

Statewide Suitability Analysis for Managed Aquifer Recharge (MAR) using Surface Infiltration Methods

Ann E. H. Hanson, Andrew L. Bobst, Ginette Abdo, John I. LaFave, Mary Sutherland

Montana Bureau of Mines and Geology

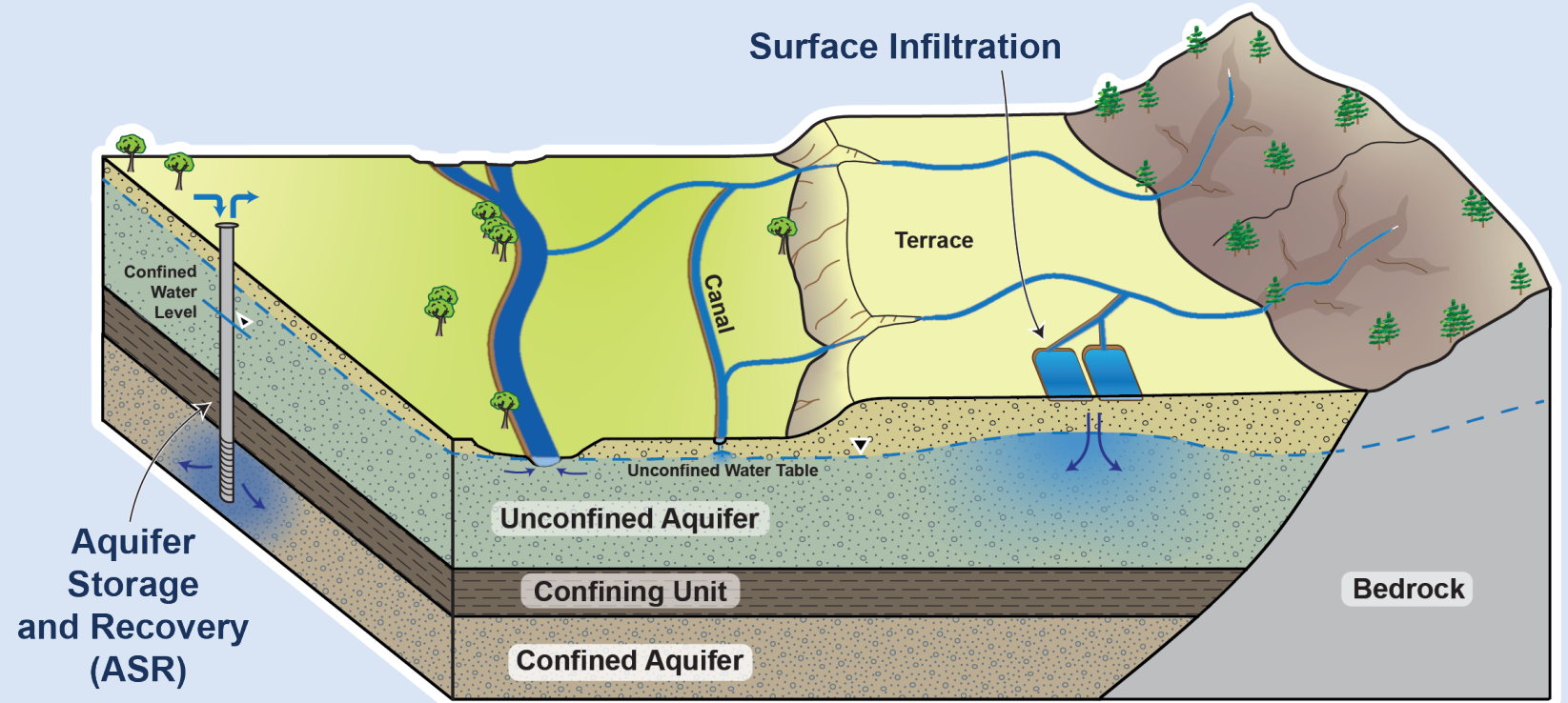


Background

Managed Aquifer Recharge (MAR) provides a means to supplement water supplies by intentionally recharging aquifers; it is a method to “**slow water down**” or store water with the intent of recovering water later during times of need or to achieve an ecological benefit (NGWA, 2024).

Two common types:

1. Surface Infiltration
2. Aquifer Storage & Recovery



Background



Background

Site Screening Considerations –

What is necessary to make Surface Infiltration possible?

Purpose/Scope:

- How much water is needed?
- What is it needed for?
- What time of year is it needed?

Hydrogeology:

- Transmissive Aquifer
- Available Storage
- Permeable Soils
- Topography

Location:

- Distance to Source Water
- Land Ownership

Other:

- Water Quality of Source and Aquifer
- Engineering Considerations
- Cost/Upkeep
- Regulatory requirements



Background

Site Screening Considerations –

What is necessary to make Surface Infiltration possible?

Purpose/Scope:

- How much water is needed?
- What is it needed for?
- What time of year is it needed?

