Groundwater Response to Natural Infrastructure in Dryland Streams

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Introduction

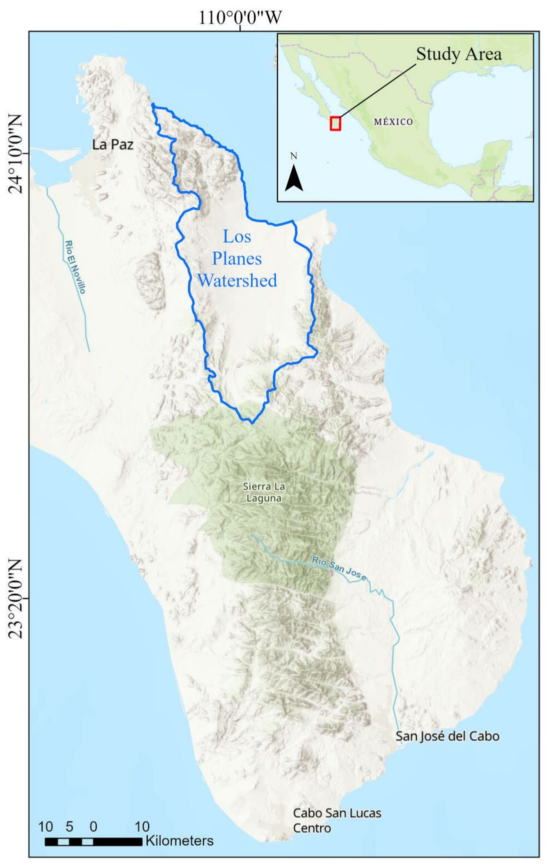


Figure 1. Study area.

Figure credit, and learn more about this project here:

Rural communities in arid Baja California Sur, Mexico, rely on groundwater for water supply. Mean annual precipitation of 200 millimeters per year recharges the aquifers during infrequent storms that mainly occur between the months of August through November. Manmade detention structures, known as Natural Infrastructure in Dryland Streams (NIDS), are a nature-based solution for restoring ephemeral channels by slowing and dispersing flashy streamflow in an area impacted by grazing. However, effects of NIDS on groundwater recharge have not been quantified.

Examples of structures in the study area

Gabion

Jute Bag Dam

Rock Dam

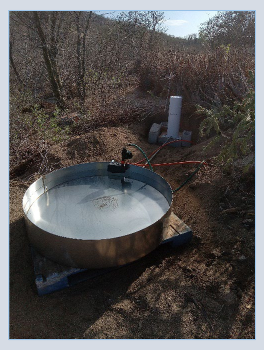
Research Question: Does Natural Infrastructure in Dryland Streams enhance groundwater recharge?

Methods

At a research station and small community in Baja California Sur, Mexico, we instrumented wells in 4 small watersheds to assess impacts of NIDS on recharge and groundwater hydrology in the headwaters of the Los Planes Watershed (Figure 1). We installed pressure transducers in the middle of the channel or upstream of NIDS in (Figure 3):

- 2 monitoring wells in a watershed without NIDS or grazing,
- 4 monitoring wells in a watershed with NIDS but without grazing,
- 7 private supply wells in a watershed with NIDS and grazing,
- 4 monitoring wells in a watershed before newly-constructed NIDS filled from the first storm event.
- 6 surface water gages, 3 meteorological stations, 18 discrete water level measurement sites, and several inventoried springs supplement this network.

