Reducing extraneous water: detection and condition assessment of leaking private sewers

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Introduction

Leakages in sewerage systems and associated issues of environmental protection and structural safety have exercised the minds of waste water experts over a long period. In addition to comprehensive rehabilitation measures, extensive research and development work has been undertaken (c.f. [1], [2]). While the initial emphasis was placed on the exfiltration of waste water and the associated environmental hazards – particularly for groundwater – the technical and legal debate is now increasingly focused on infiltration issues. These issues, particularly those considered under the general heading of "extraneous water" are increasing in significance. As early as 1989, Pfeiff [3] defined extraneous water as an "unwanted discharge in the sewerage system because of this additional water being an unnecessary burden upon the sewerage system itself and upon the waste water treatment plant". Aside from the sewerage system itself, the efficiency of special structures such as stormwater basins will also be impaired by the influx of extraneous water.

While the EU framework Water Directive in particular [3] has focused attention on the issue of extraneous water, the effects of dilution have a specific role to play in the determination of the adequate elimination of the contaminant load.

Extraneous water may also have a direct influence upon the customers convenience, in terms of waste water disposal. Backflow due to the hydraulic overloading of a sewerage system may have highly unpleasant consequences for residents, leading to a corresponding interplay between the public, local politicians and system operators. The resulting measures are mostly associated with high costs.

The issue of extraneous water is made particularly inflammatory by the fact that the rehabilitation of the public sewerage system tends to shift the problem to private waste water systems, rather than resolving the issue altogether (c.f. e.g. [4], [5]). If the aim is to prioritise rehabilitation measures in accordance with the source of problems, the investigation of extraneous water sources from private sewerage systems will be a significant factor. This will involve both, the specific localisation of infiltration inflow from private house connections and the detection of leaks and illicit inlet tubes within the private sewerage systems.

Specific site localisation

Initial indications of the nature and extent of an extraneous water inflow from the catchment area of a sewage treatment plant may be provided by the discharge data measured at this plant. The rate of extraneous water may then be determined by e.g. one of the following methods (c.f. [6]):

- **The "annual sewage discharge" method**, based upon the difference between the "annual volume of sewage", calculated from the measured discharge volumes of a sewage treatment plant, and drinking water consumption.

- **The "moving minimum" method**, whereby the dry weather discharge for each day is determined regarding the minimum discharge of the past 21 days [7]. The rate of extraneous water is then derived from the difference between the dry weather discharge determined by this method and the anticipated daily discharge of sewage.

- **The "triangulation" method**, based upon the evaluation of multi-year discharge hydrograph curves, not only taking into account the dry weather discharge but also the influence of rainy days, among other factors [8].

Beyond this the following methods are more suitable for the precise localisation of infiltration sources within a given sewage system:

- **Flow measurements during the minimum night-time discharge period**, i.e. the determination of the night-time discharges from the subcatchment areas of the system and from the sewage treatment plant, regarding a residual sewage discharge [5], or the

- **"Chemical" method**, a qualitative approach, as initially applied e.g. in the Swiss research undertaken in 1984 [9]. The starting point for this method is the reduction of pollutant concentrations associated with the diluting effect of extraneous water (c.f. [10]).

A combination of these methods is conceivable. Layout plans of the sewerage system make it possible to divide the complex drainage network into easily surveyable subcatchment areas, each of which draining into a main sewer. Discharges from these subcatchment areas will then be compared on the basis of flow volume measurements, associated with the determination of specific contaminant concentrations (e.g. COD, c.f. [10]), where applicable. Finally, those subcatchment areas which contribute substantially to the inflow of extraneous water will be identified. Further discharge measurements at the node points of these subcatchment areas will then lead to the identification of critical sources of extraneous water. An example of results obtained from flow measurements in a sewage system is set out in Figure 1.