Hydrogeology:

- Transmissive Aquifer
- Available Storage
- Permeable Soils
- Topography

Location:

- Distance to Source Water
- Land Ownership

Other:

- Water Quality of Source and Aquifer
- Engineering Considerations
- Cost/Upkeep
- Regulatory requirements



Considerations differ depending on:

- 1. MAR method desired**
- 2. Purpose and scope of study**



Purpose & Scope

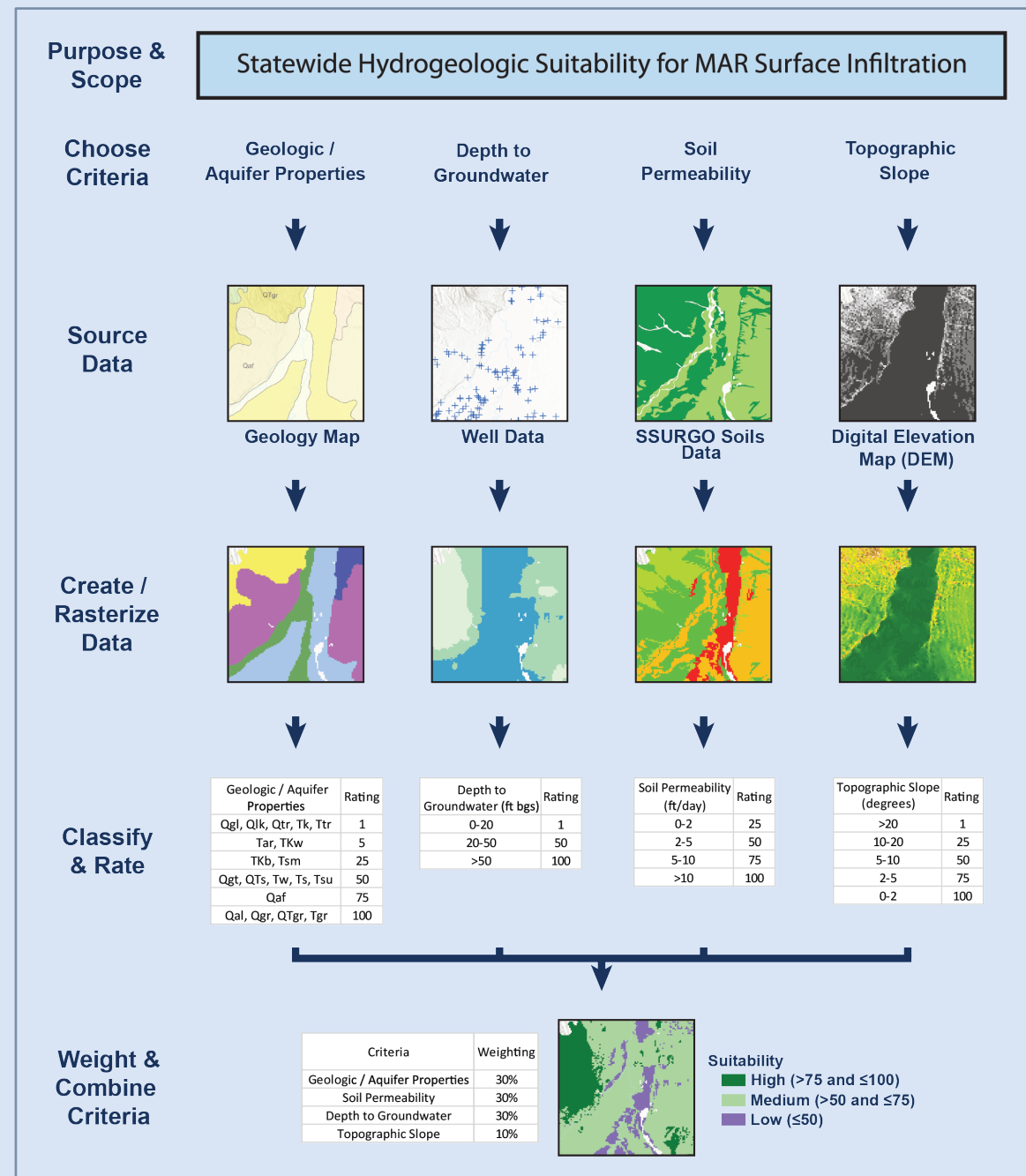
- Surface Infiltration Suitability
- State-wide
- Basin-fill and Alluvial Surficial Aquifers
- Hydrogeologic Properties
- Publicly Available Information
- First-Level Screening Tool

Methods

Multi-Criteria Decision Analysis (MCDA) – method of evaluating and combining geospatial data

Four Criteria were chosen:

