An Assessment of Hydrological Risks to Historic Buildings and Compounds with a view to their Prevention and Limiting the Negative Impacts of Climate Change and Anthropopressure

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INTRODUCTION

Climate change and its environmental impacts are not limited to a specific time and area. They affect areas of historic provenance as well as the contemporary. The currently occurring phenomena may reveal their consequences in the years to come. The obligations Poland has assumed under international and EU conventions and agreements oblige all state institutions to cooperate to limit and combat the adverse effects of climate change. These phenomena are particularly damaging in urbanised quarters and in historic sites they may pose a critical threat to cultural heritage. Therefore, these recommendations, although directed at heritage preservation authorities, take account of the multi-faceted cooperation between various entities that aim at protecting the common good – i.e., monuments and sites – and involve both local governments and business or scientific circles which collaborate to prevent these negative phenomena. Within the framework of their activities, preservation authorities can – and should – initiate cooperation between entities and identify optimal design solutions to secure national heritage.

Historic urbanised areas have been subjected to strong anthropopressure over the centuries. Therefore, on these most culturally valuable sites, we are confronted with the greatest variety of archaeological, building, architectural, technical, and other artefacts. Any decision undertaken by conservation services, particularly those concerning a new construction that interferes with the ground, should take account of these factors.

The principle of *restaurare et conservare est novam vitam dare* has it that restoration and conservation give new life, which means that in heritage protection, it is essential to ensure an historical sites' functioning and social usefulness. However, the basic principle of historic preservation and heritage handling in general is the precautionary principle primum non nocere – first of all do no harm. Therefore, the introduction of new functions must not endanger historic structures.

Whenever a decision is made regarding the possible impact of a planned construction project on a historic property (an individual site, a compound, or an area), it must be based on a reliable and thorough assessment as to whether the given activity poses a direct or indirect threat to the monument, taking into account the potential future effects of the action or not. This principle follows directly from the provisions of Article 77 § 1 of the Code of Administrative Procedure (KPA): "The public administration body is obliged to collect and consider all evidence exhaustively" and Article 75 § 1: "Anything that may contribute to the clarification of the case and is not contrary to the law should be admitted as evidence. In particular, evidence may include documents, witness testimonies, expert opinions, and visual examinations".

Numerous examples from Poland, including those coming from the practice of Voivodeship Historic Preservation Offices indicate the occurrence of hydrological risks to historic buildings and sites located within historic urbanised areas. In recent years, these problems have become increasingly crucial given the abruptness and catastrophic dimension of events associated with climate change (extremely high summer temperatures, prolonged periods of drought, sudden and torrential precipitation, flooding, and others), as well as the intensification of construction projects' pressure on historic areas. To appropriately safeguard historic properties, action is needed to reliably identify and counteract the adverse and dangerous effects of hydrological phenomena. The aforementioned effect can only be achieved if conclusions resulting from scientific research, spatial management practice, and experience in conducting construction projects, are taken into account, given the simultaneous close cooperation of preservation authorities with representatives of local government units, scientists, and practitioners representing various disciplines. Due to the scale and importance of the problem and the large number of stakeholders, it is an active – or even the leading role of the heritage preservation authorities – to participate in procedures and to indicate specific measures as recommended or obligatory. In certain situations, with an exceptionally high degree of complexity and where the value of historic buildings is high, it may be necessary to settle doubts and to make a reliable assessment of the impact of any planned projects on historic properties through the preservation authorities appointing an interdisciplinary advisory team composed of scientists and spatial management and project's practitioners, and including representatives of local government units and other participants of the project process.

The recommendations presented below are based on contemporary interdisciplinary knowledge of historical urban areas and the hydrological processes within them – both natural and anthropogenic. This knowledge needs to be further supplemented and significantly expanded, particularly in terms of its instrumentation as regards the collection and analysis of a wide range of measurement data which is used for monitoring and forecasting any adverse phenomena and processes and, above all, to prevent emergency events.

GENERAL RECOMMENDATIONS

1. Each case of assessing the impact of a construction project on historic properties requires an individual, substantive approach, which must consider local and often specific environmental conditions. The assessment of the impact of a construction project, which involves the disturbance of the land surface, should be based on the results of direct geological-engineering analyses and hydrogeological as well as hydrological and botanical surveys. To ensure the safety of historic buildings, impact assessments for these types of projects should be applied, using the latest and most advanced research methods, including measuring and monitoring systems and computer modelling methods.

