# Groundwater Level Remote Monitoring Using Optical Power Measurement in Fiber Bragg Grating

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**Abstract:** Groundwater level provides critical insight to public resource allocation and climate variability. Remote monitoring of groundwater level is demonstrated, based on wavelength-shift induced optical power change in fiber Bragg grating caused by water pressure fluctuations.


## 1. Introduction

Groundwater is the largest fresh water resource on our planet [1]. Located deep below the Earth's surface, the ground water reservoir is a key resource to mitigate climate events such as extreme droughts and floods. Groundwater is also a significant component of surface-water resources, the discharge of which sustains the flow of streams and the water height in lakes and wetlands. Groundwater depth can fluctuate depending on short-term and long-term variables such as rainfall, quantity of water pumped above ground, and land usage. When water level recedes and becomes very deep, drought can occur. Water-level measurements are essential to understanding hydrologic stresses and how they affect the recharge, storage, and discharge of groundwater. Long term monitoring of this variable depth provides critical insight in dealing with public resource allocation and climate variability [2]. Current methods of depth measurement require an individual to travel to the area in question and record the data at an observation well by hand. Measurements are taken by either lowering a conductive probe or weighted tape measure into an observation well [3]. Depending on the well's depth and the quantity of sediment in it, it can become difficult for a researcher to determine when the measuring device has reached the bottom [3] and potentially lead to inaccurate data. Therefore, it is critical to develop a long-term groundwater level monitoring system to provide the essential underground data needed for evaluating changes of the groundwater level over time and to allow for accurate forecasting, management, and protection.

Fiber Bragg grating (FBG) sensors have been widely used as a sensor for a wide range of applications including structural health monitoring, biomedical application, and aerospace engineering. While FBG has been used to measure flow rate and water level in a tank, the use of FBG for monitoring water level within underground soil has not been demonstrated. The ability to monitor water level underground provides flexibility to the monitoring location and prevents inaccurate measurement due to the drawdown effect caused by pumping of a well in an unconfined aquifer [4]. A cross section visualization of the water table structure is shown in Fig. 1. The structure consists of the saturated zone at the bottom and an unsaturated zone above it. Water table is the interface between the saturated zone and unsaturated zone.

In this paper, we propose and experimentally demonstrate the use of FBG within underground soil for remote and long-term monitoring of groundwater level. Two or more FBG sensors perpendicular to the water table are secured on a fixture, such as a pipe, a stake, or a wall, as illustrated in the zoom-in of Fig. 1. The quantity of FBG sensors is governed by the desired resolution and range of measurements. Depending on the position of the water table, the pressure experienced by each FBG and along the FBG region gradually changes. Unlike existing labor-intensive, single-measurement approaches, the proposed remote monitoring scheme provides long-term, accurate, and reliable water level data for scientist to gain insight of this precious natural resources.

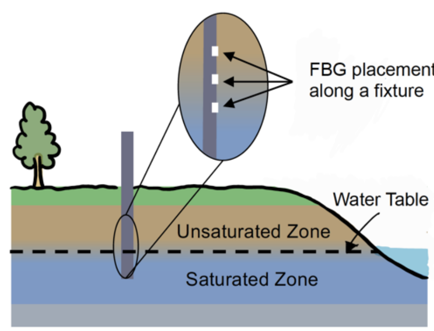


Figure 1: A cross section visualization of FBG placement for long term data collection of ground water level.

## 2. Principle and Experimental Setup

The orientation of the FBG sensor is an important factor in how the force exerted by the change in water level is detected. A preliminary experiment was performed to investigate the effect of FBG sensor orientation and its sensitivity to soil moisture fluctuations, as illustrated in Fig. 2(a). A 1550-nm FBG (blue) is placed vertically in the soil, while a 1552-nm FBG (green) is placed horizontally in the soil. A resistive moisture sensor is also placed vertically in the soil as a reference. Water is dripping on to the top of the soil such that absorption in the soil at the

FBGs level can be observed. Water concentration in the soil changes the pressure applied to the FBGs, essentially changing the reflected wavelength. However, since the wavelength shift is small, reflection power measurement is used to obtain more significant change in measurement value caused by the change in soil moisture. Laser wavelength is aligned at the rising slope of the FBG reflection spectrum, such that power measurement can be achieved for both shorter and longer wavelength shift of the FBG. For instance, the laser wavelength for the 1550-nm FBG is at 1549.329 nm. Wavelength shift to the left will result in an increase in optical power, while wavelength shift to the right will result in a decrease in optical power.