1. Geologic/Aquifer Properties
2. Depth to Groundwater
3. Soil Permeability
4. Topographic Slope



Methods

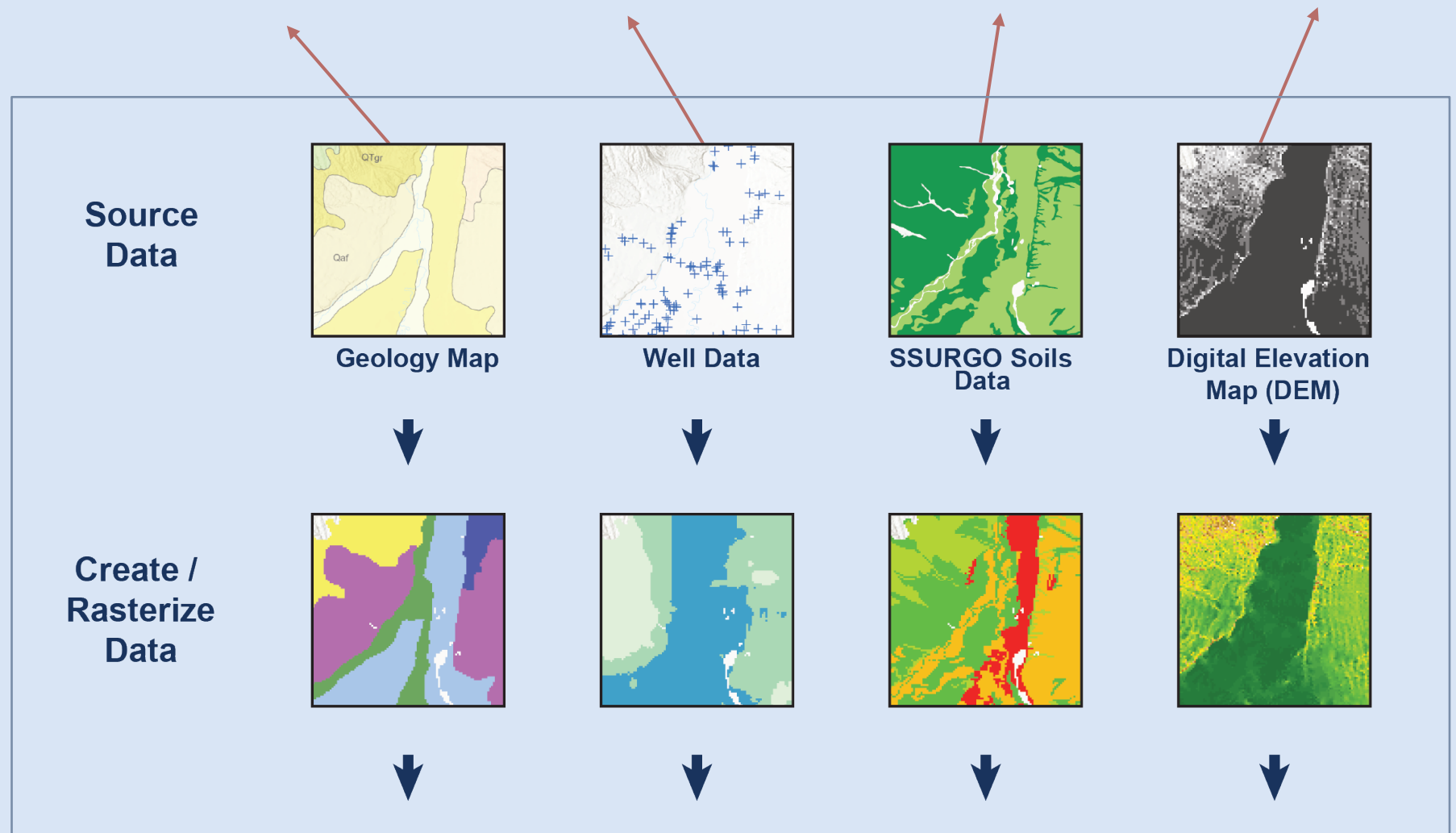
Publicly available information was used to assess each criterion.

MBMG 1:500K
Statewide
Geology

Groundwater
Level Data from
GWIC

USDA Soil Survey
Geographic Data
(K_{sat})

USGS 10-
meter DEM



Methods

Each criteria was split up into groups and rated 1 (low suitability) to 100 (high suitability)

Divisions and ratings are subjective but are based on:

1. Previously published MAR suitability studies
2. Assessing multiple classification schemes
3. Professional judgement

Classify & Rate

Geologic / Aquifer Properties	Rating
Qgl, Qlk, Qtr, Tk, Ttr	1
Tar, TKw	5
TKb, Tsm	25
Qgt, QTs, Tw, Ts, Tsu	50
Qaf	75
Qal, Qgr, QTgr, Tgr	100

Depth to Groundwater (ft bgs)	Rating
0-20	1
20-50	50
>50	100

Soil Permeability (ft/day)	Rating
0-2	25
2-5	50
5-10	75
>10	100

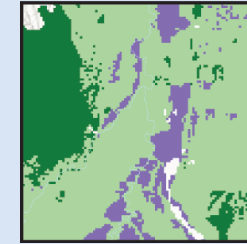
Topographic Slope (degrees)	Rating
>20	1
10-20	25
5-10	50
2-5	75
0-2	100



Methods

Weight & Combine Criteria

Criteria	Weighting
Geologic / Aquifer Properties	30%
Soil Permeability	30%
Depth to Groundwater	30%
Topographic Slope	10%

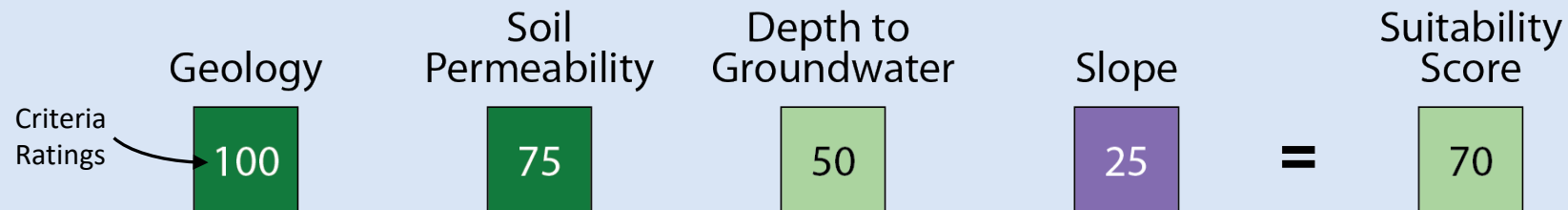


Suitability
■ High (>75 and ≤100)
■ Medium (>50 and ≤75)
■ Low (≤50)

For each raster cell, a Weighted Linear Combination equation was used to calculate the MAR suitability:

$$\text{MAR Surface Infiltration Suitability} = \sum \text{criteria weight} \times \text{rating within criterion}$$

