Staff Gauge

A Guide to Measuring Aquifer Recharge through the Water Balance Method

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WELL LABS
WATER · ENVIRONMENT · LAND · LIVELIHOODS

Environmental Defense Fund

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About the MEL Toolbox

The MEL toolbox simplifies scientific methods for grassroots practitioners to effectively monitor, evaluate, and learn from watershed management interventions in India. It compiles existing methodologies into an accessible format to support impact assessments that are robust despite limited resources and short project timelines. By strengthening evaluation capacity, the toolbox enables users to maximise the benefits of watershed interventions. As a living document, it will evolve through testing with partner organisations and the inclusion of new methodologies to enhance MEL practices.

This document is Part 2 of the MEL Toolbox series. Click to view Part 1, Part 3, and Part 4.

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About WELL Labs

Water, Environment, Land and Livelihoods (WELL) Labs co-creates research and innovation for social impact in the areas of land and water sustainability. It collaborates with partners to design and curate systemic, science-based solutions to enable a high quality of human life and nurture the environment. WELL Labs is part of the Institute for Financial Management and Research (IFMR) Society.

About EDF

A global nonprofit, Environmental Defense Fund collaborates with governments, NGOs, research and academic institutions, corporates and others to support and advance India's vision of shared, sustainable prosperity. It combines scientific and economic foundations, a broad network of partnerships and a pragmatic approach in support of India's ambitions.

What is the tool?

A staff gauge is a vertical ruler that measures the water level in surface water bodies and storage structures.

How is it useful?

This easy and lowcost technique allows the water level to be captured daily or weekly, which can then be used to estimate groundwater recharge.

Who can use it?

NGOs or community members can deploy the staff gauge in water storage structures like check dams, percolation tanks, lakes, and reservoirs.

What Is the Staff Gauge?

The staff gauge is a tool used in watershed management to collect data for water balance calculations. The method involves installing a vertical ruler to measure changes in water levels in surface water bodies and storage structures, to record data at regular intervals. This data can be used to calculate a region's water balance, which is a way to captures all inputs, outputs, and storage changes within a hydrological system over a specific period. Using the water balance equation, one can calculate groundwater recharge after accounting for losses through evaporation, which is not possible from secondary sources.

This is a low-cost method that can be adopted at a large scale. In India, especially in semiarid regions, there is considerable spatial heterogeneity in rainfall patterns. This makes the staff gauge method especially useful as it can be easily applied to multiple water storage structures.

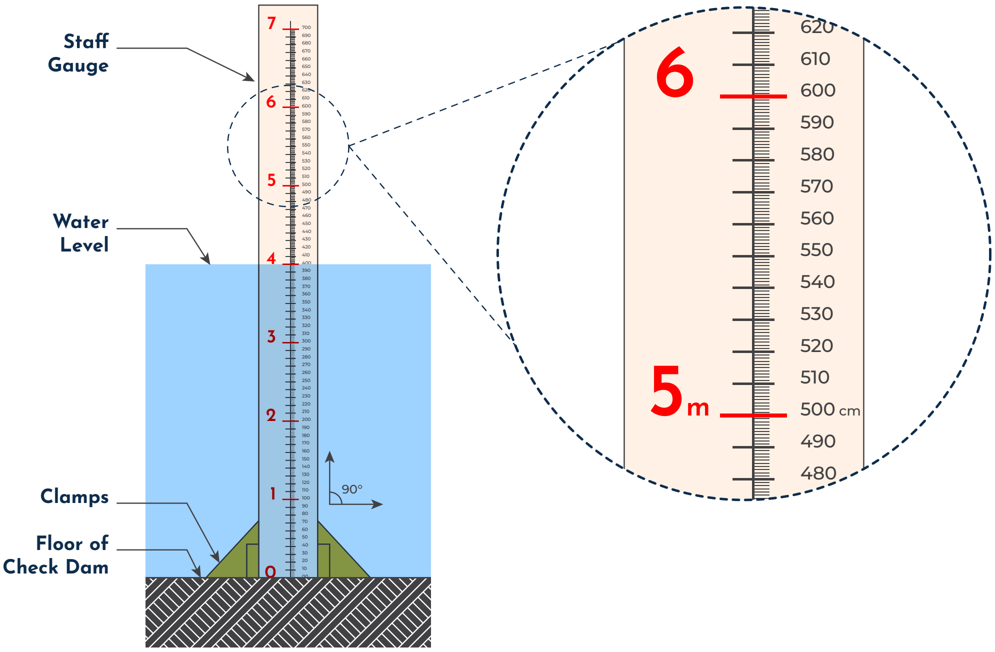

Figure 1: Setup of a staff gauge to measure changes in the water level.

