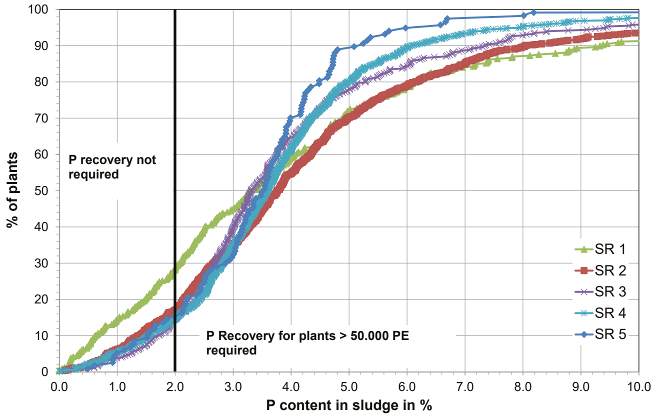

Fig. 3: Frequency of the P content in the resulting sewage sludge being below the calculated value from the eliminated P load and sludge in % dry mass by plant sizes

flow values were nevertheless around the same so the high level of elimination of nutrients achieved in the previous year has been improved on again nationwide.

Significant, as compared to the results of the other regional groups, are the higher N and P-elimination performances in the north and north-east regional groups. This is due to the significantly higher concentrations in the inflow. The separate systems, which are more widespread in these German federal states, may be amongst the reasons for this.

On the whole, as a federal average, it was possible to meet or significantly exceed the requirements of the EU Urban Waste Water Treatment Directive, again in 2018. It is still nevertheless necessary for some installations (sewer network and wastewater treatment plants) to be brought up to the present state of the art.

The reference value used to determine the specific wastewater input and the specific electricity consumption was the average plant load in relation to number of residents from the average COD inflow. A specific COD load of 120 g/(PE · d) was assumed here.

The specific resultant wastewater is 82 m³/(PE · a) in the national average. In the north and north-east regional groups the specific resultant wastewater is far lower due to the widespread separate system. In the other regional groups, most drainage takes place in combined systems, and the rainwater makes for a considerably higher specific resultant wastewater on the wastewater treatment plants.

Data on electricity consumption, likewise, was collected in all regional groups. The specific electricity consumption [kWh/(PE · a)] was calculated for 4980 wastewater treatment plants. The specific current consumptions differ very little across the regional groups. The lowest values were for Austria and South Tyrol and for the northeast regional group while the higher values tended to be in the regional groups of Baden-Württemberg and North-Rhine Westphalia.

The COD and total nitrogen loads introduced into the bodies of water correspond largely to the respective proportions of the installed sizes, grouped into plant sizes (figure 2). Plants sizes 1 to 3, however, have an above-proportional share of phosphorus at about 27 %, although, taking their installed

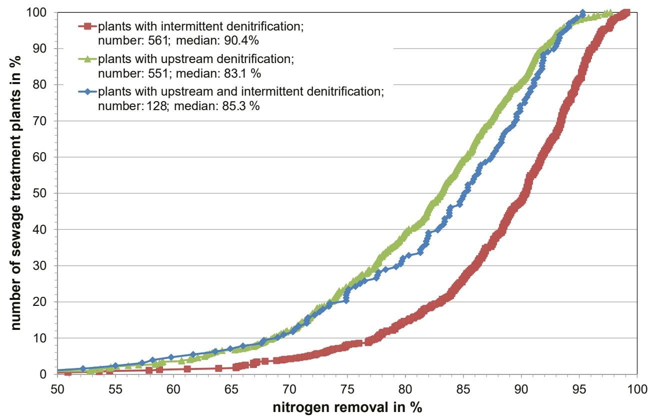

Fig. 4: Frequency of the nitrogen removal of size 4 and 5 plants being below the design value per nitrogen removal method used in %

Plant size	**denitrification process**			
	intermittent	upstream	combination of upstream and intermittent	combination of upstream, intermittent and downstream
	number			
SR 1	189	10	0	0
SR 2	515	59	12	2
SR 3	294	87	17	0
SR 4	529	454	111	8
SR 5	32	97	17	9
all	**1559**	**707**	**157**	**19**

Table 2: Number of different processes for nitrogen removal in the DWA performance verification

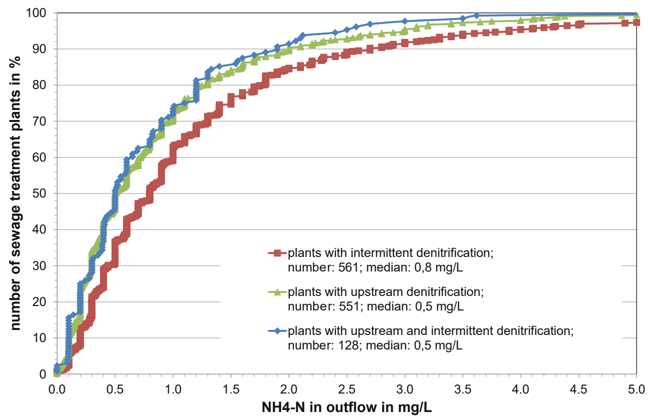

Fig. 5: Frequency of the NH_4-N run-off values of systems of plant size 4 and 5 being below design value according to the nitrogen removal process used

size into account, these plants only represent a proportion of 8 %. The high proportion of plant sizes 1 to 3 is caused by those systems which are not legally required to implement phosphorous elimination.

With regard to the new sewage sludge regulation, the P-content in the sewage sludge was calculated from the eliminated P-loads and the sludge volume (figure 3). Nevertheless, incorrect sludge load details cannot be excluded because for the calculation of the dry sludge mass the dried solid content analysis of a sample is required which must be representative of the actual sludge volume. A representative sample is, however, difficult to obtain due to the inhomogeneities within the dewatered sludge. The illustrated results should be viewed with reservations. However, it is clear that around 85 % of plants over 1000 total number of inhabitants exhibit a P-content in sludge of more than 2 %. In treatment plants below 1000 PE only, 25 % of the systems fall below this value, probably due to lack of phosphor precipitation. P-elimination would then be no obligation for these plants.

3 Comparison of nitrogen removal processes

In the context of the annual data collection, regional groups query the processes used for nitrogen removal in the wastewater treatment plants. In the operating year 2018, a total of 2442 wastewater treatment plants was assigned to the different processes (table 2). Accordingly, the most frequently used is intermittent denitrification, particularly in plants with a capacity of up to 10,000 E. For higher capacities, upstream denitrification is more frequent. In the majority of facilities in the plant size 4, a combination of upstream and intermittent denitrification is used. Downstream denitrification is seldom found, even in plant sizes 4 and 5.