Example:



$$(30\% * 100) + (30\% * 75) + (30\% * 50) + (10\% * 25) = 70$$

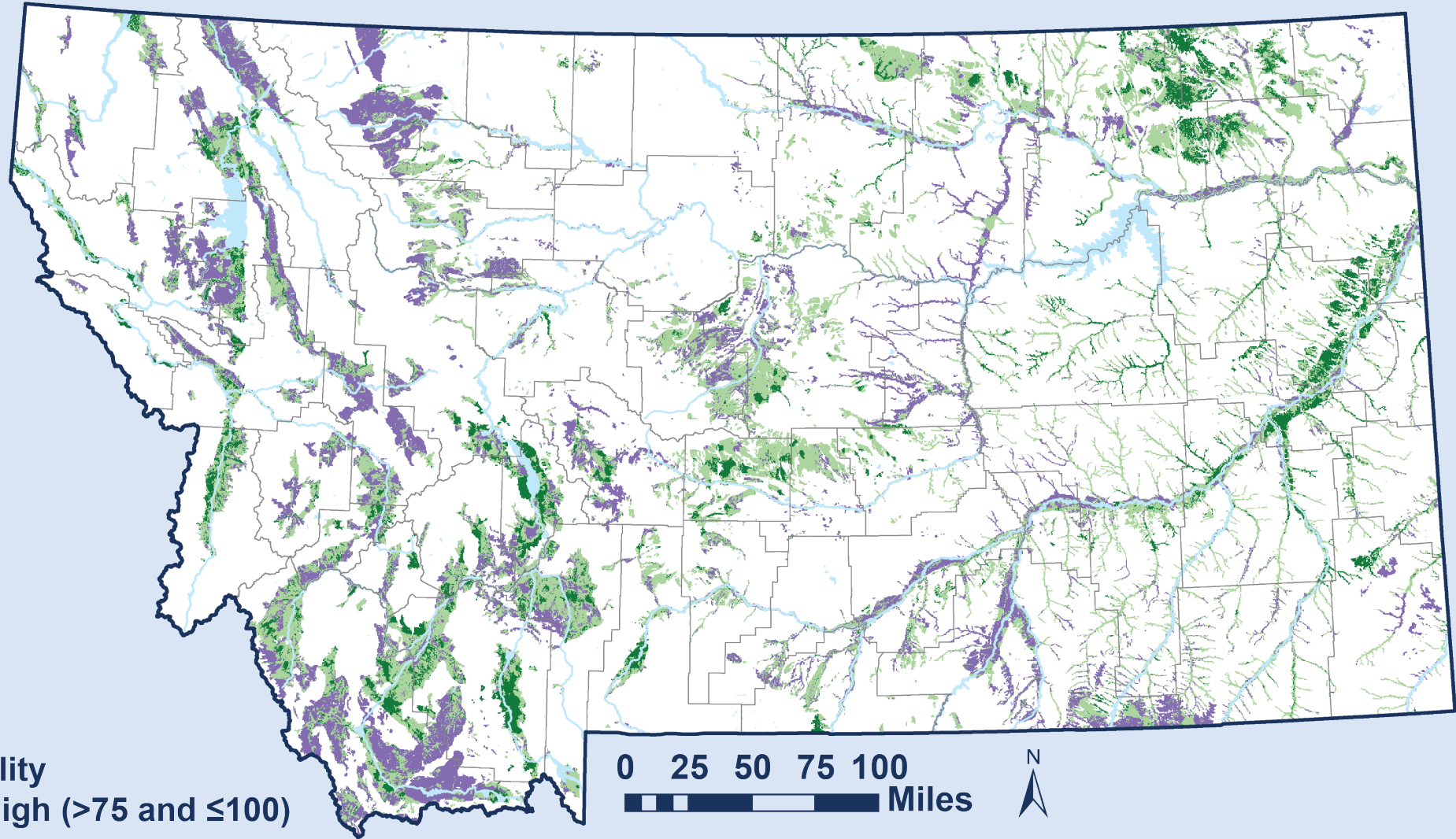
Results

16.5% of the state analyzed

15% High
(2.3 million acres)

53% Medium
(8.3 million acres)

32% Low
(5.0 million acres)



Suitability

- High (>75 and ≤100)
- Medium (>50 and ≤75)
- Low (≤50)

