Estimating Water Offset from Habitat Projects

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Presentation Overview

- NEB Guidance Project Types
- Habitat Project Types with Water Offset Potential
- Effect of Restoration Projects on the Groundwater Regime
- Estimating Water Offset Potential
  - Project Example
  - Other Case Studies
  - Key Considerations
  - Simplified Analytical Method
  - Uncertainty
- Conclusions
- Next Steps

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NEB Guidance Project Types

- Water right acquisition offset projects
- Non-acquisition water offset projects
  - Typically re-timing or temporary "storage" of high flow surface waters
  - Projects may include:
    - Managed aquifer recharge (MAR) (e.g. spreading basins, infiltration galleries, etc.)
    - Source exchanges (e.g. surface water to groundwater, shallow to deep pumping, etc.)
    - Streamflow augmentation (i.e. "pump and dump")
    - Off-channel storage
- ***Habitat and other related projects***

Habitat and Other Related Projects

- "**Projects that focus on returning stream habitat to a more natural state** such as through river-floodplain restoration, instream habitat restoration, beaver reintroduction, and beaver dam analogs.
- **Projects that protect current habitats** through riparian or upland conservation and management, forest management, or water conservation.
- **Projects that increase connectivity and fish passage between habitats** such as fish barrier removal, or reconnection of off-channel habitat."[1]

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[1]From the *Final Guidance for Determining Net Ecological Benefit, Publication 19-11-079*

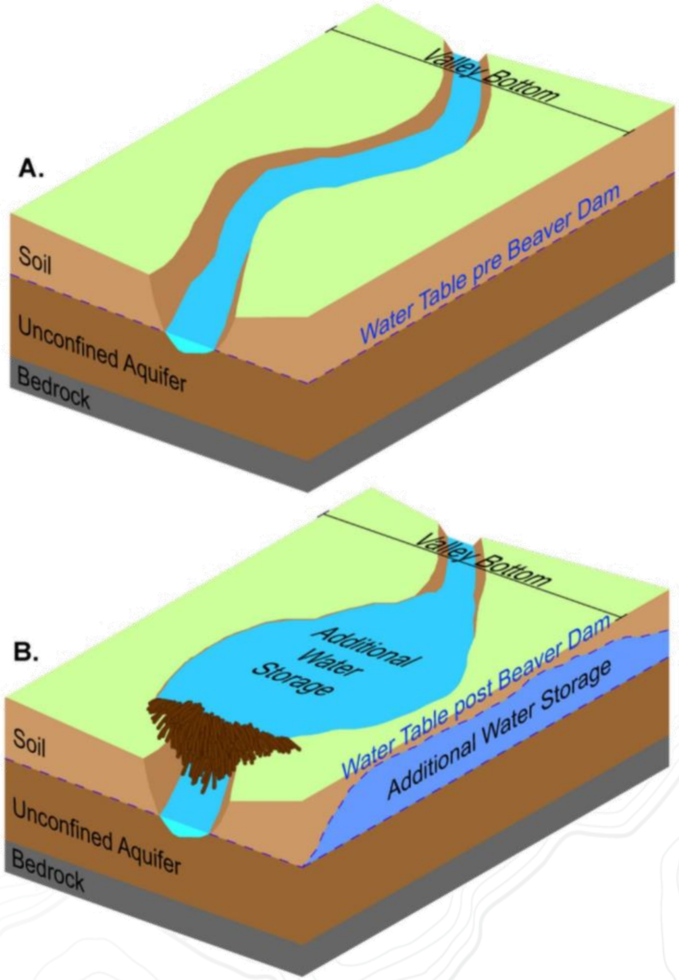
Habitat Project Types with Water Offset Potential

- Projects that can Increase In-Channel Water Levels
  - Wood Placement (to mitigate channel incision)
  - Stream Restoration / Dechannelization
  - Beaver Introduction and Analogs

- Projects that can Increase Floodplain Water Levels
  - Floodplain Restoration / Reconnection
  - Levee Setback
  - Levee Removal

Anatomy of a Habitat Project with Offset Potential

- Conceptual change in stream and groundwater table morphology following in-channel project
  - *From: Hafen K and Macfarlane WW. 2016. Can Beaver Dams Mitigate Water Scarcity Caused by Climate Change and Population Growth? StreamNotes: The Technical Newsletter of the National Stream and Aquatic Ecology Center, USDA*



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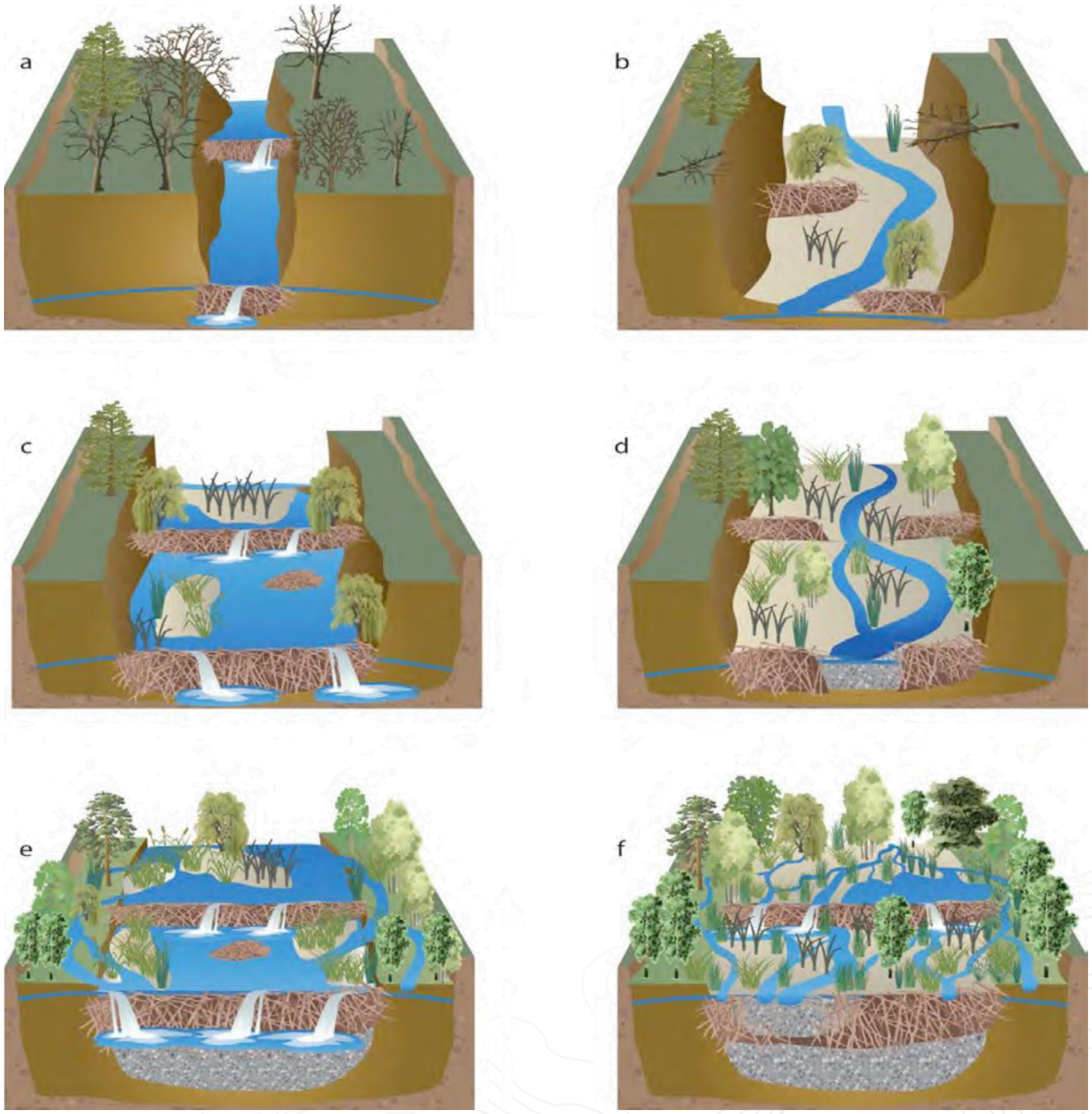
Conceptual Evolution