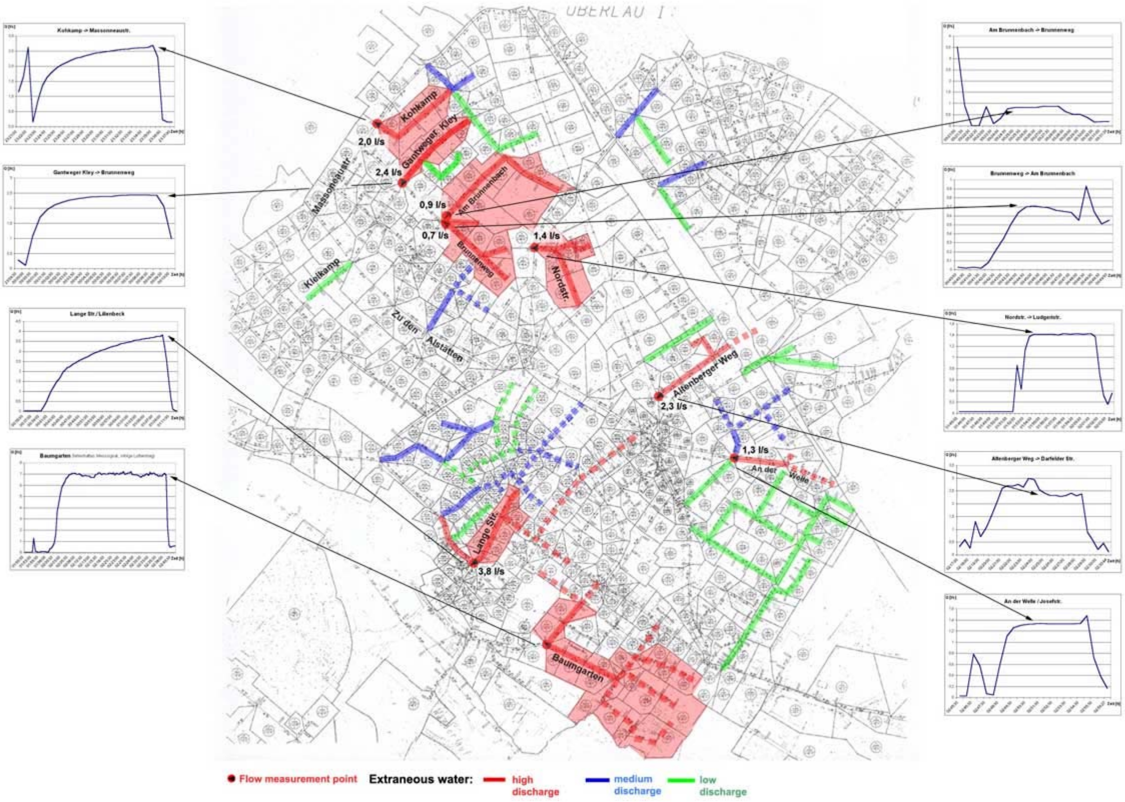


Figure 1: Results of an extraneous water measurement programme (c.f. [5])

Night-time CCTV-inspection provides a suitable method for the identification of private extraneous water sources associated with specific sites. In principle, this procedure for the identification of infiltration or the ingress of drainage water should be undertaken when the groundwater level is sufficiently high. In general, favourable groundwater conditions will prevail following the annual restoration of the groundwater table associated with the winter semester, e.g. in the months from February to April. Long-term climatic variations will also influence annual temperatures and precipitation, with a consequent impact upon groundwater restoration. For example, a lack of precipitation in 1996 led to a noticeable local minimum in the groundwater level in some areas [5].

In general, a usual CCTV-camera will be sufficient. Although the use of a satellite camera will also allow the inspection of connected pipes at the same time. Anyhow, reliable indications of defective connections and drainage systems often cannot be anticipated, even in private systems with limited branching. In each case, the camera will be positioned several minutes in front of the house connection, in order to allow the unequivocal documentation of the constant proportion of the water inflow originating from that connection. For the qualitative evaluation of influx volumes, the direct visual comparison of influxes from house connections within a single coherent subcatchment area is recommended, e.g. comparative evaluation of the influx as high, low or average for the area concerned.