Example #1

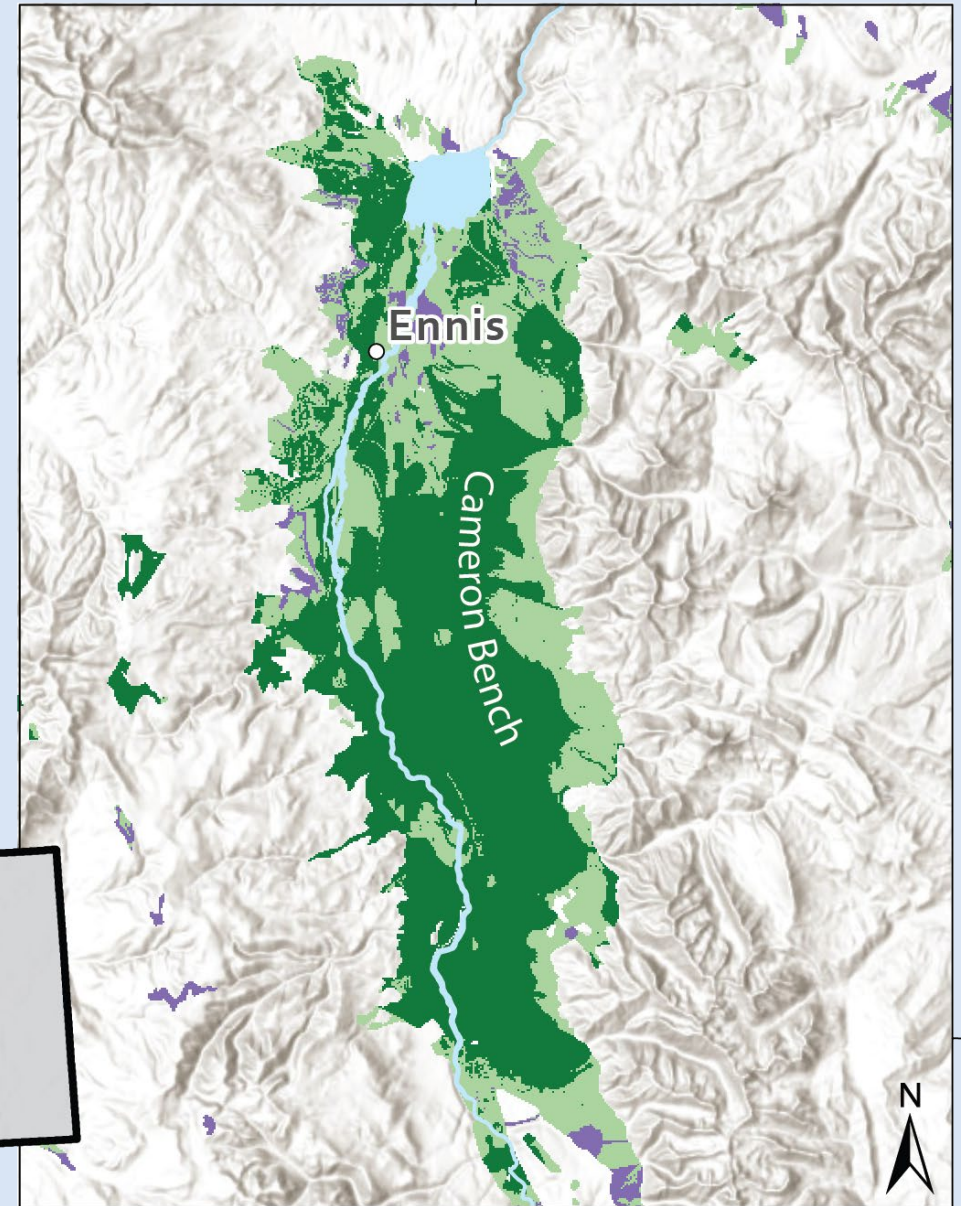
Madison Valley

Field Data (Known):

- Sand & Gravel Aquifer
>300 ft deep
- Yields >99 gpm
- Sand-dominated soils
- Static Water Level ~150 ft
- Terrace deposit
(topographically flat)

Surface Infiltration Suitability

- High (>75 and ≤100)
- Medium (>50 and ≤75)
- Low (≤50)



111°40'W

Example #1

Madison Valley

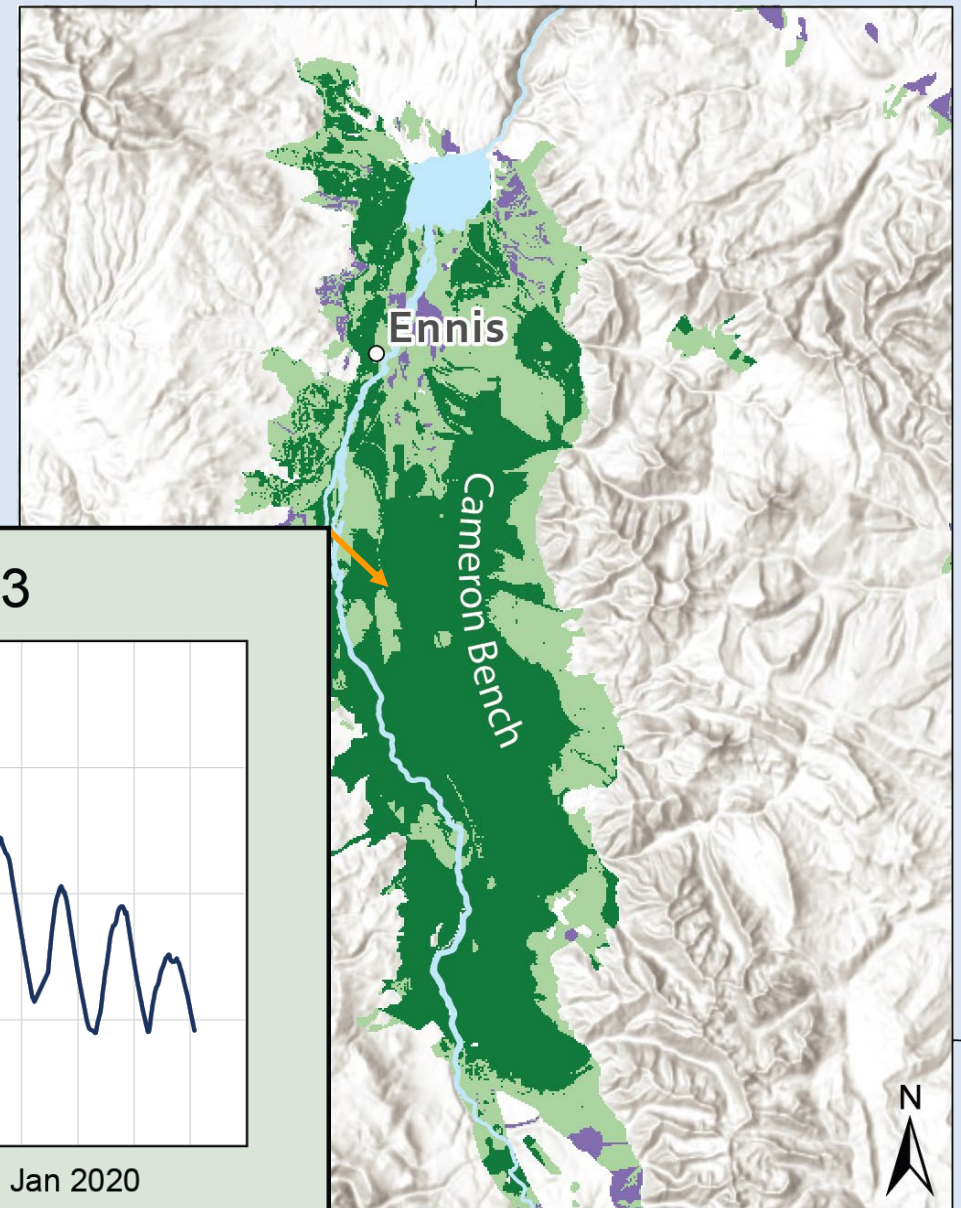
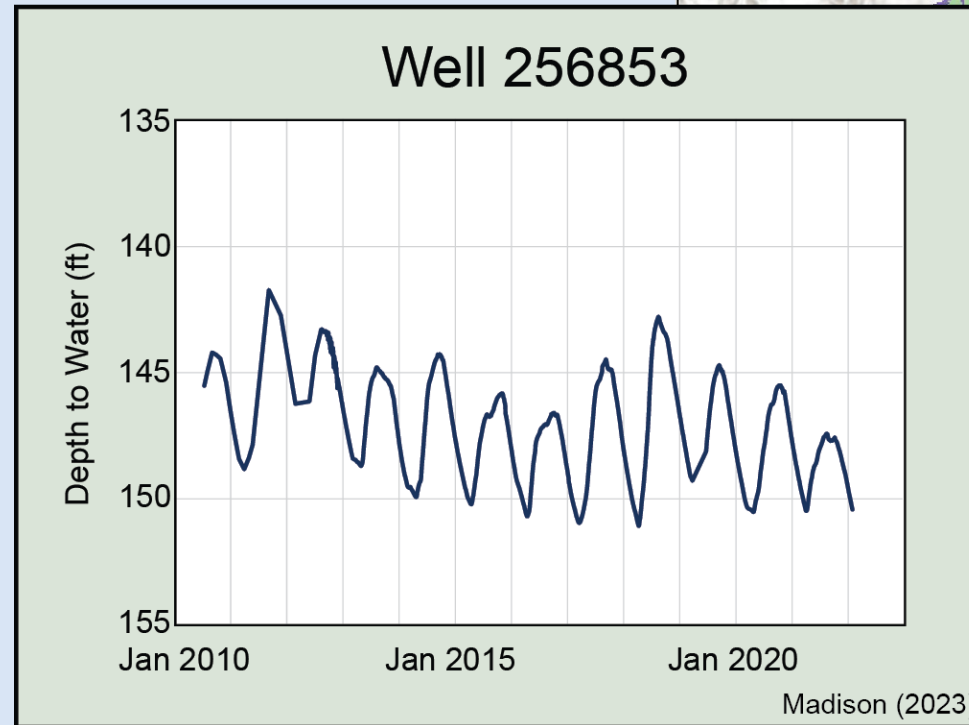
Field Data (Known):