Meteorological Stations



Private Supply Wells

Monitoring Wells

Springs

Conceptual Model

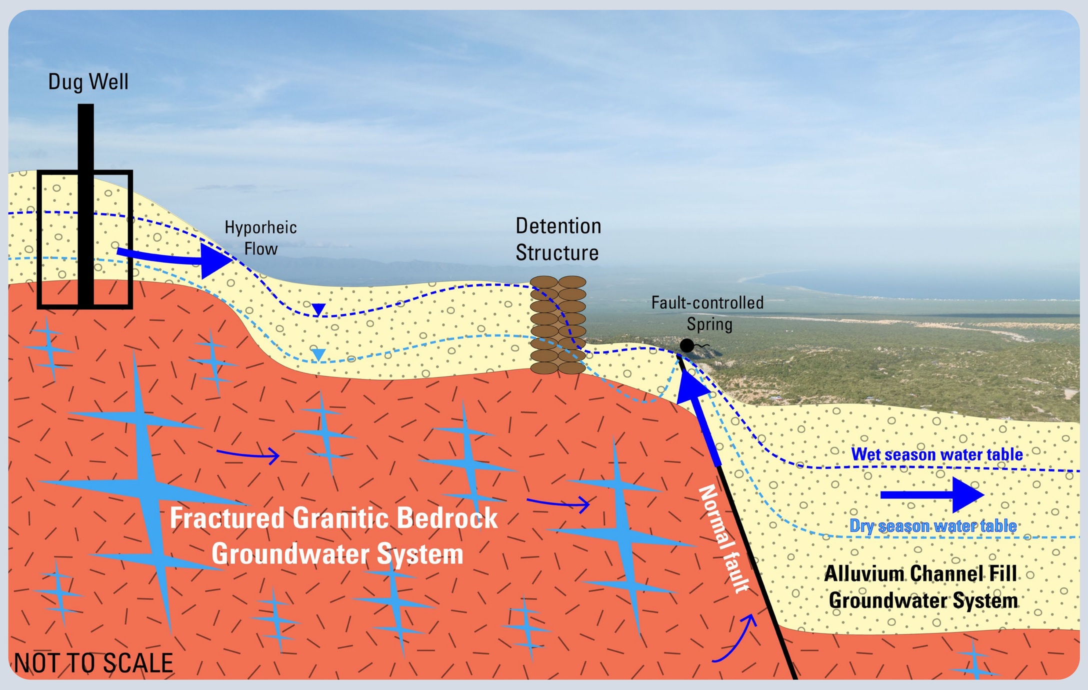


Figure 2. Conceptual model of groundwater storage in alluvial and granitic aquifers.

- Groundwater storage is limited to the west of a major fault due to a thin alluvium and highly erodible soils (Figure 2).
- Detention structures can capture sediment to slow the flow of water.
- Greater storage is expected in areas of thicker alluvium, in porosity-enhancing fractures, behind larger detention structures, in lower channel gradients, and in larger catchments (Norman and others, 2022).
- However larger structures may limit ecological benefits by increasing depth to water during drought.

Impact

- Our focus on groundwater data allows us to observe the impact of NIDS and resulting increase in sediment and water storage behind detention structures as described in previous studies (Norman and others, 2022).
- A network of wells helps us understand the underlying hydrology at restoration sites, which can inform optimization of future NIDS installations to enhance local water availability.
- Individually, small structures have a limited capacity for groundwater storage and recharge, but they may provide a larger benefit for vegetation by raising the water table during smaller events. Larger structures downstream have greater storage capacity but could limit plant and animal access to groundwater due to increased groundwater depths during drought and loss of hyporheic exchange.

Credit: Flor Cassassuce

- Increasing water availability for plants by raising the water table is expected to increase transpiration, which could be correlated to a reduction in soil moisture and groundwater storage (Atwood and others, 2023). Observing and quantifying the balance between changes in water storage and evapotranspiration resulting from NIDS can illustrate the complex and non-linear dynamics of these changing systems.