In order to facilitate the subsequent scheduling of repairs, a distinction should generally be drawn between extraneous water influxes originating from the house connection pipes and from defective joints between the lines and the main sewer.

Private systems

Since the recording of private systems, even by the use of a satellite camera system, will be limited to the vicinity of the connection or at least to the main connection pipe itself, a more extensive investigation will generally be required for the identification of the origins of extraneous water. However, the cost-effective selection of inspection and localisation methods to be applied will depend upon prior knowledge of the anticipated network structure and the properties of the sewerage pipes concerned.

In principle, the characteristics of domestic water systems are such that comparison between the latter and public sewerage systems will not be possible, or will only be possible with reservations. In most cases, domestic systems are significantly more complex. At many points in the building, individual drainage facilities for waste water disposal, e.g. from showers, toilets, washing machines and dishwashers, will be found. Moreover, rainwater drainages may be systematically connected to combined sewerlines and illicit inlet tubes and groundwater drains may be found.

Plans for private drainage systems are frequently incomplete or outdated [11]. The data of public sewerage system operators rarely includes information on private drainages in an EDP-accessible and comprehensive format [12]. In many cases, actual waste water systems are not consistent with the data included in planning documents. For example, documented drainage facilities may not be present, or drainage facilities may have been added at a later stage without being incorporated into plans [11]. For this reason, existing plans should be updated on the basis of a site inspection before any further investigations are undertaken. Ideal is the archiving in graphic data storage systems.

For the customary system structures found in Germany one has to divide between the private drainage system, with its multiple branches, and the main connecting pipe between the inspection shaft and the public sewer. The house connection generally routes the collected water directly into the public sewer, with no branches, and in most cases follows a comparatively straight course. In terms of operating conditions, these house connections are generally comparable to the public sewer. Only its smaller diameter, 150 to 200 mm, deviates from the customary dimensions applied in the public sewerage system.

The drainage system between the inspection shaft and drainage facilities in the building is generally characterised by branches and bends, limited or no access possibilities and smaller pipe diameters. This part of the waste water system often features multiple branches, e.g. a pipe which branches off from the main pipe may then undergo a further bifurcation (see Figure 2). Bends up to rectangular can be find, even if this does violate valid construction guidlines [13]. Good access possibilities, in the form of shafts within the building, will be seldom. In general, these shafts are constructed externally. In many cases, access to parts of the private sewage system will only be possible through inspection flaps in down pipes.