- Sand & Gravel Aquifer >300 ft deep
- Yields >99 gpm
- Sand-dominated soils
- Static Water Level ~150 ft
- Terrace deposit (topographically flat)

Surface Infiltration Suitability

- High (>75 and ≤100)
- Medium (>50 and ≤75)
- Low (≤50)

“Well hydrographs that reflect groundwater recharge from leaky irrigation structures”

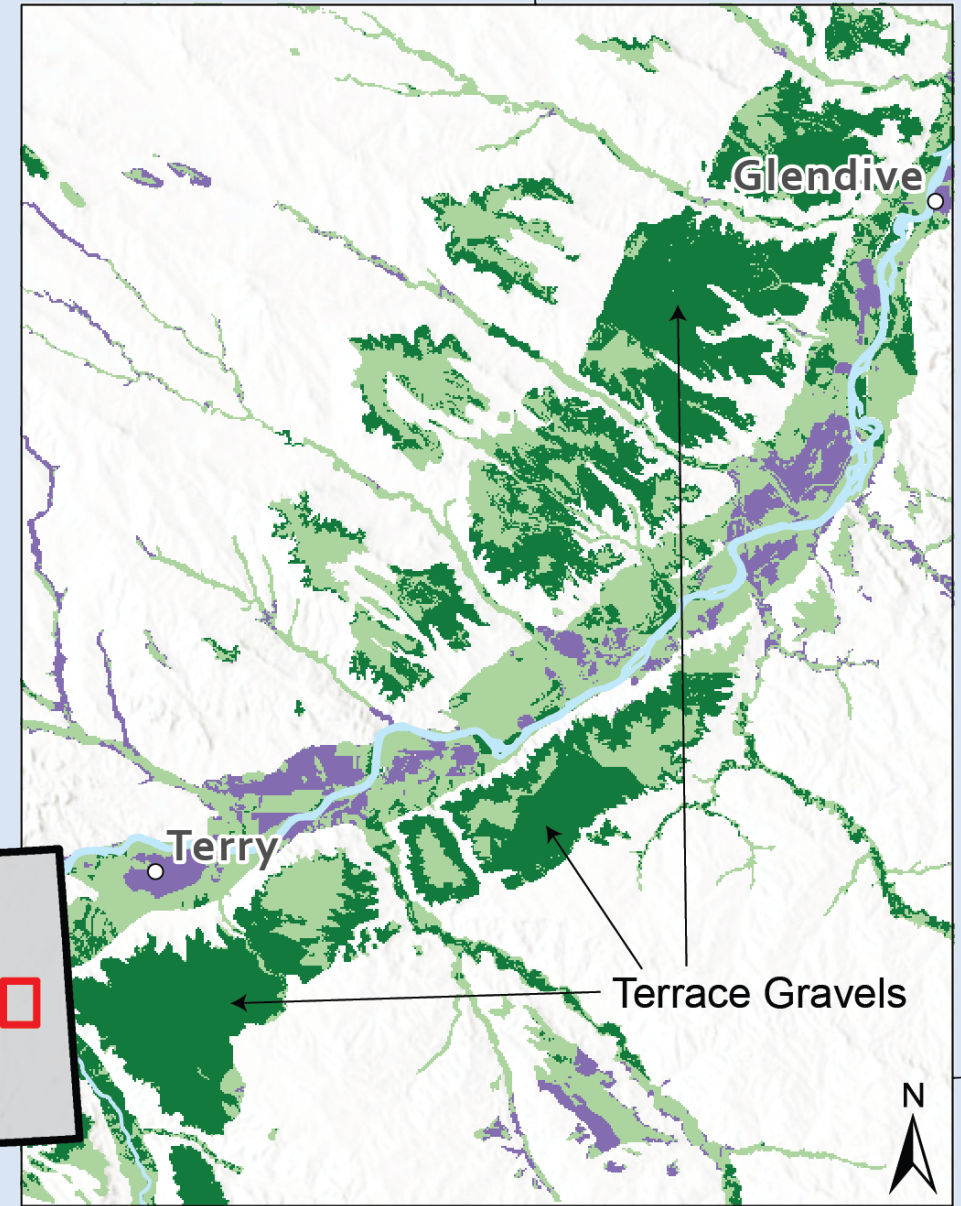
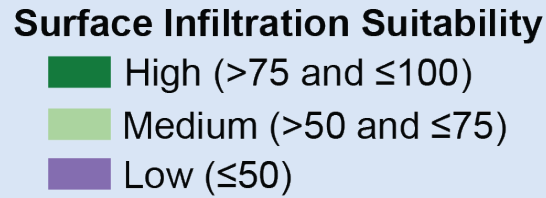


