Groundwater Recharge Estimation

Fact Sheet

October 2025

Groundwater recharge from land surface is commonly the largest inflow term in groundwater budgets, especially in irrigated agricultural settings. Estimation of recharge is a central activity of most groundwater hydrologists or hydrogeologists when analyzing or modeling groundwater systems. Although the scientific details can be found in numerous groundwater textbooks, including one focusing exclusively on recharge[1], the purpose of this fact sheet is not to summarize the recharge literature, which is enormous. Rather, the purpose is to provide landowners and Groundwater Sustainability Agencies (GSAs) with some simple approaches for estimating recharge *and* for collecting data that will be most beneficial for improving those estimates of recharge moving forward.

Fundamentally, a typical approach to recharge quantification involves estimating the rate at which water infiltrates downward through the soil surface, minus the rate at which that infiltrated water is evapotranspired (ET) by vegetation. The first method outlined below in **Section A** describes how to apply that approach. In many cases, however, neither the infiltration nor the ET are measured, requiring one to adopt a more approximate method that simply estimates the amount of water diverted onto the land and assumes that some fraction of that water is lost to ET and runoff. Although this approach is more approximate, it has been used successfully as a basis for financially compensating landowners' efforts to divert water onto their lands for recharge (e.g., Pajaro Valley[2]). A key ingredient in that simpler approach is measuring the amount of diverted water, which is covered in **Section B**. Another, relatively simple approach for estimating recharge from ponded water involves measuring the rate of decline of the pond surface which is covered below in **Section C**.

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[1] Healy, R. W. (2010). *Estimating Groundwater Recharge*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511780745.

[2] Bruce, M., Sherman, L., Bruno, E., Fisher, A., & Kiparsky, M. (2022). *Recharge Net Metering (ReNeM) is a novel, cost-effective management strategy to incentivize groundwater recharge*. https://doi.org/10.21203/rs.3.rs-2419554/v1.

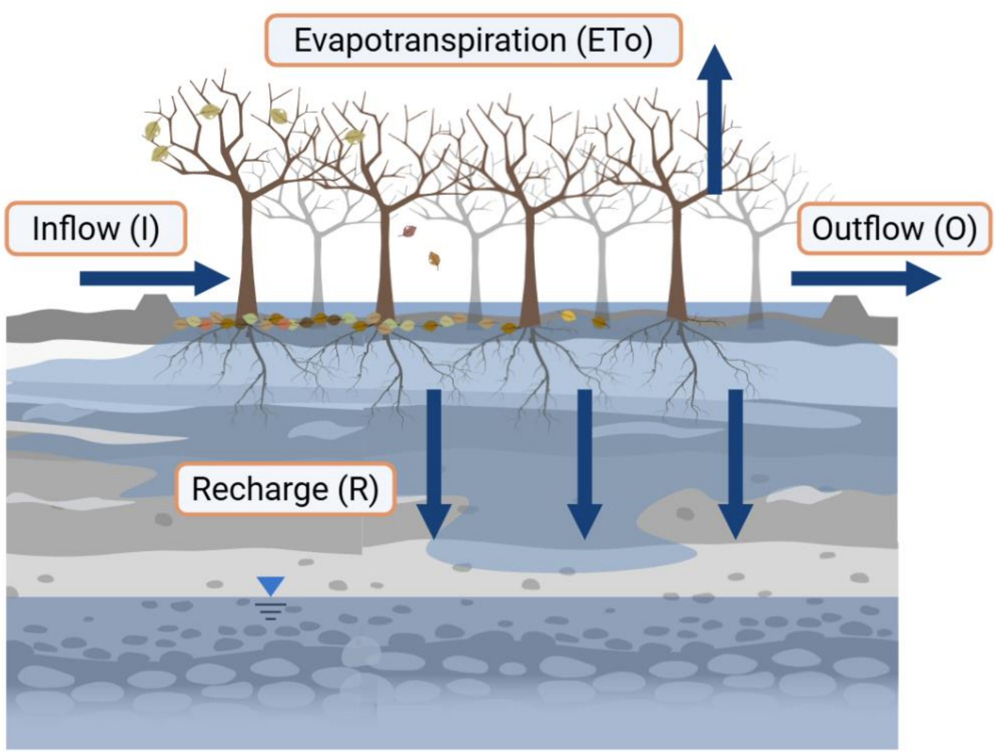
A. Simple Water Budget Approach

Measuring water applied for recharge to a field, recharge basin, dry well, subsurface tile drain system, or other recharge method is an important first step to estimate recharge. Anyone planning to recharge water should consult with their local GSA for applicable local policies and requirements. The following website is a good place to find information on recharge and GSAs: https://data.cnra.ca.gov/dataset/california-groundwater-recharge-information

During the entire time water is applied, measure or obtain the following:

1. Inflow (I) — Flood water applied to the field.
2. Outflow (O) — Surface flow, if any, leaving the field.
3. Evaporation (E) — Estimated with reference ET (ETo) from the nearest CIMIS station (https://cimis.water.ca.gov/) summed for the entire period standing water.
4. Recharge (R) equals flood water applied minus surface flow leaving minus evaporation: **R = I - O – ETo**.