- Stream and Adjacent Groundwater Table following Beaver Introduction
  - *From: Pollock, M.M., G. Lewallen, K. Woodruff, C.E. Jordan and J.M. Castro (Editors) 2015. The Beaver Restoration Guidebook: Working with Beaver to Restore Streams, Wetlands, and Floodplains. Version 1.0. United States Fish and Wildlife Service, Portland, Oregon. 189 pp*



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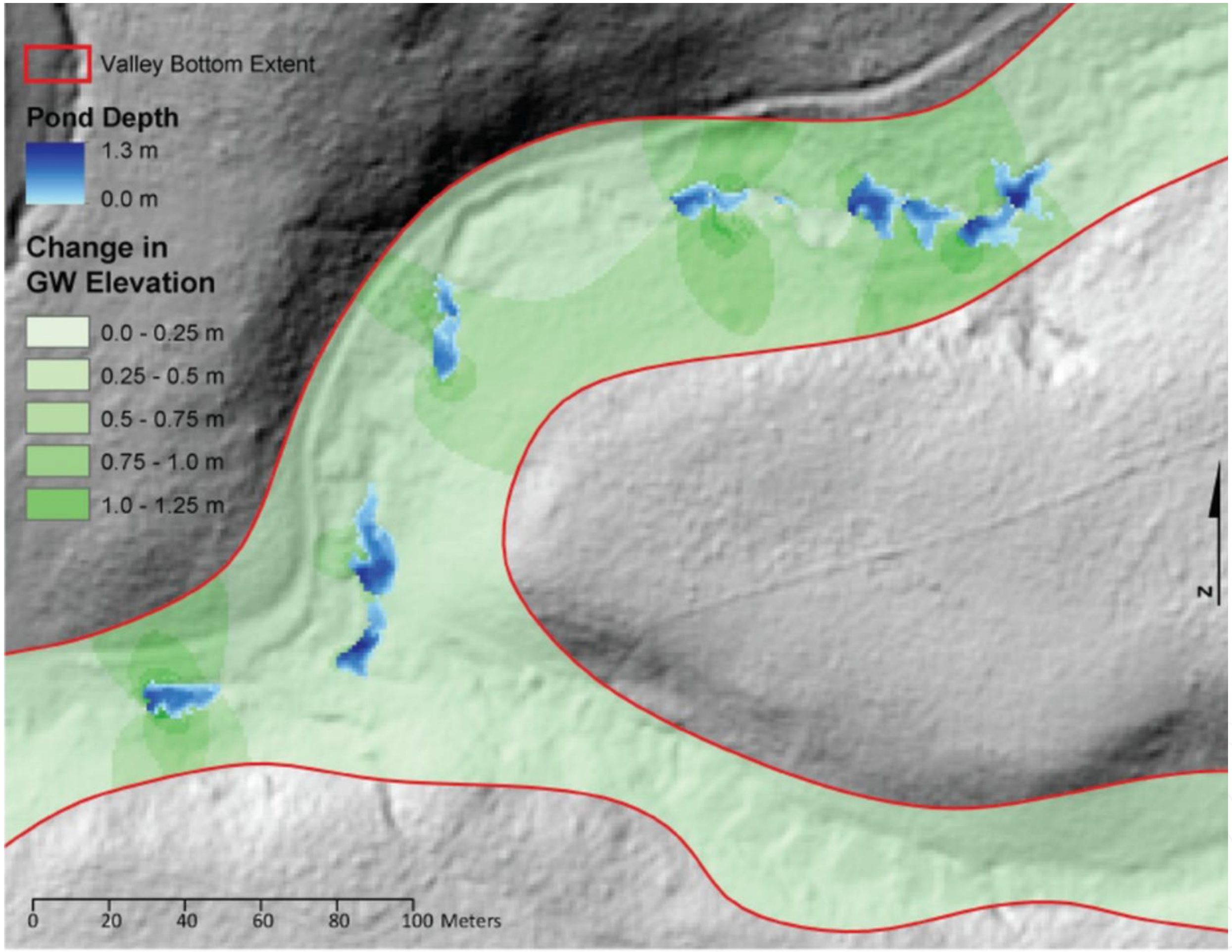
Modeled Increase in Groundwater Table Elevation following Beaver Introduction



From: Hafen K and Macfarlane WW. 2016. Can Beaver Dams Mitigate Water Scarcity Caused by Climate Change and Population Growth? StreamNotes: The Technical Newsletter of the National Stream and Aquatic Ecology Center, USDA