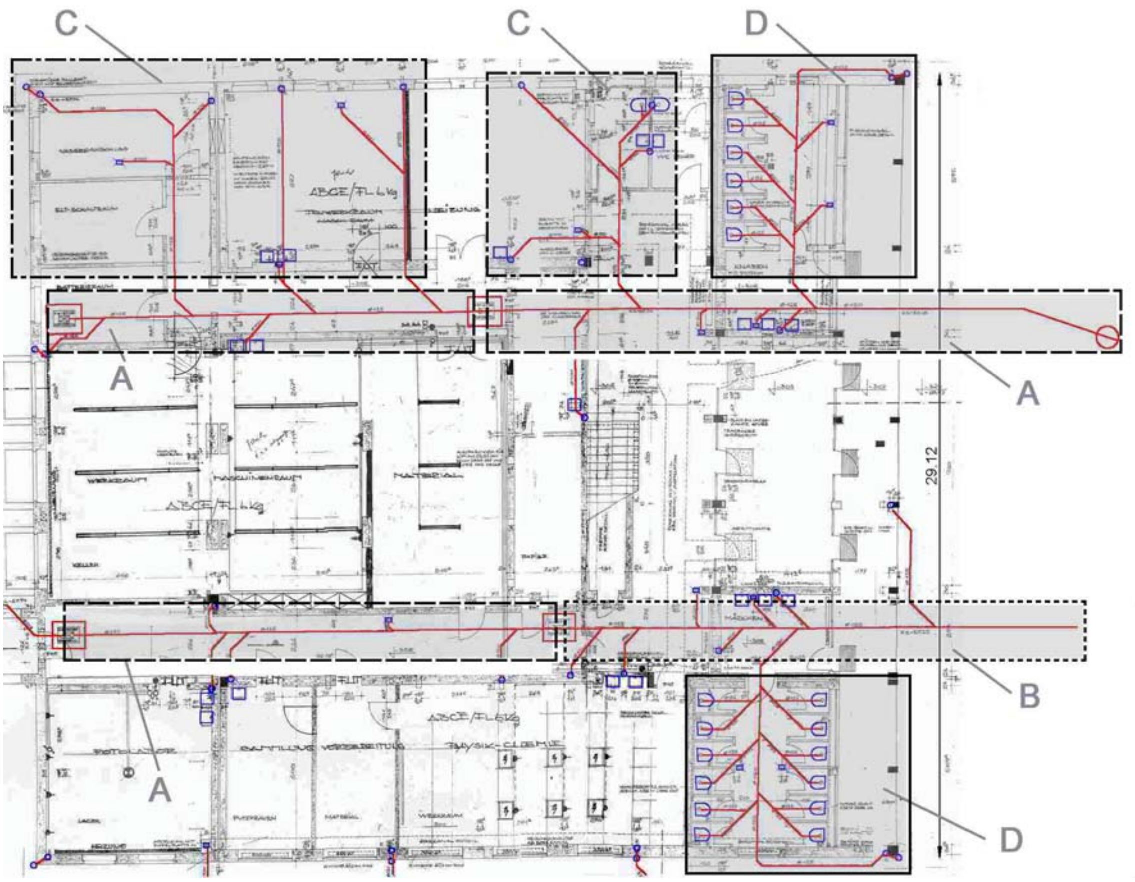


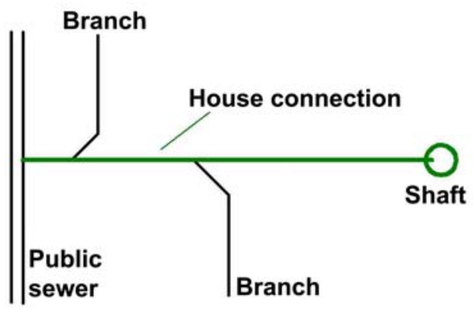
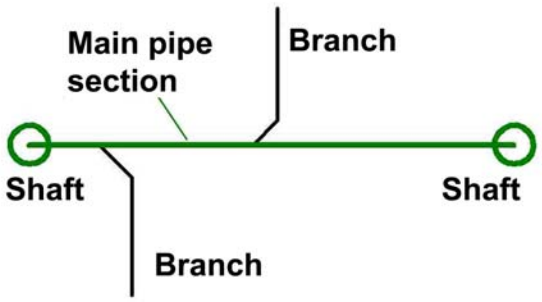
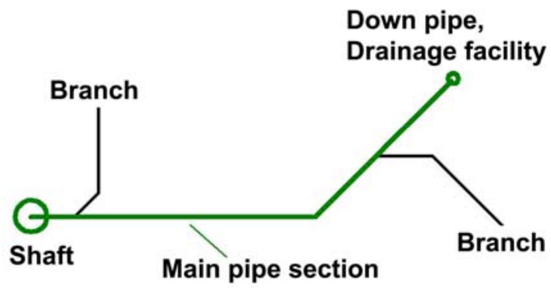
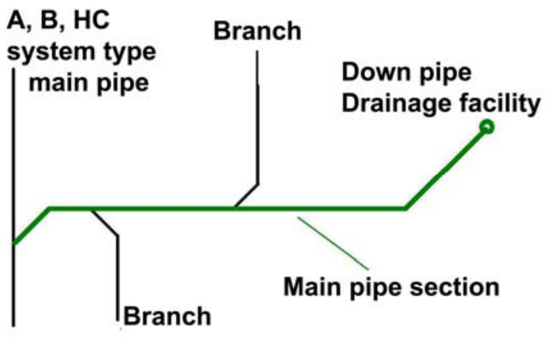
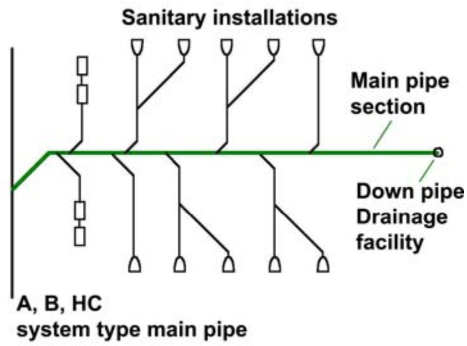
Figure 2: Example of the subdivision of the drainage system of a building into system types [11]