In most on-farm recharge cases the site would be prepared to contain water to prevent surface flow from leaving the site.



Case Study by Turlock Irrigation District (TID) and Sustainable Conservation
(Source: https://floodmar.org/project-views/entry/334/?gvid=1742)

- 36.5 acres were used for recharge in a 40-acre almond field
- Applied water was measured with flow meters used to measure Turlock Irrigation District (TID) water deliveries

Total flood period: January 12-15, 2023

- **Inflow (I)** (applied water) = 27.5 acre-feet
- **Outflow (O)** (surface runoff) = 0 acre-feet
- **Evaporation (ETo)** = 0.14 inches convert to acre-feet [0.14 inches/(12 inches/foot)]*36.5 acres= 0.42 acre-feet (Source: Denair II CIMIS ETo [3])
- **Recharge (R)** = 27.5 ac-ft – 0 ac-ft -0.42 ac-ft = 27.08 acre-feet

In addition to TID, there are other entities using or recommending this methodology, some of which can be found at the Flood-MAR Network site: https://floodmar.org/, including projects in the Chowchilla area[4] and Fresno County[5]. See also the Madera County recharge policy[6].

B. Flow Measurement Options

As mentioned in the introductory paragraph, measurement of the water inflow to a recharge site is often essential and can serve as the basis for approximate recharge estimates. For example, the recharge estimate may be based on an assumed percentage of the inflow amount. If the water is delivered by an irrigation or water district, one can commonly use their measurement of the diverted water. Table 1 provides a summary of some common flow measurement solutions. These solutions are organized by the conveyance type in which the flow measurement takes place. The first choice is always an existing measurement structure used by an irrigation or water district to measure delivered water. If a new measurement structure is required, several options are listed for both conveyance types. Following the table, two links to web sites with additional information are provided. For accurate open channel flow measurement, a site assessment and measurement structure design by an experienced professional is required. For accurate pipeline flow measurement, purchasing and installing a magnetic flowmeter or a propeller flowmeter and installing according to the manufacturer’s instructions will be sufficient in most situations.

[3] https://cimis.water.ca.gov/WSNReportCriteria.aspx
[4] https://floodmar.org/project-views/entry/314/?gvid=1742
[5] https://floodmar.org/project-views/entry/320/?gvid=1742
[6] https://www.maderacountywater.com/wp-content/uploads/2024/03/RES-NO.-2024-030.pdf

Pictures show different flow control structures and flow measurement options. Clockwise from top left: Staff gage. Buried pipe with overflow box. Rectangular weir box with staff gauge. PVC pipe with flow meter.

See Table 1 on the following page for flow measurement options.

Additional information about water measurement can be found at the websites below:

1. https://anrcatalog.ucanr.edu/pdf/8213.pdf
2. https://www.waterboards.ca.gov/waterrights/water_issues/programs/diversion_use/wm_vendors.html
3. https://www.waterboards.ca.gov/waterrights/water_issues/programs/diversion_use/water_measurement.html