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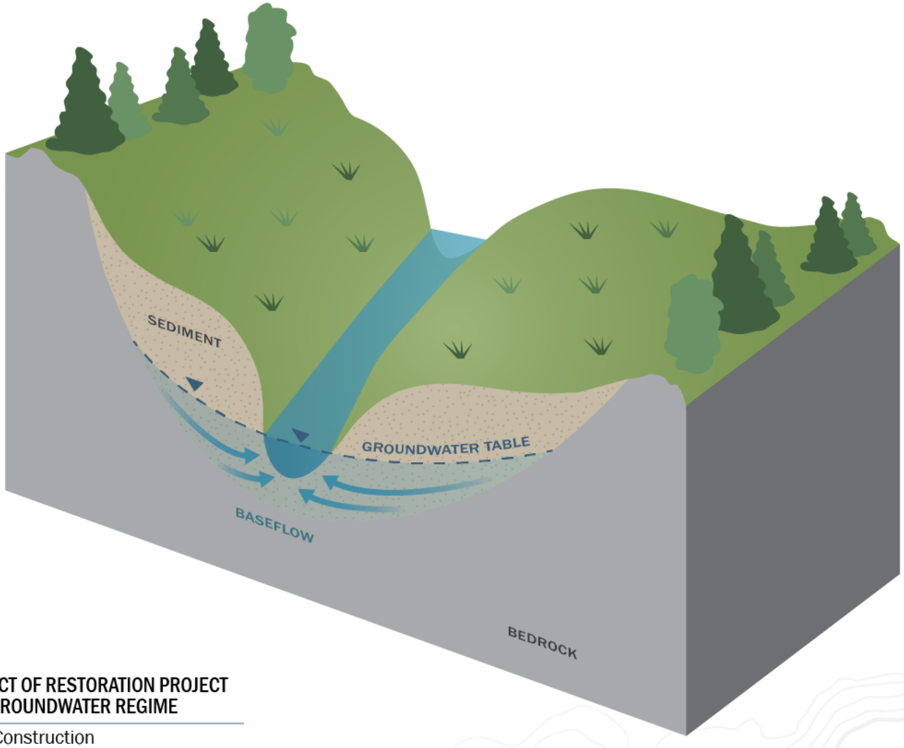
Effect of Restoration Projects on the Groundwater Regime

- Pre-Construction
  - Gaining Reach
  - Incised Channel
  - Abundant unsaturated sediment

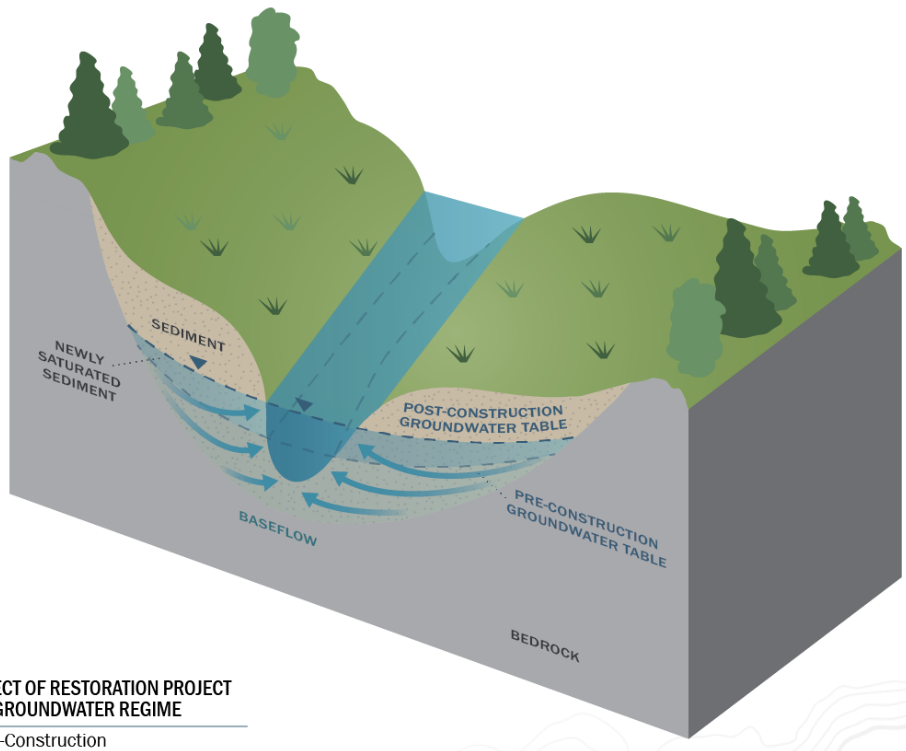


EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME

Pre-Construction

Effect of Restoration Projects on the Groundwater Regime

- Post-Construction
  - Increase in surface and groundwater levels
  - Wedge of newly saturated sediment
  - Slight decrease in hydraulic gradient (slope of groundwater table)
  - Increase in baseflow



EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME
Post-Construction

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Estimating Water Offset Potential

- Generally, projects that evaluate changes in floodplain storage and/or baseflow include the following components:
  - Monitoring well installation and long-term groundwater level monitoring
  - Stream gage installation and long-term stage/discharge monitoring
  - Aquifer testing (transmissivity, hydraulic conductivity, storage properties)
  - Groundwater/surface water modeling
  - Performance monitoring
- Next, we will briefly look at some graphics from previous floodplain restoration studies that demonstrate these project components

Floodplain Reconnection Study Components

Purpose can be to characterize:

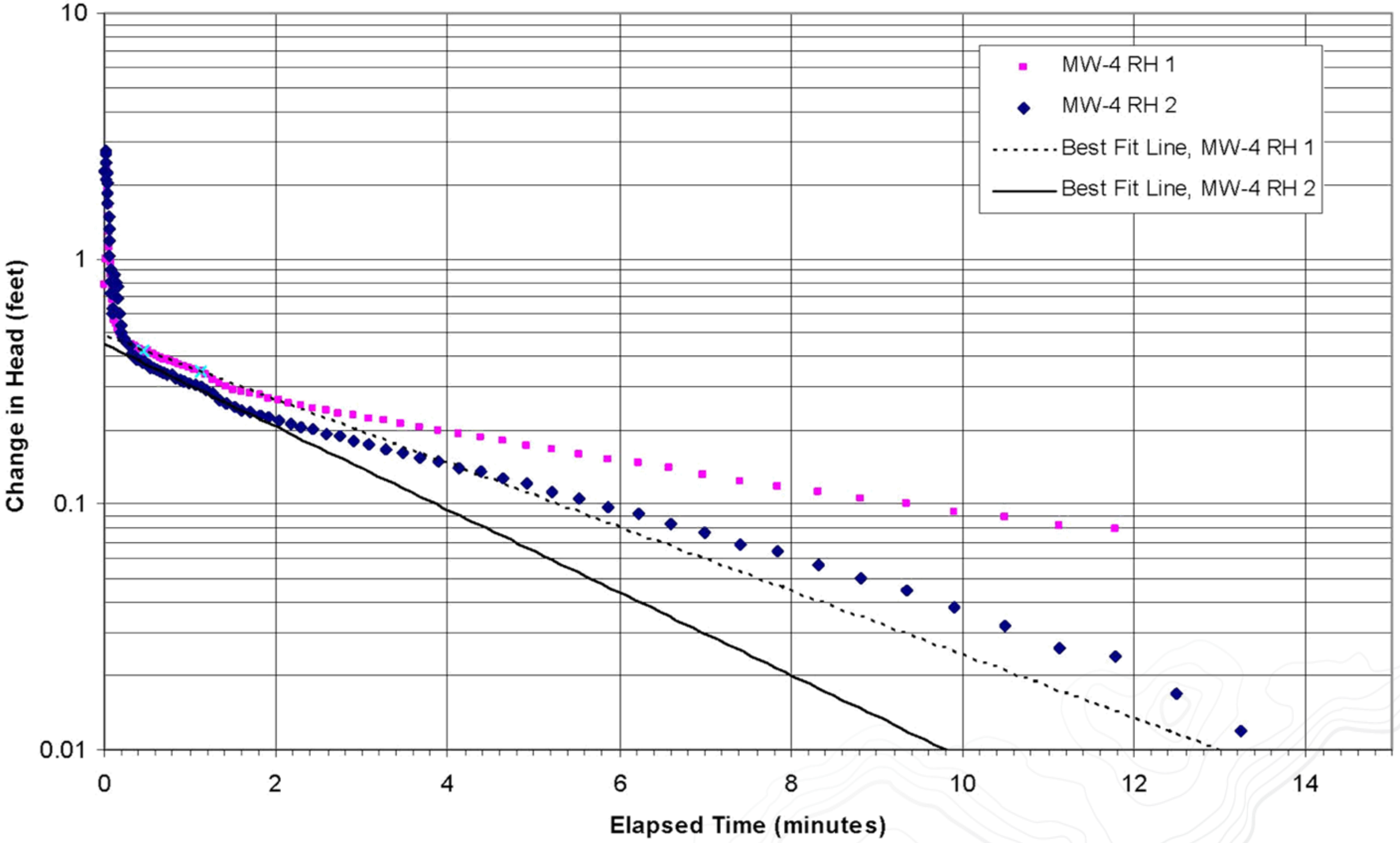
- The quantity of water offset
- The change in the timing of groundwater discharge to stream
- The change in groundwater storage

Applicable to properties of various sizes (as large as 2,500 acres or more)

Floodplain Reconnection Study Components
Installing Groundwater Monitoring Wells

Floodplain Reconnection Study Components
Measuring Stream Discharge

Floodplain Reconnection Study Components
Results of Hydraulic (Slug) Testing



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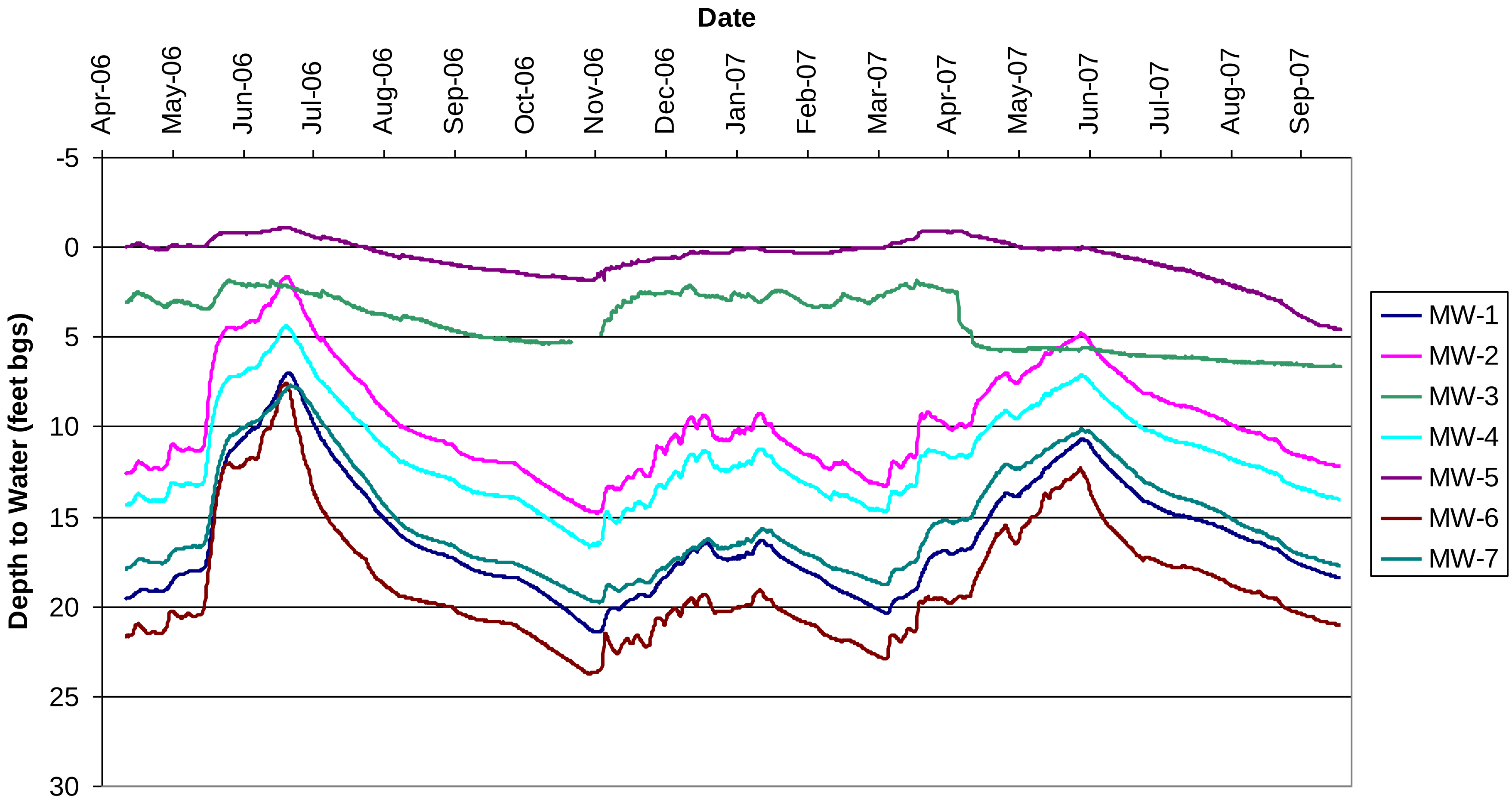
Floodplain Reconnection Study Components