The comprehensive investigation of private systems from the main sewer will not be possible using methods and equipment which are currently available on the market [11]. To date, further investigations for the identification of the sources of extraneous water have been applied on the sites themselves. In this regard, the dictates of local bylaws must be considered, together with marginal technical and organisational conditions.

Process and equipment technology

The application of methods and equipment for the localisation and inspection of domestic drains is restricted, both by the number and location of access points and by the actual system topology [11]. In larger buildings with extensively branched networks, a subdivision into as many as five different system types is recommended. These systems will have different characteristics, with associated variations in marginal conditions to be considered before proceeding further (see Table 1, c.f. Figure 2).

Table 1: Definition of system types [11]

<table>
<tr><th colspan="2">House connection (HC)</th></tr>
<tr><td>
</td><td>Drain sections which are accessible via a shaft and from the main sewer.</td></tr>
<tr><th colspan="2">Private sewer system</th></tr>
<tr><th>Type A</th><th>Type B</th></tr>
<tr><td>Section, accessible via shafts at either end.</td><td>Section (or subsystem), accessible at one end via a shaft and that may also be accessible via inspection flaps in down pipes or drainage facilities.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Type C</th><th>Type D</th></tr>
<tr><td>Subsystem which branches are only accessible via the inspection flaps of down pipes or drainage facilities</td><td>A subsystem characterised by numerous branches, ramifications and the connection of numerous drainage facilities (may have characteristics of Type B or C)</td></tr>
<tr><td>
</td><td>
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Given these circumstances, a high degree of differentiation will need to be applied to the evaluation of available procedures for the preparation and implementation of localisation and inspection measures:

- **Flow measurements**

The application of methods of flow measurement used in public sewers will generally be thwarted by the lack of access facilities and space restrictions within the private drainage system. For short-term measurements, the use of Venturi flumes, measuring weirs or base-mounted Doppler probes will be associated with disproportionately high expenditure, or will be technically unfeasible. Even currently available devices on the market for inductive flow measurement will scarcely be capable of determining the low volumes of flow anticipated within private drainage systems [11]. Research into this field is currently in progress [14].

- **Fogging**

The injection of smoke into a sewer system is a proven method used to determine whether illicit connections are the source of unintentional influxes into the public sewerage system. In rare cases, even groundwater drainages can be identified by the escape of smoke from the earth surrounding a building [15].

- **CCTV - inspection and electromagnetic detection**

The combination of visual inspection and electromagnetic detection methods, e.g. using a CCTV-camera with an integral detection probe, is recommended for the further localisation of damage or connections to drainage systems.