Results

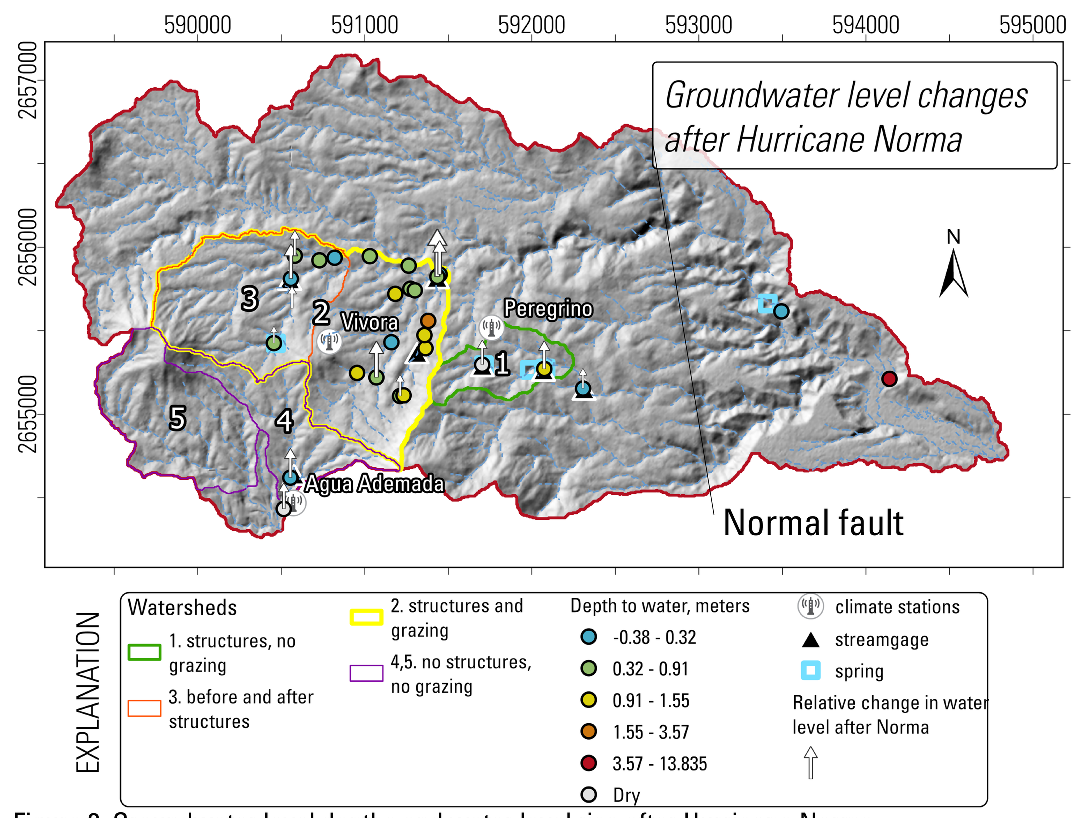
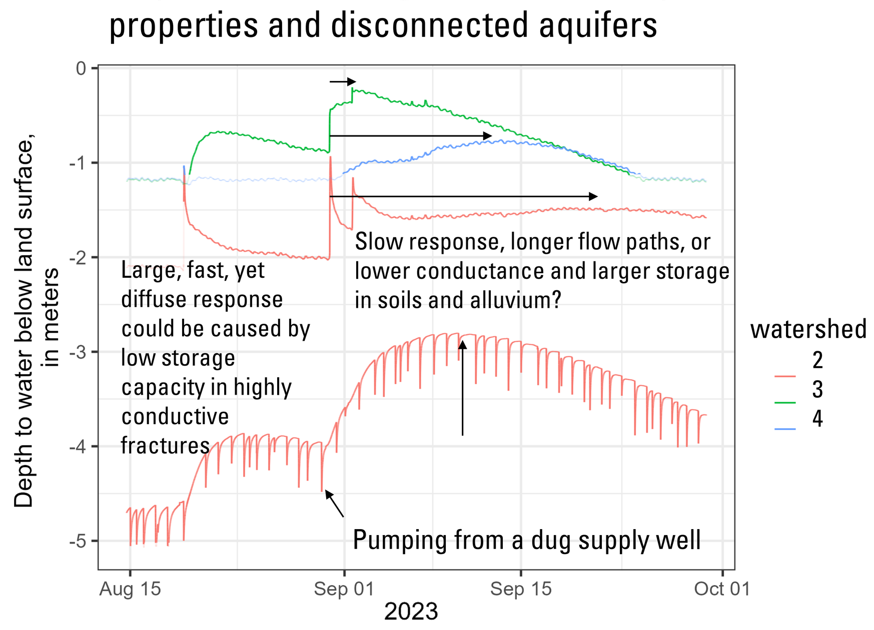