Example #2

Yellowstone River Gravels

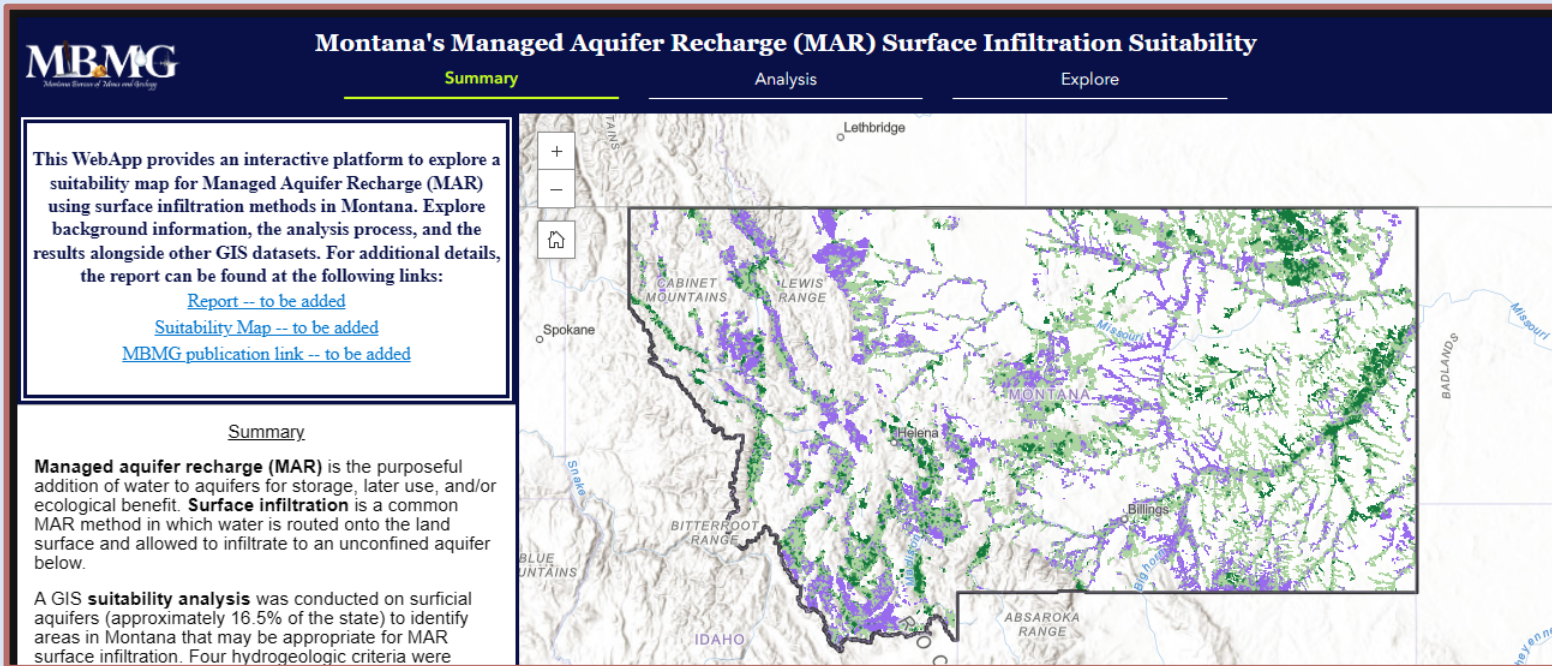
Field Data (Known):

- Sand & Gravel Aquifer 30- >100 ft thick
- Yields >35 gpm
- Soil Permeability (USDA) >5 ft/day
- Static water level >58 ft
- Terrace deposit (topographically flat)



Available WebApp

<https://gis-data-hub-mbmg.hub.arcgis.com/>
under **“Water Resources”**



The screenshot shows a web application interface with a dark blue header. The header contains the MBMG logo on the left and the title "Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability" in the center. Below the title are three tabs: "Summary" (highlighted in green), "Analysis", and "Explore".