To change the moisture level of the soil, 1 mL of water is dripped on top of the soil at 1-minute intervals for five consecutive intervals (as shown in the green shaded region in Fig. 2(b)), and water is allowed to absorb into the soil for 5 minutes (as shown in the purple shaded region) before more water is dripped on to the soil again. Light reflected by the FBG is measured by an optical power meter and recorded using LabVIEW with a sampling rate of 10 Hz for real-time data collection. As shown in Fig. 2(b), it is observed that the vertically placed 1550-nm FBG (blue curve) can clearly capture the change in water moisture and the force caused by each drop of water. The largest power change was generated by the water dripping on top of the soil, while the increase and decrease of moisture is represented by the more gradual change in power. An increase in moisture results in an increase in optical power while a decrease in moisture results in a decrease in optical power during water absorption/draining. The measured data closely reassemble the observation in the commercially available resistive moisture sensor (red curve). However, resistive moisture sensor is not suitable for long-term moisture monitoring because rusting would occur at the metal probe. On the other hand, the horizontally placed FBG at 1552 nm is not able to collect meaningful data, as shown by the grey curve. Therefore, a vertically placed FBG would be the optimal configuration for groundwater level monitoring.

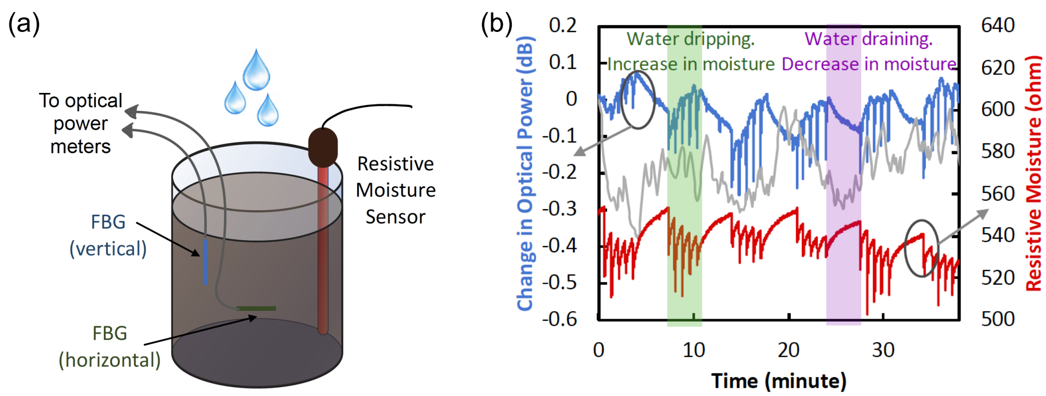


Figure 2: (a) Schematic illustration of the experiment for investigating the effect of FBG sensor orientation and the sensitivity to change in soil moisture. (b) Optical power change exhibited by a vertical FBG sensor (blue) and horizonal FBG sensor (grey). A resistive moisture sensor is also used as a reference (red).

To monitor groundwater level in a controlled environment, a cylindrical glass vessel that is 13 cm in height and 7 cm in diameter is used for the experiment. Glass was chosen as it does not deform or react with the contents of the vessel in any way. Two FBG sensors, FBG 1 at 1547.5nm and FBG 2 at 1552nm, are secured vertically to the side of the vessel, where the side acts as the fixture of the monitoring system. FBG 2 and FBG 1 are 5 cm and 2.5 cm away from the vessel's bottom, respectively. A hollow cylindrical tube was placed in the center of the vessel before the vessel is filled with potting soil. Once the soil had been added to the vessel, the soil is being compressed to reassemble an underground environment. The tube allowed for water to be added into the vessel from the bottom upwards, mimicking the development of saturation zone and eliminating force caused by water dripping onto the soil surface. The lasers for FBG 1 and FBG 2 are at 1547.701 nm and 1552.351 nm, respectively, which are aligning to the falling slope of the FBG spectra. Laser light is directed to the FBG via an optical circulator, which is then reflected by the FBGs and collected by two separate Thorlabs PM101 optical power meter for real time data collection. Water was fed to the cylindrical tube using an IV bag with a control valve. Constant flow of water was supplied to the vessel for 1 minute, then water flow was stopped for another minute to allow the soil to absorb the water. The total time elapsed until the soil had become fully saturated was 36 minutes, and a total of 325mL of water had been added to the vessel.