What Does This Toolkit Do?

This toolkit is a step-by-step guide to using the staff gauge. Apart from its installation, the document also covers how to collect water level data and process it. Additional information has been shared through recommended tutorials and a case study illustrating the application of the methodology in Rajasthan.

Where and Why Is the Staff Gauge Useful?

The staff gauge method is valuable for smallscale watershed management, particularly in micro-watersheds (~1,000 ha). In India, where rainfall is concentrated in a few months, watershed interventions help extend water availability during dry seasons.

These interventions can be in the form of line treatments, which capture water along a river or stream(for example, check dams, percolation tanks, and anicuts) or ridge area treatments, which capture rainfall from undulating terrain(for example, contour trenches and agroforestry). By enhancing groundwater recharge, they support an additional cropping cycle (rabi season) and provide a buffer against droughts. However, estimating recharge can be challenging due to factors like multiple recharge cycles, losses due to evaporation, a lack of hydrological monitoring data, and sparsely-located climate stations.

The staff gauge is an easy-to-use tool to estimate recharge rates and understand the associated governing factors. A systematic study by Dashora et al. (2018) in the Aravalli hills of Rajasthan demonstrated the application of this approach for percolation tanks.

How Can We Measure and Analyse Water Levels Using a Staff Gauge?

There are a few steps involved in estimating water balance through the staff gauge method:

1. Deploy instruments

1A. Deploy a rain gauge

1B. Install a staff gauge

2. Collect data

2A. Monitor storage water level

2B. Monitor nearby wells

3. Analyse data

3A. Estimate water volume from water levels

3B. Calculate recharge using a simple water balance equation

1. Deploy instruments

1A.

Deploy a rain gauge

Before the installation of a staff gauge, a preliminary step is the deployment of a rain gauge. Calculating rainfall is a key parameter to measure precipitation and estimate recharge. Rain gauges are the most common instrument used to measure rainfall. The data on incoming water and water losses from a rain gauge is more precise than relying on meteorological data.

How often should you collect data?

Rainfall data should be collected daily. This is recommended for the entire monsoon season for a better estimate of the water balance.

How many rain gauges should be deployed?

Different agencies have varying recommendations on how closely the rain gauges should be placed. In Bengaluru, for example, there are significant variations even among stations located within 15 km of each other. In general, the nearer the rain gauge is placed to the staff gauge, the more accurate the results.

How to install a rain gauge?

This document presents a general understanding about installing a rain gauge. Specific rain gauges would usually have their own guide books and we recommend you follow these for installation instructions.

1B.

Install a staff gauge

Select the site

The first step in installing the staff gauge is to select the appropriate site, keeping in mind a few considerations:

- Choose an accessible location for regular monitoring of the water level.
- Ensure that there is no direct water extraction (such as siphoning) from the chosen water body.
- Ensure that the site represents average water level fluctuations and is free from obstructions like vegetation and debris.
- To ensure maximum stability, avoid installing the staff at the inlet and the outlet of the water body.
- Depending on the water body's size, you can plan for more than one staff gauge at different locations.

Figure 1: The staff gauge should be placed in an appropriate location in the water body.

Develop the gauge

- The gauge can be made on a metal or plastic rod. Alternatively, it can also be painted on a side wall within the percolation pond. The gauge should be resistant to environmental effects like corrosion.

- The minimum spacing on the scale is recommended to be 1 cm. However, this can vary depending on the depth of the water body. The height of the staff should be at least 1 m above the maximum water level.

Prepare the mounting surface and install the gauge.

- In order to keep the gauge sturdy, it is recommended to secure it to a surface made of concrete, steel, or wood using clamps or by drilling holes.

- Securely mount the staff gauge in the selected location and ensure the gauge is vertical.

Record site-specific details

- Determine the highest point in the water storage structure, beyond which it would overflow. Water levels recorded above this height are usually eliminated from final calculations.

- Document the gauge's location, installation date, and any relevant information for future use.

Test and verify the functioning

- Observe the water level on the gauge over several days to ensure accuracy and visibility.

- Make adjustments if necessary to improve the stability or alignment of the gauge.

Maintain the gauge

- Periodically inspect the gauge for sediment accumulation or damage, especially post-monsoon and pre-monsoon. Clean or repair it as needed to maintain accuracy.

