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Gravity Surveys to Complement Existing AEM Surveys

A Project White Paper

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Currently, Dr. Berber has published three books/monographs, around fifty journal papers and many conference proceedings. He has worked as a referee for several journals and serves on the Editorial Board of Survey Review academic journal. In terms of research, Dr. Berber has worked on a range of projects from "Greenhouse Gas Emissions from Peat Soils" to "Monitoring the Impacts of Climate Change on Coral Reefs" to "Determining Absolute SeaLevel Change for Florida." He has also delivered several bathymetric projects.

Problem Statement

Water sustainability is a major conservation problem that requires a solution for future generations. The California drought of 2012–2016 brought the urgent need for sustainable groundwater supplies into sharp focus. The loss of surface water supplies forced farmers and urban system to compensate with increased use of groundwater, which led to dramatic decreases not only in groundwater quantity (as evidenced by significant drops in the water table), but also in water quality. Indeed, California and the Central Valley's groundwater basins have never recovered from the drought. Bringing California's groundwater table back to a level and quality that is accessible to all who rely on groundwater as their water supply is a goal of California's landmark legislation, the Sustainable Groundwater Management Act (SGMA). A common solution the decrease in groundwater storage proposed by the Groundwater Management Plans required by SGMA is to develop and implement groundwater recharge programs and monitor their ability to effect positive change in the groundwater storage as evidenced by first stabilizing the groundwater table and second by causing it to rise.

Optimizing groundwater recharge requires suitable underlying stratigraphy that allows unimpeded flow of recharge water through the soil to the groundwater aquifer. Siting groundwater recharge facilities is, therefore, highly dependent on suitable stratigraphy at the recharge site. The current approach for identifying suitable stratigraphy, Airborne Electromagnetic (AEM) surveys, are insufficient since they are limited to the upper 1,000 feet of the soil. Hence, our solution is utilizing gravity surveys to complement existing AEM surveys. Thus, the project objectives are determining underlying stratigraphy for groundwater recharge facility sites and monitoring the groundwater recharge effects on the aquifer storage as evidenced by changes in the groundwater table.

Technical Background

The worsening water scarcity problem in the San Joaquin Valley urgently requires a solution. In the agriculture industry, the unavailability of surface water and the continuous drought resulted in farms pumping from groundwater wells for irrigation purposes. This caused subsidence and an overdraft of groundwater aquifers. The majority of the San Joaquin Valley is farmland and lies on a critically over-drafted basin; it has become vital to the area to manage groundwater. The Sustainable Groundwater Management Act (SGMA) states that California must implement a groundwater management plan promoting decrease in over-pumping, thereby maintaining groundwater to a sustainable level in the aquifer (2014). An estimated 750,000 acres of farmland will become fallow land as a solution to decrease the amount of groundwater needed to achieve sustainable groundwater levels (Ellen Hanak 2019). One technology that groundwater management plans are considering, along with land fallowing, is the implementation of groundwater recharge systems at the farm level. The optimization of agricultural land for the use of recharging groundwater aquifers has been researched as Flood-MAR, the flooding of farmland with excess floodwater and has shown to be a viable recharge technology. Two drawbacks to Flood-MAR are the potential damage to permanent crops from standing water and the potential to leach legacy nutrients and chemicals from the root zone into the groundwater. Another recharge technology that utilizes primarily farmland but can be used in large open areas such as parks, is Subsurface Artificial Groundwater Recharge (SAGR). This approach to groundwater recharge is a series of underground perforated pipes placed below the root zone that allow recharge water to percolate into the groundwater table. The technology can use both relatively clean canal water, when it is available, and excess floodwater. Among the benefits of SAGR are (1) the ability to continue to farm the land while recharging, (2) eliminating damage to permanent crops from standing water because the system is located below the root zone, and (3) eliminating the possibility of leaching legacy contaminants.

All these groundwater recharge technologies depend on the ability to correctly site the recharge facility and monitor the effects of the recharge once it is implemented. Stratigraphy describes the soil for any given location, profiling the composition of the diverse types of soils beneath the surface. We would like to believe that soil is homogenous beneath our feet, but in fact it is very heterogenous due to geological events that laid down successive layers of soil over eons. The ability to efficiently measure the stratigraphy of large geographic areas has been limited until now as historically, deep borings were used to classify the stratigraphy of a location. Borings are highly discreet and expensive to carry out on a large-scale basis. Recent technologies have been developed to measure soil stratigraphy, including Airborne Electromagnetic (AEM) and gravimetric surveys.