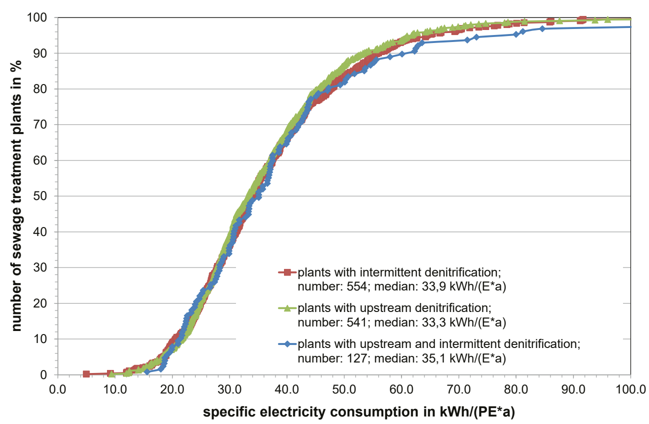

Fig. 6: Frequency of the specific electricity consumption value of plant size 4 and 5 using the nitrogen removal process being below

The following analyses are limited to plant size 4 and 5 wastewater treatment plants, because smaller plants are not subject to generally applicable requirements for denitrification and deliberate denitrification is carried out only on operational grounds in which the optimum elimination rate is not the priority.

The plants with intermittent nitrogen removal more frequently achieve significantly greater denitrification. The median value in these plants is 90.4 %. Plants with upstream denitrification show lower values (figure 4). The median value however is still very high at 83.1 %. Plants with a combination of the two processes lie in between, the median value is 85.3 %. It must be stated that around 10 % of the plants with upstream nitrogen removal achieve below 70 % denitrification. This also relates to plants which operate a combination of upstream and intermittent denitrification. Presumably the intake conditions in these cases limit the scope of the nitrogen removal.

Nevertheless higher denitrification at intermittent aeration is accompanied by higher NH_4N discharge values (figure 5). The median value in these plants is 0.8 mg/L, whereas plants with upstream denitrification exhibit a median value of only 0.5 mg/L. The plants in which the two processes are combined differ only slightly in relation to the NH_4N discharge values.

The widespread assumption that lower energy consumption results from the intermittent denitrification due to the occasional switching off of aeration is not confirmed by the analysed data. Figure 6 shows that energy consumption is practically unaffected by the denitrification processes used.

4 Summary

Participation in federal DWA performance verification was also high in the year 2018. We would like to offer our sincerest thanks to the operating personnel at the municipal wastewater treatment plants. The results provide a representative picture of the cleaning performance of wastewater treatment plants in Germany. In 2018, 5462 wastewater treatment plants participated with a design capacity of 132.2 million PE. As in the previous year, the corresponding data from ÖWAV for Austria and for South Tyrol are included for comparison. The results correspond largely to the data for German wastewater treatment plants.

On the whole, as a federal average, it was possible to meet or significantly exceed the requirements of the EU Urban Waste Water Treatment Directive, again in 2018. While for COD and nitrogen, degradation rates do not differ greatly across the different plant sizes, the wastewater treatment plants with a design capacity of fewer than 10,000 PE perform considerably worse for phosphor elimination. These wastewater treatment plants represent a proportion of about 8 % of the total design capacity, but are responsible for about 27 % of the phosphorus load introduced into the bodies of water. Causes lie with those plants which, due to an absence of statutory requirements, do not have to carry out any specific measures for phosphorus elimination.

The calculated P-content in sewage sludge in treatment plants of over 1000 total number of inhabitants and population equivalents in around 80 % of plants is over 2 %. Thus, fewer than 20 % of the plants over a connection size of 50 000 E should not be required to implement P-recovery.

With respect to nitrogen removal, the plants with intermittent denitrification perform the best. Nevertheless, this result comes with slightly higher NH_4N discharge values. It is necessary to weigh up in individual cases which parameters to assign a higher priority. In regard of specific current consumption, no process performs the best.

A further, general need for action in respect of wastewater treatment plants may be triggered in coming years as a result of statutory requirements for the construction of a fourth purification stage to remove trace substances from the wastewater. Extensive research is at present being undertaken in this field.

Acknowledgement

The DWA working group BIZ 1.1 “Wastewater treatment plant neighbourhoods” thanks all participants, lecturers and representatives of the wastewater treatment neighbourhoods for their support in this survey and analysis of the data, without which this national performance verification would not be possible. KA

Opportunities and Challenges for Non-Potable Water Reuse

Jens Haberkamp (Münster/Germany), Stefan Gramel (Frankfurt a. M./Germany), Tim Fuhrmann (Essen/Germany)

Abstract

Against the background of the world population growth, accompanied by increasing water demand on the one hand and at least regionally decreasing freshwater resources as a consequence of climate change on the other hand, reclaimed water is increasingly considered as a valuable substitute for natural water resources. DWA has recently published an extensive report covering a variety of aspects to be considered within the scope of non-potable water reuse. This article provides an overview of and excerpts from DWA Topics "Non-Potable Water Reuse – Development, Technologies and International Framework Conditions for Agricultural, Urban and Industrial Uses" [1][*].

1 Introduction

Along with the world population growth, the need for increased food and energy production, both with significant associated "water footprints," also rises [2]. Scarcity of locally available water supplies, competition for water with agriculture and energy, climate change impacts, rising energy prices, environmental restoration, and economics will require communities to reuse far more water. Thus, water reclamation and water reuse will play an important role in future water management.

Types of Water Reuse

Unplanned reuse of municipal wastewater – untreated or treated – has been practiced for many centuries with the objective of diverting human waste outside of urban settlements [3], but also by farmers in many arid and semiarid regions to irrigate their fields. Planned water reuse is defined as the beneficial use of treated wastewater and can either serve non-potable or potable applications. Non-potable water reuse includes all water applications other than the augmentation of drinking water supplies. Those practices comprise agricultural and urban landscape irrigation (Figure 1), recreational applications, car washing, firefighting, wildlife habitat maintenance, stream flow augmentation, intrabuilding applications (such as toilet-flushing), industrial cooling and processing, as well as groundwater recharge and seawater intrusion barriers [4].