2. A considerable role in shaping the hydrological conditions of an urbanised area is played by greenery. It is vital to remember that green areas consist not only of historical designed greenery compounds but also block yards, home gardens, climbing plants, and even individual trees. The impact of the greenery is linked to climate stabilisation and the maintenance of proper groundwater levels and optimal soil moisture. It would be highly advisable to have strict rules for protecting biologically active areas and preserving trees and shrubs (including moratoria on the removal of old specimens) in historic urbanised areas.

3. Whereas removing vegetation and eliminating biologically active areas can have unpredictable consequences and further aggravate the adverse effects of climate change, compensation for their loss should be sought through the reduction of impervious surfaces (the restoration of natural green covers and new planting).

4. Within historic urban areas, it is advisable to put rainwater and snowmelt management in order by collecting and using it in a controlled manner and implementing surface and groundwater monitoring systems. Efforts should also be made to make an accurate inventory of water supply and sewerage infrastructure, including both current and historical infrastructure, and to establish an effective system for detecting failures, which often reveal themselves in the long term, with the risk of a building's collapse.

RECOMMENDATIONS ON COOPERATION

1. Cooperation between heritage preservation authorities and local government units:

A. The abrupt nature of the phenomena which pose a direct and indirect threat to historic properties makes immediate remedial action necessary. It is, therefore, urgently advisable to make full use of the procedures provided for by law in allowing for the issuing of permits and administrative decisions that ensure the safety of those sites under protection, but also which initiate direct contacts among institutions to facilitate cooperation in emergency.

B. The primary identification of water relations and their risks as a part of monitored climate change should occur at the planning stage (studies, local spatial development plans, and others). Within the framework of planning work, as well as when issuing administrative decisions for developments, the protection of greenery and the impact of construction projects on monuments must be taken into account in accordance with the requirements set out in the relevant substantive legislation. In this context, it is necessary to consider the risks associated with the execution of construction works, including in particular the execution of excavations and other earthworks, e.g., those related to surface clearing or remediation of the site. Construction projects involving excavation below the foundation level of a historic building and neighbouring buildings in historic urbanised areas should only be undertaken in justified cases after an in-depth analysis of the impact of the above-mentioned activities on a historic site. A reliable answer to the feasibility and scope of the construction project is provided by a grid of geological boreholes.

C. Earthwork should be carried out with particular care, applying adequate protection of historic buildings and elements affecting their condition (e.g., greenery, ground surface morphology, water conditions, etc.).

D. For the sake of the hydrological safety of buildings and greenery, it is advisable for municipalities, as the entity responsible for spatial planning, to create a tool for collecting knowledge and information on geological and hydrological conditions together with any anthropogenic layering (both historical and contemporary) in an integrated database. This tool should allow for the ongoing monitoring of changes and any sudden events in a given area and, above all, for modelling the potential effects of specific activities and transformations of the site under protection.

2. Cooperation between heritage preservation authorities and scientists from different fields:

A. Providing the conditions for the constant exchange of knowledge and the notification of current findings is advisable. An opportunity for this is provided by the publication of research results, regular meetings and conferences, in addition to the training of heritage preservation officers on the topic of hydrological and geological risks. It is necessary for the scientific community to cooperate with the heritage preservation authorities and to secure an ongoing information exchange among regions.

B. Based on the cooperation of hydrologists (specialists in engineering geology and geotechnics), constructors and architects, good practices and model design solutions should be sought to reduce the negative impact of construction projects on water relations and, ultimately, on historic properties.

3. Cooperation between heritage preservation authorities and investors:

A. Construction intentions should be preceded by an analysis of the results of previous archaeological excavations (if conducted), which will allow the determination of the depth and structure of anthropogenic layers, including the presence of former wells, absorption pits, cellars, storage pits, and moats, which significantly affect the direction and manner of the movement of rainwater and snowmelt, as well as groundwater within the subsoil.