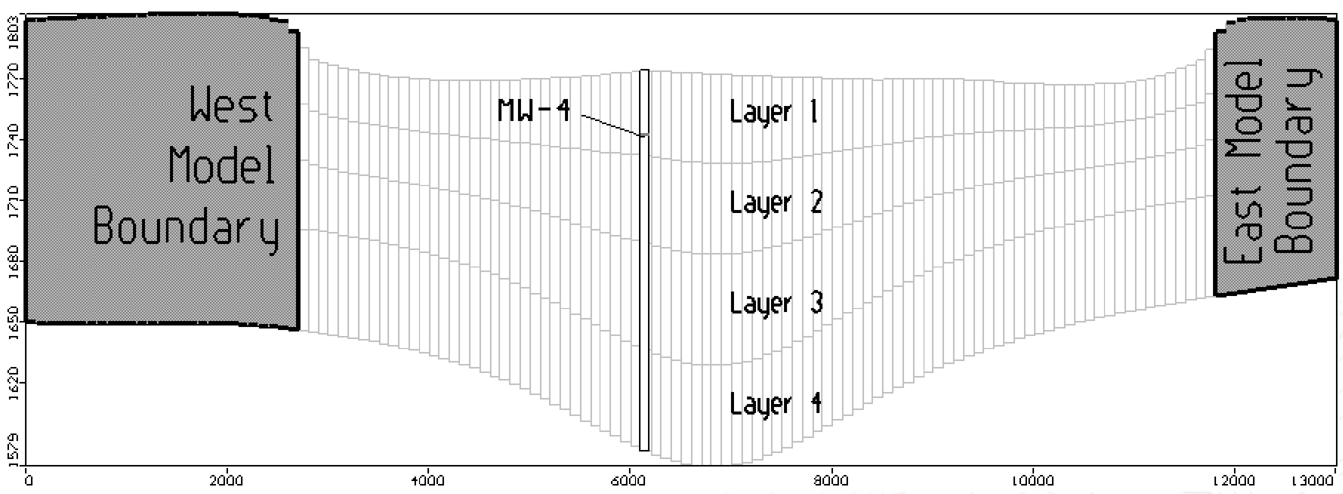
Long-term Groundwater Monitoring Data



Floodplain Reconnection Study Components

Groundwater flow models are developed to simulate the post-restoration change in:

- Groundwater levels
- The direction and quantity of hydraulic exchange between creek and river
- Storage within the alluvial aquifer
- Seasonality of the above



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Floodplain Reconnection Studies

Timeline and Cost?

- Generally 2 to 3 years
- Approximately $50K to $100K for groundwater studies on larger properties

What Type of Conclusions are Generated?

- <u>The increase in recharge to the alluvial aquifer</u>– can seasonally exceed 0.5 cfs for larger projects, much of which emerges as baseflow
- <u>The increase in groundwater levels</u> – can increase on average by 0.5 feet or more
- <u>The increase in groundwater storage in alluvial aquifer pore space</u> – can exceed 100 acre-feet on larger projects

<u>This type of approach is:</u>

- Multi-year
- Field-intensive
- Modeling-intensive
- Budget-intensive

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Case Studies: Trout Creek, near Lake Tahoe, California

- Summary Description
  - Trout Creek was reengineered in 2001 to increase stream/floodplain connectivity
  - Sinuosity was enhanced, slope decreased, and channel elevation increased over a 3,000-meter reach
  - Hydrologic impacts were characterized by detailed stream stage and groundwater level monitoring of Trout Creek before and after a channel restoration project
- Objective
  - Evaluate the effectiveness of stream channel reengineering to improve ecologic function by increasing summer water availability in riparian areas
- Conclusions
  - Restoration has a **seasonal impact**
  - **Increased streamflow** during summer; 11 percent in June and 24 percent in July
  - **Decreased depth to groundwater** across wide range of streamflow

Citation: Tague, C., S. Valentine, and M. Kotchen (2008), Effect of geomorphic channel restoration on streamflow and groundwater in a snowmelt-dominated watershed, Water Resour. Res., 44, W10415, doi:10.1029/2007WR006418

Case Studies: Ninemile Creek, Northwest Montana

- Summary Description
  - Ninemile Creek, a Clark Fork tributary, was degraded (straightened, incised) by placer mining in the 1800s
  - Trout Unlimited restored a portion (351 m reach) by filling dredge ponds and restoring a meandering channel
  - This study compared the hydrology of the restored reach with a degraded reach
  - Study components included topographic and morphologic surveys, well transects, and groundwater level monitoring
  - The study used tracer testing (including ^{222}Radon) to monitor hydraulic exchange between the Creek and aquifer
- Objective
  - Evaluate stream restoration effects on aquifer storage and hydraulic exchange between the restored reach and the adjacent alluvial aquifer
- Conclusions
  - Restoration can **increase storage and baseflow discharge**
  - In the degraded portion of the creek, groundwater was rapidly transported to the creek with reduced groundwater storage
  - In the restored reach:
    - **Longer** early season period of **alluvial recharge**
    - Groundwater **discharge was delayed**
    - **Baseflow extended** further into the low flow period
    - **Increased underflow**

Citation: Brissette, Christine M., "Stream restoration effects on hydraulic exchange, storage and alluvial aquifer discharge" (2017). Graduate Student Theses, Dissertations, & Professional Papers. 10992.