Figure 1: Water reuse for drip irrigation of public green spaces in Bahrain (source: p2m berlin)

Multiple planned non-potable reuse projects for agricultural and landscape irrigation, but also potable reuse applications, have demonstrated that the use of reclaimed water for such applications can be practiced in a safe manner. The total volume of municipal wastewater produced per day worldwide is esti-

[*] DWA Topics "Non-Potable Water Reuse" (2019) was prepared by the following members of the DWA Working Group BIZ-11.4 "Water Reuse": Prof. Dr. *Peter Cornel* (Darmstadt), Prof. Dr. *Jörg E. Drewes* (Garching), *Edgar Firmenich* (Frankfurt a. M.), Dr. *Tim Fuhrmann* (Essen), Dr. *Stefan Gramel* (Frankfurt a. M.), Prof. Dr. *Jens Haberkamp* (Münster), *Andreas Hartmann* (Braunschweig), Dr. *Wolfgang Jendrischewski* (Köln), *Volker Karl* (Bad Nauheim), Prof. Dr. *Steffen Krause* (Neubiberg), Dr. *Josef Lahnsteiner* (Vienna), Dr. *Manfred Lübken* (Bochum), Dr. *Ingmar Obermann* (Eschborn), Dr. *Florian Schmidtlein* (Essen), *Jochen Sinn* (Darmstadt), Prof. Dr. *Dörte Ziegler* (Koblenz); the following guests have contributed: Dr. *Tamara Avellán* (Dresden), Dr. *Serena Caucci* (Dresden), *Emily Fokin* (Münster), *Alexander Grieb* (Frankfurt a. M.), *Roland Knitschky* (Hennef), *Veronika Zhiteneva* (Garching)

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mated to be about 684 million m³. However, only about 30 million m³ (~ 4.4 %) receive tertiary or advanced treatment. The largest application of water reuse globally is for agricultural irrigation [5].

The German DWA Topics on Water Reuse

Water reuse practices have to be safe for users, groundwater, surface water, and soil. Thus, it is critical that the provided effluent quality is suitable for the desired use (fit for purpose) and assures safe practices. This can be accomplished by appropriate technological, administrative, financially sound, and socially accepted approaches tailored to local and regional conditions and proper risk management.

To address such issues, the first edition of DWA Topics "Treatment Steps for Water Reuse" was published in 2008, including at its core an assessment matrix of suitable treatment processes for non-potable water reuse intended to help planners with the selection of appropriate technologies. The revised DWA Topics edition "Non-Potable Water Reuse – Development, Technologies and International Framework Conditions for Agricultural, Urban and Industrial Uses" [1] has been extended by aspects related to the development and implementation of water reuse projects going beyond a technical point of view. The report is intended to provide general guidance for water utilities, consulting engineers and regulatory agencies in planning and expanding non-potable water reuse.

DWA Topics "Non-Potable Water Reuse" [1] is structured into ten sections, covering regulations and compliance, development of water reuse projects, health risk management, socio-cultural aspects and public perception, ecological and agricultural aspects, energy requirements, economics, as well as an assessment matrix regarding various treatment processes. An additional compilation of case studies provides valuable experiences from full-scale water reuse projects in the Middle East, Africa, China, Central and South America, and Europe. The following sections provide an overview of the report's contents, focusing especially on aspects regarding the development and implementation of water reuse projects.

2 Regulations and Risks

Conventionally treated municipal wastewater effluents include pathogenic microorganisms, antibiotics including antibiotic resistant bacteria and antibiotic resistance genes, as well as residual nutrients, dissolved solids, remaining levels of heavy metals, and a wide range of natural and synthetic trace organic chemicals. Their presence is generally concerning due to potential adverse impacts on human and environmental health, particularly from pathogens and chemicals. Thus, safe water reuse practices require the implementation of proper barriers to mitigate these water quality issues to levels that do not impose any adverse effects to operating staff of water reclamation facilities, users of reclaimed water, or the environment (Figure 2).

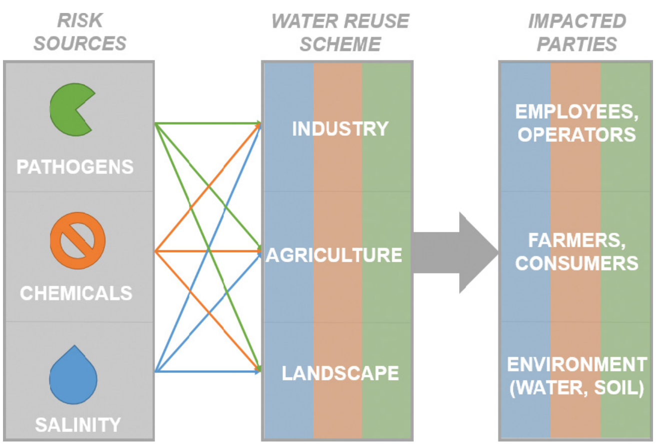

Figure 2: Risk sources and exposure in water reuse schemes

Management of Risks

To manage risks related to water reuse, government regulations have to go beyond the definition of technical standards and requirements but must also cover additional aspects such as source control programmes, water quality monitoring, and the responsibilities and rights of the parties involved (implementation organizations, operators, consumers), as well as a proper rate or fee structure for reclaimed water.

Usually, there is no lack of legally binding sets of rules and standards or of recommendations for minimum standards for water reuse in many countries. The problem in most countries with scarce water resources is not the existence or quality of the standards for the recycling of water but rather, above all, an implementation deficit with a lack of compliance and insufficient monitoring by state and/or private regulatory institutions. Often, the capacities and resources of those institutions are not appropriate to guarantee a functioning and trustworthy regulatory system.

International Guidelines

In 1992, the Food and Agriculture Organization (FAO) published recommendations for the agricultural application of reclaimed water being based on previous WHO guidelines [6] and considering health aspects as well as requirements in terms of crops and soil [7]. Extensively revised guidelines for non-potable water reuse were published by the World Health Organization (WHO) in 2006 [8]. These represent a general framework for the development of individual national directives and standards for the reduction of microbiological health hazards associated with water, and provide information regarding monitoring procedures to assure microbiological safety. Fundamentally, the quality requirements are aimed strongly towards the application purpose of the water and consider, for example, salt and nutrient contents for agricultural water uses, in addition to those of pathogens.

The WHO approach to managing risk associated with water reuse is based on the Hazard Analysis and Critical Control Point (HACCP) system for analysis and control of hazards in any treatment train, and the Stockholm framework for preventive risk assessment. Risk management frameworks feature the same steps: identify the problem, determine the hazard in the system, quantify the hazard (exposure, dose-response), assess and characterize the risk, and manage the risk (Figure 3). Risk assessment can range from a straightforward risk matrix to an extensive quantitative microbial risk assessment.

The main guideline for addressing risk in non-potable water reuse is the Sanitation Safety Planning (SSP) Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta

Figure 3: Risk management framework for determining whether a system meets tolerable risk levels (adapted from [9])

[10]. SSP is a participative approach involving all stakeholders. Risks are followed from wastewater generation through the various reuse applications (agriculture, irrigation) to their individual end points (environmental discharge, crop production). It serves to maximize benefit of wastewater or greywater reuse while minimizing illness and contamination. Responsibility for SSP implementation is shared across numerous stakeholder agencies, depending upon the reclaimed water application purpose. Due to the broad nature of SSPs, their implementation can be difficult to coordinate, particularly in developing countries. Difficulties are encountered due to lack of or incompletely established improvement plans, supporting programmes, and management procedures. Additionally, the chances of success might be reduced by problems such as lack of training for workers and farmers, lack of monitoring programmes, lack of local community education on behavioural changes needed for compliance, and lack of governmental initiative and stakeholder support.