On the left side, there is a text box with the following content:

This WebApp provides an interactive platform to explore a suitability map for Managed Aquifer Recharge (MAR) using surface infiltration methods in Montana. Explore background information, the analysis process, and the results alongside other GIS datasets. For additional details, the report can be found at the following links:

- [Report -- to be added](#)
- [Suitability Map -- to be added](#)
- [MBMG publication link -- to be added](#)

Below this text box is a "Summary" section with the following text:

Managed aquifer recharge (MAR) is the purposeful addition of water to aquifers for storage, later use, and/or ecological benefit. **Surface infiltration** is a common MAR method in which water is routed onto the land surface and allowed to infiltrate to an unconfined aquifer below.

A GIS **suitability analysis** was conducted on surficial aquifers (approximately 16.5% of the state) to identify areas in Montana that may be appropriate for MAR surface infiltration. Four hydrogeologic criteria were

The main part of the interface is a map of Montana. The map shows the state's outline and is overlaid with a network of purple and green lines representing infiltration suitability. Major mountain ranges are labeled: Cabinet Mountains, Lewis Range, Bitterroot Range, Blue Mountains, and Absaroka Range. Major cities like Lethbridge, Spokane, Helena, and Billings are also marked. The map includes standard GIS controls like a zoom in (+) and zoom out (-) button, a home button, and a map scale bar.

Available WebApp

<https://gis-data-hub-mbmg.hub.arcgis.com/>
under "Water Resources"

Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability

Summary Analysis Explore

This WebApp provides an interactive platform to explore a suitability map for Managed Aquifer Recharge (MAR) using surface infiltration methods in Montana. Explore background information, the analysis process, and the results alongside other GIS datasets. For additional details, the report can be found at the following links:

- [Report -- to be added](#)
- [Suitability Map -- to be added](#)
- [MBMG publication link -- to be added](#)

Summary

Managed aquifer recharge (MAR) is the purposeful addition of water to aquifers for storage, later use, and/or ecological benefit. **Surface infiltration** is a common MAR method in which water is routed onto the land surface and allowed to infiltrate to an unconfined aquifer below.

A GIS **suitability analysis** was conducted on surficial aquifers (approximately 16.5% of the state) to identify areas in Montana that may be appropriate for MAR surface infiltration. Four hydrogeologic criteria were

Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability

Summary Analysis Explore

Purpose & Scope MT Aquifers & MAR Analysis Steps Criteria Combining Criteria Suitability Map Results

Purpose and Scope

A statewide analysis identified areas in Montana that may be suitable for managed aquifer recharge (MAR) surface infiltration methods. This analysis was performed for surficial aquifers (basin-fill and alluvial) and it evaluated the hydrogeologic properties of an area to determine suitability. Other factors that are important to the implementation of a MAR project, such as source water availability, water quality of the source and receiving water, a needs assessment, regulatory considerations, and implementation/engineering feasibility were beyond the scope of this project and not considered. This product serves as a first-level screening tool for stakeholders to identify areas that merit a more localized and detailed suitability investigation. For additional details, the report can be found at the following links:

- [Report \(to be added\)](#)
- [Suitability Map \(to be added\)](#)
- [MBMG publication link \(to be added\)](#)



Background

Purpose & Scope

Methods

Results

Examples

Conclusions

Available WebApp

<https://gis-data-hub-mbmg.hub.arcgis.com/>
under "Water Resources"

Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability

Summary Analysis Explore

This WebApp provides an interactive platform to explore a suitability map for Managed Aquifer Recharge (MAR) using surface infiltration methods in Montana. Explore background information, the analysis process, and the results alongside other GIS datasets. For additional details, the report can be found at the following links:

Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability

Summary Analysis Explore

Purpose & Scope MT Aquifers & MAR Analysis Steps Criteria Combining Criteria Suitability Map Results

Montana's Managed Aquifer Recharge (MAR) Surface Infiltration Suitability

Summary Analysis Explore

For additional details on this study, the report can be found at the following links: [report](#), [suitability map](#), [MBMG publication link \(links to be added\)](#)

SWAMP (Stream Gaging Stations)

MBMG gaging stations

USGS gaging stations

DNRC gaging stations

Gage Locations

- SWAMP (Stream Gaging Stations)
- GWIC (MBMG)
- Township, Range, Section (BLM)
- Boundaries (MSDI)
- Watershed Boundaries (MSDI)
- Hydrography
- Irrigation
- MAR Surface Infiltration Suitability (MBMG)
- Land Cover
- Property Information
- Geology

Managed aquifer recharge (MAR) is a method of replenishing surface water bodies and aquifers. This project aims to identify areas suitable for managed aquifer recharge (MAR) for surficial aquifers (basin-fill and alluvial) to determine suitability. Other factors such as source water availability, water quality, regulatory considerations, and land use are not considered. This project aims to identify areas that merit a more detailed analysis. For additional details, the report can be found at the following links: [report](#), [suitability map](#), [MBMG publication link \(to be added\)](#)



Background

Purpose & Scope

Methods

Results

Examples

Conclusions

Conclusions

- This state-wide MAR surface infiltration suitability map is intended as an initial screening. Additional considerations should include project purpose, source water distance, water quality, regulatory requirements, etc. Site specific suitability, evaluation, and project design is necessary.
- Overall:
 - 15% (**2.3 million acres**) was considered **high**,
 - 53% (8.3 million acres) was considered medium, and
 - 32% (5.0 million acres) were considered low
- High suitability occurs in sand & gravel aquifers with sand-dominated soil profiles, edges of valleys/basins where depth to groundwater is deep, and on topographically flat areas such as terraces.
- Check out our publication and WebApp coming soon!

Questions?