Case Studies: Indian Creek, Kittitas County, Washington

- Summary Description
  - Indian Creek, a Teanaway River tributary, was degraded (incised, disconnected from floodplain) by railroad/logging/grazing
  - Beginning in 2014, the Yakama Nation and partners restored reaches of the creek to improve fish habitat
  - Restoration was based on large woody debris placement
  - This study consisted of detailed groundwater level monitoring along multiple transects

- Objective
  - Evaluate the relationship between large wood-based stream restoration and the groundwater regime

- Conclusions
  - Restoration generally resulted in **increased groundwater elevations and groundwater storage**
  - The groundwater flow regime **does not conclusively indicate** significantly increased late-season streamflow (because of hydraulic gradient changes)
  - However no streamflow data were incorporated

Citation: Boylan, Nora, "Assessing the link between large wood restoration and groundwater storage and recharge: an investigation of Indian Creek in Washington State" (2019). A THESIS submitted to Oregon State University in partial fulfillment of the requirements for the degree of Master of Science.

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Case Studies: Nash et. al. Quantitative (Water Balance) Analysis

- Summary Description
  - This study was a modeling exercise of a hypothetical stream
  - It examined three different channel incision scenarios representing a stream in various stages of restoration

- Objective
  - Evaluate theoretical impact of stream restoration on aquifer storage and streamflow

- Conclusions
  - **Less incised streams** are associated with **increased aquifer storage**
  - However, lateral groundwater flow to the less incised stream is lower because of:
    - Reduction in streambed elevation
    - Reduction in hydraulic gradient
    - Increase in riparian vegetation and associated evapotranspiration
  - This analytical exercise suggested that significant late-summer streamflow increases **might not** result from wet meadow restoration.

Citation: Nash, C. S., Selker, J. S., Grant, G. E., Lewis, S. L., & Noël, P. (2018). A physical framework for evaluating net effects of wet meadow restoration on late-summer streamflow. Ecohydrology.

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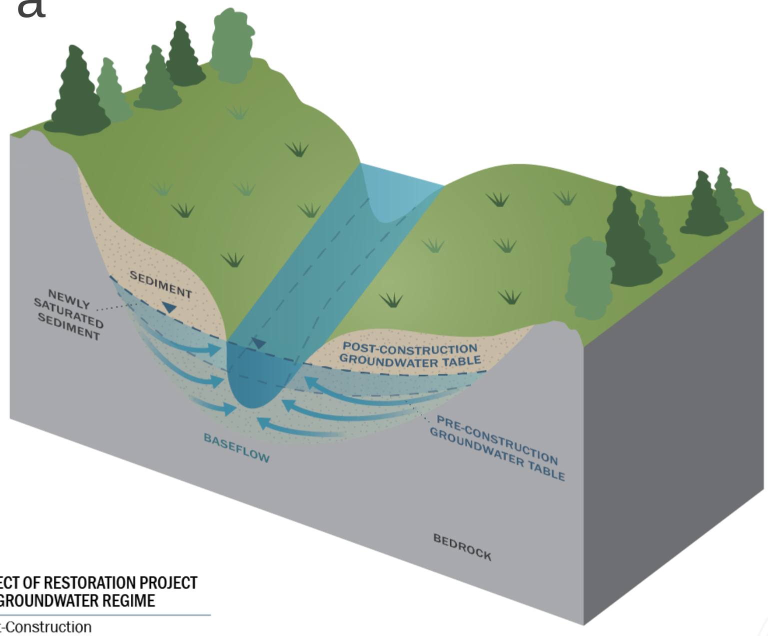
Key Considerations

- Data needs and data availability make it hard to rigorously quantify offsets from habitat projects
- Some data needs include:
  - Project design
  - River stage
  - Timing of water need (summer low-flow; winter rearing habitat)
  - Shallow groundwater levels
  - Groundwater/surface water interaction (gaining/losing)
  - Floodplain aquifer geometry and hydraulic characteristics (hydraulic gradient, hydraulic conductivity, storage characteristics, porosity)
  - Seasonal variation in the above
- Aquatic habitat limiting factors and critical habitat needs
- Published citations reviewing the water offset benefits of habitat projects have shown **conflicting results**

Estimating Water Offset Potential with Limited Time and Budget?

To quickly estimate offset quantity, consider a simplified analytical approach based on Darcy's Law that focuses on the groundwater/surface water interface:



EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME

Post-Construction

Step 1

Characterize the geometry of:

- The pre-construction stream and aquifer
- The post-construction stream and aquifer
- The newly-saturated wedge of sediments

Variables

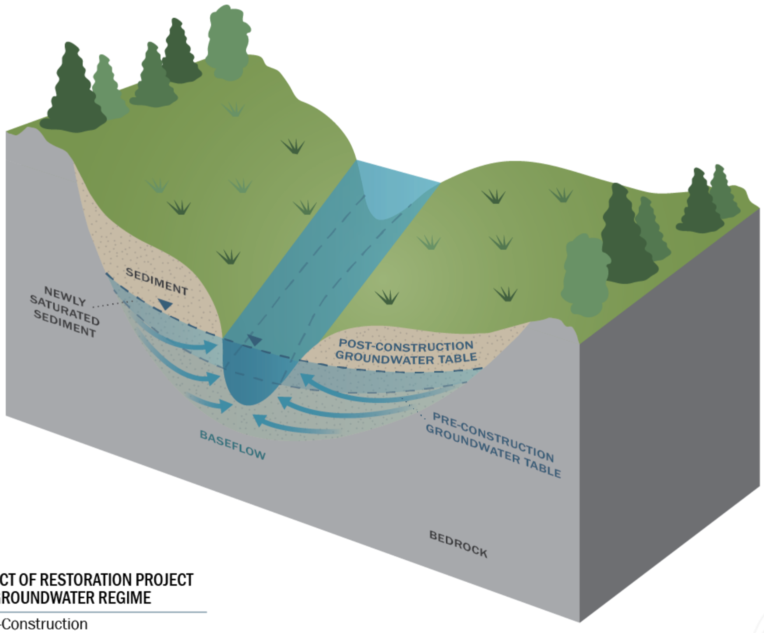
- Interface height
- Length of impacted stream reach
- Interface area
- One side of stream or two
- Gaining/losing

Estimating Water Offset Potential with Limited Time and Budget?