3 Development of Water Reuse

In most cases, sustainable development of water reuse schemes follows a typical order of development steps. These steps are mostly supported by qualified consulting experts.

As the implementation of water reuse must be rooted in an adequate institutional framework and in sufficient acceptance by relevant stakeholders, at first an initial analysis is required to determine existing regulatory frameworks for water reuse. Adequate means of public engagement for acceptance of water reuse should also be identified. Thus, once a water reuse opportunity is proposed, a preliminary assessment to determine existing local water resources and infrastructure as well as economic, institutional, legal, and social conditions should be conducted to determine whether the project is practical and necessary.

If so, an in-depth feasibility analysis is carried out. In the case of confirmation of the feasibility, an appropriate water reuse infrastructure is installed, and measures for sustainable performance, including continuous promotion of acceptance and updates to regulatory and institutional frameworks, can be implemented.

The mentioned steps are briefly described in the following. More detailed information is given in the DWA Topics issue [1].

Preliminary Assessment

The preliminary assessment includes a rough analysis of the main elements of a potential reuse project, clarifying the need and crucial aspects for water reuse. It also sets the basis for decisions about the continuation in the development of the reuse project. It mainly includes the following tasks:

- assessing the need for reclaimed water use
- quantity and quality of potential reclaimed water
- options for infrastructure
- rough economic assessment
- screening of institutional and regulatory framework
- screening of environmental and social impacts
- overall analysis, support of decision process.

Feasibility Analysis

Based on the results of the preliminary assessment, a decision process of mainly authorities and political decision-makers sets the basis for the further steps of development. In case of a positive decision, a feasibility analysis is carried out. Occasionally, the preliminary assessment and the feasibility analysis are integrated into one study. The aim of the feasibility study is mainly to analyse thoroughly all relevant aspects and to develop a concept which can be taken as basis in further development steps (design, implementation phase). Crucial aspects of the feasibility study are:

- water quality and water quantity aspects
- technology and infrastructure
- economic analysis
- environmental and social impact assessment (ESIA)
- public involvement and public awareness
- monitoring system
- general institutional and organizational aspects related to the use of reclaimed water
- relevant aspects on the water users' side.

In the case of reclaimed water being used in agriculture, there is a range of additional topics to be analysed in this subject area, mainly:

- institutional analysis and concept for development
- extension and advisory activities
- support of farmers in day-to-day work
- information systems.

Based on the results of the feasibility analysis, a concluding decision is taken. This decision is based on positions of the relevant stakeholders and other key aspects of a large infrastructure project (such as the cost-benefit ratio, interests of the user groups, options for financing and environmental criteria).

Implementation and Operation of Water Reuse Facilities

The steps of implementation (preliminary and detailed design, tendering, and infrastructure implementation including supervision works) are basically the same as in all larger infrastructure projects.

Also the first phase of operation is basically similar to other infrastructure projects in the water sector. Nevertheless, special reuse-related topics have to be focused upon, such as trainings of the operational staff, support in the operation of the special treatment steps and the water quality control system, as well as support of the farmers (if related to agriculture).

When the effluent of a wastewater treatment plant is used by third parties, the operation of the plant changes its established role. The plant now enters the water supply market as a "water seller". Thus, the offered product – reclaimed water – requires reliable quality and introduces new, additional stakeholders into the management and operation of the plant. In general, the plant must consider at least the following reuse-specific issues in addition to the operation of conventional wastewater treatment plants:

- Water quality requirements: The production of reclaimed water places more emphasis on pathogen removal with absolute limits. Higher nutrient concentrations may be allowed when the water is used for irrigation purposes.
- Continuous availability of reclaimed water supply: The plant must guarantee quality and quantity at any time and in the long term.
- Reliable, independent quality control: A stringent internal monitoring structure as well as an external monitoring by independent supervisory bodies must be implemented.
- Additional facilities: Facilities for further treatment, storage, and distribution of reclaimed water are necessary. They might be controlled by a separate operator.
- Additional stakeholders: Since the use of the reclaimed water results in several additional processes for treatment, transport, and storage, the need for contractual clarification of responsibilities arises between the operation of the treatment plant, the operation of the subsequent facilities, and the use of the water. Hence, the number of involved stakeholders significantly increases (e. g., operators of storage and distribution systems, water users, water user associations, regulators and supervisory authorities, both from the water sector as well as the sectors the reclaimed water is used for).
- Form of organization: To ensure sustainable and coordinated operation of the related facilities, the organizational structures and, more precisely, the chosen operator model are important, particularly in the context of the regional logistical, institutional, and legal conditions.

4 Technical Barriers for Pathogens

Multi-Barrier Treatment Approach

To achieve reliable protection against harmful microorganisms, disinfection procedures must significantly reduce pathogens through removal, destruction, or inactivation processes. Also considering possible by-product formation, a multi-barrier treatment approach should be utilized in all water reuse applications. The various barriers include wastewater load control, appropriate wastewater treatment, disinfection, bacterial regrowth prevention, reclaimed water quality control, occupational safety measures, as well as monitoring of soil, groundwater, and final effluent quality in water reuse systems. Following the above-mentioned Hazard Analysis and Critical Control

Points (HACCP) approach to risk management, relevant parameters (or control points) such as disinfectant concentration, integrity of membranes or seals, and water quality parameters influencing pathogen removal efficacy are identified. Appropriate operational ranges for these identified parameters must be integrated within a monitoring programme based on existing national or local regulations, as well as international recommendations.

Assessment Matrix of Treatment Technologies

Treatment technologies for pathogen removal or inactivation include membrane filtration, microscreening, cloth filtration, sand filtration, as well as additional disinfection processes, such as UV disinfection, ozonation, or chlorination.

Wastewater treatment for the production of reclaimed water should be conducted using techniques that are best suited for the individual application, taking into account national regulations and international standards. In order to support planners and decision-makers with the selection of appropriate treatment processes for safe water reuse, an assessment matrix of various wastewater treatment processes has been compiled. The matrix included in [1] provides a general evaluation of technological options, which may serve as a basis for further detailed investigations considering site-specific conditions. Each process step is assessed with regard to aspects such as water quality, costs, consumption of materials and energy, and expenditure for preventive maintenance, among others. The assessment matrix is intended to provide fast and simple support for an initial evaluation of treatment options. It is not exhaustive and will not replace the engineering investigation for site-specific decisions. However, it should be applicable for most cases and enable reasonable decisions, even when access to expert knowledge is limited.

