Overview of the HKU Depthwise HydrogeoSystem for high-resolution groundwater investigations and a vision for open-source global availability

Preface

This document unveils a revolutionary suite of technologies designed and manufactured in China at an unprecedentedly low cost. Harnessing the power of 3D printing for key components and utilizing readily available materials, these tools enable the acquisition of high-resolution groundwater data from boreholes across virtually all hydrogeological settings. Organizations can now access these innovations as part of a "technology in a box" package, empowering them to conduct high-resolution investigations and monitoring with ease. As open-source technologies, they also allow anyone outside of China to produce them locally, guided by web-based instructions for manufacturing and field deployment.

The "technology in a box" concept delivers systems in lightweight, portable formats. Some versions arrive as complete systems, ready for immediate use, while others are nearly complete, requiring only local off-the-shelf components—such as PVC pipes and polytubing—that are too bulky to ship. This approach ensures affordability, accessibility, and adaptability to diverse field conditions.

The scientific pursuit of high-resolution groundwater data began in the 1960s in the United States and Canada, driven by the need to understand contamination plumes from nuclear energy research sites. High-resolution analysis of core samples revealed radioactive constituents with good precision. In the 1970s and 1980s, makeshift systems of bundled tubes were deployed in aquifers for high-resolution understanding of landfill and agricultural contamination. These early efforts demonstrated the critical importance of detailed data in understanding groundwater systems.

In 1975, the Westbay MP system emerged as a formally engineered solution for measuring profiles of groundwater pressure distribution, a breakthrough for high-resolution of hydraulic head distribution. By 1978, it was adapted to collect water samples alongside pressure measurements. Inspired by this innovation, Dr. John Cherry and colleagues at the University of Waterloo developed an improvised system in 1982, which Solinst Canada later reengineered and commercialized. Over the following decades, several engineered systems entered the market, targeting high-resolution data on hydraulic head and water chemistry. Yet, despite their proven value in studies across North America and Europe, these technologies have remained little utilized. High costs, limited versatility, and a lack of clear frameworks have stifled their adoption in research, education, and practice.

In the 2010s, a visionary research team led by Dr. Jimmy Jiao at the University of Hong Kong, with contributions from Dr. John Cherry, transformed the field with new high-resolution multi-depth monitoring technologies. These innovations culminated in the HKU DepthWise HydrogeoSystem, a groundbreaking solution that overcomes the limitations of its predecessors. Leveraging 3D printing for key components, the system materializes complex concepts with unparalleled design flexibility at a fraction of the cost. A standout invention is the HKUniversal Seal, a low-cost yet highly effective sealing mechanism that resolves the longstanding issue of unreliable seals in multi-depth systems.

The HKU DepthWise HydrogeoSystem is remarkably versatile, addressing a wide array of challenges: groundwater contamination, flow in fractured rock and karst, groundwater-surface water interaction, groundwater supply, sponge city initiatives, geotechnical engineering (e.g., landslides and tunnels), eco-hydrology, coastal hydrogeology, and mountain hydrogeology. Its affordability and simplicity make it ideal for integration into educational programs, enabling hands-on experiential groundwater training in schools and universities worldwide.

The "technology in a box" initiative, entirely open source, aims to ignite innovation and democratize access to the tools needed for high-resolution groundwater investigations. By breaking down barriers of cost, complexity, and exclusivity, we seek to correct decades of underutilization and unlock the full potential of these transformative technologies. Our goal is clear: to empower researchers, educators, and practitioners globally, fostering broader adoption and advancing the science and practice of groundwater investigation.

Abstract

This document outlines the HKU DepthWise Hydrogeosystems (HKU-DHS) initiative, a transformative effort to advance groundwater science through high-resolution data acquisition. Developed since 2017 by the University of Hong Kong in collaboration with The Groundwater Project, HKU-DHS provides a suite of eight innovative, low-cost technologies designed for multi-depth monitoring in diverse hydrogeological settings, including porous media, fractured rock, and karst systems. These systems address the chronic issue of sparse groundwater data, offering depth-discrete measurements that reveal critical features often missed by conventional methods. Key innovations include the HKU Dual System and HKU-UW Hybrid Systems, which are versatile and adaptable for use in challenging environments such as unstable fractured rock and deep aquifers. The systems utilize advanced sealing materials like the HKUniversal seal and can be manufactured locally using widely available components, ensuring global accessibility. The aim is for the technologies manufactured by 3-D printing in China for across China but also for use across the globe for research, education and professional practice. By enabling high-resolution profiles of hydraulic heads, water quality, and contaminant distributions, HKU-DHS supports applications ranging from mountain hydrology to coastal aquifer management and agricultural impact assessments. This initiative emphasizes open-source availability, fostering global collaboration to enhance groundwater education, research, and practical problem-solving. A key goal is to shift groundwater science from a data-sparse to a data-rich field, empowering researchers and practitioners to tackle pressing environmental challenges, including climate adaptation, ecosystem protection, and sustainable resource management. Field-tested precursors to HKU-DHS have already demonstrated the transformative potential of high-resolution data in understanding complex groundwater systems.

1 Introduction

Within the various disciplines that involve borehole creation, considerable expertise exists for characterizing the media properties of the groundwater zone. There is a significant body of literature based on high-resolution profiles obtained using engineered systems installed in boreholes for multi-depth measurements. However, these systems are rarely utilized due to their high cost, the difficulty of deployment, and a lack of recognition of the negative implications of data sparsity.

This document describes an initiative aimed at advancing groundwater science beyond sparse data through a collaborative effort involving two nonprofit organizations (NGOs) operating within an open-source framework. The first is HKU DepthWise Hydrogeosystems (HKU-DHS), for which the development started 2017. The second is The Groundwater Project (gw-project.org), initiated in 2017. The GW-Project publishes free, online educational materials created by international experts on groundwater and related topics, available for free download.

The GW-Project aims to provide synthesized information on lessons learned from the use of earlier versions of high-resolution technologies, which were precursors to the HKU-DHS system, and to offer guidance on how to deploy these technologies most effectively. Each technology is designed to obtain high-resolution profiles of data from multiple depths at each drilling location. The goal is to collect depth-discrete data from each depth or zone to accurately represent in-situ groundwater conditions.

This vision has two paths: the first is for the technologies to be manufactured in China using advanced methods at the lowest possible cost for use within China and for global distribution. The second path is to provide the necessary information for organizations in other countries to produce their own versions of these technologies at the lowest possible cost. The overarching goal is to transform groundwater science into a data-rich field through the acquisition of high-resolution data, rather than allowing it to remain predominantly data-sparse.

Although some components of the systems described below are covered by patents in China, these patents are intended to establish priority recognition rather than to restrict the availability of the technologies. It is hoped that this initiative will enable professors and their students worldwide to conduct field-focused research on important problems that are currently under investigated due to high costs and a lack of guidance on how to deploy these technologies most effectively.

Our vision for HKU-DHS is for them to achieve global adoption in the study of groundwater in porous media, fractured media, and karst systems. We expect these technologies to support research in environments that are particularly data-sparse regarding groundwater, such as mountains, wetlands, coasts, forests, groundwater-dependent ecosystems, and more.

2 Conceptual Framework for HKU-DHS

Each technology within the HKU-DHS suite, with the exception of No. 8, involves the installation of an engineered assembly of tubes, pipes, and other components into a single borehole. Each tube functions as a miniature water well, operating as an open-tube piezometer designed for measuring water levels and/or for groundwater sampling.

The term "high resolution" refers to the goal of acquiring profiles with sufficient detail (resolution) to clearly identify the relevant features of the groundwater system at each location. In this context, "detail" refers to the vertical distance between each data acquisition depth. Since most of the drilling is in the vertical direction, the framework assumes that the profiles are constructed along the vertical dimension. A three-dimensional understanding of groundwater systems can be achieved by integrating an adequate number of spatially distributed vertical profiles.

In certain situations, particularly in geotechnical engineering, some boreholes are drilled at an angle or even horizontal. For these cases, adaptations of the HKU-DHS are available and suitable for installation in such angled boreholes.

The vertical distance between data acquisition depths depends on the nature and purpose of the investigation but, in practice, typically ranges from a few tens of centimeters to several meters. In conventional groundwater investigations, monitoring wells are commonly used. Generally, a single well is installed in a single borehole at each investigation location, or a few wells may be installed in multiple boreholes to form a monitoring well cluster.

However, past high-resolution investigations conducted across various hydrogeological settings have demonstrated that this conventional approach is often inadequate. It frequently leads to the lack of identification or misidentification of critical features within groundwater systems. These shortcomings commonly result in errors spanning orders of magnitude in chemical concentration measurements and mass influx calculations. Consequently, the field of groundwater science is significantly hindered by the prevalence of sparse and insufficient data.

3 The Eight Categories of HKU Technologies

The suite of eight HKU technologies described here encompasses what is needed to accomplish high-resolution groundwater investigations in nearly all types of hydrogeological circumstances (Table 1). These technologies share a common goal in their development: achieving low cost and ease of use. Two of the technologies, the HKU Dual System and the HKU-UW Hybrid System , are particularly important due to their versatility.

The HKU Dual System and the HKU Hybrid Basic are expected to become the global backbone of multi-depth monitoring. They serve both for hydraulic head monitoring and water sampling over the largest depth range and can be used for water level response tests to determine hydraulic conductivity. The HKU Dual System stands out globally because it can be manufactured at an exceptionally low relative cost. All its components are small, lightweight, and compact, allowing for low-cost shipping anywhere as a complete system.