Step 2

Estimate hydraulic conductivity (K)

- Aquifer
- Groundwater/surface water interface



EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME

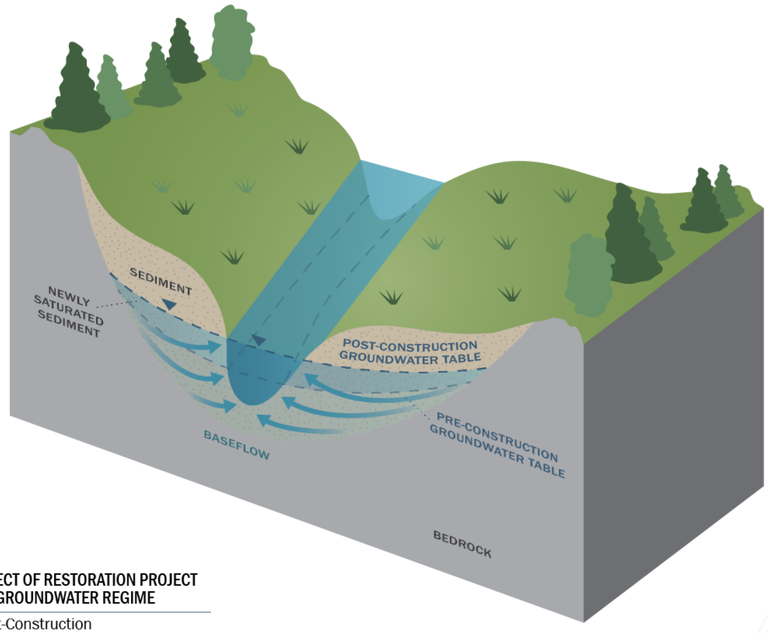
Post-Construction

Estimating Water Offset Potential with Limited Time and Budget?

Step 3

Estimate Hydraulic Gradient (dH/dL)

- Pre-construction
- Post-construction



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Post-Construction

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Estimating Water Offset Potential with Limited Time and Budget?

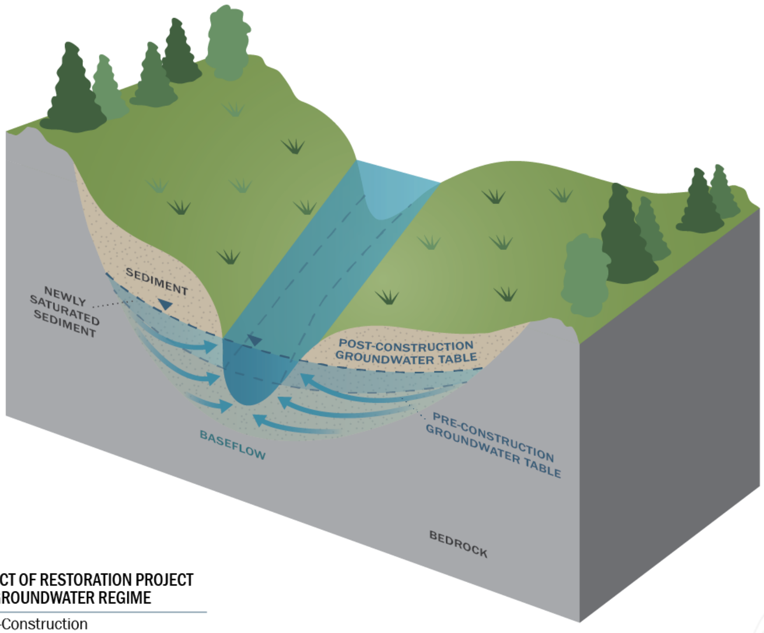
Step 4

Calculate flow (Q) through the groundwater/surface water interface for both the pre- and post-construction condition.

$$Q = K * A * dH/dL \qquad \text{Eqn 1}$$

Q_{pr} = Pre-construction flow

Q_{po} = Post-construction flow



EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME

Post-Construction

Potential offset benefit = $Q_{po} – Q_{pr}$ **Eqn 2**

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Estimating Subsurface Storage Potential with Limited Time and Budget?

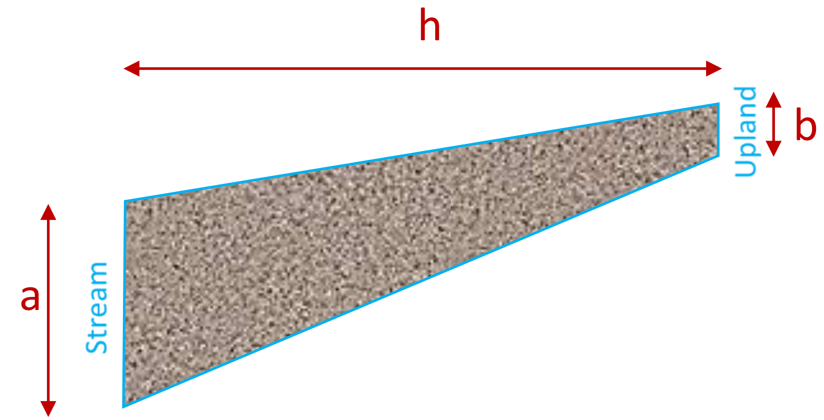
Subsurface storage potential is assumed to be equivalent to the pore space of the newly saturated wedge

Step 1

Calculate wedge volume (V)

Volume of trapezoidal prism =

(a + b)/2 * h * length of wedge Eqn 3



Step 2

Estimate effective soil porosity (n_e)

Step 3

Calculate subsurface storage potential (S_p)

$$S_p = V * n_e$$ **Eqn 4**

WRIA 7 Example
Lower Tolt Floodplain Reconnection

Project Overview

Lower Tolt River Floodplain Reconnection Project

Lower Tolt Floodplain Reconnection
Water Offset Inputs

Hydraulic conductivity

K (aquifer) = 200 feet per day (ft/d)

K (interface) = 200 ft/d

Groundwater/surface water interface area

- Pre-construction
  - Interface height = 5 ft
  - Length of impacted stream reach = 2,500 ft
  - Interface area (one side) = 12,500 ft^2
- Post-construction
  - Interface height = 8 ft
  - Length of impacted stream reach = 2,500 ft
  - Interface area (one side) = 20,000 ft^2

Hydraulic Gradient

- dH/dL (pre) = 0.007 ft/ft (approximate ground surface slope)
- dH/dL (post) = 0.005 ft/ft (30 percent reduction)

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Lower Tolt Floodplain Reconnection
Water Offset Estimate

Flow = Q = K * A * dH/dL

Pre-construction

Q_{pr} = 200 ft/d * 12,500 ft^2 * 0.007 ft/ft
Q_{pr} = 17,500 ft^3/d
Q_{pr} = 0.20 cfs