B. As part of the preparatory and pre-construction works, it is recommended to formulate a study report on the history of the urban development of the construction site, together with the immediate surroundings of the plot. Such an analysis makes it possible to obtain necessary information on the site and determine the permissible scale of the construction project without creating a conflict with existing heritage items. The scope of the study should be determined on a case-by-case basis, taking into account natural and cultural factors, particularly the history of settlement in the area. The study should consider the terrain and hydrological network. The basis of the work should be the analysis of historical maps, archival records, and the results of archaeological research.

C. At the pre-design stage of a ground-interfering construction project, it is advisable to drill a grid of geological boreholes, the depth and density of which should depend on the scope of the project and the degree of the complexity of hydrological, hydrogeological, and geological engineering (geotechnical) conditions. Site surveys should take into account the results of previous archaeological excavations. The supervision of specialists in geology or geotechnics and an archaeologist is necessary during the reconnaissance drilling (within the construction site and in the area adjacent to it) before the project's start.

D. Any work that may disturb water relations on the project site requires a water permit. The expert opinions included therein, should be based on detailed local surveys and studies of the site, not on generalised results taken from literature or regional studies. The impact of the construction project on adjacent areas should be taken into account. Possible risks should be anticipated before an administrative decision is issued, rather than seeking solutions when unfavourable phenomena accumulate.

The above listed actions will help define potential problems, avoid emergencies, exclude or minimise risks to heritage sites, and protect the developer from claims by neighbours in the event of any negative impact the construction may have on parts of neighbouring properties.

RECOMMENDATIONS FOR CONSTRUCTION MEASURES AIMED AT AVOIDING HYDROLOGICAL RISKS

In view of the need to protect monuments and limit the adverse effects of climate change, the detailed scope of activities presented below of the heritage preservation authorities, including the requirements for construction developers, results directly from whether projects qualify into the following relevant risk categories: A, B, C or D.

CATEGORY A

Construction projects involving a change in land use, including, in particular, a change in the surface from natural and permeable to sealed, terrain alterations, a change in the way rainwater is discharged, and a change in the vegetation, involving, among other things, the clearing of trees and shrubs.

Risks:

- the detrimental alteration of water on the ground, which may be forbidden under Article 234 of the Water Act;
- the dampening or flooding of the underground storeys of neighbouring buildings by rainwater and snowmelt;
- the deterioration of growth conditions for trees and shrubs due to restricted access to rainwater and snowmelt, possible decrease in vitality or decline, especially in the case of stands operating in limited rainfall retention areas (with a low groundwater table);
- the deterioration of growth conditions for trees and shrubs due to periodic waterlogging of the area, the formation of physiological drought effects causing weakening and/or death of root systems, sometimes leading to tree toppling;
- soil compaction impeding gas-water exchange;
- the disturbance of the original or existing rainwater drainage;
- localised subsidence of the ground surface or geometric deformations of the historic pavements.

The extent of the required project's impact analysis:

- the project site, immediately adjacent and other plots at a distance of up to approximately 25 m from existing trees and shrubs or those being removed

Recommended measures:

- the working out of a design for drainage of rainwater and snowmelt from the area of the
- project;
- the working out of measures to protect neighbouring properties from the potentially adverse effects of groundwater alteration;
- an inventory of trees and vegetation in an area at least equal to the project area, and optimally including the immediate vicinity i.e., within a strip at least as wide as the height of the trees growing on the plot;
- an evaluation of the condition of the trees and vegetation before, during and after the construction work – as-built inventory with recommendations for maintenance and care of greenery;
- an inventory of revealed underground installations (block canals, absorbing wells, historical sanitary installations) on the project site and, if possible, on neighbouring plots;
- surveying the inventories of historic buildings and pavements on the project site and, where possible, on neighbouring plots.

CATEGORY B

Earthworks and construction projects resulting in excavations and underground storeys in the dry layer of the subsoil, i.e., above the groundwater table, including the soil and groundwater remediation.