5 Ecological and Agricultural Aspects

Substitution of Freshwater

Consuming around 70 % of total available freshwater, the global agricultural water demand exceeds private and industrial consumption. The specific irrigation water demand depends on factors like the type of crop grown, climate, soil moisture content, and the crop's growth stage. According to an exemplary calculation included in [1], the crop water demand of an agricultural area of about 25–30 m^2 per capita can be covered by reclaimed water (assuming a rather high specific wastewater production of 200 litres per capita and day). However, although water reuse can only cover a limited proportion of the agricultural water demand, it contributes to the substitution of valuable freshwater resources.

Substitution of Fertilizers

Besides representing an additional water resource, the use of reclaimed water for irrigation provides nutrients free of charge for farmers. In the context of steadily increasing fertilizer prices over the past years, substitution of fertilizers by wastewater nutrients may play a more pronounced role in the future. The most important nutrients in wastewater irrigation are nitrogen, phosphorus, and potassium. The nutrient concentrations in reclaimed water depend on the degree of treatment. Efficient nutrient management depends on the type of crop grown, the soil structure, the expertise and training of the farmer, as well as the awareness about marginal-quality water as a nutrient source. A systematic and targeted nutrient supply by reclaimed water is sophisticated, since the crops' nutrient demand shows strong seasonal differences for both perennial plants, such as those grown in orchards, and field crops, which have different nutrient demands depending on their growth phase. In the context of water reuse, it is therefore recommended to count on only partial nutrient application and avoid applying in excess. In the case of partial supply, the farmers may additionally fertilize with mineral fertilizer. In case of excess application, the groundwater can possibly be impacted.

In addition to the substitution of irrigation water and fertilizer, further agricultural aspects regarding different irrigation methods, as well as the risk and management of salt accumulation in the soil are discussed in [1].

6 Energetic Aspects

Water and energy are inevitably interlinked. Water is required for exploring and processing conventional primary energy sources and for cooling when converting them into electric power, as well as in hydropower or biomass generation. On the other hand, energy is needed for running the water cycle.

Water reuse can reduce energy demands in the water cycle, especially where energy consumption for conveyance, transport, treatment and distribution of freshwater is high. Comparing the energy demands associated with freshwater production and distribution with the potential energy demands for provision of reclaimed water allows decision-making bodies to determine whether water reuse is feasible, from an energetic point of view, for specific applications.

Figure 4 exemplarily summarizes energy demands for all stages of the urban water cycle from water supply to wastewater treatment and discharge, taken from experiences in California and other locations. Utilization of reclaimed water (pink boxes) can be more energy efficient than supplying freshwater (blue boxes). In California, energy associated with recycling (0.11–0.32 kWh/m^3) is comparable to energy associated with conveyance, treatment and distribution, which ranges from

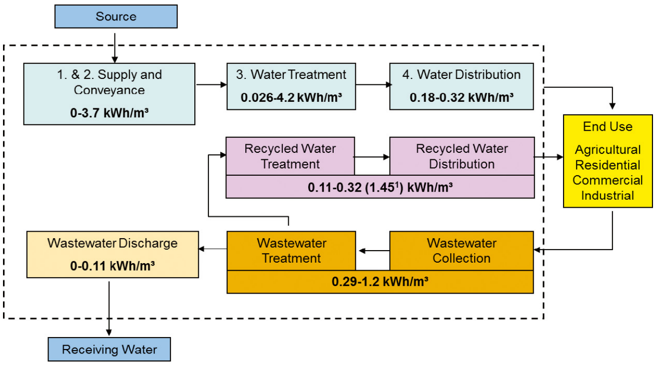

Figure 4: Range of energy intensities for water use cycle segments, based on values from California (blue: freshwater; pink: recycled water, brown: wastewater; adapted from [11], values converted in metric units, [1)] [12]: energy consumption for direct potable reuse including microfiltration, reverse osmosis and advanced oxidation)

0.21 (0.18 + 0.026) kWh/m³ to more than 4.5 kWh/m³, when assuming either long distance transport or desalination for treatment.

Energy consumption for adequate reclaimed water generation varies considerably depending on the raw water source (e. g., treated or untreated wastewater) as well as on the required quality of the reclaimed water. Tertiary treated, disinfected wastewater, especially after membrane bioreactors, often needs almost no additional treatment for agricultural irrigation or non-potable intra-urban uses, like street cleaning, irrigation or even toilet flushing. The more stringent the effluent standards are (i. e., the more energy is already embedded in the wastewater treatment), the less energy is required to produce reclaimed water.

7 Economic Aspects

As crucial step of the preparation of a reuse project, an economic analysis has to be carried out. In the context of the detailed analysis of a reuse project (cf. chapter 3), a cost estimation based on potential alternatives of a reuse scheme is required. The cost estimation represents the basic data for an economic analysis. Tables 1 and 2 categorize the costs for investment as well as for operation and maintenance.
In the economic analysis, quantitative methods, such as dynamic cost calculation (mainly the prime cost) and cash flow analysis, are applied. In comparison with other projects in the water sector, reuse projects face two specific obstacles:

- A high range of uncertainty of the input data: Methods such as sensitivity analysis, Monte Carlo method, and scenario analysis are usually applied to develop results considering the uncertainty.
- An unclear situation for the reference of the costs: The reference for a comparison of reclaimed water is difficult because tariffs (in particular for irrigation) are often much lower than the level required for cost-coverage. Therefore, it is recommended to compare the costs of the envisaged reuse project (e. g., prime cost) with different existing values, mainly the real costs of existing water production, the costs of other new water resources, and the tariffs.

Selected treatment techniques		Floor space required	Structural engineering	Mechanical engineering	E+MCR technology
Sedimentation	With precipitation/flocculation	low	medium	low	low
	Without flocculation	low	medium	low	low
Activated sludge process	Carbon elimination	low	medium	medium	high
	Nutrient elimination	low	medium	medium	high
Filtration (downstream)	Rapid filtration	low	low	low	low
	Slow filtration	low	low	low	low
	Dual media filtration	low	low	low	low
Precipitation/flocculation (downstream)		low	low	low	low
Membrane		low	high	high	high
UV		low	low	medium	medium
Ozone		low	high	high	high
Polishing pond		high	low	low	low
Chlorine		low	low	medium	low

Category	Costs in (€/E)	Floor space required in (m²/E)
high	> 1,000	> 1
medium	600 to 1,000	0.3 to 1
low	≤ 600	≤ 0.3

Table 1: Assessment of investment costs

With regard to the financing of investment costs of reuse projects, besides existing financial resources of an authority or a company, also normal bank loans, loans from development institutions (such as development banks), subsidies, and BOT models play an important role.