The examination of the main drains and their feeders in **Type HC, A and B systems** will ideally involve the use of satellite cameras in the main private drainpipe. However, as a prerequisite for this operation, the main drain must follow a straight course with no bends. Additionally it must have a minimum diameter of 150 mm (in order to accommodate the smallest models on the market) and must be free of severe damage such as the misalignment of sleeve connectors, subsidence, fragmentation or cross-sectional distortion. Moreover, at least one shaft must be constructed as an open conduit, since the size of models available on the market preclude their insertion into the system via a inspection flap. A satellite camera head can then be used for the inspection of both, lateral branches and the main drains **of Type C and D systems**. Where the use of a satellite camera is not possible, a camera on carriage with a rotating panning video-head should be used for the inspection of the main drains in **Type HC, A and B systems**. Where even this option is not feasible, the use of a high flushing pressure camera is recommended. Although this type of camera will allow the simultaneous cleaning of the drain concerned, the available perspective will be severely restricted by the fixed axial camera head. Due to this constraint, a more detailed inspection of the interior drain wall, e.g. the inspection of joints between connected pipes, is not possible.

The comprehensive recording of the status of complete **Type C and D systems** will only be possible with substantial expenditure, in terms of both technology and time. Where applicable, the inspection of drains at specific points in systems of these types will be possible by the use of a sliding camera, in some cases with a rotating panning head, via inspection flaps in down pipes or via the outfalls of drainage facilities following the dismantling of the latter.

Where even the provision of access is associated with high expenditure, the insertion of an endoscope via drainage facilities may be a rational option. The same applies to lateral branches in Type HC, A and B systems.

Where visual inspection reveals severe damage, leaks or groundwater infiltration, the loss of leak-tightness in the vicinity of the drain concerned should be assumed as a matter of course. Inspection during periods of high groundwater levels or the increased occurrence of stratum water is recommended.

- **Tracers**

Orientation in the private sewer system can be further facilitated by the addition of tracers to the water at drainage points. During the camera surveillance of branches, even drains which cannot be inspected or located can then be associated with their corresponding drainage points. In addition to the determination of the location and condition of drains, it will therefore be possible to undertake the classification of branches and inlet points in a single operating sequence.

- **Leak testing**

Where the structural and operational condition of a drain is deemed to be satisfactory on the basis of a visual inspection, and no further leaks are detectable, the ultimate evaluation of the ex- or infiltration potential will only be possible on the basis of leak testing using air or water.

For the testing of a **complete drainage system, lateral branches** or **Type C and D systems**, **water fullness testing**, as described e.g. in DIN 1986 [13] should be undertaken. In these areas tests with high pressure cannot generally be undertaken, or will be associated with high expenditure. However, there may be shortcomings in criteria for water fullness testing. In [13], for example, prior knowledge of the course, length and rated diameter of the drains considered is a prerequisite for the calculation of water loss values. However, the exact recording of the course and length of lateral branches and of **Type C and D subsystems**, as indicated above, will only be possible with very high expenditure or may be completely unfeasible.

Pressure testing of domestic sewers **using air or water**, in accordance with the criteria defined in **EN 1610**, will only be a reasonable option, in terms of acceptable costs, for the main drains in **Type HC, A and B systems**. Air pressure testing may be selected as an initial option, as this procedure can generally be completed more rapidly than water pressure testing. In case of doubts regarding test results, water pressure testing should then be undertaken for confirmation purposes.

- **Cleaning**

Prior to inspection and leak testing, the cleaning of pipes affected by often substantial dirt accumulation will be necessary. Cleaning of the main drains in **Type HC, A and B systems** should be undertaken using water at high pressure. Where substantial accumulations of dirt cannot be removed by high-pressure cleaning, an spiral machine may be used. In lateral branches and in **Type C and D systems**, high-pressure cleaning should only be undertaken where access is possible via the outfall of toilets , and where the possibility of severe damage (e.g. to interior fittings) resulting from the backflow of water has been ruled out. As an alternative, a spiral machine with additional water flushing may be used.