Table 1 The key features of each of the 8 Categories of HKU-DHS

Technology	Function	Design	Key Features	Advantages
1. HKU Dual Purpose System	Water level measurements and groundwater sampling.	Multi-tube assembly using thin-walled PVC pipes.	- Uses HKUniversal seal (expands upon contact with water).	- Lightweight, compact, and low-cost. - Can exceed 500 meters depth.
2. HKU-UW Basic Hybrid System	Multi-depth monitoring for hydraulic head and water sampling.	Flexible poly tubing bundled inside standard PVC pipes.	- No glue chemicals (reduces contamination). - Improved port design using 3D printing**.**	- Locally manufacturable. - Suitable for stable boreholes and removable after use.
3. HKU-UW Manufactured Hybrid System	Multi-depth monitoring with enhanced manufacturing.	Most components (except PVC casing and polytubes) are 3D-printed.	- Small, lightweight, and low-cost shipping. - Open-source design.	- Promotes global accessibility. - Cost-effective and adaptable.
4. HKU Groundwater Samplers	Multi-depth groundwater sampling.	Assembly of small-diameter tubes, each extending to a different depth.	- Cannot measure water levels (single-purpose). - Compact design with multiple ports.	- Ideal for detailed vertical sampling. - Low-cost and easy to deploy.
5. HKU Combined System	Combines water level measurement and groundwater sampling.	Stiff PVC pipes (for water levels) + flexible polytubes (for sampling).	- PVC tubes accommodate transducers. - Polytubes allow sampling without disturbing levels.	- Versatile and cost-effective. - Suitable for applications requiring both data types.
6. HKU Water Wells in Fractured Rock	Reduces contamination risks in fractured rock wells.	Extends steel casing deeper and uses HKUniversal seals at multiple depths.	- Prevents surface contamination. - Suitable for small-diameter wells in rugged terrains.	- Cost-effective for remote areas. - Improves access to clean water in challenging environments.
7. HKU/Geotec System	Measures water pressure at multiple depths for geotechnical applications.	Modified for installation in angled or horizontal boreholes.	- Pressure transducers and data loggers for continuous monitoring. - Real-time data transmission.	- Ideal for slope stability and tunnel monitoring. - Adaptable to challenging installations.
8. HKU Miniature Drive-Point Wells	High-resolution groundwater profiling in shallow settings.	Small-diameter well points connected to polytubes, driven by vibratory hammers.	- Can penetrate up to 40 meters. - Low-cost and minimally disruptive.	- Ideal for areas where conventional drilling is impractical. - Provides detailed vertical profiles.

Another important system from a global perspective is the HKU-UW Basic Hybrid System , as it can be easily produced in most countries using materials that are readily available at low cost and simple equipment. Both the HKU Hybrid systems are well-suited for use in boreholes in bedrock. These system can be deployed in stable holes and removed after a period of use.

It is expected that the HKU Dual System can be deployed much deeper than the Hybrid System , likely exceeding 500 meters, although its depth capability needs to be determined through field tests.

3.1 HKU Dual Purpose System:

This system serves for both water level measurements and groundwater sampling (Figures 1-3). It is a multi-tube assembly in which the tubes are made of standard thin-walled PVC pipe with an inside diameter large enough to accommodate the insertion of devices for measuring water levels, as well as small-diameter sampling pumps (Patent Application No. 2024212951878). This system incorporates a new type of seal, the HKUniversal seal (Patent Application No. 2024223031380), which expands upon contact with water, similar to bentonite clay. However, the HKUniversal seal material is more versatile and effective than bentonite.

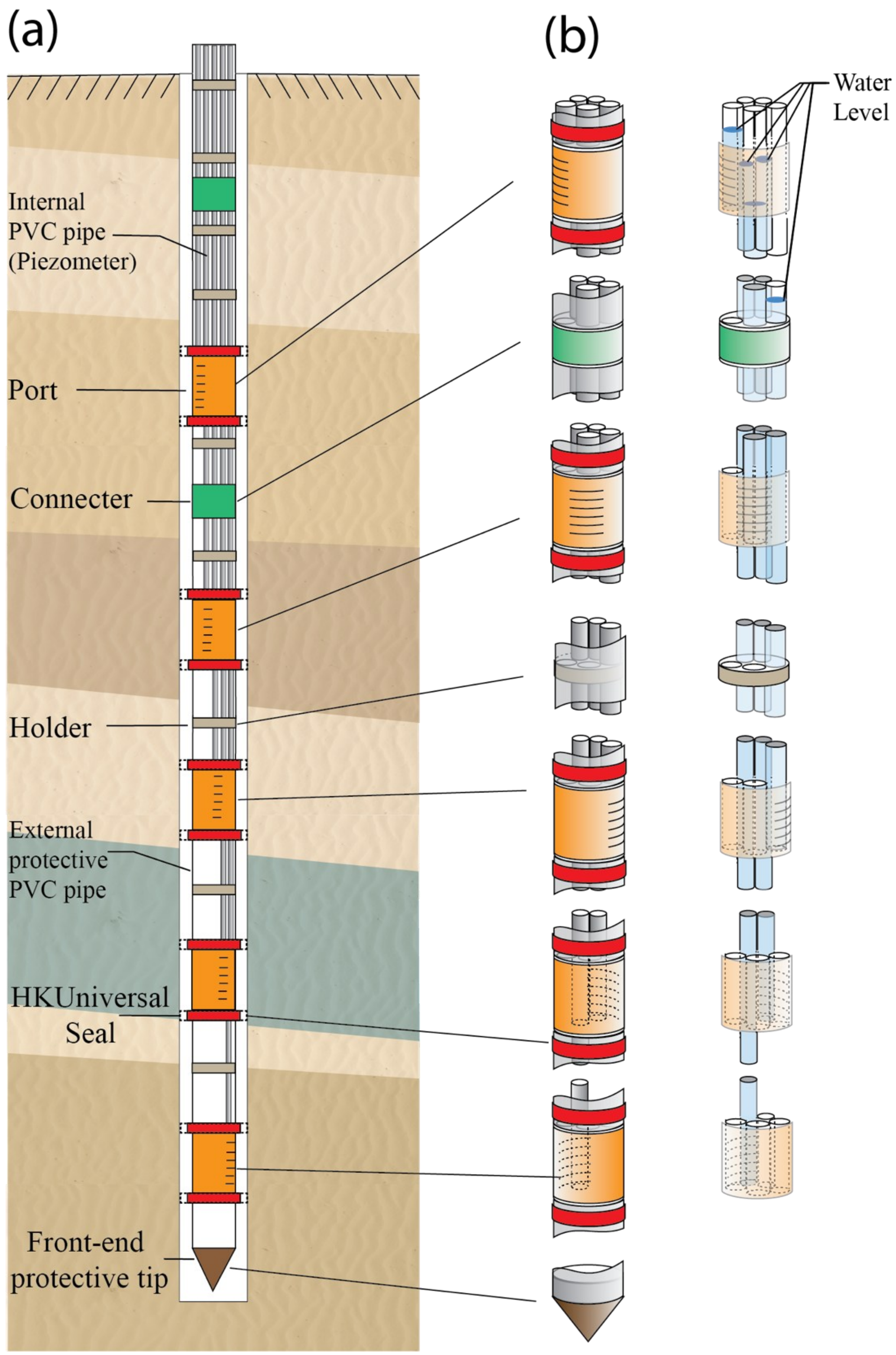

Figure 1 HKU Multi-Depth Dual Purpose System. The figure here shows a system with 5 PVC pipes.

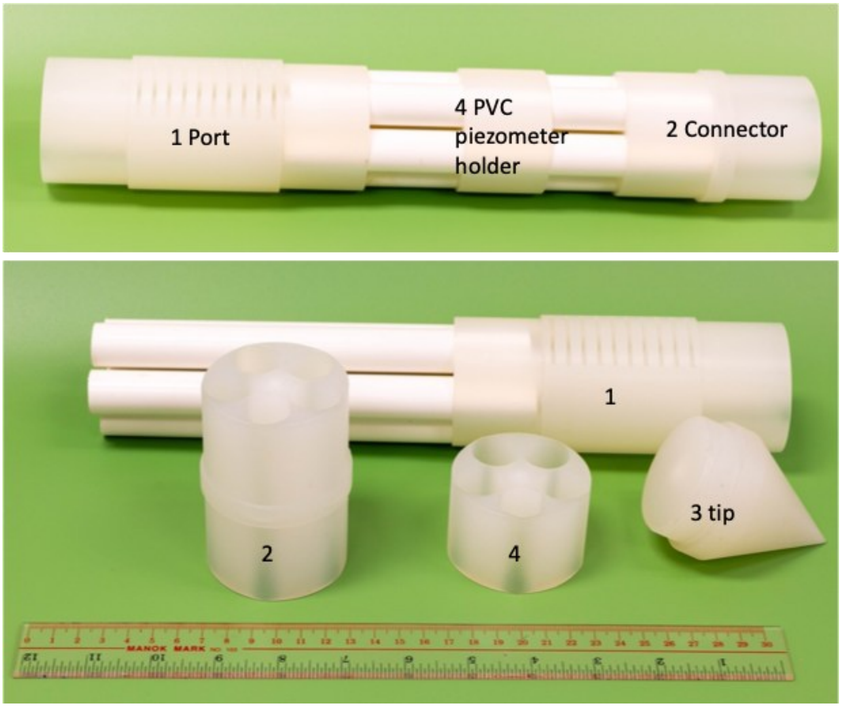

Figure 2 Details of the key components such as port, connector, PVC piezometer holder for the 5-depth dual purpose system.