The Department of Water Resources (DWR) is conducting statewide AEM surveys. AEM data will be collected in all high- and medium-priority groundwater basins, where data collection is feasible. The AEM surveys collect statewide dataset that improves the understanding of aquifer structures. Additionally, it is expected that these surveys' findings will be used in the development or refinement of hydrogeologic conceptual models and identify areas for recharging groundwater. AEM data will not be collected over residential areas and structures containing people or confined livestock for safety reasons. The collection of AEM data uses an antenna and receiver mounted on a hoop that is towed beneath a helicopter which flies at an altitude of 200 feet above the ground. The hoop is about midway between the helicopter and the ground at an altitude of 100 feet. Thus, due to safety reasons AEM data cannot be collected in places where people and animals live, which will create data void regions throughout the entire state. These data void regions can be filled by gravity surveys. Gravimetric surveys are a non-invasive technique to portray underground structures with no safety issue. In other words, gravimetric surveys can be used to map and determine distribution of the subsurface stratigraphy and groundwater. Furthermore, gravimetric surveys can be implemented to densify AEM data. Further, unlike AEM surveys, gravimetric surveys are not limited to the upper 1,000 feet of the soil. Unlike borings, both technologies can efficiently create a continuous, large-scale mapping of subsurface soil conditions and groundwater.

The ability to accurately measure the positive effects of groundwater recharge, e.g., the rise in the groundwater table is a vital component of any recharge program. Groundwater levels can be measured in numerous ways. The primary method is to measure the groundwater level in existing wells, which are discontinuous and expensive to build, maintain, and measure individually. Gravimetric surveys can measure groundwater levels quickly without the need to construct and maintain wells. Gravimetric surveys use a gravity meter that can be easily moved from location to location to measure the earth's gravitational field at specific locations. Gravimetric surveys have been used for numerous applications in engineering and environmental studies, including locating subsurface voids, karst features, underground stream valleys, and mapping water table levels and volume (Heiskanen and Vening Meinesz, 1958; Torge, 1989; Telford et al., 1995; Hofmann-Wellenhof and Moritz, 2006). The technology utilizes the differences in the acceleration of gravity caused by different mass densities within the soil matrix, which produce measurable variations in the gravitational field. These variations can then be interpreted by a variety of analytical and computer software methods to determine the depth, geometry, and density that causes the gravity field variations (Mickus, 2004). The change is the density of soils above and below the water table provides the information needed by the gravimetric survey to accurately determine the groundwater table.

Technical Challenges

There are two technical challenges facing the implementation of gravimetric surveys. These challenges also affect the AEM surveys. The two challenges both involve the accurate interpretation of the data gathered by the gravimetric survey. The technology uses the differences in the acceleration of gravity caused by different mass densities within the soil matrix, which produce measurable variations in the gravitational field. These variations can then be interpreted by a variety of analytical and computer software methods to determine the depth, geometry, and density that causes the gravity field variations (Mickus, 2004). For instance, the change in the density of soils above and below the water table provides the information needed by the gravimetric survey to accurately determine the groundwater table. The accurate interpretation of the differences in the acceleration of gravity caused by the different soils and the presence of groundwater is critical to the success of the use of this technology. The technical challenge is to use control stations to interpret the changes in acceleration and reference that information in the analytical software to produce useable mapping of the stratigraphy and the groundwater levels within a community.

Changes in the amount of water stored in underground aquifers cause slight changes in Earth's gravitational field. These small changes in the earth's gravity are detectable by highly precise gravity meter instruments. In order to take the measurements, generally a grid is set up in the project area or the stations where the gravimeter will be set up to trace the target underground, such as an underground river. Taking regular measurements, for instance every month, every season, and every year, enables changes to be depicted over time, adding a fourth dimension to the data. While taking the measurements, gravity stations must be surveyed in closed loops to ensure measurement repeatability and to help assess measurement accuracy; during the data processing instrument drift is removed. Gravity meters are sensitive to sudden vibrations; as such, while the gravity meter is being moved from station to station, care needs to be taken to avoid jarring the instrument. Moreover, during the entire survey period, the gravity meter must be sheltered from wind and sun exposure. Furthermore, the gravity meter must be allowed to stabilize for a short period, approximately 10 minutes, at the survey station prior to taking gravity measurements to ensure consistency of gravity measurements and to minimize measurement errors. Hence, we will be following these field procedures to ensure accurate results. In the end, our results will be compared against the moisture meter information to find out whether there is any correlation.