Risks:

- a change in the condition of water on land that may be prohibited under Article 234 of the Water Law;
- the dampness or flooding of the neighbouring buildings' underground storeys caused by rainwater and snowmelt;
- the deterioration of growth conditions for trees and shrubs due to reduced access to rainwater and snowmelt, possible decrease in vitality or decline, especially in the case of stands operating in limited rainfall retention areas (with a low groundwater table);
- the deterioration of growth conditions for trees and shrubs due to periodic waterlogging of the area, the formation of physiological drought effects causing the weakening and/or decline of root systems, which secondarily can lead to the overturning of trees;

- the deformation of the ground surface in the vicinity of excavation works
- the uneven settlement of neighbouring buildings as a result of a change in the para-mechanics of the soils underlying the foundations of existing buildings, the creation of new or the enlargement of existing damage to walls and ceilings in the form of cracks or scratches, excessive deflections, and deviation from the plumb;
- the localised collapses or geometric deformations of historic pavements.

Scope of the required construction project's impact analysis:

- the project site, immediately adjacent plots and other plots at a greater distance, i.e., within a strip of land with a range defined by three times the depth of the construction pit which is calculated in all directions from the boundaries of the construction pit.

Recommended measures:

- the working out of a design for draining rainwater and snowmelt from the project area;
- the working out of measures to protect neighbouring properties from the potential adverse effects of groundwater alteration;
- the working out of measures to protect neighbouring buildings from potential land subsidence;
- the preparation of geological-engineering documentation for the construction project (the area of the construction project's site along with its impact area) with the use of geotechnical parameters verified by field research and methods of numerical modelling;
- inventory of trees and vegetation in the project's area xi including in the immediate vicinity, i.e., a strip of land at least equal in width to three times the depth of the excavation
- an evaluation of the condition of trees and vegetation before, during and after construction work – as-built inventory with recommendations for the maintenance and care of greenery;
- the exclusion of any results derived from the so-called Driscoll's formula due to their low reliability and high analytical error, regardless of water and ground conditions;
- the preparation of a study to determine the relative zone of influence of all types of excavation works on neighbouring structures. Recommended methods are contained in "Instrukcje, Wytyczne, Poradniki" ("Instruction, Guidelines, Manuals") series of Instytut Techniki Budowlanej (Building Research Institute – ITB), e.g., Instruction 376/2020 "Ochrona zabudowy w sąsiedztwie głębokich wykopów" ("Protection of buildings in the vicinity of deep excavations");

- an inventory of revealed underground installations (such as block channels, absorbing wells, historic sanitary installations) in the construction project's area and in the project's impact area;
- the geodetic monitoring of existing facilities before, during, and after the project's completion – in the project's area and in its impact zone until the resulting processes have been stabilized.

CATEGORY C

Earthworks and construction projects resulting in excavations and underground storeys being built in the wet layer of the ground, i.e., below the groundwater table, without dewatering the rock mass, where waterproofing membranes are used.

Risks:

- the dampness or flooding of the underground floors of neighbouring buildings by rainwater, snowmelt and groundwater;
- the deterioration of growth conditions for trees and shrubs due to restricted access to rainwater and snowmelt, possible reduction in vitality or decline, especially in the case of stands operating in limited rainfall retention areas (with a low groundwater table);
- the deterioration of growth conditions for trees and shrubs due to periodic soil erosion, the creation of physiological drought effects causing weakening and/or death of root systems, which can secondarily lead to tree toppling;
- the uneven settlement of neighbouring buildings due to changes in the mechanical parameters of the soils underlying the foundations of existing buildings, the formation of new or enlarged damage on walls and ceilings in the form of cracks or scratches, excessive deflections, and deviation from the plumb;
- the localised collapses or geometric deformations of historic pavements.

The extent of the required construction project's impact analysis:

- the project site and immediately adjacent plots and other plots at a greater distance, within a belt with a range of 100 m from the inserted waterproof screen.

Recommended measures:

- the preparation of geological-engineering documentation for the impact area of the project (the project area taken to include the area of its influence) using geotechnical parameters and numerical modelling methods verified by field surveys;
- the preparation of hydrogeological documentation for the area of the project's (the project's area along with its impact area) using hydrogeological parameters verified by field research and numerical modelling methods;