For the financing of operation and maintenance (O/M), tariffs, taxes, and subsidies play the predominant role. The financing completely by tariffs is often seen as the ideal solution. Nevertheless, in reality subsidies play a major role particularly in developing countries, but also in industrialized countries. During the analysis of the feasibility, the stability of the O/M-financing has to be analysed, including a partial financing through subsidies.

8 Conclusion and Outlook

The lack of freshwater resources is the main driver for water reuse. However, early participation of all relevant stakeholders in the implementation of water reuse projects and consideration of socio-cultural conditions are necessary to stimulate acceptance. Moreover, the permanent coverage of all costs for investment as well as operation and maintenance of water reuse systems has to be ensured in order to attain sustainable success.

Microbial risks are of major concern in terms of water reuse. A variety of established physical and chemical processes for advanced wastewater treatment is available for pathogen re-

Selected treatment techniques		Personnel requirements/costs	Energy requirements/costs	Disposal of residues	Operational resources	Maintenance costs
Sedimentation	With precipitation/flocculation	low	low	high	high	low
	Without flocculation	low	low	medium	low	low
Activated sludge process	Carbon elimination	medium	high	medium	medium	medium
	Nutrient elimination	medium	high	medium	medium	medium
Filtration (downstream)	Rapid filtration	low	low	low	low	medium
	Slow filtration	low	low	low	low	medium
	Dual media filtration	low	low	low	low	medium
Precipitation/flocculation (downstream)		low	low	low	medium	medium
Membrane		high	high	high	high	high
UV		low	low	low	low	low
Ozone		medium	medium	medium	medium	medium
Polishing pond		low	low	low	low	low
Chlorine		low	low	low	low	low

Category	Costs in (€/m³)	Energy requirement in (kWh/m³)
high	> 0.4	> 0.02
medium	0.06 to 0.40	0.002 to 0.020
low	≤ 0.06	≤ 0.002

Table 2: Assessment of costs for operation and maintenance

moval in order to ensure the required effluent quality. Regulations and standards for water reuse have often been limited to the definition of quality requirements for reclaimed water. Recently, the multi-barrier approach focusing on health-based targets for risk management in water reuse recommended by the WHO has increasingly been adopted by standardization institutions (cf. [13]) as well as legislative bodies, e. g., the European Parlament, which has recently adapted a European Regulationon minimum requirements for water reuse for agricultural irrigation [14].

Water reuse can significantly contribute to the substitution of freshwater resources, reduce the demand for mineral fertilizer, and help minimizing the energy embedded in the water cycle, thus reducing greenhouse gas emissions. However, an often increased salinity of reclaimed water may require measures for minimizing the risk of salt accumulation in the soil. This includes the selection of appropriate irrigation methods, e.g., drip or sub-surface irrigation, which can also provide an additional barrier against the microbial contamination of farmers and crops.

Use of reclaimed water, especially for irrigation purposes, has been practised for a long time in regions suffering from water scarcity. With regard to changing rainfall patterns in consequence of the global climate change and an increasing need for seasonal irrigation, it is expected that water reuse will further gain relevance also in regions with rather high average water availability. Not least, the substitution of freshwater resources by reclaimed water contributes to securing future drinking water supply especially in arid and semi-arid regions, and therefore also to the realization of the United Nations' Sustainable Development Goals.

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Authors

Prof. Dr.-Ing. Jens Haberkamp
Münster University of Applied Sciences
Institute for Infrastructure · Water · Resources · Environment (IWARU)
Corrensstraße 25, 48149 Münster, Germany

corresponding author, e-mail: haberkamp@fh-muenster.de

Dr.-Ing. Stefan Gramel
KfW Development Bank
Palmengartenstraße 5–9, 60325 Frankfurt am Main, Germany

Dr.-Ing. Tim Fuhrmann
Emscher Wassertechnik GmbH
Brunnenstraße 37, 45128 Essen, Germany

International Operator Partnerships between Municipal Water Companies

Background, Experience and Perspectives

Claudia Wendland, Christian Günner (Hamburg/Germany), Ann-Ulrike Henning (Berlin/Germany), Lucatina Ercolano and Leonardo van Straaten (Hamburg/Germany)

Abstract

Water suppliers and sewage disposal companies are important players in sustainable development of towns and municipalities worldwide and contribute to the 2030 Agenda of the United Nations. Operator partnerships have been implemented successfully under the description WOP (Water Operators' Partnership) for years and are funded worldwide amongst others by the Office for the Global Water Operators' Partnerships Alliance (GWOPA) of UN Habitat. The German Federal Ministry for Economic Cooperation and Development (BMZ) has now launched the pilot project "Operator Platform to Strengthen Partnerships of Municipal Enterprises Worldwide" to implement four pilot partnerships between municipal German operators and international operators over a three-year project period. The aim of the partnerships is to support operators, particularly in developing and emerging countries, in supplying their local towns and municipalities with effective, sustainable, independent and reliable services. The pilot phase is supposed to run for 3 years. The experience gained from this is intended to form the basis for developing a permanent BMZ programme for the implementation of operator partnerships. Long term cooperation should be established between municipal operators from Germany and their "pendants" in the south.

Background

Many municipalities and municipal companies have been making an important contribution to development cooperation for years, for example in the context of city partnerships, including in the water and/or wastewater sector. In 2015 the German

Fig. 1: Sustainability goals of the United Nations (SDG)

Bundestag in its judgement “Use of development policy opportunities in urbanisation” urged the Federal Government to promote stronger cooperation of German municipalities with municipalities in developing and emerging countries.

The conference of interior ministers and senators of the German federal states (IMK) in June 2019 explicitly strengthened the commitment of German municipalities *and their companies* in development work. The IMK emphases in its judgement that this joint local commitment contributes substantially to implementing the 2030 Agenda of the United Nations and the UN targets for sustainable development [1].

Together with all other United Nations members, Germany signed up in 2015 to implementation of the 2030 Agenda and thus to the achievement of the 17 “SDGs” (Sustainable Development Goals) [2] (Figure 1). The 2030 Agenda is not a successor of the Millennium Development Goals. It is above all a transformation agenda which will make life on this earth worth living for future generations. It addresses all signatory states, whether northern or southern hemisphere.

The 2030 Agenda must therefore be implemented in and by Germany. The guiding principles of the 2030 Agenda also include global partnerships. SDG 17 explicitly names the promotion of partnerships as autonomous goal.