Post-construction

Q_{po} = 200 ft/d * 20,000 ft^2 * 0.005 ft/ft
Q_{po} = 20,000 ft^3/d
Q_{po} = 0.23 cfs

Potential offset benefit = $Q_{po} - Q_{pr}$ = 0.03 cfs or 21 ac-ft/yr
Eqn 4

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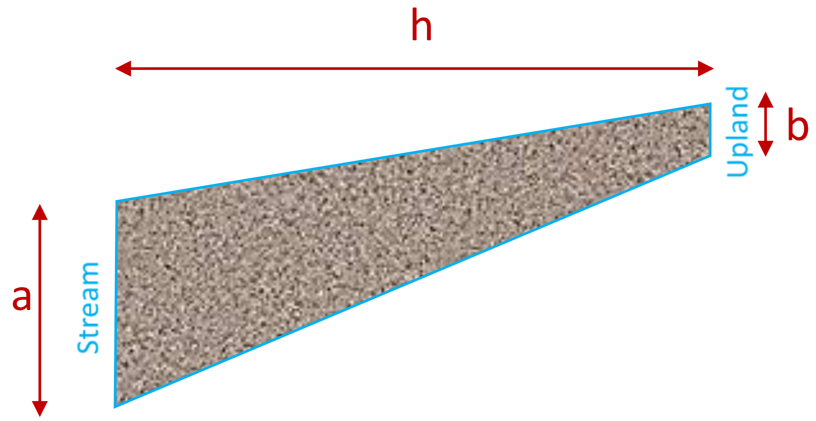
Lower Tolt Floodplain Reconnection
Subsurface Storage Potential Estimate

- Inputs
  - a = 3 ft
  - b = 1 ft
  - h = 850 ft
  - Length of wedge = 2,500 ft
  - One side
  - N_e = 30 percent



- Wedge volume = 4,250,000 ft^3

- **Results**

  S_p = 1,275,000 ft^3 or 29 acre-feet

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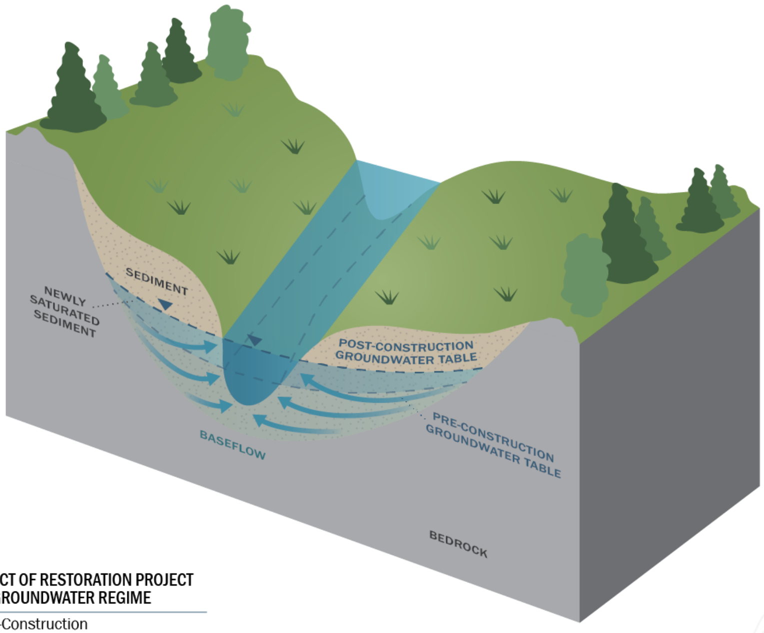
Disadvantages to this approach

- Uncertainty
  - Hydrogeologic conceptual model (floodplain connection, gaining/losing, etc.) could be inaccurate
  - Assumptions are imprecise
    - Floodplain water level impact
    - Hydraulic conductivity
    - Hydraulic gradient
    - Effective porosity
  - Results are imprecise
- Analysis is steady-state
  - Does not provide information on seasonality or timing of benefits



EFFECT OF RESTORATION PROJECT ON GROUNDWATER REGIME
Post-Construction

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Uncertainty

- "Difficult to quantify the offset benefits, potentially increasing uncertainty in calculating water offset quantities for the plan, and therefore potentially increasing uncertainty in the plan's conclusions and assurances."[1]
- Why is it difficult to quantify?
  - Method based on assumptions
  - Scarcity of existing, baseline monitoring projects and examples
  - Some habitat projects will not provide offset water on a reliable, annual basis (they need occasional, unpredictable flood flows to introduce water into the habitat space and therefore may not reliably provide offset water needed to offset new, permit-exempt uses on an annual basis)
  - Simulation of system through models is data intensive

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[1]From the *Final Guidance for Determining Net Ecological Benefit, Publication 19-11-079*

Conclusions

- The NEB Guidance requires offset for as long as the new PE wells are in use
- Water offsets for habitat projects are very difficult to quantify with certainty
- Offsets can be expected to generally be low, particularly for smaller sites/projects
- Rigorous investigation methods are time-, labor-, and budget-intensive
- Due to time and resource limitations, GeoEngineers proposes a simplified analytical method to estimate water offset potential for habitat projects that is defensible (using realistic assumptions) given the likely small offset volumes
- Habitat projects are of value and can contribute to NEB without having a precisely quantifiable offset (NEB Guidance Section 3.2.3.5D)

Next Steps

- There are hundreds of habitat projects inventoried per WRIA – detailed offset analysis is not practical
- The following characteristics tend to increase the offset benefit:
  - Large water level (groundwater table) impact
  - Increased length of impacted reach
  - High hydraulic conductivity of aquifer/interface
  - High hydraulic gradient
- The following characteristics tend to extend the offset benefit further into the low-flow period:
  - Large water level (groundwater table) impact
  - Broad alluvial valley/thick sediment sequence
  - Low hydraulic conductivity of aquifer/interface (conflict with above)
  - Low hydraulic gradient (conflict with above)

Next Steps

- Analyzing a subset of likely projects to estimate water offset potential could be an appropriate next step. The subset could be filtered from the full inventory list by prioritizing for:
  - Project type (levee setback, floodplain restoration, etc.)
  - Project size (floodplain acreage, length of reach, etc.)
  - Aquifer characteristics (geologic unit, minimum anticipated K, etc.)

- The consultant team could evaluate the subset using a methodology similar to the Lower Tolt example

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Questions?

Thank you!