Scientific Approach

Gravimetric Survey of Stratigraphy
Gravity meters measure variations in the Earth's gravitational field whereby gravity anomalies are generated. Gravity anomalies depend upon density contrast. After the necessary corrections have been made, the Bouguer anomaly depicts the information about the subsurface density i.e., low (negative) values of Bouguer anomaly indicate lower density beneath the measurement point, and high (positive) values of Bouguer anomaly indicate higher density beneath the point. In practice, gravity measurements are combined with the geological information at hand to determine what type of interpretation may be made. Usually, combination of all geological and geophysical information available gives a more complete picture than any of the several sources considered separately. To obtain gravity anomaly more clearly, isolation and enhancement techniques such as removal of the regional trends and filtering out noise are applied. Then, approximate interpretation techniques are used to estimate the size and depth of sources. Next, to determine source parameters, forward techniques are used i.e., a skilled guess of the structure is made, in other words, the model is prepared, and the anomaly this would produce is calculated and compared to the observations, the data at hand. Finally, the model is adjusted and recalculated by using an iterative approach and each iteration can be done by hand, automated, or a combination of the two. After forward techniques, inverse techniques are employed to translate results into meaningful geologic model i.e., with inverse techniques usually we fix certain parameters such as source geometry or depth, and invert for remaining parameters e.g., density contrast. On the other hand, there are an infinite number of structures that could generate observations. That's why all existing geological and geophysical information is needed, such as densities of known rocks and minerals. In our Information Age, extensive computer programs are available to produce underground images for the users. It is for these reasons that the purchase of GeoSoft software is requested in this proposal. GeoSoft is one of the most powerful and commonly used software available for gravity surveys and their interpretations. When considering the instruments' cost, the cost of GeoSoft software ($3,042) is relatively minimal and is definitely worth the investment.

Gravimetric Survey of Groundwater
In this study, we will carry out gravity meter surveys because gravity change is a direct measurement of the change in total water stored in an aquifer. Pool (2008) stated that gravity-change data are useful for estimating aquifer-storage change, for estimating recharge in groundwater systems, and for estimating the aquifer storage coefficient. Prior to gravity surveys, wells were dug to monitor the water-table level; nonetheless, a well's water level doesn't translate exactly to groundwater storage because the properties of the soil subsurface and the aquifer composition must be known. Importantly, gravity measurements are completely noninvasive and have none of the permitting requirements or potential for contamination that exist when drilling groundwater wells.

In this project, a relative gravimeter (for example, a CG–5 AutoGrav gravity meter manufactured by Scintrex) (Scintrex Corporation 2018) will be used to observe from the ground surface to the groundwater table. A gridded data collection will be used within the SAGR system's influence to track the change in the groundwater table over time and to detect any local rise in the groundwater table. The gravity surveys in the SAGR area will be connected to a base station (the base station may be a relative or absolute-gravity station). We plan to establish a gravity station at each corner of the project site grids, so there will be 8-10 gravity stations to occupy in this project. These remaining stations will be measured to create a closed loop, starting with the base station and repeating in the same order multiple times during a field survey to ensure measurement repeatability. Each grid point will be occupied for 10 minutes to ensure consistency: five minutes to stabilize the gravity meter and five more minutes to take the measurement. These occupation times will ensure consistency of gravity measurements and minimize measurement errors. Then these measurements will be averaged to obtain the tide-corrected gravity value for a given grid point, which will be later processed to remove instrument drift. Care will be taken while moving the gravity meter from station to station. Using this approach, we expect to determine groundwater-storage volume with high accuracy. Gehman et al. (2009) stated that water level changes predicted from the gravity data agree on average to within ±0.45 meter. Thus, we expect to determine water level changes in our project site with approximately 0.5-meter precision.

Budget

CGS Gravimeter - $103,000

GeoSoft software annual subscription - $5,000

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