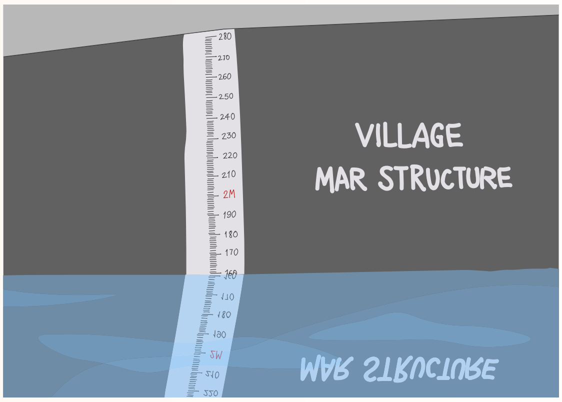

Figure 3: Illustration of a gauge painted on a managed aquifer recharge (MAR) structure, adopted from Dashora et al. (2017).

2. Collect data

2A.

Monitor storage water level

When should you begin monitoring?

Once the gauge is installed, begin monitoring the water level after the first large rainfall event when the structure becomes filled to at least half its capacity.

How do you collect the data?

- Record the water level in the staff gauge through a photo and a reading.
- Maintain the data both physically and digitally to avoid any loss of data.
- If the water has overflown on any day, mention the days.
- Collect the data until the water storage structure becomes empty.

Here is a suggested template to record the water level data.

How often should you record the data?

Record the data on a daily for regions with high recharge rates. For cases where the water level fluctuation is minimal, the frequency can be reduced to once a week.

2B.

Monitor nearby wells
(optional but recommended)

Open wells located downstream of a percolation tank are a good indicator of the effectiveness of recharge. Measuring the water levels in these wells can give a sense of aquifer recharge from the water storage structure. If the aquifer characteristics are sufficiently understood, this method can help validate the rate of recharge as a result of the water storage structure.

This step is optional, but recommended for a more accurate estimate.

How do you select wells?

We suggest monitoring at least two wells downstream of the water storage structure where the staff gauge is installed.

Select wells that are not actively being used for irrigation. If the wells selected are being used, then the well water extraction data should also be collected. This includes the number and timestamp of the start of irrigation, rate of pumping, and duration of pumping. Mark the coordinates of the selected wells.

How often should you collect the data?

Ideally, the wells should be monitored at the same frequency as the water storage structure. However, if the water levels in the wells are not fluctuating significantly, the frequency can be reduced. For example, if the water storage structure is being monitored weekly, the wells can be monitored once in two weeks.

3A.

Estimate water volume from water levels

First, estimate the area-elevation curve and the volume-elevation curve of the water storage structures. These can be done through a dumpy level survey[1]. This helps establish the depth of the storage body at different points in space and thus, determine the surface area at each contour level.

If the storage structure is dry, conduct the survey manually using the survey equipment and manual tools to measure the depths and areas. It may be possible in some cases to conduct the survey manually even if water is present. If a manual survey is not possible, a sonar device can be used to gather information about the depth and surface of a full water body.

Once the measurements are gathered, they need to be plotted on a formula. The following trapezoidal estimation formula can be used to measure the volume between contours:

V = 1/6 (Ao +4 Am + At) (Dt - Do)

V: Volume between contours (m3)
Ao, Am and At: Areas for three contour levels at the top, middle, and bottom respectively (m2)
Dt: Reduced level of the top contour (m)
Do: Reduced level of the bottom contour (m)

It is assumed that the bottom of the water body is a cone as shown in the figure below. The volume of this cone is calculated separately and added to the overall volume.