Figure 3 A HKU 18-depth dual purpose system was installed into interlayered sandstone and shale geological system in in Chiao-Tung University in Taiwan to study slope stability. (a) Holes of ports are marked and numbered. (b) PVC tubes (piezometers) are numbered and organized using holders. (c) Organized PVC tubes are inserted in large protective pipes. (d) Ports are connected. (e) Seals are wrapped at desired depth. (f) The system is inserted in the borehole section by section.

3.2 HKU-UW Basic Hybrid System:

This system serves the same general data acquisition purpose as the Dual-Purpose System and can be manufactured almost anywhere using local materials and without the need for sophisticated equipment. It is assembled from rolls of flexible poly tubing, which are inserted as a tubing bundle inside coupled lengths of standard PVC pipe. The design is derived from that described by Cherry and Johnson (1982), which evolved into the commercially available Solinst-Waterloo System, as shown on the Solinst Canada website. However, the HKU–UW Basic Hybrid System incorporates three key design modifications compared to the Cherry and Johnson version.

The first modification is the use of a small screw inserted into the couplings, eliminating the need for glue chemicals that could contaminate water samples. The second is the use of the Universal seal, a new sealant material produced in China for the geotechnical industry, which is both low-cost and environmentally friendly. The third is a significantly improved port design, manufactured using 3D printing, which is more durable and better suited for hydraulic testing.

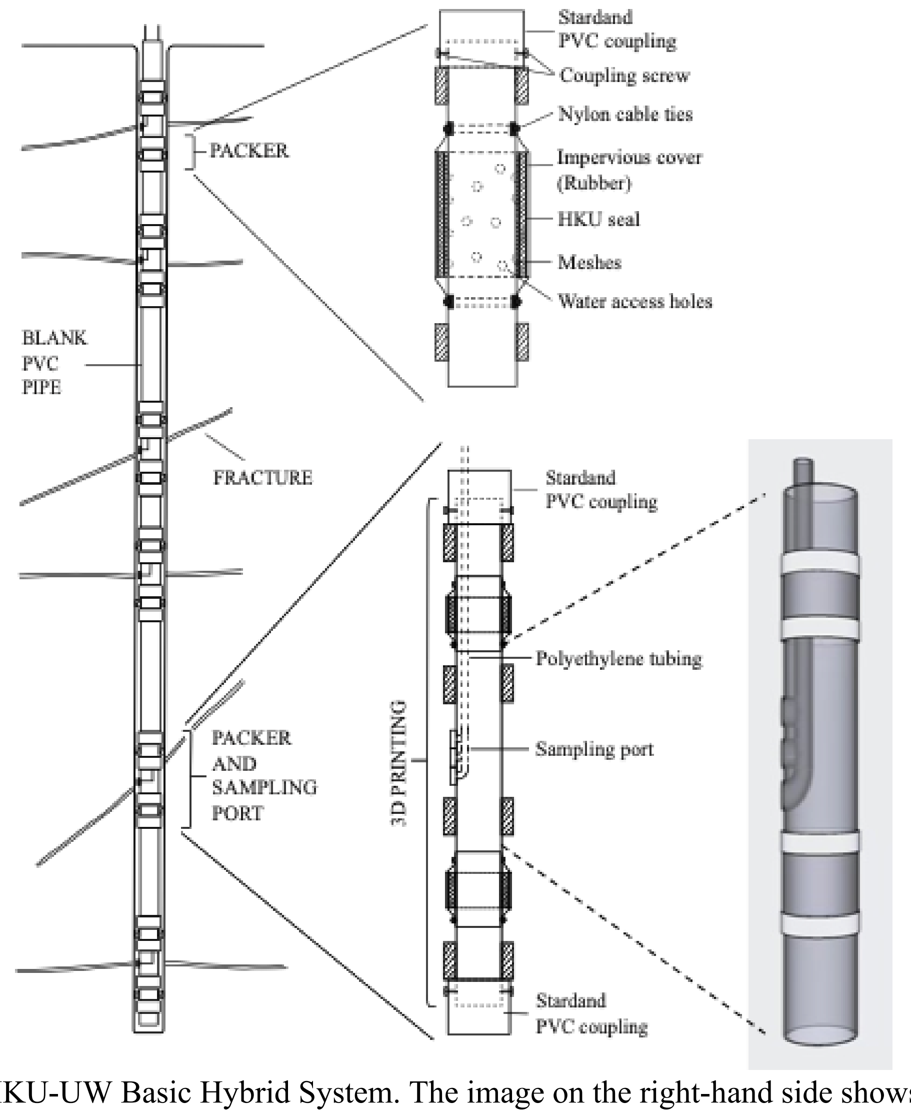

Figure 4 HKU-UW Basic Hybrid System. The image on the right-hand side shows the port produced by 3D printer

3.3 HKU-UW Manufactured Hybrid System:

There is a second version of the Hybrid System, which has the same functional features as the Basic Hybrid System described above. However, in this version, all components except two—the PVC casing and the polytubes—are manufactured using 3D printing. This version is referred to as the Manufactured Hybrid System. Users must purchase the PVC casing (pipe) and polytubes locally as off-the-shelf components, while the 3D-printed components are supplied by the HKU DHS. These 3D-printed parts are small in size and lightweight, ensuring low-cost shipping. Alternatively, users can employ 3D printing to manufacture the components locally. As a result, both Hybrid Systems are openly available to all, promoting independence and accessibility.

3.4 HKU Groundwater Samplers

This technology consists of an assembly of small-diameter tubes, where each tube extends to a different depth, enabling water sampling at multiple depths (e.g., 20–30 depths). The diameter of the tubes is too small to allow for water level measurements, making this a single-purpose system designed exclusively for sampling (Patent No. 202520168772X).

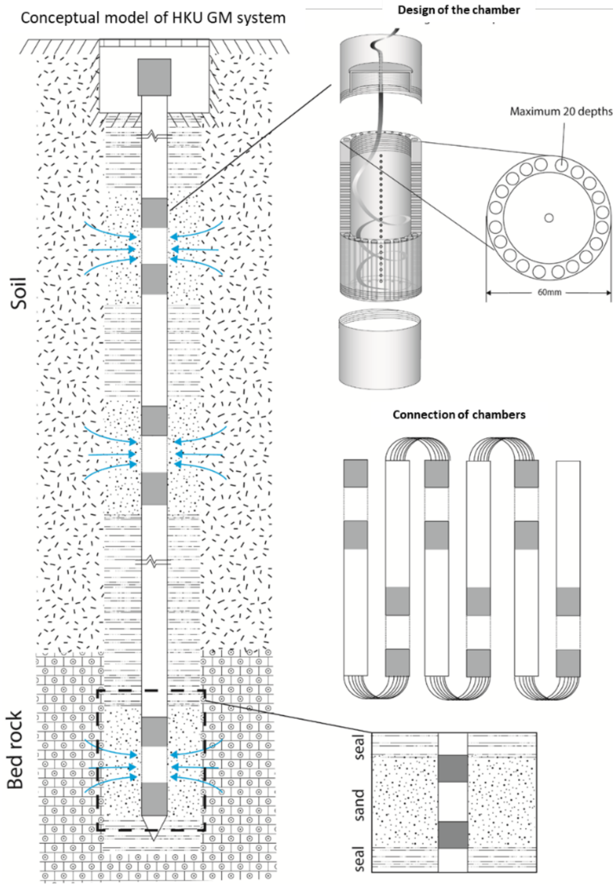

Figure 5 20-port HKU Groundwater Sampler of 60 mm diameter installed in a hole of 92 mm diameter in Pearl River Delta, China (left). Details of the structure of a port and the holes for tubes around this port which are used to sample water from ports below (top right). The sampler consists of many sections with length 1 to 4 m (middle right). Each port has seals above and below (right bottom).

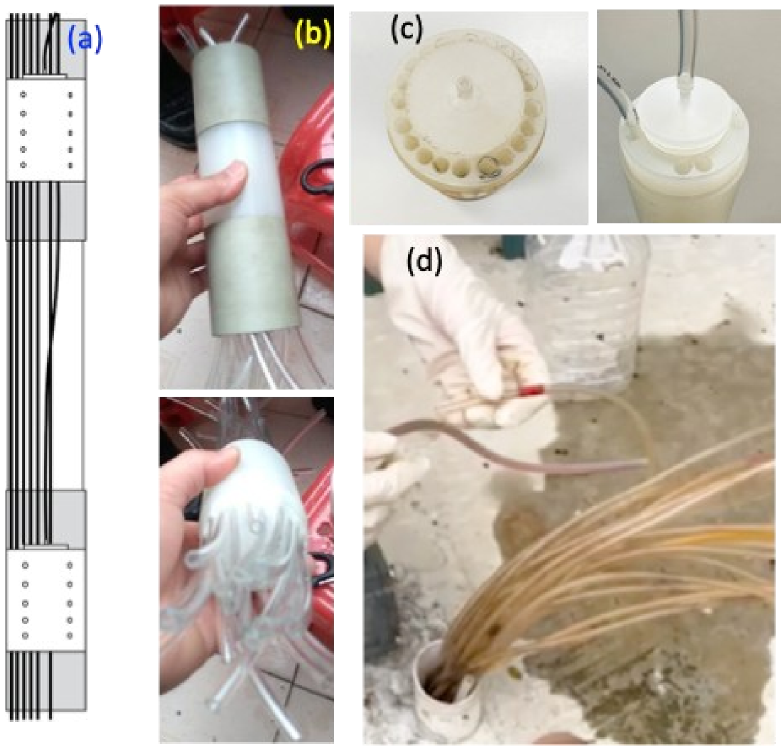

Figure 6 Some details of the HKU Groundwater Sampler installed in Pearl River Delta. (a) two of the sampling ports are shown. The holes of the ports serves as water inlets. Each port is linked to only one tube. (b) A real port with tubes. (c) holes around a sample chamber. The top of the chamber is linked with a tube which is used to sample from this chamber. This particular sampler has 20 holes so it can sample water from 20 depths. (d) A peristaltic pump is used to sample water from the sampling system with 20 ports.