- drilling piezometric boreholes in the area of impact of the project for the purpose of monitoring the state of the soil and water environment before, during and after the project;
- an assessment of the condition of trees and vegetation in the project area including the immediate vicinity, i.e., a strip of land at least three times the depth of the excavation;
- monitoring and assessment of the condition of the trees and vegetation before, during and after the construction work – as-built assessment with recommendations for the maintenance and care of the greenery;
- whenever possible, it is recommended that an expert assessment of the technical condition of the buildings adjacent to the planned project is performed;
- the preparation of a detailed architectural and structural inventory in the form of drawings and photographs of the current technical condition of the building, taking into account all kinds of defects and technical damage;
- preparing a study to determine the relative zone of influence of all types of excavation on neighbouring structures. Recommended methods are those contained in "Instrukcje, Wytyczne, Poradniki" ("Instructions, Guidelines, Manual") series of Instytut Techniki Budowlanej (Building Research Institute - ITB), e.g., Instruction 376/2020)
- "Ochrona zabudowy w sąsiedztwie głębokich wykopów" (the protection of buildings in the vicinity of deep excavations);
- the exclusion of results derived from the so-called Driscoll's formula due to their low reliability and high analytical error, regardless of water and ground conditions;
- the geodetic monitoring of existing facilities (before, during, and after the project) on the project site and in the impact area;
- an inventory of revealed underground installations (such as: block channels, absorbing wells, historical sanitary installations) in the project area and in the area of its influence, until the resulting processes have stabilised;
- where technical methods of lowering elevated groundwater levels are used, e.g., by means of horizontal drainage systems, drawing documentation should be prepared with the layout of the elements and determination of the impact of the designed solutions on neighbouring buildings.

CATEGORY D

Earthworks and construction projects resulting in excavations and underground storeys executed in the wet layer of the subsoil, i.e., below the groundwater table, where rock mass drainage is used, that is, where groundwater is discharged from drainage facilities, including drilled wells, well complexes, and wellpoints, water collection wells, sumps, ditches and so on.

Risks:

- the subsidence of the land surface in the vicinity of the excavations and in the area of the cone of depression, and damage to buildings;
- the dampness or flooding of the underground floors of neighbouring buildings by rainwater and snowmelt;
- the deterioration of growth conditions for trees and shrubs as a result of restricted access to rainwater and snowmelt, the possible reduction in their vitality and/or death, especially in the case of stands operating in limited rainfall retention areas (with a low groundwater table) in the area of a potential drainage system cone of depression;
- the deterioration of growth conditions for trees and shrubs due to the periodic waterlogging of the area, the creation of a physiological drought effect causing the weakening and/or death of root systems, with secondary possibility of this leading to tree toppling;
- the uneven settlement of neighbouring buildings as a result of a change in the mechanical properties of the soil beneath the foundations of existing buildings, the formation of new or increased damage to walls and ceilings in the form of cracks or scratches, excessive deflections, and deviation from the plumb in the area of the potential extent of the drainage system cone of depression;
- the localised collapse or geometric deformation of historic pavements in the area of the potential extent of the drainage system cone of depression.

The extent of the required project's impact analysis:

- the project site and immediately adjacent plots, as well as other properties at a greater distance, i.e., in the area of influence of the drainage system must take into account any excavation or the contour of the drainage system and the cone of depression caused by the drainage system of the above-mentioned pit and be calculated using the analytical Sichardt's formula.

Recommended measures:

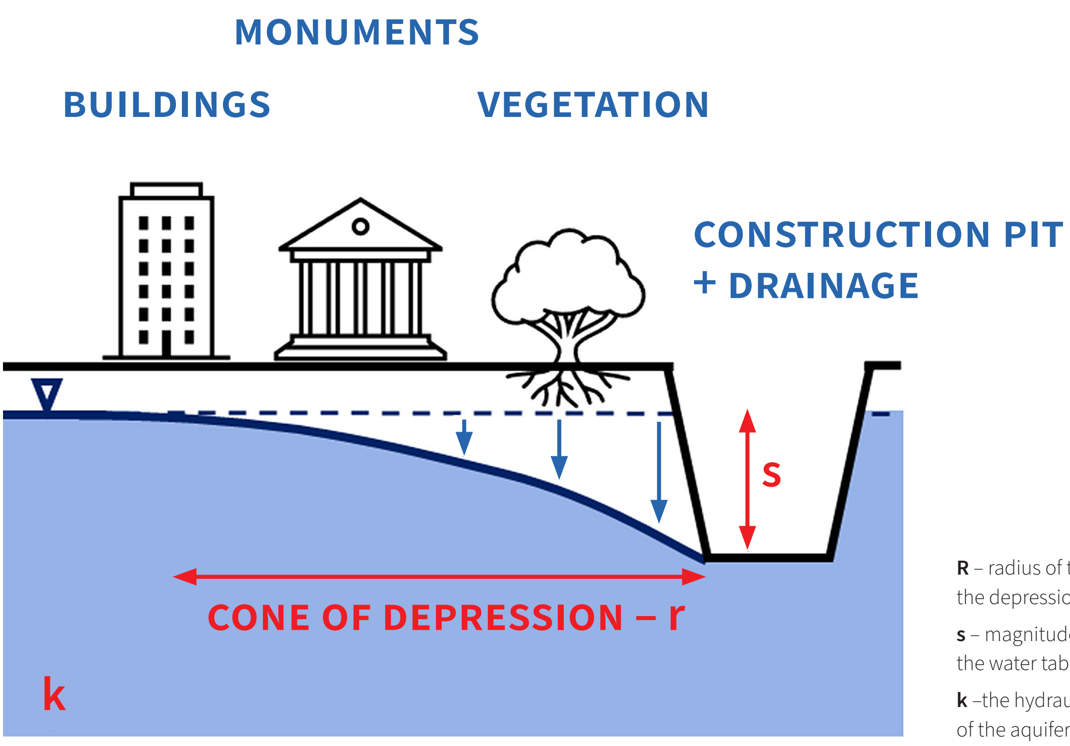
- the preparation of geological-engineering documentation for the project's impact area (the project site including the its impact area) using geotechnical parameters and numerical modelling methods verified by field surveys;
- the preparation of hydrogeological documentation for the impact project's area of impact (the project site along with the area of its influence) with the use of hydrogeological parameters verified by field research and numerical modelling methods;
- exclusion of the possibility of dewatering rock masses containing sand, gravel, and silt formations by pumping water directly from water collection wells or sump and ditches located at the bottom of the excavation, even if the side walls are supported;

- drilling piezometric boreholes in the area of impact of the project for the purpose of monitoring the state of the soil and water environment before, during, and after the project;
- drawing up an inventory of trees and vegetation in the project area and considering the impact zone of the project, i.e., the potential cone of depression caused by the operation of the drainage system;
- monitoring and the assessment of the condition of the stand of trees and vegetation before, during and after construction work – as-built inventory with recommendations for the maintenance and care of greenery;
- imposing an obligation to water the vegetation during and after the project according to the results of soil moisture tests and an obligation to restore groundwater levels;
- the exclusion of results derived from the so-called Driscoll's formula due to their low reliability and high analytical error, irrespective of the water and ground conditions; and its lack of reliability and because it is subject to high analytical error, regardless of water and ground conditions;
- the execution of a structure and construction expert's opinion on all structures adjacent to the planned project, together with a determination of the form and extent of the impact of future construction work on them;
- the completion of a detailed architectural and structural inventory in the form of drawings and photographs of the current technical state, taking into account all kinds of defects and technical damage;
- a study to determine the relative impact zone of any excavations on neighbouring structures. Recommended methods are those contained in the series of "Instrukcje, wytyczne, poradniki" ("Instructions, Guidelines, Manuals") series of Instytut Techniki Budowlanej (Building Research Institute – ITB), e.g., Instruction 376/2020 "Ochrona zabudowy w sąsiedztwie głębokich wykopów" ("The protection of buildings in the vicinity of deep excavations");
- deciding not to consider the dependencies presented in the Driscoll's formula, used for all construction projects regardless of the soil and water conditions;
- the geodetic monitoring of existing facilities before, during and after the project – until the resulting processes the area of the potential cone of depression caused by the operation of the drainage system have stabilised;
- an inventory of revealed underground installations (such as block channels, absorption wells, historic sanitary installations) in the area of the potential cone of depression caused by the operation of the drainage system;
- where technical methods of groundwater level lowering are used, the preparation of drawing documentation with the layout of the elements and the impact of the designed solutions on neighbouring buildings.