Table 1. Flow Measurement Options

Diversion/ Conveyance	Measurement Option	Accuracy	Data Required	Data Collection	Setup	Maintenance
Open Channel	Existing Irrigation or Water District Device	5 to 12 % error	Varies according to District infrastructure	Manually during daily site visit, logged or telemetered every 15 minutes	None--use existing device	District maintains, may require level or flow readings to be read daily
Open Channel	Gate in structure	5 to 20+% error	Upstream and downstream levels and gate opening	Manually during daily site visit, logged or telemetered every 15 minutes	Construct structure and install gate and staff gauge	Periodically clean approach and downstream channels and staff gauge
Open Channel	Weir/flume	5 to 20+% error	Upstream and, sometimes, downstream levels	Manually during daily site visit, logged or telemetered every 15 minutes	Construct structure and install level measurement (pressure transducer or other device) and staff gauge	Periodically clean approach and downstream channels and staff gauge
Open Channel	Acoustic Velocity Meter	5 to 20+% error	Flow rate	Manually during daily site visit, logged or telemetered every 15 minutes	Install in channel with staff gage and calibrate.	Periodically clean approach and staff gauge and check calibration.
Pipeline	Existing Irrigation or Water District Device	5 to 12 % error	Flow rate	Manually during daily site visit, logged or telemetered every 15 minutes	None--use existing device	District maintains, may require flow readings to be read daily
Pipeline	Magnetic Flowmeter	2 to 5% error	Flow rate	Manually during daily site visit, logged or telemetered every 15 minutes	Install in pipeline per manufacturer's guidelines, typically 2 to 3X pipe diameter straight upstream and downstream	Calibrate at least every five years.
Pipeline	Propeller Flowmeter	2 to 15% error	Flow rate	Manually during daily site visit, logged or telemetered every 15 minutes	Install in pipeline per manufacturer's guidelines, typically 10X pipe diameter straight upstream and 5X pipe diameter downstream	Calibrate at least every two years.

C. Direct Measurement of Ponded Water Infiltration

Measuring the rate at which water seeps into the ground provides an additional and relatively simple means to estimating the total recharge amount in cases where water has ponded in a closed depression. The rate at which water infiltrates into the soil often changes over the course of a recharge event due to the change in soil water content and the fact that the percolating water might encounter less permeable soil layers that can slow the vertical penetration of the water. The infiltration rate might also decline over time as the result of clogging, especially when the source water has a high sediment load. While soil infiltration tests performed at point locations might give a good indication of the infiltration rate that one might expect at a recharge site, there is also spatial variability in the soil over the spreading area that can influence the net recharge rate. One method that allows computing a bulk recharge rate over the entire ponded area is to estimate the infiltration rate based on the falling head method. The falling head method requires measurement of the ponded water depth on the soil surface over time using either a staff gauge and manual readings or using a water level sensor. An example of observed ponded water level data is given in Figure 1. The California Department of Water Resources (DWR) and the State Water Resources Control Board may also require inflow measurements for recharge documentation; however, in the ponded water recharge scenario described below, such measurements would not be absolutely necessary if one only seeks quantification of the recharge.

Once the water is shut off at the end of the recharge period, the ponded water depth will decline (typically at a linear rate) over time as the remaining water seeps into the ground. To estimate a bulk infiltration rate, we can use the declining part of the ponding depth data and fit a linear trend line to the data, where the slope of the linear trendline represents the infiltration rate per unit time.

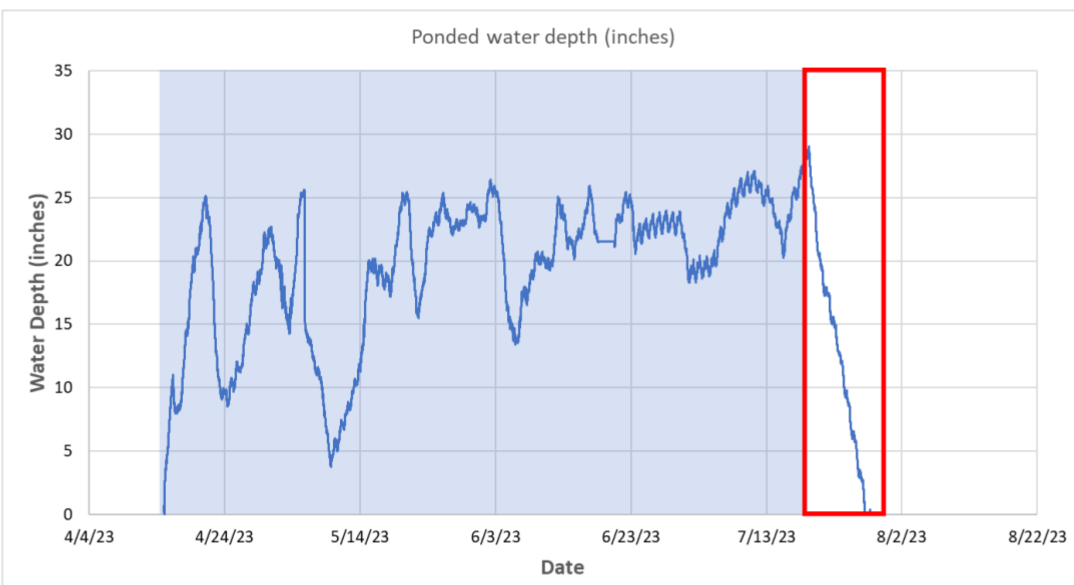


Figure 1: Example of measured ponding depth on the soil surface of a recharge site. The light blue shaded area indicates the time when water was applied for recharge. The recharge rate would be estimated based on the falling head data (i.e. falling ponding depth) once the water is shut off as indicated by the red box.