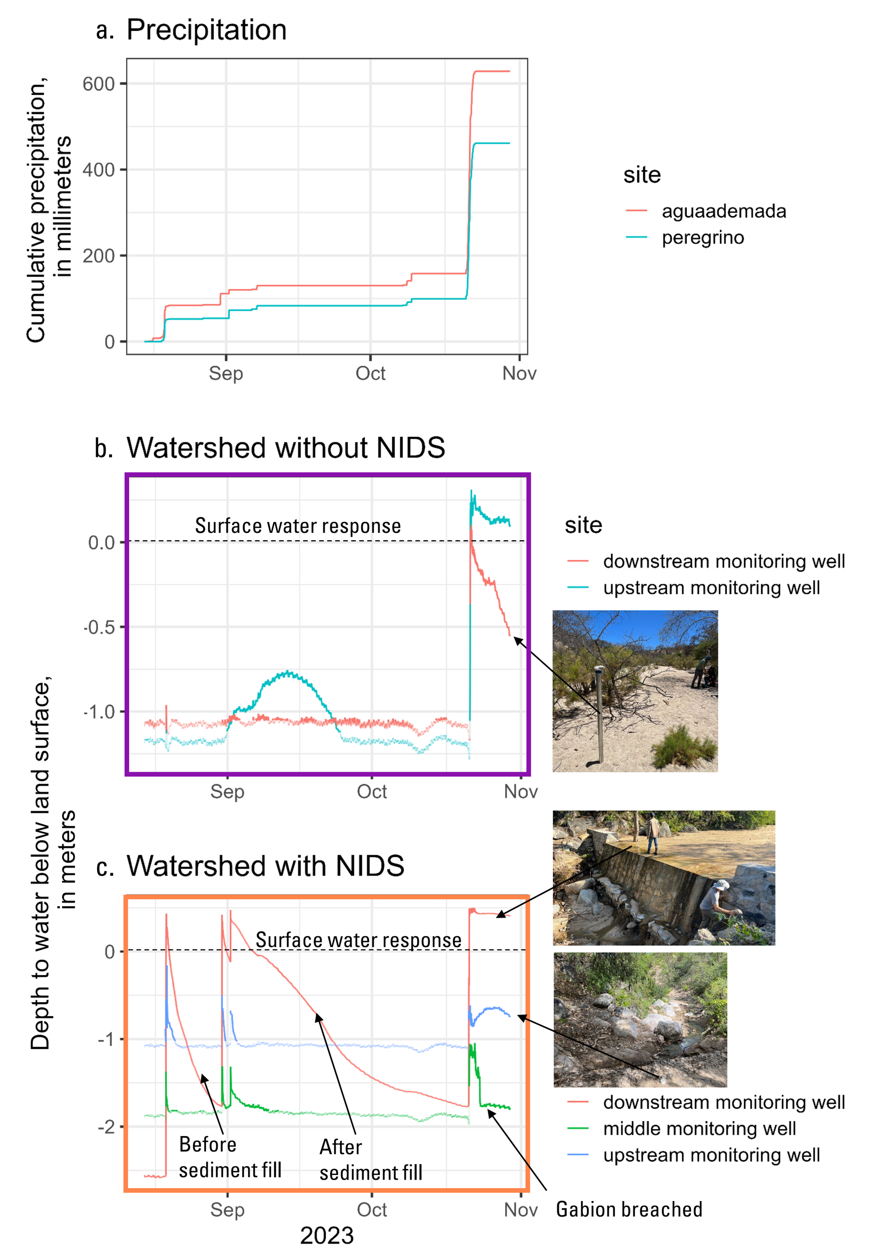
Figure 3. Groundwater level depths and water level rise after Hurricane Norma.

- The magnitude of the change in water levels after Hurricane Norma indicates locations where the storm had the largest impact on hydraulic heads and gradients (Figure 3).
- Because all monitored sites had saturated conditions (as indicated by surface water flow and shallow depths-to-water), the channel bed elevation and therefore the top of the NIDS elevation was a limit to additional storage from this historic rain event.
- Six storm events, including hurricane Norma, were recorded in 2023 (5a). Groundwater levels rose rapidly after four of these events in a watershed with NIDS, indicating recharge in response to precipitation; however, groundwater levels rose after only two events in the watershed without NIDS (5b).
- After each storm event, groundwater levels receded at different rates upstream of NIDS (5c), whereas initially static levels rose for several weeks near suspected bedrock fracture zones (4 & 5b).
- Lag and attenuation of peaks in the groundwater hydrographs (4) indicate that flow is occurring through hydrologic units characterized by lower conductivity, greater storage capacity, longer flow paths, or a combination of factors.

4. Lagged and attenuated groundwater responses indicating differences in aquifer properties and disconnected aquifers



5. Groundwater response upstream of NIDS



- Larger structures sustained higher water levels for longer than smaller structures (5c) and no structures (5b).
- Structures quickly filled with sand, resulting in slower recession rates during the second and third events.
- Mass of sediment and water is conserved, and monitoring wells are only measuring zones of accumulation upstream of NIDS.

Next Steps

- The impacts of NIDS on recharge volumes will be further explored using geophysical data and groundwater modeling. Continued groundwater data collection and analysis for another rainy season will allow us to further correlate groundwater-level responses with differing conditions at each well.
- Identifying wells with and without connection with the fractured aquifers will further understanding of groundwater-level responses to precipitation events and NIDS.

References

Atwood, A., Hille, M., Clark, M. K., Rengers, F., Ntarlagiannis, D., Townsend, K., & West, A. J. (2023). Importance of subsurface water for hydrological response during storms in a post-wildfire bedrock landscape. *Nature Communications*, 14(1), Article 1. https://doi.org/10.1038/s41467-023-39095-z

Norman, L. M., Lal, R., Wohl, E., Fairfax, E., Gellis, A. C., & Pollock, M. M. (2022). Natural infrastructure in dryland streams (NIDS) can establish regenerative wetland sinks that reverse desertification and strengthen climate resilience. *Science of The Total Environment, 849*, 157738. https://doi.org/10.1016/j.scitotenv.2022.157738