Cone of depression – a depression (lowering) of the surface of the groundwater table around a well, intake, mine, etc., caused by pumping. A cone of depression is represented through lines of equal depression. When a well is pumped in a homogeneous layer, the cone of depression shows cylindrical symmetry (lines of equal depression are circles) and is characterised by the depression in the well and the radius of the cone of depression. Under the actual conditions of groundwater flow, the cone of depression assumes the asymmetrical shape of an ellipse elongated in the direction of water inflow. Numerous experimental formulae and graphical methods are used to calculate the extent of the cone of depression, especially in terms of calculation of water inflow to wells. One of these is the Sichardt's formula, which is suggested for use.

(compiled by M. Czop)

Source: T. Bocheńska et al, *Słownik hydrogeologiczny*, Państwowy Instytut Geologiczny, Warsaw 2002, https://www.gov.pl/web/klimat/hydrogeologia (accessed: May 2022).



R – radius of the extent of the depression

s – magnitude of lowering of the water table (depression)

k –the hydraulic conductivity of the aquifer being drained

Vadose (unsaturated) zone – the area contained between the ground surface and the capillary rise zone. In the vadose zone, the rock voids are filled with air and water occurring in the form of water vapour, bound water (hygroscopic water, membrane water) and unbound water (suspended and seeping water).

Source: T. Bocheńska et al., op. cit.

Saturation zone – the zone of occurrence of rocks in which the free spaces (pores, fractures, karst voids) are entirely filled with water. The upper surface of this zone (groundwater table) borders the vadose zone.

Source: T. Bocheńska et al., op. cit.

Detrimental alteration of water on the ground – the totality of activities outlined in Article 234 of the Polish Water Law. It may consist in: 1) changing the direction and intensity of rainwater or snowmelt outflow or the direction of water outflow from springs – to the detriment of neighbouring land; 2) the discharge of water and the introduction of sewage into neighbouring land. It may be caused by a change in the shape of the plot's surface as a result of earthwork, including, in particular, the construction of embankments and ditches, or even by a change in land use, including, for example, a change in the character of the surface from that of natural to sealed.

Source: Act of 20 July 2017. Water Law (Journal of Laws 2017, item 1566).

Hydrogeological damage – damage to the surface and the structures/buildings erected on it resulting from a change in hydrogeological conditions. The most severe hydrogeological damage occurs within the cones of depression of wells and drainage systems, where drainage lowers the groundwater table, which can cause subsidence of the land surface, often unevenly.

Source: T. Bocheńska et al., op. cit.

Groundwater – free water subject to gravity, occurring in the saturation zone below the groundwater table within aquifers. The groundwater in circulation, of atmospheric or meteorological origin, i.e., precipitation fed, fresh, with mineralisation below 1.0 or 2.0 g/dm^3 is of the most importance. The recharge of groundwater takes place through infiltration, which begins with the infiltration of a portion of the precipitation and snowmelt water and continues through the vadose zone (between the land surface and the groundwater table), within which the water is partly stored (soil retention, groundwater retention), partially drained (subsurface, mid-flow) and evaporates (groundwater evaporation). In the saturation zone, the water flows towards surface watercourses and reservoirs (groundwater outflow, groundwater drainage) and retains some water (underground retention).

Source: T. Bocheńska et al., op. cit.

Subsurface (suspended) waters – water of the vadose zone occurring above the groundwater table, also generally referred to as suspended waters: bound waters, capillary waters (some of which are soil waters), and free water moving by gravity, flowing through the vadose zone to the groundwater table, to free groundwater. Suspended aquifers and very shallow groundwater (low-thickness aeration zone) are also sometimes categorised as suspended waters.

Source: T. Bocheńska et al., op. cit.

Sichardt's formula – a theoretical relationship used to determine the extent of a cone of depression for a well or drainage system (in the so-called "large diameter well" method). Originally developed for unconfined aquifers recharged by the infiltration of rainwater and snowmelt, it can also be used in practice for confined aquifers, i.e., it is universal for all types of hydrogeological conditions.

The equation reads:

$$R = 3000\ s\sqrt{k}$$

where:

R – the radius of the extent of the cone of depression [m];
s – the magnitude of the lowering of the water table (depression) as a result of pumping water from a well, a group of wells or other drainage systems (e.g., wellpoints systems, sumps, ditches and others) [m];
k – the hydraulic conductivity of the aquifer being drained [m/s].