The role of municipal water companies

German water companies have long been implementing many of these goals in Germany in the frame of services of general interest. They are responsible above all for sustainability goal 6 (clean water and sanitary systems) and they have a significant involvement in the implementation of further SDGs such as SDG 11 (sustainable cities and communities) or – as major employment and ordering parties – in SDG 8 (decent work and economic growth).

Worldwide, powerful water operators are key stakeholders for the implementation of SDG 6. To achieve the associated goals, an estimated investment of 150 billion US dollars per year is required [3]. In addition, a continuously increasing amount is required to ensure long term effective operation of the invested infrastructure and thus water and wastewater services for the population. The ratio of investment to operating costs will turn around as soon as ever more systems are permanently in operation. Unfortunately, many international operators currently resemble “leaky tubs”, from which the water (or funding) is leaking through multiple gaps [4]. There is therefore often a lack of trust on the part of credit suppliers and investors. And trust would be presisely required to direct the increasingly necessary funding to the right places. Furthermore, the actual requirement exceeds the available resources of the public development cooperation (DC) by a long way [1].

The concept of operator partnerships

The establishment and reinforcement of highly performing operators is required by many protagonists, e. g. the World Bank [5]. Some of the development cooperation measures launched in this context are already directed at municipal water companies.

Fig. 2: Water Operators' Partnerships – peer Learning at eye level (GWOPA)

At the same time, a practical model has been in place for 15 years to improve operator expertise through "peer learning" and thus promote eye-level cooperation: Water Operators' Partnerships, WOPs for short (Figure 2). In the Netherlands for example the WOP approach has been implemented very successfully for a long time.

To promote WOPs at the international Level, UN Habitat created the Global Water Operators' Partnerships Alliance (GWOPA) in 2009. In the context of its UN mandate, UN Habitat is responsible for the issues of urban development, and housing provision in developing and emerging countries. The GWOPA was established as a global centre for the political, financial and technical support and coordination of WOPs.

WOPs are as recognised as a successful mechanism for achieving development goals and realising human rights to water and sanitation systems [6]. As a rule these are partnerships between municipal operators based on the following guiding principles [7]:

- WOPs concentrate on increasing the capacity of operator's staff and the mentor operator does not take the no operational management responsibility.
- WOPs are needs-orientated.
- WOPs are peer partnerships at eye-level, which are created directly between two or more operators (north-south, south-south, rarely north-north).
- WOPs are "not-for-profit" partnerships and are not used for commercial purposes.

Germany also recognises that the water operator partnerships – WOPs – are a practical instrument for implementation of SDG 6 worldwide [8]. The Federal Government has (together with the Netherlands) successfully applied for the hosting and financing of the GWOPA Secretariat. In spring 2020, the secretariat moved from Barcelona to the UN-Campus in Bonn [9]. The work of the secretariat includes amongst other things the implementation from 2020 of a WOP programme commissioned and financed by the EU.

Further support for the peer-learning operator partnerships comes from the Canadian Initiative "Blue Communities" under the leadership of the holder of the alternative Nobel prize Maude Barlow. Blue Communities are cities and local authorities which have committed themselves to promoting international water partnerships as one of four principles. As well as the 49 worldwide communities (cities, local authorities, churches, orders and universities) so far the German cities of Augsburg, Berlin, Marburg, Munich and Kempten (Allgäu) have recognised the principles of the "Blue Communities" [10].

Developments in Germany

Against the background illustrated above its stands to reason that German municipal water companies, with their specific know-how, will become more active internationally. The benefit of cooperation-based operator partnerships is that they offer highly sustainable support to municipal operators at a local level. Eye-level cooperation means that there is no dependency of local operators on German partners, and the local water companies generate added value directly because they retain responsibility for their facilities.

The previous reservation of German municipal companies often lays in uncertainty as to whether the legal framework in Germany would actually permit an international commitment. A legal appraisal in 2018 for the Service Agency for Communities in One World (SKEW) concluded that the majority of municipal water companies in Germany can, under certain conditions, engage internationally in accordance with the constitution and municipal economic law [11].

The public purpose lies in the constitutionally-guaranteed authority of municipalities to commit to development policy, as Schmidt explains in the study. Key sections from the overall result of the study are provided below: *"The constitutional guarantee of a municipality's self-administration also extends to the development cooperation by the municipality itself or its companies. As a matter of principle, no contributions or fees may be drained for the financing of such cooperation. [...] Federal company law allows municipal companies under civil law to participate in municipal development cooperation if the company's articles of association or a comparable constitutional structure provide starting points for such activities. [...] The needs and performance of the municipality are met if the cooperation is with a foreign municipal enterprise in the same or a similar sector and the cooperation partners are comparable in size".* [11]

It follows that municipal water companies can enter into partnership projects with similarly-sized local operators. In order to avoid any possible risks in terms of municipal taxes or pricing, their commitment should be fully reimbursed (full cost coverage of working hours and travel expenses). An interna-

A delegation from Jordan visits the Hamburg sewage treatment plant Köhlbrandhöft on the Elbe river.

Fig. 3 At eye level and Peer-to-Peer

tional commitment of German municipal water companies under the flag of sustainability goal 17 is therefore both possible and, as shown above, very useful and desirable.

Pilot project – BMZ operator platform

Within the framework of the development cooperation, Germany provides substantial financial resources for the development of water and sanitation infrastructures worldwide. Germany is one of the largest bilateral donors in the water sector. Capital-intensive infrastructure alone however does not enable an efficient water service. This requires capable operators. This is why the German Organisation for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit – GIZ), on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), also supports local water companies, for example with "Technical Cooperation" measures.

However these are still not enough. The German Water Partnership (GWP), as the network of the internationally-orientated fraction of the German water industry, has therefore developed the idea of a new model for partnerships between municipal operators from Germany and operators from developing and emerging countries together with German operators through its "Operation and Capacity Development" working group and in close cooperation with German DC organisations, especially GIZ. This model is designed to address the local needs of the municipal water companies [12]. The substantial difference to the concepts of the WOPs of GWOPA outlined above is that, in accordance with the aforementioned statutory general conditions for companies in the German municipal economy, all project costs are covered (full cost funding). Another difference takes account of the fact that there are many small municipal water companies in Germany which, left to their own devices, would have difficulties in implementing operator partnership projects. The GWP concept therefore provides for municipal water and wastewater companies to join forces and jointly enter into a partnership which is managed by a sufficiently experienced and efficient water company (lead partner).