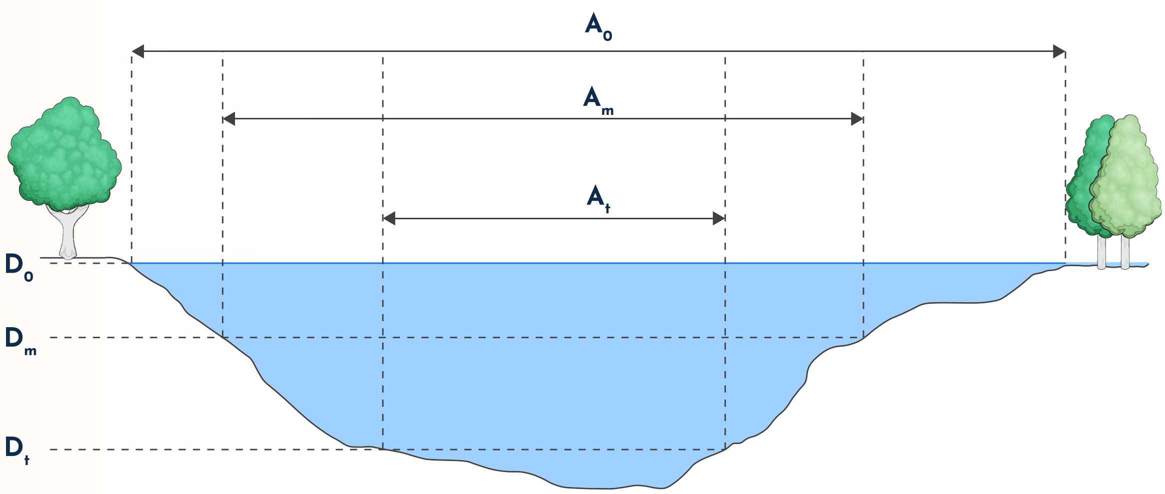

Figure 4: Cross-section of a water body illustrating the dimensions used in the formula adopted from Huser (2023).

[1]The dumpy level is an optical surveying and levelling instrument used to determine the elevation of different points at a site. Levelling is the process of determining the relative heights or elevations of points on the Earth's surface, whether on the ground or below it.

3B.

Calculate recharge using a simple water balance equation

The water balance for a water storage tank would be:

Inflow = Recharge + Evaporation + Change in tank water storage + Outflow from the tank

To estimate recharge, we calculate dry weather infiltration rate (DWIF). This is estimated when there is no active inflow or outflow from the structure. In this situation, the recharge would simply be equivalent to the change in the water level in the reservoir, after accounting for water loss through evaporation. So, the water balance equation would be as follows:

$R = \Delta H - E$

R: Recharge to aquifers (mm)
ΔH: Change in the height of water level in the structure (mm)
E: Evaporation to be estimated from secondary temperature and humidity data (mm)

The equation is valid as long as there is no spillage or inflow into the reservoir.

Since outflow is not being measured, the days where the water level crosses the overflow point will be eliminated from the calculation.

Therefore, DWIF is calculated only when the following conditions are met:

- **Condition 1:** No outflow
  Water level (t+1 day) < Overflow height

- **Condition 2:** No inflow, decrease in water level is equal to or greater than evaporative losses
  Water level (t+1 day) < Overflow height

't' refers to the day of a rainfall event, t+1 is the next day, when the rise in water level is reflected.

Data on the evaporation rate estimated from the pan evaporation method or from secondary data can be assumed to be constant. The in-situ measurement of evaporation is often missing in India and deployment of weather stations can be expensive. As an alternative, this data can be retrieved from reanalysis datasets[2] or remote sensing products available regionally or globally. This helps overcome the challenge of procuring data on actual evaporation, albeit with a tradeoff in accuracy[3].

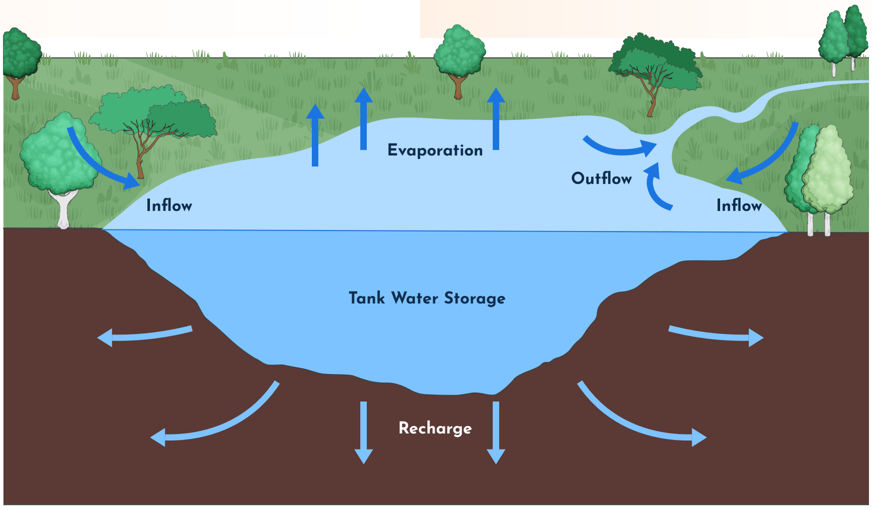

Figure 5: A visualisation of the water balance of a waterbody.

Conclusion

The staff gauge can bridge an important gap in groundwater recharge estimation. The ease of use and affordability makes it convenient and practical to adopt widely. Regular data collection from a staff gauge and its integration into a water balance equation can help overcome the limitations of secondary data sources, giving more accurate, real-time insights. This approach can be widely applied to improve groundwater management, enhance agricultural resilience, and support sustainable water resources management.

An Alternative

An alternative to the staff gauge method is a HOBO digital sensor. It eliminates the need for regular monitoring, but is more expensive.