Permeability classes	Limit values of hydraulic conductivity – k [m/s]	Typical soils/rocks
Very good	Over 1×10^{-3}	rock debris, colluvium, gravels and sand gravels, coarse sands
Good	$1\times10^{-4} – 1\times10^{-3}$	differentiated and medium-grained sands, massive rocks with dense network of cracks and fissures
Medium	$1\times10^{-5} – 1\times10^{-4}$	fine-grained sands, alluvial soils on a sandy base, loess, weak clayey sands (developed on sandy soils), organic soils and grounds (seedbed soils)
Weak	$1\times10^{-6} – 1\times10^{-5}$	aeolian sands, loamy sands, alluvial soils, fen soils on loess and silts, and rendzina in valleys and basins
Very weak (semi-permeable formations)	$1\times10^{-8} – 1\times10^{-6}$	clays, silts and loamy silt, loamy loess, alluvial soils, mudstone, sandy loam, massive rocks with low fracture index
Practically zero (practically impermeable formations)	below 1×10^{-8}	heavy clays, heavy loams, silty loams, fen soils on heavy clays and marls, solid rock i.e., without fractures

Using the limit values of the hydraulic conductivity for typical geological formations found in the bedrock of historic buildings, a simplified version of the Sichardt's formula is obtained, in which the radius of the extent of the cone of depression (R) depends only on the magnitude of the lowering of the groundwater table (s) by the well or drainage system. The simplified version of the Sichardt's formula has the following forms:

- for gravels and coarse-, medium- and fine-grained sands:
  $k = 1\times10^{-3}$ m/s → R ≈ 95 s
- for fine sands, loess, fen soils and organic soils:
  $k = 1\times10^{-4}$ m/s → R ≈ 30 s
- for aeolian sands, clayey and loamy sands and muds:
  $k = 1\times10^{-5}$ m/s R ≈ 10 s

(compiled by M. Czop)

Sources: M. Rogoż, *Metody obliczeniowe w hydrogeologii* (*Calculation methods in hydrogeology*), Wydawnictwo Naukowe Śląsk, Katowice 2012; T. Bocheńska et al., op. cit.

Driscoll's formula – a theoretical relationship describing the scale (magnitude) of the hazard from the stand for existing buildings expressed by the value of the IP coefficient. The result obtained is subject to significant error due to the very general nature and high discretion of the calculation parameters. The basic prerequisite for the application of the Driscoll's formula is the presence of only cohesive soils in the ground and the location of the groundwater table below the foundation level of the building. The practical application of this relationship for typical geological and hydrogeological conditions, including much more complicated ones which do not meet the above-mentioned assumptions, is completely wrong. There are newer and more reliable indications for assessing the risks to buildings posed by the proximity of trees and effectively counteracting these risks.

(compiled by W. Bobek, R. Paruch)

Source: R. Driscoll, H. Skinner, *Subsidence damage to domestic buildings. A guide to good technical practice*, IHS BRE Press, Watford 2007.

Hydrological risks to historic buildings and sites – the totality of natural and man-made processes and phenomena adversely affecting historic buildings and sites, whose main causative factor is water in various states of aggregation originating from precipitation (rainwater and snowmelt) and also occurring in groundwaters (aerated waters and groundwaters) or supplied by human activities (e.g., sewage, tap water, irrigation water, and others). Hydrological risks cover a wide range of unfavourable processes and phenomena, mainly cracking and deformation and other damage related to subsidence (compaction) or the swelling of soils due to changes in natural water conditions in the ground and subsoil and the swamping of the ground and underground storeys of buildings, including rising damp and periodic and permanent flooding.

(compiled by M. Czop)

Groundwater table – the surface separating the saturation zone from the vadose zone (the capillary zone from the free groundwater zone). The groundwater table formed by natural hydrogeological processes may be artificially altered: a) by being lowered – as a result of water abstraction by wells and drainage systems, including construction drains, and b) by being raised – as a result of increased recharge of the aquifer by rainfall and snowmelt or from other seepage and the use of waterproofing barriers, including those executed as part of construction work.

Source: T. Bocheńska et al., op. cit.