Cleaning operations in preparation for inspections will generally be more intensive than those required for the maintenance of the functional capability of the drains concerned. In particular, critical consideration should be given to the use of spiral machine. It is conceivable that the percussive effect of the spiral machine or its drive chains might cause damage to previously undamaged pipes. Then, as a result of cleaning operations, the pipes can lose leak-tightness or existing damage might be exacerbated. The cleaning of certain sections can be totally impossible. In principle, more substantial fat deposits may be anticipated as in public sewers. Even where high-pressure nozzles are used, a number of cleaning operations will be required.

- **Diversion of sewerage during inspection**

For the time of an inspection or leak testing of private sewerage systems an alternative drainage facility may be needed. Measures for a diversion of sewerage require extensive planning and, in general, are highly time-intensive. In consequence, access to combined water systems during precipitation should be avoided as a matter of principle. Investigations in multiple-family dwellings and public buildings in general use are costly. In this case, the prior notification of tenants will be a matter of priority. The disconnection of the water supply during investigations is recommended, as this obviates the need for diversion e.g. for the performance of air overpressure tests in **Type HC, A and B systems**.

Where the disconnection of the water supply is not possible, or where the testing of a combined water system is to be undertaken during precipitation, alternative drainage facilities will be restricted to vertical down pipes in most cases. Special devices are produced for this purpose, although these are not generally available on the market. These devices are equipped with a balloon which is inserted into a down pipe via a inspection flap, then inflated. By this method, waste water is diverted into a pump. A crusher is arranged upstream of the pump, in which solids are broken down into smaller particles. Waste water is then pumped via a hose into the nearest shaft.

For the purposes of water fullness testing, e.g. in accordance with DIN 1986, it should be borne in mind that sufficient residual water may be present in drainage facilities (e.g. in WC cisterns) which may then penetrate the test zone and falsify the test results. As a precaution, down pipes which have sufficiently large inspection flaps should be closed by the insertion of a test balloon above the flap.

- **Requirement for development**

In general, using currently available procedures for localisation, inspection and cleaning, lateral branches can only be accessed via drainage facilities or via inspection flaps in down pipes. In consequence, a combined procedure involving a number of processes and devices – to be applied at various points in the building – will be necessary for localisation, inspection, cleaning and leak-tightness testing of the various elements of the site drainage system. These measures will consume substantial resources, in terms of both planning and costs. Moreover, the actual conduct of the on-site inspection may involve considerable interference in the use of the buildings concerned, e.g. where the removal of furniture is necessary, or where drainage facilities are brought out of service, or even removed, for a given period of time. The development of new processes or new equipment technologies should target the comprehensive investigation of the site drainage system from one central point (e.g. the inspection shaft) or from the public sewer.

The devices concerned should have outstanding capacity for the negotiation of bends, in order to allow further branches – of anticipated diameters down to 70 mm – to be accessed even from a lateral branch. A second issue is the range of inspection methods. In order to allow the investigation of remote sections of the drain system, the device should be fitted with a propulsive mechanism. In order to improve propulsion and facilitate the cleaning of all areas, the incorporation of a flushing nozzle would be a rational option. The incorporation of an electromagnetic detection transmitter into the device will allow the course and depth of all drains to be plotted. Ideally, devices should provide the option for section-by-section leak-tightness testing in all areas of the system.

Some companies have already come to grips with these new requirements and have developed new and appropriate equipment technologies (c.f. [16], [17]). Basic scope for the practical application of a number of these devices has already been investigated in the course of an IKT–research programme [11]. Selected processes are currently undergoing testing and further development in large-scale field trials involving local authority system operators [18].

Cooperation with the public

The investigation of site drainage systems will invariably require careful preparation and the prior definition of the process involved in close collaboration with the members of the public affected. There will be fundamental differences in preparation and overall expenditure for single-family dwellings, multiple-family dwellings and public buildings [11]. For example, in the case of smaller systems in single-family dwellings, the water leak-tightness testing of the entire system may be more productive and cost-effective than comprehensive cctv-inspection. In multiple-family dwellings, discussions will need to be undertaken with the affected parties. In public buildings, large numbers of Type D branched sections will generally be found in the vicinity of public toilets.