Figure 7 A 20-tube groundwater sampler system is installed in the Quaternary aquifer-aquitard system in the Pearl River Delta, China. The deepest tube reached the depth of 78 m.

3.5 HKU Combined System:

This system combines stiff, thin-walled PVC pipes, which serve as miniature wells, with smaller, flexible polytubes dedicated solely to water sampling. It is expected that, in most applications, these systems will likely include significantly more water sampling tubes than miniature PVC wells. The advantage of this combination is that the PVC tubes can accommodate transducers for continuous water level measurements, while the polytubes are used to collect water samples without the need to remove the transducers. Additionally, the PVC tubes can also be used for groundwater sampling if necessary.

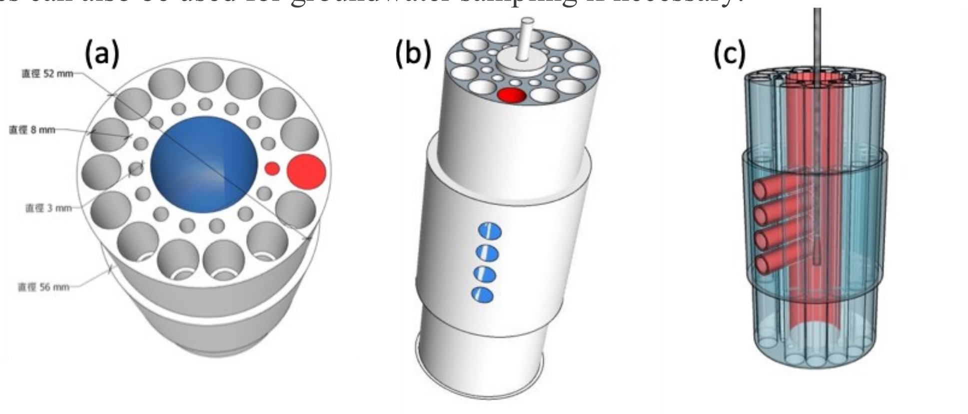

Figure 8 The details of the port in HKU Combined System. (a): The chamber (blue) is used for storing water for sampling groundwater via a small flexible polytube. (b): The blue holes are ports for groundwater to communicate with a stiff thin-walled PVC pipe (red) for water level measurement and water sampling. (c): Dark red color shows the ports connected to the chamber and the chamber with a small flexible polytube inserted in the middle for water sampling.

3.6 HKU Water Wells in Fractured Rock

The conventional design for water wells, particularly in fractured rock, often results in wells that are exceptionally prone to contamination from surface sources, particularly fecal contamination from humans and animals. This is especially true for hand-dug, large-diameter wells, which can be easily accessed by animals and insects. The susceptibility of these traditional wells to contamination arises from their construction process: a hole is drilled through the overburden to penetrate a short distance into the top of the rock or, if there is no overburden, the hole is drilled a short distance into the bare rock. A steel casing is then set with a seal of injected cement slurry between the steel pipe and the drill hole wall. In either case, the hole is drilled deeper beyond the bottom of the casing to ensure sufficient water is drawn from rock fractures.

Although the bottom of the drill hole (the bottom of the well) is relatively deep, the well effectively functions as a shallow well in terms of susceptibility to contamination from surface sources. When the well is pumped, water is drawn into the well bore from all depths, including the shallowest fractures, which provide pathways for contamination to mix with water drawn from greater depths.

In the HKU design for bedrock water wells, the steel casing is extended substantially deeper into the borehole, and the HKUniversal seals are attached to the steel casing at a few depths, including at the bottom of the casing just above the open water intake interval. Generally, the deeper the steel casing extends, the less likely the well will draw in contamination from surface sources. Although the HKUniversal seals are thin, they effectively prevent water from moving downward along the casing. Their thin profile allows for the creation of successful water wells in bedrock using relatively small-diameter holes, which can be drilled with small, even portable, drilling machines. This reduces drilling costs and makes it feasible to create small-diameter water wells in rough terrain, such as mountainous areas, where many such wells are needed globally. Hundreds of millions of people living in such terrain suffer from a lack of access to clean water, and conventional methods often fail to provide viable solutions. Wells with HKUniversal seals offer a promising alternative.

Well drillers are in the business of making money, and any changes to their routine must come at minimal cost to them. The HKUniversal seals make this possible, offering a cost-effective and practical solution for creating safer, more reliable water wells.

3.7 HKU/Geotec system

This system is similar to the HKU Dual System but is specifically designed for recording water pressure at multiple depths within a single borehole. Groundwater pressure profiles are critical for slope stability and other geotechnical monitoring applications, as increases in groundwater pressure at specific points in a slope or tunnel (known as excess porewater pressure) are often the key factor in stability assessments.

This system includes design modifications that make it particularly suitable for installation in angled or even horizontal boreholes, which are essential in many geotechnical scenarios. The modifications involve the addition of minor components to prevent scraping or abrasion of the packer exterior against the borehole wall. For horizontal holes, additional components are included to facilitate the ease of pushing the assembly into the hole.

Each tube (port) is equipped with a pressure transducer connected to a data logger, enabling continuous measurement of porewater pressure along the borehole. The data can be transmitted in real time to stakeholders who require it for analysis and decision-making.

3.8 HKU Miniature Drive-Point Wells

This system comprises several components that enable a single well point, connected to a small-diameter poly tube, to be driven into the ground to substantial depths using an electric or gasoline-powered vibratory hammer. In some situations, these well points can penetrate as deep as 40 meters. In locations with suitable geological deposits, a cluster of many such drive-point wells can provide high-resolution groundwater profiles.

In addition to its low deployment cost, this method is particularly advantageous in terrain conditions where conventional drilling activities would be too disruptive (Luo et al., 2017).

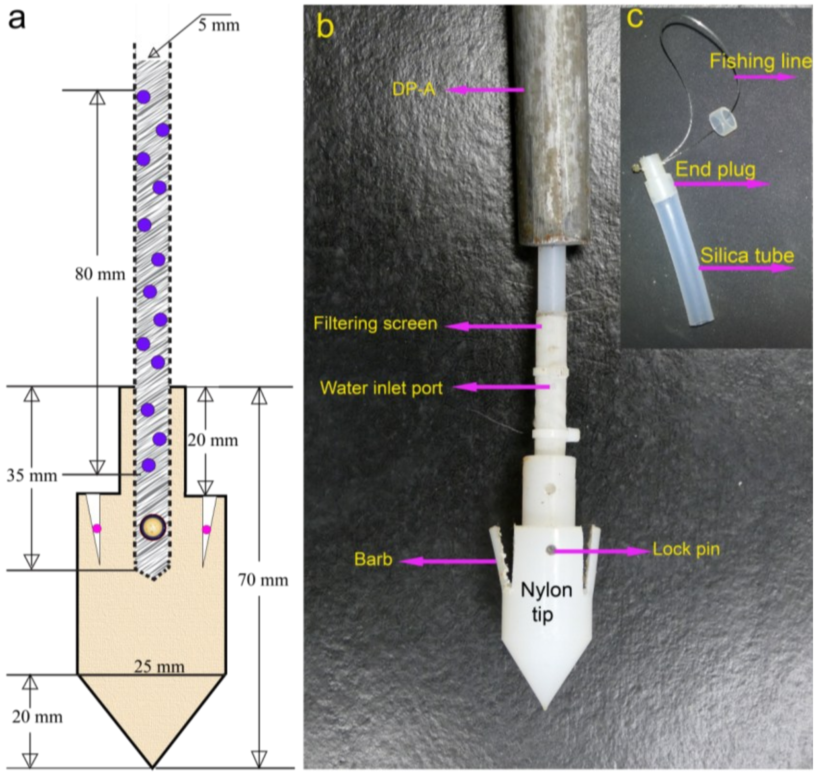

Figure 9. Detailed geometry of the tip (a), photo of the tip connected with a water tube inside a driving pipe (b) and an end plug unit (c) (Luo et al, 2017).