[2] *Reanalysis datasets are a comprehensive record of climate conditions over a specific period, created by assimilating historical observations into modern forecasting models.*

[3] *Remote sensing data is often available only at coarse spatial resolutions (that is, less detail is available), resulting in lower accuracy.*

Case Study

Estimating recharge from johads in Neemli, Rajasthan

The Aravalli hills of Rajasthan have a series of traditional water harvesting structures called johads (earthen embankments), which were created to capture the run-off generated from hills and ridges. They store the collected run-off for a longer period of time, thus contributing to aquifer recharge.

The environmental NGO Tarun Bharat Sangh has worked with communities to build johads in the Aravalli hills in large numbers. These structures are typically 20 m in length and about 4-7 m in height.

Gwal Wala Bandh is one such structure in Neemli, Alwar district of Rajasthan. It is a medium-sized check dam constructed in September 2023, with a storage potential of 2.14 crore litres and a catchment area of 0.06 km2. The overflow height beyond which spillage occurs is 2 m.

WELL Labs and Tarun Bharat Singh installed a staff gauge in the structure before the onset of monsoon and monitored it from 26 June 2024 to 30 September 2024, when the water levels decreased.

Figure 6: Gwal Wala Bandh. Photo credit: Rahul Sisodia

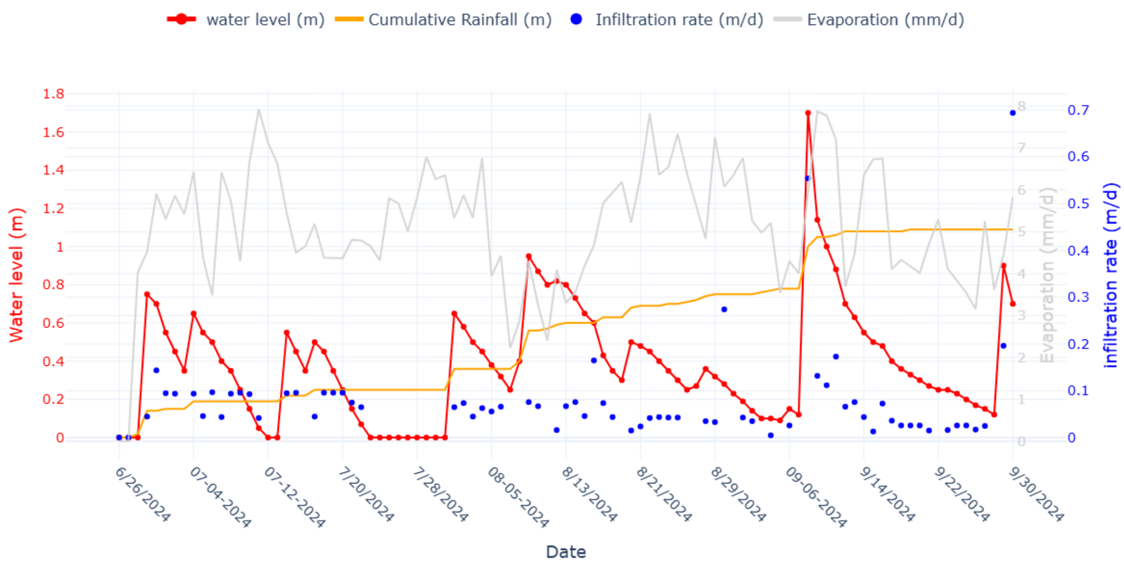

Figure 7: A median infiltration rate of 65 mm/day was recorded from the structure, indicating quick recharge and low siltation.

A rain gauge was installed about 0.34 km from the storage structure. Data from the staff gauge was collected daily. Evaporation data was used from the satellite ERA-5 Land dataset available at a scale of 9 km x 9 km.

A detailed time series of the water level was captured, which provided several insights into the recharge structure:

1. The structure did not overflow, indicating that the storage volume is sufficient to capture runoff from the catchment.

2. There were three major instances in this period when the check dam filled with rain. In the first two instances, the water level went up to around 1 m. This indicates that the structure is wide in shape and can accommodate run-off from rainfall events of around 150 mm magnitude. In the third instance, on September 8, the water level went up to 1.7 m with a rainfall event of 215 mm.

3. The slope of the receding limb indicates the rate of recharge. Here, the median rate of infiltration was 65 mm/day.

If the rate of infiltration in the structure falls, it indicates that there is siltation in the storage body, impeding connectivity with the aquifer. Alternatively, it may mean that the percolation tank has become hydraulically connected with the underground water table — there is no effective recharge, but there is equilibrium between the two.

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