The age of pipe systems will have a considerable influence upon their anticipated leak-tightness, and will therefore be critical to the definition of the procedure to be applied for inspection and leak testing. In relatively new systems, even the increased expenditure associated with section-by-section leak testing may be acceptable, where the presence of leak-tight sections leads to a significant reduction in rehabilitation costs. Conversely, in the case of buildings constructed in Germany prior to 1965, particularly where no replacement or rehabilitation operations have been recorded in the interim, the logic of leak testing should be subject to critical consideration. The connecting systems installed at the time (featuring tarred cord sealing) are such that leaks should be assumed as a matter of course. In consequence, direct preparations may be made for the completion of rehabilitation. This applies particularly where significant extraneous water influxes from private house connections have been identified, and where these are associated with high groundwater levels.

In Germany, the organisational demarcation between public and private drains is generally regulated by local authority. For example, all drains on a private site may be classified as private drains. In many cases, the inspection shaft may be designated as the point of transition. More rarely, all drains, including the connection to the main sewer, may be classified as private facilities. The involvement of the site owner concerned in the investigation of private drains is both necessary and desirable. Many local authorities can already draw upon experience derived from cooperative arrangements. Positive results will generally be achieved where the local system operator regards its role as a service provider with close ties to the public [4], [19]. An example of this approach would be the incorporation of both the public house connection and private ground drains into an overall rehabilitation programme.

Prospects

In principle, the question remains of how the ingress of extraneous water is to be reconciled with statutory and technical requirements, e.g. as defined in DIN 1986. This factor is of particular significance where – as in the German province of North Rhine-Westphalia – statutory regulations [20] refer directly to technical standards. Infiltration risks, which dominate the issue of extraneous water, are not directly considered in these regulations. For the purposes of water protection based upon the consideration of exfiltration risks, leakage testing standards primarily define requirements for drains which may be required to carry problematic waste water and which are located in sensitive groundwater preservation areas. Under other marginal conditions, e.g. in the case of domestic wastewater outside groundwater preservation areas, a visual inspection will generally be sufficient. Whilst a requirement for "standard leak-tightness" will prevent any hazard to groundwater, such a requirement will not resolve the issue of extraneous water. However, the large numbers of domestic drains are such that the latter will play a key role in the determination of extraneous water influxes.

From a scientific point of view, the extent to which standardised internal pressure leak tests will provide an effective indication of infiltration potential as groundwater levels rise in future has yet to be resolved. Future research on this issue will be undertaken by IKT.

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[20] Berichtsentwurf zum Forschungsvorhaben „Sanierung von Hausanschlussleitungen -Pilotprojekt Stadt Würselen“ *(Draft research report on the „Rehabilitation of house connections – Pilot project in the town of Würselen“)*; IKT-Institut für Unterirdische Infrastruktur, 2003.

[21] Bauordnung für das Land Nordrhein-Westfalen (Landesbauordnung – BauO NRW); hier §45, in der Fassung der Bekanntmachung vom 07.03.1995, zuletzt geändert am 24.10.1998; zusammen mit der Verwaltungsvorschrift zur Landesbauordnung-VV BauO NRW – RdErl. d. Ministeriums für Städtebau und Wohnen, Kultur und Sport v. 12.10.2000 – Bekanntmachung im Ministerialblatt für das Land NRW – Nummer 71 vom 23. November 2000 *(Building regulation for the Land of North Rhine – Westphalia (Landesbauordnung – BauO NRW); §45, in the version published on 7th March 1995, last amended on 24th October 1998; in conjunction with the Administrative Order on the Land building regulation (VV BauO NRW) – Circular issued by the Ministry for Town Planning, Housing, Culture and Sport of 12th October 2000 – published in the Ministerial Gazette for the Land of North Rhine – Westphalia, no. 71 of 23rd November 2000).*