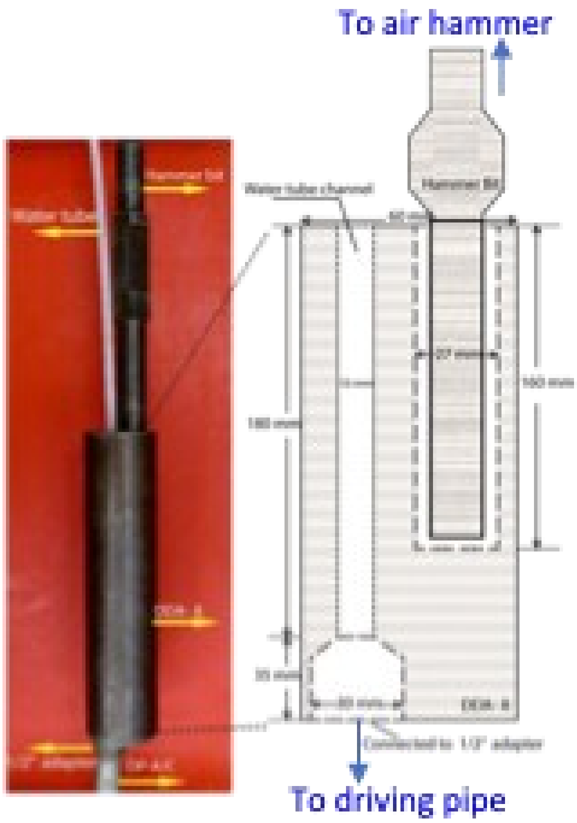

Figure 10. Schematics of the drive-down system of the sampling system (Luo et al, 2017).

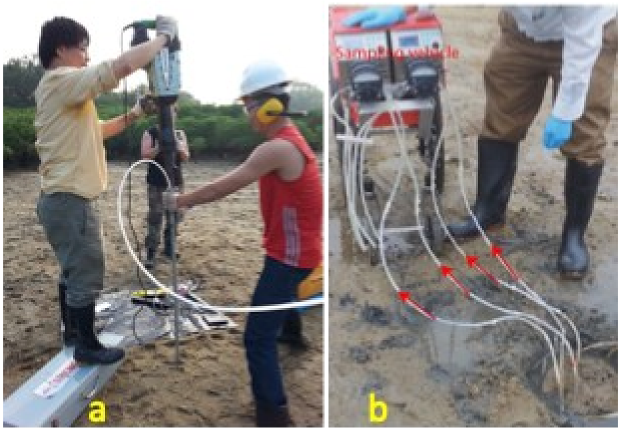

Figure 11: Air hammer is used to drive the sampling system down to the desired depth (a) and Water is sampled from different depths using a peristaltic pump (b).

4 HKUniversal Seals

Seals have long been the Achilles' heel of groundwater monitoring systems, particularly in fractured rock and karst environments. The HKUniversal Seals (Figure 12) design offers a variety of options, including those suitable for replacing the packers in commercially available multi-depth systems, such as the Westbay system and the more recent G360 multi-depth system. Such a replacement would allow these systems to be produced at a significantly lower cost.

In fractured rock, the existing commercially available multi-depth systems perform best in holes drilled using diamond core drilling, which produces smooth borehole walls. However, this type of drilling is generally much more expensive than methods that result in rough walls. To address this, HKUniversal Seal has developed a design (Patent Application No. 2024223031380) specifically aimed at being effective in rough-walled drill holes.

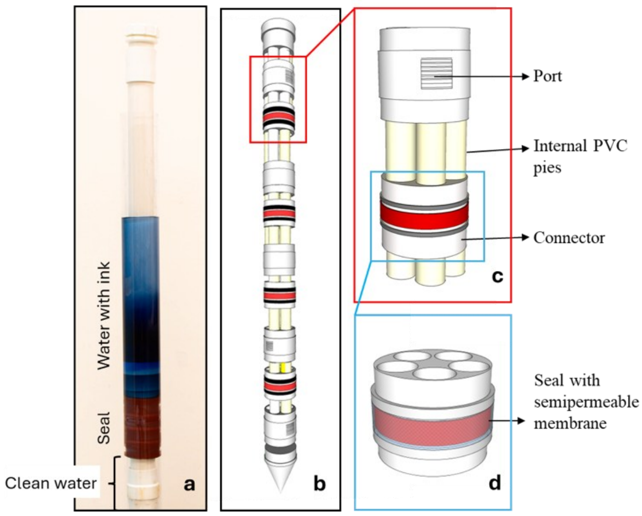

Figure 12. (a) Performance of HKUiversal seal in a plastic tube, (b) Conceptual model of the seal, (c) Demonstration of a port and connector combination, (d) Detail of connector integrating seal. A semipermeable membrane is used to let water flow in to expand the seal but not the chemicals in the seal to escape. This design is generally not needed.

5 Unique Features of the HKU Hybrid Systems

Compared to other systems, the HKU hybrid basic system has two unique attributes. First, it can be easily manufactured in almost any country, allowing it to be produced close to where it will be used. It is assembled almost entirely from common off-the-shelf components, including: poly tubing, PVC pipe, external non-threaded PVC couplings.

The HKUniversal seals can be assembled with minimal machining of the packer components. The seal material can be purchased in bulk from China at a low cost. Both the HKU-UW hybrid and the manufactured version can be designed to be removable by using deflatable packers. These packers are inflated by water pressure, and when the pressure is released later, the packers deflate, allowing the system to be removed in situations where the borehole is stable.

5.1 Number of ports and depth of deployment

The number of data acquisition depths (ports) in each borehole depends on the specific design selected for the drilling location. However, the general aim for both the dual system and the hybrid system is to achieve between 8 and 30 ports. The HKU dual and hybrid systems are most suitable for use in boreholes with diameters ranging from approximately 80 mm (3 inches) to 160 mm (6 inches)**.** Larger boreholes can accommodate larger systems with additional ports.

In most hydrological circumstances, particularly in fractured rock applications, seals must be positioned between each port to ensure that the measurements at each port accurately represent the groundwater conditions in the formation within the port. The maximum practical depth to which the HKU dual system and the hybrid system can be deployed is likely greater than 500 m, though this will need to be confirmed through field experience.

5.2 Opportunities provided by these systems

The HKU-DHS offer numerous new opportunities for field investigations. These systems provide high-quality field data, which is essential for rigorously testing hypotheses, as well as calibrating and verifying models based on precise observational methods. In recent decades, groundwater research has largely focused on advancing mathematical models. However, these models often lack rigorous calibration and verification against field data. Additionally, much of the research has relied on various forms of remote sensing, including ground and airborne methods, as well as satellite imagery. While these approaches can offer valuable insights, they have rarely been sufficiently ground-truthed, leading to conclusions that are often speculative.

A key goal of this initiative to globalize the availability of high-resolution data acquisition methods is to foster continuous improvements to the technologies. By making these systems widely accessible, contributions can come from anyone, anywhere—similar to the collaborative development seen in open-source software. This open-source approach to technological innovation can become a standard practice, driving advancements and ensuring that the tools evolve to meet the needs of researchers and practitioners worldwide.

5.3 Terminology: System Diagnosis, Characterization and Monitoring

We do not refer to the HKU dual system or other multi-depth systems as "monitoring systems" because their functionality extends far beyond monitoring. According to the Oxford Dictionary, to *monitor* means "to observe and check the progress or quality of something over a period of time; keep under systematic review." We adopt the premise that monitoring is conducted to better understand a groundwater system after it has been sufficiently investigated to achieve the level of understanding required to design a data acquisition system tailored to the specific goal of monitoring—namely, data acquisition over a relatively long period.

For effective monitoring, monitoring points must be strategically positioned based on prior data acquisition, where the emphasis is on collecting spatially distributed data to understand how the system functions. This prior information-gathering phase is referred to as the system characterization phase. This phase involves investigations to diagnose the problem or problems so that monitoring can be effective in addressing the specific questions for which long-term data acquisition is needed.

In some cases, a multi-depth system may include a large number of monitoring points in each profile during the characterization phase. Later, the same installed system can transition to a monitoring role, where a smaller number of strategically selected sampling points are used to minimize sampling efforts while still providing answers to the prescribed questions.

A significant issue contributing to the sparse data problem in groundwater science is that many groundwater monitoring networks not only suffer from sparse data but also often have poorly positioned monitoring points. This is because the network design is frequently based on minimal prior knowledge of the hydrogeological conditions.

5.4 Installation of multi depth systems in the most challenging circumstances

There are two specific types of hydrological circumstances that present exceptional challenges for the installation of multi-depth systems. Both involve overcoming difficulties in unstable geological materials, where the need is to install very deep multi-depth systems.

In some regions around the world, aquifers are exceptionally thick, extending to depths of 1,000 meters or more, where multi-depth monitoring is essential. Similarly, fractured rock environments often feature unstable boreholes, complicating installations.

Unconsolidated Deposits

In unconsolidated deposits, multi-depth systems such as the Westbay MP system have been used at substantial depths. However, this requires the prior installation of a multi-screen well, into which the multi-depth system is placed. In this arrangement, the ports of the multi-depth system are positioned alongside the screens of the multi-screen well, which effectively serves as the borehole.

The successful installation of multi-screen wells to provide deep access for multi-depth systems relies on the expertise of drillers in areas with deep aquifers. These drillers have developed specialized capabilities for installing deep water wells, including well casings with multiple screens to access many depth intervals. The recommended drilling methods for successful use of multi depth systems are discussed in Appendix. Once the multi-screen casing is in place, a multi-depth system—such as the HKU dual system or the HKU Hybrid system—can be installed.

A globally notable example of multi-depth systems monitoring a multi-aquifer unconsolidated basin is in Orange County, California, where more than 50 Westbay MP systems were installed decades ago to monitor depths of up to 500 meters.

Unstable Fractured Rock

Installing multi-depth systems in unstable fractured rock requires a different approach. The system must be inserted to the bottom of the borehole inside a steel casing, which is the drill stem used during drilling. The multi-depth system is inserted down to the bottom of the drill stem, after which the casing is withdrawn.