Using the example in Figure 1, Figure 2 shows a close-up of the falling ponding depth data at the end of the recharge event. The ponding depth data shown in Figure 1 was acquired with a water level data logger at 10-min intervals. Replotting the data of interest with an hourly time stamp on the x-axis instead of the date-time makes interpreting the linear equation fitted to the data easier. Fitting a linear trend line to the ponding depth data with hourly time intervals on the x-axis results in the following equation shown in Figure 2:

y = -0.1268x + 26.191

where **y** is the **ponding depth in inches** and **x** is the **time**, which in this case was converted to **hours**. The slope of the trendline in the equation is –0.1268 or in other words the ponding depth is falling at a rate of 0.1268 inches per hour. Converting this rate to a more convenient time unit (e.g. rate per day) is more intuitive and can be done by:

$$\text{Recharge rate} = -0.1268\,\frac{\text{inches}}{\text{hour}} * 24\,\frac{\text{inches}}{\text{day}} = \mathbf{3.04}\,\frac{\textbf{in}}{\textbf{day}}$$

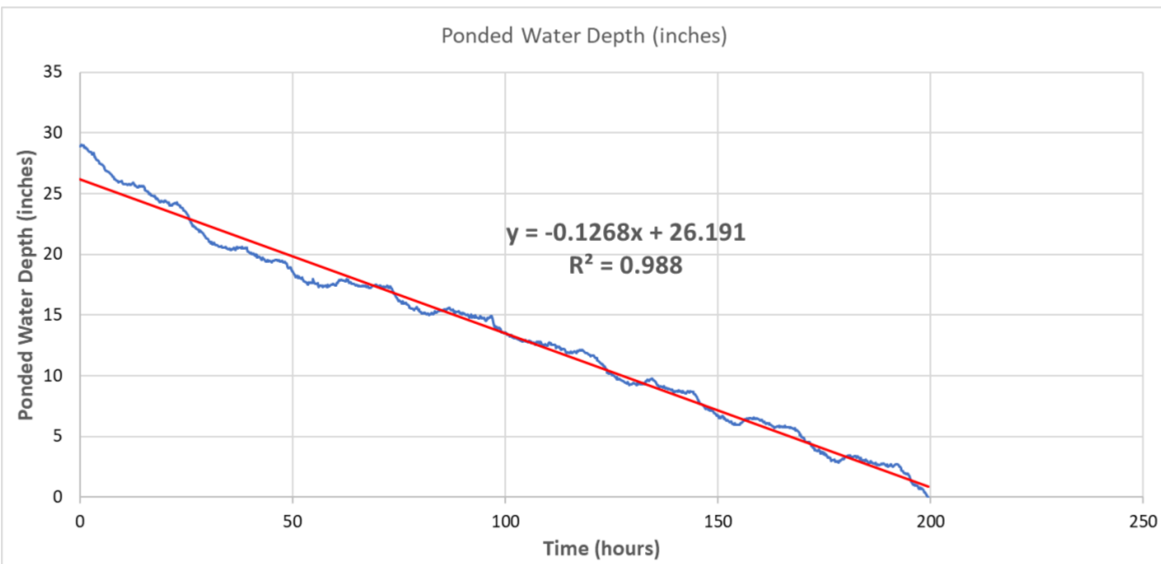


Figure 2: Close-up of the falling ponding depth once the water is shut off. Fitting a linear trend line to the data will provide the slope of the trendline, which represents the infiltration rate per unit time.

Once the recharge rate is estimated it can be multiplied by the total time over which water was applied to a recharge sites. In the example provided above, the recharge rate was determined to be 3.04 inches per day. Let's assume a recharge site was flooded for 12 days, we would multiply the rate times the area of the site times the recharge duration to estimate a total recharge volume. If the recharge area is again 20 acres, we would calculate the following:

$$R = \frac{3.04\,\frac{\text{inches}}{\text{day}}}{12\ \text{inches/foot}} * 12\ \text{days} * 20\ \text{acres} = 60.86\ \text{acre-feet}$$

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The Flood-MAR Network is a vibrant collaboration of individuals and organizations dedicated to promoting Flood-MAR implementation in California. The purpose of the Flood-MAR network is to improve water availability, flood risk reduction, and groundwater recharge to sustain communities and ecosystems through Flood-MAR implementation. www.floodmar.org

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