### 3. Results and Discussion

Figure 3 shows the optical power change experienced by the two FBG sensors throughout the experiment, where FBG 1 (red) is at the bottom while FBG 2 (blue) is at the top. The green shaded region indicates constant flow of water to the vessel, while purple shaded region indicates no water flow. Water flow is turned on and off periodically for the whole 36 minutes, but only some regions are indicated in Fig. 3(b) for clear illustration. The first red solid line indicates water is reaching the bottom of FBG 1, while the red dashed line indicates water is reaching the top of FBG 1. Within the first five minutes, FBG 1 became fully submerged by the rising water level in the soil. This caused a 13dBm decrease in reflected optical power from FBG 1. Once FBG 1 had been completely submerged, it did not detect any other fluctuations in water level as shown by the region greater than 5 minutes. The experiment had been video recorded to confirm the moments when each FBG had been submerged by the water. Water flow has been turned on and off between the 5-minute and 22-minute time frame. As water was added into the glass vessel at a constant rate for one minute, the pressure exerted by the water was also increasing. When the flow of water had stopped for a minute, the soil absorbed some water allowing for a decrease in water pressure. As the water level begins to approach FBG 2 between the 9-minute and 20-minute time frame, this variance in water pressure causes the increase and decrease in reflected power seen in FBG 2. The water level reached FBG 2 at 22 minutes as indicated by the blue solid line and passed FBG 2 at 24 minutes as indicated by the blue dashed line. During this time, FBG 2 exhibited a 6dBm decrease in reflected optical power. The power fluctuations due to waterflow are no longer seen in either FBG 1 or FBG 2 as the water pressure becomes relatively constant when the soil is fully saturated.

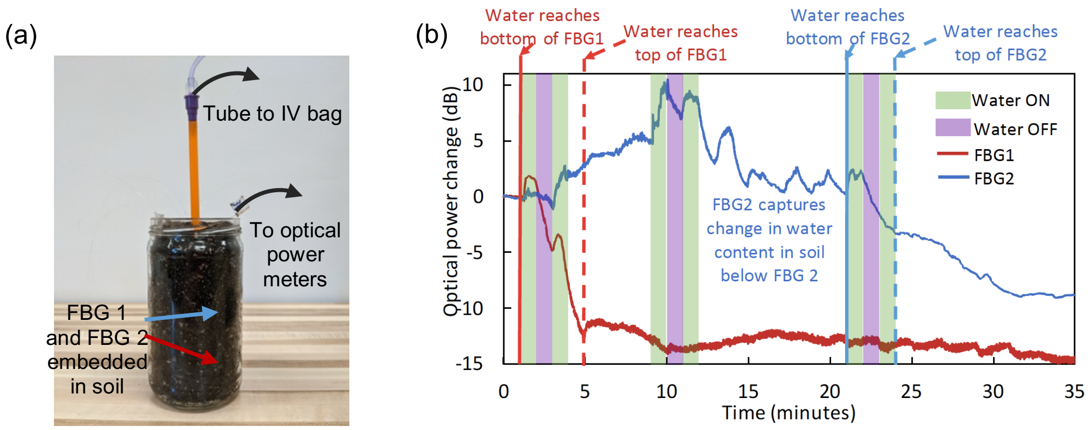


Figure 3: (a) Photo of the in-soil water level monitoring experiment. (b) Optical power change in both FBG sensors represents the water level in the soil.

Because the height of each embedded FBG is known, one can conclude that the water level is at the same depth as that particular FBG when a large power change is exhibited by the FBG as shown in Fig. 3(b). Using the optical power change data along with the recording of the experiment, it can be concluded that the water level had reached a height of 2.5 cm after 5 minutes and 5 cm after 24 minutes had passed. This setup can be altered so that any number of FBG sensors can be used to measure water depth over any given range. The distance between FBG sensors can also be shortened to increase resolution and accuracy. Additionally, when the water level is close to an FBG, it is possible to observe whether water is saturating or being absorbed by the soil. This can be seen in Fig. 3(b) with the increase in optical power caused by the saturation of the soil and the decrease in optical power caused by the absorption of water. As the water level begins to drop, due to variables such as drought or heavy draw from local wells, the sensors would exhibit an increase in optical power and become more sensitive to the variable pressure in the drier soil.

## 4. Conclusion

We demonstrated the feasibility to monitor ground water level remotely using fiber Braggs grating sensors. Our initial experiment fixed sensors at a known height and retrieved real-time measurements of the current groundwater level as the change in reflection power of the vertically embedded FBGs. Using multiple sensors allows for higher resolution and a larger range groundwater level to be monitored. Compared to current methods, the strength of our proposed method is that there is no need for a designated observing well or an on-site specialist. Therefore, long-term monitoring becomes feasible to obtain accurate information about changes in ground water level to help scientists and governments take informed remediation actions in the event of extreme droughts and floods.

## 5. References


[1] Taylor, Richard G., Bridget Scanlon, Petra Döll, Matt Rodell, Rens Van Beek, Yoshihide Wada, Laurent Longuevergne et al. "Ground water and climate change." Nature climate change 3, no. 4 (2013): 322-329.

[2] Alley, William M., and Charles J. Taylor. 2001. "Ground-Water-Level Monitoring and the importance of Long-Term Water-Level Data." U.S. Geological Survey Circular 1217 0-68.

[3] Striggow, Brian. 2013. Groundwater Level and Well Depth Measurement. Operating Procedure, Athens: U.S Environmental Protection Agency.

[4] Papadopulos, Istavros S., and Hilton H. Cooper Jr. "Drawdown in a well of large diameter." Water Resources Research 3, no. 1 (1967): 241-244.