A critical requirement is that the seals, which inflate upon contact with water, must be attached to the multi-depth system so that they expand to form seals as the casing is withdrawn. The HKUniversal seals can be specifically designed to accommodate this installation method.

The HKU dual system and the two HKU hybrid systems are designed for installation in unstable boreholes drilled into fractured rock—a common issue in bedrock drilling. Unstable holes occur when rock fragments dislodge from the borehole walls after drill rods are removed, sometimes forming blockages that prevent the installation of wells or multi-depth devices. This document focuses on diamond bit cored holes, which are ideal for multi-depth systems due to their smooth borehole walls that ensure optimal packer seals.

The Westbay system is the only long-established multi-depth system designed for installation in unstable rock boreholes. This is because the PVC pipe containing the valve ports has a small enough diameter to allow water-inflated packers fitted over it to fit inside HQ drill rods used for drilling 101.6 mm (4-inch) diameter holes. Once the Westbay system is lowered to the bottom of the hole, each packer is inflated individually as the drill rod is incrementally raised above each packer. This method ensures that instability is not an issue, as each packer is expanded by water pressure to create a reliable seal.

The HKU dual system and its hybrid versions feature packer designs suitable for installation in unstable rock; however, laboratory testing is necessary to confirm packer performance. For the HKU system, a larger cored hole is required compared to the Westbay system to accommodate PVC casing with a sufficiently large inner diameter (ID) to house multiple tubes for numerous ports (e.g., 15–20 ports).

The PQ-size core drilling, a standardized option, is the best choice as it creates a borehole with a diameter of 122 mm (4.8 inches). The drill stem has an inner diameter (ID) of 101.5 mm and an outer diameter (OD) of 114.5 mm (4.5 inches). For the HKU dual system with packers to fit inside this drill stem, its assembled OD must be slightly smaller; for this discussion, 98 mm has been tentatively selected, though further consideration is needed.

The standard PVC pipe for this system has an OD of 89 mm (3 inches), allowing the swelling seal to have a thickness of 5 mm. This material must swell from 89 mm to fill the 122 mm hole, requiring expansion into an annular space of (122 - 89) / 2 = 16.5 mm per side. Thus, the swelling seal needs to expand approximately threefold. When fully expanded, the swelling pressure against the borehole wall must be appropriate for sealing. Swelling seal can have a swelling potential up to a sixfold, producing effective swelling pressure for a reliable seal.

For a 122 mm ID borehole, the HKU dual system or the two HKU hybrid systems can have an OD of 90 mm, accommodating either 31 PVC piezometers (10 mm ID, 12 mm OD) or 23 PVC piezometers (12 mm ID, 14 mm OD), allowing the use of pressure sensors with diameters of 6 mm.

The HKU system, designed for unstable rock, is lowered inside the drill stem to the bottom of the hole. The drill stem is then immediately withdrawn, and the packers inflate over a few hours to fill the annulus. The packers are relatively low-cost, allowing many to be used between ports at minimal expense. This maximizes the likelihood of achieving effective seals in holes with some instability.

5.5 The need to develop low cost pressure measuring devices and related data recording

To fully utilize multi-depth systems, it is essential to have a water pressure-measuring device in each of the mini tubes. In addition to water pressure, some devices also measure temperature and electrical conductivity, which is an indicator of salinity. There are two primary technology options for such devices:

Self-Contained Devices: These devices record data internally, and to access the data, the device must be removed and the data downloaded. The device, attached to a string, is lowered into the tube to a position below the water level. These are often referred to as “divers”, a name derived from one of the first commercially available devices of this type. Today, there are many versions of such devices in the marketplace under different names.

Cabled Devices: This type of technology uses a cable that extends below the water level, transmitting signals to the surface for recording by a data logger.

Advancements in technology have allowed for smaller-diameter water level sensors, enabling multi-depth systems to have a significantly larger number of ports for a given borehole size. However, a major issue with both of these technologies, when purchased from the commercial marketplace, is their relatively high cost. In some cases, the total cost of these devices can exceed the cost of the multi-depth system itself.

This highlights the need to develop low-cost versions of these sensors and data loggers. The prospects for achieving this are promising because the cost of the individual components used in sensors and data loggers is a fraction of the commercial price for the fully assembled units. Therefore, it may be possible to create affordable alternatives that maintain the necessary functionality and accuracy.

6 A vision for topic domains where HKU- DHS offers great opportunities

The aim of this section is to inspire readers by highlighting potential applications across a wide range of fields. We provide a brief overview of opportunities for acquiring high-resolution data to explore critical topics where groundwater knowledge is either limited or virtually nonexistent.

6.1 Understanding groundwater in mountains

Mountainous regions are vital for providing water to nearly a billion people worldwide. However, their hydrogeology is still poorly understood due to the difficulties of accessing and monitoring steep, fractured rock terrains. HKU technologies are uniquely suited to study groundwater occurrence and flow in these challenging environments. By delivering high-resolution data at multiple depths, these systems can help unravel the complex interactions between surface water, groundwater, human activities, and climate in mountain catchments.

Many communities in mountainous areas rely on subsistence agriculture and face water poverty due to contaminated drinking-water springs or insufficient water supply. This scarcity contributes significantly to illness and mortality. A practical solution to address this issue is the drilling of water wells. Since the water requirements for drinking, food preparation, and hygiene are relatively modest, the HKU water well design offers a feasible option. These wells are particularly suitable for installation using portable, human-operated drilling machines, making them ideal for remote and rugged terrains where traditional drilling methods are impractical. By enabling reliable access to clean water, HKU technologies can significantly improve the quality of life for these communities while advancing our understanding of mountain hydrogeology.

6.2 Depletion of aquifers and drying of the continents

Aquifer depletion and continental drying are widely discussed, yet the critical parameter—the water table position—is rarely monitored accurately. Often, the potentiometric surface of confined aquifers serves as a surrogate, introducing unquantified errors. Depletion reflects pore space drainage, best measured by tracking water table elevation changes—a practice seldom implemented. Conventional wells, with long intake zones, yield blended water levels that obscure the actual water table. The HKU Dual Purpose system excels in this context, offering precise vertical spacing to effectively monitor and understand water table behavior.

6.3 Effects of agriculture on groundwater on groundwater quality:

To assess groundwater contamination from crop agriculture, monitoring should focus on the water-table zone, where fluctuations occur due to precipitation and irrigation, and the shallow groundwater below. Agricultural impacts typically occur in flat areas where vertical infiltration recharges groundwater, and horizontal flow dominates beneath the water table. To determine the chemical composition of this zone, high-resolution vertical sampling with small intervals (e.g., a few centimeters in granular media) is essential. The HKU Combined System is ideal for this purpose and can integrate with other tools to sample the capillary fringe when needed.

6.4 Coastal hydrogeology:

Coastal aquifers face mounting pressure from over-extraction, leading to saltwater intrusion and land subsidence, which makes sea-level rise more impactful. To assess seawater intrusion and contaminant flux into oceans, HKU-DHS can be deployed as coastal transects (monitoring fencelines) to identify the freshwater and saline water interface. Proper spacing of monitoring points is crucial to avoid data gaps and ensure accurate insights. These systems monitor salinity gradients and groundwater levels at multiple depths, offering vital data for managing saltwater intrusion.

6.5 Water origins, flow, and contamination in karst

Karst and other solution channel systems cover 12% of Earth's surface and support nearly 20% of the global population, yet studies have rarely used multi-depth monitoring in the rock surrounding caverns. HKU technologies are ideal for karst investigations, as they can be easily installed in boreholes drilled through karst systems or in holes made by portable machines maneuverable in karst openings. These systems enable the measurement of water pressure and groundwater chemistry in the rock beyond caverns, providing insights into cavern formation and surface contamination threats. Currently, only the behavior of water within caverns is well understood, while the surrounding rock remains a "black box." HKU technologies unlock this critical data gap.

6.6 Urban Groundwater, Flooding and Sponge Cities

Climate change is exacerbating urban flooding, challenging traditional city drainage systems designed based on historical rainfall data. To address this, the sponge city concept, pioneered in China, promotes green infrastructure such as parks, waterways, and wetlands to slow runoff and enhance subsurface water storage. However, few sponge city projects incorporate groundwater monitoring, particularly water table levels, which are critical for evaluating their hydrologic performance. Monitoring urban water tables provides key insights into how effectively green spaces function as part of the sponge system. HKU technologies require minimal land use and are capable of being installed underground while transmitting real-time data to stakeholders. This approach ensures accurate assessment of subsurface urban hydrology with minimal disruption.

6.7 Determining the effects of agriculture

Agriculture is the largest consumer of groundwater globally and a major cause of widespread contamination, often due to inefficient water use and excessive application of fertilizers and pesticides. HKU technologies offer a powerful solution for monitoring groundwater more effectively than any other available methods. These systems can provide real-time data on groundwater levels and salinity, accessible to all stakeholders—farmers, food production agencies, environmental managers, and the public. Given that food production has environmental impacts, making agricultural monitoring data publicly available is as critical as raising awareness about climate change and its effects on humanity. Transforming agriculture is one of the toughest challenges in environmental management, facing resistance from farmers and the agricultural industry. Thus, it is essential to make relevant, understandable data widely accessible to drive informed decision-making and foster sustainable practices.