A second study commissioned by SKEW [13] assessed as positive the feasibility of partnerships in terms of the GWP-approach between German and international operators. According to the results of the study, about 1–5 % of the employees in the surveyed companies in Germany are interested in working abroad and therefore have the corresponding motivation. However, because this group of people are often also the top performers in the companies, long-term assignments are only considered in individual cases. In the GWP model therefore "rolling" posts of several, similarly qualified persons are proposed for any one function. In addition to enhanced personnel development (e. g. management development or workforce satisfaction), the companies surveyed named the improvement of the employer brand and the positive image for their own company or a meaningful contribution to Agenda 2030 as added values. Factors such as security, achievability and adequate infrastructure are the deciding factors for those surveyed municipal companies in the selection of countries for potential partnerships.

In 2019 the BMZ adopted the GWP approach and planned the start of the operator platform pilot programme. The programme will entail four operator partnerships which have been formed after a matching-process organised by BMZ with GIZ and SKEW. The planned partner countries in the pilot phase are Jordan, Morocco, Ukraine and Zambia. Various German municipal water companies will be participating, wherein each partnership will be managed by a Lead Partner.

The pilot phase should entail the following partnerships between one international and up to two German Lead Partners (together with further German operators): RADEEMA (Morocco) with the Oldenburgisch-Ostfriesischer Wasserverband (OOWV, Oldenburg), Lviv Vodokanal (Ukraine) with the Dresdener Stadtentwässerung and the Berliner Wasserbetriebe, Lukanga WSC (Zambia) with Gelsenwasser (Gelsenkirchen) and Emschergenossenschaft/Lippeverband (Essen) and Miyahuna (Jordanien) with Hamburg Wasser and hanseWasser (Bremen).

The Lead Partners will manage the projects and maintain the direct contact with the international "Pendant" as well as GWP, GIZ and SKEW. They will coordinate the work outside Germany of their own employees and that of the other German partners.

In principle, the aim is to establish long-term cooperation that will be effective beyond the pilot phase. If implementation is successful, the BMZ plans to expand the project into a permanent DC programme and, if necessary, to extend it to other sectors of general interest (e. g. waste management, energy supply).

The operator platform is an innovative cooperation model, to be used initially only in the cooperation of municipal water companies and the development cooperation. It will be financed by the BMZ and implemented by the GIZ and SKEW. Implementation will be carried out in cooperation with the German Water Partnership (GWP) and the Association of Municipal Companies (VKU).

Experience with similar partnership projects by Hamburg Wasser

Hamburg Wasser is north Germany's largest municipal water company and it has a long-standing history of international commitment. For almost 40 years, the company has been send-ing specialists for worldwide assignments in developing and emerging countries via its subsidiary Consulaqua. The specialists contribute their expertise to DC projects financed, for example, by the Kreditanstalt für Wiederaufbau, GIZ or other DC contractors. Experience has shown that the traditional development cooperation is often too short-term to be able to achieve sustainable improvements in the operation of water and wastewater infrastructure.

Nevertheless, there have also been positive experiences. This is so particularly when the projects are longer term and partners work at eye level: Hamburg Wasser carried out two EU projects in the countries Ruanda and Tanzania. In Hamburg's twin city of Dar es Salaam (Tanzania), the municipal water utility and experts from Hamburg Wasser worked, among other things, to optimise geographical information systems, improve leakage detection and rapid repair in the water network and increase energy efficiency. A variety of interactive Capacity building took place in the operation department. Considerable cost savings were achieved in Ruanda: 24 % was saved by minimising water loss from the pipe network, 18 % through increased energy efficiency in the pumps and 44 % through decreased use of chemicals in the water treatment. Evaluation by EU experts confirmed the success of this project in simultaneously identifying strengths and difficulties in the realization of such projects.

The longest and most successful partnership cooperation to date is between Hamburg Wasser and the municipal operator of the water supply, wastewater treatment and networks of the city of Nablus in the Palestinian autonomous regions. Since 2012 the partners have been working on several formally independent projects successively on the improvement of safe drinking water supply and wastewater disposal for the city and surrounding municipalities. Initially, the technical components of drinking water networks and energy efficiency were covered followed by the operation of sewage treatment facilities and energetic sewage sludge treatment as well as non-technical areas, in particular organisational development, commercial and operational optimisation processes.

As a result of the cooperation, the efficiency of the operator in Nablus has improved considerably, as has the working situation and the appreciation of the Palestinian "peers" for sustainable operation. Their motivation and commitment have increased considerably. Also, the intercultural exchange at a personal level has made a considerable contribution to dismantling mutual prejudices. Prolonged cooperation should also help to ensure that high investment in drinking water and wastewater facilities financed from German tax money, which can only create impact through proper and professional operation (including maintenance), do not end up as "investment ruins". The experience from the cooperation between Hamburg Wasser and the Nablus city administration shows that cooperation at eye level is essential. Sufficient time is needed to understand the structures, the institutions and the socio-cultural environment of the partner company and to create the necessary trust at the employee level.

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Authors

Dr.-Ing. Claudia Wendland, Dipl.-Ing. Christian Günner,
MSC. Lucatina Ercolano, Dipl.-Geol. Leonardo van Straaten
Hamburg Wasser
Billhorner Deich 2, 20539 Hamburg, Germany

E-Mail: claudia.wendland@hamburgwasser.de

Dipl.-Soz.-Wiss. Ann-Ulrike Henning
German Organisation for International cooperation (GIZ)
by order of the BMZ as development cooperation scout for the German Water Partnership
German Water Partnership e. V.
Reinhardtstraße 32, 10117 Berlin, Germany

Operator Partnerships between Municipal Water Companies – launch of pilot project

Water and sanitation companies are key players in the sustainable development of cities and communities around the world, thus contributing centrally to the achievement of the UN 2030 Agenda. For many years numerous so-called Water Operators' Partnerships (WOPs) have been successfully implemented and supported worldwide by the secretariat of the Global Water Operators' Partnerships Alliance (GWOPA) of UN Habitat. In order to use the Know-how of German municipal water operators complementary to technical and financial cooperation to German Federal Ministry for Economic Cooperation and Development (BMZ) has now launched the pilot project "Utility Platform for Strengthening Partnerships of Municipal Utilities in the Water Sector Worldwide" establishing four pilot partnerships between German municipal operators (water and sanitation) and international operators. The project is implemented by GIZ and Engagement Global together with German Water Partnership e. V. (GWP) and VKU as the German association for local public utilities. The key objective of the partnerships is the peer to peer exchange between the municipal utilities in order to improve water and sanitation services for their cities and communities. The pilot phase is planned until 2022. Its results and experiences could form the basis for a longer-term approach for the implementation of operator partnerships, also beyond communal service provision in water and sanitation. The aim is to establish lasting professional relations between municipal operators from Germany and their counterparts.

Visit by Miyahuna LLC Water company from Amman, Jordan, to Hamburger Stadtentwässerung during project preparation (©HamburgWasser)

Contact:

Heiko Heidemann
(e-mail: heiko.heidemann@giz.de)

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