6.8 Protection of Ecological Systems

Within the water cycle, the water table serves as a critical diagnostic parameter. HKU technologies enable the monitoring of groundwater levels and quality in ecologically sensitive areas such as riparian zones and wetlands. Recognizing the water table's overall level is vital for assessing environmental conditions. Understanding the interactions between groundwater and ecosystems is key to sustainable water management and biodiversity enhancement. The water table is particularly crucial for ecological systems: significant drops can cause wetlands, including peatlands, to wither and become fire-prone, dry up streams and springs in upland catchments, and erode the resilience of water-dependent ecosystems. Despite this, reliable water table maps are scarce. Effective state-of-the-environment assessments require water table monitoring networks featuring multi-depth systems like the HKU Dual or Hybrid systems, which offer automated recording and data transmission capabilities.

6.9 Gravity driven groundwater flow systems

There is extensive literature on gravity-driven groundwater flow systems, primarily based on observations of recharge and discharge areas, flowing wells, springs, groundwater age distributions, and isotopic tracers. Typically, these studies rely on hydraulic head data from sparse monitoring wells, often with only one or a few wells at varying depths. However, the literature on groundwater flow systems remains limited, particularly in terms of direct data that can only be obtained through multi-depth monitoring. Studies show that without measured head profiles, the understanding of head distribution is often unrepresentative of the actual conditions revealed by multi-depth systems. Additionally, samples from multi-depth systems are point-specific with minimal vertical blending, avoiding the uncertainty in groundwater age measurements caused by blending in traditional wells. High-resolution data further demonstrate that interpretations of flow systems based on geological data as an indicator of hydraulic conductivity are often inaccurate compared to the detailed head distributions provided by HKU technologies.

6.10 Groundwater contamination

High-resolution investigations reveal that groundwater contaminant concentrations can vary significantly over small vertical distances, often undetected by conventional methods. This is due to layered geological deposits with varying permeability, creating steep concentration gradients. Reliable assessments of contamination require high-resolution sampling, where HKU technologies offer the most cost-effective and efficient solutions. Current groundwater regulations in North America and Europe focus on fixed concentration thresholds (maximum concentration level, MCL), which are inadequate for assessing risks. Instead, evaluating total contaminant mass fluxes from plumes—achievable with HKU technologies—provides a more accurate understanding of risks to human health and ecosystems.

6.11 Groundwater and the mining industry

Modern society relies on the mining industry to supply essential metals, yet its significant water usage and pollution often go unrecognized. Despite being a major water consumer and contaminator, the mining industry receives minimal public and political attention, resulting in inadequate impact assessments and long-term monitoring in most countries. Mining operations primarily involve bedrock excavations, necessitating robust groundwater monitoring. The HKU Dual Purpose and Hybrid Systems are ideal for this, offering depth-discrete data critical for understanding complex groundwater systems in mining areas. These systems are cost-effective and adaptable, suitable for installation in rough terrain using diamond core drilling machines, common in mining. As mining is set to expand significantly to support renewable energy and electric vehicles, government regulations must mandate comprehensive, three-dimensional groundwater monitoring to ensure sustainable management in mining environments.

6.12 Controlled field experiments

Intensive research in the USA and Canada (1978–2015) advanced understanding of contaminant transport and fate in groundwater, including solutes, immiscible liquids (e.g., LNAPLs, DNAPLs), particles (e.g., viruses, nanoparticles), and methane gas. Controlled release field experiments became crucial, introducing chemicals into groundwater to track their behavior over months or years under near-natural flow conditions. These experiments provide critical insights into contaminant migration, model validation, and remediation strategies, particularly during chemical mass removal or in-situ destruction phases. However, such experiments remain limited in China and for emerging contaminants like PFAS in the West, as climate research dominates attention. HKU technologies offer a cost-effective and efficient solution to advance these critical investigations.

6.13 Groundwater education

High-resolution profiles must become a core component of groundwater education. Currently, the focus is on data from springs and wells that meet human water needs, as well as scattered monitoring wells and drill holes that provide diverse data (e.g., geology, water quality, isotopes). While it is acknowledged that groundwater systems are three-dimensional with significant temporal variability, and that geology plays a critical role, this understanding is rarely demonstrated due to a lack of necessary data. Without high-resolution profiles of hydraulic head and water chemistry, evidence of the three-dimensional nature of groundwater systems remains insufficient. In contrast, disciplines like oceanography, limnology, and atmospheric science rely heavily on multi-elevation measurements. Multi-depth profiles are almost absent in groundwater textbooks, hindering the development of strong spatial thinking.

To enhance groundwater education, universities and high schools should enable students to gather meaningful local groundwater data. This can be achieved by drilling a few shallow boreholes on campuses and installing HKU systems, which are cost-effective and adaptable. Using low-cost drilling methods and HKU technologies, this approach is now feasible at an exceptionally low cost, providing students with hands-on opportunities to explore and understand groundwater systems effectively.

7 Concluding remarks

The HKU DepthWise Hydrogeosystems (HKU-DHS) initiative represents a transformative leap in groundwater science, addressing the longstanding challenge of data sparsity through innovative, cost-effective, and high-resolution monitoring technologies. Designed for versatility and adaptability, these systems enable depth-discrete measurements across diverse hydrogeological settings, including fractured rock, karst, coastal aquifers, and urban environments. By providing detailed insights into groundwater levels, chemistry, and flow dynamics, HKU-DHS empowers researchers and practitioners to tackle critical issues such as aquifer depletion, saltwater intrusion, agricultural contamination, and climate-induced water stress.

A cornerstone of this initiative is its open-source framework, fostering global collaboration and accessibility. This approach democratizes access to advanced groundwater monitoring tools, encouraging continuous innovation tailored to local needs. Furthermore, the integration of HKU technologies into education and research promises to enhance spatial understanding of groundwater systems, bridging gaps left by traditional methods. As mining, agriculture, and urbanization intensify their demands on water resources, HKU-DHS offers timely solutions for sustainable management and biodiversity protection.

The HKU Dual System and Hybrid Systems stand out globally for their low cost, ease of deployment, and ability to provide high-resolution data essential for understanding complex groundwater systems. These technologies are particularly suited for challenging environments, such as mountainous regions, unstable fractured rock, and deep aquifers, where conventional methods often fall short. By shifting the paradigm from sparse to data-rich groundwater investigations, the initiative lays the foundation for evidence-based policies and adaptive strategies.

In recent decades, groundwater science has relied heavily on indirect methods, such as geophysical surveys, satellites, and data mining, which, while insightful, lack sufficient ground-truthing. The HKU-DHS partnership with The Groundwater Project aims to address this gap by promoting high-resolution data acquisition as the norm rather than the exception. In the long-term vision, any organization seeking high-resolution groundwater data can engage with the HKU-DHS Project or its affiliates to access the necessary information and technologies at a relatively low cost. This global effort will not only advance scientific understanding but also ensure equitable access to clean water, supporting resilient ecosystems and communities in the face of a changing climate.

8 Documents for references and further reading

Below is a list of references, patents, and case studies for readers interested in learning more about multi-depth monitoring systems and their applications in groundwater studies. Many of these references describe older multi-depth technologies and highlight the value of high-resolution data obtained from them. The importance of high-resolution data in understanding various types of groundwater systems is evident from field applications of technologies that predate the HKU-HDS. These earlier technologies can be considered precursors to the HKU-HDS. The patents and case studies listed are exclusively focused on the HKU-HDS or research based on the HKU-HDS.

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9 Appendix:

Requirements for successful use of multi depth systems

Success in the use of multi-depth technologies comes from the effective pairing of the borehole drilling method with 1) the particular version of the multi-depth system selected for the borehole and 2) the design of the seal positioned between the ports to prevent hydraulic cross-connections. It is essential to select the drilling method most appropriate for the geology and the intended pairing. This requires an understanding of the drilling methods available, as well as the design options from which to select the multi-depth system.

In groundwater studies, investigators typically select drilling methods that are best known for constructing monitoring wells or water supply wells. However, for the purpose of high-resolution, multi-depth systems, in many cases, the most appropriate drilling methods come from commercial drilling sectors that are not well known to hydrogeologists. Therefore, we present below a summary of all the types of drilling methods, categorized into two groups:

Group 1: Install inside the drilling systems

1. Conventional (old-fashioned) percussion drilling
2. Diamond bit coring in rock or consolidated clayey deposits `
3. Water jetting of casing
4. Sonic/roto-sonic drilling
5. Augering using with hollow auger stems

Group 2: Install in open unsupported boreholes

6. Mud rotary drilling with tricone bits
7. Downhole hammer drilling in rock
8. Augering- using solid auger stems
9. Manual well drilling without power driven equipment

The drilling methods designated as 1, 3, 6, 7, and 8 are used primarily to construct water wells, while the others are used primarily in geotechnical or environmental investigations, including contaminated sites. Those in the first group allow the multi-depth system to be installed down the inside of the drill casing (also referred to as drill stem or drill rods). In contrast, those in the second group require the multi-depth system to be installed into an open hole that is unsupported by piping.

In pairing the multi-depth system with the drilling method, the primary challenge is to achieve reliable seals so that each monitoring or sampling port is hydraulically isolated from each other. In nearly all circumstances, this requires at least one seal between each port to ensure hydraulic separation.

The one exception where seals are not necessary occurs when the geologic material quickly calves in or squeezes around the multi-depth system, effectively eliminating the potential for vertical cross-connections. This situation is common in boreholes drilled in cohesionless granular deposits or very soft clayey deposits, especially when there are no significant layers of low-permeability materials such as clay and silt, or when the clayey material is so soft that it squeezes tightly around the multi-depth device. After the multi-depth device is installed inside the drill casing, hollow-stem auger, or jetted pipe and when the casing, auger, or pipe is withdrawn from the hole, the calving or squeezing action occurs rapidly enough to prevent preferential vertical flow along the system. However, if the entire length of the borehole intended for multi-depth monitoring contains one or more geological layers that do not quickly calve or squeeze around the system, seals must be used in these segments of the borehole.

In general, the lowest-cost drilling method is the one commonly used by water well drillers. However, in some cases, these drilling methods are not suitable for creating the reliable seals. As a result, the lowest-cost drilling option is not always the best choice for installing multi-depth systems with effective seals. It is generally recommended that multi-depth systems be installed in boreholes where the geology is already known, either from previous drilling nearby or, preferably, from information obtained through core sampling and/or geophysical logging.

Conventional percussion drilling (cable tool drilling)

In this form of drilling, a steel pipe serves as the drilling casing. It has a hard cutting edge at the bottom and is pounded by the repetitive dropping of a weight suspended on a pulley (steel cable). During this process, the geologic materials at the bottom of the hole are broken up into cuttings, which are removed by lowering a bailing cylinder into the hole. The cylinder is then pulled to the surface on a steel cable and emptied. The drill casing is filled with water, but water is not forced to circulate, and there is no need to add drilling mud.

Once the bottom of the hole is reached, the multi-depth assembly is lowered down inside the drill casing to the bottom, after which the drill casing is removed. However, the seals must be put in place before removal. If the geologic materials that have been drilled through are cohesive and do not calve or slough into the annular space between the multi-depth assembly and the borehole wall, then the standard HKUniversal seals attached to the assembly can be used. These seals will swell over several hours to fill the annular space.

However, if the geologic materials are loose and quickly calve or slough in some zones but not others, the drill casing must be selected to be large enough to accommodate the seals. The seal section should be very long so that there is no much space for the unstable geological materials to collapse.

Diamond bit core drilling

In circumstances where multi-depth systems are to be installed in hard rock or dense, consolidated clayey material, the most suitable drilling method is diamond core drilling, which provides continuous core samples. These core samples can be examined before the multi-depth device is installed in the drill hole, allowing the HKU multi-depth system to be assembled for compatibility with the local hydrogeology. The selection of port and seal positions can be performed in the field because the HKU systems are modular. Components, including ports, seals, couplings, and blank sections, can be assembled to align with the local hydrogeology.

Water jetting of casing

This method is commonly used to construct water wells in rural areas of North America and Europe, but it can be applied almost anywhere with favorable geological conditions. This technique is referred to as manual drilling because the equipment used is small enough to be moved by a single person. Since no drilling machine is required, this method has the lowest cost when geological conditions are suitable.

In this method, a high-pressure water pump, sometimes called a mud pump, is connected to a water-filled barrel. The water is forced under high pressure through a length of PVC pipe, such as a 1-inch-diameter pipe, positioned vertically on the ground. The high-pressure water jet creates a hole in the ground. Once the small-diameter pipe reaches a depth of several meters, a larger-diameter PVC pipe, such as a 4-inch-diameter pipe, is manually pushed into the hole and rotated to follow the smaller-diameter hole while the jetting process continues to remove geological material.

This method works best in unconsolidated geologic deposits consisting mostly of sand or fine gravel and is capable of penetrating substantial thicknesses of clay or silt. Depths of many tens of meters can be achieved under favorable conditions. Once the desired depth is reached, the jetting tube is removed, and a 3-inch-diameter multi-depth system is inserted into the bottom of the 4-inch-diameter casing. This multi-depth system would have attached seals.

If the geologic deposits are sufficiently cohesionless to quickly squeeze in around the multi-depth assembly as the 4-inch casing is removed, then the multi-depth system is successfully created without the need for additional seals.

Sonic/roto-sonic drilling

Sonic and Roto-sonic drilling machines are common in North America and Europe and are increasingly available in China. This drilling method is primarily used for geotechnical or environmental investigations and is rarely employed for constructing water wells. However, it is exceptionally well-suited for installing multi-depth devices because it does not require bentonite or any other additives to the drill water to stabilize the hole, and only a relatively small amount of drilling water is needed.

In this method, a steel casing is driven into the ground by a machine that applies high-frequency (sonic) vibrations to the bottom of the steel casing, where a hard bit uses these vibrations to cut through all but the hardest rock. This type of drilling is commonly used in areas where geological materials are variable, including all types of sediments and rock boulders. The drilling can penetrate through overburden and extend a substantial depth into bedrock, particularly sedimentary bedrock. The multi-depth system is installed inside the drill casing. If the hole is stable, seals can be used directly. If the hole is unstable, the assembly can include long seal sections as discussed before.

Mud rotary drilling with tricone bits

Engine-driven percussion drilling became the standard method for drilling water wells when the commercial water well industry began two centuries ago. However, it was subsequently replaced almost entirely in many countries by conventional rotary drilling. Creating a water well using rotary drilling takes much less time than percussion drilling.

However, for holes into which multi-depth systems are installed, rotary drilling has a significant disadvantage: a drilling fluid, typically bentonite mixed with water, is used to increase the density of the fluid in the hole, which is necessary to keep the hole open until the well is installed. This fluid prevents unstable parts of the hole from collapsing. The mud slurry is mostly flushed out by the driller once the desired depth is reached, and after the well is installed, water is flushed through the well screen to remove any remaining mud.

Bentonite is a geochemically reactive material, and for multi-depth systems, it can be difficult or impossible to flush out the mud sufficiently to ensure that the bentonite does not influence the water chemistry or alter the hydraulic conductivity that can be measured at each port using small-scale hydraulic tests. In situations where a multi-depth device is not used to determine groundwater chemistry or other aspects of water composition, this concern may be irrelevant. In cases where a relatively large number of monitoring ports are desired, rotary drilling can be used to drill holes with a relatively large diameter. These larger holes allow the multi-depth system to accommodate many more ports than would be feasible in a diamond-drilled hole of normal size.

However, there are circumstances where conventional rotary drilling can be used to create holes for installing multi-depth systems. For example, in intact bedrock, the hole can be drilled using water alone, without mud. In such cases, the multi-level system can be installed in the same manner as it would be if the hole were drilled using diamond bit core drilling. Diamond bit core drilling has the advantage of providing core samples, which are used to determine the geology and guide the positioning of the ports and seals.

However, at locations where the geology is already known, or in situations where cost savings on drilling are a priority, conventional rotary drilling can be advantageous. A potential drawback of rotary drilling in rock is that it often results in a rough-walled hole with vertical grooves or channels. These features can compromise the reliability of the seals in preventing vertical cross-connections between ports. Therefore, the seals must be specifically designed to address this issue.

Downhole hammer drilling

This is an effective method for quickly drilling stable and straight holes in both hard and soft rock. The method is widely used in the construction, oil and gas, and water well industries. The equipment consists of an air compressor, connected via an air hose to an assembly at the bottom of the hole. This assembly includes an air hammer with a cutting head attached to a piston.

As the drill string rotates, the air hammer strikes downward on the rock, with the drill bit receiving its striking power from a piston inside the hammer, activated by compressed air. This action, combined with the rotational movement of the drill string, breaks up the rock. The compressed air also serves as the flushing medium, though clean water is sometimes used in conjunction. The air (and water, if used) carries the cuttings up and out of the borehole through the annular gap between the drill pipe and the borehole wall.

In this drilling method, the nature of the geology is clearly evident from the drill cuttings because they are not obscured by mud or excessive water flow. Additionally, the method produces a clean hole. Once drilling is complete, the drilling assembly is removed. The method promotes hole stability, which is essential for installing a multi-depth system in an open hole. This method is especially effective for drilling stable holes with diameters in the range of 3.5 to 5 inches, which is well-suited for installing multi-depth systems with multiple ports.

Drilling using solid stem augers

In many areas, drilling equipment that uses solid stem augers is available for creating boreholes, primarily for the geotechnical industry. During the drilling process, geological material is sampled by hammering or pressing steel cylinders into the material to collect coarse samples. This type of drilling is most commonly used in areas where the geological deposits consist of soft or even consolidated clay- or silt-rich materials.

The holes created using this method are generally between three and four inches in diameter, making them well-suited for the installation of multi-depth devices, provided the holes remain open after the auger and sampling equipment is removed. Once the equipment is withdrawn, the multi-depth assemblies equipped with attached seals can be installed.

Manual well drilling without power equipment

In rural areas of developing countries, it is common for water wells to be created using various types of manual drilling methods that do not rely on power equipment (i.e., no gasoline or electrical devices). Some of these methods are suitable for installing multi-depth monitoring systems for groundwater investigations, such as those aimed at studying harmful constituents like arsenic, fluoride, uranium, and others. In such investigations, the use of appropriate manual drilling methods can be the most cost-effective and least intrusive approach, particularly in areas where local entrepreneurs already use these techniques to drill wells.

Typically, when reporting the occurrence of these health-impacting constituents in developing countries, data are obtained from a single well at each location or from wells with long water intake intervals. As a result, the understanding of the spatial distribution of these constituents is either limited to specific depths or obscured by the blending of water from different levels that enters the well. However, data from multi-level monitoring wells indicate that high-resolution, multi-depth sampling is necessary to better understand these issues and identify the depths where safe drinking water can be accessed for farm wells.

Further investigations are needed to determine which of the various manual drilling methods are most suitable for installing multi-depth systems in these contexts.